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Late Ordovician palaeogeography and the positions of the Kazakh terranes through analysis of their brachiopod faunas

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ABSTRACT:

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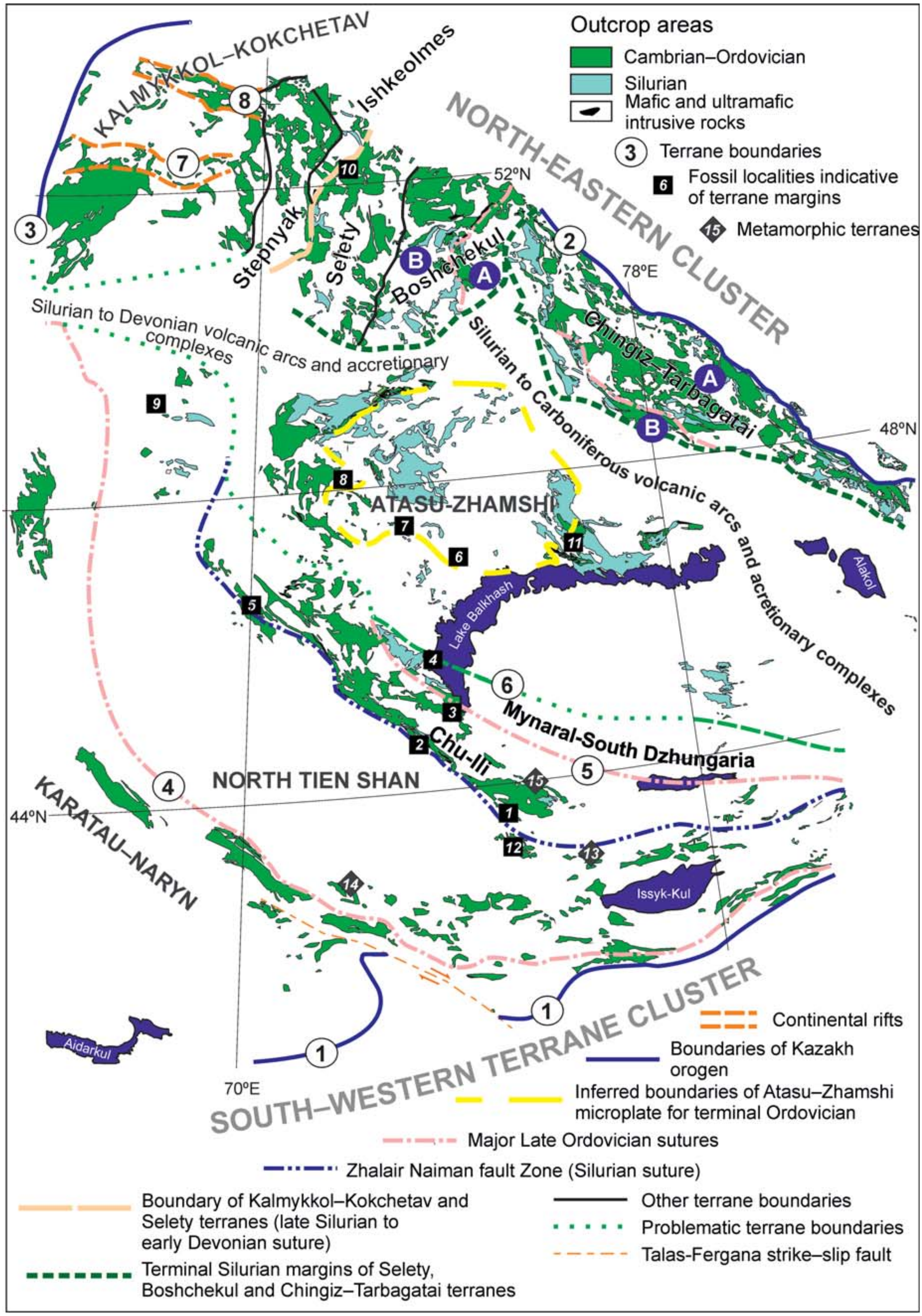
Detailed biogeographical and biofacies analyses of the Late Ordovician brachiopod faunas with 160 genera, grouped into 94 faunas from individual lithotectonic units within the Kazakh Orogen strongly support an archipelago model for that time in that area. The Kazakh island arcs and microcontinents within several separate clusters were located in the tropics on both sides of the Equator. Key units, from which the Late Ordovician faunas are now well known, include the Boshchekul, Chingiz-Tarbagatai, and Chu-Ili terranes. The development of brachiopod biogeography within the nearly ten million year time span of the Late Ordovician from about 458 to 443 Ma (Sandbian, Katian, and Hirnantian), is supported by much new data, including our revised identifications from the Kazakh Orogen and elsewhere. The Kazakh archipelago was west of the Australasian segment of the Gondwana Supercontinent, and relatively near the Tarim, South China and North China continents, apart from the Atashu-Zhamshi Microcontinent, which probably occupied a relatively isolated position on the south-western margin of the archipelago. Distinct faunal signatures indicate that the Kazakh terranes were far away from Baltica and Siberia throughout the Ordovician. Although some earlier terranes had joined each other before the Middle Ordovician, the amalgamation of Kazakh terranes into the single continent of Kazakhstania by the end of the Ordovician is very unlikely. The Late Ordovician brachiopods from the other continents are also compared with the Kazakh faunas and global provincialisation statistically determined.

Key words: Sandbian; Katian; Brachiopods; Kazakhstan; Palaeogeography; Central Asian Orogenic Belt.

INTRODUCTION

The chief objective of this paper is to review the affinities of the benthic faunas, particularly the abundant brachiopods, from key units which existed in the Late Ordovician within the Kazakh Orogen of the Central Asian Orogenic Belt (CAOB) so as to define their biogeographical signatures and hence their relative palaeogeographical positions both to each other and also to the adjacent continents. The Kazakh Orogen is taken here to include not only most of the country of Kazakhstan, but also north-eastern Uzbekistan, north Kyrgyzstan and parts of south-west China (Text-fig. 1).

The Ordovician was a time of divided continents and spectacular biodiversification, which in a relatively short time transformed marine life in extensive epeiric seas, on continental shelves, and in the


Outcrop areas
Cambrian–Ordovician
Silurian
Mafic and ultramafic intrusive rocks
3 Terrane boundaries
6 Fossil localities indicative of terrane margins
15 Metamorphic terranes
KALMYKKOL–KOKCHETAV
Ishkeolmes
Stepnyak
Selety
Boshchekul
NORTH-EASTERN CLUSTER
Chingiz–Tarbagatai
52ºN
78ºE
48ºN
44ºN
70ºE
Silurian to Devonian volcanic arcs and accretionary complexes
Silurian to Carboniferous volcanic arcs and acretionary complexes
ATASU-ZHAMSHI
Lake Balkhash
Alakol
Mynaral-South Dzhungaria
Chu-Ili
NORTH TIEN SHAN
KARATAU–NARYN
Issyk-Kul
Aidarkul
SOUTH–WESTERN TERRANE CLUSTER
A
B
1
2
3
4
5
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14
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Continental rifts
Boundaries of Kazakh orogen
Inferred boundaries of Atasu–Zhamshi microplate for terminal Ordovician
Major Late Ordovician sutures
Zhalair Naiman fault Zone (Silurian suture)
Boundary of Kalmykkol–Kokchetav and Selety terranes (late Silurian to early Devonian suture)
Other terrane boundaries
Problematic terrane boundaries
Talas-Fergana strike–slip fault
Terminal Silurian margins of Selety, Boshchekul and Chingiz–Tarbagatai terranes

oceans. The relative positions of the major continents in the Ordovician are now well established (Torsvik and Cocks 2013a), but the Kazakh Orogen's identity and detailed position are not agreed. Another central task is the re-evaluation of the biogeographical connections between the Late Ordovician Kazakh faunas and the brachiopods from the rest of the world. The orientations used throughout the paper (e.g. 'north-east') are all in today's directions.

In an important book on global Ordovician biogeography (Harper *et al.* 2013), the brachiopod data for the Australasian part of the Gondwanan margin and the western CAOB were not included, and the present analysis fills that gap. The Katian was the acme of the greatest and probably the one of the most sustained intervals of diversification of life in the Phanerozoic; the Great Ordovician Biodiversification Event (GOBE) of Webby *et al.* (2004), prior to the end-Ordovician Hirnantian extinctions. By the beginning of the Katian, the diversity of the brachiopod faunas had achieved the Palaeozoic Diversity Plateau of Harper (2006), suggesting that their origination and extinction rates had reached equilibrium on a global scale. It was also the time of maximum biogeographical and biofacies differentiation in the Ordovician within marine benthic communities as a whole.

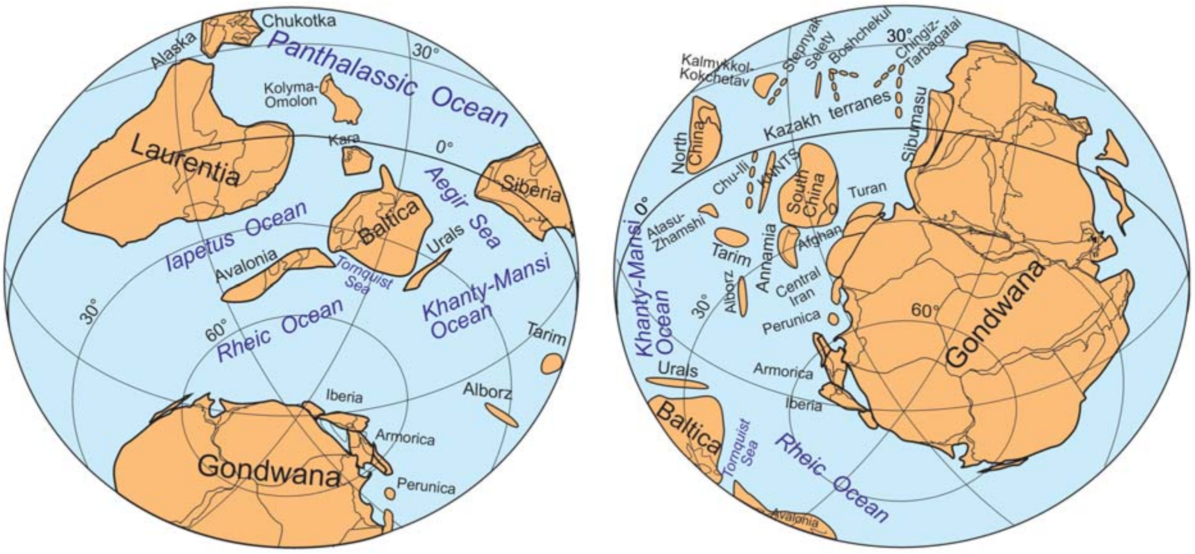
After a short summary of Ordovician global geography in the following section, we analyse each of the major Kazakh terranes in turn, together with their revised Late Ordovician brachiopod assemblages, and how they have been analysed (Section 4), followed by our conclusions on the geography of the Kazakh Orogen, which differs from many other published scenarios.

LATE ORDOVICIAN GLOBAL GEOGRAPHY

The most distinctive features of Ordovician geography were the concentration of land masses in the Southern Hemisphere, in contrast to the Northern Hemisphere, which largely consisted of the vast Panthalassic Ocean (Text-fig. 2). Gondwana was an enormous landmass which occupied most of the area within the Antarctic Circle and its Australasian segment continued northward across the Equator into the Northern Hemisphere. Reconstructions of its Polar Wander Path (Torsvik and Cocks 2013b) indicate that, during the Late Ordovician, Gondwana moved over the South Pole from central Algeria to Mauritania (Text-fig. 2).

Another large continent was Baltica, which by the end of the Ordovician had drifted north-westwards from temperate latitudes during the Ordovician, and by the end of the Katian had entered the tropics. Near the end of the Ordovician, at about 440 Ma, Baltica merged with the microcontinent of Avalonia after closure of the Tornquist Ocean between the two (Cocks and Torsvik 2005). At the start of the Ordovician, Baltica was separated from Laurentia by the Iapetus Ocean, then 5,000 km wide, but by the end of the Ordovician the Iapetus was reduced to the size of today's Mediterranean Sea, whereas the Rheic Ocean separating Avalonia and Baltica from Gondwana was almost 3000 km wide. Siberia (including the peri-Siberian terrane units in Mongolia and Altai-Sayan) was in the tropics, but at some distance from the other continents and much of it lay to the north of the Equator, although Siberia was inverted in relation to the present day (Cocks and Torsvik 2007).

← Text-fig. 1. Modern map of the Kazakh Orogen showing the geographical distribution of the Cambrian, Ordovician and Silurian deposits, mafic and ultramafic rocks, and first-order early Palaeozoic terrane boundaries. Boundaries of the Kazakh Orogen: 1, Turkestan oceanic suture (after Burtman 2006); 2, Gornostaev Shear Zone, boundary with Zharma-Saur unit of Şengör and Natal'in (1996), peri-Siberian Palaeozoic magmatic arc and accretionary complex; 3. Valerianov Fault Zone; 4. Terskey Suture of Burtman (2006); 5, Passive margin of the Mynaral-South Dzhingaria Terrane and the Late Ordovician (Sandbian) suture; 6, Inferred terminal Ordovician north-eastern margin of the composite Karatau-Naryn-North Tien Shan Microplate; 7, Chistopolie continental rift zone; 8, Rift system separating Kokchetav and Shat massifs. Localities of fossil associations indicative of plate margins: *1*, Radiolarian assemblage in deep-water black limestones, Oisu beds, (Sandbian, uppermost *Pacificograptus pacificus* graptolite Zone) in the Dulankara Mountains (Nazarov and Popov 1980); *2*, *Triplococcus*-dominated radiolarian assemblage from the Akzhal Formation (Darriwilian) in the Akzhak Mountains (Danelian and Popov 2003), *3*, Ordovician (Katian) to Llandovery graptolites of the *Pacificograptus pacificus* to *Coronograptus cyphus* zones (Apollonov *et al.* 1980), 5.5 km south-west of Karasai railway station. *4*. Olenid trilobite biofacies in Early Katian black graptolitic shales at Ak-Kerme Peninsula (Nikitin *et al.* 1980; Ghobadi Pour *et al.* 2011, fig. 2.20); *5*, Isograptid graptolite biofacies and thin pelagic layers of radiolarian cherts in distal turbidites from the 'Kusheke' Formation (Floian to Dapingian) at North Betpak-Dala (Nikitina *et al.* 2008; Popov *et al.* 2009); *6*, Deep water limestones of the Shundy Formation (Darriwilian) with radiolarians and hexactinellide sponges (Nazarov and Popov 1980); *7*, *Triplococcus*-dominated radiolarian assemblage and associated olenid trilobite biofacies from the Shundy Formation (Darriwilian) at Aksuran Mountain (Pouille *et al.* 2013); *8*, Radiolarian cherts and tuffites of the Taldyespe Formation with Katian conodonts and Llandovery to Wenlock conodonts and graptolites of the Egizkara Formation (Nikitin 2002; Koren *et al.* 2003); *9*, Isograptid graptolite biofacies in the Kusheke Formation (Dapingian) in Baikanur Region, 4 km south of Kuyandy Lake (Tsai 1974); *10*, Isograptid graptolite biofacies in the Zorievka Formation (Dapingian) at Selety River basin (Tsai 1974); *11*, Radiolarian cherts of Itmurundy, Kazyk, and Turetai formations with Darriwilian to Sandbian conodonts at Itmurundy, North Balkash Region; *12*, Continuous Tremadocian to Floian sedimentary succession (Agalatas, Kendyktas and Kurdai formations) with olenide trilobite biofacies (Lisogor 1961; Popov and Holmer 1994). Metamorphic terranes: *13*, Aktyuz; *14* Makbal; *15*, Anrakhai



Text-fig. 2. Global palaeogeographical reconstruction for the Early Katian

Gondwana was surrounded by a number of satellite continents, including the united South China and Annamia (Indochina), North China, and Tarim. Several terrane units, including Armorica, Perunica, Sibumasu, which had previously been considered as isolated microcontinents in the Ordovician by many workers, are now seen as located within the margins of the Gondwana supercontinent and they only separated from it by the opening of the Palaeotethys and Neotethys oceans at various times in the Devonian and Permian (Torsvik and Cocks 2013a, 2013b).

The configuration of the major continents had a significant impact on the oceanic and atmospheric circulation. In particular, the South Subpolar Current must have been turned northwards along western Gondwana. By analogy with the Humboldt Current, which nowadays follows the western coastline of South America, the South Subpolar Current would have brought cold water to almost equatorial latitudes (Popov *et al.* 2013), and had a considerable cooling influence on the western edge of the Australasian sector of Gondwana, an influence stronger during times of global cooling. Equatorial oceanic currents and counter-currents undoubtedly facilitated faunal exchange between the shelves of Australasian Gondwana, the Kazakh terranes, North China and even Laurentia, which were all in equatorial latitudes during the Ordovician (Text-fig. 2).

The existence of a large land mass at the Equator would have also resulted in the development of monsoon conditions (Wilde 1991; Armstrong *et al.* 2009; Parrish 2012). One of its major futures was a reversed seasonal oceanic circulation in equatorial latitudes west of the Australasian coast of Gondwana (Wilde 1991), and the South China, Tarim and the Kazakh microcontinents and island arcs would have been strongly influenced by the monsoon climate, which would have strengthened during global warming, while the South Subpolar Current weakened (Popov *et al.* 2007). In those periods, warm water benthic faunas would have spread down to the southern temperate latitudes along the west cost of Gondwana through the so-called 'overlap zone' (Fortey and Cocks 2003). The Early Palaeozoic terranes of Central Iran, Alborz, Kopet-Dagh, Afghanistan, and Zerafshan-Hissar in Uzbekistan were within that overlap zone, and were either integral parts of the Gondwana margin or small microcontinents nearby.

The Ordovician, and the Katian in particular, was the time when widespread epicratonic seas covered significant part of the major continents, including Laurentia, Baltica, Siberia, South China and the Australasian segment of Gondwana. As the GOBE progressed, benthic faunas colonised new niches in those epicratonic basins; in particular, the brachiopods and trilobites developed certain degree of endemism, which make them valuable biogeographic indicators. One of the major features of the Great Ordovician Biodiversification was the substantial increase in the β-diversity of benthic faunas (Fortey and Cocks 2003; Harper 2006).

In contrast with the relatively quiet later half of the Cambrian, the Ordovician had the largest amount of volcanism around the world in the Palaeozoic.

Much of it was island arc volcanism, which is best documented in the Iapetus Ocean region (Huff 2008; Keller and Lehnert 2010), but extensive Ordovician volcanism also occurred along the margin of the Australasian segment of Gondwana (Cawood 2005; Cawood and Buchan 2007), as well as in the Kazakh terranes. There were two Ordovician maxima of island arc volcanism in the latter, in the Dapingian to Darriwilian and in the Katian (Nikitin 1972, 1973).

THE KAZAKH TERRANES AND THEIR LATE ORDOVICIAN BRACHIOPOD FAUNAS

The many terrane units of the Kazakh Orogen (Text-fig. 1) are today surrounded by three large continents, whose Palaeozoic positions and orientations are now well known. To the north-east lies Siberia and peri-Siberia, which is separated from the Kazakh Orogen by the Gornostaev Shear Zone (Text-figs 1, 2), and the two areas did not come close until Carboniferous times. To the north-west lies Baltica, whose adjacent terranes originally included Tourgai (now within the Kazakh Orogen area) and others to its west (Hawkins *et al.* 2016), but again it was at some distance from the Kazakh Orogen in the Ordovician. The largest adjacent land mass was the supercontinent of Gondwana. Thus, South China, North China, and Tarim were all in the general vicinity of the Kazakh Orogen, but their Ordovician positions relative to Gondwana are poorly constrained.

Since the seminal works by Şengör *et al.* (1993) and Şengör and Natal'in (1996), the number of publications on various aspects of the Palaeozoic tectonic history of the Altaids, including the Kazakh Orogen, has steadily increased. Although the elegant model by those authors of the Altaid Orogen evolution, termed the Kipchak Arc model, has not found much support in subsequent research; however, their designation of orogenic-collage components in the Kazakh orogenic collage remains unmatched both in the depth of their analysis and in the quantity of data considered. We have largely followed these publications in their definition of the second order tectonostratigraphic units, although there are some modifications in the definition of the terrane boundaries.

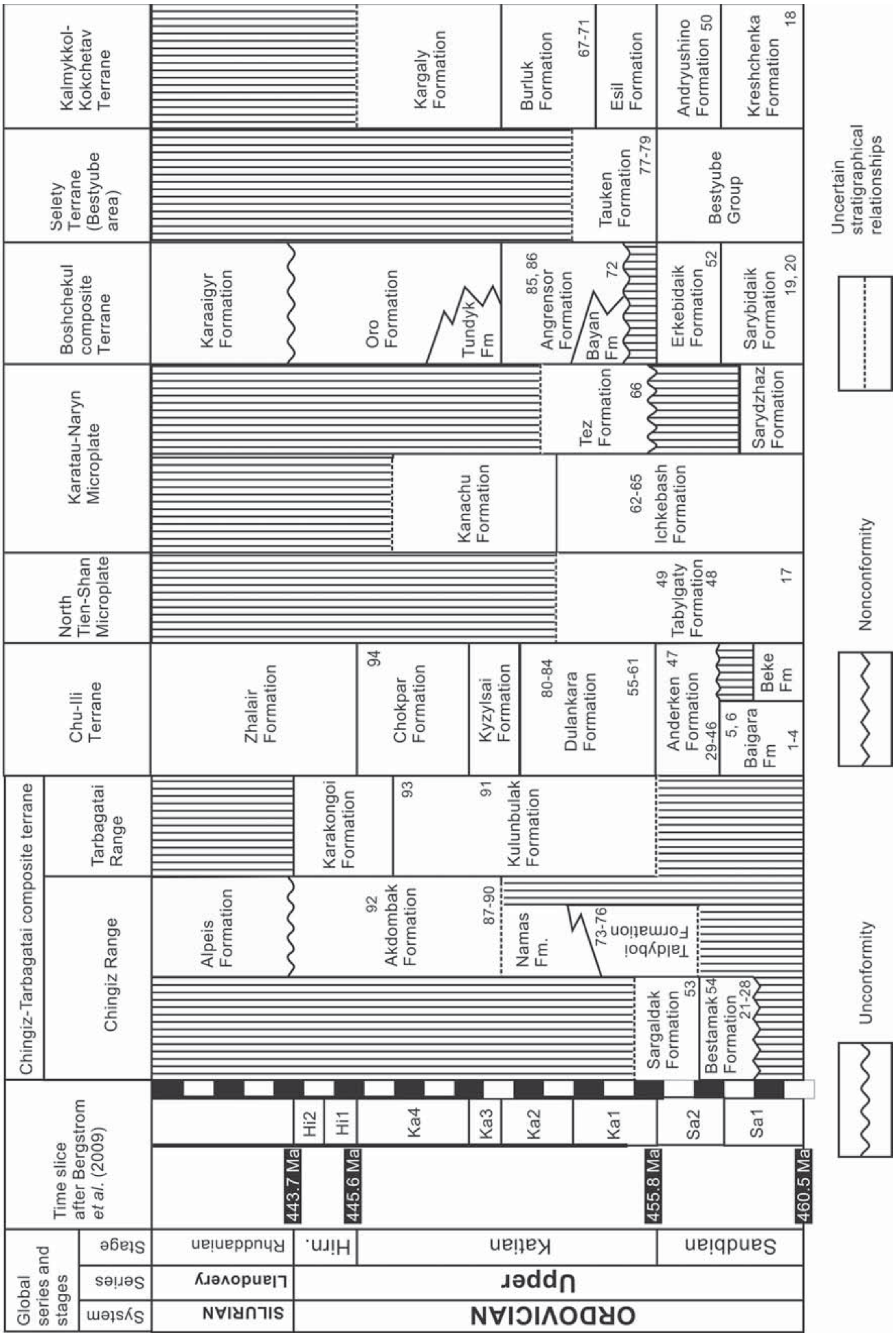
Great uncertainty still exists about the Early Palaeozoic geography and history of the numerous Palaeozoic microcontinents and island arcs within the Kazakh Orogen, which is one of the largest accretionary orogens of the Palaeozoic.

If properly applied, palaeontological evidence can contribute substantially towards resolving such ambiguities (Fortey and Cocks 2003), and may also be helpful in identification of the boundaries and the longitudinal position of the terranes, which cannot be solved by palaeomagnetism alone. The brachiopods are highly sensitive instrument for biogeographical analysis, as summarised in Fortey and Cocks (2003) and Harper *et al.* (2013). The position of the Kazakh terranes in subequatorial latitudes minimalised the influence of short term climatic fluctuations, which would have more strongly affected faunas in temperate latitudes. Therefore it is rather unlikely that changing environmental conditions made a strong effect on the faunal composition within the 2–3 My time slices used in our analysis. Almost all the analysed faunas inhabited island shelves facing the oceans and marginal seas which excludes any significant pH and salinity fluctuations characteristic of many epeiric seas.

We recognise here two major clusters of Lower Palaeozoic terranes in the Kazakh Orogen, the South-Western and North-Eastern, as well as two individual microcontinents, Kalmykkul-Kokchetav and Atashu-Zhamshi (Text-fig. 1). Each has a different history, and their unification within 'Kazakhstania' did not take place until well after the Ordovician. Most of the individual terranes within each cluster are composite, and are often bounded by subduction-accretion complexes, which include island arcs and small crustal fragments which docked to their margins at different times.

In the Appendix, there is a list of brachiopod genera from each tectonic unit, which have been individually revised by us partly from the original published papers and their photographs but also from specimens we have seen, and are thus very often different from the names given in the original publications. In addition, since the locality details are imprecise in many of the older Soviet publications, new coordinates are given in some cases, using original unpublished manuscripts and field notes and also Google Earth. The locality numbers are those in many other publications: some were originally allocated by VSEGEI, St Petersburg, and others by the Kazakh Academy, but, although there is no published list of those numbers, they are repeated here, not least since they are to be found on specimen labels in many museums, including our own. Benthic associations (BA) are given where known. Information on sedimentary successions and detailed stratigraphical position of the individual faunas used in the analyses can be found in cited publications.

Our analysis and figures in the Late Ordovician, have followed the time slices of Webby *et al.* (2004),



Text-fig. 3. Correlation chart for the Upper Ordovician of Kazakhstan, including formations with relevant brachiopod faunas (modified from Popov and Cocks 2014). Characteristic faunas are numbered as in the text

Bergström *et al.* (2009) and others, as follows: Sa1, Early Sandbian (previously 'earliest Caradoc'); Sa2, Late Sandbian (Early Caradoc); Ka1, Early Katian ('Middle Caradoc'); Ka2, Middle Katian ('Late Caradoc); Ka3, early Late Katian ('Early Ashgill'); Ka4, latest Katian ('Middle Ashgill'); and H, Hirnantian ('Late Ashgill') (Text-fig. 3).

South-western terrane cluster

The south-western cluster consists of three major units: the Karatau-Naryn Microcontinent (the southern part of the Valerianov-Chatkal and Baikanur-Taklas units), and the North Tien Shan Microcontinent (the Dzhezkazgan-Kyrgyz Unit), plus the Chu-Ili Terrane (the Zhalair-Naiman Unit). The unit names are from Şengör and Natal'in (1996).

Karatau-Naryn Microcontinent and North Tien Shan

The Karatau-Naryn and North Tien Shan terranes amalgamated into a single enlarged microcontinent (KNNTS) near the start of our period, in Late Darriwilian and Early Sandbian times at about 460 Ma. The combined unit was at the north-western margin of the Kazakh Orogen. Before amalgamation, the Karatau-Naryn terrane extended for almost 1500 km as a narrow belt not more than 200 km wide. Its latest Precambrian to Lower Cambrian sedimentary succession is similar to South China, and the Early Cambrian trilobite and brachiopod faunas show affinities down to the species level (Popov *et al.* 2009), and faunal links between Karatau-Naryn and South China remained strong from the Drumian (Cambrian) until the Floian (Early Ordovician).

The north-western margin of Karatau-Naryn faced North Tien-Shan and was passive throughout the Cambrian and Early to Middle Ordovician. The southern and partly western boundary of the KNNTS is defined by a Late Palaeozoic suture, the Chatkal and South Fergana sutures of Biske (1996) or the Turkestan Suture (Text-fig. 1.1) of Burtman (2006) and Biske (1995). Burtman (2006) also recognized two major episodes of volcanic activity along the southern and western boundary of KNNTS in the Early Devonian and in the mid-Carboniferous to Permian, while no active margin development is known there from the Cambrian and Ordovician. Precambrian (Late Ediacaran, not Cryogenian) diamictites of the Baikanur Formation are sedimentological markers in Karatau-Naryn (Chumakov 2011), but are unknown from other tectonostratigraphic units in the Kazakh Orogen (Arnaud *et al.* 2011).

The core of The North Tien Shan Microcontinent is Precambrian basement. Its southern and south-western margins represent an accretionary wedge which includes remnants of an island arc, the Karadzorgo Island Arc of Burtman (2006), which accreted in the Early Ordovician, as well as a back arc basin, and suprasubductional ophiolites (Mikolaichuk *et al.* 1997; Degtyarev *et al.* 2013). The northern boundary of the terrane is hidden under the later sedimentary cover of the Tengis depression; nevertheless, the occurrence of the characteristic isograptid graptolite biofacies in the oceanic distal turbidites of the Middle Ordovician Kusheke Formation (Text-fig. 1.9) south of Lake Tengiz (Tsai 1974) indicates the position of the plate margin at that time. North Tien Shan was united with the Karatau-Naryn Microcontinent at the Terskei Suture of Burtman (2006), which is probably of Sandbian age.

The Middle to Upper Ordovician (Late Darriwilian to Sandbian) brachiopod faunas of North Tien Shan were documented by Nikitina (1985) and Misius (1986). Those brachiopods show close similarity to the contemporaneous faunas of Chu-Ili down to the species level (Nikitina *et al.* 2006, and our own work here) suggesting that at that time separation between these two terranes was sufficiently narrow to allow relatively free exchange between shallow shelf faunas. Island arc volcanism occurred along the north-eastern margin of North Tien Shan in the Late Darriwilian to Katian, and the (in ascending order) Rgaity, Sarybastau, Keskintas, and Urysai formations include significant units of andesite, dacite and rhyolite volcanics and tuffs (Nikitin 1972); however, only the Rgaity Formation is accurately dated by Late Darriwilian brachiopods (Nikitina 1985). The Keskintas Formation is at least partly Katian, because it contains the tabulate coral *Plasmoporella* sp. (Nikitin 1972). These long-known data contradict the statement of Kröner *et al.* (2012, p. 921) that there no evidence of syn-collisional volcanic activity, despite the extensive occurrence of Late Ordovician and Silurian granites along the north-western margin of North Tien Shan. Moreover, the widespread development of the Upper Ordovician volcanic rocks indicates that, by the beginning of the Late Ordovician, subduction had commenced under the north-eastern margin of North Tien Shan. Displacement of the magmatic front and change in the polarity of subduction may be correlated with the docking of Karatau-Naryn to the southern margin of North Tien Shan.

Three Sandbian and five Early Katian brachiopod faunas from Karatau-Naryn and four from North Tien Shan are within our biogeographical analysis

(Text-fig. 3; for details see Appendix, faunas 16, 17, 48, 49, 62–66). Apart from Fauna 16, the listed faunal assemblages are composite, and derived from the individual localities of Misius (1986).

Chu-Ili Terrane

Popov *et al.* (2009) concluded that Chu-Ili was a Japanese type active margin and an accretionary wedge in front of the North Tien Shan Microcontinent, and the Early Palaeozoic sedimentary and palaeontological record for Chu-Ili is the best in the Kazakh Orogen. The south-western boundary of Chu-Ili is the Zhalair-Naiman Fault Zone (Text-fig. 1), which is a neotectonic strike-slip fault complex developed along an Early Palaeozoic suture. The south-western margin of Chu-Ili has northward-dipping homoclinal sequences of Cambrian (Furongian) and Lower to Middle Ordovician siliciclastic slope-rise deposits, including the Dzhambul, Karatal and Kushaky formations, which are traceable almost continuously for up to 600 km (Popov *et al.* 2009). Continuous transition from the Ordovician to the Silurian in the outer shelf graptolite facies (Chokpar and Zhalair Formations) can be seen in a number of sections for almost 170 km along the south-western margin of Chu-Ili between Dulankara and Maizhyralgan Mountains (Apollonov *et al.* 1980).

Chu-Ili was separated from the North Tien Shan Microcontinent throughout the Ordovician. Accretion of the two in the Early Ordovician (Late Floian: 480 to 475 Ma), depicted by Kröner *et al.* (2012, fig. 19), is not supported because, firstly, there is no evidence for the existence of an active margin along the south-western side of Chu-Ili facing Zhalair-Naiman; secondly, instead of a hypothetical Lower to Middle Ordovician accretionary wedge attached to Chu-Ili, successions of oligomict slope-rise deposits of the Upper Cambrian to Middle Ordovician rocks can be traced almost continuously for 600 km along its south-western margin. Some contain pelagic layers of radiolarian cherts and graptolites characteristic of the isograptid biofacies (e.g. the “Kogashik” Formation) (Text-fig. 1.5). Zhalair-Naiman evolved as a backarc basin sometime in the mid Cambrian (Popov *et al.* 2009; Alekseiev *et al.* 2012; Kröner *et al.* 2012). Unlike the opposite side of Chu-Ili, there is no extensive accretionary wedge developed between Chu-Ili and North Tien Shan along the Zhalair-Naiman suture (Popov *et al.* 2009), suggesting that there was little subduction-accretion involved, which is not consistent with the elimination of a sizeable ocean suggested in some models. There is no good geochemistry by which to trace the source of ophiolites (the so-called Ashchisu Formation) obducted along the south-western margin of Chu-Ili, and they may be suprasubductional ophiolites (Popov *et al.* 2009). Ryazantsev *et al.* (2009, p. 5) suggested that these ophiolites are rift related and probably formed as a result of the back-arc spreading.

The north-eastern margin of Chu-Ili is an accretionary collage of arc-prism-ophiolite complexes in several tectonostratigraphical units, overlain by the deposits of a Darriwilian forearc basin, which evolved in the Sandbian into a foredeep basin, and was filled with sediments by the end of the Katian (Popov *et al.* 2009). Active subduction under Chu-Ili was interrupted sometime in the Sandbian after the docking of the small Mynaral-South Dzhungaria Terrane of uncertain origin (Popov *et al.* 2009), which did not represent the south-eastern margin of the Atashu-Zhamshi Terrane as often asserted. By Silurian times, the magmatic front had migrated about 100 km north-east towards the margins of a newly accreted Mynaral-South Dzhungaria Terrane. Intensive island arc volcanism in this area took place almost continuously from the Silurian to the mid-Devonian (Abdullin *et al.* 1980; Koren *et al.* 2003).

The Chu-Ili accretionary wedge has the longest continuous record of ocean biogenic sedimentation for the entire Palaeozoic (Tolmacheva *et al.* 2001; 2004). Those are the ribbon-banded cherts of the Burubaital Formation, which were originally radiolarian oozes which accumulated on the oceanic floor with only a little input of fine clastics and with a net deposition rate of just a few centimetres per thousand years. Thus the condensed deposition of of pure radiolarites without significant input of siliciclastic and volcanoclastic material for almost 40 Ma makes the backarc basin of an active volcanic arc inferred by Alekseiev *et al.* (2011) look improbable. The sequence of jaspers in the Ushkyzyl and Balgashoky formations in the Chingiz Range on the opposite side of the Kazakh Orogen (Zhylkaidarov 1998), which accumulated in backarc basins with deposition rates almost one magnitude higher than the Burubaital Formation, due to greater input of siliciclastic and volcanoclastic sediments. Yet in many papers (e.g. Alekseiev *et al.* 2011; Kröner *et al.* 2012), the existence of an oceanic basin along the north-eastern margin of Chu-Ili in the Ordovician is not recognised: Degtyarev and Ryazantsev (2007, p. 89) and Tolmacheva *et al.* (2011) even suggested that accumulation of the Burubaital Formation occurred not in the ocean but in a continental rift.

Mixed Precambrian and Cambrian zircon ages from 535 Ma (Fortunian) to 489.9 (mid Furongian) for the metamorphic rocks in the Anarkhai Massif (Kröner *et a*l. 2007) suggest that the basement of Chu-Ili is not Precambrian, as previously thought (Abdullin *et al.* 1980), but heterogenous, comprising fragmented continental crust and metamorphosed Early Palaeozoic volcanic and sedimentary rocks which were parts of the Cambrian accretion-subduction complex along the north-eastern margin of Chu-Ili, which implies active margin development through the Cambrian (Popov *et al.* 2009, p. 47; Alekseiev *et al.* 2011). Thus the north-eastern Chu-Ili margin preserves an almost uninterrupted record of island arc volcanism which lasted for almost 130 My from the Cambrian (Terreneuvian) to the Early Devonian.

Many of the localities yielded brachiopods which have not yet been exhaustively revised, but we have examined the original specimens where references are not cited. Stratigraphical position of the discussed faunas (1–15, 29–47, 55–61, 80–84, 92) is indicated on Text-fig. 3. More details on these faunas can be found also in the Appendix and also in publications by Rukavishnikova (1956), Popov (1980), Popov and Rukavishnikova (1986), Nikitin and Popov (1996), Nikitin *et al.* (1996), Popov *et al.* (1997, 1999, 2000, 2002), Nikitina *et al.* (2006), and Popov and Cocks (2006).

North-Eastern Terrane Cluster

The number, names, and boundaries of the units recognised for the north-eastern cluster of Kazakh terranes varies considerably from one paper to another. However, we include here the Chingiz-Tarbagatai, Boshchekul, and Selety units (Text-fig. 1). The eastern part of the Kazakh Orogen is an amalgamation of several Early to Middle Palaeozoic island arcs developed either on oceanic crust as suggested by Kröner *et al.* (2014), or on a heterogenous basement (Kovach *et al.* 2014; Stepanets *et al.* 2014). The granitoid rocks within the region are characterised by strong positive Nd and Hf isotopic signatures, making this part of the Kazakh Orogen the major area of juvenile crust formation in the Early Palaeozoic (Kröner *et al.* 2014). The units and their boundaries vary (Şéngör and Natal'in 1996; Apollonov 2000; Xiao *et al.* 2010; Degtyarev 2012); however, there is little doubt that they are terranes resulting from the amalgamation of several volcanic arcs including accretionary wedges and back-arc basins. The Ordovician faunas of the Boshchekul and Chingiz-Tarbagatai composite terranes are relatively well documented, whereas, in the other terranes, age constraints for the Lower Palaeozoic rocks are poor (Esenov *et al.* 1972; Nikitin *et al.* 1996). Although Cambrian and Ordovician trilobite collections were made by the late Nikolai Ivshin and Mikhail Apollonov, they are now inaccessible, and thus only the publications on the Ordovician rhynchonelliform brachiopods are available for our biogeographical assessment.

Chingiz-Tarbagatai Terrane

The Chingiz-Tarbagatai Terrane is an amalgamation of several Early Palaeozoic island arcs. In the north-east it is bordered by Ordovician to Devonian ophiolites and Middle Devonian to Carboniferous island arc volcanics of the Zharma-Saur Terrane (Şengör and Natal'in 1996). The tectonostratigraphical units recognised south-west of the Chingiz-Tarbagatai Terrane (simply termed 'Silurian to Carboniferous volcanic arcs and accretionary complexes' on Text-fig. 1) include the Bayanaul-Akbastau, Tekturmas and Dzhungar-Balkhash terranes of Şengör and Natal'in (1996), the Bakanas and Kazyk terranes of Apollonov (2000), and the north-eastern parts of the Dzhungar-Balkhash and Balkhash-Ili terranes of Xiao *et al.* (2010). They are mainly Silurian to Carboniferous island arc volcanics and sedimentary rocks, and Cambrian and Ordovician rocks are rare or absent, apart from a few Ordovician ophiolites (Nikitin 2001). They are most likely arc-prism-ophiolite complexes, as well as Silurian to Carboniferous volcanic arcs and backarc basins formed in front of the Ordovician volcanic arcs.

At some time in the Late Katian to Llandovery, there was arc to arc collision which resulted in amalgamation between the north-eastern component of the Chingiz-Tarbagatai Terrane and its south-western component (the south-eastern segment of the Baudaulet-Akbastau volcanic arc of Degtyarev 2012). The line of the suture is accentuated by allochthonous complexes of mafic and ultramaphic rocks and associated jaspers and radiolarian cherts (Zhylkaidarov 1998; Nikitin 2001; Degtyarev 2012; Stepanets 2015a). The polarity of subduction under the south-western component is uncertain (Degtyarev 2012, p. 150), while the existence of a sizeable accretionary complex along the south-western margin of Chingiz-Tarbagatai suggests that collision resulted from the migration of the magmatic front and repositioning of the subduction zone along the south-western margin of the terrane (Text-fig. 1).

The Late Ordovician (Sandbian to Hirnantian) rhynchonelliform brachiopods of the Chingiz Range are well documented (Nikitin and Popov 1984; Popov and Cocks 2014), but trilobite data came mostly from the Upper Ordovician of the Tarbagatai Range (Kolobova, 1972; 1983; Ghobadi Pour *et al.* 2011a, 2011c). The occurrence of *Dulanaspis*, *Pliomerina*, and *Sinocybele* in the latter assemblages is a clear signature of the Late Ordovician east Peri-Gondwana *Eokosovopeltis–Pliomerina* Fauna (Edgecombe and Webby 2006; Zhou and Zhou 2006).

Revised here are ten Sandbian (Faunas 21–28, 53, 54) and 11 Katian brachiopod faunas (73–76, 87–91, 93, 94) for biogeographical analysis (for more details see also Nikitin and Popov 1984; Pushkin and Popov 1990; Popov and Cocks 2014), and the stratigraphical positions of the discussed faunas are indicated on Text-fig. 3, while some characteristic genera are illustrated on Text-figs 4, 5.

Boshchekul Terrane

The Boshchekul Composite Terrane (Text-fig. 1) includes two major components representing Early Palaeozoic volcanic island arcs which collided during the Late Ordovician, forming a suture seen in the Maikain-Ekibastuz ophiolitic Belt (Nikitin *et al.* 2006, fig. 1). The western component of the Boshchekul Terrane is made up of the Ermentau-Niyaz Massif, probably representing a Cambrian remnant island arc, and an Ordovician volcanic arc and subduction-accretion complex, while between them a back arc basin developed in the Cambrian (Furongian) to Mid Ordovician. The spectrum of zircon ages from the Ermentau-Niyaz Massif (Kovach *et al.* 2014) overlaps with that of the Kalmykkol-Kokchetav Microcontinent (Degtyarev *et al.* 2015), and thus it is likely that Kalmykkol-Kokchetav was a source of crustal fragments from island arcs within the western component of the Boshchekul Terrane.

Olistoliths of shallow-water Furongian limestones in turbidites of the Satpak and Olenty formations, and radiolarian cherts of the lowermost Erzhan Formation (Popov and Holmer 1994) and the Akdym Group (Nikitin 1991) are good indications of extension and rapid subsidence of the area related to the development of a back arc basin and probable collapse of an island carbonate platform; however, no trace of extensive Furongian carbonate sedimentation has been found *in situ* in Boshchekul. It is possible that the Selety Terrane, which supported the Furongian carbonate platform (Selety Formation) and the Boshchekul Terrane are detached parts of a single Cambrian tectonostratigraphical unit, but the evidence is inconclusive. Stepanets (2015a, p. 47, fig. 2) concluded that basalts associated with the Akdym Series probably belong to a back-arc basin developed on the sialic crust. If true, the northern segment of the Ermentau-Yili Unit of Windley *et al.* (2007), Alekseev *et al.* (2011), Bazhenov *et al.* (2012), and Wilhelm *et al.* (2012) (= Akdym Unit of Şengör and Natal'in, 1996, p. 520) was not an Ordovician accretionary wedge developed in front of the island arc active margin, but a backarc basin, which probably closed sometime in Late Katian time and is characterised by widespread olistostrome formation (Borisyenok *et al.* 1985). It was probably also the time when amalgamation of the eastern and western components of the Boshchekul Terrane occurred. In contrast, the extensive accretionary wedge in front of the Chu-Ili Terrane continued to grow throughout the Silurian and Early Devonian (Bandaletov and Palets 1980; Popov *et al.* 2009).

Şengör and Natal'in (1996) and other authors considered that the western component of the Boshchekul Terrane is a detached segment of the Chingiz-Tarbagatai island arc, but that is rather unlikely from faunal and sedimentological data. Unlike Chingiz-Tarbagatai, no Furongian volcanic activity is reported in western Boshchekul.

There is no record of Dapingian and Darriwilian brachiopod and trilobite faunas within the Boshchekul Terrane. Only three species were documented by Nikitin (1974), and Nikiforova and Popov (1981) from the moderately diverse Sandbian fauna of Boshchekul; however, significant undescribed Sandbian collections (now in the National Museum of Wales) are analysed here. By the Mid Katian, there was ongoing collision between island arcs in the eastern and western components of the Boshchekul Terrane which resulted in thrusting, the formation of olistostromes (including olistoliths of intra-subduction complex serpentinite), volcanics and cherts (Stepanets *et al.* 1998; Stepanets and Gridina 2011), and the extensive growth of organic build-ups with brachiopod faunas (Nikitin *et al.* 2006).

The Early Palaeozoic lithostratigraphy and geological history of the eastern component of the Boshchekul Terrane, east of the Maikain-Ekibastuz ophiolitic belt, was revised by Stepanets *et al.* (2014). The age constraints for the Cambrian part of the Early Palaeozoic succession are poor and based on a single occurrence of *Kutorgina* identified by Gorjansky (in Esenov *et al.* 1972). The Lower to Middle Ordovician part of the succession dated by conodonts is of island arc volcanics, radiolarian cherts, and siliciclastic sediments (including turbidites), which were probably deposited in a back arc-basin. There is no evidence of volcanic activity in the Late Ordovician, and carbonate sedimentation commenced during the

Katian, when limestones of the Keregetas Formation included diverse brachiopod and trilobite faunas associated with organic build-ups. The Mid Katian brachiopod fauna of the Keregetas Limestone is similar to the contemporaneous fauna of carbonate build-ups on the opposite side of the Maikain-Ekibastuz ophiolitic belt (Nikitin *et al.* 2006), suggesting free faunal exchange. Stepanets *et al.* (2014) argued for possible older continental crust reworking, which makes association of this terrane with the Chingiz-Tarbagatai island arcs unlikely; however, that requires further study. Data on the Late Ordovician brachiopod faunas of the Boshchekul Terrane is incomplete, although faunal diversity is underestimated, but the six Late Ordovician brachiopod associations (Faunas 19, 20, 52, 72, 85, 86) are distinct enough for biogeographical assessment. Their positions are indicated on Text-fig. 3, and more details are in the Appendix, Nikitin (1974), Nikiforova and Popov (1981), and Nikitin *et al.* (2006).

Selety Terrane

The Selety unit was interpreted by Degtyarev (2012) as a Cambrian volcanic arc which became inactive in the Furongian and Ordovician (Nikitin 1991). The timing of the amalgamation of the Selety terrane with the Kalmykkol-Kokchetav Microplate is uncertain, but was probably after the Katian. Three Early Katian faunas of different benthic associations (Faunas 77–79) are used for the biogeographical assessment of the Selety Terrane, and their stratigraphical positions are on Text-fig. 3 (for more details see Nikitin *et al.* 2003).

Kalmykkol-Kokchetav Microcontinent

As well as the core Kalmykkol-Kokchetav Microcontinent, this includes the Kokchetav and Shat units. The Early Palaeozoic history of Kalmykkol-Kokchetav was told by Dobretsov *et al.* (2006), Korobkin and Smirnov (2006) and Degtyarev *et al.* (2016). In spite of some inconsistencies, the data in those papers indicate that the microcontinent does not represent the northern extensions of tectonostratigraphic units today further south, as inferred, for example, by Degtyarev and Ryazantsev (2007) and Alekseiev *et al.* (2011), but those units have different geological histories, as shown by the timings of major accretionary events, origin and direction of subduction, and sedimentary history. The spectrum of zircon ages from the Ermentau-Niyaz Massif (Kovach *et al.* 2014) overlaps significantly with those of the Kalmykkol-Kokchetav Microcontinent (Degtyarev *et al.* 2015). Thus it is likely that Kalmykkol-Kokchetav was a source of crustal fragments within the western of the Boshchekul Terrane. The Precambrian zircon age spectra of Kalmykkol-Kokchetav have no similarity with those of Tarim and North Tien Shan (Degtyarev *et al.* 2015, p. 587), although Kröner *et al.* (2012) stated that Late Precambrian zirconic spectra of North Tian Shan show similarity to ‘Mid Tien Shan’ (= Karatau Naryn) and Tarim.

There is little evidence of a shallow marine sedimentation on the flanks of the Kokchetav Massif (Esenov *et al.* 1972; Nikitin 1991; Degtyarev 2016, fig. 1), suggesting a general uplift and deep erosion. The Cambrian (Furongian) to Mid Ordovician biostratigraphy is based on conodonts and radiolarians, which occur in the thin pelagic layers of the siliciclastic rocks representing turbidites, which were deposited on the flanks of the linear structures, probably, continental rifts. One of the rifts separated the Kokchetav and Shat Precambrian massifs, while another (the ‘Chirtopolie Zone’) separated the Kokchetav Massif from the Kalmykkol Zone. Some of them could have reached the stage of the Red Sea rift today. Development of rift systems then is supported by the rift-related volcanism and plutonism in the Kokchetav and Stepnyak units (Degtyarev *et al.* 2012, 2016), although, the Chirtopolie Zone cannot be considered an oceanic suture, as inferred by Degtyarev *et al.* (2016), because the sedimentation within the zone is not characteristic of an accretionary wedge. Also, the continuous Cambrian (Furongian) to Mid Ordovician sedimentation, represented almost exclusively by gravity-transported deposits on both flanks of developing rift systems and the associated conodont faunas (Tsai *et al.* 2001; Degtyarev *et al.* 2016) do not indicate any major ‘Arenig unconformity’. There was also no island arc volcanism then. By the beginning of the Late Ordovician, the rifting had failed and, after thermal relaxtion and subsidence, the eastern margin of the Kokchetav-Kalmykkol microcontinent was flooded by shallow sea. The island arc volcanism occurred in the area much later, in the Late Katian (Nikitin 1972, 1973, 1991).

The Stepnyak unit (Text-fig. 1) was interpreted by Dobretsov *et al.* (2006), and Korobkin and Smirnov (2006) as an Ordovician volcanic arc and backarc basin, which docked to the east margin of Kalmykkol-Kokchetav microcontinent sometime in the Mid Ordovician. However, Degtyarev (2012) argued that intensive Early to Mid Ordovician volcanism in the region occurred within a continental rift system, while island arc related volcanism is occurred in the Late

Darriwilian-Katian, which has good support from the geological data in the cited publication. Although, Late Ordovician granitic magmatism in the Stepnyak Unit suggests an Andean- or Japanese-type continental arc environment (Kröner *et al.* 2007) at that time.

The Selety and Stepnyak units are separated by the Ishkeolmes unit of Şengör and Natal'in (1996), who interpreted it as an accretionary wedge which might have been formed in front of the Stepnyak volcanic arc, but the polarity of subduction is uncertain. Pure ribbon-banded radiolarian cherts of the Ishkeolmes and Iradyr formations contain a sequence of conodonts from the Cambrian (Furongian) *Eoconodontus notchpeakensis* Biozone to the Lower Ordovician (Floian) *Prioniodus elegans* Biozone (Tolmacheva and Degtyarev 2012). Such continuous sedimentation of radiolarian oozes for almost 15 my suggests oceanic separation between the Selety and Stepnyak island arcs in those times. The records of Ordovician brachiopod faunas from the Kalmykkol-Kokchetav and Stepnyak terranes are the best for the Early Katian (Faunas 67–71), while only three Sandbian brachiopod associations are documented (Faunas 18, 50, 51), as shown in Text-fig. 3 and in the Appendix.

Atashu-Zhamshi Microcontinent

The only significant block with Precambrian basement within this area is the Atashu-Zhamshi Microcontinent of Apollonov (2000), which is partially equivalent to the Atasu-Mointy unit of Şengör and Natal'in (1996). Within the Kazakh Orogen it is the only sizeable region apart from Malyi Karatau where carbonate sedimentation occurred with little interruption from the Ediacaran to the Mid Ordovician (Apollonov *et al.* 1990; Nikitin *et al.* 1991). The outcrop areas of the Ordovician deposits within Atashu-Zhamshi are very small and patchy; although they are mostly confined to the western side of the terrane (Text-fig. 1). The south-western margin of Atashu-Zhamshi faces the extensive Silurian to Devonian accretionary wedge which formed in front of the Chu-Ili Terrane (which was not a part of Atashu-Zhamshi as sometimes averred). The Late Ordovician plate boundary, as reassessed here, largely coincided with the western margin of the Lower Palaeozoic carbonate platform and is delineated by deposits of Cambrian (Furongian) to Middle Ordovician carbonate slope rise deposits and pelagic carbonates with radiolarians and trilobites characteristic of the olenid biofacies (Apollonov *et al.* 1990; Pouille *et al.* 2013; 2014) (Text-fig. 1.7). These plate boundary markers are almost as good as ophiolites. Further south, there are upper Cambrian carbonate turbidites, lower Ordovician radiolarian cherts, and Darriwilian deep water limestones with radiolarians and hexactinellide sponges in the area north-east of Sarykumy railway station (Text-fig. 1.6), while radiolarian cherts of the Mid to Upper Ordovician Itmurundy, Kazyk, and Turetai formations (Text-fig. 1.11) obducted onto the plate margins indicate its south-eastern limits. In spite of being scattered, those Ordovician localities indicate strongly that the southern margin of the Ordovician Atashu-Zhamshi Microcontinent mainly follows the northern coast of Lake Balkhash, and the significant southward extension of the terrane suggested by Apollonov (2000), Degtyarev (2012), and Xiao *et al.* (2015) looks unlikely (Text-fig. 1). The Tekeli area has also been considered as a southern prolongation of the terrane, but there is little evidence for that. The north and north-eastern Atashu-Zhamshi Microcontinent shows passive margin development through the Cambrian to the Mid Ordovician, while the Late Ordovician was the time of subduction and island arc volcanism. The Tecturmas Unit north of Atasu-Zhamshi (Antonyuk *et al.* 2015; Stepanets 2015b) is probably a volcanic arc and back-arc basin which docked to Atasu-Zhamshi sometime in the Silurian.

The Atashu-Zhamshi Microcontinent was probably the final unit to join the Kazakh orogenic collage. It is separated from the south-western and north-eastern Kazakh terrane clusters by extensive accretionary wedges, including Silurian to Upper Palaeozoic deposits, while Ordovician to Permian island arc volcanism is evident along the north-eastern margin of the terrane (Esenov *et al.* 1972; Seitmuratova 2002).

COMPARATIVE ANALYSIS OF THE BRACHIOPOD FAUNAS

Significant progress has been made in our knowledge of Kazakh brachiopod faunas over the past twenty years. Biogeographical analysis of the Late Ordovician Kazakh brachiopod faunas here is based on the extensive database assembled by the authors, which includes 160 rhynchonelliform and craniiform genera and subgenera from 234 localities in Kazakhstan and 124 localities from Kyrgyzstan grouped into 94 individual faunas. Genus-level similarity between the faunas within each time slice is based on presence-absence data measured using the Raup-Crick Similarity Index, which is calculated via a 'Monte-Carlo' randomization procedure to determine the frequency of a comparable similarity level in two hundred randomly replicated samples of the same size (Raup and Crick 1979). The resulting cluster analyses were identified by using the PAST programme (Hammer *et al.* 2001; Hammer and Harper 2006). The advantage of the Raup-Crick cluster analysis is that it performs better by comparison with other multivariate techniques when it is applied to datasets with significant variations in the diversity in the analysed samples. That is supported in a number of publications (e.g. Nikitin *et al.* 2006; Percival *et al.* 2011; Harper *et al.* 2013; Sohrabi and Jin 2013). The Jaccard similarity index was also used in the assessment of the biogeographical separation of the faunas in the different Kazakh terranes. In addition, the same dataset for the Katian Kazakh faunas was subjected to a Principal Component Analysis. That binary dataset is suitable for analysis through the variance-covariance algorithm of the PAST software (Hammer *et al.* 2001; Hammar and Harper 2006).

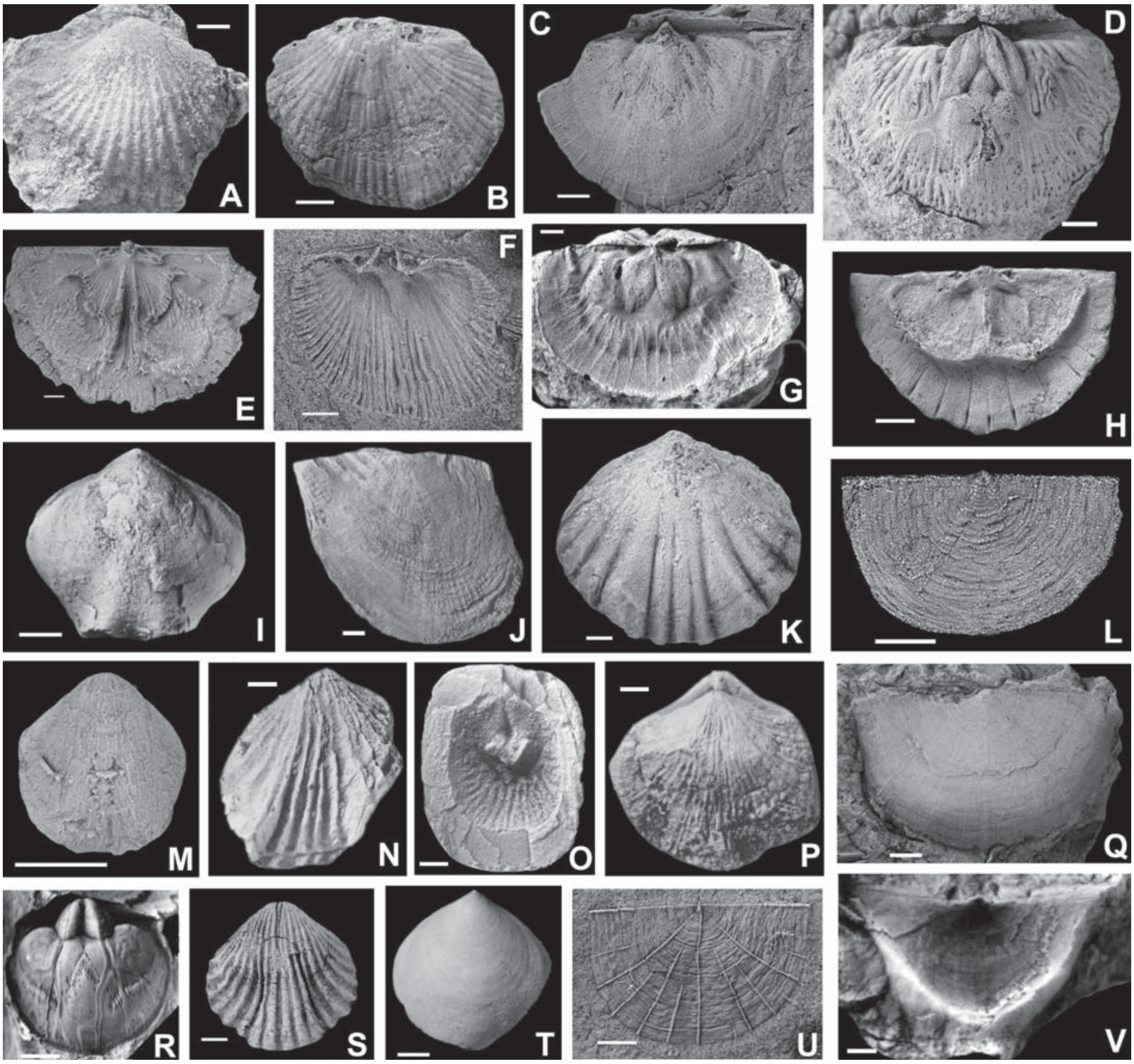
LATE ORDOVICIAN HISTORY OF THE KAZAKH OROGEN

The arrival of the Palaeozoic Evolutionary Fauna (PEF) in the extensive Kazakh terrane area was relatively late and also diachronous. The oldest diverse brachiopod dominated communities with the characteristic biota of the PEF are in the Early Darriwilian of the Chu-Ili Terrane (Nikitina *et al.* 2006), but their arrival was delayed until the latest Darriwilian or Early Sandbian for the Chingiz-Tarbagatai Terrane and for the Kalmykkol-Kokchetav units, as well as for the adjacent island arcs. That suggests that the Kazakh terranes were at some distance from the major continents at the time.

A number of the Darriwilian brachiopods from Chu-Ili, including *Aporthophyla*, *Idiostrophia*, *Leptella*, *Leptellina*, *Neostrophia*, *Taphrodonta*, *Toquimia*, and *Trematorthis*, can be considered as pantropical components of the Darriwilian fauna. However, substantial endemism developed rapidly during the Darriwilian in the Chu-Ili fauna, and up to 47% of the genera there are either local endemics, or neoendemics not known from rocks of Darriwilian age elsewhere. Another feature of the shallow shelf Darriwilian brachiopod assemblages in Chu-Ili is the occurrence of genera such as *Martellia* and *Yangtzeella*, which are unknown from the Darriwilian of the Australasian sector of Gondwana or from other Kazakh terranes, but characteristic of temperate latitude peri-Gondwanan faunas of the South China Continent and the Iranian and Turkish Tauride terranes (Cocks and Fortey 1988; Percival *et al.* 2009; Ghobadi Pour *et al.* 2011b). That may suggest that the south-western cluster of Kazakh terranes and microcontinents (Chu-Ili, North Tien Shan, and Karatau Naryn) was relatively near South China, unlike other parts of Kazakhstan. That is supported by the occurrence of the Early Ordovician (Floian) trilobite *Tanhungshania* in Karatau-Naryn, which is otherwise known from South China and temperate latitude peri-Gondwana (Alborz, Turkish Taurides, and Armorica), but is unknown elsewhere in Kazakhstan, or in the Australasian sector of Gondwana (Popov *et al.* 2009). In contrast, reedocalymenine trilobites and the *Saucrorthis* Brachiopod Association, common in South China, are unknown from the Kazakh terranes (Turvey 2005b; Ghobadi Pour *et al.* 2011c; Percival *et al.* 2011).

Early Sandbian invasion

Near Mid to Late Ordovician boundary time, brachiopod assemblages with characters typical of the Palaeozoic Evolutionary Fauna spread across all the major Kazakh terranes, and their diversity increased up to as many as 50 genera. However, some key faunas are still inadequately published, although we have made preliminary identifications of the generic composition of some faunas based from the available collections. The most diverse Late Dariwillian to Early Sandbian brachiopod faunas are from the Chu-Ili Terrane, where 41 rhynchonelliform genera and one craniiform have been documented (Nikitina *et al.* 2006). Thirty five (85%) of those are newcomers, and not represented in the earlier Darriwilian faunas. Between them, 9 genera (22%) are unknown in the Sandbian of other Kazakh terranes, while only two (*Synambonites* and *Testaprica*) were Kazakh endemics during the Sandbian. High turnover rates and the extinction of a significant part of the Darriwilian fauna resulted in the substantial reorganisation of benthic communities. In the assemblages of the shallow shelf (BA2), the most significant feature was the proliferation of the oligotaxic to monotaxic rhynchonellide-dominated *Ancistrorhyncha* Association (Table 2; faunas 1 and 7). The restricted carbonate shelf on the side of Chu-Ili facing the North Tien Shan Terrane was inhabited by the medium-diversity mixed strophomenoid-plectorthoid *Scaphorthis*–*Strophomena* Association (Table 2, BA2; Fauna 2) and the Plectorthoid Association (Table 2, BA3; Faunas 3 and 4). The latter is characteristic of dasyclad-bearing limestones and occupied a similar envi-



Text-fig. 4. Key Sandbian brachiopods from the Kazakh terranes useful as palaeogeographical indicators. A, *Ancistrorhyncha modesta* Popov in Nikiforova and Popov, 1981, Chu-Ili Terrane, area c. 5 km south-west of Alakol Lake, unnamed formation (Sa1); NMW 98.28G.1976, dorsal valve exterior. B, *Esilia* cf. *tchetverikovae* Nikitin and Popov, 1985, Chu-Ili Terrane, area c. 7 km south-west of the Alakol Lake, unnamed formation (Sa1); BC 62426, ventral view of conjoined valves. C, *Ishimia mediasiatica* Misius, 1986, Chu-Ili Terrane, area c. 4 km south-west of the Alakol Lake, unnamed formation (Sa1); BC 62352, ventral internal mould. D, *Dulankarella larga* Popov, Cocks & Nikitin, 2002, Chu-Ili Terrane, area c. 4 km south-west of Alakol Lake, unnamed formation (Sa1); BB 52376, ventral internal mould. E, *Isophragma princeps* Popov, 1980, Chu-Ili Terrane, area c. 4 km south-west of Alakol Lake, unnamed formation (Sa1); BC 62350, ventral internal mould. F, *Scaphorthis recurva* Nikitina, 1985, North Tien Shan Terrane, southern Kendyktas Range, Rgaity Formation (Da3–Sb1); NMW 98.66G.980, latex cast of dorsal valve interior. G, *Tesikella necopina* (Popov, 1980), Chu-Ili Terrane, Kopalysai, Anderken Formation (Sa2); BC 56881, ventral internal mould. H, *Acculina acculica* Misius *in* Misius and Ushatinskaya, 1977, Chu-Ili Terrane, area c. 4 km south-west of the Alakol Lake, unnamed formation (Sa1); BC62369, latex cast of dorsal valve interior. I, *Parastrophina plena* Sapelnikov and Rukavishnikova, 1975, Chu-Ili Terrane, Kuyandysai, Anderken Formation (Sa2); BC 57562, dorsal view of conjoined valves. J, *Colaptomena insolita* (Nikitina, 1985), Chu-Ili Terrane, southern Betpak-Dala desert, area c. 7 km south-west of Baigara Mountain Baigara Formation (Da3); NMW 98.28G.924, ventral view of conjoined valves. K, *Camerella* sp., Boshchekul Terrane, Ekibastuz Region, Sarybidaik, Sarybidaik Formation (Sa1); NMW 98.65G.2651, ventral view of conjoined valves. L, *Foliomena* sp., Kalmykkol-Kokchetav terrane, Akkan-Burluk River, Andryushenka Formation (Sa1); NMW 2014.26G.9, latex cast of ventral exterior. M, *Rozmanospira mica* (Nikitin and Popov, 1984), Chu-Ili Terrane, area c. 7 km south-west of the Alakol Lake, unnamed formation (Sa1); NMW 98.28G.1989, ventral view of conjoined valves. N, *Plectocamara* sp., Chu-Ili Terrane, southern Betpak-Dala desert, area c. 7 km south-west of Baigara Mountain, Baigara Formation (Da3); NMW 98.28G.2155, ventral view of conjoined valves. O, *Pseudocrania karatalensis* Popov in Nazarov and Popov, 1980, Chu-Ili Terrane, southern Betpak-Dala Desert, Karatal Dry River, Baigara Formation (Sa1); ventral valve interior. P, *Sonkulina* cf. *prima* Misius, 1986, NMW96.28G.1866, Chu-Ili Terrane, southern Betpak-

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Benthic assemblage	Normal current activity		Organic build-ups, medium to high diversity	Quiet water, disaerobic conditions may develop
	low to medium diversity	medium to high diversity		
1				
2	*Pseudolingula–Kopella* Association *Aporthophyla* Association			
3	Assemblage with *Leptellina*	*Martellia–Pomatotrema* Association		
4	Assemblage with *Leptellina* and *Asperdelia*	*Taphrodonta* Association		*Metacamerella* Association
5				

Table 1. Early to Mid Darriwilian (Time slices Da1-2) community framework for the Chu-Ili Terrane

Benthic assemblage	Normal current activity		Generally quiet, affected by seasonal storms	Quiet waters, disaerobic conditions may develop
	low to medium diversity	medium to high diversity		
1				
2	*Ancistrorhyncha* Association *Testaprica* Association		*Scaphorthis–Strophomena* Association	
3	*Acculina* Association	*Eoanastrophia* Association	*Plectorthoid* Association	
4				*Bimuria–Grammoplecia* Association
5				

Table 2. Latest Darriwilian to Early Sandbian (Time Slices Da3-Sa1) community framework for the Chu-Ili Terrane

ronment as the Early to Mid Darriwilian *Martellia–Pomatotrema* Association (Table 1, BA3), although the genera were different. At the opposite side of the Chu-Ili Terrane, dasyclad-bearing algal limestones contain the *Eoanastrophia* Association (Table 2, BA3; Faunas 12 to 15), which, unlike the Plectorthoid Association, lacks distinct dominant taxa, while plectorthoids, strophomenoids and plectambonitoides are represented by different genera, apart from *Sowerbyella*, which is present in both associations.

The *Testaprica* Association (Table 2, BA2; Fauna 10) occupied a similar environment to the *Scaphorthis–Strophomena* Association. In both, strophomenoids and plectorthoids are dominant, while *Strophomena* is replaced by *Testaprica* and *Scaphorthis* by a new plectorthid genus related to *Plectorthis* itself. There is also the *Acculina* Association, which is dominated by plectambonitoid taxa, with *Acculina* and *Sowerbyella* as the most abundant, and often includes *Bandaleta*, *Dulankarella*, *Ishimia*, *Isophragma*, and *Mabella* as minor components (Text-fig. 4). That was the precursor of the eponymous association which was widespread across the Chu-Ili Terrane during the Late Sandbian (Popov *et al*. 2002).

The *Bimuria–Grammoplecia* Association (Table 2, BA4; Faunas 5 and 6) is the only association of the outer shelf yet documented in Chu-Ili. Its characteristic feature is the occurrence of *Bimuria*, which has a short stratigraphical range within the Chu-Ili Terrane, and is confined to the Early Sandbian. Two other characteristic genera are *Grammoplecia* and *Kajnaria*, which subsequently moved into a different environment associated with carbonate mud-mounds.

It is likely that numerous endemic genera among the plectambonitoid families Leptellinidae, Palaeostrophomenidae, and Plectambonitidae from the Early Sandbian of Chu-Ili (Text-fig. 4; *Bandaleta*, *Dulankarella*, *Kajnaria*, *Ishimia*, *Mabella*, and *Shlyginia*) evolved as result of phyletic radiation in local lineages, since representatives of those families had also been present in the Darriwilian. The same is probably true for *Christiania*; but other strophomenoids, such as *Colaptomena*, *Glyptomena*, *Limbimurina*, and *Strophomena* (*Strophomena*), were newcom-

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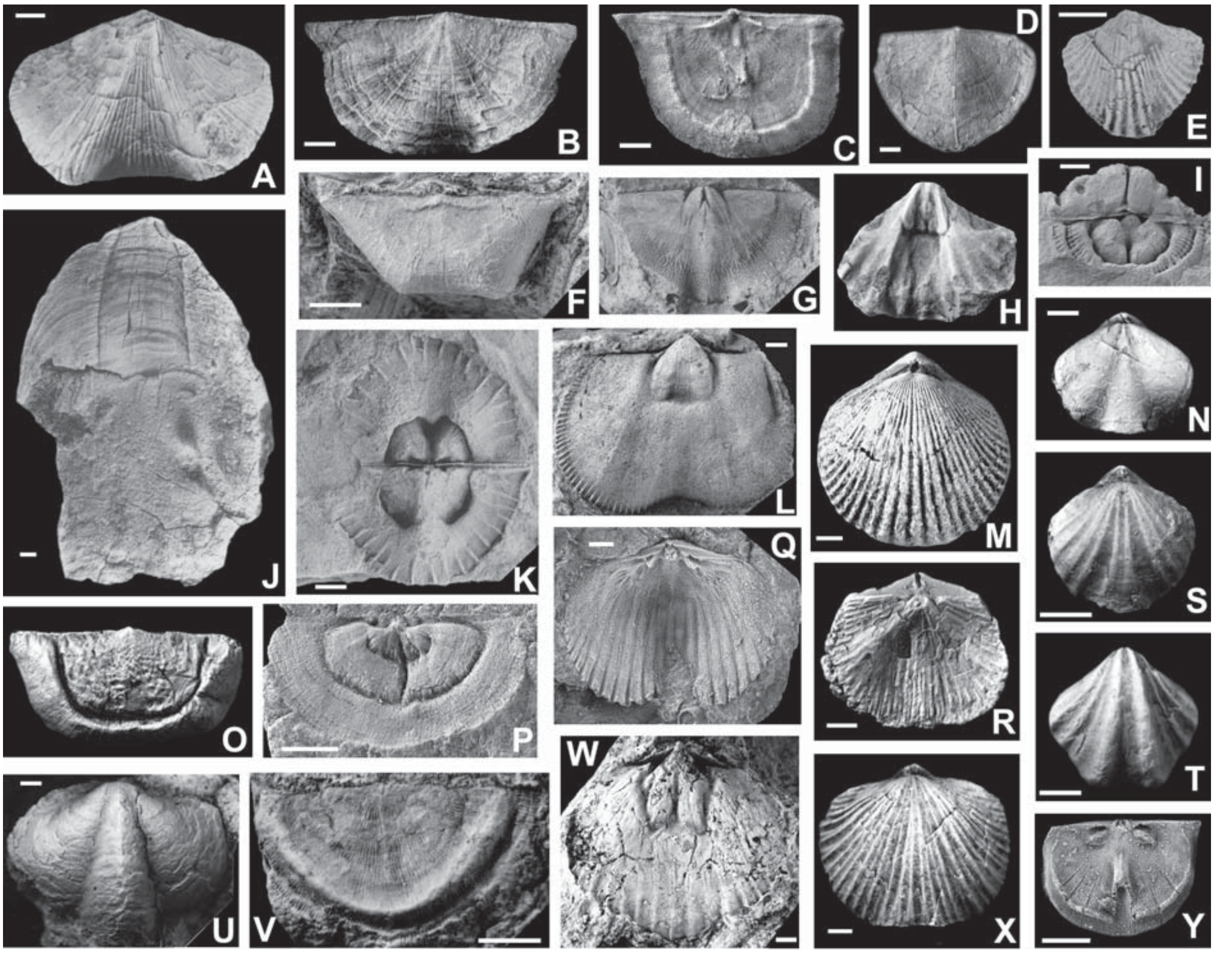
Dala Desert, Karatal Dry River, Baigara Formation (Sa1); CNIGR 251/11352, dorsal view of a pair of conjoined valves. Q, *Shlyginia fragilis* (Rukavishnikova, 1956), Boshchekul Terrane, Amambaisor Lake, Bayan Formation (Sb2); NMW 98.65G.2751, ventral valve exterior. R, *Mabella conferta* (Popov, 1985); Chu-Ili Terrane, Kopalysai, Anderken Formation (Sb2); BC 57443, ventral internal mould. S, *Eoanastrophia kurdaica* Sapelnikov and Rukavishnikova, 1975, Chu-Ili Terrane, area c. 7 km south-west of Alakol Lake, unnamed formation (Sa1); NMW 98.28G.1981, dorsal view of conjoined valves. T, *Liostrophia pravula* Popov *et al.*, 2002, Chu-Ili Terrane, Kuyandysai (Sa2); BC 57550, dorsal view of conjoined valves. U, *Tenuimena* aff. *planissima* Nikitina *et al.*, 2006, Chu-Ili Terrane, West Balkhash Region, area c. 7 km south-west of Alakol Lake, unnamed formation (Sa1); BC62406, latex cast of dorsal valve exterior. V, *Craspedelia tata* Popov, 1980, Chu-Ili Terrane, Anderkenyn Akchoku, Anderken Formation (Sa2); BC 57410, dorsal valve exterior



Text-fig. 5. Key Katian brachiopods from the Kazakh terranes useful as palaeogeographical indicators. A, *Qilianotryma suspectum* (Popov in Nikiforova *et al.*, 1982); Chu-Ili Terrane, Dulankara Mountains, Dulankara Formation, Akkol Member (Ka2); CNIGR 25/11943, holotype, ventral view of conjoined valves. B, *Holtedahlina orientalis* Popov and Cocks, 2006, Chu-Ili Terrane, Dulankara Mountains, Dulankara Formation, Degeres Member (Ka2), BC 57819, latex cast of ventral exterior. C, *Platymena tersa* Popov and Cocks, 2006, Chu-Ili Terrane, Dulankara Mountains, Dulankara Formation, Degeres Member (Ka2), BC 57622, latex cast of dorsal interior. D, *Sortanella quinquecostata* Nikitin and Popov, 1996, Chu-Ili Terrane, northern Betpak-Dala Desert, unnamed formation (Ka1); CNIGR 12877, ventral view of conjoined valves. E, *Pusillaguta gibbera* Misius, 1986, Chingiz-Tarbagatai Terrane, Ashchisu River, Taldyboi Formation (Ka1); NMW 2001.38G.625, ventral view of conjoined valves. F, *Nikitinamena bicostata* Popov and Cocks, 2006, Chu-Ili Terrane, Dulankara Mountains, Dulankara Formation, Degeres Member (Ka2); BC 57717, ventral valve exterior. G, *Gunningblandella* sp., Chu-Ili Terrane, Dulankara Mountains, Dulankara Formation, Degeres Member (Ka2); BC 57712, ventral internal mould. H, *Ogmoplecia nesca* Popov and Cocks, 2006, Chu-Ili Terrane, Dulankara Mountains, Dulankara Formation, Degeres Member (Ka2); BC 57618, ventral internal mould. I, *Kassinella kasbalensis* Popov and Cocks, 2014, Chingiz-Tarbagatai Terrane, Akdombak Mountain, Akdombak Formation (Ka1); BC 58707, holotype, internal moulds of disarticulated valves. J, *Palaeotrimerella medojevi* Popov *et al*. 1997, Chu-Ili Terrane, West Balkhash Region, Burultas valley; Dulankara Formation (Ka1), PMKz38, X1.5, holotype, ventral valve interior (Popov *et al.* 1997, fig. 8.1). K, *Metambonites subcarinatus* Popov and Cocks, 2006, Chu-Ili Terrane, Dulankara Mountains, Dulankara Formation, Degeres Member (Ka2); BC 57733, holotype, internal moulds of disarticulated valves. L, *Weberorthis brevis* (Rukavishnikova, 1956), Chu-Ili Terrane, Dulankara Mountains, Dulankara Formation, Degeres Member (Ka2); BC 57749, ventral internal mould. M, *Rongatrypa zvontsovi* Nikitin *et al.* 2006, Selety Terrane, west side of Selety River, Tauken Formation (Ka1); NMW98.30G.54, holotype, dorsal view of conjoined valves. N, *Nikolaispira tripartita* Nikitin *et al.*, 2006, Boshchekul Terrane, Odak, Angrensor Formation (Ka2–3), NMW 98.65G. 1929, dorsal view of conjoined valves. O, *Leptaena* (*Ygdrasilomena*) *reticulata* Nikitin *et al.*, 2006, Boshchekul Terrane, Odak, Angrensor Formation (Ka2–3), NMW 98.65G.432, ventral valve exterior. P, *Diambonioidea koknaiensis* Popov and Cocks, 2014, Chingiz-Tarbagatai Terrane, Akdombak Mountain, Akdombak Formation (Ka2–3); BC 58716, dorsal internal mould. Q, *Bokotorthis abayi* (Klenina, 1984), Chingiz-Tarbagatai Terrane, Ashchisu River, Taldyboi Formation (Ka1); NMW 2001.38G.465, latex cast of dorsal interior. R, *Epitomyonia* cf. *glypha* Wright, 1968, Boshchekul Terrane, Odak, Angrensor Formation (Ka2–3), NMW 98.65G.897, ventral valve exterior. S, *Sulcatospira prima* Popov *et al.*, 1999; Boshchekul Terrane, Koskarasu, Koskarasu Beds (Ka1); NMW 98.65G.1780, dorsal view of conjoined valves. T, *Pectenospira* aff. *pectenata* Popov *et al.*, 1999; Boshchekul Terrane, Odak, Angrensor Formation (Ka2–3); NMW 98.65G.1864, ventral view of conjoined valves. U, *Odakella odakensis* Nikitin *et al.*, 2006, Boshchekul Terrane, Odak, Angrensor Formation (Ka2–3); NMW 98.65G.2182, dorsal valve exterior. V, *Synambonites ricinium* Nikitin *et al.*, 2006, Boshchekul Terrane, Odak,

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Benthic assemblage	Normal current activity			Organic build-ups, medium to high diversity	Generally quiet, affected by seasonal storms	Quiet waters, disaerobic conditions may develop
	low to medium diversity		medium to high diversity			
1	*Ectenoglossa* Association					
2	*Scaphorthis* Association	*Stophomena* Association			*Usunia* Association	
3	*Ancistrorhyncha* Association	*Palaeotrimerella* Association		*Rozmanospira* Association		
	Camerella Association					
4			*Bimuria* Association			
5						Linguliform microbrachiopod−hexactinellide sponge association

Table 3. Early Sandbian (Time Slice Sa1) community framework for the Chingiz-Tarbagatai Terrane

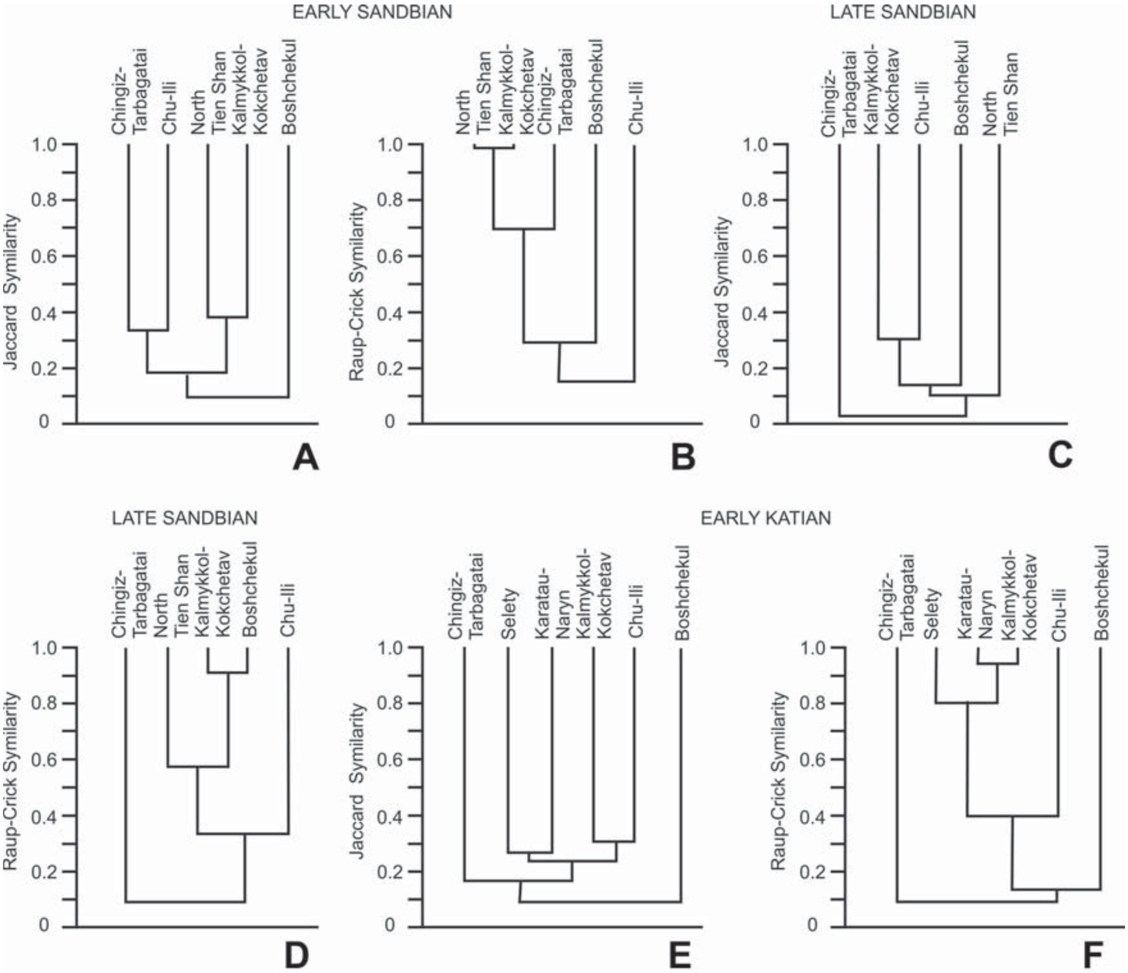
ers which immigrated from other areas, many from South China (Zhan *et al.* 2013). Plectorthids apart from *Scaphorthis* (Text-fig. 4F) are represented by local endemics, but that family is unknown in the Darriwilian of the Kazakh terranes.

In contrast to Chu-Ili, only nine rhynchonelliform brachiopod genera are known from the Early Sandbian (Rgaity Formation) of North Tien Shan (Nikitina 1985), whilst a local variant of the *Scaphorthis–Strophomena* Association (BA2; Fauna 16) occurs in the part of the Chu-Ili facing the north-eastern margin of North Tien Shan. Apart from *Oepikina*, which is otherwise unknown in the Kazakh terranes, and *Paralenorthis* (= *Orthambonites*), which is present in the Early to Mid Darriwilian of Chu-Ili, but absent from the Sandbian, all the other taxa (e.g. *Acculina acculica* Misius in Misius and Ushatinskaya, 1977 (= *A. villosa* Nikitina, 1985), *Colaptolepta* (= *Macrocoelia*) *insolita* Nikitina, 1985 (Text-fig. 4J), *Scaphorthis recurva* Nikitina, 1985 (Text-fig. 4F), *Strophomena rukavishnikovae* Nikitina, 1985) are in common with the *Scaphorthis–Strophomena* Association from the lower part of the Baigara Formation in Chu-Ili. The same is true for the low diversity fauna in the *Ishimia* Beds (Fauna 17) of the Tabylgaty Formation (Text-fig. 3) in the Moldo-Too Range (Misius, 1986). That assemblage represents a local variety of the Plectorthoid Association (Table 2), which, as well as in North Tien Shan, also occurs in the Kalmykkol-Kokchetav Terrane. The rhynchonellide dominated associations and rich BA2–3 faunas from Chu-Ili do not occur in North Tien Shan. That might be a consequence of separation between Chu-Ili and Tien Shan, which prevented free faunal exchange in both directions, or perhaps the high proportion of species in the Early Sandbian faunas of North Tien Shan, which are identical to those from Chu-Ili, may have been caused by conditions favourable for faunal dispersal from North Tien Shan, where there was much volcanism.

In the Kalmykkol-Kokchetav Terrane a medium-diversity brachiopod fauna of Early Sandbian age is known from a single locality (Sample 1524, Fauna 18) in the Kupriyanovka Formation (Text-fig. 3). That assemblage is a local variety of the Plectorthoid Association. Most of the genera are in common with North Tien Shan and Chu-Ili; however, *Colaptomena*, *Ishimia*, and *Strophomena* (*Strophomena*) are represented by endemic species unknown elsewhere in Kazakhstan.

The Early Sandbian brachiopods from the Chingiz-Tarbagatai Terrane were documented by Nikitin and Popov (1984). The fauna described by Klenina (1984) from the Abai Formation is not Darriwilian (= Llanvirn in Klenina's paper), but Sandbian; however, apart from *Bicuspina* and possibly *Sowerbyella*, all the generic identifications in that paper are doubtful. Shoal complexes (BA2) there were populated by *Scaphorthis* and *Strophomena* in monotaxic or oligotaxic assemblages (Table 3; Faunas 21, 22 and 28), unlike in Chu-Ili and North Tien Shan. These were probably opportunistic taxa which had newly migrated into the region. In Chingiz-Tarbagatai there is the Bestamak Limestone, which is the earliest Kazakh record of carbonate mud-mounds, which was part of a chain of carbonate build-ups extending for more than 60 km. The brachiopods in the build-ups includes the earliest trimerellides (Nikitin and

Angrensor Formation (Ka2–3); NMW 98.65G.446, dorsal valve exterior. W, *Dinorthis taukensis* Nikitin *et al.*, 2003, Selety Terrane, west side of Selety River, Tauken Formation (Ka1); NMW 98.30G.30, ventral internal mould. X, *Eospirigerina milleri* Nikitin *et al.*, 2006, Boshchekul Terrane, Odak, Angrensor Formation (Ka2–3); NMW 98.65G. 1690, dorsal view of conjoined valves. Y, *Mabella multicostata* (Rukavishnikova, 1956), Kalmykkol-Kokchetav terrane, Akkan-Burluk River, NMW 2014.26G.44, latex cast of dorsal interior

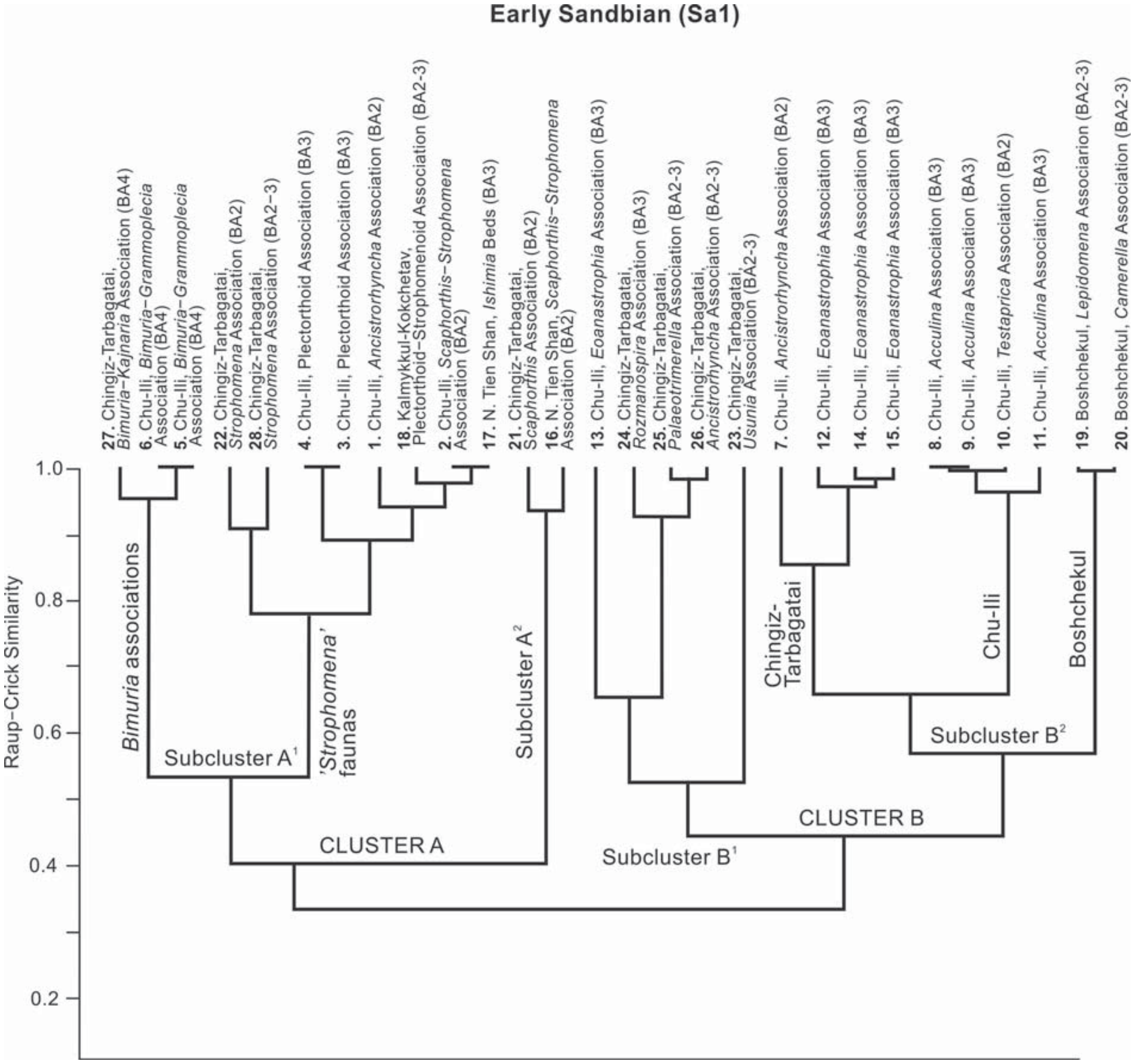


Text-fig. 6. Cluster analyses of composite faunal lists of Late Ordovician brachiopod faunas representing individual terranes; (a, b), Early Sandbian (Time Slice Sa1); (c, d) Late Sandbian (Time Slice Sa2); (e, f) Early Katian (Time Slice Ka1); (a, c, e) Jaccard Similarity; (b, d, f) Raup-Crick Similarity

Popov 1984), Among them, *Usunia* forms an oligotaxic association (Table 3; Fauna 23) together with the lingulide *Pseudolingula*, which is preserved in its burrows *in situ* and abundant ostracods, which are often preserved inside the trimerellide shells. That association inhabited soft lime mud within a rimmed carbonate shelf (probably BA2 or BA3). The oligotaxic *Palaeotrimerella* Association (Table 3, BA2–3; Fauna 25) was also dominated by trimerellides (*Ovidiella*, *Palaeotrimerella*, and *Usunia*) which occur with the rhynchonelliforms *Chaganella* and *Esilia*, unidentified asaphid trilobites, bivalves, and gastropods. The *Rozmanospira* Association (Table 3, BA3; Fauna 24) is the earliest association dominated by spirebearers (the minute smooth lissatrypidine *Rozmanospira*), and can be considered as a precursor of the *Kellerella–Parastrophina* Association which proliferated in carbonate build-ups during the Late Sandbian and Katian.

The *Bimuria* Association, which lived in the outer shelf (Table 3, BA4; Fauna 27) was probably vicariant to the *Bimuria–Grammoplecia* Association of Chu-Ili, which inhabited a similar environment; however, it differs in the absence of triplesiids and in the presence of *Anoptambonites*, which appears to be the earliest occurrence of the genus.

Our knowledge of the Early Sandbian of Boshchekul is based on a fauna from Sarybidaik southwestern of Ekibastuz, which inhabited a small carbonate platform (BA2–3) which probably formed on the caldera of a large volcanic build-up. Two different associations are recognised. The first, termed here the *Lepidomena* Association (Fauna 19), is characterised by the abundance of plectambonitoids, e.g.



Text-fig. 7. Cluster analysis (Raup-Crick Similarity) of the Early Sandbian (Time Slice Sa1) brachiopod faunas from the Kazakh terranes

Bandaleta, *Lepidomena*, and *Shlyginia*. The second, the *Camerella* Association (Fauna 20), includes abundant rhynchonellides (*Ancistrorhyncha*) and camerelloids (*Camerella*).

Cluster analyses of faunal lists representing individual terranes using different similarity indices show quite different results. Low values of the Jaccard similarity indices (below 0.4) are probably due to the strongly varied sizes of the analysed faunas (Text-fig. 6a), while the probabilistic Raup-Crick similarity, applicable for unknown and variable sample sizes, shows close similarity between the Early Sandbian faunas of the Kalmykkol-Kokchetav, North Tien Shan, and Chingiz terranes (Text-fig. 6b), which may indicate a single major dispersal centre for those pioneering faunas.

The Raup-Crick cluster analysis of 28 individual Early Sandbian faunas (Text-fig. 7) reveals significance of biofacies differentiation in the formation of island faunas of shallow shelves (BA23) on the Kazakh terranes, which must be taken in account in the analyses of biogeographical differentiation (Fortey and Cocks 2003), and which was demonstrated for the Kazakh terranes by Nikitin *et al.* (2006). Two first-order clusters can be recognised (Text-fig. 9). Cluster A consists of two second-order subclusters. Among them, Subcluster A^1 unites the brachiopod faunas from the Chu-Ili Terrane in the Zhalair-Naiman Basin with the faunas of North Tien Shan and Kalmykkol-Kokchetav. Cluster A also contains two second-order subclusters. Subcluster A^2 (Text-fig. 7), includes the monotaxic *Scaphorthis* Association from Chingiz-Tarbagatai and the *Scaphorthis–Strophomena* Association from North Tien Shan, both characteristic of the shallow clastic shelf (BA2). It shows little similarity (c. 0.4) with Subcluster A^1, which includes brachiopod associations from several Kazakh terranes. The largest group within Subcluster A^1 includes the faunas from the *Ishimia* Beds of North Tien Shan (Fauna 17) and Kalmykkol-Kokchetav (Fauna 18), both BA2–3, which are similar to each other (Text-fig. 7). The *Ancistrorhyncha*, *Scaphorthis–Strophomena*, and Plectorthoid associations inhabited the shallow carbonate shelf (BA2–3) on the south-western margin of Chu-Ili facing the Zhalair-Naiman Basin (Faunas 14), and the more distant *Strophomena* Association inhabited the shallow clastic shelf (BA2–3) in Chingiz-Tarbagatai (Faunas 22, 28). All those faunas include *Strophomena* (*Strophomena*), which is absent from all the other Early Sandbian Kazakh faunas except the *Scaphorthis–Strophomena* Association of North Tien Shan. Another characteristic taxon is *Colaptomena*, which is absent from Chingiz-Tarbagatai. The *Bimuria* Association of Chu-Ili and Chingiz-Tarbagatai (Text-fig. 7, Faunas 5, 6, and 27), which is characteristic of the outer shelf environments (BA4), forms another third-order cluster which is distantly linked (0.4, Raup-Crick similarity index) with the '*Strophomena'* faunas.

Cluster B also includes two second-order subclusters: Subcluster B^1, which unites several faunas from the Chingiz Terrane associated with carbonate build-ups (Text-fig. 7, Faunas 23 to 26); and Subcluster B^2, which includes brachiopod associations of BA2–3 (Faunas 7 to 15) which inhabited the opposite active margin of Chu-Ili (Popov *et al.* 2009), with faunas of clastic (8 to 11) and carbonate (12 to 15) shelf clearly separated from each other, and two brachiopod faunas from the Boshchekul Terrane (Faunas 19 and 20).

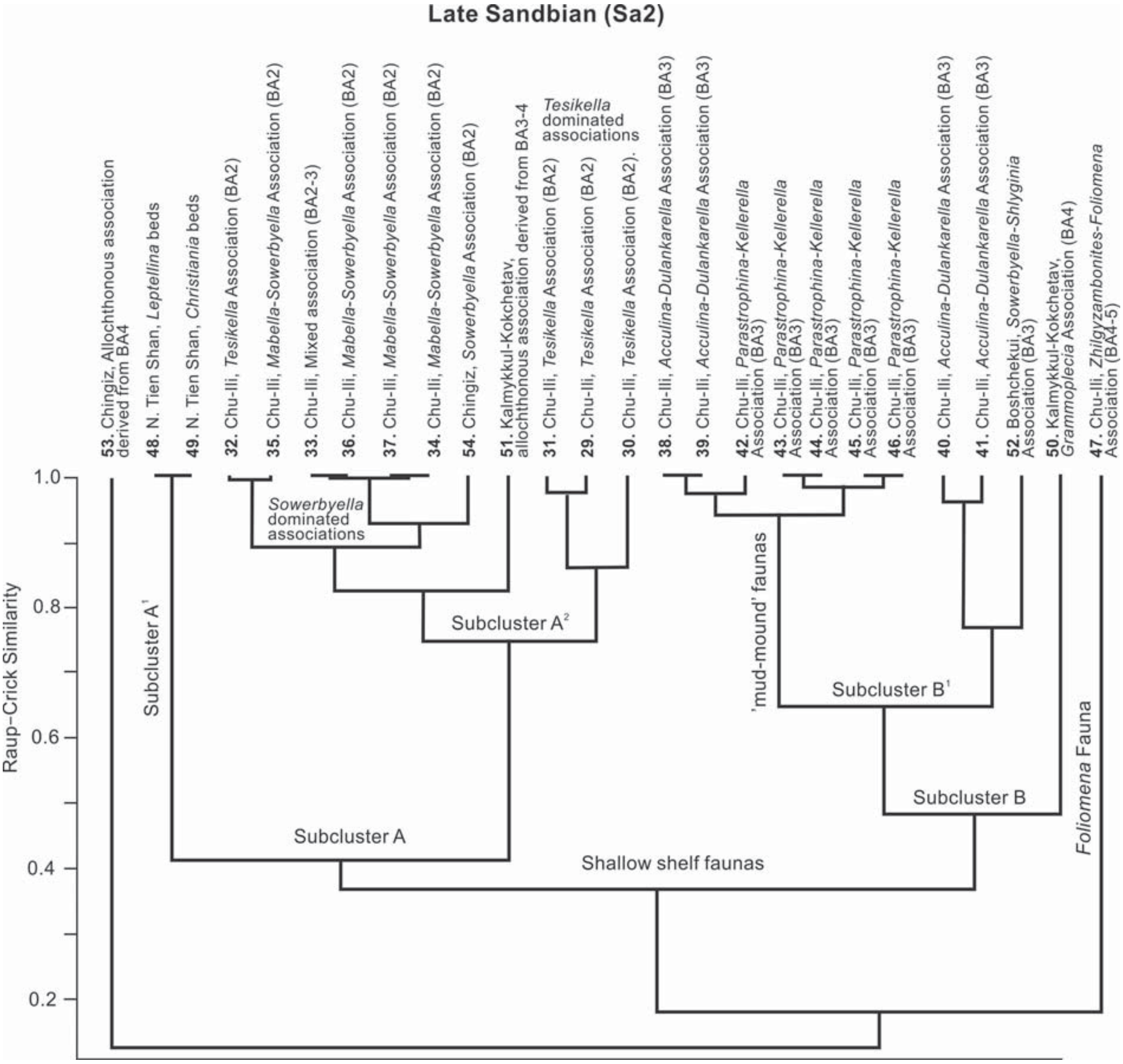
The distribution pattern of Early Sandbian faunas suggests that the newly arrived faunas of the Kokchetav-Kalmykkul and North Tien Shan terranes had the same centre of origin, perhaps at the Zhalair-Naiman margin of the Chu-Ili Terrane, which had diverse Late Darriwilian faunas. It was probably also the cradle for newly evolved endemic plectambonitoid taxa and a major stepping stone for strophomenoid taxa which immigrated from South China sometime in the latest Sandbian to Early Darriwilian.

The faunal signatures from the Chingiz-Tarbagatai Terrane are mixed. There was certainly some faunal exchange with the Chu-Ili terrane, as seen in some endemic Kazakh plectambonitoids (e.g. *Kajnaria*, *Mabella*, *Shlyginia*) and the distribution of the *Strophomena* Association on shallow clastic shelf. Species of *Camerella* and early rhynchonellides (*Ancistrorhyncha*) suggest possible links to contemporary Laurentian faunas (Nikitin and Popov 1984), while the earliest occurrence of distinctive groups such as trimerellides and lissatrypoids hint at pre-Sandbian biodiversification and immigration events which are missing in the preserved fossil record.

Late Sandbian emergence of 'mud-mound faunas'

The Late Sandbian (Time Slice Sb2) faunas are best known from the Chu-Ili Terrane, with 51 genera documented (of the 71 recorded in all the Kazakh terranes), and Popov *et al.* (2002) gave details of the faunal diversity and brachiopod community structure. The faunas of the shallow clastic shelf form a single third-order cluster (Text-fig. 8) which is quite unlike (Raup-Crick Similarity < 0.2) the faunas of the outer shelf in the Chu-Ili and Chingiz-Tarbagatai terranes. All the other Late Sandbian faunas are distributed between two subclusters: Subcluster A, which includes the faunas from North Tien Shan documented by Misius (1986; Faunas 48 and 49), which show Raup-Crick Similarity values of c. 0.4 in relation to the shallow clastic shelf faunas of the Chu-Ili Terrane, which also cluster together (Text-fig. 10, Subcluster A^2). The diversity of the North Tien Shan faunas was low, but of the ten genera there were three new arrivals, including *Chaulistomella* and *Drepanorhyncha*, which are unknown in other Kazakh terranes, and *Gacella*, which is also present in Chu-Ili, where it occurs as a minor component in the mud-mound faunas. Other genera, including *Christiania*, *Eoanastrophia*, *Leptellina*, Plectorthidae gen. et sp. nov. 1, *Shlyginia*, *Sonculina*, and *Strophomena* (*Strophomena*), are common in Late Darriwilian to Early Sandbian shallow shelf brachiopod associations in the parts of the Chu-Ili Terrane facing the Zhalair Naiman basin, but apart from *Christiania* and *Shlyginia*, they are unknown in the Late Sandbian faunas of Chu-Ili. This all suggests that there was limited faunal exchange then between Chu-Ili and North Tien Shan, in spite of a significant increase in a- and b-biodiversity in Chu-Ili.

The shallow clastic shelves of Chu-Ili (Text-fig. 8, Subcluster A2) were populated by the low-diversity *Tessikella* Association (Faunas 29 to 32) and the low- to medium-diversity *Sowerbyella–Mabella* Association



Text-fig. 8. Cluster analysis (Raup-Crick Similarity) of the Late Sandbian (Time Slice Sa2) brachiopod faunas from the Kazakh terranes

(Faunas 34 to 36) (Popov *et al.* 2002), which show little inheritance from the Early Sandbian faunas which occupied similar environments. The *Tessikella* Association was seaward of the lingulide-dominated assemblages in the shore to basin transect (Table 3) and probably spread into Chu-Ili through habitats occupied in the Early Sandbian by the rhynchonellide-dominated *Ancistrorhyncha* Association, whilst the *Sowerbyella–Mabella* Association (Table 3) probably replaced Early Sandbian strophomenoid-dominated associations. A similar *Sowerbyella*-dominated association is also known from Chingiz-Tarbagatai (Text-fig. 8; Fauna 54) and it also appears in the '*Sowerbyella*' subcluster, while the moderately diverse *Sowerbyella*-dominated assemblage of the Boshchekul Terrane (Text-fig. 8; Fauna 53), which inhabited carbonate muds, is more closely linked with the carbonate build-up faunas in Subcluster B.

During the Late Sandbian, carbonate build-ups, usually mud-mounds, became increasingly common in the Kazakh terranes, and are known from the Boshchekul, Chu-Ili, and Stepnyak units, although the data in Nikitin *et al.* (1974) are significantly outdated. The associations in the Anderken build-ups in Chu-Ili (Popov *et al.* 2002) were closely linked with those build-ups and form a single fourth-order group within Subcluster B. The strophomenide-dominated *Acculina–Dulankarella* Association (Table 3; Text-fig. 8; Faunas 37 to 41) are characteristic of algal limestones with abundant dasyclad algae deposited on the build-up flanks. Its genera are significantly different from the Late Darriwilian to Early Sandbian plectorthid and *Eoanastrophia* Association, which inhabited a similar environment with prolific dasyclad algae and which commonly includes *Glyptambonites*, *Glyptorthis*, *Phragmorthis*, *Sowerbyella*, and *Triplesia*), although there are some genera (e.g. *Acculina*, *Christiania*, *Dulankarella*, *Limbimurina*, *Mabella*, and *Sowerbyella*) in common with the Early Sandbian *Acculina* Association of the shallow clastic shelf, although the Late Sandbian *Acculina–Dulankarella* Association shows a significant increase in generic diversity and includes some new arrivals. Some of the latter (e.g. *Anoptambonites*, *Craspedelia*, *Foliomena*, *Grammoplecia*, *Kajnaria*, and *Skenidioides*) migrated from Early Sandbian associations characteristic of the outer shelf in the Kazakh terranes and elsewhere, whilst others (*Placotriplesia*, *Sortanella*, and *Teretelasmella*) are new endemics. The mud-mound core with widespread hardgrounds was inhabited by the *Parastrophina–Kellerella* Association (Text-fig. 8; Faunas 42 to 46), which was dominated by camerelloids (*Ilistrophina*, *Liostrophia*, *Parastrophina*, *Plectosyntrophia*?, and *Schizostrophina*) and early spirebearers, including the earliest athyridides *Kellerella* and *Nikolaispira* and the atrypidine *Pectenospira*. Most of those genera were endemic, and are also present as minor components in the *Acculina–Dulankarella* Association. Medium-diversity faunas in the outer shelf (BA4–5) were replaced by the low-diversity *Foliomena* and *Kassinella* associations (Text-fig. 8; Fauna 47), which were linked to contemporary faunas in South China (Rong *et al.* 1999). The Late Sandbian faunas in the carbonate build-ups (BA3) and the outer shelf (BA4–5) show little similarity to faunas of the same age in the shallow clastic shelf in Chu-Ili and other Kazakh terranes (Text-fig. 10).

The Late Sandbian faunas of the Chingiz-Tarbagatai Terrane are known only from allochthonous brachiopod assemblages (total 11 genera) in two associations displaced by mass flows. One is a low-diversity *Sowerbyella* Association (Fauna 54) characterised by abundant *Sowerbyella* and *Shlyginia*, and which also includes *Eodalmanella*. Those genera are important components of the *Sowerbyella–Mabella* and *Tessikella* associations in Chu-Ili, but the outcome of the Raup-Crick cluster analysis suggest closer similarity to the *Sowerbyella*-dominated faunas of Chu-Ili. The Chingiz association also includes the rhynchonellide *Dorytreta*, which is unknown in other Kazakh terranes but present in Laurentia, and the early atrypidine *Sulcatospira*, which became common in other Kazakh terranes only from the Early Katian. The second association in Chingiz-Tarbagatai (Fauna 53) is characteristic of the outer shelf (BA4); it is the most dissimilar to other contemporaneous Kazakh faunas (Raup-Crick Similarity well below 0.1), and a significant proportion of its genera are unknown from the Upper Ordovician in the other Kazakh terranes. In particular, *Aulie* was a short-lived local endemic, *Perimecocoelia* and *Productorthis* may have had Laurentian roots, while *Archaeorthis* and *Tuvinia* are probably survivors of the Kazakh Darriwilian faunas (Nikitina *et al.* 2006) which migrated into deeper waters from the shallow shelf.

In the Stepnyak Unit of the Kalmykkol-Kokchetav Microcontinent, the existence of the Late Sandbian stromatactis-bearing mud-mounds was first recognised by Valdar Jaanusson (personal com. 1993); however, the rich brachiopod faunas associated with those build-ups are known only from preliminary identifications (e.g. by Nikitin 1972) which require revision. An exception is an allochthonous high-diversity assemblage of 24 genera recovered from mass flow deposits in the middle part of the Lidievka Formation (Fauna 51) which includes *Acculina*, *Anoptambonites*, *Christiania*, *Craspedelia*, *Dolerorthis*, *Grammoplecia*, *Kajnaria*, *Phragmorthis*, *Ptychoglyptus*, *Shlyginia*, and *Sowerbyella* (*Sowerbyella*), which are characteristic of the Late Sandbian *Acculina–Dulankarella* Association of Chu-Ili, but in the Raup-Crick Cluster Analysis it appears at the base of the '*Sowerbyella'* subcluster. Further assessment of this assemblage is difficult due to its mixed character. That allochthonous assemblage also includes *Kassinella* and *Durranella* (BA 4–5), while the deeper-water *Foliomena* occurs sporadically in graptolitic shales in Kalmykkol-Kokchetav.

A small subcluster with the monotaxic *Grammoplecia* Association (Fauna 50; BA 4) of the Kalmykkol-Kokchetav Terrane (Text-fig. 8) is quite distinct (Raup-Crick similarity index slightly above 0.4) from the shallow-water faunas of Chu-Ili and Boshchekul.

In general, the Raup-Crick cluster analysis of 26 Late Sandbian Kazakh individual faunas reflects the major impact of the 'mud-mound' faunas' proliferation, which resulted in a significant increase of the total brachiopod α and β diversity in Chu-Ili. Those mud-mound faunas form a separate cluster with little similarity to the faunas found in clastic shelves (BA

Benthic assemblage	Normal current activity		Organic build-ups, medium to high diversity	Generally quiet, affected by seasonal storms	Quiet waters, disaerobic conditions may develop
	low to medium diversity	medium to high diversity			
1	*Ectenoglossa* Association				
2	*Tesikella* Association			*Adensu* Association	
	Mabella–Sowerbyella Association				
3			*Acculina–Dulankarella* Association		
			Parastrophina–Kellerella Association		
4					*Foliomena* Association
5					*Tenuimena* Association

Table 4. Late Sandbian (Time slices Sa2) community framework for the Chu-Ili Terrane

2–3) of the Chu-Ili and other Kazakh terranes. The same is true for the deeper-water brachiopod associations (BA 4–5) of the Chu-Ili and Chingiz-Tarbagatai terranes. In contrast, proliferation of *Sowerbyella*-dominated brachiopod associations occurred almost simultaneously in all the Kazakh terranes.

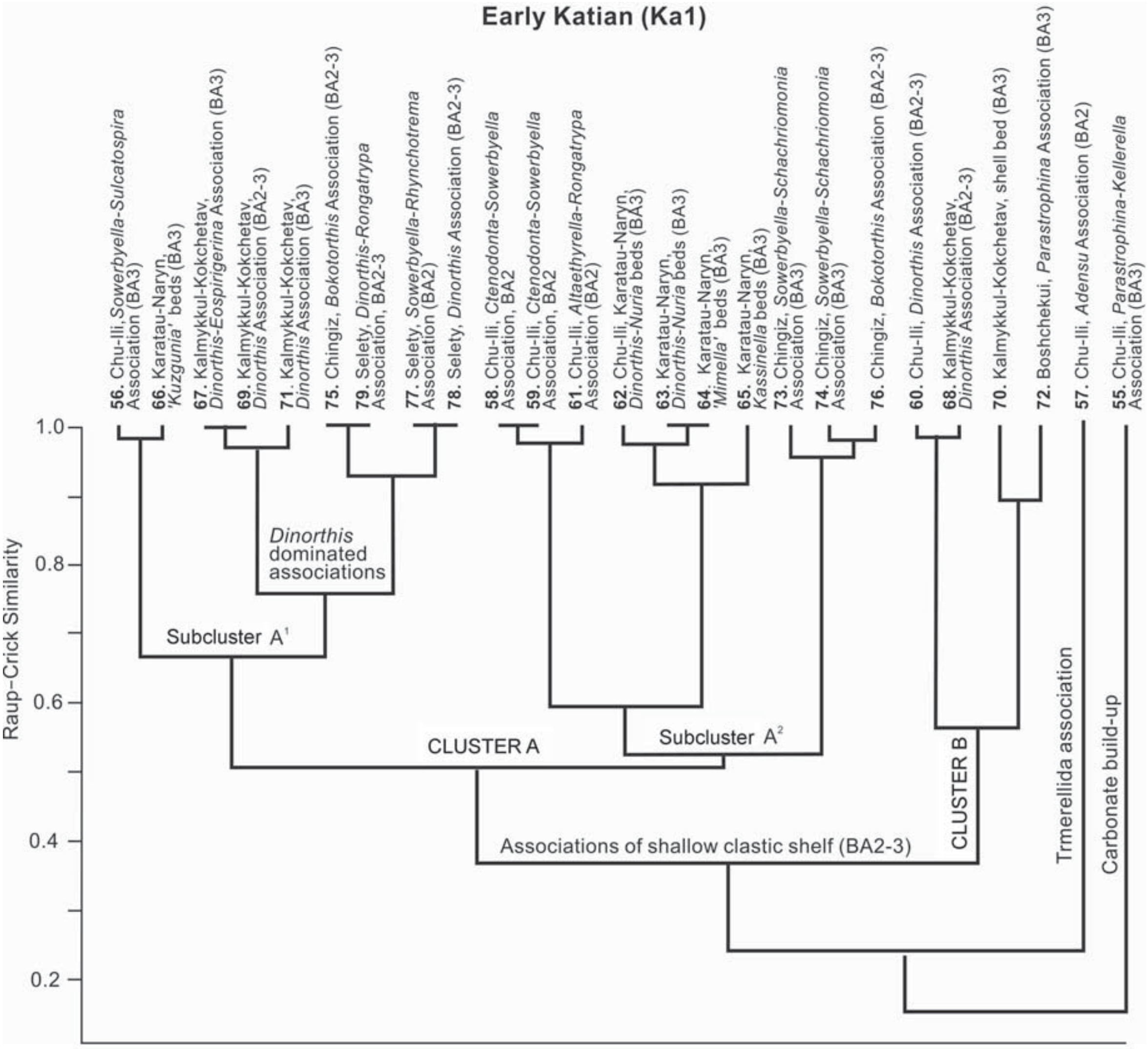
The Raup-Crick cluster analysis of a 'whole lot' brachiopod generic composition of the faunas from individual terranes shows significant separation of the faunas of Chingiz-Tarbagatai (and to a lesser degree Chu-Ili) from faunas in the other Kazakh terranes (Text-fig. 6d), which may be because deeper-water brachiopod associations of BA 4-5 and mud-mound associated faunas are not properly documented from Kalmykkol-Kokchetav, North Tien Shan, and Boshchekul. The distinct separation of the Chingiz-Tarbagatai faunas is also a major outcome of the Jaccard cluster analysis, while faunas of other terranes form a loose cluster with the highest values of similarity index between Chu-Ili and Kalmykkol-Kokchetav only slightly exceeding 0.3 in value.

Early Katian peak of faunal disparity

Early Katian (Time Slice Ka1) brachiopod faunas are relatively well documented in the Kazakh Orogen, with 52 genera recorded. The apparent decline in generic diversity by comparison with the Late Sandbian is mainly because of inadequate knowledge of the faunas associated with the carbonate build-ups, which became relatively widespread in the Stepnyak Unit of Kalmykkol-Kokchetav and in the Boschekul Terrane, but which are poorly documented. There are no published Katian brachiopods known from North Tien Shan; however, there is good stratigraphical evidence that it had already amalgamated with Karatau-Naryn before the Late Ordovician (Mikolaichuk *et al.* 1997; Burtman 2006). The shelves of Karatau-Naryn supported a moderately diverse (17 genera) brachiopod fauna (Misius 1986). Early Katian brachiopod faunas are also known from Chingiz-Tarbagatai (Popov and Cocks, 2014), Selety (Nikitin *et al.* 2003), and Kalmykkol-Kokchetav, while in the Boshchekul Terrane an inadequately known brachiopod fauna of that age is known from a single locality, probably associated with mud-mound flank deposits (Nikitin *et al.* 2006).

The Early Katian was a time of significant reorganisation in the shallow shelf (BA 2–3) benthic communities, which are known from most of the Kazakh terranes. The *Sowerbyella*-dominated brachiopod associations had been prevalent in the Late Sandbian shallow shelves; however, dinorthids and atrypides became increasingly abundant in the Early Katian and are often commoner than plectambonitoids in BA 2. While Early Katian plectambonitoid and atrypide taxa were mainly descended from local lineages, the appearance of dinorthids was new, with Laurentia as a probable source.

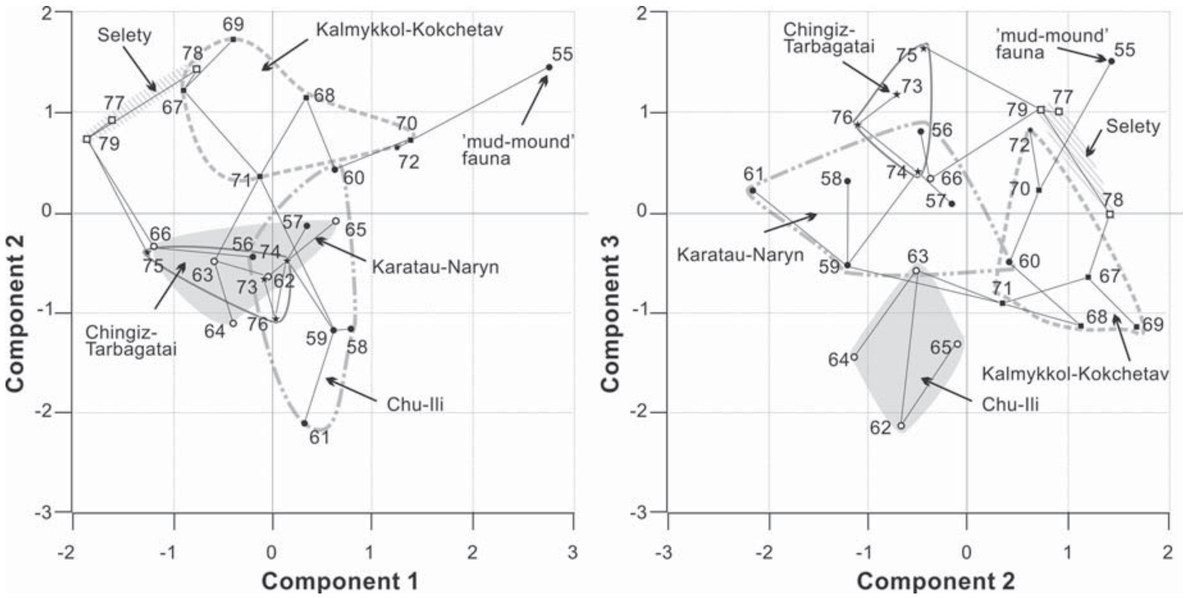
In spite of the decline in generic diversity (from 44 to 34) the Early Katian of the Chu-Ili Terrane retained the highest levels of α and β diversity by comparison with contemporaneous faunas in the other Kazakh terranes. There were also strong differences in generic composition between the benthic associations of the shallow clastic shelf and the carbonate build-ups. In particular, the *Parastrophina–Kellerella* Association (Table 5; Text-fig. 9, Fauna 55), characteristic of a mud-mound core in Chu-Ili, has little in common (Raup-Crick Similarity about 0.1) with other Kazakh faunas. The decline in generic diversity of the mud-mound faunas was probably linked to the disappearance of dasyclad algal limestones and the associated high-diversity *Acculina–Dulankarella* Association. The low-diversity trimerellide-dominated *Adensu* Association (Table 5; Text-fig. 9, Fauna 57) on the flanks of carbonate build-ups, was new to Chu-Ili, although similar trimerellide associations



Text-fig. 9. Cluster analysis (Raup-Crick Similarity) of the Early Katian (Time Slice Ka1) brachiopod faunas from the Kazakh terranes

occurred in the Chingiz-Taragatai Terrane in the Early Sandbian, where they are also linked with carbonate build-ups.

The proportion of dinorthids and atrypidines increased significantly in shallow-water brachiopod faunas across all the Kazakh terranes, which resulted in the formation of mixed *Sowerbyella*-dinorthid, *Sowerbyella*-atrypide, and dinorthid-atrypide communities with vicariant dinorthid and atrypid species and genera characteristic of some individual terranes. In Chingiz-Tarbagatai (Table 6), the dinorthid *Bokotorthis* (Text-figs 5Q, 9, Faunas 75 and 76) and atrypide *Schachriamonia* (Text-fig. 9; Faunas 73 and 74) are the most characteristic. In the Selety, Kokchetav-Kalmykkol, and Karatau-Naryn terranes, *Dinorthis* (Text-fig. 5W) was the most abundant (Text-fig. 9, Faunas 62, 63, 68, 69, and 71), though represented by different species. Whilst three dinorthid genera (*Bokotorthis*, *Dinorthis*, and *Plaesiomys*) occur in Chu-Ili, only *Plaesiomys* proliferated in the *Sowerbyella*-dominated associations (Table 5; Text-fig. 9, Faunas 75 and 76), while the *Dinorthis* Association in Chu-Ili (Table 5; Text-fig. 11, Fauna 60) lacks *Sowerbyella*, although the other plectambonitoids *Dulankarella* and *Shlyginia* are common. The Early Katian Kazakh shallow-water (BA 2–3) brachiopod associations are unique in their abundance of the early representatives of the Suborder Atrypidina, which have no analogues elsewhere. In Chingiz-Tarbagatai, the early atrypidines are represented by



Text-fig. 10. Two-dimensional Principal Component Analysis plots on first, second and third eigenvectors of 23 Early Katian brachiopod localities from the Kazakh terranes

Schachriomonia and *Rongatrypa* (Text-fig. 5M), with the latter tending to form monotaxic associations which probably occupied the same ecological niches as the rhynchonellide communities of BA2 elsewhere (Table 6; Popov and Cocks 2014). In Chu-Ili there was a mixed *Altaethyrella–Rongatrypa* Association, which achieved maximum generic diversity in echinoderm grainstones accumulated in shoal complexes (Table 5; Text-fig. 9, Fauna 61). In the *Sowerbyella*-dominated associations of BA3, the atrypidine *Sulcatospira* was among the most common components (Table. 5; Text-fig. 9, Fauna 56). *Sulcatospira* was also among the most common taxa in the Tez Formation of Sarydzhas (eastern Karatau-Naryn Terrane) (Text-fig. 9, Fauna 66), where the local endemic *Nuria* was probably vicariant to *Rongatrypa*. In Kalmykkol-Kokchetav, *Sowerbyella* was a relatively minor component in the shallow clastic shelf associations, which were largely dominated by *Dinorthis*.

With a few exceptions (Text-fig. 9, Cluster B), the brachiopod associations of the shallow clastic shelf (BA23) group together in a single third-order cluster (Text-fig. 9, Cluster A), although there is a clear separation between the faunas of the north-western terrane cluster (Kalmykkol-Kokchetav and Selety) and all the other Kazakh faunas (Text-fig. 9, Subcluster A^1). The only exception is the *Sulcatospira*-dominated associations of Chu-Ili and Karatau-Naryn, which form a small subcluster distantly linked with Kalmykkol-Kokchetav and Selety. Remarkably, dinorthid, atrypidine, and *Sowerbyella*-dominated associations retained their palaeogeographical signature, exhibiting community-wide vicariance. The only noticeable exception is the anomalous occurrence of the *Bokotorthis* Association from the Chingiz-Tarbagatai Terrane (Text-fig. 9, Fauna 75).

Among other Kazakh faunas (Text-fig. 9, Subcluster A^2), the Early Katian brachiopod associations of Chu-Ili (Text-fig. 9, Faunas 58 to 60) and Karatau-Naryn (Text-fig. 9, Faunas 62 to 65) became more similar, while the faunas of Chingiz-Tarbagatai (Text-fig. 9, Faunas 73, 74, and 76) were somewhat more distant.

There are also some aberrant associations which are placed some way away from the other Kazakh faunas (Text-fig. 9, Subcluster B^2). Among them, the *Parastrophina* Association of the Boshchekul Terrane (Text-fig. 9; Fauna 72) inhabited the flanks of carbonate build ups. It forms the fourth-order cluster, together with a small allochthonous association from the Kalmykkol-Kokchetav Terrane (Text-fig. 11, Fauna 70), which includes taxa usually common in carbonate build-ups (e.g. *Anoptambonites*, *Christiania*, *Dulankarella*, *Grammoplecia*, and *Parastrophina*); however, the original habitat of that association remains unknown.

The results of the Principal Component Analysis of the same data set demonstrate that the brachiopod associations of Kalmykkol-Kokchetav (Text-fig. 10, Faunas 67 to 69, and 71) plot as a loose cluster with

Benthic assemblage	Normal current activity		Organic build-ups, medium to high diversity	Generally quiet, affected by seasonal storms	Quiet waters, disaerobic conditions may develop
	low to medium diversity	medium to high diversity			
1	Lingulide Association				
2	*Ctenodonta–Sowerbyella* Association	*Altaethyrella–Rongatrypa* Association		*Palaeotrimerella* Association	
	Mabella–Sowerbyella Association				
3	*Sowerbyella–Sulcatospira* Association		*Parastrophina–Kellerella* Association		
4					
5					

Table 5. Early Katian (Time slices Ka1) community framework for the Chu-Ili Terrane. Note the absence of benthic units from Benthic Assemblage 4 and 5

Benthic assemblage	Normal current activity		Organic build-ups, medium to high diversity	Generally quiet, affected by seasonal storms	Quiet waters, disaerobic conditions may develop
	low to medium diversity	medium to high diversity			
1	*Ectenoglossa* Association				
2	*Rongatrypa* Association	*Bokotorthis* Association		*Mabella* Association	
	Mabella–Sowerbyella Association				
3	*Sowerbyella–Schachriomonia* Association				
4					*Kassinella* Association
5					

Table 6. Early Katian (Time slice Ka1) community framework for the Chingiz-Tarbagatai Terrane

low positive to moderate negative scores along axis 1, low to moderate positive scores along axis 2 and low negative scores along axis 3. The only exception is Fauna 70, which clusters with brachiopod associations in Boshchekul and Chu-Ili associated with carbonate build ups (Text-fig. 10, Faunas 55 and 72). They all show moderate to high positive scores along axis 1, and low to moderate positive scores along axes 2 and 3. Brachiopod associations of the shallow clastic shelf in the Selety Terrane (Text-fig. 10, Faunas 77 to 79) show moderate to high negative scores along axis 1 and low to moderate positive scores along axes 2 and 3. They form a distinct separate cluster which only slightly overlaps with the cluster of faunas from Kalmykkol-Kokchetav. The associations of the Karatau-Naryn Terrane (Text-fig. 10, Faunas 62 to 66) form a separate cluster, with mainly low to medium negative scores along all three axes. The brachiopod associations of the shallow clastic shelves of Chingiz-Tarbagatai (Text-fig. 10, Faunas 73 to 76) and Chu-Ili (Text-fig. 12, Faunas 55 to 61) overlap significantly and show low positive to medium negative scores along axis 1 and low to high negative scores along axis 2; however, higher positive scores along axis 3 are more characteristic of the brachiopod associations from Chingiz-Tarbagatai.

Both cluster and the principal component analyses of the individual Kazakh faunas suggest clear separation of the brachiopod associations linked with carbonate build-ups. Those faunas retain medium to high β-diversity, but show little interaction with other Kazakh faunas. There is substantial increase in α-diversity across shallow clastic shelf biofacies. Characters of community structure and proliferation of dinorthides and atrypidines, which are largely unknown in older Kazakh faunas, suggest significance of colonisation with subsequent vicariance on a community level (Hickerson and Meyer 2008) and diversification of the brachiopod faunas on the shallow clastic shelves of Chu-Ili, Karatau-Naryn, Kalmykkol-Kokchetav, and Selety. The atrypidine *Sulcatospira* is represented in the Late Sandbian *Sowerbyella*-dominated associations of Chingiz-Tarbagatai, while another early atrypidine, *Pectenospira*, is relatively common in the Late Sandbian faunas of Chu-Ili associated with carbonate build-ups. In addition, Chu-Ili was the only place from which all three Early Katian Kazakh dinorthid genera (*Bokotorthis*, *Dinothis*, and *Plaesiomys*) are known. All that suggests that the Chu-Ili Terrane retained the highest taxonomic diversity in the Darriwilian to Early Katian by comparison with the other Kazakh terranes, and that, together

Benthic assemblage	Normal current activity		Rough water	Generally quiet, affected by seasonal storms	Quiet water, disaerobic conditions may develop	
	low to medium diversity	medium to high diversity				
1						
2	Assemblage with *Sowerbyella* and *Testaprica*			*Monomerella* Association		
3	*Sowerbyella–Schachriomonia* Association	Assemblage with *Enbektenorthis*	*Holorhynchus* Association	Assemblage with *Mabella* and *Phragmorthis*		
4					*Foliomena* Association	*Dalmanella–Nankinolithus* Association
5						

Table 7. Mid to late Katian (Time slice Ka2–4) community framework for the Chingiz-Tarbagatai Terrane

with the Chingiz-Tarbagatai Terrane, they were the two chief areas for the reception of incoming genera. It is also likely that throughout the Early Katian all the Kazakh terranes were separated by significant barriers which prevented free exchange and facilitated peripheral endemism.

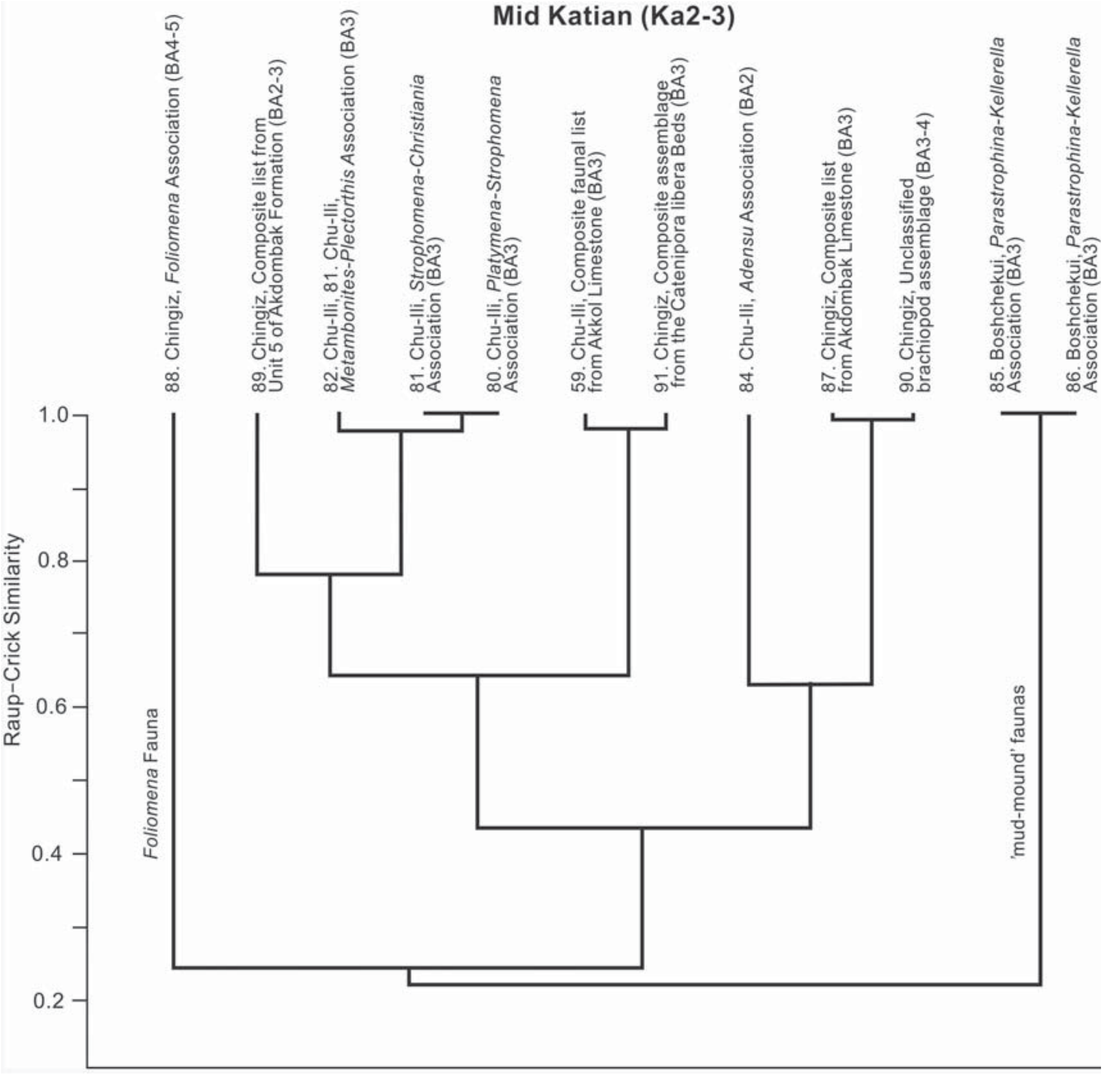
The outcome of 'whole lot' cluster analyses of the brachiopod genera (Fig. 6) shows closest affinity between the faunas of Selety and Kalmykkol-Kokchetav, whilst the fauna of the Boshchekul Terrane was the most distant from other Kazakh faunas. The faunas of the Chu-Ili and Karatau-Naryn terranes form a single subcluster according to Jaccard similarity (Text-fig. 6c), while the results of the Raup-Crick cluster analysis (Text-fig. 6d) suggest closer similarity of the brachiopod fauna of Karatau-Naryn to the faunas of Selety and Kalmykkol-Kokchetav.

Middle Katian

The Middle Katian (Time Slices Ka2 and Ka3) rhynchonelliform and craniiform brachiopods (total 67 genera) are best documented from the Chu-Ili, Boshchekul, and Chingiz-Tarbagatai terranes. Only a single genus (*Rongatrypa*) is known from the Kalmykkol-Kokchetav Terrane, although there are no brachiopod faunas yet documented from the Selety, North Tien Shan, and Karatau-Naryn terranes. There was a significant increase in the generic diversity in Boshchekul (up to 32 genera) and Chingiz-Tarbagatai (up to 37 genera), while generic diversity in the Chu-Ili Terrane dropped down to 31 genera, mainly because of the disappearance of organic carbonate build-ups and associated faunas.

All the faunas from Boshchekul belong to the *Parastrophina–Kellerella* Association, which is characteristic of hardgrounds in the mud-mound core. They show very low similarity to contemporary brachiopod faunas elsewhere, as shown by the Raup-Crick cluster analysis (Text-fig. 11), and are clearly separated in the Principal Component Analisys in having high positive scores along axis 1 (Text-fig. 12). As demonstrated by Nikitin *et al.* (2006), the brachiopod fauna of Boshchekul shows the closest similarity in generic composition to the Late Sandbian to Early Katian mud-mound associated faunas of Chu-Ili, which were also assigned to the *Parastrophina–Kellerella* Association. The Boshchekul mud-mound associated faunas have a high camerelloid component, the early athyridides *Kellerella* and *Nikolaispira* (Text-fig. 5N), and show significant proliferation in the early atrypidines, including *Eospirigerina* (Text-fig. 5X), *Euroatrypa*, *Pectenospira* (Text-fig. 5T), and *Qilianotryma*, and also the earliest spiriferide *Odakella* (Text-fig. 5U).

The *Foliomena* Association (Text-fig. 11, Fauna 88), from the Chingiz-Tarbagatai Terrane (Table 7), is the only Mid Katian deeper-water brachiopod association (BA 4–5) known from the Kazakh terranes. It is quite unlike the Kazakh faunas of the shallow shelf, as shown by the Raup-Crick Similarity Analysis (Text-fig. 12), but is similar to contemporary faunas in South China (Popov and Cocks, 2014). There is no clear separation between the Middle Katian Chu-Ili and Chingiz-Tarbagatai faunas of the shallow shelf. In particular, the strophomenide-dominated BA2–3 fauna of Chingiz-Tarbagatai (Text-fig. 11; Fauna 89) bunches with similar associations from the Degeres Beds of Chu-Ili (Table 8; Text-fig. 11; Faunas 80 to 82), while a diverse fauna from the Akkol Beds in Chu-Ili (Text-fig. 11; Fauna 89) clusters with the brachiopod assemblage of the *Catenipora libera* Beds of the Tarbagatai Range (Text-fig. 11; Fauna 91). That may reflect similar community structure, but the rich Mid to Late Katian faunas of the Tarbagatai Range require further study. The principal component analysis shows similar results (Text-fig. 12). The faunas of Chu-Ili and Chingiz-Tarbagatai form loose clusters



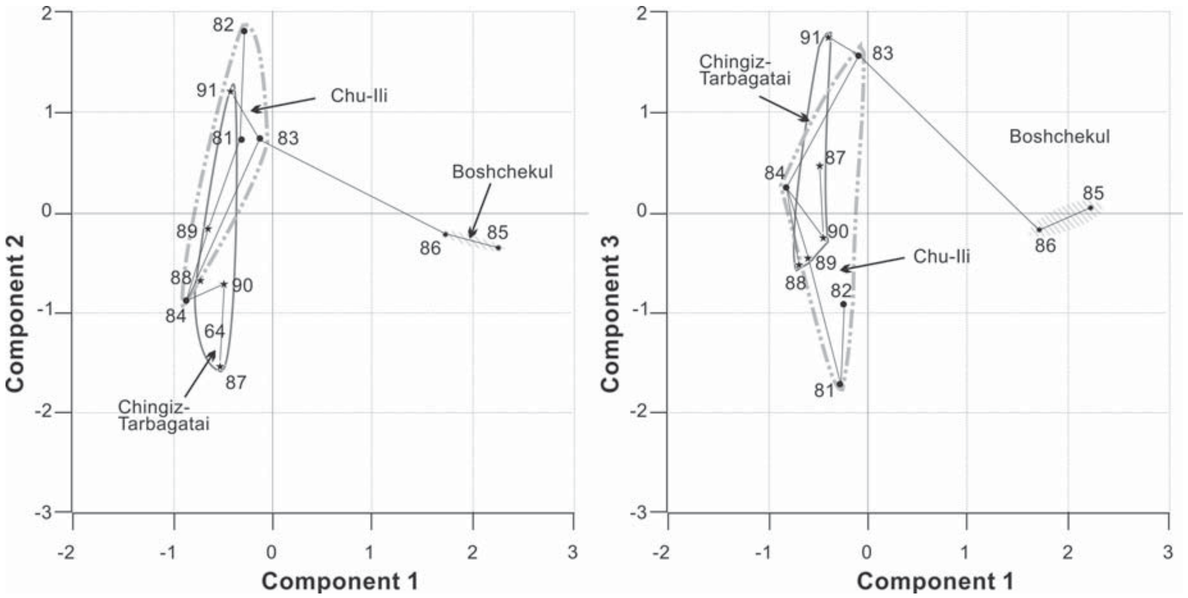
Text-fig. 11. Cluster analysis (using Raup-Crick Similarity) of the Mid Katian (Time Slices Ka2 and Ka3) brachiopod faunas from the Kazakh terranes

with mainly negative scores along axis 1; however, brachiopod associations from Chingiz-Tarbagatai tend to show positive scores along axis 3, while the scores of strophomenide-dominated brachiopod associations from Chu-Ili are moderately negative.

Late Katian

Knowledge of Late Katian (Time Slice Ka4) brachiopod faunas from the Kazakh terranes is relatively poor. The best documented faunas are from Chingiz-Tarbagatai (24 genera); however, a diverse brachiopod fauna from the *Holorhynchus giganteus* Beds of the Tarbagatai Range (Fauna 94) is still awaiting study. That fauna is similar to a somewhat older Mid Katian fauna from the *Catenipora libera* Beds (Fauna 91), but differs in the abundance of the early pentameridine *Holorhynchus*. In the Akdombak Formation of the Chingiz Range, a moderately diverse brachiopod fauna (Fauna 93) includes four pentameridines (*Brevilamnulella*, *Eoconchidium*, *Galeatellina*, and *Holorhynchus*) of which two are endemic. The low-diversity deep water *Dalmanella–Nankinolithus* Association (Table 7; BA4) spread in disaerobic environments associated with graptolitic black shales in the upper part of the Akdombak Formation in the Chingiz Range (Popov and Cocks 2014).

Nikitin *et al.* (1980) is the only published record of Late Katian brachiopods from Chu-Ili. A composite list (Fauna 92) based on that publication includes



Text-fig. 12. Two-dimensional Principal Component Analysis plots on first, second and third eigenvectors of 12 Mid Katian brachiopod localities from the Kazakh terranes

twenty genera associated with an organic carbonate build-up, the Ulkuntas Limestone (*Paraorthograptus pacificus* graptolite Biozone), which was in part displaced and preserved in slope rise deposits. It differs from the Early to Mid Katian faunas in the proliferation of archaic pentameridines, including *Brevilamnulella*, *Holorhynchus*, *Proconchidium*, and *Prostricklandia*. There are also significant new arrivals, including *Coolinia*, *Dalmanella*, *Eostropheodonta*, *Giraldibella*, *Hindella*, and *Leptaena (Leptaena)*, which are unknown from other Kazakh terranes, but survived into the Hirnantian (Nikitin *et al.* 1980; Rong *et al.* 2002). Some of them are usually associated with faunas of temperate latitudes in the Late Ordovician, which may suggest that their immigration may have occurred during the cooling episode before expansion of the *Holorhynchus* Fauna. According to Loi *et al.* (2010, fig. 14, Sequence 4), such an event occurred in the Late, but not the latest, Katian.

Hirnantian

There are only two brachiopod faunas of Hirnantian age in the Kazakh terranes. They are markedly different from each other, but both reflect little continuity from the preceding Katian assemblages described above. The first is in the Chu-Ili Terrane, from which Nikitin *et al.* (1980) described a traditional *Hirnantia* Fauna, reviewed by Rong *et al.* (2002). The other fauna is from the Chingiz-Tarbagatai Terrane (Popov and Cocks 2014), which contains few typical elements

Benthic assemblage	Normal current activity		Organic build-ups, and algal limestones, medium to high diversity	Generally quiet, affected by seasonal storms	Quiet waters, dis-aerobic conditions may develop
	low to medium diversity	medium to high diversity			
1					
2				*Adensu* Association	
3	*Platymena–Strophomena* Association	*Strophomena–Christiania* Association	*Rhynchonellid*-atrypid associations		
		Plectorthis–Metambonites Association			
4					
5					

Table 8. Mid Katian (Time slices Ka2) community framework for the Chi-Ili Terrane. Note the absence of benthic units from Benthic Assemblage 4 and 5

of the *Hirnantia* Fauna, apart from *Eostropheodonta*, *Leptaena*, and *Dalmanella*, although *Kozlowskites*, *Chonetoidea*, *Cliftonia*, *Craniops*, *Katastrophomena*, and *Epitomyonia* also occur, and many were new immigrants to the area. However, the fauna has little in common with the Edgewood *Hirnantia* Fauna known from other tropical regions. Thus the Hirnantian faunas are not critical in determining Kazakh geography.

INTERPRETATION AND DISCUSSION

The Kazakh terranes in a global context

Understanding the biogeographical patterns of the Mid and Late Ordovician faunas that spread along the low latitudes is incomplete without analysis of the effects of the Great Ordovician Biodiversification (Webby *et al.* 2004) on the dispersion of newly evolved taxa. That biodiversification resulted not only in a dramatic increase in taxonomic diversity on a global scale, but also in the fundamental transformation of the benthic community structure. It included replacement of the trilobite- and lingulate brachiopod- dominated associations of the Cambrian Evolutionary Fauna by more advanced and structured benthic assemblages of the Palaeozoic Evolutionary Fauna (PEF), which were dominated by filter-feeders (Sepkoski 1981). The global pattern also reveals that the onset of the benthic associations dominated by the PEF was diachronous on the shelves of major continents, and occurred in several pulses characterised by increased faunal turnover and the immigration of new components, which transformed the overall biota. That onset occurred earlier in Gondwana than in Baltica, and benthos characteristic of the PEF emerged in Laurentia only by the beginning of the Darriwilian, whereas their arrival in Siberia, which was the most isolated continent of that time, was delayed until the beginning of the Sandbian (Bassett *et. al.* 2002). This pattern suggests that the PEF first evolved in temperate- and low-latitude Gondwana and later dispersed to the other continents.

The location of the Kazakh terranes and island arcs west of the Australasian segment of Gondwana is supported by clear signals from the brachiopods and trilobites, which indicate strong links with the contemporary faunas of Australia, Tarim, and North and South China (Popov *et al.* 2002, 2009; Fortey and Cocks 2003; Nikitin *et al.* 2006; Ghobadi Pour *et al.* 2011b; Percival *et al.* 2011; Popov and Cocks 2006, 2014).

A key factor which has been neglected is the effects of the substantial volcanic activity in the Kazakh Archipelago and Australasian sector of Gondwana during the Middle and Late Ordovician. An influx of sea-rafted pumice favours the dispersion of benthic organisms across the oceans today, and some of them (e.g. corals) stay alive for almost a year (Bryan *et al.* 2004). From that it seems likely that the equatorial position of the Ordovician Kazakh terranes, and in particular the Chingiz-Tarbagatai volcanic arcs and their ejected pumice, would have favoured faunal exchange with the Australasian sector of Gondwana due to the prevailing direction of the equatorial currents (Text-fig. 13).

Many Darriwilian brachiopods from the Chu-Ili Terrane, including *Aporthophyla*, *Idiostrophia*, *Leptella*, *Leptellina*, *Neostrophia*, *Taphrodonta*, *Toquimia*, and *Trematorthis*, are distinctive pantropical elements of the Darriwilian fauna. However, as shown by Popov *et al.* (2016), the Darriwilian faunas of the Australasian segment of Gondwana, including Australia, Sibumasu and Tibet), associated small continents (South China) and island arcs (Chu-Ili) cluster together and can be assigned to the separate Australasian Province, while they show clear separation from the the peri-Laurentian faunas usually included in the Toquima-Table Head Province of Neuman and Harper (1992). Thus there was no single pantropical Low Latitude Province for the most of the Darriwilian.

Another feature of the shallow-shelf Darriwilian brachiopod assemblages in Chu-Ili was the presence of genera such as *Martellia* and *Yangtzeella*, which are unknown from the Darriwilian of the Australasian sector of Gondwana or from the other Kazakh terranes, but are characteristic of temperate latitude peri-Gondwanan faunas of South China, and in the Iranian and Turkish Tauride terranes (Cocks and Fortey 1988; Percival *et al.* 2009; Ghobadi Pour *et al.* 2011b). That may suggest that the south-western Kazakh terrane cluster (Chu-Ili, North Tien Shan, and Karatau-Naryn) was relatively near South China, unlike the other Kazakh Terranes. That is supported by the occurrence of the Early Ordovician (Floian) trilobite *Tanhungshania* in Karatu-Naryn, a genus otherwise known from South China and temperate latitude peri-Gondwana (e.g., Alborz, Turkish Taurides, and Armorica), but is unknown elsewhere in Kazakhstan, or in the Australasian sector of Gondwana (Popov *et al.* 2009). Distinctive reedocalymenine trilobites and the *Saucrorthis* Brachiopod Association are unknown from the Kazakh Terranes (Turvey 2005a; Ghobadi Pour *et al.* 2011a; Percival *et al.* 2011).

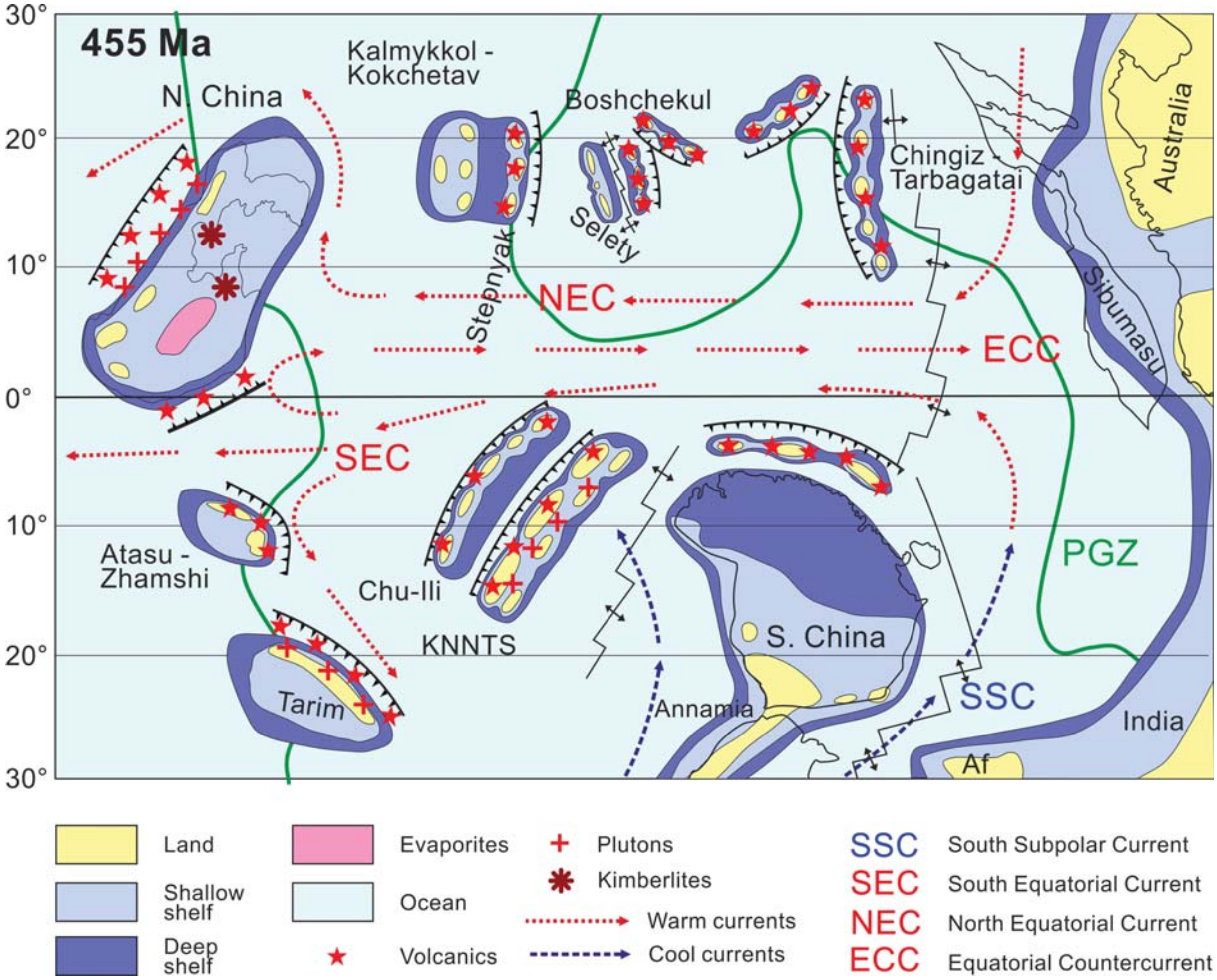
A cluster analysis of the Darriwilian and Sandbian peri-Gondwanan faunas (Percival *et al.* 2011, fig. 2A), shows that the Kazakh faunas form a single cluster with contemporary Australasian faunas, whereas the South China faunas clustered separately. A similar pattern is seen in the Darriwilian trilobites and in South China the shallow shelf asaphid biofacies were dominated by genera of the Subfamily Nobiliasaphinae, especially *Liomegalaspides* (Turvey 2005a). Study of asaphids from the Chu-Ili Terrane reveals two distinct genera *Damiraspis* and *Farasaphus* which occur in the Australasian sector of Gondwana (Thailand and New South Wales) as well as Argentina (Ghobadi Pour 2009; Ghobadi Pour *et al.* 2011c). Zhou and Zhen (2009) noted that *Eokosovopeltis*, one of the index taxa for the *Eokosovopeltis–Pliomerina* Province of Webby *et al.* (2000), was already present in the Sandbian of North China, the Australasian sector of Gondwana, and the Kazakh terranes, but did not appear in South China until the Katian.

The most detailed data on the Katian biogeography of the Australasian sector of Gondwana and associated terranes and microcontinents are in Nikitin *et al.* (2006) and Percival *et al.* (2011). The Katian faunas of the Australasian segment of Gondwana and associated units group into four clusters, which partly reflect biofacies differentiation. The Early to Mid Katian Kazakh faunas from Chu-Ili, Chingiz-Tarbagatai, Boshchekul, and possibly from Karatau-Naryn, Kalmykkol-Kokchetav, and Selety, cluster together with the mid Katian fauna of New South Wales and a latest Katian *Holorhynchus* fauna from the Chingiz-Tarbagatai Terrane (Percival *et al.* 2011, fig. 2B). Those faunas weakly link with another cluster formed by the Late Katian faunas of South China and the Early Bolindian fauna of New South Wales. All those faunas were different from the mid shelf (BA3) faunas of Tasmania and the Eastonian faunas of New South Wales.

Analysis of the Katian brachiopod biogeography (Nikitin *et al.* 2006) also included faunas from Baltica, located then at slightly higer latitudes, and the tropical faunas of Laurentia and Siberia, which helps to assess the position of the faunas of tropical peri-Gondwana in a global context. The analysis show the Kazakh faunas and the Late Katian faunas of South China grouping together to form a loose cluster with the Katian faunas of New South Wales. Those peri-Gondwana faunas show some similarity (Raup-Crick Similarity c. 0.45) to the Katian faunas of Baltica and to a lesser extent with the faunas of Siberia and the Midcontinent of Laurentia (Raup-Crick Similarity c. 0.4), which form a separate cluster; while the faunas which lived on the Laurentian and Siberian cratonic margins were the most remote.

There are some distinctive brachiopod genera, e.g. *Chaganella*, *Dulankarella*, *Shlyginia*, and *Testaprica*, which occur in Chingiz-Tarbagatai and New South Wales, but not in the Ordovician of South China, whilst *Mabella* occurs in South China occasionally only in the uppermost Katian *Pacificograptus pacificus* graptolite Zone. The Katian fauna of the Chingiz Terrane shows a higher degree of endemism than previously recognised; in particular, *Alpeis*, *Ashinaorthis*, *Buminomena*, *Wrightiops*, and the Family Alpeisidae are endemic to the terrane. In contrast, *Glyptomenoides, Metambonites*, *Nikitinamena*, *Ogmoplecia*, *Sortanella*, *Synambonites*, and *Weberorthis* (Text-fig. 5), which are quite common in the Chu-Ili Terrane (and also *Metambonites* and *Synambonites* in South China) are not known from the Chingiz-Tarbagatai Terrane.

While the probable location of the Kazakh Archipelago in relation to the Australasian sector of Gondwana is now well defined, its position in relation to the South and North China continents is not. South China was near the western coast of the Gondwana Supercontinent (probably with a transform boundary), and slowly drifted northwards. In the Early to Middle Ordovician it was located in temperate latitudes, and reached the tropics near the end of the Darriwilian (Cocks and Torsvik 2013, fig. 8). However, that fast northern drift has been questioned from studies of some peri-Gondwanan faunas, in particular, the *Saucrorthis* brachiopod Fauna and reedocalymenine trilobites can be used as good biogeographical markers (Cocks and Zhan 1998; Turvey 2005a; Ghobadi Pour *et al.* 2011c; Zhan *et al.* 2014). Both the latter are unknown in the Australasian segment of Gondwana and the Kazakh Terranes, which were located in the tropics. Reedocalymenine trilobites spread widely along the west Gondwana margin in the Middle and Late Ordovician and are also known from South China, Alborz, Annamia, and Tarim, but they did not enter tropical latitudes. The *Saucrorthis* Fauna is mainly confined to South China, although it is also reported from the Darriwilian of the Iranian Alborz Terrane, the Shan States of Burma, and western Yunnan, the two latter then parts of Gondwana. The Alborz Terrane was located in temperate latitudes at some distance from Gondwana and experienced successive invasions of cold water faunas (Ghobadi Pour *et al.* 2011b). Thus the most likely scenario is that South China was still located in the subtopics (c. 20° to 30° S) during the Darriwilian and Sandbian



Text-fig. 13. Inferred position of the Kazakh terranes west of the Australasian segment of Gondwana: a snapshot for Early Katian time. Abbreviations: Af, Afghan Terrane; KNNTS, amalgamated Karatau-Naryn and North Tien Shan Microcontinent; PGZ, plume generation zone

and it approached the Equator only at the very end of the Ordovician. During the Sandbian and most of the Katian, South China was an area of a widespread black shale accumulation (Munnecke *et al*. 2011) with proliferation of the *Foliomena* and *Kassinella* brachiopod associations (Rong *et al*. 1999). Both associations are also found on the shelves of the Kazakh terranes during the Sandbian and Early to Mid Katian times (Tables 4, 6, 7), much earlier than in other parts of the world. When black shale deposition had mainly ceased on the South China shallow shelves in the latest Katian (*Pacificograptus pacificus* Biozone), newly invaded brachiopods show strong links with the Late Ordovician faunas of the Kazakh terranes (Zhan and Cocks 1998; Nikitin *et al*. 2006; Percival *et al*. 2011).

This biogeographically-based reconstruction (Text-fig. 13) agrees well with the inferred oceanic circulation patterns in the low latitudes west of the Gondwanan coast. It is probable that the cool-water South Subpolar Current running along the western Gondwanan coast would have had an effect on climate comparable to the present-day Humboldt Current. As a result, average annual temperatures of surface waters along the coasts of the South China continent during the Early to Mid Ordovician would have been considerably lower than in subequatorial peri-Gondwana, which prevented the immigration of some warm-water taxa (Ghobadi Pour *et al*. 2009, 2011c). Only when South China entered low latitudes in the latest Katian did affinity with the shallow shelf faunas of the Kazakh terranes become firmly established.

Both the Karatau-Naryn and North Tien Shan terranes represent narrow strips of shredded continental crust more than 1,500 km long, and their width did not exceed 200 to 300 km. Their amalgamation at the beginning of the Late Ordovician was the result of frontal collision. So it is likely that both terranes were produced by successive destruction of the same plate margin, which was probably South China, while through the Cambrian and Early to Mid Ordovician they were separated from each other and from South China by marginal marine basins rather than by wide oceans. Strong sedimentological and faunal links between the Ediacaran to lower Cambrian successions of South China and Karatau-Naryn were recognised long ago by Rozanov *in* Rozanov and Sokolov (1984). The North Tien Shan rifting from Karatau-Naryn may have been as late as Cambrian Stage 4, a time which coincided with a significant tectonic reorganization of the north-eastern margin of the Karatau-Naryn Terrane (Popov *et al*. 2009). That is supported by the changing patterns of carbonate sedimentation in Malyi Karatau, which was controlled by the rifted boundaries of a passive continental margin after the beginning of the Middle Cambrian (Stage 4) (Cook *et al*. 1991; Allen *et al*. 2001). The Neoproterozoic zircon spectra of North Tien Shan (Kröner *et al*. 2012) and South China (Li *et al*. 2015) show distinct similarity to Tarim, and may suggest that the three terranes became separated during the breakup of the Rodinia supercontinent.

The position of North China and Tarim in relation to the Kazakh terranes during the Ordovician Period is less certain. The brachiopod faunas of North China are inadequately known; however, an assemblage described by Fu (1982) from the Jinhe Formation of north-west China contains numerous taxa which are common in the Kazakh mud-mound faunas (e.g. *Parastrophina*, *Pectenospira*, *Plectosyntrophia*?, *Didymelasma*, and *Schizostrophina*), but which are unknown in South China (Popov *et al*. 2009). *Eokosovopeltis*, which is a key trilobite in the *Eokosovopeltis–Pliomerina* Province of Webby *et al*. (2000) is also remarkable by its absence from the Sandbian and early Katian of South China (Zhou and Zhen 2009), and those authors also mentioned that the Australian trilobite faunas had its closest affinities with those of North China. That might support a position for North China in low northern latitudes, as suggested by Zhao *et al*. (1996), where it would also have been influenced by equatorial currents.

Although by no means certain, a position for Tarim in the southern subtropics west of the South China plate appears to be the most probable, thus placing Tarim near the Atashu-Zhamshi Microcontinent, which was apparently the most isolated terrane within the Kazakh archipelago. In contrast to the poorly known Late Ordovician brachiopods (only a small Late Katian *Foliomena* Association¸ which includes *Kassinella*), Tarim's trilobites are relatively well known. They include *Ampyxinella*, *Birmanites*, *Dulanaspis*, *Ovalocephalus*, *Lisogorites*, and distinctive three-segmented raphiophorids, which are also known from South China and the Kazakh terranes (Fortey and Cocks 2003; Zhou and Zhen 2009). The reedocalymenine *Calymenesun* is confined only to South China, Tarim, and Indo-China (Turvey 2005a).

Palaeogeographical conclusions for the Kazakh terranes

The Middle and Late Ordovician faunas of Chu-Ili, Chingiz and Boshchekul (Text-fig. 1), are identified as the key tectonostratigraphic units for understanding the tectonic evolution and positioning of the Kazakh Orogen in the Early Palaeozoic. The Early Katian faunas of the Karatau-Naryn unit were described by Misius (1986), whose data have been reassessed by Popov *et al*. (2009), and Popov and Cocks (2014). The Katian brachiopods of Kalmykkol-Kokchetav are under study and some preliminary results are included here. The Late Darriwilian to Sandbian brachiopod faunas of North Tien Shan were documented by Nikitina (1985) and Misius (1986), and those from Chu-Ili by Nikitina *et al*. (2006) and Popov *et al*. (2002).

The earliest known biogenic sediments in the ocean are the Late Cambrian radiolarian oozes, but it was in the Ordovician when biogenic sedimentation commenced in the open ocean on a global scale, such as on the oceanic plate subducted along the active margin of Chu-Ili (Tolmacheva *et al*. 2001). As the Ordovician developed during the Tremadocian to Sandbian, extensive radiolarian oozes (now preserved as ribbon-banded cherts) accumulated along the narrow belts in equatorial settings within the accretionary complexes of Kazakhstan (Tolmacheva *et al*. 2004; 2009; Tolmacheva and Degtyarev 2012; Stepanets and Gridina 2011), as well as in south-east Australia (Percival 2012), and southern Scotland (Aitchison 1998). Radiolarian oozes accumulate today in narrow belts characterised by high primary biological productivity on both sides of the Equator between 20° N and 20° S beneath the equatorial upwelling zone, which coincide with the tropical equatorial zones of divergence (Kennett 1982). The distribution of the Ordovician ribbon-banded radiolarian cherts closely mirrors this pattern. Outside that area there was no biogenic sedimentation and a sedimentary cover on the ocean floor was reduced to a thin venier of pelagic clays with atmospheric dust as the primary source.

Those sediments largely disappeared in the oceanic trench during subduction processes while biogenic oceanic sediments, which are the main source of the material included into modern accretionary wedges, did not exist outside subequatorial latitudes throughout the Palaeozoic. Due to the extremely low sedimentation rate (1.5 m per My for Burubaital cherts: Tolmacheva *et al.* 2004), continuous deposition of pure radiolarian cherts without significant supply of fine siliciclastic for sizeable periods of time was impossible on the plate passive margins, whilst in the back arc basins the thickness of hemipelagic sediments increased significantly due to high supply of fine siliciclastic and volcanic material (Zhylkaidarov, 1998; Popov *et al.* 2009; Metcalf and Shervais 2008, p. 213). Together with the few reliable palaeomagnetic data, there are thus some objective constraints when evaluating previous palaeogeographical models.

The extensive volcanism also had important implications for faunal dispersal and exchange. As pointed out by the late Robert Neuman (personal communication, 1991), mature island arc volcanism produces high quantities of pumice which created pumice rafts, which makes possible for the benthic animals attached to them to spread with oceanic currents towards the shelves of adjacent terranes. Volcanic eruptions today in the Tonga-Kermadec volcanic arc were a source of pumice which reached the eastern Australia shores, up to 5000 km distant, in 7 to 8 months (Bryan *et al.* 2012), and their attached biota includes a wide range of benthic organisms, including barnacles, corals, serpulid worms, oysters and bryozoans. Similar events in the Ordovician would have helped the dispersal of a wide range of animals, including corals, craniiform and rhynchonelliform brachiopods, bryozoans, and ostracods. The shelves of isolated Ordovician microcontinents and intraoceanic volcanic arcs were also important centres which aided generic migration (Neuman 1972; Harper 2006). In particular, the Kazakh island arcs were the centres of origination and dispersion of the spire-bearing brachiopods such as atrypides, athyridides, and spiriferides (Bassett *et al.* 1999; Popov *et al.* 1999), and also the craniiform trimerellides (Popov *et al.* 1997). Thus identifying the dispersion patterns of the newly-evolved brachiopod groups, as well as other benthic animals, gives significant new information on the relative geographical position of terranes and continents.

It seems likely that the Australasian sector of Gondwana was the major origin of migrants to the Kazakh terranes in the Darriwilian to Early Sandbian. An analysis of the Darriwilian and Sandbian peri-Gondwanan faunas (Percival *et al.* 2011, fig. 2A; Popov *et al.* 2016, fig. 11), demonstrated that the Kazakh faunas form a single cluster with contemporaneous Australasian faunas, whilst the South China faunas clustered separately. A similar pattern was demonstrated for the Darriwilian trilobites, and in South China the shallow shelf asaphid biofacies were dominated by the Subfamily Nobiliasaphinae and especially *Liomegalaspides* (Turvey 2005a). The asaphids of Chu-Ili include two genera, *Damiraspis* and *Farasaphus*, which also occur in the Australasian sector of Gondwana (Thailand and New South Wales) as well as in Argentina (Ghobadi Pour *et al.* 2009, 2011a). *Eokosovopeltis*, one of the index taxa for the *Eokosovopeltis–Pliomerina* Province of Webby *et al.* (2000), was already present in the Sandbian of North China, the Australasian sector of Gondwana and the Kazakh terranes, but did not appear in South China until the Katian (Zhou and Zhen 2009).

There are some distinctive brachiopod genera, e. g. *Mabella*, *Shlyginia*, *Testaprica*, which occur in Chingiz-Tarbagatai and New South Wales, but not in South China. The Katian fauna of the Chingiz-Tarbagatai Terrane shows a higher degree of endemism than before: in particular *Alpeis*, *Ashinaorthis*, *Buminomena*, *Wrightiops*, and the Family Alpeisidae are endemic there. In contrast, brachiopods such as *Glyptomenoides, Metambonites*, *Nikitinamena*, *Ogmoplecia*, *Sortanella*, *Synambonites*, and *Weberorthis*, which are quite common in Chu-Ili (as well as *Metambonites* and *Synambonites* in South China), are not known from Chingiz-Tarbagatai.

To summarise, in the Mid Ordovician the Kazakh terranes were populated by faunas with strong links to equatorial Gondwana and to a lesser extent to South China, and their faunas occupied intraoceanic locations in the tropics well isolated from both Baltica and Siberia. The most probable location of the archipelago was within low latitudes on both sides of the Equator west and north-west of the Australasian sector of Gondwana and somewhat north and probably north and north-west of South China (Text-figs 2, 13). The Kazakh terranes were to the north-east of South China. The south-western Kazakh cluster (Chu-Ili, North Tien Shan and Karatau-Naryn) was near South China, whilst the Chingiz-Tarbagatai volcanic island arcs were north-east of the south-western cluster, and in better faunal contact with the Australasian sector of Gondwana. The position of the Kalmykkul-Kokchetav microcontinent is less well-constrained, but its most likely location was in the intraoceanic space in the low northern latitudes north-west of the southern Kazakh terrane cluster.

This biogeographically-based reconstruction agrees well with the inferred oceanic circulation patterns in the low latitudes west of the north-western Gondwanan coast at that time. It is probable that the cool-water South Subpolar Current running along the western Gondwanan coast had an effect on the climate comparable to the present-day Humboldt Current. As a result, average annual temperatures of surface waters along the coasts of the South China continent during the Early to Mid Ordovician would have been lower than in subequatorial peri-Gondwana, which would have prevented the immigration of some warm-water taxa (Ghobadi Pour *et al.* 2009; 2011b). Only in the Katian, when South China entered lower latitudes (Cocks and Torsvik 2013), did its affinity with the shallow shelf faunas of the Kazakh terranes become more firmly established (Percival *et al.* 2011). Another important palaeogeographical feature was the presence of the huge Gondwanan land mass, suggesting a monsoon regime and seasonally reversing oceanic surface circulation in the tropics west of that continent (Wilde 1991).

The earliest brachiopod-dominated associations with community structure characteristic of the Palaeozoic Evolutionary Fauna are from the Early Darriwilian of Chu-Ili (Nikitina *et al.* 2006), which apparently immigrated into the region: the typical bryozoans, rhynchonelliform brachiopods, and ostracods had already evolved elsewhere in the Late Tremadocian and Floian (Bassett *et al.* 2002). The core of the Darriwilian brachiopod associations in Chu-Ili (Table 1) is formed by genera (e.g. *Aporthophyla*, *Idiostrophia*, *Leptella*, *Leptellina*, *Neostrophia*, *Taphrodonta*, *Toquimia*, and *Trematorthis*) which were components of the Darriwilian pantropical fauna; however, there is also a significant proportion of endemics (48%), including the earliest representatives of the suborder Orthotetidina and the Family Parallelelasmatidae (Nikitina *et al.* 2006).

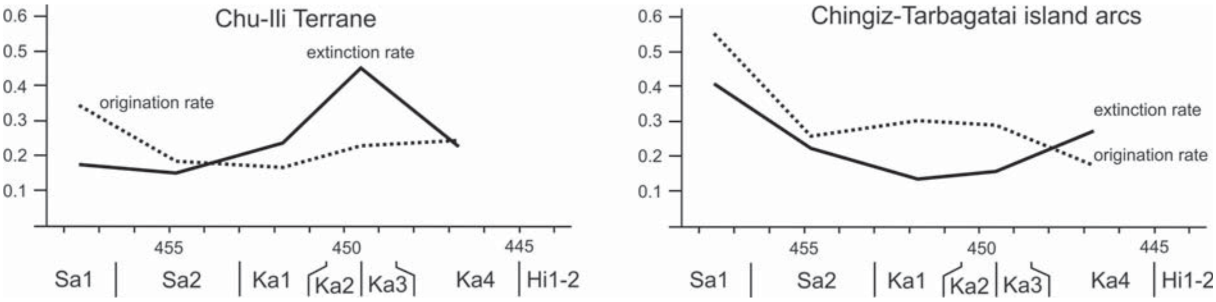
Aporthophyla occurs in the Selety and North Tien Shan terranes (Nikitin and Popov 1983; Nikitin 1991), but no other Darriwilian brachiopods are known from those regions. All that suggests that Chu-Ili was an isolated terrane in the Darriwilian and located in tropical latitudes, perhaps near South China and the Australasian sector of Gondwana (Nikitina *et al.* 2006; Percival *et al.* 2011).

The Palaeozoic Evolutionary Fauna came later to the other Kazakh terranes, including Kalmykkol-Kokchetav, Boshchekul, and Chingiz-Tarbagatai, near Darriwilian–Sandbian boundary time, suggesting their separation from the southern cluster of Kazakh Terranes then. The co-occurrence of such brachiopods *Dulankarella*, *Ishimia*, *Kajnaria*, and *Shlyginia* suggests a common origin for those pioneering faunas, which may have migrated from Chu-Ili and North Tien Shan (Misius 1986; Popov *et al.* 2002; Nikitina *et al.* 2006).

The distinctive brachiopods *Martellia* and *Yangtzeella* do not occur in the Kazakh terranes apart from Chu-Ili, but are characteristic of the Dapingian to Darriwilian faunas in South China, Iranian terranes, and the Turkish Taurides (Fortey and Cocks 2003; Percival *et al.* 2009; Nikitina *et al.* 2006; Ghobadi Pour *et al.* 2011a). The *Foliomena* Fauna was mainly endemic to South China in the Sandbian and Early Katian (Rong *et al.* 1999); however, in the Late Sandbian it had also reached Chu-Ili (Popov *et al.* 2002), Kokchetav-Kalmykkol, and Chingiz-Tarbagatai (Popov and Cocks 2014), as parts of an almost cosmopolitan distribution. In contrast, the diverse brachiopod fauna that emerged suddenly in South China in the latest Katian (Zhan and Cocks 1998) includes a number of characteristic genera, e.g. *Altaethyrella*, *Eospirigerina*, *Ovalospira* [= *Schachriomonia*], *Metambonites*, *Qilianotryma*, and *Sulcatospira*, which had made their earlier appearances in the Early to Middle Katian of the Kazakh terranes and are all known from Chu-Ili.

The latest Katian (*pacificus* Biozone) in Chu-Ili is characterised by widespread deposition of black graptolitic shales along the margins of the Zhalair-Naiman basin and the growth of carbonate build-ups populated by a distinctive brachiopod fauna including large pentameridines, including *Brevilamnulella*, *Proconchidium*, *Holorhynchus*, *Prostricklandia*, and *Tcherskidium* (Nikitin *et al.* 1980). There was also large scale immigration of genera, for example *Coolinia*, *Dalmanella*, *Eoplectodonta*, *Giraldibella*, *Hindella*, *Sowerbyella* (*Rugosowerbyella*, and *Streptis*), which had no roots in East Gondwana, but are characteristic of the Late Katian faunas of Baltica and the Mediterranean segment of Gondwana (Apollonov *et al.* 1980). That dispersal pattern was probably caused by the occasional influence of the oceanic South Subpolar Current which must have run along the western coast of Gondwana. By analogy with the present-day Humboldt Current, which runs down the west coast of South America, that Ordovician South Subpolar Current would have been strengthened during episodes of cooler climate, when it would have reached low latitudes near the Equator.

Close faunal links of the Karatau-Naryn Terrane with South China throughout the Cambrian are well established (Popov *et al.* 2009). By the end of the Mid Ordovician, the Karatau-Naryn and North Tien Shan terranes merged into a unit was populated by



Text-fig. 14. Comparative origination and extinction rates (lineage per million years; Lma) for Sandbian to Katian rhynchonelliform and craniiform brachiopod genera from selected Kazakh terranes. The Lma for origination and extinction rates (y axis) is plotted as the number of genus originations (or extinctions) within the particular chronostratigraphical time interval, divided by the total generic diversity within the unit, divided by the chronological duration of the interval (Patzkowsky and Holland, 1997); calculations for Lma are plotted at the mid point of each time interval

low-diversity brachiopod fauna varying from eight genera in the early Sandbian to 16 genera in the Early Katian. The Early Sandbian fauna of North Tien Shan is similar to the fauna on the opposite side of the Zhalair-Naiman basin in the Chu-Ili Terrane, but similarity between the faunas in those areas decreased in the Late Sandbian and early Katian, while between North Tien Shan/Karatau-Naryn and Kokchetav-Kalmykkol it had increased considerably at the generic level by the Early Katian.

The generic diversity of the Early Sandbian faunas of the Kokchetav-Kalmykkol and Boshchelkul terranes was low, and biofacies differentiation was not well established there. The absence of older benthic assemblages in those units suggest that pioneering populations appeared there following dispersal across the oceanic barriers through the shelves of microcontinents or island arc systems (Cracraft 1994). The limited faunal exchanges and existence of vicariant species suggest the existence of oceanic barriers, and isolation of Kokchetav-Kalmykkol and Boshchelkul from the other Kazakh terranes. The Katian faunas from Kalmykkol-Kokchetav and Boshchekul show closer Raup-Crick similarity to the contemporary faunas of the Karatau-Naryn terrane, and considerable overlap between the Early Katian faunas of them is evident from the Principal Component Analysis. Both are characterised by the proliferation of *Dinorthis*-dominated brachiopod associations on the shallow clastic shelves, although that genus is represented by vicariant species, with different rhynchonellide and atrypide genera in the faunas. That may suggest that, while isolation between faunas still persisted, Kalmykkol-Kokchetav were nearer the South-Western terrane Cluster in the Early Katian than the Eastern Cluster (Chingiz-Tarbagatai and Boshchekul).

The Chingiz-Tarbagatai island arc system, which supported the earliest brachiopod associations linked with microbial carbonate build-ups and included the earliest trimerellides and spirebearers of the Suborder Lissatrypida, was probably another significant centre for faunal dispersal, but the Mid Ordovician brachiopod faunas are undescribed from there. The brachiopod faunas of Chingiz-Tarbagatai were considerably different from those in the other clusters until the end of the Ordovician and turnover rates in Chingiz-Tarbagatai and Chu-Ili were also different (Text-fig. 14). While extinction rates were low in Chingiz-Tarbagatai through the Middle to Late Katian, there was increased turnover and immigration of cold water taxa into the Late Katian shelves of Chu-Ili, followed by invasion of the *Hirnantia* Fauna in the Hirnantian, a fauna unknown in the other Kazakh terranes.

Comparison of the Late Ordovician faunas from the two Kazakh terrane clusters suggest their considerable separation of from many hundred to a few thousand kilometres (Fortey and Cocks 2003), which persisted until the end of the Ordovician. Considerable isolation of Boshchekul from Chingiz-Tarbagatai and Chu-Ili from North Tien Shan also persisted through the Late Ordovician.

Ordovician biogeography set against previous models of the Kazakh Orogen and the Early Palaeozoic formation of Kazakhstania

In their review of the Palaeozoic history of the Western Altaids, Xiao *et al.* (2010) recognised that there are several competing models, which they classified as: (1) oroclinal bending and strike-slip faulting (e.g. Şengör *et al.* 1993; Şengör and Natal'in 1996; Yakubchuk *et al.* 2001; von Raumer *et al.* 2003;

Yakubchuk 2004; 2008); (2) Early Palaeozoic composite continent models (e.g. Kheraskova *et al.* 2003; Degtyarev and Ryazantsev 2007); and (3) multiple terrane amalgamation models (e.g. Zonenshain *et al.* 1990; Mossakovsky *et al.* 1993; Windley *et al.* 2007). There are also composite models including Early Palaeozoic continent formation plus oroclinal bending (Bazhenov *et al.* 2012; Xiao *et al.* 2015). Amongst those many papers, the provocative and inspiring Kipchak Arc model of Şengör *et al.* (1993) and Şengör and Natal'in (1996) is outstanding due to its substantial analysis of published material. However, the existence of a single linear volcanic arc between Baltica and Siberia has not found support in subsequent studies (summary in Xiao *et al.* 2010). Since then, despite the continuous flow of papers on the formation of Kazakhstania, and new data on isotope geochemistry and some data on Early Palaeozoic palaeomagnetism, many have not cited the published regional geology, Early Palaeozoic lithostratigraphy, sedimentology, and biostratigraphy.

A Kazakhstania continent before the end of the Ordovician was first suggested by Khain (1977) and was followed in subsequent Russian publications (e.g. Filippova *et al.* 2001; Bazhenov *et al.* 2012, p. 185, etc.), with Degtarev and Ryazantsev (2007) suggesting an even earlier date. Wilhelm *et al.* (2012, p. 317) and Biske (2015, p. 9) postulated that substantial geochemical, geochronological, palaeomagnetic and geological data published since Sengör and Natal'in (1996) have corroborated the pre-Silurian formation of Kazakhstania by multiple amalgamation of island arcs and microcontinents, and they quote Windley *et al.* (2007); Abrajevitch *et al.* (2008); Alexeyev *et al.* (2011); Biske and Seltmann (2010), and other papers.

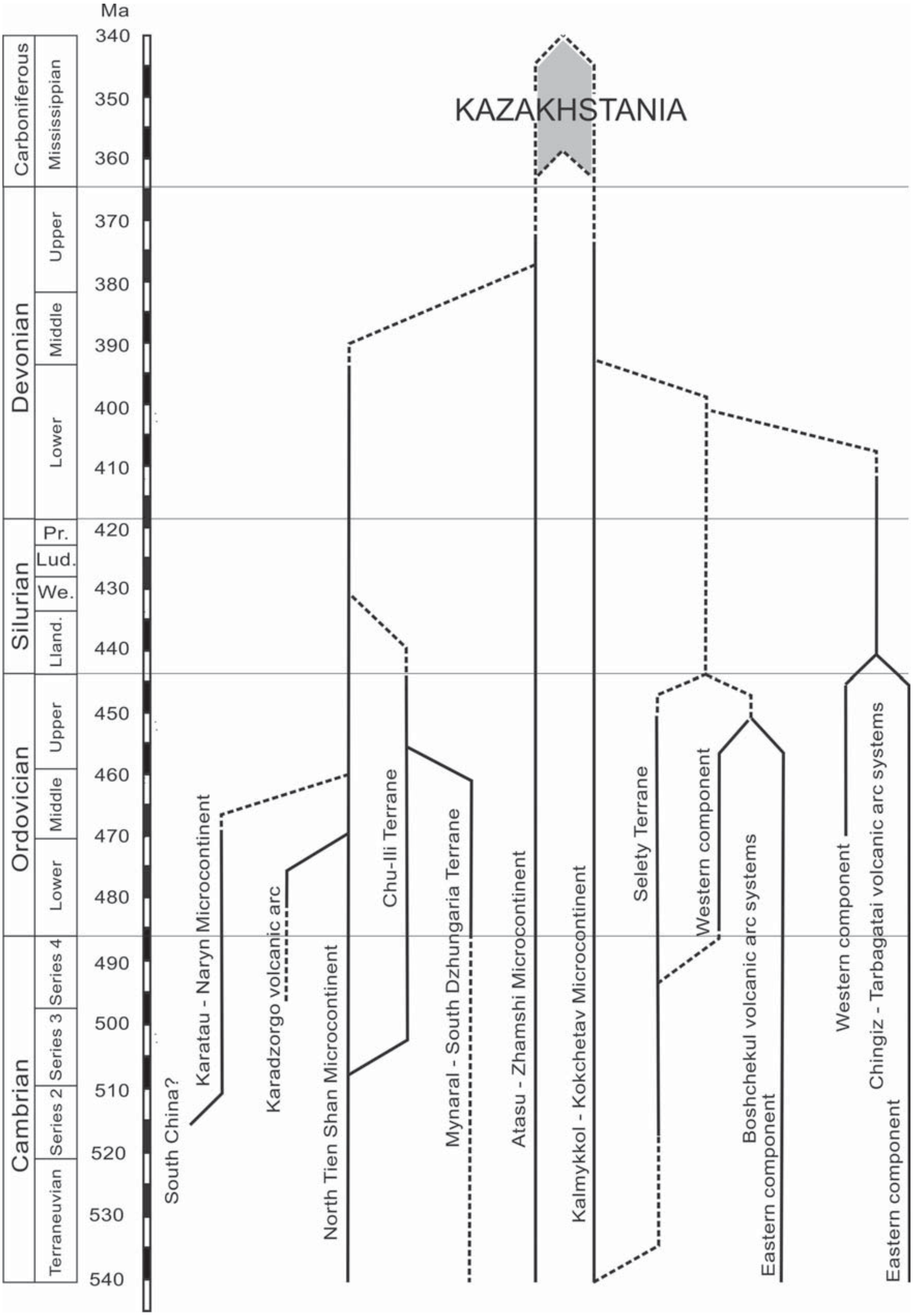
While several diachronous accretionary events did take place during the Ordovician in various parts of the Kazakh Orogen (Text-fig. 15), none of the above publications contain convincing evidence that amalgamation of the Kazakh terranes into a single continent actually occurred then. In particular, it is difficult to understand how a south-western suture separating the Aktau-Junggar unit of Wilhelm *et al.* (2012, p. 318) and Bazhenov *et al.* (2012) (the Atashu-Zhamshi Microcontinent here) could have been formed by the end of the Ordovician, when the Agadyr Terrane, on the north-western margin of Atashu-Zhamshi (Text-fig. 1.6), contains a condensed succession of radiolarian cherts and tuffites, dated by Landovery to Wenlock conodonts and graptolites (Nikitin, 1991; Koren *et al.* 2003), from which siliciclastic material is virtually absent, thus indicating oceans separating the local microcontinents. There is also an extensive accretionary wedge, including Silurian to Early Devonian volcanic and sedimentary rocks, on the opposite side of the suture (Bandaletov, 1968; Bandaletov *et al.* 1980; Popov *et al.* 2009). Thus there must have been a sizeable marine basin southwest of Atashu-Zhamshi throughout the Silurian.

The alleged cessation of sedimentation during the Hirnantian-Rhuddanian along the 'Yermentau-Yili accretionary wedge' of Alekseiev *et al.* (2011, p. 807) and Wilhelm *et al.* (2012, p. 318) is incorrect, since Hirnantian and Rhuddanian deposits are well-documented from the West Balkhash Region (Apollonov *et al.* 1980; Modzalevskaya and Popov, 1995; Popov *et al.* 2009, fig. 17) (Text-fig. 1.3, 1.4). There is also no Ordovician accretionary wedge in the Ermentau Terrane, which probably represents an Early Cambrian remnant island arc (exposed today in the Ermentau-Niyaz Massif) and an Ordovician back-arc basin.

There is also no trace of a major accretionary event near the Ordovician–Silurian boundary (the inferred 'Hirnantian-Rhuddanian Event' of some authors) along the south-eastern margin of the Chu-Ili Terrane facing the Zhalair-Naiman fault zone, since there is a continuous Ordovician–Silurian succession in many localities exposed for almost 170 km (Apollonov *et al.* 1980), which includes widespread outer shelf graptolite-bearing sediments of the Chokpar and Zhalair formations deposited from the *Paraorthograptus pacificus* (upper Katian) to the *Parakidograptus acuminatus* (Rhuddanian) zones. However, there is a major regional unconformity at the lower boundary of the uppermost Llandovery Betkainar Formation (Koren *et al.* 2003, fig. 3).

There are also problems with a mysterious 'Arenig event', which Wilhelm *et al.* (2012, p. 318) stated was the time when most of the Kazakh sutures formed, since the provided references (Dobretsov *et al.* 2006; Degtyarev and Ryazantsev, 2007; Kröner *et al.* 2007; Biske and Seltmann, 2010; Alexeiev *et al.* 2011; Kröner *et al.* 2012; Rojas-Agramonte *et al.* 2014) do not contain detailed analyses of local and regional geology supported by sedimentological, lithological, and biostratigraphical data. Thus the criteria used by Wilhelm *et al.* (2012, p. 318) as diagnostic for the inferred pan-Kazakh accretionary event (e.g. cessation of arc activity, stratigraphic unconformities, olistostromes, flysch deposits, HP metamorphism, folding, and granitic intrusions) cannot be supported.

The available data indicates that cessation of volcanic arc activity in the Selety and Boshchekul volcanic arcs in reality occurred much earlier, in the



Text-fig. 15. Flow chart showing the history and amalgamations of the Kazakh terranes from the Cambrian to the Carboniferous. Dotted lines are less well constrained than the solid lines middle Cambrian (Nikitin 1991, table 4.2), while discontinuity in sedimentation (the so-called 'Amgian Event') might have been caused by subsidence of an inactive arc due to thermal relaxation and a significant decrease in the input of clastic sediments at a time when biogenic pelagic sedimentation had not yet commenced, a plausible alternative not previously suggested. At the same time, island arc volcanism continued uninterrupted along the active (north-eastern) margin of the Chu-Ili Terrane (Popov *et al.* 2009). There is no evidence of Lower Ordovician to Dapingian volcanism on either side of the Zhalair-Naiman Fault Zone (Popov *et al.* 2009).

The Lower to Middle Ordovician volcanism in the Stepnyak unit is rift-related (Degtyarev 2012, p. 244), whilst the island arc volcanism, which started in the late Darriwilian to Sandbian, continued through the Ordovician (Nikitin 1972; 1973; 1991, Table 5.3), and terminated sometime in the Silurian (Serykh *et al.* 1972, p. 118). Within the second half of the Cambrian to Mid Ordovician, the Kalmykkol-Kokchetav microcontinent indicates general uplift and erosion, while the Cambrian (Furongian) to Mid Ordovician Darriwilian sedimentation continued without interruption within the continental rift systems (Nikitin 1991; Tsai *et al.* 2001; Degtyarev *et al.* 2016). There is no indication of a major Lower Ordovician regional unconformity.

The orogenic events recorded in the Makbal metamorphic terrane (Text-fig. 1) situated on the south-western margin of the North Tian Shan Microconrtinent (Rojas-Agramonte *et al.* 2014) may be related to several accretionary events in the Early to Mid Ordovician and resulted finally in the amalgamation of the North Tien Shan and Karatau-Naryn microcontinents (Mikolaichuk *et al.* 1997; Burtman 2006), but they had no relation to the Zhalair-Naiman suture as suggested by Rojas-Agramonte *et al.* 2014, fig. 10). In the best-documented Lower Ordovician section along the Agalatas River about 14 km east of Kurdai (former Georgievka) in the south Kendyktyas Range, facing Zhalair-Naiman, there is a continuous succession of siliciclastic and carbonate rocks (Kendyktas, Agalatas and Kurdai formations) deposited in outer to mid shelf environments with no sign of unconformity within the Tremadocian to Floian (Popov and Holmer 1994; Popov *et al.* 2001), so there was no collision and related uplift along the north-eastern margin of North Tien Shan. The occurrence of the olenid trilobite biofacies with *Bienvillia* (= *Agalatus*) in the Floian Kurdai Formation (Lissogor 1961) suggests the presence of a sizeable marine basin in Zhalair-Niman then.

Olistostromes can be formed not only during thrusting events, but are also relatively common along active continental margins (formed in back-arc basins) and also along passive continental margins (Festa *et al.* 2014), although interpretation of the environment in which they formed requires sedimentological studies and knowledge of the local geology. There is nothing exceptional in the olistostrome horizons in the Floian to Dapingian (formerly 'Arenig') of Kazakhstan, since they are also known in the Cambrian (Furongian), Sandbian and mid Katian of the Chingiz-Tarbagatai Terrane (Nikitin 1991, Tables 4.2, 5.5), from the Tremadocian to the Darriwilian (Satpak, Olenty and Erzhan formations), and from the Middle and Late Katian (Oro and Tundyk formations, Agyrek olistostrome) in the Boshchekul Terrane (Nikitin 1991, table 5.5; Nikitin *et al.* 2006; Popov and Holmer 1994; Stepanets *et al.* 1998; Stepanets and Gridina 2011). Along the active margin on the south-western side of Chu-Ili, olistostromes formed in the Cambrian (Darbaza Formation) and in the Sandbian (Popov *et al.* 2009, p. 38, fig. 13a, c), and they are also common in the Silurian Mynaral Group (Bandaletov and Palets 1980). But there is no Early Ordovician olistostrome deposition in those areas; although there are Early Ordovician olistostromes in the west of the Boshchekul Terrane, in the Satpak, Olenty and Erzhan formations (Popov and Holmer 1994). In the Erzhan Formation large olistoliths of Cambrian (Furongian) limestone occur in the radiolarian cherts (Popov, field observation), which suggest that those olistostromes formed due to extension and rapid subsidence, perhaps during the formation of the back-arc basin. The Lower Ordovician ('Arenig') olistostrome in the Tokai Mountains was formed in a backarc basin (Degtyarev *et al.* 1995, p. 211), probably due to a reset of the backarc spreading zone, and was not therefore part of a continental collision.

Olistostrome horizons in the base of the Zhamanshuruk Formation (Early Katian), in the Llandovery Ashchiozek Formation, as well as in the Upper Devonian, are seen in the accretionary wedge along the north-eastern margin of Atashu-Zhamshi (Nikitin 2001; Stepanets 2015a). Olistostromes in the Karadzhorgo Formation formed on the slope of an active volcanic arc before that island arc was accreted to the margin of the North Tien Shan Microcontinent, probably in the Dapingian ('middle Arenig'), while the continent-to-continent collision of North Tien Shan and Karatau-Naryn occurred much later, close to the Middle to Upper Ordovician boundary (Mikolaichuk *et al.* 1997, p. 33; Burtman 2006).

Indeed, in Sarydzhas on the north-eastern passive margin of Karatau-Naryn, deposition of turbidites in the Oldzhobai and East Sarydzhas formations (dated by radiolarians and conodonts) took place continuously throughout the Lower and Middle Ordovician (Danelian *et al*. 2011). Those turbidites are overlain unconformably by shallow marine siliciclastic sediments and shell beds of the Early Katian Tez Formation, which is part of an onlap assemblage formed after the amalgamation of North Tien Shan and Karatau-Naryn. Turbidites accumulated more or less continuously on the active and passive margins of all the Kazakh island arcs and microcontinents throughout the Palaeozoic, many with Ordovician and Silurian graptolites (Bandaletov 1968; Nikitin 1972; Tsai 1974; 1976; Koren *et al*. 2003). Thus it is difficult to understand how the accumulation of turbidites can be deemed as relevant to a pan-Kazakh orogenic event in the 'Arenig'? Application of the occurrence of high pressure metamorphic rocks as indicators of the inferred 'Arenig Event' is also doubtful, and lacks supporting evidence from the contemporaneous sedimentary record, and it is difficult to comment on the alleged 'Arenig' folding, and granitic intrusions, because no adequate references were provided.

Late Ordovician positions of the Kazakh terranes: biogeography and palaeomagnetism reconciled

The only plausible model for the Lower Palaeozoic of the Kazakh Orogen is the archipelago first proposed by Zonenshain *et al*. (1990). In the Ordovician, that archipelago was located on both sides of the Equator, probably between the northern and southern tropical divergence zones with a little latitudinal displacement, as can be seen from extensive accumulation of the radiolarian oozes in surrounding seas.

Early Palaeozoic palaeomagnetic data on the Kazakh terranes are sparse and do not provide complete coverage either through time or for the different terrane units. In particular Cambrian, Ordovician, and Silurian palaeolatitudes are based on single or few sites, and there is often uncertainty if the measured polarity was normal or reversed (Collins *et al*. 2003, p. 240; Bazhenov *et al*. 2012, p. 984). Magnetic pole polarity reversals through the Ordovician should be also taken into account. Precise age assignments of the palaeomagnetic samples are often confusing, either because data on the sampled lithostratigraphical units are not presented, or the authors have not adopted modern chronostratigraphy. Models which involve oroclinal bending conclude that Chingiz lay in northerly palaeolatitudes (e.g. Bazhenov *et al*. 2012), so that position of the terrane in subequatorial southerly latitudes does not require large scale rotation (Collins et al. 2003). However, notwithstanding their possible polarity, palaeolatitudes obtained for the Early to Mid Ordovician (12.2±3.6°) of Chingiz (Collins *et al*. 2003) are in a good agreement with widespread deposition of radiolarian oozes in backarc basins and surrounding oceans (Zhylkaidarov 1998; Nikitin 2001; Degtyarev 2011; Stepanets 2015a).

Palaeomagnetic data for the Late Ordovician of North Tien Shan (Bazhenov *et al*. 2003) suggests its position in low subequatorial latitudes (6–9°). They also postulated the slow drift of North Tien Shan to the north (from 9°S to 16°N), with an average polarward velocity of 2 cm per year from the Sandbian to the Carboniferous (Bashkirian). Data for the Ordovician of North Tien Shan show similar values (about 9°S), while they indicate the position of the Chu-Ili Terrane in low northern latitudes (12.4° + 7.7°/− 6.6°) during the Late Silurian to Early Devonian (Alexyutin *et al*. 2005), who also concluded that, while the Ordovician rocks show northerly declinations, a few data from the Chingiz Range consistently show southerly declinations (Collins *et al*. 2003). Thus the position of the south-western cluster of Kazakh terranes in low southern latitudes (Text-fig. 13) looks well established from biogeographical, palaeomagnetic, and sedimentological data. However, the latitudinal position of the subduction zone in front of the North Tien Shan active margin suggested by Bazhenov *et al*. (2012) and Xiao *et al*. (2015) is questionable. As concluded by Popov *et al*. (2009), the sedimentary cover of the oceanic crust slab within the accretionary wedge in front of the Chu-Ili Terrane preserves a continuous record of the radiolarian ooze sedimentation there for almost 40 My (Tolmacheva *et al*. 2001, 2004). That is unique for the Ordovician record of pelagic sedimentation and would have occurred only if the subducted oceanic plate had a strong latitudinal component in its movement. Accumulation of radiolarian oozes occurs today at the abyssal depths in narrow belts, and are characterized by high primary biological productivity associated with equatorial divergence (Murdmaa 1987). Consequently, the front of the volcanic arc ran approximately north-south. The Chu-Ili Terrane is considered here as a Japanese-type active margin of the North Tien Shan Microcontinent and was separated from the latter by the Zhalair-Naiman back-arc basin, with maximum extent probably sometime in the Darriwilian–Sandbian. That separation was wide enough to delay the colonisation of North Tien Shan by the brachiopods characteristic of the Palaeozoic Evolutionary Faunas until the Early Sandbian, indicating that the separation was probably between 500 and 1000 km in the Darriwilian to Early Sandbian, and gradually decreased in the Late Ordovician.

It is not easy to evaluate the probable palaeogeographical position of the Kalmykkul-Kokchetav Terrane. According to Bazhenov *et al.* (2012), the Upper Ordovician palaeomagnetic samples from the Kalmykkul-Kokchetav (Ishim), Stepnyak (Saga Formation) and Ishkeolmes units show shallow negative inclinations, unlike contemporaneous samples from South Tien Shan, suggesting their tropical position (about 10° N) in the Northern Hemisphere, which mirrors the position of the south-western cluster of Kazakh terranes. In fact the Saga Formation is of Late Ordovician (Sandbian) age, while other samples are Early to Middle Katian. Bazhenov *et al.* (2012) applied sophisticated procedures to invert the position of Kalmykkol-Kokchetav to bring it closer to the south-western cluster of Kazakh terranes; a procedure which appears unnecessary. However, there is considerable difference of Precambrian zircon spectra between Kalmykkol-Kokchetav from one side and North Tien Shan and Tarim blocks from other side (Degtyarev *et al.* 2015).

The Lower Palaeozoic geology of the south-western cluster and Kalmykkol-Kokchetav is quite different, and the Palaeozoic Evolutionary Faunas benthic assemblages arrived in Kalmykkol-Kokchetav only in the Early Sandbian, suggesting a relatively isolated position. Those pioneering faunas show closest similarity to the latest Darriwilian faunas of the Chu-Ili Terrane facing the Zhalair-Naiman Basin, although some endemicity of the brachiopod faunas of Kalmykkol-Kokchetav persisted throughout the Late Ordovician. Thus a separation of c. 2000 km between the sampled areas, which is over twice their separation today, appears probable.

The time of amalgamation of the south-western cluster and Kalmykkol-Kokchetav cannot be defined with any degree of certainty, since the probable suture is hidden under the sedimentary cover of the Tengiz Depression, where deposits older than Devonian age are unknown (Ozdoev 2012). Nevertheless the occurrence of isograptid graptolites in the Dapingian to Early Darriwilian of the Kusheke Formation, south of Lake Tengiz (Tsai 1974, pp. 10, 27) on the southern side of the Tengiz Depression (Text-fig. 1.9), is an indication of a plate margin there (Fortey and Cocks, 2003, p. 249). Although the Early to Mid Devonian island arc volcanism in the Ulutau Region (Zaitsev *et al.* 1972; Nikitin 1991, Table 8.3), along the northern margin of the microcontinent, formed as a result of the amalgamation of the south-western cluster of terranes, it might have remained separate from Kalmykkol-Kokchetav until the Devonian. Analysis of existing geological data (Esenov *et al.* 1971, 1972) and simple analysis of the published geological maps (e.g. Dumler 1981; Li 2008) reveal that there are at least three Devonian volcanic belts across Kazakhstan. One can be traced along the eastern and northern margins of the amalgamated south-western Terrane Cluster. Another belt is the active margin of the Chingiz-Tarbagatai island arc system, which shows almost continuous record of island arc volcanism through the Early Palaeozoic. Some interruptions in volcanic activity (Degtyarev 2012) may have been related to the reorganisation of the magmatic front due to the growing accretionary wedge. The third volcanic belt can be seen north of the Silurian Tekturmas Suture, and probably evolved from the Boshchekul Island Arc system. It is also traceable to the west along the southern margins of the Selety Terrane and the Kalmykkol-Kokchetav microplate. Unfortunately, the interpretation of the Devonian volcanism in the Kazakh Orogen has had little attention, due to the widespread belief that the amalgamation of Kazakh terranes into a single microcontinent was already complete by the end of the Ordovician.

No reliable palaeomagnetic data is available for the Ordovician of the Boshchekul and Atashu-Zhamshi units; nevertheless, extensive accumulation of radiolarian oozes during the Early to Mid Ordovician (the Akdym and Erzhan formations of Boshchekul; and the Itmurundy, Kazyk, Chazhagai, Tyuretai, Zhamshi formations of Atasu-Zhamshi) suggest that both regions were within the tropical divergence zone (Apollonov 1990; Zhylkaidarov 1998; Nikitin 1991, 2001, 2002).

CONCLUSIONS

Detailed biogeograpical and biofacies analyses of 94 Late Ordovician brachiopod faunas from individual lithotectonic units within the Kazakh Orogen strongly support an archipelago model, with two units located on both sides of the Equator west of the Australasian segment of the Gondwana supercontinent, and in relative proximity to the Tarim, South China and North China continents, while the Atashu-Zhamshi microcontinent probably occupied an isolated position on the south-western margin of the archipelago. Distinct faunal signatures prove significant oceanic isolation of all the Kazakh terranes from Baltica and Siberia throughout the Ordovician.

Thus the Kazakh archipelago must have occupied considerable space, perhaps several thousand kilometres, on both sides of the Equator to the west of the Australasian segment of Gondwana. There is no quantative measure to assess biogeographical distances between terranes; however, Fortey and Cocks (2003, fig. 2) suggested that chance faunal recruitment of marine benthos between terranes steadily increases when they are separated by less than 1000 km; while oceanic separation of over about 2000 km makes that chance negligible and is enough to delimit a major biogeographical boundary. It seems probable that almost all the Kazakh terranes were on a convergent course through the Ordovician, and a slow northward drift of the southern terrane cluster by an average velocity of 2 cm/year can be inferred from the palaeomagnetic data (Bazhenov *et al.* 2003). We realise that our suggested reconstruction (Text-figs 3, 13) is only a rough estimation of the arrangements of individual units within the archipelago. It is not possible to define the original shapes and sizes of the Kazakh units with any precision because of the subsequent lithosphere erosion in the subduction zones and disintegration of the plate margins during oblique collisions (Kröner 2015; Kirscher and Bachtadse 2015). The plate boundaries changed through time because of the accretionary growth along their active margins and slope progradation along their passive margins, and the palaeogeography was further complicated by the existence of sizeable back-arc basins, which were opening and closing, and whose existence and dimensions are usually underestimated.

The Chu-Ili, North Tien Shan and Karatau-Naryn terranes probably occupied a south-western position in the archipelago. By the Early Katian, North Tien Shan and Karatau-Naryn had merged to form a unified microcontinent for which we retain the name ‘North Tien Shan’. The south-eastern and southern margins of North Tien Shan are characterised by passive margin development, while the Andean-type continental volcanic arc activity, which originated in the Darriwilian, continued along its north-western and northern margins. The Chu-Ili Terrane evolved in the mid Cambrian as a Japanese-type volcanic arc (Popov *et al.* 2009) and by the Katian it was separated from the Tien Shan Microcontinent by the sizeable Zhalair-Naiman back-arc basin. Thus North Tien Shan and Chu-Ili formed a double arc volcanic arc system during the Mid to Late Ordovician, as suggested by Sengör and Natal’in (1996), but the subduction polarity was the opposite of that stated by them. A sizeable accretionary wedge had grown along the active Chu-Ili margin by the beginning of the Late Ordovician (the ‘Sarytuna’ and ‘Buruntau’ tectonofacies zones). Sometime in the Sandbian, a small terrane of uncertain origin (the Mynaral-South Dzhunngaria Terrane of Popov *et al.* 2009) docked along the Chu-Ili active margin, which resulted in slab detachment and the resetting of the magmatic front. The occurrence of olenid trilobite biofacies in the Ak-Kerme Peninsula (Ghobadi Pour *et al.* 2011c) indicates the new position of the Chu-Ili margin in Katian time, while the constant presence of tuffs throughout the Ordovician–Silurian succession in Karasai (Apollonov *et al.* 1980) suggest that island arc volcanism persisted in the area. Island arc volcanism and accretionary wedge growth in front of Chu-Ili continued until the Devonian. As judged by the faunas, there was significant separation of Chu-Ili and Atashu-Zhamshi, which in the Katian probably exceeded 1000 km.

The most distinct feature of Mezo–Cenozoic accretionary wedges is the widespread presence of biogenic pelagic sediments scraped from the subducted slab of the oceanic crust as it smoothly disappears into the trench driven by gravity. In the absence of the biogenic pelagic sedimentation outside the equatorial convergence zones through the Palaeozoic the only sediments along the Palaeozoic active and passive margins were produced due to the gravity-driven sediment transport. Not surprisingly, there are constant problems with the identification of reduced accretionary wedges and a polarity of subduction in almost all the plate tectonic models proposed for the Kazakh Orogen. There the occurrence of condensed successions of pure radiolarian cherts without significant fine siliciclastic and volcanic components is a decisive criterion for the recognition of Early Palaeozoic accretionary wedges in tropical areas (Popov *et al.* 2009).

Almost all the ophiolites in the Kazakh Orogen are probably suprasubductional (Yakubchuk 1990; Windley *et al.* 2007, p. 41; Stepanets 2015a, 2015b), apart from the Balkybek ophiolite terrane in Chingiz-Tarbagatai (Degtyarev 1999). Thus they differ petrologically and geochemically from the igneous rocks originated in the ancient mid-oceanic spredding centres, while a structural setting of such ophiolites in the course of emplacement suggests the upper plate within convergent margin system as a likely place of their origin (Metcalf and Shervais 2008, p. 217). Therefore the condensed succession of pure radiolarian cherts, not the presence or absence of ophiolites, should be considered as the decisive factor in recognizing the Sarytuma and Ishkeolmes zones as the the best-preserved accretionary wedges in the Kazakh Orogen.

The Atashu-Zhamshi Microcontinent possibly occupied a marginal position in the Kazakh Archipelago at its south-western corner. Pelagic carbonate sedimentation on the south-western margin of the carbonate platform facing Chu-Ili preserves abundant radiolarian faunas and trilobites characteristic of the olenid biofacies (Nazarov and Popov 1980; Pouille *et al.* 2013, 2014) which is a good indication of a position at the continental margin. The termination of carbonate sedimentation was probably correlated with the onset of an Andean-type continental volcanic arc along its north-eastern margin in the latest Sandbian to Early Katian.

A position for the Chingiz-Tarbagatai volcanic arc system to the north of the Equator looks preferable, because associated Sandbian to Katian brachiopod faunas include many taxa, which were immigrants from Laurentia (e.g. *Craspedelia*, *Dorytreta*, *Perimecocoelia*, and *Productorthis*) and which are unknown in other Kazakh terranes. The long distance dispersal of those taxa can best be explained by pumice rafting along equatorial currents. It is possible that at least some of the volcanic arcs incorporated to the Chingiz-Tarbagatai composite terrane might represent the detached active margin of Australasian Gondwana. The early dispersal of trimerellides, which probably originally evolved on shelves of the Chingiz-Tarbagatai island arcs, towards Australasian Gondwana (Popov *et al.* 1997, 2013), is in strong support of that suggestion. The two island arcs within the Chingiz-Tarbagatai system were nearing each other in the Katian, but had not yet amalgamated. Northerly subduction under the eastern arc is likely, while the polarity of the western arc remains unknown (Degtyarev 2012). The positioning of the Chingiz-Tarbagatai volcanic arc system north of the Equator would require its large scale rotation (almost 180°) according to Collins *et al.* (2003), so that the polarity of the subduction in the Ordovician should be opposite. However, the few palaeomagnetic measurements available there are of dubious worth (Kirscher and Bachtadse 2015), while part of the observed rotation might be assigned to the stress fraction of the area due to subsequent oblique subduction. Thus a north-easterly direction of subduction is inferred in our reconstruction. Location of the Chingiz-Tarbagatai volcanic arc system at about 10° N implies significant separation from Atashu-Zhamshi in the Katian, probably well over 1000 km. Nevertheless those terranes are separated today by extensive Silurian to Early Carboniferous accretionary wedges, which implies an 80 to 100 My drift history before amalgamation of the units occurred.

The Boshchekul Terrane was a separate volcanic arc system some distance from Chingiz-Tarbagatai. However, the latter shares some genera with the pioneering brachiopod fauna which arrived in Boshchekul in the Early Sandbian, which suggests that the distance between terranes was somewhat below 1000 km. Those pioneering faunas show closer links to the faunas of the active margin of Chu-Ili. The western and eastern components amalgamated sometime in the Mid to Late Katian; however, it was an oblique collision, which could have started in the Early Katian and resulted in arc-slicing, arc-shaving, widespread olistostrome formation, and in the extensive growth of carbonate build-ups along the forming suture, culminating in the Middle Katian. That amalgamation resulted in significant tectonic reorganisation of the terrane and the formation of a new volcanic arc system in the Silurian.

If the Selety Terrane is considered as a remnant arc detached from the Boshchekul Terrane and separated from it by a back-arc basin, it could represent an important stepping-stone for faunal migration; however, except for the Katian, the brachiopod faunas of Selety are poorly known. In the Early Ordovician the Selety and Stepnyak units were separated by an ocean, but by the Katian that ocean was reduced to a few hundred kilometres in width.

Thus neither the existing data on the Lower Palaeozoic geology and palaeontology or our new analyses of the Kazakh Orogen support the large scale orocline bending of a large single volcanic arc, nor in the formation of the Kazakhstania Continent by the end of the Ordovician. That also agrees with the comprehensive analysis of the existing Palaeozoic palaeomagnetic records for the Kazakh Orogen by Kirscher and Bachtadse (2015).

Most of the existing models of geological history and plate tectonic development of the Kazakh Orogen through the Palaeozoic suffer significantly from inadequate use of published geological information, lack of lithofacies and biofacies analyses and poor handling of available data on the regional bio- and lithostratigraphy. It is certain that the complicated Palaeozoic geological history of the Kazakh Orogen and archipelago cannot be resolved by application of palaeomagnetic and high resolution geochemical studies alone, without support from other fields, such as geology and palaeontology.

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REFERENCES

Abdullin, A.A., Volkov, V.M., Shcherba, G.N., Patalakha, E.I. and Nikitchenko, I.I. (Eds) 1980. Chu-Ili ore belt. Part 1. Geology of the Chu-Ili Region, pp. 1–503. Nauka; Alma-Ata. [In Russian]

Abrajevitch, A., Van der Voo, R., Bazhenov, M.L., Levashova, N.M. and McCausland, P.J.A. 2008. The role of the Kazakhstan orocline in the late Paleozoic amalgamation of Eurasia. *Tectonophysics*, **455**, 61–76.

Aitchison, J.C. 1998. A lower Ordovician (Arenig) radiolarian fauna from the Ballantrae Complex, Scotland. *Scottish Journal of Geology*, **34**, 73–82.

Alexeiev, D.V., Ryazantsev, A.V., Kröner, A., Tretyakov, A.A., Xia, X. and Liu, D.Y. 2012. Geochemical data and zircon ages for rocks in a high-pressure belt of Chu-Yili Mountains, southern Kazakhstan: implications for the earliest stages of accretion in Kazakhstan and the Tianshan. *Journal of Asian Earth Sciences*, **42**, 805–820.

Alexyutin, M.V., Bachtadse, V., Alexeiev, D.V. and Nikitina, O.I. 2005. Palaeomagnetism of Ordovician and Silurian rocks from the Chu-Yili and Kendyktas Mountains, South Kazakhstan. *Geophysical Journal International*, **162**, 321–331.

Allen, M.B., Alsop, G.I. and 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.

Antonyuk, P.M., Maslova, I.G. and Mukhtarov, Zh. M. 2015. Tekturmas ophiolitic belt, composition, age and geodynamics. In: Materialy Mezhdunarodnoi nauchno-prakticheskoi konferentsii “Geologiya, minerageniya i perspektivy razvitiya mineralno-syr’yevykh resursov Respubliki Kazakhstan”, posvyashchennoi 75-letiyu Instituta geologicheskikh nauk im. K.I. Satpayeva, 26–27 Noyabrya 2015, K. I. Satpayev Institute of Geological Sciences, pp. 57–27. Almaty. [In Russian]

Apollonov, M.K. 2000. Geodynamic evolution of Kazakhstan in the Early Palaeozoic (from classic plate tectonic positions). In: Bespaev, H.A. (Ed.), Geodynamics and minerogeny of Kazakhstan. VAC Publishing House; Almaty, pp. 46–63. [In Russian]

Apollonov, M.K., Bandaletov, S.M. and Nikitin, I.F. (Eds) 1980. Ordovician–Silurian boundary in Kazakhstan, pp. 1–300. Nauka Publishers; Alma-Ata. [In Russian]

Apollonov, M.K., Zhemchuzhnikov, V.A. and Dubinina, S.V. 1990. Ordovician of the north-western Balkhash area. *Izvestiya Akademii Nauk Kazakhskoi SSR, Seriya Geologicheskaya*, **1990(4)**, 3–16. [In Russian]

Armstrong, H.A., Baldini, J., Challands, T.J., Gröcke, D.R. and Owen, A.W. 2009. Response of the inter-tropical convergence zone to southern hemisphere cooling during upper Ordovician glaciation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **284**, 227–236.

Arnaud, E., Halverson, G.P. and Shields-Zhou, G. 2011. The geological record of Neoproterozoic ice ages. In: Arnaud, E., Halverson, G. P. and Shields-Zhou, G. (Eds.), The Geological record of Neoproterozoic glaciations. *Geological Society, London, Memoirs*, **36**, pp. 1–16.

Bandaletov, S.M., 1968. Silurian of Kazakhstan, pp. 1–155. Nauka; Alma-Ata. [In Russian, English summary]

Bandaletov, S.M. and Palets, L.M. 1980. Silurian System. In: Abdullin, A.A., Volkov, V.M., Shcherba, G.N., Patalakha, E.I., Nikitchenko, I.I. (Eds), Chu-Ili Ore Belt. Part 1. Geology of the Chu-Ili Region, pp. 79–108. Nauka Publishers; Alma-Ata. [In Russian]

Bassett, M.G., Popov, L.E. and Holmer, L.E. 2002. Brachiopods: Cambrian–Tremadoc precursors to Ordovician radiation events. *Geological Society, London, Special Publications*, **194**, 20–33.

Bassett, M.G., Popov, L.E. and Sokiran, L.V. 1999. Patterns of diversification in Ordovician cyrtomatodont rhynchonellate brachiopods. *Acta Universitatis Carolinae, Geologica*, **43**, 329–332.

Bazhenov, M.L., Collins, A.Q., Degtyarev, K.E., Levashova, N.M., Mikolaichuk, A.V., Pavlov, V.E. and Van der Voo, R. 2003. Paleozoic northward drift of the North Tian Shan (Central Asia) as revealed by Ordovician and Carboniferous paleomagnetism. *Tectonophysics*, **366**, 113–141.

Bazhenov, M.L., Levashova N.M., Degtyarev, K.E, Van der Voo, R., Abrajevitch, A.V. and McCausland, P.J.A., 2012. Unraveling the early–middle Paleozoic paleogeography of Kazakhstan on the basis of Ordovician and Devonian paleomagnetic results. *Gondwana Research*, **22**, 974–991.

Bergström, S.M., Gutiérrez-Marco, J.C.and Dronov, A., 2009. The new chronostratigraphic classification of the Ordovician System and its relations to major regional series and stages and to δ^{13}C chemostratigraphy. *Lethaia*, **42**, 97–107.

Biske, Y.S., 1995. Late Palaeozoic collision of Tarim and Kyrgyz-Kazakh palaeocontinents. *Geotektonika*, **1**, 31–39. [In Russian]

Biske, Y.S. 2015. Geology and evolution of Central Asian Orogenic Belt in Kazakhstan and the western Tien Shan. In: Alfred Kröner, A. (Ed.), The Central Asian Orogenic Belt. Beiträge zur regionalen Geologie der Erde, **32**, pp. 6–49. Borntraeger; Stuttgart.

Biske, Y.S. and Seltmann, R. 2010. Paleozoic Tian-Shan as a transitional region between the Rheic and Urals-Turkestan oceans. *Gondwana Research*, **17**, 602–613.

Borisyenok, V.I., Gerasimova, N.A. and Zaitsev, Yu.A. 1985. New data on the Lower Palaeozoic stratigraphy of Yermyentau-Niyaz anticlinorium. Materialy po geologii Tsentral'nogo Kazakhstana, **20**, 10–35.

Bryan, S.E., Cook, A., Evans, J.P., Colls, P.W., Wells, M.G., Lawrence, M.G., Jell, J.S., Greig, A. and Leslie, R. 2012. Rapid, long-distance dispersal by pumice rafting. *PLoS ONE*, **7(7)**, e40583. DOI:10.1371/journal.pone.0040583.

Burtman, V.S. 2006. Tien Shan and High Asia. Tectonics and geodynamics in the Palaeozoic. *Trudy Geologicheskogo Instituta*, **570**, 1–214. [In Russian]

Cawood, P.A. 2005. Terra Australis Orogen: Rodinia breakup and development of the Pacific and Iapetus margins of Gondwana during the Neoproterozoic and Paleozoic. *Earth-Science Reviews*, **69**, 249–279.

Cawood, P.A. and Buchan, C. 2007. Linking accretionary orogenesis with supercontinent assembly. *Earth-Science Reviews*, **82**, 217–256.

Chumakov, N.M. 2011. Glacial deposits of the Baykonur Formation, Kazakhstan and Kyrgyzstan. In: Arnaud, E., Halverson, G.P. and Shields-Zhou, G. (Eds), The Geological record of Neoproterozoic glaciations. *Geological Society, London*, *Memoir*, **36**, 303–307.

Cocks, L.R.M. and Fortey, R.A. 1988. Lower Palaeozoic facies and faunas around Gondwana. *Geological Society, London, Special Publication*, **37**, 183–200.

Cocks, L.R.M., Fortey, R.A. and Lee, C.P. 2005 A review of Lower and Middle Palaeozoic biostratigraphy in west peninsular Malaya and southern Thailand in its context within the Sibumasu Terrane. *Journal of Asian Earth Sciences*, **24**, 703–717.

Cocks, L.R.M. and Torsvik, T.H. 2005. Baltica from the late Precambrian to mid-Palaeozoic times: the gain and loss of a terrane's identity. *Earth-Science Reviews*, **72**, 39–66.

Cocks, L.R.M. and Torsvik, T. H. 2007. Siberia, the wandering northern terrane, and its changing geography through the Palaeozoic. *Earth-Science Reviews*, **82**, 29–74.

Cocks, L.R.M. and Torsvik, T.H. 2013. The dynamic evolution of the Palaeozoic geography of eastern Asia. *Earth-Science Reviews*, **117**, 40–79.

Cocks, L.R.M. and Zhan, R. 1998. Caradoc brachiopods from the Shan states, Burma (Myanmar). Bulletin of the British Museum (Natural History), *Geology*, **54**, 109–130.

Collins, A.Q., Degtyarev, K.E., Levashova, N.M., Bazhenov, M.L. and van der Voo, R. 2003. Early Paleozoic paleomagnetism of east Kazakhstan: implications for paleolatitudinal drift of tectonic elements within the Ural-Mongol Belt. *Tectonophysics*, **277**, 229–247.

Cook, H.E., Taylor, M.E. Apollonov, M.K., Ergaliev, G.K., Sargaskaev, Z.S., Zhemchuzhnikov, S.V., Dubinina, S.V. and Melnikova, L.M., 1991. Comparison of two early Palaeozoic carbonate submarine fans – western United States and southern Kazakhstan, Soviet Union. In: Cooper, J.D. and Stevens, C.H. (Eds), Paleozoic paleogeography of the Western United States. Pacific Section, *Society for Sedimentary Geology (SEPM)*, **67**, 847–872.

Cracraft, J. 1994. Species diversity, biogeography, and the evolution of biotas. *American Zoologist*, **34**, 33–47.

Danelian,T. and Popov, L.E. 2003. Ordovician radiolarian biodiversity: insights based on new and revised data from Kazakhstan. *Bulletin de la Societé Géologique de France*, **174**, 325–335.

Danelian, T., Popov, L.E., Tolmacheva, T.Y., Ghobadi Pour, M., Neyevin, A.V. and Mikolaichuk, A.V. 2011. Ordovician radiolaria and conodonts from the peri-Gondwanan Karatau-Naryn terrane (Sarydzhaz, eastern Kyrgyzstan). *Geobios*, **44**, 587–599.

Degtyarev, K.E. 1999. Tectonic evolution of the Early Paleozoic active margin in Kazakhstan. *Trudy Geologisceskovo Instituta*. **513**, 1–124. [In Russian]

Degtyarev, K.E. 2011. Tectonic evolution of Early Palaeozoic island-arc systems and continental crust formation in the Caledonides of Kazakhstan and the North Tien Shan. *Geotectonics*, **45**, 28–57. [In Russian]

Degtyarev, K.E. 2012. Tectonic evolution of the Early Palaeozoic island arc systems and continental core formation of Kazakhstanian Caledonides. *Transactions of the Geological Institute*, **602**, 1–289. [In Russian]

Degtyarev, K.E. and Ryazantsev, A.V., 2007. Cambrian arc-continent collision in the Paleozoides of Kazakhstan. *Geotectonics*, **41**, 63–86. [In Russian]

Degtyarev, K.E., Serezhnikova, E.A. and Dubinina, S.V., 1995. The most ancient olistostromes of Kazakhstan. *Doklady Akademii Nauk*, **431**, 503–508. [In Russian]

Degtyarev, K.E., Ryazantsev, A.V., Tretyakov, A.A., Tolmacheva, T.Y., Yakubchuk, A.S., Kotov, A.B., Salnikova, E.B. and Kovach, V.P. 2013. Neoproterozoic–Early Paleozoic tectonic evolution of the western part of the Kyrgyz Ridge (Northern Tian Shan) Caledonides. *Geotectonics*, **47**, 377–417.

Degtyarev, K.E., Kovach, A.A., Tretyakov, A.B., Kotov, A.B. and Wang, K. 2015. Age and sources of Precambrian zircon-rutile deposits in the Kokchetav sialic massif (northern Kazakhstan). *Doklady Akademii Nauk*, **464**, 584–588. [In Russian]

Degtyarev, K.E., Tolmacheva, T.Y., Tretyakov, A.A., Kotov, A.B. and Shatagin, K.N. 2016. Cambrian to Lower Ordovician complexes of the Kokchetav Massif and its fringing (Northern Kazakhstan): Structure, age, and tectonic settings. *Geotectonics*, **50**, 71–142. [English edition]

Dobretsov, N.L., Buslov, M.M., Zhimulev, F.I., Travin, A.V. and Zayachkovsky, A.A., 2006. Vendian–Early Ordovician geodynamic evolution and model for exhumation of ultrahigh- and high-pressure rocks from the Kokchetav subduction-collision zone (northern Kazakhstan). *Russian Geology and Geophysics*, **47**, 424–440. [In Russian]

Dumler, L.F. (Ed.) 1981. Geological map of Kazakh SSR. 1:500,000 scale. Explanatory notes, pp. 1–325. Ministry of Geology of Kazakh SSR, Alma-Ata. [In Russian]

Edgecombe, G.D. and Webby, B.D. 2006. The Ordovician encrinurid trilobite *Sinocybele* from New South Wales and its biogeographic significance. *Memoirs of the Association of Australasian Palaeontologists*, **32**, 413–422.

Esenov, Sh.E., Galitskii, V.V., Kostenko, N.N. and Shlygin, A.E. (Eds), 1971. Southern Kazakhstan. *Geology of USSR*, **40**. Volume 1, pp. 1–534; Volume 2, pp. 1–105, Nedra, Moscow. [In Russian]

Esenov, Sh.E., Shlygin, A.E., Lyapichev, G.F. and Avdeev, A.V. (Eds) 1972. Central Kazakhstan. *Geology of USSR*, **20**. Volume 1, pp. 1–469; volume 2, pp. 1–194, Nedra, Moscow. [In Russian]

Festa, A., Dilek, Y., Gawlick, H.J. and Missoni, S., 2014. Mass-transport deposits, olistostromes and soft-sediment deformation in modern and ancient continental margins, and associated natural hazards. *Marine Geology*, **356**, 1–4.

Filippova, I., Bush, V. and Didenko, A., 2001. Middle Palaeozoic subduction belts: The leading factor in the formation of the Asian fold-and-thrust belt. *Russian Journal of Earth Sciences*, **3**, 405–426. [In Russian]

Fortey, R.A. and Cocks, L.R.M. 2003. Palaeontological evidence bearing on global Ordovician–Silurian continental reconstructions. *Earth-Science Reviews*, **61**, 245–307.

Fu, L. 1982. Phylum Brachiopoda. In: Xian Institute of Geology and Mineral Resources (Eds), Palaeontological Atlas of northwest China (Shaanxi, Ganzu and Ningxia Provinces). 1. Precambrian to Early Palaeozoic. pp. 95–179. Geological Publishing House; Beijing. [In Chinese]

Ghobadi Pour, M., McCobb, L.M.E., Owens, R.M. and Popov, L.E. 2011a. Late Ordovican trilobites from the Karagach Formation of the western Tarbagatai Range, Kazakhstan. Earth and Environmental *Transactions of the Royal Society of Edinburgh*, **101**, 161–187.

Ghobadi Pour, M., Popov, L.E., Kebria-ee Zadeh, M.R. and Baars, C. 2011b. Middle Ordovician (Darriwilian) brachiopods associated with the *Neseuretus* biofacies, eastern Alborz Mountains, Iran. *Memoirs of the Association of Australasian Palaeontologists*, **42**, 263–283.

Ghobadi Pour, M., Popov, L.E., McCobb, L.M.E. and Percival, I. 2011c. New data on the Late Ordovician trilobite faunas of Kazakhstan: implications for biogeography of tropical peri-Gondwana. In: Gutiérrez-Marco, J.C., Rábano, I., García-Bellido, D. (Eds.), Ordovician of the World. *Cuadernos del Museo Geominero*, **14**, 171–178.

Hobadi Pour, M., Popov, L.E. and Vinogradova, E.V. 2009. Mid Ordovician (late Darriwilian) trilobites of northern Betpak-Dala desert in Central Kazakhstan. *Memoirs of the Association of Australasian Palaeontologists*, **37**, 327–349.

Hammer, Ø. and Harper, D.A.T. 2006. Paleontological Data Analysis, pp. 1–368. Blackwell; Oxford..

Hammer, Ø., Harper, D.A.T. and Ryan, P.D. 2001. Past: Paleontological Statistics Software Package for Education Data Analysis. *Palaeontologia Electronica*, **4**, 1–9.

Harper, D.A.T. 2006. The Ordovician biodiversification: setting an agenda for marine life. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **232**, 148–166.

Harper, D.A.T., Rasmussen, C.M. Ø., Liljeroth, M., Blodgett, R.B., Candela, Y., Jin, J., Percival, I.G., Rong, J., Villas, E. and Zhan, R.B. 2013. Biodiversity, biogeography and phylogeography of Ordovician rhynchonelliform brachiopods. *Geological Society, London, Memoir*, **38**, 127–144.

Hawkins, T., Smith, M. P., Herrington, R. J., Maslennikov, V., Boyce, A. J., and Jeffries, T. 2016. The geology and genesis of the iron skarns of the Turgai belt, northwestern Kazakhstan. *Ore Geology Reviews*. (doi:10.1016/j.oregeorev.2015.10.016)

Hickerson, M.J. and Meyer, C.P. 2008. Testing comparative phylogeographic models of marine vicariance and dispersal using a hierarchical Bayesian approach. *BMC evolutionary biology*, **8**, 322. (doi: 10.1186/1471-2148-8-322)

Huff, W.D. 2008. Ordovician K-bentonites: issues in interpreting and correlating ancient tephras. *Quaternary International*. **178**, 276–287.

Jaanusson, V. 1973. Aspects of carbonate sedimentation in the Ordovician of Baltoscandia. *Lethaia*, **6**, 11–34.

Keller, M. and Lehnert, O. 2010. Ordovician paleokarst and quartz sand: Evidence of volcanically triggered extreme climates? *Palaeogeography, Palaeoclimatology, Palaeoecology*, **296**, 297–309.

Kennett, J.P. 1982. Marine Geology. Englewood Cliffs, pp. 1–813. New Jersey; Prentice-Hall.

Khain, V.E., 1977. Regional Geotectonics (Extra-Alpine Europe and Western Asia), 1–360 pp. Nedra Publishers; Moscow. [In Russian]

Khain, E.V., Bibikova, E.V., Salnikova, E.B., Kroner, A., Gibsher, A.S., Didenko, A.N., Degtyarev, K.E. and Fedotova, A.A. 2003. The Palaeo-Asian ocean in the Neoproterozoic and early Palaeozoic: new geochronologic data and palaeotectonic reconstructions. *Precambrian Research*, **122**, 329–358.

Kheraskova, T.N., Didenko, A.N., Bush, V.A. and Volozh, Y.A. 2003. The Vendian–Early Paleozoic history of the continental margin of Eastern Paleogondwana, Paleoasian Ocean, and Central Asian Foldbelt. *Russian Journal of Earth Sciences*, **5**, 165–184. [In Russian]

Kirscher, U. and Bachtadse, V. 2015. Palaeozoic critical review. In: Kröner, A. (Ed.), The Central Asian Orogenic Belt. *Beiträge zur regionalen Geologie der Erde*, **32**. Borntraeger, Stuttgart, pp. 50–65.

Klenina, L.N. 1984. Brachiopods and biostratigraphy of the Middle and Upper Ordovician of Chingiz-Tarbagatai Meganticlinorium. In: S. M. Bandaletov (Ed.), Brachiopods and biostratigraphy of the Middle and Upper Ordovician of the Chingiz Ranges. Nauka, Alma-Ata, pp. 6–125. [In Russian]

Kolobova, I.M. 1972. New Late Ordovician trilobites from south-eastern Kazakhstan., In: Zanina, I.E. (Ed.) Novyie vidy drevnikh rastenii i bespozvonochnykh. Nauka, Moscow. pp. 242–246. [In Russian]

Kolobova, I. M., 1983. Some new Ordovician trilobites of eastern Kazakhstan (Chingiz Range). *Ezhegodnik Paleontologicheskogo obshchestva*, **26**, 248–262. [In Russian]

Koren, T.N., Popov, L.E., Degtjarev, K.E., Kovalevsky, O.P. and Modzalevskaya, T.L. 2003. Kazakhstan in the Silurian. *New York State Museum Bulletin*, **493**, 323–334.

Korobkin, V.V. and Smirnov, A.V., 2006, Palaeozoic tectonics and geodynamics of volcanic arcs in northern Kazakhstan. *Russian Geology and Geophysics*, **47**, 462–474. [In Russian]

Kovach, V.P., Ryazantsev, A.V., Tretyakov, A.A., Degtyarev, K.E., Tolmacheva, E.V., Wang, K., Kotov, A.V., Chun, S. and Jahn, B. 2014. U-Pb Age of detrital zircons from neoproterozoic placers of the Erementau-Niyaz Massif as a reflection of stages of Precambrian tectono-magmatic evolution of northern Kazakhstan. *Doklady Akademii Nauk*, **455**, 300–304. [In Russian]

Kröner, A. 2015. The Central Asian Orogenic Belt – present knowledge and comparison with the SW Pacific. In: Kröner, A. (Ed.), The Central Asian Orogenic Belt. Beiträge zur regionalen Geologie der Erde, **32**, pp. 1–5. Borntraeger; Stuttgart.

Kröner, A., Alexeiev, D.V., Hegner, E., Rojas-Agramonte, Y., Corsini, M., Chao, Y., Wong, J., Windley, B.F., Liu, D. and Tretyakov, A.A. 2012. Zircon and muscovite ages, geochemistry, and Nd-Hf isotopes for the Aktyuz metamorphic terrane: evidence for an Early Ordovician collisional belt in the northern Tianshan of Kyrgyzstan. *Gondwana Research*, **21**, 901–927.

Kröner, A., Kovach, V., Belousova, E., Hegner, E., Armstrong, R., Dolgopolova, A., Seltmann, R., Alexeiev, D.V., Hoffmann, J E., Wong, J., Sun, M., Cai, K., Wang, T., Tong, Y., Wilde, S.A.,

Degtyarev, K.E. and Rytsk, E. 2014. Reassessment of continental growth during the accretionary history of the Central Asian Orogenic Belt. *Gondwana Research*, **25**, 103–125.

Kröner, A., Windley, B.F., Badarch, G., Tomurtogoo, O., Hegner, E., Jahn, B.M., Gruschka, S., Khain, E.V., Demoux, A. and Wingate, M.T.D. 2007. Accretionary growth and crust formation in the Central Asian Orogenic Belt and comparison with the Arabian-Nubian shield. *Geological Society of America, Memoir*, **200**, 181–209.

Li., T. (Ed.) 2008. Atlas of Geological Maps of Central Asia and Adjacent Areas. 8 sheets, 1:2500000, Geological Publishing House; Beijing.

Li, Z., Qiu, N., Chang, J. and Yang, X. 2015. Precambrian evolution of the Tarim Block and its tectonic affinity to other major continental blocks in China: New clues from U-Pb geochronology and Lu-Hf isotopes of detrital zircons. *Precambrian Research*, **270**, 1–21.

Lisogor, K.A., 1961. Trilobites of Tremadoc and adjacent strata of Kendyktas. *Trudy Geologischeskovo Instituta*, **18**, 55–92. [In Russian]

Loi, A., Ghienne, J. F., Dabard, M.P., Paris, F., Botquelen, A., Christ, N. and Destombes, J. 2010. The Late Ordovician glacio-eustatic record from a high-latitude storm-dominated shelf succession: the Bou Ingarf section (Anti-Atlas, Southern Morocco). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **296**, 332–358.

Metcalf, R.V. and Shervais, J.W. 2008, Suprasubduction-zone ophiolites: Is there really an ophiolite conundrum? In Wright, J.E., and Shervais, J.W. (Eds), Ophiolites, Arcs, and Batholiths: A Tribute to Cliff Hopson: *Geological Society of America Special Paper*, **438**, 191–222,

Mikolaichuk, A.V., Kurenkov, S.A., Degtyarev, K.E.and Rubtsov, V.I. 1997. Main stages of geodynamic evolution of North Tien Shan in the late Precambrian–early Palaeozoic. *Geotektonika*, **6**, 16–34. [In Russian]

Misius, P.P. 1986. Ordovician brachiopods of northern Kirgizia, pp. 1–254. Ilim; Frunze. [In Russian]

Misius, P.P., Ushatinskaya, G.T. 1977. New Ordovician and Silurian strophomenids from Kazakhstan and northern Kirgiziya. Novye vidy drevnikh rastenii i bespozvonochnykh SSSR, **4**, 113–116. [In Russian]

Modzalevskaya, T.L. and Popov, L.E. 1995. Earliest Silurian articulate brachiopods from central Kazakhstan. *Acta Palaeontologica Polonica*, **40**, 399–426.

Mossakovskii A.A., Ruzhentsev, S.V., Samygin, S.G. and Kheraskova, T.N. 1993. Geodynamic evolution of the Central-Asia folded belt and history of its development. *Geotectonics*, **27**, 3–32. [In Russian]

Munnecke, A., Zhang, Y., Liu, X. and Cheng, J. 2011. Stable carbon isotope stratigraphy in the Ordovician of South China. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **307**, 17–43.

Murdmaa, I.O. 1987. Facies of the oceans, pp. 1–303. Nauka, Moscow. [In Russian]

Nazarov, B.B. and Popov, L.E. 1980. Stratigraphy and fauna of Ordovician siliceous-carbonate deposits of Kazakhstan. *Trudy Geologicheskogo Instituta Akademii Nauk SSSR*, **331**, 1–190. [In Russian]

Nedovizin, A.A. 1961. On the stratigraphy of the Akzhal Formation in the Chu-Ili Mountains. *Izvestiya Akademii Nauk Kazakhskoi SSR*, **2**, 26–34. [In Russian]

Neuman, R.B. 1972. Brachiopods of early Ordovician volcanic islands. Proceedings of the 24th International Geological Congress, Montreal, **7**, 297–302.

Neuman, R.B. and Harper, D.A.T. 1992. Paleogeographic significance of Arenig–Llanvirn Toquima-Table Head and Celtic brachiopod assemblages. In: Webby, B.D., Laurie, J. R. (Eds), Global perspectives on Ordovician Geology, pp 241–254. Balkema; Rotterdam.

Nikiforova, O.I. and Popov, L.E. 1981. New data on the Ordovician rhynchonellids of Kazakhstan and central Asia. *Paleontologicheskii Zhurnal*, **1981(1)**, 54–67. [In Russian]

Nikitin, I.F. 1972. Ordovician of Kazakhstan. Part 1. Stratigraphy, pp. 1–242. Nauka; Alma-Ata. [In Russian]

Nikitin, I.F. 1973. Ordovician of Kazakhstan. Part 2. Palaeogeography, palaeotectonics, pp. 1–100. Nauka; Alma-Ata. [In Russian]

Nikitin, I.F. 1974. New Middle Ordovician Plectambonitacea Plectambonitacea (Brachiopoda) from Kazakhstan. *Paleontologicheskii Zhurnal*, **1974 (3)**, 55–66. [In Russian]

Nikitin, I. F. (Ed.) 1991. Decisions of the Third Stratigraphical Conference on the Precambrian and Phanerozoic of Kazakhstan, Almaty, 1986. Part I. Precambrian and Palaeozoic, pp. 1–148. VSEGEI; St. Petersburg – Alma-Ata. [In Russian]

Nikitin, I.F. 2001. On the Ordovician volcano-siliceous deposits of the north-east Balkhash Region. *Geologiya Kazakhstana*, **2001 (1)**, 4–9. [In Russian]

Nikitin, I.F. and Popov, L.E. 1983. The Middle Ordovician orthoideans and plectambonitoideans from the northern Ishim river basin and the river Akhzar in Central Kazakhstan (Brachiopoda). *Ezhegodnik Vsesoyuznogo Paleontologicheskogo Obshchestva*, **26**, 228–247. [In Russian]

Nikitin, I.F. and Popov, L.E. 1984. Part II. Brachiopods from the Bestamak and Sargaldak formations (Middle Ordovician). In: Bandaletov, S.M. (Ed.), Brachiopods and biostratigraphy of the Middle and Upper Ordovician of the Chingiz Ranges, pp. 126–166. Nauka; Alma-Ata. [In Russian]

Nikitin, I.F. and Popov, L.E. 1985. Ordovician strophomenides (Brachiopoda) from the northern Priishimiye (Central Kazakhstan). *Ezhegodnik Vsesoyuznogo Paleontologicheskogo Obshchestva*, **28**, 34–49. [In Russian]

Nikitin, I.F. and Popov, L.E. 1996. Strophomenid and triplesiid brachiopods from an Upper Ordovician carbonate mound in central Kazakhstan. *Alcheringa*, **20**, 1–20.

Nikitin, I.F. Popov, L.E. and Bassett, M.G. 2003. Late Ordovician brachiopods from the Selety river basin, north Central Kazakhstan. *Acta Palaeontologica Polonica*, **48**, 39–54.

Nikitin, I.F., Popov, L.E. and Bassett, M.G. 2006. Late Ordovician rhynchonelliformean brachiopods of north-central Kazakhstan. *National Museum of Wales Geological Series*, **25**, 223–294.

Nikitin, I.F., Popov, L.E. and Holmer, L.E. 1996. Late Ordovician brachiopod assemblage of Hiberno-Salairian type from Central Kazakhstan. *GFF*, **117**, 8–96.

Nikitin, I.F., Popov, L.E. and Rukavishnikova, T.B. 1980. Class Articulata (articulate brachiopods). In: Apollonov, M.K., Bandaletov, S.M.and Nikitin, I.F. (Eds.), Ordovician-Silurian boundary in Kazakhstan, pp. 37–74. Nauka; Alma-Ata. [In Russian]

Nikitina, O.I. 1985. A new brachiopod association from the Middle Ordovician of southern Kazakhstan. *Paleontologicheskii Zhurnal*, **1985(4)**, 21–29. [In Russian]

Nikitina, O.I., Popov, L.E., Neuman, R.B., Bassett, M.G. and Holmer, L.E. 2006. Mid Ordovician (Darriwilian) brachiopods of South Kazakhstan. *National Museum of Wales Geological Series*, **25**, 145–222.

Ozdoev, S.M. 2012. Prospects oil-and-gas-bearing sedimentary basins of Kazakhstan. *Proceedings of the National Academy of Sciences of the Republic of Kazakhstan, Series of geology and technical science*, **2012(1)**, 61–76. [In Russian]

Parrish, J.T. 2012. Gondwanan palaeogeography and palaeoclimatology. In: Taylor, T.N, Taylor, E.L. (Eds), Antarctic paleobiology: its role in the reconstruction of Gondwana, pp. 5–26. Springer Science and Business Media; New York.

Patzkowsky, M.E. and Holland, S.M. 1997. Patterns of turnover in Middle and Upper Ordovician brachiopods of the eastern United States: a test of coordinated stasis. *Paleobiology*, **23**, 420–443.

Percival, I.G. 2012. Biotic characteristics of Ordovician deep-water cherts from Eastern Australia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **367**, 63–72.

Percival, I.G., Popov, L.E., Zhan, R. and Ghobadi Pour, M. 2011. Patterns of origination and dispersal of Middle to Late Ordovician brachiopods: examples from South China, East Gondwana, and Kazakh terranes. In: Gutiérrez-Marco, J.C., Rábano, I., García-Bellido, D. (Eds), Ordovician of the World. *Cuadernos del Museo Geominero*, **14**, 413–419.

Percival, I.G., Wright, A., Nicoll, R.S.and Hamedi, M.A. 2009. *Martellia* and associated Middle Ordovician brachiopods from the Katkoyeh Formation, east-central Iran. *Memoirs of the Association of Australasian Palaeontologists*, **37**, 315–325.

Popov, L.E. 1980. New brachiopod species from the Middle Ordovician of the Chu-Ili Range. *Ezhegodnik Vsesoyuznogo Paleontologicheskogo obshchestva*, **23**, 139–158. [In Russian]

Popov, L.E., Bassett, M.G. Zhemchuzhnikov, V.G. Holmer, L.E. and Klishevich, I.A. 2009. Gondwanan faunal signatures from Early Palaeozoic terranes of Kazakhstan and Central Asia: evidence and tectonic implications. *Geological Society, London, Special Publication*, **325**, 23–64.

Popov, L.E. and Cocks, L.R.M. 2006. Late Ordovician brachiopods from the Dulankara Formation of the Chu-Ili Range, Kazakhstan: their systematics, palaeoecology and palaeobiogeography. *Palaeontology*, **49**, 247–283.

Popov, L.E. and Cocks, L.R.M. 2014. Late Ordovician brachiopods from the Chingiz Terrane, Kazakhstan, and their palaeogeography. *Journal of Systematic Palaeontology*, **12**, 687–758.

Popov, L.E., Cocks, L.R.M. and Nikitin, I.F. 2002. Upper Ordovician brachiopods from the Anderken Formation, Kazakhstan: their ecology and systematics. Bulletin of the British Museum (Natural History), *Geology*, **58**, 13–79.

Popov, L.E., Ebbestad, J.O.R, Mambetov, A. and Apayarov, F.K. 2007. A low diversity shallow water lingulid brachiopod-gastropod association from the Upper Ordovician of Kyrgyz Range. *Acta Palaeontologica Polonica*, **52**, 27–40.

Popov, L.E. and Holmer, L.E. 1994. Cambrian–Ordovician lingulate brachiopods from Scandinavia, Kazakhstan, and South Ural Mountains. *Fossils and Strata*, **35**, 1–156.

Popov, L.E., Holmer, L.E., Bassett, M.G., Ghobadi Pour, M. and Percival, I.G. 2013. Biogeography of Ordovician linguliform and craniiform brachiopods. *Geological Society, London*, *Memoir*, **38**, 117–126.

Popov, L.E., Holmer, L.E. and Gorjansky, V.Y. 1997. Late Ordovician and Early Silurian trimerellide brachiopods from Kazakhstan. *Journal of Paleontology*, **71**, 584–598.

Popov, L.E., Kebria-ee Zadeh, M.R., Ghobadi Pour, M., Holmer, L.E. and Modzalevskaya, T.L. 2013. Cambrian (Furongian) rhynchonelliform brachiopods from the Eastern Alborz Mountains, Iran. *Bulletin of Geosciences*, **88**, 525–538.

Popov, L.E., Kebriaee-Zadeh, M.R. and Ghobadi Pour, M. 2016. Emergence of the Saucrorthis Fauna in the Middle Ordovician of northern Iran. *Australasian Palaeontological Memoirs*, **49**, 485–514.

Popov, L.E., Nikitin, I.F. and Cocks, L.R.M. 2000. Late Ordovician brachiopods from the Otar member of the Chu-Ili Range, south Kazakhstan. *Palaeontology*, **43**, 833–870.

Popov, L.E., Nikitin, I.F. and Sokiran, E.V. 1999. The earliest atrypides and athyridides (Brachiopoda) from the Ordovician of Kazakhstan. *Palaeontology*, **42**, 625–661.

Popov, L.E. and Rukavishnikova, T.B. 1986. A new family of gigantic inarticulate brachiopods from the Upper Ordovician of Kazakhstan. Paleontologicheskiy Zhurnal **1986(1)**, 56–60. [In Russian]

Popov, L.E., Vinn, O. and Nikitina, O.I. 2001. Brachiopods of the redefined family Tritoechiidae from the Ordovician of Kazakhstan and South Urals. *Geobios*, **32**, 131–155.

Pouille, L., Danelian, T., Ghobadi Pour, M. and Popov, L.E. 2013. New and revised inaniguttid Radiolaria and associated trilobites from the Upper Darriwilian (Ordovician) Shundy Formation of Kazakhstan. *Journal of Paleontology*, **87**, 1143–1159.

Pouille, L., Danelian, T. and Popov, L.E. 2014. A diverse Upper Darriwilian radiolarian assemblage from the Shundy Formation of Kazakhstan: insights into late Middle Ordovician radiolarian biodiversity. *Journal of Micropalaeontology*, **33**, 149–163.

Pushkin, A.I. and Popov, L.E. 1990. First record of the Late Ordovician bryozoans in the Tarbagatai Range. *Ezhegodnik Vsesoiuznogo Paleontologicheskogo Obshchestva*, **32**, 19–34. [In Russian]

Raup, D.M. and Crick, R.E. 1979. Measurement of faunal similarity in paleontology. *Journal of Paleontology*, **53**, 1213–1227.

Rojas-Agramonte, Y., Kröner, A., Alexeiev, D.V., Jeffreys, T., Khudoley, A.K., Wong, J., Geng, H., Shu, L., Semiletkin, S.A., Mikolaichuk, A.V., Kiselev, V.V. and Seltmann, R. 2014. Detrital and igneous zircon ages for supracrustal rocks of the Kyrgyz Tianshan and implications for crustal growth in the southern Central Asian Orogenic Belt. *Gondwana Research*, **26**, 957–974.

Rong, J., Chen, X. and Harper, D.A.T. 2002. The latest Ordovician *Hirnantia* Fauna in time and space. *Lethaia*, **35**, 231–249.

Rong, J., Zhan, R., Harper, D.A.T. 1999. Late Ordovician (Caradoc-Ashgill) brachiopod faunas with *Foliomena* based on data from China. *Palaios*, **14**, 412–431.

Rozanov, A.Y. and Sokolov, B.S. (Eds) 1984. Lower Cambrian stage subdivision. Stratigraphy, pp. 1–184. Nauka; Moscow. [In Russian]

Rukavishnikova, T.B. 1956. Ordovician brachiopods of the Chu-Ili Range. *Trudy Geologicheskogo Instituta Akademii Nauk SSSR*, **1**, 105–168. [In Russian]

Rukavishnikova, T.B. 1961. Brachiopods of the Lower Ordovician of the Kendyktas Range. *Trudy Geologicheskogo Instituta Akademii Nauk SSSR*, **18**, 29–54. [In Russian]

Ryazantsev, A.V., Degtyarev, K.E., Kotov, A.B., Sal'nikova, E.B., Anisimova, I.V. and Yakovleva, S.Z. 2009. Ophiolite sections of the Dzhalair-Nayman zone, South Kazakhstan: their structure and age substantiation. *Doklady Akademii Nauk*, **427 (3)**, 1–6.

Sapelnikov, V.P. and Rukavishnikova, T.B. 1975. The Upper Ordovician, Silurian and Lower Devonian pentamerids of Kazakhstan, pp. 1–227. Nauka; Sverdlovsk. [In Russian]

Seitmuratova, E.Yu. 2002. Late Palaeozoic volcahogenic and volcano-sedimentary formations of Zhongaro-Balkhash fold belt (stratigraphy and geologo-petrographical features), pp. 1–254. Satpaev Institute of Geological Sciences; Almaty. [In Russian]

Şengör, A.M.C. and Natal'in, B.A. 1996. Paleotectonics of Asia: fragments of a synthesis. In: Yin, A. andHarrison, M. (Eds), The Tectonic Evolution of Asia, pp. 486–640. Cambridge University Press; Cambridge.

Şengör, A.M.C., Natal'in, B.A. and Burtman, V.S. 1993. Evolution of the Altaid collage and Palaeozoic crustal growth in Eurasia. *Nature*, **364**, 299–306.

Sepkoski, J.J. Jr. 1981. A factor analysis description of the Phanerozoic marine fossil record. *Paleobiology*, **7**, 36–53.

Serykh, V.I., Shulga, V.M., Lyapichev, G.F., Zaitsev, Y.A. and Ememyanenko, P.F. 1972. Kokchetav-North Tien Shan fold belt. In: Esenov, S.E., Lyapichev, G.F., Shlygin, E.D. (Eds), Geology of the USSR, Central Kazakhstan, geological description, vol. 20(2), pp 109–125. Nedra; Moscow. [In Russian]

Sohrabi, A. and Jin, J. 2013. Global palaeobiogeography of brachiopod faunas during the early Katian (Late Ordovician) greenhouse episode. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **389**, 78–86.

Stepanets, V.G. 2015a. Geology and geodynamics of ophiolites of Central Kazakhstan, 362 pp. Karaganda State Technical University; Karaganda. [In Russian]

Stepanets, V.G. 2015b. To the issue on geodynamical nature of ophiolites of Tekmurass accretionary prism (Central Kazakhstan). *Gorno-geologicheskii Zhurnal*, **41–42**, 17–39. [In Russian]

Stepanets, V.G., Antonyuk, P.M. and Kryazheva, T.V. 2014. Lower Cambrian and Ordovician geology of the Maikain ore field. *Izvestiya Natsionalnoi Akademii Nauk Respubliki Kazakhstan*, **2014 (5)**, 11–27 [In Russian]

Stepanets, V.G. and Gridina, N.M. 2011. Upper Ordovician olistostromes of the Agyrek and Kosgombai Mountains: problems of correlation between Lower Paleozoic sedimentary and sedimentary-volcanogenic complexes in central Kazakhstan. *Stratigraphy and Geological Correlation*, **19**, 473–485. [In Russian]

Stepanets, V.G., Gridina, N.M. and Konik, V.E. 1998. Upper Ordovician olistostromes and stratigraphy of volcano-siliceous complexes of Agyrek and Kosgombai Mountains (Central Kazakhstan). *Geologiya Kazakhstana*, **1998(1)**, 12–23. [In Russian]

Tolmacheva, T.Y., Danelian, T. and Popov, L.E. 2001. Evidence for 15 m.y. of continuous deep-sea biogenic siliceous sedimentation in early Paleozoic oceans. *Geology*, **29**, 755–758.

Tolmacheva, T.Y. and Degtyarev, K.E. 2012. Late Cambrian–Early Ordovician condensed oceanic siliceous deposits in the Iradyr zone, Northern Kazakhstan. *Doklady, Earth Sciences*, **444**, 681–686.

Tolmacheva, T.Y., Degtyarev, K.E., Ryazantsev, A.V. and Nikitina, O.I. 2009. Conodonts from the Upper Ordovician siliceous rocks of central Kazakhstan. *Paleontological Journal*, **43**, 1498–1512. [In Russian]

Tolmacheva, T.Y., Degtyarev, K.E., Samuelsson, J. and Holmer, L.E. 2008. Middle Cambrian to Lower Ordovician faunas from the Chingiz Mountain Range, Central Kazakhstan. *Alcheringa*, **32**, 447–467.

Tolmacheva, T.Y., Holmer, L.E., Popov, L.E. and Gogin, I.Y. 2004. Conodont biostratigraphy and faunal assemblages in radiolarian ribbon-banded cherts of the Burubaital Formation, West Balkhash Region, Kazakhstan. *Geological Magazine*, **141**, 699–715.

Tolmacheva T.Y., Ryazantsev A.V., Degtyarev K.E. and Nikitina O.I. 2011. Middle–Upper Cambrian volcanogenic-cherty-siliciclastic formations of the Chu-Yili and Kendyktas Mountains (South Kazakhstan): structure of the sections, age substantionation and depositional environments. "The current state of Earth Sciences" International Conference, dedicated to the memory of V.E. Khain, Moscow, February 1–4, 2011, pp. 1875–1880. Moscow State University.

Torsvik, T.H. and Cocks, L.R.M. 2013a. New global palaeogeographical reconstructions for the Early Palaeozoic and their generation. *Geological Society, London, Memoir*, **38**, 5–24.

Torsvik, T.H. and Cocks, L.R.M. 2013b. Gondwana from top to base in space and time. *Gondwana Research*, **24**, 999–1030.

Torsvik, T.H., Van der Voo, R., Preeden, U., Mac Niocaill, C., Steinberger, B., Doubrovine, P.V., van Hinsbergen, D.J., Domeier, M., Gaina, C., Tohver, E. and Meert, J.G. 2012. Phanerozoic polar wander, paleogeography and dynamics. *Earth-Science Reviews*, **114**, 325–368.

Tsai, D.T. 1974. The Early Ordovician graptolites of Kazakhstan, 127 pp. Nauka; Moscow. [In Russian]

Tsai, D.T. 1976. Graptolites of the Middle Ordovician of Kazakhstan, 76 pp. Nauka; Alma-Ata. [In Russian]

Tsai, D.T., Nikitin, I.F., Apollonov, M.K., Popov, L.E. and Tolmacheva, T.Y. 2001. On the age of volcano-siliceous deposits of Kokchetau and Shatsk massifs and their surroundings. *Geologiya Kazakhstana*, **2001(2)**, 4–12. [In Russian]

Turvey, S.T. 2005a. Reedocalymenine trilobites from the Ordovician of central and eastern Asia, and a review of species assigned to *Neseuretus*. *Palaeontology*, **48**, 549–575.

Turvey, S.T. 2005b. Phylogeny of the Reedocalymeninae (Trilobita): implications for early Ordovician biogeography of Gondwana. *Geological Society, London, Special Publication*, **194**, 53–68.

von Raumer, J.F., Stampfli, G.M. and Bussy, F. 2003. Gondwana-derived microcontinents – the constituents of the Variscan and Alpine collisional orogens. *Tectonophysics*, **365**, 7–22.

Webby, B.D., Paris, F., Droser, M.L. and Percival, I.G. (Eds) 2004. The great Ordovician Biodiversification Event, 484 pp. Columbia University Press; New York.

Webby, B.D., Percival, I.G., Edgecombe, G.D., Cooper, R.A., VandenBerg, A.H.M., Pickett, J.W., Pojeta, J. Jr., Playford, G., Winchester-Seeto,, T., Young, G.C., Zhen, Y., Nicoll, R.S., Ross, J.R.P. and Schallreuter, R. 2000. Ordovician palaeobiogeography of Australasia. *Australasian Association of Palaeontologists Memoir*, **23**, 63–128.

Wilde, P. 1991. Oceanography of the Ordovician. *Geological Survey of Canada, Paper*, **90**, 283–298.

Wilhem, C., Windley, B.F. and Stampfli, G.M. 2012. The Altaids of Central Asia: a tectonic and evolutionary innovative review. *Earth-Science Reviews*, **113**, 303–341.

Windley, B.F., Alexeiev, D., Xiao, W., Kröner, A. and Badarch, G. 2007. Tectonic models for accretion of the Central Asian Orogenic Belt. *Journal of the Geological Society, London*, **164**, 31–47.

Xiao, W., Huang, B., Han, C., Sun, S. and 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.

Xiao, W.J., Windley, B.F., Sun, of S., Li, J.L., Huang, B.C., Han, C.M. and Chen, H.L. 2015. A tale of amalgamation of three collage systems in the Permian–Middle Triassic in central-east Asia: oroclines, sutures, and terminal accretion. *Annual Review of Earth and Planetary Sciences*, **43**, 16.1–16.31.

Yakubchuk, A. 1990. Tectonic position of ophiolite zones in the Paleozoic structure of the Central Kazakhstan. *Geotectonics*, **1990 (5)**, 55–68.

Yakubchuk, A. 2004. Architecture and mineral deposit settings of the Altaid orogenic collage: a revised model. *Journal of Asian Earth Sciences*, **23**, 761–779.

Yakubchuk, A. 2008. Re-deciphering the tectonic jigsaw puzzle of northern Eurasia. *Journal of Asian Earth Sciences*, **32**, 82–101.

Yakubchuk, A.S., Seltmann, R., Shatov, V. and Cole, A. 2001. The Altaids: tectonic evolution and metallogeny. *Society of Economic Geologists Newsletter*, **46**, 6–14

Zaitsev, Yu.A., Golubovskii, M.V. and Martynova, M.V. 1972. Devonian System. Ulutau anticlinorium. In: Esenov, Sh.E., Shlygin, E.D., Lyapichev, G.F. and Avdeev, A.V. (Eds), Geology of the USSR, Central Kazakhstan, geological description, vol. 20 (1) , pp. 50–57. Nedra; Moscow. [In Russian]

Zhan R. and Cocks, L.R.M. 1998. Late Ordovician brachiopods from the South China Plate and their palaeogeographical significance. *Special Papers in Palaeontology*, **59**, 1–70.

Zhan, R., Jin J., Rong, J. and Liang, Y. 2013. The earliest known strophomenoids (Brachiopoda) from early Middle Ordovician rocks of South China. *Palaeontology*, **56**, 1121–1148.

Zhan, R., Luan, X., Huang, B., Liang, Y., Wang, G. and Wang, Y. 2014. Darriwilian *Saucrorthis* Fauna: implications for the Great Ordovician Biodiversification Event (GOBE). *Estonian Journal of Earth Sciences*, **63**, 323–328.

Zhao, X., Coe, R.S., Gilder, S. A. and Frost, G.M. 1996. Palaeomagnetic constraints on the palaeogeography of China: implications for Gondwanaland. *Australian Journal of Earth Sciences*, **43**, 643–672.

Zhou Z. and Zhen Y. (Eds) 2009. Trilobite record of China, 1–402 pp. Science Press; Beijing.

Zhou, Z.and Zhou, Z. 2006. Late Ordovician trilobites from the Zhusilenghaierhan area, Ejin Banner, western Inner Mongolia. *Memoirs of the Association of Australasian Palaeontologists*, **32**, 383–411.

Zhylkaidarov, A. 1998. Conodonts from Ordovician ophiolites of central Kazakhstan. *Acta Palaeontologica Polonica*, **43**, 53–68.

Zonenshain, L.P., Kuzmin, M.I. and Natapov, L.M. 1990. Geology of the USSR: A plate tectonic synthesis. *Geodynamic Monograph. American Geophysical Union, Washington, Geodynamics Series*, **21**, 1–242.

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APPENDIX 1

Early Sandbian (Time Slice Sa1)

Chu-Ili Terrane

1 (Sa1). *Ancistrorhyncha* Association (BA2). Localities F-1020 and F-1020a [45°11'20" N; 72°21'1" E] collected by Popov in 1973–1974 from shell beds in the lower part of the Baigara Formation about 6 km south-west of Baigara Mountain. The assemblage is dominated by the rhynchonellide *Ancistrorhyncha* (more than 70%) which occurs with a new plectorthid genus and *Strophomena* (*Strophomena*).

2 (Sa1). *Scaphorthis–Strophomena* Association (BA2). Locality F-1021 [45°11'20" N; 72°21'1" E] collected by Popov and Tsai in 1973 and 1974 from silty limestone in the lower part of the Baigara Formation about 6 km south-west of Baigara Mountain. *Scaphorthis* (38%) and Plectorthidae gen. et sp. nov. 1 (24%), the strophomenoids *Colaptomena* (9%) (Fig. 4J) and *Strophomena* (*Strophomena*) (9%), and the plectambonitoid (*Sowerbyella*) (14%). Other taxa, including *Acculina*, *Plectocamara* (Fig. 4N), and *Sonculina*, are together only 6% of the total abundance.

3 (Sa1). Plectorthoid Association (BA3). Locality F-1022 [45°11'20" N; 72°21'1" E] sampled by Popov and Tsai in 1973 and 1974 from argillaceous limestone with abundant dasyclad algae in the lower Baigara Formation 6 km south-west of Baigara Mountain. More than 90% of the specimens are conjoined valves, sometimes preserved in life position. Plectorthidae gen. et sp. nov. 1 is dominant (76%). Other components include *Lepidomena* (10%), and *Sowerbyella* (*Sowerbyella*) (5%), but the rest, including *Apatomorpha*, *Colaptomena*, *Grammoplecia*, *Eremotoechia*, *Leptellina*, *Plectocamara*, *Sonculina*, and *Strophomena* (*Strophomena*), only constitute 9%.

4 (Sa1). Plectorthoid Association (BA3). Locality F-1023 [45°11'20" N; 72°21'1" E] collected by Popov and Tsai in 1973 and 1974 from argillaceous limestone with abundant dasycladic algae in the lower part of the Baigara Formation 6 km south-west of Baigara Mountain. More than 90% of the speciments in the locality are conjoined valves. Dominated by Plectorthidae gen. et sp. nov. 1 (61%). Other components include *Eremotoechia* (13%), *Sowerbyella* (*Sowerbyella*) (10%), and *Sonculina* (5%), but the others, including *Apatomorpha*, *Bimuria*, *Colaptomena*, *Grammoplecia*, *Lepidomena*, *Leptellina*, and *Strophomena* (*Strophomena*), only total 11%.

5 (Sa1). *Bimuria–Grammoplecia* Association (BA4). Locality F-1026 [45°15'48"N; 72°5'59 "E] collected by Popov and Tsai in 1973–1974 from dark grey siltstones in the middle Baigara Formation on the west side of the Karatal dry river, West Balkhash Region. *Grammoplecia* (53%), *Sowerbyella* (*Sowerbyella*) (15%), and *Bimuria* (10%) are the most common genera and *Eremotoechia*, *Kajnaria*, Plectorthidae gen. et sp. nov. 1, *Pseudocrania*, *Sonculina*, and *Ishimia*?, together total 22%.

6 (Sa1). *Bimuria–Grammoplecia* Association (BA4). Locality F-1026b [45°15'46" N; 72°6'4" E] collected by Popov and Tsai in 1973 and 1974 from nodular argillaceous limestones in the middle Baigara Formation on the west side of the Karatal dry river, West Balkhash Region. 86% of the specimens are articulated. *Grammoplecia* (40%), *Bimuria* (25%), *Eremotoechia* (19%), and *Christiania* (8%), but other genera, including *Atelelasma*, Furcitellidae gen. indet., *Kajnaria*, Plectorthidae gen. et sp. nov. 1, *Pseudocrania* (Text-fig. 4O), and *Titanambonites*? only total 8%.

7 (Sa1). *Ancistrorhyncha* Association (BA2). Locality N-6 [44°49'37" N; 74°4'53" E] sampled by Popov and Nikitin in 1981 and 1982 from a shell bed in an arkosic sandstone at the base of an unnamed formation 4.7 km south-west of Lake Alakul, West Balkhash. An accumulation of disarticulated valves of *Ancistrorhyncha modesta* Popov in Nikiforova and Popov, 1981 (Fig. 4A), and unidentified bivalve molluscs.

8 (Sa1). *Acculina* Association (BA3). Locality 812 [44°49'24" N; 74° 6'59" E] sampled by Nikitin and Popov in 1981 from calcareous siltstones in an unnamed formation 3.9 km south-west of Lake Alakul, West Balkhash. *Acculina* (Text-fig. 4H), *Christiania*, *Dulankarella* (Text-fig. 4D), *Glyptomena*, *Ishimia* (Text-fig. 4C), *Isophragma* (Text-fig. 4E), *Limbimurina*, *Mabella*, Plectorthidae gen. et sp. nov. 2, *Sowerbyella* (*Sowerbyella*), and *Testaprica*.

9 (Sa1). *Acculina* Association (BA3). Locality 813 [44°49'43"N, 74° 6'37" E] sampled by Nikitin and Popov in 1981 from calcareous siltstones in an unnamed formation 3.7 km south-west of Lake Alakul, West Balkhash Region. *Acculina*, *Dulankarella*, *Glyptomena*, *Ishimia*, *Isophragma*, Plectorthidae gen. et sp. nov. 2, *Sowerbyella* (*Sowerbyella*), and *Testaprica*.

10 (Sa1). *Testaprica* Association (BA2). Locality 814 [44°49'37" N; 74° 6'43"E] sampled by Nikitin and Popov in 1981 from calcareous silty sandstones in an unnamed formation 3.5 km south-west of Lake Alakul, West Balkhash. Plectorthidae gen. et sp. nov. 2 (50%), *Testaprica* (45%), and a few *Ishimia*.

11 (Sa1). *Acculina* Association (BA3), Locality 816 [44°49'37"N; 74° 6'5"E] sampled by Nikitin and Popov in 1981 from calcareous silty sandstones in an unnamed formation 3.5 km south-west of Lake Alakul, West Balkhash. *Acculina*, *Bandaleta*, *Bimuria*, *Dulankarella*, Plectorthidae gen. et sp. nov. 2, and *Sowerbyella* (*Sowerbyella*).

12 (Sa1). *Eoanastrophia* Association (BA3). Locality 8120-4b [44°48'58" N; 74° 2'13" E] sampled by Nikitin and Popov in 1981 from a bed of algal limestone with dasyclad algae in the lower part of an unnamed formation 8 km south-west of Lake Alakul,

West Balkhash. *Eoanastrophia* (Fig. 4S), *Ishimia*, and *Triplesia.*

13 (Sa1). *Eoanastrophia* Association (BA3). Locality 8121 [44°48'58" N; 74° 2'13" E] sampled by Nikitin and Popov in 1981 from a bed of algal limestone with dasyclad algae in the lower part of an unnamed formation 8 km south-west of Lake Alakul, West Balkhash. *Cooperia*, *Eichwaldia*, *Eoanastrophia*, *Esilia*, *Glyptorthis*, *Liostrophia. Phragmorthis*, Plectorthidae gen. et sp. nov. 2, *Rozmanospira*, *Sowerbyella*, and *Sphenotreta*.

14 (Sa1). *Eoanastrophia* Association (BA3). Locality 8124 [44°48'57" N; 74° 2'25" E] sampled by Nikitin and Popov in 1981 from a bed of algal limestone with dasyclad algae in the lower part of an unnamed formation 7.9 km south-west of Lake Alakul, West Balkhash. *Bandaleta*, *Eoanastrophia*, *Ishimia*, *Limbilurina*, *Liostrophia*, and Plectorthidae gen. et sp. nov. 2.

15 (Sa1). *Eoanastrophia* Association (BA3). Locality 8233 [44°48'59" N; 74° 2'50" E] sampled by Nikitin and Popov in 1982 from a bed of algal limestone with dasyclad algae in the lower part of an unnamed formation 7.9 km south-west of Lake Alakul, West Balkhash. *Bandaleta*, *Eoanastrophia*, *Esilia*, *Glyptorthis*, *Ishimia*, and *Phragnmorthis*.

North-Tien Shan and Karatau-Naryn microcontinents

16 (Late Darriwilian to Early Sandbian). *Scaphorthis–Strophomena* Association (BA2). Based on Nikitina (1985) [43°10' N; 74°45'E] from intercalated sandstones and siltstones in the middle Rgaity Formation at the outskirts of the Talapty temporary settlement, southern Kendyktas Range. *Acculina*, *Colaptomena*, *Oepikina*?, *Paralenorthis* and *Scaphorthis* (Text-fig. 4F).

17 (Sa1). *Ishimia* Beds (BA3) of Misius (1986). Low diversity fauna from several localities in the Tabylgaty Formation on the northern slope of the Moldo-Too Range in the lower reaches of the Tazasu, Shorsu and Tabylgaty rivers. *Acculina*, *Ishimia*, Plectorthidae gen. et sp. nov. 1, *Sowerbyella* (*Sowerbyella*), and *Strophomena* (*Strophomena*).

Kalmykkol–Kokchetav Microcontinent

18 (Sb1). Plectorthoid–Strophomenoid Association (BA2–3). Locality 1524 [53°19'33.39" N; 66°58'15.13" E] from bioclastic limestones of the Kupriyanovka Formation on the west bank of the Ishim River in the southern outskirts of Kupriyanovka village, Ishim River Basin near Stavropoliye (Nikitin, 1974; Nikitin and Popov, 1983; 1985). *Colaptomena* (9%), Dolerorthidae gen et sp. 1 (2%), *Esilia* (13%), *Ishimia* (15%), Plectorthidae new gen. 1 (30%), *Shlyginia* (6%), *Sowerbyella* (*Sowerbyella*) (8%), *Strophomena* (*Strophomena*) (12%), and *Titanambonites*? (5%).

Boshchekul Terrane

19 (Sa1). *Lepidomena* Association (BA2–3). Locality 6/n [51°40'42" N; 74°58'27" E] sampled by Nikitin in 1955 from algal limestones of the Sarybidaik Formation at Sarybidaik, west of Ekibastuz. *Actinomena*, *Ancistrorhyncha*, *Bandaleta*, *Lepidomena*, Plectorthidae gen. nov. 2, and *Shlyginia*.

20 (Sa1). *Camerella* Association (BA2–3). Locality 7842 [51°41'21"N; 74°59'41" E] sampled by Nikitin and Popov in 1978 from algal limestones of the Sarybidaik Formation at Sarybidaik, west of Ekibastuz. *Ancistrorhyncha*, *Camerella* (Text-fig. 4K), *Colaptomena*, *Glyptomena*. *Shlyginia*, and Plectorthidae gen. nov, 2.

Chingiz-Tarbagatai Terrane

21 (Sa1). *Scaphorthis* Association (BA2). Locality 79130 [49° 6'43" N; 78°31'46" E] from calcareous arkosic sandstones in the lower Bestamak Formation on the north side of the Chagan River, northern slope of Aktas Ridge, 0.85 km north-west from Konur-Aulie cave (Nikitin and Popov, 1984). *Scaphorthis*.

22 (Sa1). *Strophomena* Association (BA2). Locality 79137 [49° 6'36" N, 78°31'54"E] from calcareous arkosic sandstones in the lower Bestamak Formation, north side of River Chagan on the northern slope of Aktas Ridge, 0.6 km north-west from Konur-Aulie cave (Nikitin and Popov 1984). *Strophomena* (*Strophomena*) and Furcitellidae gen. indet.

23 (Sa1). *Usunia* Association (BA2–3). Locality 79132 [49°13'46"N; 78°19'51" E] from dark grey limestone in the lower Bestamak Formation, north side of River Chagan, 0.3 km north of Bestamak village (Nikitin and Popov, 1984). *Usunia*.

24 (Sa1). *Rozmanospira* Association (BA3); Locality 564 [49°13'52"N; 78°19'26"E] from bioclastic limestone in the lower Bestamak Formation, north side of River Chagan, 0.4 km north from Bestamak village (Nikitin and Popov 1984). The assemblage is dominated by the early lissatrypidine *Rozmanospira* (56%). Other taxa include *Ancistrothyncha* (6%), *Sowerbyella* (*Sowerbyella*) (25%), and *Triplesia* (5%), but *Camerella*, *Christiania*, *Esilia*, and *Glyptorthis* are together only about 8%.

25 (Sa1). *Palaeotrimerella* Association (BA2–3). Locality 564A [49°13'52"N; 78°19'26"E] from bioclastic limestone in the lower part of the Bestamak Formation on the north side of the Chagan River, 0.4 km north from Bestamak village (Nikitin and Popov 1984). *Esilia*, *Chaganella*, *Ovidiella*, *Palaeotrimerella*, and *Usunia*.

26 (Sa1). *Ancistrorhyncha* Association (BA2–3). Data based on Locality 821 [49°13'51" N; 78°19'30" E] from light grey bioclastic limestone in the lower Bestamak Formation on the north side of Chagan River, 0.4 km north of Bestamak village (Nikitin and Popov 1984). *Ancistrorhyncha*, *Esilia*, and *Glyptorthis*.

27 (Sa1). *Bimuria–Kajnaria* Association (BA4). Locality 638 [49°20'13" N, 78°7'23" E] from bioclastic limestones of Bestamak Formation 18 km north-west of Sarybulak River mouth, Chingiz Range (Nikitin and Popov, 1985). *Anoptambonites*, *Bimuria*, *Ishimia*, *Kajnaria*, and Plectorthidae new gen.1.

28 (Sa1). *Strophomena* Association (BA2–3). Locality 639 [49°21'26" N, 78°6'47" E] from the lower Bestamak Formation 18.5 km north-west of the Sarybulak River mouth, Chingiz Range (Nikitin and Popov 1985). *Camerella*, *Leptellina*, and *Strophomena*.

Late Sandbian (Time Slice Sa2)

Chu-Ili Terrane

29 (Sa2). *Tesikella* Association (BA2); Localities 7611 and 8128 from the Lower Anderken Formation in Anderkenyn-Akchoku and Kuiandy-Sai (Popov *et al.* 2002). *Acculina*, *Eodalmanella*?, *Pionodema*, *Plectorthis*, *Rhynchotrema*, and *Tesikella* (Text-fig. 4G).

30 (Sa2). *Tesikella* Association (BA2). Locality F-1018a from the Anderken Formation in the Kotnak Mountains, south Betpak-Dala (Popov *et al*. 2002). *Longvillia*, *Sowerbyella* (*Sowerbyella*), and *Tesikella*.

31 (Sa2). *Tesikella* Association (BA2). Locality 818a from the Anderken Formation in the Burultas Valley, West Balkhash Region (Popov *et al*. 2002). *Eodalmanella*?, *Mabella*, and *Tesikella*.

32 (Sa2). *Tesikella* Association (BA2). Locality F-1024b [45°16'40" N; 72° 9'30" E] on the east side of the Karatak Dry River near Sorbulak Spring, southern Betpak-Dala desert (Popov *et al*. 2002). *Christiania*, *Phragmorthis*, *Sowerbyella* (*Sowerbyella*), and *Tesikella*.

33 (Sa2). Mixed association from a bar system (BA2–3). Locality F-1018 from the Anderken Formation 6 km south-west of Kotnak Mountain (Popov *et al*. 2002). *Acculina*, *Anoptambonites*, *Bicusopina*, *Christiania*, *Didymelasma*, *Eodalmanella*, *Glyptomena*, *Isophragma*, *Limbimurina*, *Llongvillia*, *Mabella*, *Phragmorthis*, *Plectorthis*, *Shlyginia*, *Sowerbyella* (*Sowerbyella*), and *Tesikella*.

34 (Sa2). *Mabella–Sowerbyella* Association (BA2). Localities F-100b, 8128a, and 8128b from the Anderken Formation at Anderkenyn-Akchoku, Chu-Ili Range (Popov *et al.* 2002). *Anoptambonites*, *Eodalmanella*?, *Glyptomena*, *Mabella* (Text-fig. 4R), *Paracraniops*, *Shlyginia*, and *Sowerbyella* (*Sowerbyella*).

35 (Sa2). *Mabella–Sowerbyella* Association (BA2); Locality 7613 from the Anderken Formation at Kuyandy-Sai, Chu-Ili Range (Popov *et al*. 2002). *Christiania*, *Glyptomena*, *Mabella*, *Phragmorthis*, *Pionodema*, *Rhynchotrema*, *Shlyginia*, and *Sowerbyella* (*Sowerbyella*),

36 (Sa2). *Mabella–Sowerbyella* Association (BA2). Localities 8229 and 8230, Anderken Formation, Kuyandy-Sai, Chu-Ili Range (Popov *et al.* 2002). *Anoptambonites*, *Eodalmanella*?, *Glyptomena*, *Mabella*, *Phragmorthis*, *Pionodema*, *Shlyginia*, and *Sowerbyella* (*Sowerbyella*).

37 (Sa2). *Mabella–Sowerbyella* Association (BA2). Locality F-100b, Anderken Formation, Anderkenyn-Akchoku, Chu-Ili Range (Popov *et al*. 2002). *Anoptambonites*, *Eodalmanella*, *Glyptomena*, *Mabella*, *Shlyginia*, and *Sowerbyella* (*Sowerbyella*).

38 (Sa2). *Acculina–Dulankarella* Association (BA3). Locality F-626, Anderken Formation, Anderkenyn-Akchoku, Chu-Ili Range (Popov *et al*. 2002). *Acculina*, *Anoptambonites*, *Bicuspina*, *Christiania*, *Craspedelia*, *Dolerorthis*, *Dulankarella*, Furcitellinae gen. et sp. indet., *Gacella*, *Glyptorthis*, *Grammoplecia*, *Kajnaria*, *Kellerella*, *Parastrophina*, *Pectenospira*, *Phragmorthis*, *Placotriplesia*, *Plectosyntrophia*, *Rhynchotrema*, *Schizostrophina*, *Sortanella*, *Sowerbyella* (*Sowerbyella*), and *Teratelasmella*.

39 (Sa2). *Acculina–Dulankarella* Association (BA3). Locality F-100, Anderken Formation, Anderkenyn-Akchoku, Chu-Ili Range (Popov *et al*. 2002). *Acculina*, *Anoptambonites*, *Bicuspina*, *Christiania*, *Craspedelia*, *Dolerorthis*, *Dulankarella*, Furcitellinae gen. et sp. indet., *Gacella*, *Glyptambonites*, *Kajnaria*, *Kellerella*, *Leptaena* (*Ygdrasilomena*), *Liostrophia*, *Mabella*, *Nikolaispira*, *Parastrophina*, *Pectenospira*, *Placotriplesia*, *Plectosyntrophia*?, *Rhynchotrema*, *Schizostrophina*, *Sortanella*, *Sowerbyella* (*Sowerbyella*), and *Teratelasmella*.

40 (Sa2). *Acculina–Dulankarella* Association (BA3). Locality F-1041a, unnamed formation, Burultas, West Balkhash Region (Popov *et al*. 2002). *Acculina*, *Bellimurina*, *Christiania*, *Dulankarella*, Furcitellinae gen. et sp. indet., *Kajnaria*, *Mabella*, *Parastrophina*, *Placotriplesia*, and *Plectorthis*.

41 (Sa2). *Acculina–Dulankarella* Association (BA3). Locality 82258, Anderken Formation, Uzunbulak, Chu-Ili Range (Popov *et al*. 2002). *Acculina*, *Anoptambonites*, *Austinella*, *Christiania*, *Gacella*, *Parastrophina*, *Placotriplesia*, *Shlyginia*, and *Sowerbyella* (*Sowerbyella*).

42 (Sa2). *Parastrophina–Kellerella* Association (BA3). Locality F-628, Anderken Formation, Anderkenyn-Akchoku, Chu-Ili Range (Popov *et al*. 2002). *Bellimurina*, *Christiania*, *Craspedelia*, *Dolerorthis*, Furcitellinae gen. et sp. indet., *Gacella*, *Glyptorthis*, *Grammoplecia*, *Kajnaria*, *Leptaena* (*Ygdrasilomena*), *Liostrophia*, *Mabella*, *Parastrophina* (Text-fig. 4I), *Plectorthis*, *Rhynchotrema*, *Schizostrophina*, *Shlyginia*, *Sortanella*, *Teratelasmella*, and *Triplesia*.

43 (Sa2). *Parastrophina–Kellerella* Association (BA3); Localities 8223, 8223a, and 8223b, Anderken Formation, Anderkenyn-Akchoku, Chu-Ili Range (Popov *et al*. 2002). *Anoptambonites*, *Christiania*, *Craspedelia*, *Dolerorthis*, *Foliomena*, *Glyptorthis*, *Kajnaria*, *Kellerella*, *Leptaena* (*Ygdrasilomena*), *Liostrophia*, *Nikolaispira*, *Parastrophina*, *Pectenospira*, *Phragmor-*

this, *Placotriplesia*, *Schizostrophina* and *Sowerbyella* (*Sowerbyella*).

44 (Sa2). *Parastrophina–Kellerella* Association (BA3). Locality 8214, Anderken Formation, Ashchisu, Chu-Ili Range (Popov *et al*. 2002). *Bellimurina*, *Christiania*, *Craspedelia*, *Dolerorthis*, *Glyptorthis*, *Grammoplecia*, *Parastrophina*, *Pectenospira*, *Placotriplesia*, *Skenidioides*, and *Sowerbyella* (*Sowerbyella*).

45 (Sa2). *Parastrophina–Kellerella* Association (BA3). Locality 2538, Anderken Formation, Kuyandysai, Chu-Ili Range (Popov *et al.* 2002). *Acculina*, *Anoptambonites*, *Bellimurina*, *Bowanorthis*?, *Christiania*, *Craspedelia* (Text-fig. 4V), *Didymelasma*, *Dolerorthis*, *Glyptorthis*, *Kellerella*, *Leptaena (Ygdrasilomena)*, *Liostrophia*, *Nikolaispira*, *Parastrophina*, *Pectenospira*, *Phaceloorthis*, *Phragmorthis*, *Placotriplesia*, *Plectorthis*, *Plectosyntrophia*?, *Rhynchotrema*, *Schizostrophina*, *Sortanella*, *Sowerbyella* (*Sowerbyella*), and *Triplesia*.

46 (Sa2). *Parastrophina–Kellerella* Association (BA3). Locality 948, Anderken Formation, Tesik River, Chu-Ili Range (Popov *et al.* 2002). *Bellimurina*, *Bowanorthis*?, *Craspedelia*, *Dolerorthis*, *Glyptorthis*, *Ilistrophina*, *Kellerella*, *Liostrophia*, *Nikolaispira*, *Parastrophina*, *Pectenospira*, *Rhynchotrema*, *Sortanella*, and *Sowerbyella* (*Sowerbyella*).

47 (Sa2). *Zhilgyzambonites–Foliomena* Association (BA4–5). Localities 2531, 8251, and 8255 Anderken Formation, Anderkenyn-Akchoku, Chu-Ili Range (Popov *et al*. 2002). *Anisopleurella*, *Foliomena*, *Olgambonites*, *Sericoidea* (= *Chonetoidea*), and *Zhilgyzambonites.*

North-Tien Shan and Karatau-Naryn microcontinents

48 (Sa2). *Leptellina* Beds in the Tabylgaty Formation, Shorsu River (Misius, 1986); *Drepanorhyncha*, *Eoanastrophia* (= *Kokomerena*), *Gacella*, *Leptellina*, Plectorthidae gen. et sp. nov. 1, *Shlyginia* (= *Leptellina*), *Sonculina*, and *Strophomena* (*Strophomena*).

49 (Sa2). *Christiania* beds in the Tabylgaty Formation, Shorsu River (Misius, 1986). *Chaulistomella*, *Christiania*, *Drepanorhyncha*, *Eoanastrophia* (= *Kokomerena*), *Leptellina*, *Shlyginia* (= *Leptellina*), and *Sonculina.*

Kalmykkol-Kokchetav Microcontinent

50 (Sb2). *Grammoplecia* Association (BA4). Locality 504 [53°19’10.46” N; 66°57’27” E] from the Andryushinka Formation on the west side of the Ishim River near Kupriyanovka village (Nikitin and Popov 1983). A monotaxic association of *Grammoplecia*.

51 (Sb2). Allochthonous association derived from BA3–4. Locality F-6a [52°22’44” N; 71°24’59” E] sampled by Nikitin, Popov and Apollonov in 1973 from the mass flow deposits in the Middle Lidievka Formation near Lidievka village, north-central Kazakhstan. *Acculina*, *Anoptambonites*, *Bimuria*, *Christiania*, *Craspidelia*, *Dolerorthis*, *Durranella*, *Eodalmanella*?, *Glyptambonites*, *Glyptomena*, *Grammoplecia*, *Isophragma*, *Kajnaria*, *Kassinella*, *Leptellina*, *Limbimurina*, *Phragmorthis*, *Ptychoglyptus*, *Shlyginia*, *Skenidioides*, *Sonculina*, *Sortanella*, *Sowerbyella* (*Sowerbyella*), and *Strophomena* (*Strophomena*).

Boshchekul Terrane

52 (Sa2). *Sowerbyella* Association (BA3). Locality 23/n [51°40’3”N; 75° 7’37”E] sampled by Nikitin and Popov in 1978 from limestones of Bayan Formation at the southern side of Amambaisor Lake west of Ekibastuz. *Anoptambonites*, *Bellimurina*, *Kassinella*, *Pionodema*, *Plectorthis*, *Shlyginia* (Text-fig. 4Q), *Sowerbyella*.

Chingiz-Tarbagatai Terrane

53 (Sa2). Allochthonous association (BA4). Locality 565 [coordinates 49°5’31” N; 78°30’21” E]) in mass flow deposits in the middle Sargaldak Formation, west side of the Sargaldak River 2.15 km upstream of the river mouth (Nikitin and Popov 1985). *Archaeorthis*, *Aulie*, *Camerella*, *Craspedelia*, *Eoanastrophia*, *Perimecocoelia*, *Productorthis*, *Ptychoglyptus*, and *Tuvinia*.

54 (Sa2). *Sowerbyella* Association (BA2). Localities 79134, 79134a [49° 6’7” N; 78°32’2” E], 79135 [49° 6’7” N; 78°32’2” E], 79136 [49° 6’45” N; 78°30’46” E]) in mass flow deposits in the upper part of the Bestamak Formation, north side of the Chagan River upstream of the Sargaldak river mouth, Chingiz Range (Nikitin and Popov, 1984). *Dorytreta* (6%), *Eodalmanella* (6%), *Shlyginia* (28%), *Sulcatospira* (6%), *Triplesia*, and *Sowerbyella* (*Sowerbyella*) (54%).

Early Katian (Time Slice Ka1)

Chu-Ili Terrane

55 (Ka1). *Parastrophina–Kellerella* Association (BA3). Locality 1014 [46°42’40” N, 70°03’48” E] from a bioclastic limestone in the mud-mound core in the lower part of the unnamed formation (*Amsassia chaetetoides* Beds), North Betpak-Dala Desert (Nikitin and Popov 1996; Nikitin *et al.* 1996). *Anoptambonites*, *Austinella*, *Bandaleta*, *Christiania*, *Craspedelia*, *Dolerorthis*, *Kellerella*, *Leptaena* (*Ygdrasilomena*) [= *Limbimurina*], *Nikolaispira*, *Parastrophina*, *Ptychopleurella*, *Rostricellula*, *Shlyginia*, *Sortanella* (Fig. 5D), *Sowerbyella*, and *Triplesia*.

56 (Ka1). *Sowerbyella–Sulcatospira* Association (BA3). Locality 82258 [N43°35’, E75°25’] from the Dulankara Formation south of the limestone quarry in Zhartas (Popov *et al.* 1997; Popov *et al.* 1999). *Altaethyrella*, *Dulankarella*, *Eodinobolus*, *Mabella*, *Sowerbyella*, and *Sulcatospira*.

57 (Ka1). *Adensu* Association (BA2). Data based on Locality 9305 [45°5’ N, 73°29’ E] (Popov *et al.* 1997),

from argillaceous limestones in an unnamed formation (Dulankara Formation stratigraphical equivalent) in Burultas Valley, Sarytuma, West Balkhash. *Adensu*, *Eodinobolus*, and *Palaeotrimerella* (Fig. 5J).

58 (Ka1). *Ctenodonta–Sowerbyella* Association (BA2). Locality 543a from the Dulankara Formation (Otar Member) in Dulankara Mountains, Chu-Ili Range (Popov *et al*. 2000; Popov and Cocks 2006). *Grammoplecia*, *Plaesiomys*, *Shlyginia*, *Sowerbyella*, and *Weberorthis*.

59 (Ka1). *Ctenodonta–Sowerbyella* Association (BA2). Locality 719 from the Dulankara Formation (Otar Member), Dulankara Mountans, Chu-Ili Range (Popov *et al*. 2000; Popov and Cocks 2006). *Plaesiomys*, *Shlyginia*, *Sowerbyella*, *Strophomena* (*Strophomena*), and *Weberorthis*.

60 (Ka1). *Dinorthis* Association (BA2–3). Locality 849 from the Dulankara Formation (Otar Member), Dulankara Mountans, Chu-Ili Range (Popov *et al*. 2000; Popov and Cocks 2006). *Christiania*, *Dinorthis*, *Dulankarella*, and *Shlyginia*.

61 (Ka1). *Altaethyrella–Rongatrypa* Association (BA2). Localities K-131, 542, 837, 837a and 2541 from the Dulankara Formation (Otar Member), Dulankara Mountans, Chu-Ili Range (Popov *et al*. 2000; Popov and Cocks 2006). *Altaethyrella*, *Bokotorthis*, *Christiania*, *Dulankarella*, *Dzhebaglina*, *Karomena*, *Parastrophina*, *Paraoligorhyncha*, *Plaesiomys*, *Rongatrypa* [= *Nalivkinia* (*Pronalivkinia*)], *Shlyginia*, *Sowerbyella* (*Sowerbyella*), S*trophomena* (S*trophomena*), *Sulcatospira*, and *Weberorthis* [= *Hebertella*].

North-Tien Shan and Karatau-Naryn microcontinents

62. (Ka1) *Dinorthis–Nuria* beds (BA3). Ichkebash Formation of the Dzhetym-Too Range (Misius 1986). *Dinorthis*, *Dzhebaglina*, *Kassinella*, *Nuria*, *Strophomena* (S*trophomena*), and *Weberorthis* [= *Mimella*].

63. (Ka1) *Dinorthis–Nuria* beds (BA3). Ichkebash Formation of the Dzhebagly Mountains (Misius 1986). *Dinorthis*, *Dzhebaglina*, *Nuria*, *Strophomena* (*Strophomena*), and *Sowerbyella* (*Sowerbyella*).

64. (Ka1) '*Mimella*' beds (BA3). Ichkebash Formation of the Dzhebagly Mountains (Misius 1986). *Altaethyrella*, *Ashinaorthis* (= *Mimella*), *Bicuspina* [= *Oxoplecia*], *Dinorthis*, *Dzhebaglina*, *Nuria*, *Sowerbyella* (*Sowerbyella*), and *Strophomena* (*Strophomena*).

65. (Ka1) *Kassinella* beds (BA3). Ichkebash Formation of the Dzhebagly Mountains (Misius 1986). *Anoptambonites* [= *Palaeostrophomena*], *Bicuspina* [= *Oxoplecia*], *Christiania*, *Kassinella*, *Nuria*, *Sowerbyella* (*Sowerbyella*), and *Strophomena* (*Strophomena*).

66. (Ka1) '*Kuzgunia*' beds, BA3. Tez Formation of the Sarydzhaz Region (Misius 1986; and Popov unpublished). *Altaethyrella*, *Dinorthis*, *Mabella*, *Nuria*, *Pusilogutta*, *Rongatrypa* [= *Rhynchotrema*], *Sowerbyella* (*Sowerbyella*), and *Sulcatospira* [= *Zygospira*].

Kalmykkol-Kokchetav microcontinent

67 (Ka1). *Dinorthis–Eospirigerina* Association (BA3). Locality 563 [62°45′18″N, 66°36′05″E] sampled by Nikitin in 1959 from the Burluk Formation, Akkan-Burluk River, north-central Kazakhstan. *Anoptambonites* (11%), *Dinorthis* (29%), *Eospirigerina* (20%), and *Strophomena* (*Strophomena*) (28%), while *Mabella* (Fig. 5Y), *Rhynchotrema*, *Rongatrypa*, and *Sowerbyella* (*Sowerbyella*) together total about 12%.

68 (Ka1). *Dinorthis* Association (BA2–3). Locality 533e [52°45′10″N, 66°38′08″E] sampled by Nikitin in 1959 from the Burluk Formation, Akkan-Burluk River, north-central Kazakhstan. *Anoptambonites* (10%), *Dinorthis* (71%), *Eospirigerina* (7%) as the most common taxa, while *Buminomena*, *Dulankarella*, *Shlyginia*, and *Strophomena* (*Strophomena*) total 12%.

69 (Ka1). *Dinorthis* Association (BA3); Localities 538 [52°45′12″N, 66°36′35″E] and 538a sampled by Nikitin in 1959 from the Burluk Formation, Akkan-Burluk River, north-central Kazakhstan. *Anoptambonites* (13%) and *Dinorthis* (62%) are the dominant taxa, while *Acculina*, *Eoanastrophia*, *Mabella*, *Rhynchotrema*, *Strophomena* (*Strophomena*), and *Triplesia* total about 25%.

70 (Ka1). Shell bed (BA3). Locality 612 [52°45′17″N, 66°38′00″E] sampled by Nikitin in 1955, from the Burluk Formation, Akkan-Burluk River, north-central Kazakhstan. *Anoptambonites*, *Christiania*, *Dulankarella*, *Grammoplecia*, and *Parastrophina*.

71 (Ka1). *Dinorthis* Association (BA3); Localities 893a, 893b [52°48′54″N, 66°32′20″E] sampled by Nikitin in 1955 from the Burluk Formation, on the southern side of the River Ishim, opposite Stavropolskoye village. *Dinorthis*, *Eospirigerina*, *Sowerbyella* (*Sowerbyella*), *Strophomena* (*Strophomena*), and *Triplesia*.

Boshchekul Terrane

72 (Ka1). *Parastrophina* Association (BA3). Locality 539 Koskarasu Beds, Koskarasu River valley (Nikitin *et al*. 2006). *Altaethyrella*, *Anoptambonites*, *Dolerorthis*, *Eospirigerina*, *Epitomyonia* (= *Dicoelosia*), *Glyptorthis*, *Grammoplecia*, *Liostrophia*, *Parastrophina*, and *Sulcatospira* (Text-fig. 5S).

Chingiz-Tarbagatai Terrane

73 (Ka1). *Sowerbyella–Schachriomonia* Association (BA3). Locality 2133, Taldyboi Formation, Ashchisu River, Chingiz Range (Popov and Cocks 2014). *Ashinaorthis*, *Buminomena*, *Grammoplecia*, *Pusillogutta*, *Schachriomonia*, *Sowerbyella*.

74 (Ka2). *Sowerbyella–Schachriomonia* Association (BA3). Locality 1835, west side of River Taldyboi (Popov and Cocks 2014). *Acculina*, *Schachriomonia*, *Sowerbyella* (*Sowerbyella*).

75 (Ka2). *Bokotorthis* Association (BA2–3). Locality 1858, Namas River (Popov and Cocks 2014) *Ashinaorthis*, *Bokotorthis*, *Buminomena*, *Mabella*, *Para-*

craniops, *Rongatrypa*, *Sowerbyella* (*Sowerbyella*), *Strophomena (Tetraphalerella)*.

76 (Ka2). *Bokotorthis abayi* Association (BA2–3). Locality 2423, Taldyboi River (Popov and Cocks 2014). *Ashinaorthis*, *Bokotorthis*, *Schachriomonia*, *Sowerbyella* (*Sowerbyella*), *Wrightiops*.

Selety Terrame

77 (Ka1). *Sowerbyella–Rhynchotrema* Association (BA2). Locality 550a (Nikitin *et al.* 2003), from the Tauken Formation, Selety River basin. *Rhynchotrema* (48%), *Sowerbyella* (35%), *Strophomena* (*Tetraphalerella*) (10%), while *Dinorthis* (Fig. 5W), *Buminomena*? [= *Glyptomena*], *Rongatrypa* [= *Nalivkinia* (*Pronalivkinia*)], *Skenidioides*, *Sulcatospira*, and *Triplesia* total about 7%.

78 (Ka1). *Dinorthis* Association (BA2–3). Locality 790 (Nikitin *et al.* 2003), from the Tauken Formation of the Selety River basin. Assemblage dominated by *Dinorthis* (76%), and other genera include *Buminomena*? [= *Glyptomena*], *Anoptambonites*, *Rongatrypa*, and *Rhynchotrema*.

79 (Ka1). *Dinorthis–Rongatrypa* Association, BA2–3. Locality 790 (Nikitin *et al.* 2003), from the Tauken Formation of the Selety River basin. Assemblage dominated by *Dinorthis* (39%), *Rhynchotrema* (20%), *Rongatrypa* (39%) (Text-fig. 5M), whereas other genera, including *Buminomena*, *Mabella*, *Sowerbyella* (*Sowerbyella*), *Sulcatospira*, and *Strophomena* (*Tetraphalerella*), total about 2%.

Mid Katian (Time Slice Ka2–3)

Chu-Ili terrane

80 (Ka2–3). *Platymena–Strophomena* Association (BA3); Localities 132, 136, 836, and 857a, Dulankara Formation (Degeres Member), Dulankara Mountains (Popov and Cocks 2006). *Altaethyrella*, *Christiania*, *Glyptomenoides*, *Paracraniops, Platymena* (Text-fig. 5C), *Phragmorthis*, *Qilianotryma*, *Shlyginia*, *Sowerbyella* (*Sowerbyella*), *Strophomena* (*Strophomena*), and *Weberorthis* (Text-fig. 5L).

81 (Ka2–3). *Strophomena–Christiania* Association (BA3); Localities 132 and 857a, Dulankara Formation (Degeres Member), Dulankara Mountains (Popov and Cocks 2006). *Altaethyrella*, *Christiania*, *Epitomyonia*, *Holtedahlina*, *Leangella*, *Metambonites*, *Platymena*, *Phragmorthis*, *Ogmoplecia*, *Qilianotryma*, *Shlyginia*, *Sowerbyella* (*Sowerbyella*), *Strophomena* (*Strophomena*), and *Weberorthis*.

82 (Ka2–3). *Metambonites–Plectorthis* Association (BA3); Localities 828, 828a, and 858a, Dulankara Formation, (Degeres Member), Dulankara Mountains (Popov and Cocks 2006). *Altaethyrella*, *Anoptambonites*, *Christiania, Glyptambonites*, *Glyptomenoides, Gunningblandella* (Text-fig. 5G), *Holtedahlina* (Text-fig. 5B), *Leangella, Metambonites* (Text-fig. 5K), *Nikitinamena* (Text-fig. 5F), *Ogmoplecia* (Text-fig. 5H), *Qilianotryma* (Fig. 5A), *Rhipidomena*, *Phragmorthis*, *Plectorthis*, *Sowerbyella* (*Sowerbyella*), and *Strophomena* (*Strophomena*).

83 (Ka2–3). Akkol Limestone (BA3). Localities 219 and 827, Dulankara Formation (Akkol Member), Dulankara Mountains (Popov and Cocks 2006). *Altaethyrella*, *Anoptambonites*, *Bandaleta*, *Bokotorthis*, *Christiania, Dolerorthis*, *Dulankarella, Eospirigrina, Glyptambonites*, *Leangella*, *Metambonites*, *Nikitinamena*, *Placotriplesia*, *Ptychopleurella*, *Qilianotryma*, *Schachriomonia*, and *Sowerbyella* (*Sowerbyella*).

84 (Ka2–3). *Adensu* Association Dulankara Formation (Akkol Member), Babasai (Popov and Rukavishnikova, 1986). *Adensu*, *Bokotorthis*, and *Sulcatospira.*

Boshchekul terrane

85 (Ka2–3). *Parastrophina–Kellerella* Association (BA3); Locality 1017, Odak Beds in the Angrensor Formation, Odak (Nikitin *et al.* 2006). *Actinomena*, *Altaethyrella*, *Anoptambonites*, *Bellimurina*, *Christiania*, *Cooperia, Dolerorthis*, *Dulankarella*, *Dzhebaglina, Eoplectodonta*, *Eospirigerina* (Text-fig. 5X), *Epitomyonia* (Text-fig. 5R), *Euroatrypa*, *Glyptorthis*, *Grammoplecia*, *Gunnarella*, *Holtedahlina*, *Kellerella*, *Leangella, Leptaena* (*Ygdrasilomena*) (Text-fig. 5O), *Liostrophia*, *Nikolaispira* (Text-fig. 5N), *Odakella* (Text-fig. 5U), *Parastrophina*, *Pectenospira* (Text-fig. 5T), *Placotriplesia*, *Plectorthis*, *Qilianotryma*, *Shlyginia*, *Sinambonites* (Text-fig. 5V), *Sortanella*, and *Sowerbyella* (*Sowerbyella*).

86 (Ka2–3). *Parastrophina–Kellerella* Association (BA3); Locality 66a, Keregetas Limestone, Angrensor Formation, Maikain (Nikitin *et al.* 2006). *Actinomena*, *Altaethyrella*, *Christiania*, *Cooperia*, *Dolerorthis*, *Dulankarella*, *Eoplectodonta*, *Eospirigerina, Epitomyonia, Euroatrypa*, *Glyptorthis, Holtedahlina, Ilistrophina*, *Kellerella*, *Leangella*, *Nikolaispira*, *Parastrophina*, *Placotriplesia*, *Plectorthis*, *Qilianotryma*, *Sortanella*, and *Sowerbyella* (*Sowerbyella*).

Cingiz-Tarbagatai Terrane

87 (Ka2–3). Akdombak Limestone (BA3). Localities 563, 7963, 7875, 79149) Akdombak Formation, upper reaches of Bakanas River; (Popov and Cocks 2014) *Anoptambonites*, *Bellimurina*, *Bokotorthis, Dulankarella*, *Epitomyonia*, *Ilistrophina*, *Mabella, Monomerella*, *Phaceloorthis*, *Phragmorthis*, *Qilianotryma*, *Schachriomonia*, *Shlyginia.*

88 (Ka2–3). *Foliomena* Association (BA4–5). Akdombak Formation, Tolen River (Popov and Cocks, 2014). *Dalmanella, Diambonioidea, Foliomena, Kassinella, Leangella*.

89 (Ka2–3). Localities 3115, 3132, 3136, Akdombak Formation, Unit 5 (BA2–3). Tolen River (Popov and Cocks, 2014). *Alpeis*, *Anoptambonites*, *Christiania*, *Leangella*, *Olgambonites*, *Platymena*, *Schachriomonia*, *Sowerbyella* (*Sowerbyella*), *Testaprica.*

90 (Ka2–3). Locality 8506, Akdombak Formation (BA3–4). Tolen River (Popov and Cocks, 2014); *Anoptambonites*, *Bokotorthis*, *Christiania*, *Dulankarella*, *Enbektenorthis*, *Holtedahlina*, *Mabella*, *Phragmorthis*, *Plectorthis, Shlyginia.*

91 (Ka2–3). *Catenipora libera* Beds (BA3). Kulunbulak Formation, Abak-Tiigen Stream, Tarbagatai Range (Pushkin and Popov 1990; Popov unpublished). *Acculina*, *Altaethyrella* [= *Otarorhyncha*], *Anoptambonites*, *Ashinaorthis*, *Bandaleta*, *Bellimurina*, *Bokotorthis* [= *Plaesiomys*], *Christiania*, *Dulankarella*, *Eodinobolus*, *Eospirigerina*, *Glyptambonites*, *Holtedahlina*, *Metambonites*, *Plectorthis*, *Rongatrypa*, *Schachriomonia*, *Sowerbyella* (*Sowerbyella*).

Late Katian (Time Slice Ka3)

Chu-Ili Terrane

92 (Ka4). Ulkuntas Limestone (Apollonov *et al*. 1980), (BA3–4) Akzhar River. *Altaethyrella* [= *Rhynchotrema*], *Brevilamnulella*, *Coolinia*, *Dalmanella*, *Eoplectodonta*, *Eospirigerina*, *Eostropheodonta*, *Giraldibella, Hindella* (= *Cryptothyrella*), *Holorhynchus*, *Iliella, Kassinella* (*Kassinella*), *Leptaena* (*Leptaena*), *Proconchidium*, *Prostricklandia*, *Sortanella*, *Sowerbyella* (*Rugosowerbyella*), *Streptis, Sulcatospira* [= *Zygospiraella*], *Tcherskidium*, and *Triplesia.*

Chingiz-Tarbagatai Terrane

93 (Ka4). Akdombak Formation (BA3), Chingiz. Chingiz Range (Sapelnikov and Rukavishnikova, 1975; Popov and Cocks 2014). *Alpeis*, *Brevilamnulella*, *Eoconchidium*, *Galeatellina*, *Holorhynchus*, *Mabella*, *Rongatrypa*, *Rostricellula*, *Sowerbyella*, and *Testaprica*.

94 (Ka4), Tarbagatai. Tarbagatai Range, Bazar River basin, Kulunbulak Formation, *Holorhynchus giganteus* Beds (Pushkin and Popov 1990; Popov unpublished) (BA3). *Acculina*, *Altaethyrella* [= *Otarorhyncha*], *Anoptambonites*, *Bandaleta*, *Bellimurina*, *Bokotorthis* [= *Plaesiomys*], *Christiania*, *Dulankarella*, *Eospirigerina*, *Holorhynchus*, *Leptaena* (*Ygdrasilomena*), *Pectenospira*, *Phragmorthis*, *Plectorthis*, *Rongatrypa* [= *Pronalivkinia*], *Schachriomonia*, and *Sowerbyella* (*Sowerbyella*).