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An early Emsian (Zlichovian) ammonoid assemblage from Sangibaland Mountain (Shakhimardan River Basin) (South Tien Shan, Kyrgyzstan)

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Abstract Early Emsian (Zlichovian) ammonoids are recorded from a section of neritic deposits on the western and northwestern slopes of Sangibaland Mountain (right bank of the Shakhimardan River, near the village of Jiydelik, South Fergana, South Tien Shan, Kyrgyzstan) including other faunas such as conodonts, dacryoconarids, brachiopods, trilobites, and corals. The ammonoid fauna includes *Erbenoceras* cf. *solitarium* (Barrande, 1865), *E. kimi* Bogoslovsky, 1980 and new species of teicherticeratids. This combination of taxa allows the host beds to be correlated with the Zlichovian LDIII Zone. Ammonoids come from the Katran Formation, from beds previously recognised as the Sandal Formation, which is well–known for its neritic assemblages, interpreted as inhabitants of shallow shelf zones in the northern regions of the Paleozoic Alai–Tarim Terrane. Near the end of the Zlichovian, when the Dalejan transgression spread to the Sangibaland Region, ammonoids colonised the neritic basin near a carbonate platform, already inhabited by abundant benthic fauna. The co-occurrence of neritic and pelagic organisms is a useful feature providing a basis for the correlation between the pelagic and neritic successions of the lower Emsian (Zlichovian).

Keywords Ammonoids · Devonian · Emsian · Zlichovian · South Tien Shan

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Introduction

The correlation of the Devonian neritic and hemipelagic facies with deep-water carbonates is a challenging task, required for calibrating and correlating zonal schemes based on benthic and pelagic fossils. This is particularly pertinent for the Pragian–Emsian boundary beds, which are currently a focus of attention due to calls for a new definition of the Pragian–Emsian boundary (e.g. Walliser 1997; Chlupáč and Lukes 1999; Jansen et al. 2007; Jansen 2012; Carls and Valenzuela-Ríos 2007; Carls et al. 2008, 2009; De Baets et al. 2009, 2010, 2013a, b; Becker et al. 2010; Baranov et al. 2014; Aboussalam et al. 2015). A new basal Emsian biostratigraphic index is sought in the Kitab area, at a higher level than the current Global Boundary Stratotype Section and Point (GSSP) defined by the FAD of the conodont *Eocostapolygnathus kitabicus* (Yolkin et al., 1998) and is likely to be at the level of the FAD of *Eocostapolygnathus excavatus* (Izokh et al., 2011) or of its "subspecies/morphotype 114" (sensu Carls and Valenzuela-Ríos 2002). In this paper, the Emsian is used in the current Zinzilban GSSP definition, which is not identical to the German traditional use or to the Zlichovian. Large parts of the Pragian are stratigraphically the same as the lower part of the GSSP Emsian and Kitabian; and therefore, additional connotations, such as "traditional Pragian of Bohemia," are used to avoid confusion.

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The shallow Devonian facies are traditionally referred to as the "Hercynian" limestones and "Rhenish" siliciclastics with diverse and abundant brachiopod faunas. The pelagic "Bohemian" facies correspond to deep-water carbonates with ammonoids, conodonts, and dacryoconarid tentaculites (Erben 1960, 1964, 1965). Ammonoids have also been recorded (rarely) from the intercalations of deep-water carbonates in the neritic and siliciclastic Rhenish facies (Chlupáč 1976; Mittmeyer 1982; Chlupáč and Kukal 1988, De Baets et al. 2009, 2013a, b), which helps correlation. Recently, considerable advances have been made in correlating the two scales. Jansen et al. (2007) revised the assignments of the Lower Devonian to Eifelian successions in the Dra Valley (Morocco) and correlated pelagic and neritic successions and compared them to the regional subdivisions in the Rheinish Massif (Germany) and the Ardennes (Belgium). Jansen (2016) summarised the rhenotypic and hercynotypic facies and described the rhynchonelliformean brachiopod faunas from the Rhenish Massif (Germany), which he interpreted against the background of sedimentary sequences and facies development. He redefined the predominant rhenotypic ("Rhenish") facies as a neritic-siliciclastic facies type. De Baets et al. (2010) and Aboussalam et al. (2015) correlated limonitized fauna from the pelagic facies of the Tafilalt and also from the more pelagic lower part of the Mdaour–El–Kbir Formation and the top of the Merza–Akhsaï Formation at Mdaour–El–Kbir (Dra Valley, western Anti-Atlas), which were useful in correlating the Zlichovian beds of the Anti-Atlas from the eastern Tafilalt (Klug 2001, 2002; Klug et al. 2008, 2013) with those in the Dra Valley (Becker et al. 2008). De Baets et al. (2013a) recorded the first occurrences of lower Emsian ammonoids in the dark-grey siltstones associated with bivalves and chonetid brachiopods, which supported the correlation with the strata of the Singhofen–Vallendar age of the middle Kaub Formation (containing the famous Hunsrück ammonoid fauna) (De Baets et al. 2013b) and the Lower Emsian of Belgium (De Baets et al. 2013a).

In the South Tien Shan, Emsian ammonoids are mainly known from two areas in the Zeravshan Range: in the Kitab Reserve in the upper part of the Norbonak Beds (formerly Kimovsk Beds) and mostly, in the lower to middle part of the Dzhaus Beds (Bogoslovsky 1980; Becker et al. 2010; Kim et al. 2012) and in the Shirdagh Stow, also in the Dzhaus Beds (Bogoslovsky 1980, 1984) and on the Khanakasu River (Yatskov 1990).

In the South Tien Shan, brachiopod-ammonoid localities are known to be present in the neritic limestones of the Katran Formation (South Fergana, Kyrgyzstan, Fig. 1)

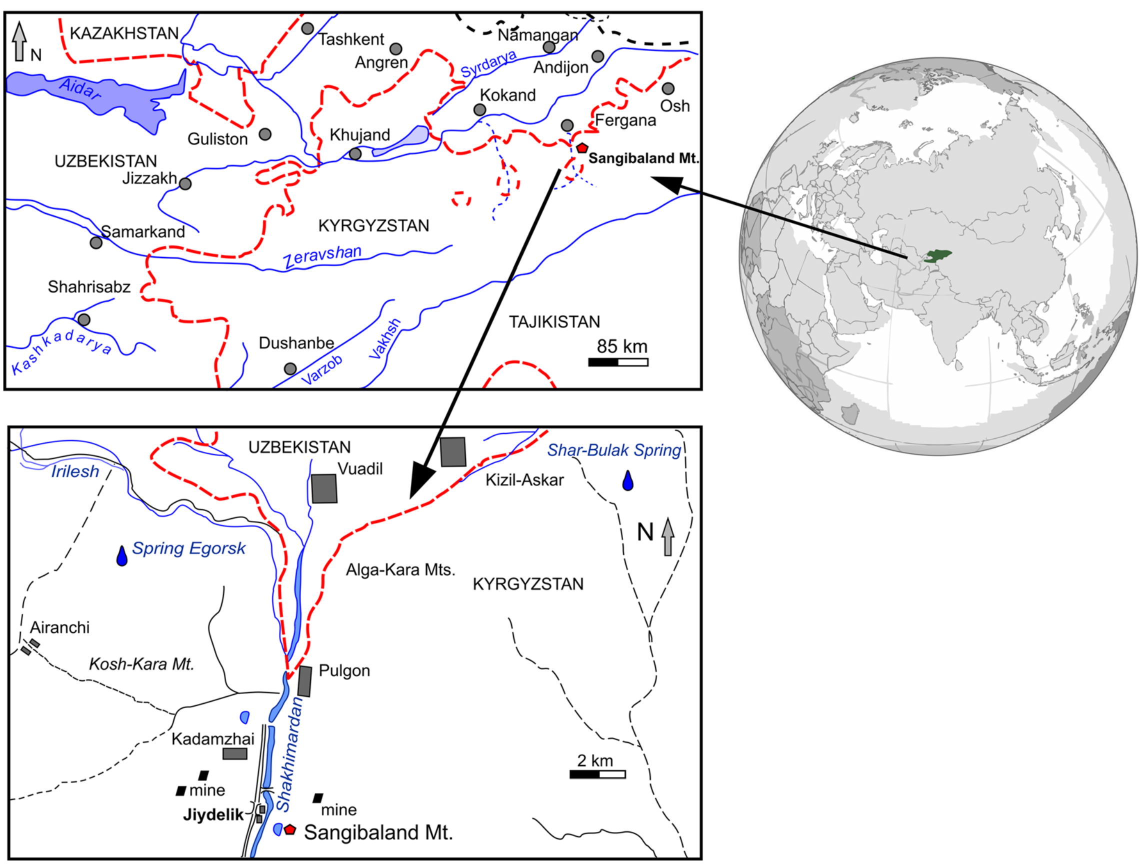

Fig. 1 Locality of the Sangibaland section on the right bank of the Shakhimardan River (Kyrgyzstan, Batken Province, Kadamzhai District, Jiydelik Village)

(Rzhonsnitskaya et al. 1978, 1982; Rzhonsnitskaya 1982, 1983), but the ammonoid fauna was only recently systematically studied (Nikolaeva et al. in prep.). This well-exposed succession of strata with diverse and abundant brachiopod, coral and trilobite fossil faunas was the basis for the regional biostratigraphic brachiopod-based schemes (Rzhonsnitskaya et al. 1978, 1982; Rzhonsnitskaya 1982, 1983). In 1976 M.A., Rzhonsnitskaya discovered the first early Emsian (Zlichovian) ammonoids in the succession of Sangibaland Mountain and sent the material for identification to the Paleontological Institute (Moscow), where it remains (Rzhonsnitskaya et al. 1978 and unpublished correspondence; material housed in the Paleontological Institute, Moscow, Russia). After that discovery, the upper part of the succession cropping out on the western and northwestern slopes of Sangibaland Mountain, and containing beds with ammonoids, was confirmed as falling in the Zlichovian. It later became apparent that Zlichovian ammonoids can be found at several stratigraphic levels including the lower and middle parts of the former Sandal Formation (Rzhonsnitskaya 1982; Rzhonsnitskaya et al. 1982), now recognized as the Katran Formation (the Sandal Formation was taken out of the official mapping legend for this region in 1977, Y.B. Savitsky, pers. comm.), while the Sandalian Regional Substage has remained (Starshinin and Savitsky 1993).

In 1987–1988, A.I. Kim and M.V. Erina re-examined the section and provided a new log, published here for the first time (Fig. 3). The section they measured was running in a different direction from Rzhonsnitskaya's profile (see Rzhonsnitskaya et al. 1982 and Figs. 4 and 5), but also covered the entire thickness of Sangibaland Mountain section. They discovered and identified dacryoconarids and conodonts in the same succession, which are discussed here for the first time. The purposes of this paper are to give an overview of the geological setting, to characterize the fossil content and zonations, and to discuss the sedimentary environment of the neritic deposits of Sangi baland Mountain.

Geological setting

Devonian strata are widely exposed in the South Fergana area of the South Tien Shan thrust-and-fold belt (Fig. 2), where they are represented by formations deposited in basins associated with the northern regions of the Alai-Tarim terrane. They include strikingly different facies located in close proximity to one

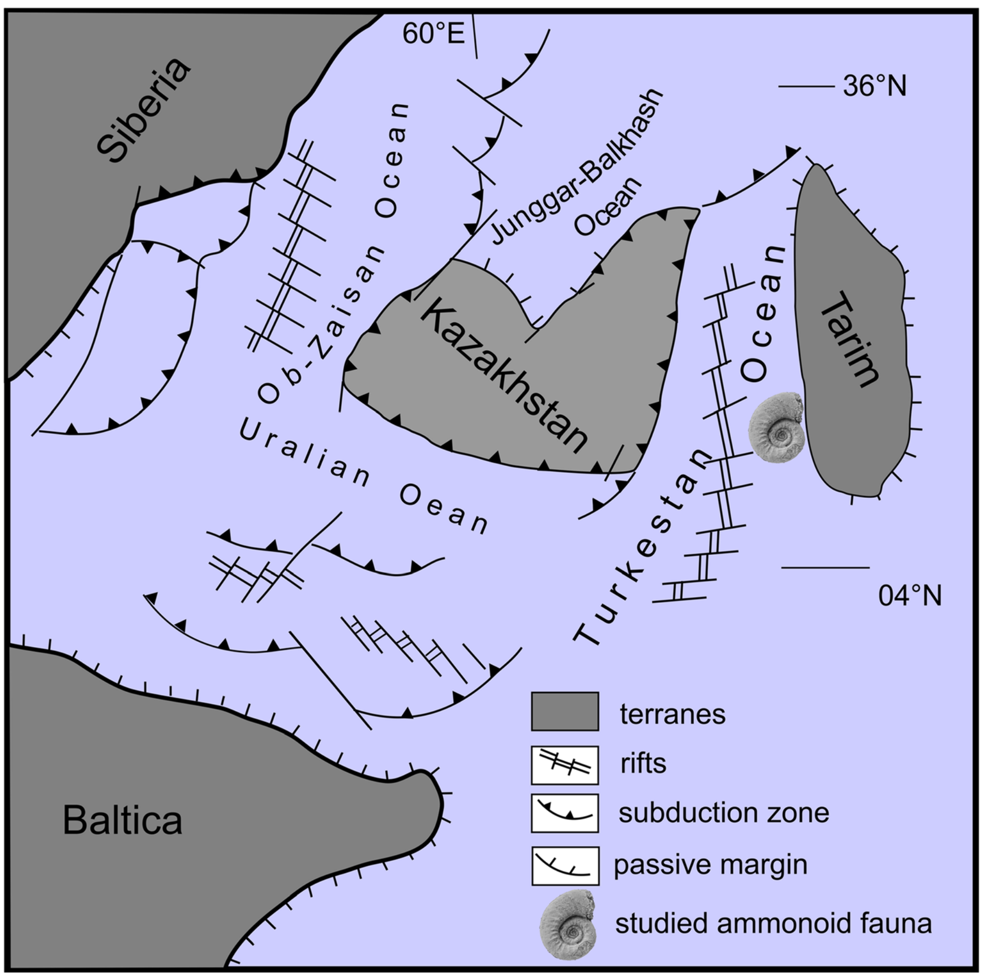

Fig. 2 Palinspastic map of the Central Asian Orogenic Belt for the Early Devonian (modified from Filippova et al. 2001 and Windley et al. 2007)

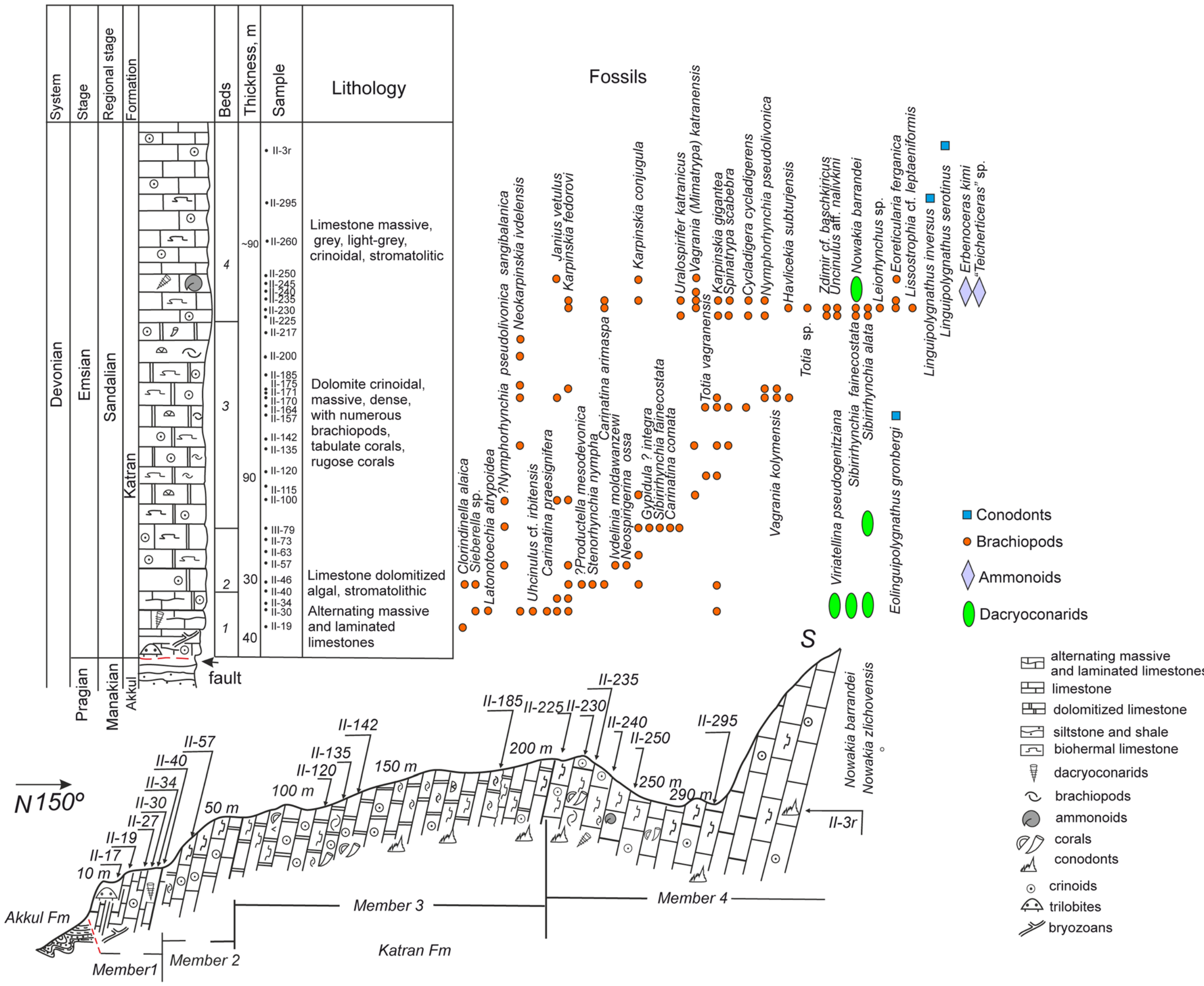

Fig. 3 Lithological log showing the distribution of fossils in the Sangibaland section compiled by Erina and Kim in 1988 (unpublished report for the Geological Survey "PGO Tashkent-Geologiya, Uzbekistan")

another due to the complex regional geology (thrusts and nappes, Biske 1965, 1996, 2004, 2015; Burtman 2008, 2015). There is a general agreement that the South Tien Shan thrust-and-fold belt was formed due to convergence and eventual collision of the Kazakhstan continent with the Tarim, Alai and Turan microcontinents (Alexeiev et al. 2015). In the Silurian–Devonian, the northern margin of the Alai–Tarim terrane was facing the passive slope of the Turkestan Ocean (or South Tianshan Ocean sensu Long et al. 2011; Ge et al. 2014; Burtman 2015, etc.), which existed until the Late Carboniferous closure, followed by the continental collision. Various plate tectonic models were discussed (Filippova et al. 2001; Windley et al. 2007; Long et al. 2011; Burtman 2012, 2015). In the Devonian, this area included a variety of pelagic and neritic basins, constituting outer and inner facies zones, of which the inner zone was uplifted in the Silurian–Devonian (Burtman 2015). This was followed by the accumulation of thick series of neritic facies with extremely abundant assemblages of benthic organisms and organic buildups (Veber 1934; Rzhonsnitskaya et al. 1978, 1982, Bogoslovsky 1982, 1983). There are several well-known sections of the Lower Emsian in this area (Klishevich et al. 1985; Kim et al. 1982, 1985, 1988). The Sangibaland section is one of the best exposed, and so far the only one known to contain identifiable early Emsian ammonoids (Rzhonsnitskaya et al. 1978, 1982). The section consists of light grey neritic limestones, crops out on the western and northwestern slopes of Sangibaland Mountain (right bank of the Shakhimardan River, near the village of Jiydelik, 3 km upstream of the Kadamzhai Mine) and contains ammonoids, conodonts, dacryoconarids, brachiopods, trilobites, and corals. This limestone series overlying the siltstone and sandstone beds of the Akkul Formation is assigned to the Katran Formation. Ammonoids come from several levels in the Sandal Formation, but mostly from Member 4, recognised as the Sanguvalyan "Horizon" by Rzhonsnitskaya (1982) (named after “Sanguvalyan Mountain,” the name used by Veber (1934) for Sangibaland Mountain). This section was extensively studied in the 1970s–1980s (Goryanov et al. 1978; Rzhonsnitskaya et al. 1978, 1982; Starshinin and Savitsky 1993). The names “Sandal Formations” and “Sanguvalyan Horizon” are no longer in use, having been replaced by the Katran Formation (Starshinin and Savitsky 1993). The name Sandalian Regional Stage (“Horizon”) is still in use.

The Katran Formation is composed of various types of open-sea carbonates including carbonate buildups, shallow-water detrital limestone and relatively deeper flank facies (terminology as defined by Harris et al. 1985). The first studies of this section in the 1980s provided the first summary on the rock succession and fossils and their comparison to contemporary sections in the area (Goryanov et al. 1978; Rzhonsnitskaya et al. 1978, 1982). It was originally thought that a large portion of this section was Pragian in age, based on the brachiopod assemblage (Rzhonsnitskaya et al. 1978). It later became apparent that Zlichovian ammonoids come from the lower third of the section (Bed 11 of the Sangibaland section of Rzhonsnitskaya), and it was shown that the Zlichovian dacryoconarids *Nowakia zlichovensis* Bouček, 1964 and ?*Nowakia* ex gr. *barrandei* Bouček and Prantl, 1959 come from near the base of the section. It is not possible to estimate which part of the succession can still be attributed to the Pragian in its traditional sense, possibly the first 30 m at the base below the level with Zlichovian dacryoconarids.

Locality details

The Sangibaland section is located 100–150 m to the east of a small abandoned village near Jiydelik Village, near Jiydelik Lake (40.091476 N, 71.716931 E). The section begins at the tectonic contact of the limestones of the Katran Formation (formerly Sandal Formation) with the siliciclastics of the Akkul Formation (Fig. 3). Near the tectonic contact with the limestones, the siliciclastics of the Akkul Formation are deformed, and at the beginning of the section, they are covered by talus. The beds are upturned. The lowermost exposed beds of the Katran Formation are composed of grey massive, crinoid limestones with abundant crinoid stems and intercalating laminated carbonate beds with a strong admixture of siliciclastics. The Akkul Formation contains the brachiopods *Ferganella turkestanica* Nikiforova, 1937 and *Spirigerina* cf. *supramarginalis* (Khalfin, 1948) (Rzhonsnitskaya 1982). Brachiopods listed below and in Fig. 3 were identified by Irina A. Kim and Yu. V. Savitsky. Lists of fossils and a stratigraphic log can also be found in Rzhonsnitskaya (1982) and Rzhonsnitskaya et al. (1982). This log, slightly modified, is reproduced in this paper (Fig. 4). The section described below and shown in Fig. 3 was measured at an angle to the section measured by Rzhonsnitskaya et al. (1982) (Figs. 4, 5), but it contains a somewhat similar succession of units and has a similar thickness. The first ammonoid record in Fig. 3 is recorded in Member 4, at 250 m above the base of the Katran Formation. Rzhonsnitskaya et al.’s (1982) log (Fig. 4) is difficult to correlate with the section described here (Fig. 3) because there is a considerable lateral variation of lithology and faunal content, while no detailed description was published by Rzhonsnitskaya et al. (1982). Rzhonsnitskaya’s field notes on this section are unavailable and possibly lost (Y.V. Savitsky, pers. comm.). We reproduce a marked photograph of the section from Rzhonsnitskaya et al. (1982) with “Beds” indicated (markings are copied from the original by Rzhonsnitskaya et al. (1982)), but note that no Beds were shown in the log published in the same paper. Rzhonsnitskaya et al. (1982) cited several lower ammonoid occurrences, from 60 m above the top of the section, which were not subsequently recorded. These rapid lateral facies and faunal changes are associated with the nature of the section representing a series of mounds and debris flow deposits of varying thickness, in places containing accumulations of brachiopods, corals, ammonoids and crinoids.

Pragian? and Lower Emsian (Zlichovian) (Fig. 3)

(1) Member 1 (0–40 m)

Alternation of light–grey and grey, massive and fissured, laminated argillaceous limestone. Both types of limestone are fissured, but the argillaceous limestones are distinctly deformed and boudinaged. Massive limestones are composed of numerous fragmented crinoid stems which are strongly recrystallized. The first 10 m contains brachiopods, bryozoans, tabulate corals, conodonts and trilobites. At 17 and 19 m, brachiopod samples II–17 and II–19 were collected (Fig. 3). At 27 m, conodont sample II–27 was collected from laminated limestones. At 30 m, sample II–30 (z) contained trilobites and brachiopods *Karpinskia gigantea* Khodalevich, 1937, *Karpinskia* ex gr. *conjugula* Tschernyschev, 1885, *Nymphorhynchia pseudolivonica* (Barrande, 1847), *Sieberella* sp., *Ivdelinia procerula* (Barrande, 1879), (Rzhonsnitskaya 1982) and others (see Fig. 3) with Spiriferida and Atrypida, characteristic of the Sandalian Regional Stage (Rzhonsnitskaya et al. 1982). This composition is typical of the “*Karpinskia*” assemblage, which is hardly known west of the Urals (Boucot et al. 1969, p. 16). At 30 m, the limestones contain the gastropods *Platyceras* sp. At 34 m, the limestones become light grey crinoid–detrital, with carbonate cement and with abundant benthic fossils dominated by brachiopods, bivalves, trilobites and ostracodes. This level contained some tabulate corals and the dacryoconarids *Nowakia zlichovensis* Bouček, 1964 and ?*Nowakia* ex gr. *barrandei* Bouček and Prantl, 1959.

Age: Most brachiopod are indicative of the Sandalian Regional Stage (Rzhonsnitskaya et al. 1982), while the dacryoconarids *Nowakia zlichovensis* Bouček, 1964 and

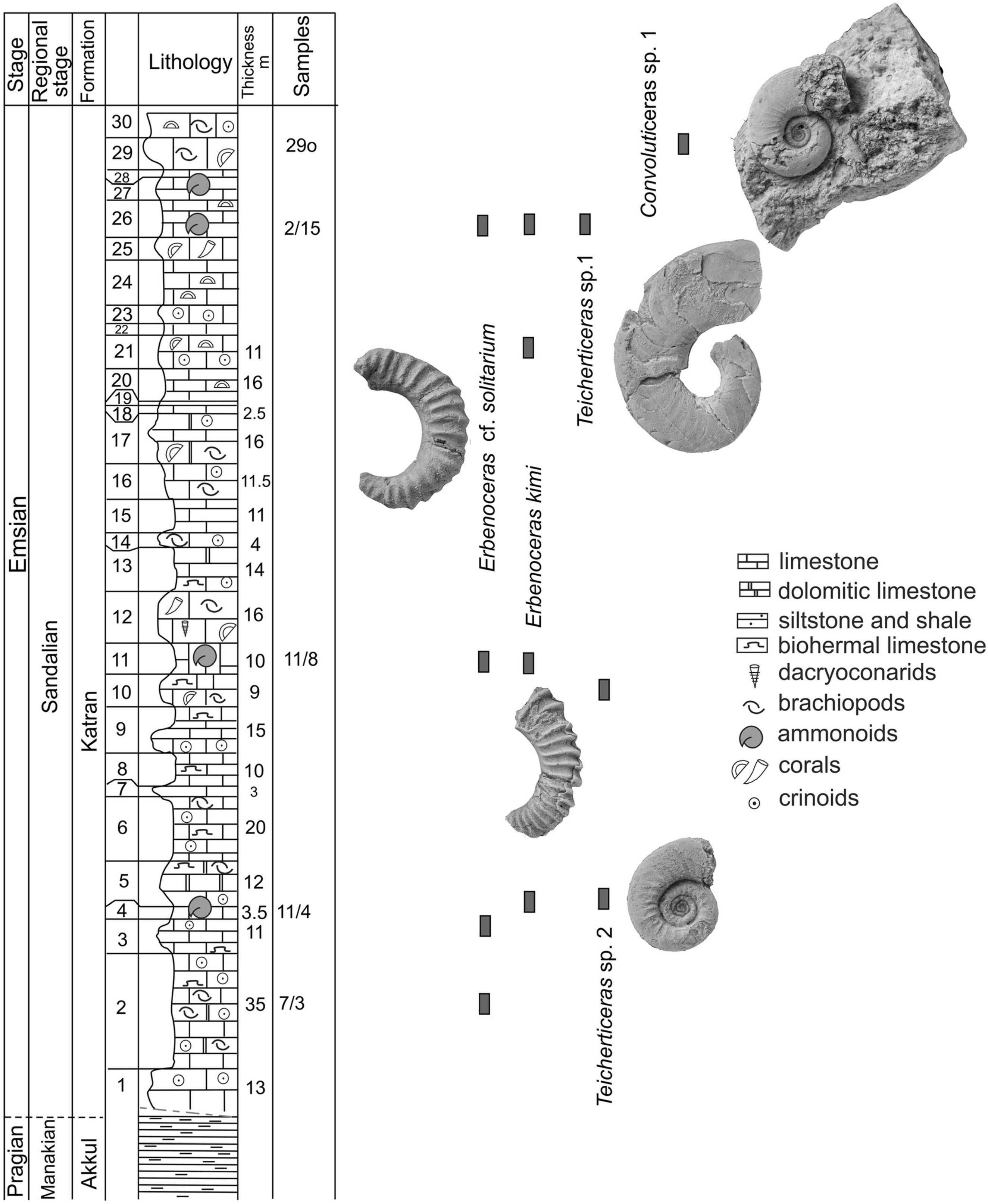

Fig. 4 Lithological log showing the distribution of ammonoids in the Sangibaland section (modified from Rzhonsnitskaya 1982. The generic assignments are provisional.)

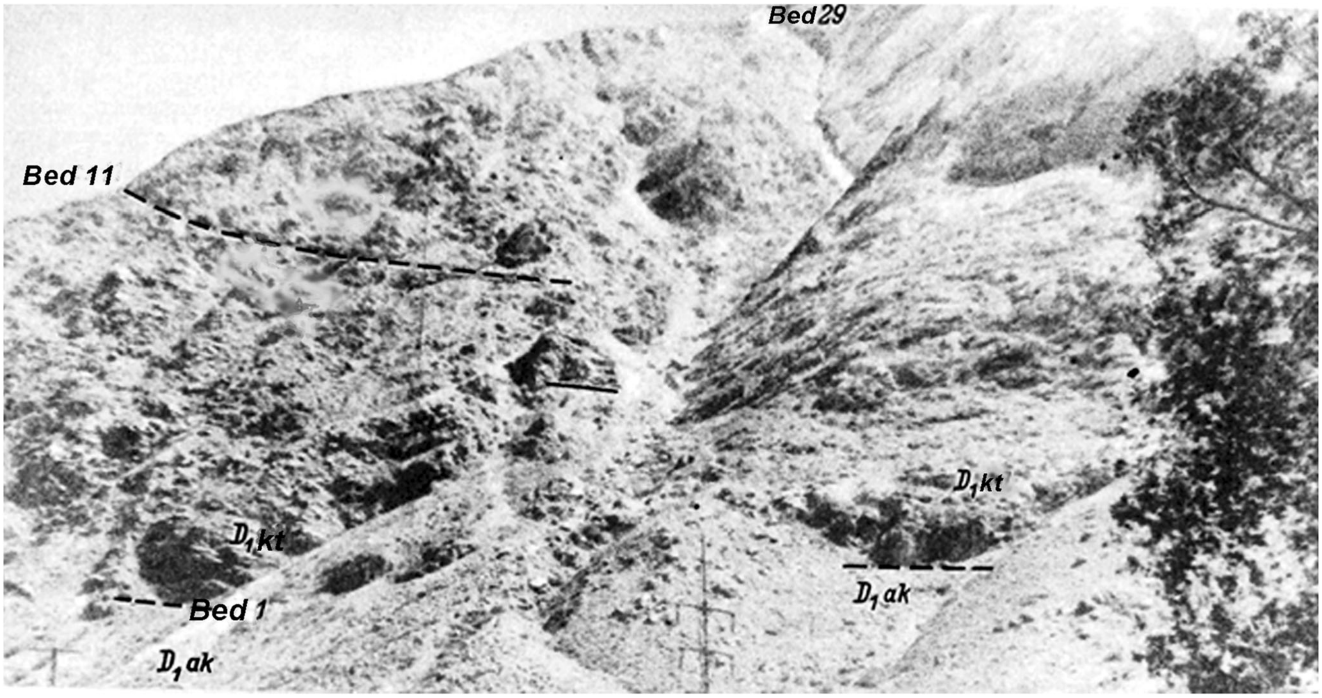

Fig. 5 Photograph of the northwest slope of Sangibaland Mountain (right bank of the Shakhimardan River near the village of Jiydelik) showing the two measured sections (modified after Rzhonsnitskaya et al. 1982, the section along the crest and a dry gully in the top left corner of the photograph, Fig. 4). The section measured by Erina and Kim (1988) (Fig. 3) is at an angle to Rzhonsnitskaya's section, but its precise position is not shown on this photograph as it partly lies outside its limits. Abbreviations: *D1ak*–Lower Devonian, Akkul Formation; *D1kt*–Lower Devonian, Katran Formation

?*Nowakia* ex gr. *barrandei* Bouček and Prantl, 1959 enable the correlation of this part of the Sandalian with the Zlichovian.

The next 34 to 40 m of the section are covered by talus, with a few outcrops of limestone blocks.

(2) Member 2 (40–80 m)

The limestone is light grey, massive, and partly dolomitized and contains crinoids, brachiopods, and corals. Brachiopods include Rhynchonellida, *Karpinskia* ex gr. *conjugula*, *K.* ex gr. *fedorovi*, *K. gigantea* and others (Sample II–40).

At 46 m, apart from the continuing species *Clorindinella alaica* (Rzhonsnitskaya, 1975), *Sieberella* sp., *Neospirigerina ossa* (Nalivkin, 1960, etc.), the interval from 40 to 80 m is mainly composed of crinoidal–detrital grey and light grey limestone with crinoid fragments, small algal bioherms and fine-grained detrital limestone. The fossils are unequally spread in the rocks and form nest-like aggregates. Some levels contain small microbial mounds, e.g. a 1.5-m-thick mound at 79 m surrounded by a dolomitized limestone, in which the mound can be traced for up to 5–7m in thickness. The nowakiids *Nowakia zlichovensis* Bouček, 1964 were recorded at 74 m, in association with brachiopods, crinoids and corals. **Age:** Sandalian Regional Stage (Zlichovian), as indicated by the above-cited brachiopods and the dacryoconarids *Nowakia zlichovensis* Bouček, 1964.

(3) Member 3 (79–220 m)

This part is composed of light-grey and bluish-grey, massive dolostone, with crinoids, brachiopods, gastropods, and corals. The rocks are fine- and medium-grained, in places with vitreous luster, dense, with a splintery fracture and microbial aggregates. Fossils form net-like aggregates and consist mainly of crinoids, represented by large stems and cups, and brachiopods. Less common are corals and gastropods. Brachiopods are represented by *Karpinskia gigantea*, *Gypidula integra* (Barrande, 1879), *Carinatina comata* (Barrande, 1847), *Sibirirhynchia fainecostata* (Torbakova, 1959) and *Vagrania kolymensis* (Nalivkin, 1936), etc. (Fig. 3). Corals include colonial and solitary Rugosa, favositids and branching tabulate corals. The rocks at 135 m contained pentamerids and colonial rugose corals (sample II–135 (z)). The interval at 142 m contained brachiopods (sample II–142 (z)), most probably from a piece of loose rock.

Brachiopods at 100–160 m are generally characteristic of the Pragian–Lower Emsian, and no change in the assemblage could be traced, since the rocks are very dense and not clearly bedded. Dolostones are dominant from 80 to 200 m of the section, whereas above 200 m, the proportion of crinoid–microbial limestone begins to increase, and the transition from dolostone to limestone is gradual.

Age: Sandalian Regional Stage, because of the characteristic brachiopods associations (Rzhonsnitskaya 1982; Starshinin and Savitsky 1993).

(4) Member 4. Interval 220–250 m

At the base of this member, crinoid–microbial limestones become clearly dominant in the section. It comprises grey and light-grey crinoidal–microbial limestone with microbial buildups; crinoid columns and cups are very abundant in the adjacent beds of limestone. Brachiopods are very abundant (*Karpinskia conjugula*, *Carinatina arimaspa* (Eichwald 1840), *Uralospirifer katranicus* Savitsky in Kiselev (1993), etc.) (Fig. 3). Other fossils include numerous gastropods and fenestellid bryozoans and, less commonly, stromatoporoids, tabulate and rugose corals. The limestones are massive and fractured, and no bedding is clearly visible, although it is possible to estimate that they dip 70° to 340° N. At 230–250 m algal–crinoid, bryozoan limestone is sometimes brecciated. It contains brachiopods (*Karpinskia, Nymphorhynchia*, *Eospirifer*, *Carinatina*, *Conchidiella*, *Cymostrophia* and *Gypidula*) and fenestellid bryozoans. Algal frames surround mud-mound-like cores with sorted detrital limestone filling in the spaces of the frames. In the microbial mounds, the brachiopod shells are complete (with both valves joined together) while in the detrital limestone, the valves are separated. Corals and stromatoporoids are less common but represented by large fragments, including massive and branching tabulate corals, solitary and colonial Rugosa, diverse gastropods and fenestellid bryozoans. Conodonts from sample II–230 included *Eopolygnathus gronbergi* (Carls and Gandl, 1969) and *L. inversus* (Klapper and Johnson, 1975). Ammonoids and dacryoconarids (*Nowakia barrandei*) are present at 240 m. Sample II–240 contained the dacryoconarids (*Nowakia barrandei*). Ammonoids from sample II–240 (unpublished report for the Geological Survey, Erina and Kim, 1988), are similar to those published by Rzhonsnitskaya et al. (1978, 1982) whose collection includes *Erbenoceras kimi* Bogoslovsky, 1980 *Erbenoceras* cf. *solitarium* (Barrande, 1865), "*Teicherticeras*" sp. 1, "*Teicherticeras*" sp. 2 and "*Convoluticeras*" sp. The distribution of this ammonoid fauna in the section is shown in Fig. 4, cited from Rzhonsnitskaya et al. (1982). The distribution of other fossils, including conodonts and brachiopods, can also be found in Rzhonsnitskaya et al. (1982).

Age: Sandalian Regional Stage, Zlichovian, as suggested by the presence of characteristic Sandalian brachiopods and *Linguipolygnathus inversus*, the index species of the *inversus* Zone high in the Zlichovian, which partly overlaps with the *Now* . *barrandei* Zone (e.g. Becker and Aboussalam 2011).

Regional stages

The Sandalian Regional Stage (Horizon) was established among other regional stages of Central Asia to enable regional correlations (Rzhonsnitskaya et al. 1978) and was based on the range of the Sandal Formation. The Sandal "Hercynian" formation was established by Veber (1934) with the type section on Sandal Mountain (Isfara Region, Fergana). The Sandalian Regional Stage was established as corresponding to the brachiopod *Latonotoechia atrypoidea–Karpinskia conjugula–Sieberella sieberi ulanica* Zone (Rzhonsnitskaya et al. 1978), which was originally correlated with the upper Pragian–Zlichovian (and possibly Dalejan).

Goryanov et al. (1978) assigned the lower 200 m of the Sangibaland section to the Sandalian Regional Stage and the upper 100 m to a new, unnamed regional stage.

Rzhonsnitskaya et al. (1978) established the Sanguvalyanian Regional Stage (Horizon), as beds with the FAD of *Ivdelinia moldawanzewi* Andronov, 1961 and, in the lower part, with *Erbenoceras*, and considered this horizon to be of Zlichovian age. Considering the occurrence of the ammonoid genus *Erbenoceras* in the "middle part of the section," Rzhonsnitskaya et al. (1978) placed the lower boundary of the Sanguvalyanian Regional Stage at the level of the lowermost occurrence of *Erbenoceras* sp. (then approximately 177 m from the base of the section). The Sanguvalyanian Regional Stage has not been accepted, as it cannot be traced regionally. All the deposits assigned by Rzhonsnitskaya et al. (1978, 1982) to the Sanguvalyanian are currently assigned to the Sandalian and are considered to represent the Katran Formation.

Goryanov et al. (1979) described a Devonian succession on the left bank of the Shakhimardan River near the village of Shakhimardan (Kuralimtau Mountains). They established the Shakhimardan Formation and correlated an interval of Beds 29–40 with the Sandalian Regional Stage. They also questioned the previous correlation of the Sandalian Regional Stage with the Pragian and suggested that the upper part of the Sandalian Regional Stage was probably Zlichovian.

Rzhonsnitskaya et al. (1982) reviewed the brachiopod zonation of the Sandalian Regional Stage and added more levels of ammonoid occurrences. These levels are shown in Fig. 4. Rzhonsnitskaya et al. (1982) assigned the Sandal Formation to the Zlichovian.

Klishevich et al. (1985) gave a list of regional subdivisions based on this section, discussed their correlation with the dacryoconarid zonation and showed that the Sandalian Regional Stage ("Horizon") corresponds to the *barrandei* dacryoconarid zone and the *gronbergi* conodont zone.

Kim et al. (1988, p. 708) noted that the regional scheme of the area was very complex, but were able to correlate formations that crop out to the west of Sangibaland Mountain, between Isfara and Mount Kyk, and correlated the Sandalian to the Kitabian Regional Stage. The Kitabian

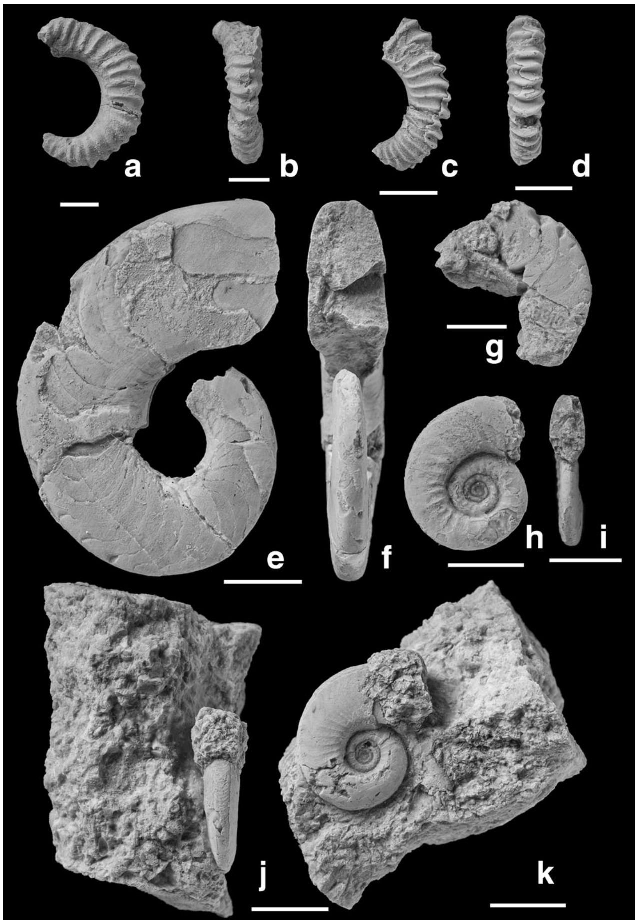

Fig. 6 Ammonoids from the Sangibaland section. **a**, **b** *Erbenoceras* cf. *solitarium* Barrande; **c**, **d** *Erbenoceras kimi* Bogoslovsky; **e**–**g** "*Teicherticeras*" sp. 1; **h**, **i** "*Teicherticeras*" sp. 2; **j**, **k** "*Convoluticeras*" sp. 1. *Scale bars* 2 cm

Regional stage in its type area in the Khodzhakurgan Formation (Zeravshan Range) includes the Zinzilban, Norbonak, Dzhaus, and Obisafit Beds (Kim et al. 1978; Sapelnikov et al. 2004).

Kim (2011) refined the regional dacryoconarid zonal scheme and mentioned that the succession of the zones within the Kitabian Stage in South Fergana was the same as in the Zeravshan range.

Ammonoid assemblage

The ammonoids illustrated in Fig. 6 are to be systematically described by Nikolaeva (in prep) and therefore the new species are cited here in open nomenclature. The assemblage contains specimens of *Erbenoceras kimi* (Fig. 6c, d), which are similar to the type material described by Bogoslovsky (1980, 1984) from the Dzhaus Beds of Shirdak (=Shirdagh) and in the Khodzha Kurgan Gorge (Bogoslovsky 1980; Becker et al. 2010). The specimens from Sangibaland do not have intercalated secondary ribs as in *Erbenoceras khanakasuense* Yatskov, 1990. Becker et al. (2010) indicated that some specimens from the type series of *E. kimi* have intercalated ribs, which supports their assignment to *E. khanakasuense*, but possibly warrants a new genus, as this feature is typical of another clade leading to *Mimosphinctes*. One of the ribbed specimens is identified as *E.* cf. *solitarium* (Barrande) (Fig. 6a, b) as it has more strongly bent ribs across the venter and more convex flanks than *E. kimi* (Fig. 6c, d). The assemblage contains several different teicherticeratids. The nomenclature and taxonomy of the family Teicherticeratidae are not completely resolved, as the type series of *Gyroceratites desideratus* Teichert (1948), the type species of *Teicherticeras* Erben, 1960, contains representatives of more than one species (House 1962; Bogoslovsky 1969; Nikolaeva 2007; Becker et al. 2010). A new teicherticeratid from Sangibaland (Fig. 6e–g) has a concave dorsal zone and a dorsal lobe, and hence, differs from the holotype of *Teicherticeras desideratum*, which according to Erben (1965) lacks both. If the diagnosis of *Teicherticeras* is restricted to the characters observed in the holotype of the type species and a new genus is established for teicherticeratids with a concave zone and a dorsal lobe, most species previously assigned to *Teicherticeras* will fall into this new genus, including our "*Teicherticeras*" sp. 1 (Fig. 6e–g). There is a second new species (Fig. 6h–i) with a low whorl expansion rate and subparallel flanks, and this should probably also be assigned to a new genus and species provisionally cited here as "*Teicherticeras*" sp. 2. Species of *Erbenoceras* and teicherticeratids dominate the assemblage.

The ammonoid fauna of the Sangibaland Mountain section suggests an early Emsian age and can be limited to the Zlichovian as it contains zonal markers of the Western Europe ammonoid succession, e.g. Bohemia (Chlupáč 1976; Chlupáč and Turek 1983). No species of *Mimagoniatites* have yet been found in this locality, which probably indicates that the beds are contemporary with the main part of Unit I of the Tafilat succession (Becker and House 1994, 2000; Becker and Aboussalam 2011). Also, *N. barrandei* does not enter below the middle part of Unit I, which also agrees with the *L. inversus* range (R.T. Becker, pers. comm).

It is also comparable with faunas from the Dzhaus Beds of the Zeravshan Range (Bogoslovsky 1980; Becker et al. 2010; Aboussalam et al. 2015) and the Northern Caucasus (Nikolaeva 2007). (1) No *Gyroceratites* or *Anetoceras* have been found so far, but this might be due to regional bias or paucity of the material. Übelacker et al. (2016) proposed a palaeoecological explanation why *Teicherticeras* s.l. has a wider distribution than *Anetoceras*, but this requires further testing. There is an indication that the host beds are close in age to "Unit I, *Anetoceras* Limestone" (Hollard 1963a, b; Bultynck and Hollard 1980; Bultynck and Walliser 2000a, b; Bultynck et al. 2000; Aboussalam et al. 2015): possibly *Erbenoceras* beds in Belka et al. (1999) and lower to middle part of the *Erbenoceras* Limestone of Klug et al. (2013). A similar fauna was found in the Lower Devonian siliciclastic-carbonate series in Shebalino

(Gornyi Altai, Russia) (Bogoslovsky and Udodov 1982) where it is attributed to the equivalents of the Zlichovian.

Sedimentary settings and ammonoid habitats

In the Emsian, the sedimentary complex of Sangibaland Mountain and adjacent areas developed near the southeastern coast of the Turkestan (or South Tianshan) Ocean (Fig. 3) close to the offshore end of a large shallow carbonate platform(s) with multiple mud mounds. The diversity of the sedimentary environments was observed early and has been mentioned repeatedly in the geological literature of the region (e.g. Biske 1965; Biske et al. 1982; Burtman 2008, 2015). To a large extent, the complex mosaic of Lower Devonian deposits, with deep-water carbonates and shales adjacent to carbonate buildups and mounds, inherits the Silurian seafloor mosaic topography (Rinenberg 1986), but the most active reef-building and mound-building activity happened in the Early–Middle Devonian.

Devonian mounds and reefs are widespread in the Tien Shan, especially in the South Tien Shan (Ivanovsky et al. 1997). The succession studied is one of a series of large Devonian carbonate buildups known in the Alai Mountains (Veber 1934; Rzhonsnitskaya et al. 1978, 1982). Ammonoid, conodont and dacryoconarid biostratigraphies suggest that the carbonate sedimentation commenced in the Pragian (Rzhonsnitskaya 1982) and continued throughout the early Emsian. The succession of Sangibaland Mountain is certainly shallow-water neritic, and it requires further lithological and sedimentological study. Unlike many other sections containing ammonoid occurrences of this age, there is no evidence of hypoxic conditions (no shale intercalations, no gaps in benthic faunas), but the appearance of the ammonoid fauna may still indicate that the depositional conditions in the Sangibaland Basin at the end of the Zlichovian became more marine, with an increase in pelagic faunal elements, with ammonoids, conodonts and tentaculites becoming more abundant. Ammonoids are likely to have been buried not very far from where they normally lived, which suggests that they were demersal and could tolerate shallow-water conditions. Additional studies are needed to analyze the lithology and sedimentology of the succession, which can lead to a better understanding of the sedimentary environment and geological context.

Conclusions

The continuous succession of shallow-water carbonates of Sangibaland Mountain is interpreted as representing a series of mounds and flank facies containing an ammonoid assemblage co-occurring with brachiopods, crinoids, trilobites, corals, conodonts and dacryoconarids. The ammonoid faunas are found at several levels and date the carbonates as Zlichovian, allowing the assignment of the Sandalian Regional Stage to the LD III Zone sensu Becker and House (1994) (*Erbenoceras* Beds). This is supported by the presence of the dacryoconarid *N. barrandei* and the conodont *E. gronbergi*; however, the occurrence of *L. inversus*, which would normally indicate a higher ammonoid zone (*Mimagoniatites*), is still not well understood. Further biostratigraphic studies are needed in this section to establish the refined correlation of the conodont and ammonoid zonations. This would contribute to the discussion of the subdivision of the Emsian into substages.

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Compliance with ethical standards

Conflict of interest: The authors declare that they have no conflict of interest.

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