Geological Quarterly, 2004, **48** (3): 233–244

Stratigraphy and geological events at the Frasnian-Famennian boundary in the Southern Urals

Andrey B. VEIMARN, Valery N. PUCHKOV, Alevtina N. ABRAMOVA , Olga V. ARTYUSHKOVA, Vladimir N. BARYSHEV, Kirill E. DEGTYARYOV, Lyudmila I. KONONOVA, Viktor A. MASLOV, Viktor M. MOSEJCHUK, Vladimir N. PAZUKHIN, Natalia V. PRAVIKOVA, Alexander V. TEVELEV and Alla V. YARKOVA

Veimarn A. B., Puchkov V. N., Abramova A. N., Artyushkova O. V., Baryshev V. N., Degtyaryov K. E., Kononova L. I., Maslov V. A., Mosejchuk V. M., Pazukhin V. N., Pravikova N. V., Tevelev A. V. and Yarkova A. V. (2004) — Stratigraphy and geological events at the Frasnian-Famennian boundary in the Southern Urals. Geol. Quart., **48** (3): 233–244. Warszawa.

Detailed biostratigraphic correlation of late Frasnian and Famennian sections in the Southern Urals shows that the key global scale events near the boundary of Frasnian and Famennian are clearly expressed in combination with important regional scale tectonic events. The maximum regression occured during *triangularis* zones time, being recorded as common hiatuses. The beginning of specific ultra-potassic mantle volcanism took place during the *linguiformis* Zone. Processes of olistostrome deposition, uplift of the Uraltau zone, the start of flysch deposition, and exhumation of the high pressure-low temperature Maksiutovo metamorphic complex also took place very close to the Frasnian-Famennian boundary, as the general regression coincided with active local tectonic movements as the Magnitogorsk island arc collised with the East European continent. The global scale events at the F-F boundary are connected with activity of the Late Devonian superplume, which encompassed a vast area of the Kazakhstanian, East European, Siberian, Gondwana and South Chinese plates.

Andrey B. Veimarn, Lyudmila I. Kononova, Natalia V. Pravikova, Alexander V. Tevelev, Geological Department of the M. V., Lomonosov Moscow State University, Leninskie Gory, RU-119992 Moscow, Russia; e-mail: npravikova@mail.ru; Viktor N. Puchkov, Alevtina N. Abramova, Ol'ga V. Artyushkova, Vladimir N. Baryshev, Viktor A. Maslov, Vladimir N. Pazukhin, Institute of Geology, Ufimian Scientific Centre of the Russian Academy of Sciences, K. Marks 16/2, RU-450000 Ufa, Russia; Kirill E.Degtyaryov, Geological Institute of Russian Academy of Sciences, Pyzhevskiy 7, RU-109017 Moscow, Russia; Viktor M. Mosejchuk, Alla V. Yarkova, Federal Geological Enterprise ChelyabinskGeolKart, Omskaya 89, Chelyabinsk, Russia (received: February 16, 2004; accepted: July 23, 2004).

Key words: Frasnian-Famennian boundary, Southern Urals, conodonts, superplume.

INTRODUCTION

Work on the second edition of the 1:200 000 scale State geological map of the Russian Federation has resulted in stratigraphic correlation of Upper Devonian deposits of the Southern Urals of different facies (Fig. 1), based on conodont standard zones, building upon recent biostratigraphic studies (Kononova, 1979; Puchkov, 1979; Kochetkova *et al*., 1980; Biostratigrafiya…, 1983; Kochetkova *et al*., 1985; Fauna…, 1987; Puchkov and Ivanov, 1987; Maslov *et al*., 1993; Pazukhin *et al*., 1996; Abramova *et al*., 1998; Puchkov *et al*., 1998; Pazukhin *et al*., 1998; Abramova, 1999; Maslov *et al*., 1999; Maslov and Artyushkova, 2000, 2002; Abramova and Artyushkova, 2002; Akhmetshina *et al*., 2002; Yakupov *et al*., 2002). The updated conodont zonation has allowed more precise correlation of individual sections and so has facilitated the regional, inter-regional and global correlation of events.

The Famennian-Tournaisian strata and fauna of the Southern Urals has been described in detail in several publications (e.g. Kochetkova *et al*., 1980; Biostratigrafiya…, 1983; Kochetkova *et al*., 1985; Pazukhin *et al*., 1996, 1998) and therefore no detailed description is given herein. Special attention is given to the Frasnian-Famennian boundary interval starting from the latest Frasnian Late *rhenana* and *linguiformis* conodont zones.

Application of stratigraphic data for precise restoration of geological history requires knowledge of the relative and absolute time duration of each conodont zone. The detailed sedimentological research of Belyaeva (2000), carried out in the Pechora and Volga–Urals basins, allowed her to test a chronometric scale of duration for Late Devonian time in these areas. Precise correlation of selected horizons with standard

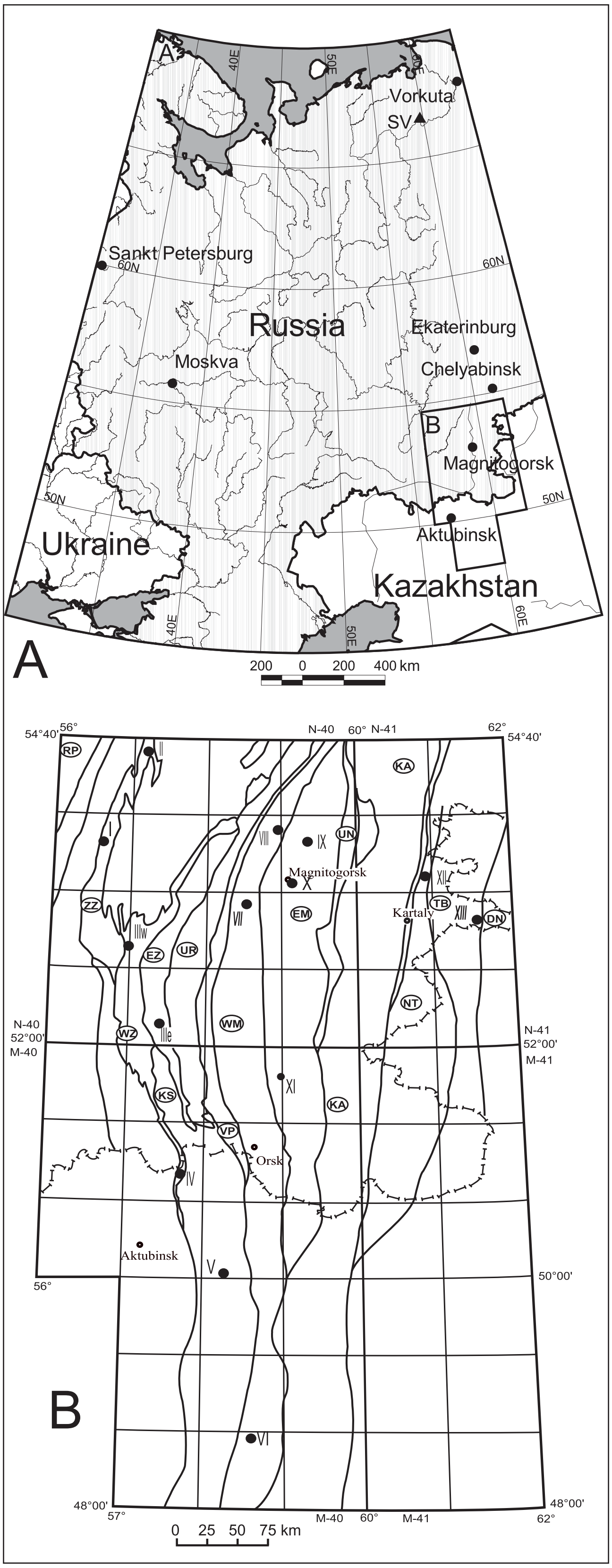

Fig. 1. A — location of area studied in Western Russia, SV — Syviu River area in the Polar Urals (Yudina *et al*., 2002); B — zonation scheme of the Palaeozoic deposits in the Southern Urals (Legenda…, 1998) and location of stratigraphic columns shown in Figure 2

RP — East European (Russian) Platform; ZZ — Zilim–Zigan zone; WZ — West Zilair zone; EZ — East Zilair zone; KS — Kurgan–Samara zone; UR — Uraltau zone; VP — Voznesensk–Prisakmara zone; WM — West Magnitogorsk zone; EM — East Magnitogorsk zone; UN — Ui–Novoorenburg zone; KA — Kochkar–Adamovska zone; NT — Nizhnesanarsk–Tekeldytau zone; TB — Troitsk–Buructal zone; DN — Denisov zone; I–XIII — numbers of stratigraphic sections (Fig. 2)

conodont zones allowed estimation of the relative duration of conodont zones with acceptable levels of error. The vertical scale in Figures 2 and 3 shows this pattern of relative extent of conodont zones. The problem of absolute time values is more difficult. At the XXXI International Geological Congress in Brazil 2000, the International Stratigraphic Commission suggested early and late time boundaries for the Famennian Stage of 355 and 370 Ma. Delimitation of conodont zones follows these dates, though more precise radiometric dates are needed. An alternative timescale for the conodont zones was given by Sandberg and Ziegler (1996).

The goal of this paper is to correlate the stratigraphic sections of the Southern Urals that contain the F-F boundary, delineate the corresponding sedimentary and volcanic events, and connect them to regional and global tectonic processes. This paper further develops and expands the ideas introduced by Veimarn *et al*. (2002*b*).

CHARACTERISTICS AND CORRELATION OF SECTIONS

The Famennian strata of the Southern Urals were formed in various palaeogeographic and palaeogeodynamic conditions. The Famennian was the time when the development of the palaeoceanic zone separating the East European (Laurussian) continent from that of Kazakhstanian was nearing its end (Puchkov, 2000). In this domain were numerous microcontinents and volcanic arcs divided by basins of different character. The subsequent Variscan orogeny resulted in the complex fold system of the Urals, with a nappe-fold structure and the presence of extended, approximately N–S trending faults system, often deformed by significant strike-slip movement (Fig. 1). This complex structural deformation, and the tectonically distorted facies patterns, meant that it was necessary to establish zones of stable enough character to subdivide the Palaeozoic deposits in the sheet legends to the State geological maps (Legenda …, 1998).

ZILIM–ZIGAN ZONE

Famennian strata, deposited on the eastern margin of the East European continent, are present in the Zilim–Zigan zone (Fig. 1), which is considered as part of the Belsk–Elets structural-facies zone traceable along the whole western slope of the Urals (Puchkov, 2002).

In the Late Devonian, the Zilim–Zigan zone included the Inser–Usolsk trough — a southeastern part of one of the branches of the Kama–Kinel trough system. In this part of Kama–Kinel system, the following facies types have been established (Belyaeva and Stashkova, 1999): (1) an outer shallow shelf zone, (2) an inner shallow shelf zone, (3) slope and (4) basin. In the Zilim–Zigan trough, the Upper Devonian strata can be subdivided in detail using conodonts (Kochetkova *et al*., 1985; Pazukhin *et al*., 1998; Abramova, 1999; Abramova and Artyushkova, 2004). In most sections the stratigraphic unconformity at the F-F boundary is distinctive (Veimarn *et al*., 1997; Abramova, 1999). Strata of the *linguiformis* and *triangularis* zones are partially or wholly absent, only the basinal section, exemplified by the Lemesa succession, being complete. According to Abramova (1999), the entire section contains goniatites indicative of relatively deep-water conditions of sedimentation. However, while the Late *rhenana* Zone is represented by pale grey thick-bedded limestones, the lithological composition of the *linguiformis* and *triangularis* zones is highly variable (Fig. 2 section II). In the *linguiformis* Zone (0.47 m thick) thin-bedded pale grey limestone is replaced by brown thin-bedded dolomite, brownish-grey limestone and, finally, dark grey, bituminous Domanik-type limestone in which goniatites are accompanied by orthoceratites, bivalves, gastropods and brachiopods. The *triangularis* zones (1.22 m thick) are represented by alternating brownish and dark grey thinly platy, locally dolomitized, often silicified micritic limestones, as well as by brown to dark grey, thin-bedded fine-grained friable sandstones, siltstones and greenish-grey (up to bright green) sandy clay. These rocks compose also the lower part of the *crepida* zones, being replaced in its upper part by brownish-grey to pale grey, pinkish, medium-bedded limestone with stylolitic seams filled with a bituminous organic substance.

The most complete succession of shallow shelf and slope facies is seen in the Ryauzyak section (Kochetkova *et al*., 1985; Abramova, 1999; Abramova and Artyushkova, 2004). Here again there are no strata of the Late *triangularis* Zone; the Early and Middle *triangularis* zones are represented by shallow-water brachiopod shelly beds (Fig. 2, section I). Higher in the succession are pale grey, pinkish-grey, thin-bedded, fine-grained organogenic limestones corresponding to the *crepida*, *rhomboidea*, *marginifera*, *trachytera*(?) and *postera* zones. The upper part of the Famennian Stage is represented by grey platy limestones with irregular bedding surfaces showing foraminifers, cephalopods, brachiopods, ostracods, trilobites, crinoids and conodonts of the *expansa* zones, dark grey and grey, thin-bedded, micritic limestones, locally silicified, with foraminifera, ostracods and conodonts of the *praesulcata* zones. The Famennian strata in this section are 25.3 m thick.

Figure 3 shows hiatuses in the sections studied (Veimarn *et al*., 1997; Abramova, 1999). These section occure along a belt trending approximately N–S, extending up to 120 km across the Inser–Usolsk trough from its basinal part represented in the Lemezinsky section (II on Fig. 1) to the Zigan section typical of a shallow shelf development, located 20 km to the south of the locality at Ryauzyak (I on Fig. 1; Fig. 3). The global regression, which broadly coincides with the F-F boundary, abruptly changed to a transgression (see Johnson *et al*., 1985) and this is well reflected in the successions. The regression maximum falls in the *triangularis* zones. The stratigraphic distribution of the numerous hiatuses suggests that sedimentation within the Inser–Usolsk trough was periodically interrupted from the *linguiformis* Zone up to the *rhomboidea* zones. Various tectonic movements are also recorded as the influx of terrigenous material into the basinal succession. The lower Famennian limestones are typically pink in colour, and this was probably connected with a change to oxidizing conditions in the sedimentary environment.

ZILAIR ZONE

The extreme southeastern part of the Zilim–Zigan zone borders with the West Zilair zone, which further east is replaced by the East Zilair zone (Fig. 1). The Famennian strata are represented mainly by flysch-like greywacke of the Zilair Formation with differences in composition between the western and eastern zones limited mainly to the lower parts of the sections (Pazukhin *et al*., 1996; Puchkov *et al*., 1998; Puchkov, 2000, 2002; Abramova and Artyushkova, 2002; Yakupov *et al*., 2002).

At the eastern limb of the Zilair synform, in the top part of the middle-upper Frasnian section, within variously coloured siliceous and clayey sheles of the Ibragimovo Horizon there appear layers of siltstone and graded greywacke sandstone, the latter having their basal parts composed of a conglomerate that typically contains fine fragments of the underlying chert (III on Figs. 1 and 2). The average thickness of greywacke beds is about 3 m, while the chert units capping the rhythms are usually around 0.5 m thick (Puchkov, 1979). Upwards in the section the Zilair Formation represents a proximal flysch with a significant content of sandstone and some chert layers. Conodonts suggest that the fine-grained terrigenous material, from a source located in the east, first appeared in the Late *rhenana* to *linguiformis* Zone interval (Fig. 2). Higher in the section, though still in the lower part of the Zilair Formation, a layer of clayey siliceous sheles within the greywacke succession contains conodonts of the Late *triangularis* to Early *crepida* Zone interval (Pazukhin *et al*., 1995; Puchkov *et al*., 1998).

In the Chernaya River mouth section, 150 km to the north, the F-F boundary, characterised in detail by conodonts (Abramova and Artyushkova, 2002, 2004; Yakupov *et al*., 2002), is located within interbedded dark grey siliceous argillite and grey, greenish-grey shale with subordinate layers of dark grey limestone-clay siltstone. The base of the Zilair Formation, placed at the lowest sandstone layer, coincides with the boundary of the Middle and Late *triangularis* zones.

On the western limb of the Zilair synform, the lower part of the Zilair Formation is represented by a distal greywacke flysch composed mostly of siltstone and shale with rare intercalations of platy chert. The formation usually overlies massive limestone. In sections of the Kurair Creek and along the right bank of the Ik River (III on Figs. 1 and 2), in the uppermost part of this limestone, conodonts of the Late *triangularis* to Late *crepida* zones are found and a chert close to the base of Zilair Formation is assigned to the Latest *crepida* to *rhomboidea* Zone interval (Puchkov *et al*., 1998). Somewhat different stratigraphic relationships are observed to the north-east, near Yaumbaevo village. The limestone of the Late *rhenana* Zone is overlain without any trace of erosion by the basal, chert-free, fine-grained greywacke of the Zilair Formation. The chert in this section is replaced by layers and concretions of clay-rich limestone. The limestone contains conodonts of the Late *triangularis* Zone (Abramova *et al*., 1998). A west-directed younging of the Zilair Formation was proposed by Puchkov (2002); this point of view is not shared by Artyushkova and Maslov.

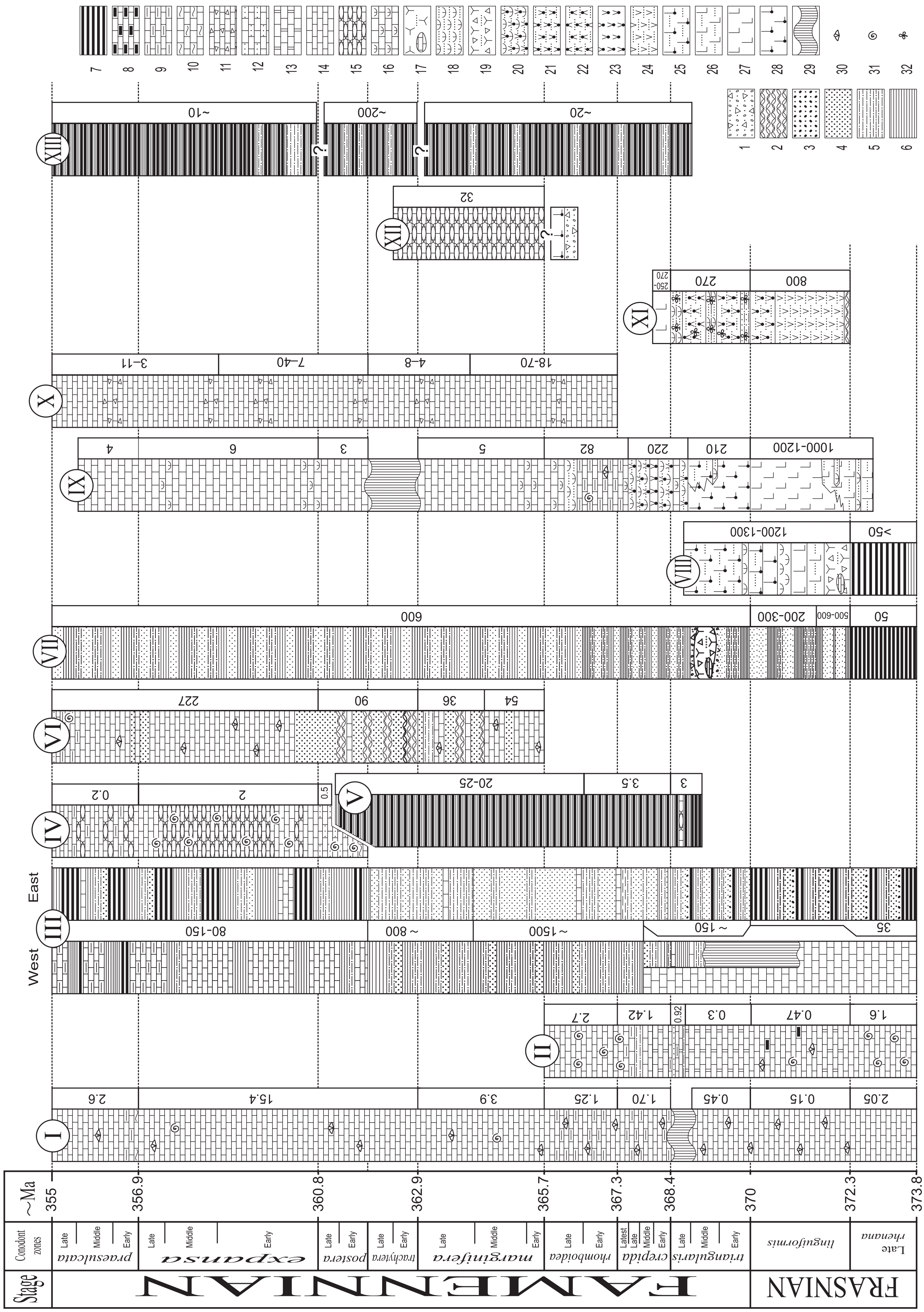
Stage
FAMENNIAN
FRASNIAN
Conodont zones
~Ma
praesulcata
expansa
postera
trachytera
marginifera
rhomboidea
crepida
triangularis
linguiformis
Late rhenana
Late
Middle
Early
Latest
355
356.9
360.8
362.9
365.7
367.3
368.4
370
372.3
373.8
I
II
III
West
East
IV
V
VI
VII
VIII
IX
X
XI
XII
XIII
2.6
15.4
3.9
1.25
1.70
0.45
0.15
2.05
2.7
1.42
0.92
0.3
0.47
1.6
80-150
~ 800
~ 1500
~ 150
35
0.2
2
0.5
20-25
3.5
3
227
90
36
54
600
200-300
500-600
50
1200-1300
>50
4
6
3
5
82
220
210
1000-1200
3–11
7–40
4–8
18-70
270
800
250-270
32
~10
~200
~20
?

Fig. 2. Correlation of stratigraphic columns of the uppermost Frasnian and Famennian in the Southern Urals

I — Ryauzyak (Kochetkova *et al*., 1985; Abramova, 1999), II — Lemezinsky (Abramova, 1999), III — western and eastern parts of the Zilair synclinal trough (Puchkov, 1979; Pazukhin *et al*., 1996; Abramova *et al*., 1998; Puchkov *et al*., 1998; Puchkov, 2000), IV — Kiya River (Biostratigrafiya…, 1983), V — Bakay River (Puchkov and Ivanov, 1987), VI — Burtybay Creek (Fauna…, 1987), VII — Biyagoda (Artyushkova and Maslov, unpubl. data), VIII — Vyatsky village (Maslov *et al*., 1999), IX — wells E 3 and E 5 (Kashina *et al*., unpubl. data), X — Magnitnaya Mountain (Gasudarstvennaya…, in press), XI — Solonchatka Creek, confluence with Karaganka Rriver (Rikhter, 1968; Beguchev, 1972), XII — quarry Varna I (Tevelev *et al*., unpubl. data), XIII — confluence of Kamyshly-Ayat and Archagly-Ayat rivers (Aristov and Degtyarev, unpubl. data; Degtyarev *et al*., 2000); the vertical scale of the columns shows the relative durations of the conodont zones (Belyaeva, 2003); for an explanation of our figures of the absolute ages see the text; the thickness is given in metres; lithology: 1 — sedimentary breccia, 2 — conglomerate, 3 — gravel, 4 — sandstone, 5 — siltstone, 6 — shale, 7 — siliceous and carbonate shale, 8 — bituminous limestone, 9 — argillaceous limestone, 10 — siliceous limestone, 11 — clastic limestone and calcareous conglomerate, 12 — sandy limestone, 13 — dolomitic limestone and dolomite, 14 — limestone and marmorised limestone, 15 — lumpy limestone, 16 — tuffaceous limestone, 17 — olistostrome, 18 — tuffaceous sandstone and gravel, 19 — tuffaceous breccia, 20 — trachyandesitic tuff and tuffaceous sandstone, 21 — trachyandesitic tuff, 22 — trachydacitic tuff, 23 — trachyandesite, 24 — andesitic tuff, 25 — trachybasaltic tuff, 26 — basaltic tuff, 27 — basalt, 28 — trachybasalt, 29 — hiatus, 30 — brachiopods, 31 — ammonoids, 32 — flora

The lower part of the Zilair Formation, termed the Yaumbaevo unit, is estimated as 150–200 m thick (Keller, 1949). The overlying Astashskovo and Avashly units include alternating sandstone, siltstone and shale. The conodont dating of these units is incomplete, but based on their position in the section, the age is within the Middle *crepida* to Early *trachytera* Zone interval. The Astashskovo unit differs by a more conglomeratic composition; medium- and fine-grained sandstones prevail, but coarse-grained sandstones are also present, grading into fine conglomerate. Dark, greenish-grey shales are also present and plant remains are abundant. Layers of limestone and lenses of tuff occur in the Ik River section (Keller, 1949). In the Avashly unit, more fine-grained rocks with subordinate sandstone prevail. The Astashskovo and Avashly units are estimated as approximately 1500 and 800 m thick, respectively. The overlying Yamashly unit has a complete conodont documentation, covering the Famennian *postera*, *expansa* and *praesulcata* zones (Pazukhin *et al*., 1995). It is composed of greenish-grey and dark grey, frequently silicified shale and greenish-yellow-grey jasper-like silicite with layers of limestone. The increase in abundance of carbonates from the south to the north is typical. The Famennian part of the Yamashly unit is 80–150 m thick.

KURAGAN–SAKMARA ZONE

In the northern part of the Kuragan–Sakmara zone (Fig. 1), elements with a chaotic structure at the base of the Zilair Formation were observed (Ryazantsev *et al*., 2000). The variegated siliceous tuffite of some olistoliths contain the Frasnian species *Palmatolepis hassi* Müller et Müller, and higher up, in the cherty to clastic olistostrome matrix, *Palmatolepis glabra prima* Ziegler et Huddle was found, indicating the *crepida–marginifera* Zone interval.

On the left bank of the Ural River, along its Kiya River tributary and further south on the Dombar River and Zhaksy–Kargala River, within the southern continuation of the West Zilair zone, the Kiya Formation as well as the Zilair Formation have long been recognised (Rozman, 1962). The relations of the Kiya Formation with the Zilair Formation were originally not clear. The conodont biostratigraphy by Puchkov and Ivanov (1987) indicated that the Zilair and the Kiya formations belong to different facies of the same age and were brought into contact tectonically. The underlying Frasnian Eginda Formation is mainly siliceous in composition; the upper part is similar to the Ibragimovo Horizon of the East Zilair zone. In a section of the Eginda River, the cherts of the Eginda Formation are gradually replaced up-section by greywacke sandstone, siltstone and shale of the Zilair Formation. In the lower part of the latter unit, conodonts of the *crepida* zones were collected (Puchkov and Ivanov, 1987).

In this tectonically complicated area Tchibrikova (1997) established the oldest package of the Zilair Formation which, based on an assemblage of spores, corresponds to the Late *rhenana* to *linguiformis* Zone interval. This is the only locality in the Southern Urals where the lower part of the Zilair Formation

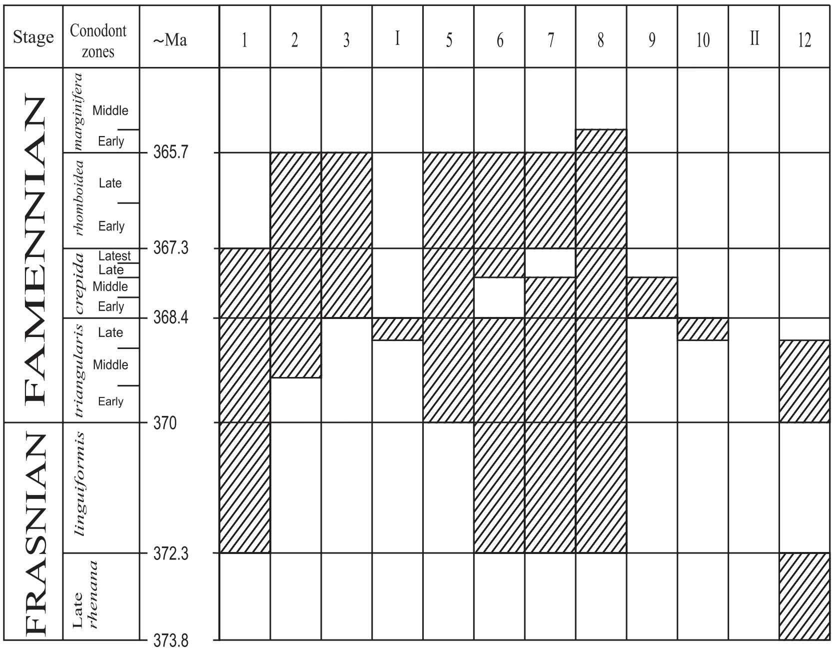

Fig. 3. Hiatus intervals (hatchured) in the Frasnian-Famennian sections of the Zilim–Zigan zone across the Inzer–Usolsk through

Sections (Veimarn *et al*., 1996; Abramova, 1999): 1 — Zigan, 2 — Kuk-Karauk 2, 3 — Kuk-Karauk 1, I — Ryauzyak, 5 — Mendym 1, 6 — Mendym 2, 7 — Mendym 3, 8 — Kushelga, 9 — Akkyr, 10 — Kuktash, II — Lemezinsky, 12 — Gabdyukovo is attributed to the upper Frasnian, though there are sections where the upper Frasnian rocks are very similar in lithology to the Zilair Formation (e.g. the Tashtugay and Tolubay sections of the Mukas Formation, see below).

The Kiya Formation contains abundant ammonoid, trilobite and conodont faunas, characterising both the bottom and top of the Famennian. It is composed mainly of pale grey and greenish platy thin-bedded clayey siliceous slate with subordinate layers of shale, chert, siliceous sandstone, limestone, and bituminous shale. The relative proportions of these lithologies are highly variable. The section at Kiya River (Fig. 2 section IV) corresponds to only the three upper conodont zones of the Famennian stage and is represented by deep-water brown-grey mottled, locally pyritized, fine-grained clayey limestone with layers of finely detrital limestone. Here and in other sections the Kiya Formation is developed as cephalopod limestone (Biostratigrafiya..., 1983).

Fairly representative thin intervals of Kiya Formation lithology are found 100 km to the south-east, on the Bakay River (Puchkov and Ivanov, 1987) (Fig. 2 section V). The lower part of the succession, 3 m thick, is represented by black and dark grey foliated bituminous shale, clayey siliceous slate, siliceous siltstone, as well as less abundant calcareous shale and strongly clayey nodular limestone. The latter form continuous and concretionary layers 6–15 cm thick, composing up to 15% of the rock volume. Overlying units consist of platy clayey siliceous radiolarian slate. According to numerous conodonts, this section covers an interval from the *triangularis* up to the *postera* Zone. Lithologic features of the rocks, condensed character of the sections and the ecologic type of fossil assemblages indicate the Kiya strata to be of deep-water orgin. Their deposition mostly occurred in anoxic conditions in places remote or isolated from sources of the terrigenous material that characterises the contemporaneous Zilair Formation. More detailed study of sections on the Kiya and Bakay rivers allowed more precise determination of the Famennian succession with the establishment of eight conodont assemblages (Akhmetshina *et al*., 2002).

In the extreme south of the territory described, at the southern termination of the Mugodzhary Mountains, strata of the Famennian Stage occur in the Berchogur Syncline (VI on Fig. 1). Conodont-based dating has been accomplished for the sections in the north-east of the syncline at Burtybay Creek (Fauna..., 1987) where the strata, starting with the *marginifera* Zone (Fig. 2, section VI) include Middle Devonian basalts and tuffs.

A section of the F-F boundary beds characterised by abundant brachiopods was described by Rozman (1962) in the northwestern part of the syncline, on Bolshoy Alabas Mountain. A brachiopod-based comparison with the section at Ryauzyak River (Abramova, 1999) indicates that the limestone, deposited here with a significant stratigraphic break on volcanogenic-sedimentary rocks, can be correlated to the *linguiformis* to Early *triangularis* zones. The 50 m thick limestone is overlain by 60 m of dense reddish-grey clotty-algal limestone, referred by Rozman (1962) to the Famennian Stage. They are succeeded by pale grey, slightly pinkish limestones with *Cyrtospirifer archiaci* (Murch.), typical of the lower Famennian, and without atrypids, characteristic the Frasnian Stage. In immediate proximity, on Maly Alabas Mountain, upper Frasnian strata are thin, and breccia layers composed of angular fragments of tuff and jasper appear.

In the Berchogur Syncline, an olistostrome is widely developed (Fauna..., 1987; Stratigraficheskie skhemy..., 1993), consisting of polymictic medium and fine conglomerates with separate blocks and limestone olistolithes of considerable sizes that contain an upper Frasnian fauna. This unit probably encompasses the Late *triangularis–crepida* zones because it is covered by limestone, sandstone and conglomerate, from the base of which conodonts of the *marginifera* Zone were recovered (Fig. 2 section VI). The palaeontological and lithological study of this succession (Fauna ..., 1987) in the Burtybay and Jangansay sections has shown that the lower part of the *marginifera* Zone is composed of sandy and silty detrital limestone. It has formed near a coastline in conditions of high hydrodynamic activity typical of shoals on a shallow shelf. In the top half of the *marginifera* Zone, terrigenous rocks are widely developed: conglomerate, sandstone, greenish-yellow and red-brown siltstone, and shale, quite often containing carbonized plant debris. Judging from the variegated rock colours and the specific character of the fauna, these strata were deposited in a shallow brackish lagoon. A package of terrigenous rocks consisting of conglomerate, sandstone and siltstone was deposited above it, probably corresponding to the *trachytera*, *postera*, and perhaps to the Late *expansa* Zone. These sediments of beaches, bay-bars, and outer bars of the sea coast formed close to a provenance area with an irregular topography.

The regressive complex is overlain in the section by grey algal, detrital and clotty to clastic sandy limestones with layers of coarse-grained polymictic sandstone passing into conglomerate. The rocks contain numerous and varied faunal remains and correspond to the *expansa* and *praesulcata* zones. Deposition took place in shallow shelf conditions.

WEST MAGNITOGORSK ZONE

In the Voznesensk–Prisakmara and southern half of West Magnitogorsk zone (Fig. 1), the Famennian Stage is represented by greywacke of the Zilair Formation, very similar to the strata developed in the East Zilair zone (Mizens, 2002). However, in the northeastern part of the West Magnitogorsk zone the composition of the Late Devonian strata becomes more complicated. While the Late *rhenana* Zone is represented almost everywhere by siliceous and cherty-clayey rocks of the upper part of the Mukas Formation, the *linguiformis* Zone includes strata which are variable in composition and thickness. In the southern sections, at Tolubay River and Tashtugay Gorge (Maslov *et al*., 1993, 1999), the 10–15 m of strata assigned to the *linguiformis* Zone includes irregularly alternating polymictic sandstone and shale containing thin layers of calcareous siltstone. These sediments are very similar to the overlying Zilair Formation.

To the north, in the Biyagoda Range (Maslov *et al*., 1999), strata of the *linguiformis* Zone (Figs. 1 and 2 section VII) are represented by the Biyagoda unit, consisting of two sub-units: the rhythmically laminated sandy-silty-siliceous lower unit, up to 600 m thick, and the upper unit, composed of the Biyagoda olistostrome which is up to 310 m thick. Higher in the section, sandy, silty and shaly strata of the Zilair Formation are about

600 m thick. Conodonts of the *triangularis* zones are found in the lower part of the Zilair Formation. The upper part did not yield conodonts, therefore the proposal that it encompasses the whole Famennian Stage is tentative. North of the Biyagoda Range the thickness of the Biyagoda unit rapidly decreases.

Mizens (2002) indicated that the Biyagoda olistostrome is a complex and non-uniform accumulation of blocks, and fragments of intermediate and acid volcanics, chert, sandstone and limestone, with a poorly sorted gravel matrix. These rocks are developed over an area of approximately 20 × 50 km (see also Mizens, 2004).

To the south at Malaya Urtazymka River and Koltuban Lake, the "Koltuban Limestone" is widely developed at the same stratigraphic level as the Biyagoda olistostrome. The detailed study of Mizens (2002) has shown that this unsorted boulder conglomerate of mainly calcareous composition is comparable to debris-flow sediments.

In the north of the West Magnitogorsk zone, west of the Verkhneuralsk and Uchaly areas, the *linguiformis* Zone is represented by the Bugodak unit. In a section at Vyatsky settlement (Fig. 2 section VIII), the tuff and tuff-breccia of the lower part of the section are overlain by olistostrome with fragments of limestone (Maslov *et al*., 1999; Maslov and Artyushkova, 2002). Along strike, the olistostrome pinches out, and is replaced by tuff breccia 1000–1200 m thick. In the lower part of the section, tuff, tuffite and lavas of porphyritic, pyroxene, and plagioclase-pyroxene basalt prevail. In the upper part trachybasalts and trachyandesite-basalts dominate, this section probably including part of the *triangularis* Zone (Gasudarstvennaya..., in press). Higher, above an unexposed interval 100 m thick, 1000 m of the Zilair Formation is exposed, where its composition is very unusual. It is represented by tephraturbidites, tuffite and tuff of trachyandesite, trachyte and trachydacite composition (State..., in press). In the lower part of the section, tuff and tuffite of trachyandesite, andesite and trachyte composition prevail, associated with layers of tephroid of the same composition, whilst the upper part is chartecterised by tephroid with reworked tephra and layers of trachydacitic, trachy-rhyodacitic, rhyolitic and trachyandesitic tuff and tuffite. Admixtures of rounded fragments of basalt and trachybasalt of the Bugodak unit and limestone in the tephroid are rare.

Mizens (2002) and Puchkov (2000) proposed a palaeogeographic setting of the Zilair Formation taking into account the earlier studies of Smirnov and Smirnova (1961), Arzhavitina (1976), and Ilyinskaya (1980). The results of mineralogical studies (Willner *et al*., 2002) support the idea that the main provenance area for the Zilair Formation was the Uraltau uplift, where volcanics and quartzites co-occur with high-pressure metamorphic rocks of the Maksiutovo complex.

EAST MAGNITOGORSK ZONE

In the East Magnitogorsk zone, sections of the Upper Devonian strata reach their maximum variability. In the northern region, in the Magnitogorsk and Verkhneuralsk areas, lithologically variable upper Frasnian strata are overlain by the 500–1200 m thick Ablyazovo unit. It is composed of porphyritic pyroxene and pyroxene-plagioclase basalt, less often of andesite-basalt, trachybasalt, trachyandesite-basalt, associated lava breccias, tuff, tuffite, tephroid, tuffaceous conglomerate, tuffacceous sandstone, occasionally with layers of rhyodacite tuff, siliceous rocks and limestone (Gosudarstvennaya..., in press). An increased contribution of explosive components is characteristic. The basalt is highly enriched in Rb, K, Ba, Sr, Th and light REE. Based on conodonts, the unit is correlated mainly with the *linguiformis* Zone, though it probably includes parts of the Late *rhenana* and *triangularis* zones (Fig. 2 section IX).

The Ablyazovo unit in the areas under consideration is overlain by the Novoivanovski unit, composed mainly of trachybasalt and porphyritic trachyandesite-basalt with plagioclase, associated tuff, tuffite, occasionally with layers of tuffaceous sandstone, tuffaceous conglomerate and limestone. The limestone includs a pinkish breccia-like variety (Salikhov *et al*., 1987). The thickness of the unit is 150–800 m. In the trachybasalt, anomalously high contents of Rb, K, Sr, Ba, Th and light REE, as well as raised contents of Nb, Ta, P, Hf, Zr, Eu, Ti and heavy REE were measured. Lilac and reddish colours in these rocks are caused by hematite particles in products of glass decomposition (Gosudarstvennaya..., in press). Fossil recovery was poor, deposition probably occuring within an interval from the top of the *linguiformis* to the bottom of the *crepida* zones.

The Novoivanovski unit is conformably overlain by the Shumilino Formation. The Famennian part was seen in cores of wells E 3 and E 5, drilled to the north from Verkhneuralsk Lake (Fig. 2 sektion IX). The basal portion, about 220 m thick, consists of tuffogenic sandstone and conglomerate, tuffites, tuffs and lavas of trachyandesitic composition. This interval probably corresponds to the *crepida* Zone because it is overlain by calcareous tuffite, and then by limestone with intercalations of tuffite, bearing conodonts of the Latest *crepida* to the *rhomboidea* and up to the *praesulcata* Zone. The *rhomboidea* and *marginifera* zones have a total thickness of almost 90 m, while the *postera*, *expansa* and *praesulcata* zones are reduced to a 13 m thick interval. The Shumilino Formation probably contains hiatuses partly corresponding to the *trachytera* and *praesulcata* zones.

Farther to the south, according to the results of drilling west of Novoivanovski village, the thickness of the tuffs and trachyandesitic lavas deposited on trachybasalts of the Novoivanovski unit is considerably reduced; in places these deposits are almost absent. However, in the calcareous part of the section there are many ashy trachyandesitic tuff layers and in the topmost part acid tuffs occur. The limestones frequently alternate with calcareous breccia and conglomerate with a calcareous cement; resedimented conodont faunas are common and hiatuses are present. The depositional conditions during the *rhomboidea–praesulcata* zones were characterised by significant seismic activity accompanying the waning volcanism, and also by intense tectonic activity. This explains the origin of an olistostrome-like horizon in the upper Famennian limestone at Popovsky village (Kochetkova *et al*., 1980), immediately to the north-west of wells E 3 and E 5. The locally deeper-water basin in which this limestone was deposited is characterised by a wide distribution of ammonoids (Perna, 1914; Bogoslovsky, 1971); brachiopods have also been reported. Along with pale grey limestone, pinkish and dark red varieties (Salikhov *et al*., 1987) are widely developed.

Except for the tuffite, tuff and trachyandesitic lava, volcanic rocks of the Shumilovskaya Formation within the limits of the northern part of the East Magnitogorsk zone are represented also by trachytes, trachydacites and trachyrhyolites. These volcanic rocks belong to a single series beginning with trachybasalt of the Novoivanovski unit and have common geochemical features.

Famennian carbonate sediments within the limits of the Magnitogorsk ore-deposit are represented by the lower part of the Magnitnaya Mountain Formation (Fig. 2 section X) in which conodont zones from the *rhomboidea* to *praesulcata* zones are established, although the *trachytera* Zone is probably absent. The formation is composed of marmorized, up to marble grade, detrital limestone with layers of clastic limestone, calcareous conglomerate and breccia (Gosudarstvennaya..., in press). There is one tuffite layer and thin carbonaceous siltstone partings are notable. The limestone is usually grey, seldom pinkish and the presence of brachiopods indicates a fairly shallow-water depositional regime.

In the southern part of the East Magnitogorsk zone, the Famennian internal includes the Karagan unit (Rikhter, 1968; Beguchev, 1972) and the Budamshinski volcanic complex (Stratigraficheskie skhemy..., 1993). In the section along Solonchatka Creek (Fig. 2 section XI), the unit was subdivided into three parts by Rikhter (1968). The lower part comprises mainly bomb-rich tuff of andesitic and trachyandesitic composition, unconformably overlying Frasnian strata with a basal conglomerate. The middle part is represented by volcanomictic sandstone, siltstone and shale with abundant plant remains, as well as by layered trachyte and trachydacite tuffs. Basalt lava flows occur in the upper unit. The unit was deposited mainly in continental conditions indicated by the reddish colours of the weathered volcanic rocks. The rich flora enabled Beguchev (1972) to date this complex as lower Famennian; noting that the plant remains were encountered mostly in the upper part of the unit, he did not exclude the possibility that the lower part of the unit may belong to the upper Frasnian. The correlation of this section with conodont zones, suggested in Figure 2 is conditional, but it correlates well with more northern sequences of the East Magnitogorsk zone. Bochkarev and Yazeva (2000) demonstrated the petrochemical affinity of the Budamshinski, Ablyasovo and Novoivanovski volcanic rocks, supporting the tentative correlation. Along strike, 70 km to the south, flora remains were found in this unit (Avdonin *et al*., 1968), which according to Yurina (1988) are Famennian in age.

NIZHNESANARSK–TEKELDYTAU ZONE

In the northern part of the Kochkar–Adamovska zone (Fig. 1) Famennian strata are not known. To the east, in the Nizhnesanarsk–Tekeldytau zone, Famennian strata were described in the area of Varna village (Smirnov and Smirnova, 1961; Ivanov *et al*., 1992, 1998). A well-exposed section was recently investigated on the left bank of the Sredni Toguzak River, upstream from the mouth of the Nizhni Toguzak River, in the Varna I quarry (Fig. 2 section XII). The conodont succession indicates that the 30 m thick limestone unit, of *marginifera* to *trachytera* zones age, is overturned. A wide development of "knotty" varieties is typical of the limestone. Algal, foraminiferal-peloid, organogenic-detrital and polydetritic limestones occur in addition to calcareous sandstone, calcareous conglomerate (Ivanov *et al*., 1998) and sedimentary breccia. At the contact with the limestone, a thin horizon of amygdaloid trachybasalts occurs, markedly different from the Ordovician basalts widely distributed in this region. One hundred metres higher up in the succession, from Varna village along the Northern Toguzak River, among clotted limestones there occur, dense, clayey varieties of limestone, violet tinged on broken surfaces. Brachiopods, rugose corals, nautiloids and ammonoids were found in this unit, which can be attributed to the IIIa Zone of the *Prolobites* horizon, i.e. to the *marginifera* zones (Bogoslovsky, 1971). Most likely these strata were formed within the carbonate platform near a shelf margin slope of a deep-water basin.

TROITSK–BURUKTAL ZONE

In the extreme east of the Troitsk–Buruktal zone, immediately to the west of the Tobol Fault, in the lower reaches of the confluence of the Kamyshly-Ayat and Archagly-Ayat rivers, Degtyarev and Aristov (Degtyarev *et al*., 2000) described the approximately N–S trending Kamyshly-Ayat facies zone of deep-water Devonian strata, recognised earlier by Ivanov (1989; Fig. 2 section XIII). It is narrow (6–8 km), extends 70–80 km and is represented by a unit of tectonic sheets dipping steeply to the north-west. The strata comprise siliceous, cherty-terrigenous, olistostromal and terrigenous packages of Upper Devonian and probably Lower Carboniferous age. Siliceous rocks form outcrops up to 200 m wide or form large olistoplaques, olistolites and small exposures inside the olistostromal packages. The greater part of these strata are Famennian in age. On the left bank of the Archagly-Ayat River at the western margin of Maslokovetsky village, in a 20 m thick tectonic sheet or olistolith, composed of crenulated black and yellow platy cherts with layers of black siltstone, Aristov (Degtyarev *et al*., 2000) recovered conodonts of the Late *triangularis* to *trachytera* zones. At the right bank of the Kamyshly-Ayat River, opposite Podgorny village, a portion of the section is represented by grey and black chert with thin layers of black siliceous siltstone and shale up to 200 m thick, which corresponds to the *trachytera–postera* zones. On the same bank, opposite Maslokovetsky village conodonts characterising the *trachytera* to *praesulcata* zones were collected from grey radiolarites, occurring among grey and yellow thicky platy cherts with layers of black, 5 m thick siliceous siltstone. Thus, these strata include practically all Famennian zones from the Late *triangularis* to the *praesulcata* Zone (Fig. 2), suggesting stable deep-water conditions of deposition.

DISCUSSION

The zonal subdivision of the Famennian deposits of the Southern Urals permits correlation of the strata and geological events in the different areas, over particular time intervals, and especially of the crucial Frasnian-Famennian mass extinction boundary (Walliser 1996; Veimarn *et al*., 1998). Some key global geologic processes and events, which are characteristic of F-F boundary locations, are also clearly recorded in the Uralian oceanic basin.

SEA LEVEL CHANGES

For the Zilim–Zigan zone the eustatic oscillations of the ocean level are well established. A major regression followed by a transgression took place during the time interval corresponding to the *linguiformis*, *triangularis* and, partly, the *crepida* zones. In the Euramerican transgressive-regressive scheme of Johnson *et al*. (1985) the F-F sea level fall is much shorter, within the *linguiformis* to *triangularis* transition intervals. This difference is due to local tectonic movements in the Urals at this time. Sedimentological studies in the much less active eastern part of the East European Platform (Belyaeva and Stashkova, 1999; Belyaeva, 2000) have shown two sea level drops within the *linguiformis* and *triangularis* zones. Facies analysis of the Southern Uralian sections shows that the maximum regression, characterised by hiatuses, falls within the *triangularis* Zone (see Figs. 2 and 3), as in the interpretation by Johnson *et al*. (1985).

MAGMATIC AND TECTONIC ACTIVITY

One of the major geological events of the F-F time-span in the Southern Urals was the manifestation of a specific magmatic event (Veimarn *et al*., 1997, 2002*b*). This activity began in some parts of the region at the end of the *rhenana* Zone and continued within the *linguiformis* and *triangularis* zones. In the north of the West Magnitogorsk zone, it is recorded in the Bugodak unit (section VIII on Figs. 1 and 2) and in the closely related part of the East Magnitogorsk zone: the Ablyazovo and Novoivanovski units, and the lower part of the Shumilino Formation (section IX on Figs. 1 and 2; Moseichuk and Surin, 1998; Maslov *et al*., 1999; Gosudarstvennaya…, in press). The mostly continental Budamshinski volcanic complex was being formed in the southern part of the East Magnitogorsk zone at that time (section XI on Figs. 1 and 2; Rikhter, 1989). These units are composed mostly of basalt and trachybasalt; in some places picrobasalt, picrite and meymechite are also found. The alkalinity increases upsection, and the rocks are characterised by a sharp enrichment in K, Rb, Ba, Sr and light REE (Gosudarstvennaya….., in press; Moseichuk and Surin, 1998). Contemporaneous volcanogenic complexes were also being formed to the east of the East Magnitogorsk zone within the limits of the Ui–Novoorenburg zone (Fig. 1) where the upper Frasnian Sheludivogorsk unit is developed (Ivanov *et al*., 1996; Maslov *et al*., 1999; Tevelev and Kosheleva, 2002). It is composed of coarse porphyritic absarokite, trachybasalt, basalt, associated lava breccia and tuff (Yazeva and Bochkarev, 1998). The chemical composition of the volcanic sequence is uniform, being medium-alkaline potassic, potassium-sodic, low in titanium and weakly differentiated basaltoid. Only the K_2O content drops upsection. The normative concentrations diminish regularly from the light to the heavy REE.

The volcanic complexes are probably connected with initially subalkaline mantle magmas (Bochkarev and Yazeva, 2000). The eruptive activity and accompanying seismotectonic processes certainly exerted a great influence on sedimentation in the adjoining basins. In the middle Frasnian a generaly quiet tectonic interval predominated, with calm accumulation of thin, mainly siliceous sediments over large areas of the Southern Uralian basin. By the end of the *rhenana* Zone, in the East Zilair zone the deposition of cherts was interrupted by ubiquitous turbidity currents, indicating an intensification of tectonic activity. From the Early *triangularis* Zone, greywacke was the only component of the Zilair series, indicating that the onset of the flysch complexes was synchronous with the beginning of mantle-derived volcanism. The time of formation of boulder olistostromes and conglomerates in the West Magnitogorsk zone corresponds mainly to the middle part of the *triangularis* Zone and in some places continues up to the beginning of the *crepida* Zone (Mizens, 2002).

On a regional scale, sedimentary and magmatic events in the Southern Urals correspond to an important phase of Magnitogorsk island arc collision with the passive margin of the East European continent (Puchkov, 2002). Also at that time, the Uraltau ridge started to grow, shedding coarse terrigenous material into two flysch troughs to the east and west. From the beginning of the Famennian, the flysch included heavy metamorphic minerals, diagnostic of the Maksyutovo metamorphic complex, composing a part of the Uraltau uplift (Willner *et al*., 2002). The F-F boundary was a time of a rapid exhumation of this complex, which primarily was formed at a depth of several tens of kilometres. In contrast, near the F-F boundary, the typical subductional calc-alkaline arc volcanism acquired a tendency to higher alkalinity, indicating a deepening of the melting source area in the mantle. An *ad hoc* explanation for this paired phenomenon, given by V. Puchkov, is as follows. At the F-F boundary the process of subduction of the passive continental margin of Laurussia under the Magnitogorsk island arc came to its logical end: the subduction zone jammed and subduction stopped. As a result, the subducted slab was broken: its light, boyant continentalward part was uplifted, resulting in exhumation of the high-pressure Maksyutovo metamorphic rocks, while the oceanward, dense part started to sink to a greater depth, which resulted in melting of more alkaline magmas instead of the normal calc-alkaline ones characteristic of the previous stage. Analogous magmatic phenomenon is characteristic of the Tagil arc in the Early Devonian.

On a global scale, the F-F boundary falls within the time span of widely developed effects of dissipated rifting and basalt magmatism (Veimarn and Milanovski, 1990), described as manifestations of a mantle superplume activity (Nikishin, 2002; Veimarn *et al*., 2002*a*; Courtillot and Renne, 2003). The result of this event was Middle-Late Devonian rifting and the formation of unique deposits, exemplified by the Khibiny apatite and REE-rich deposits of the Kola Peninsula, the Fe-Mn and Ba-polymetallic deposits of Kazakhstan, and the kimberlites of Yakutia and Archangelsk. The peak of intensity of these catastrophic geological phenomena falls near the F-F boundary, underlined by a global transgression and followed by regression, when there may have been a pulse of maximum degassing of the Earth's core (Veimarn *et al*., 1998). Certainly both regional and global scale phenomena were active in the Southern Urals.

The geological events at the F-F boundary in the western part of the Southern Urals were not greatly influenced by collisional tectonic processes and are much better correlated with the Polar Urals in the Syviu River section (Yudina *et al*., 2002). Notwithstanding the fact that this section is situated 1500 km to the north, it belongs to the same basin and is a part of the same great Belsk–Elets structural-facies zone as the Zilim–Zigan zone (sections I and II of Figs. 1 and 2). The geochemical anomalies established at the F-F boundary in the Syviu section are coeval with the volcanic manifestations in the Southern Urals, while a $\delta^{13}C$ (+ 3.5‰) positive anomaly is traced at this level in most regions of the globe (Joachimski *et al*., 2002). This anomaly may be partly linked with the influence of volcanism, although numerous other factors, e.g., climate and land area changes, intensity of carbonate weathering fluctuations, development of continental plant life, intensity of organic matter burial during the anoxic Kellwasser events may have affected carbon isotope balance (Godderis and Joachimski, 2004).

MARINE ANOXIA

The Kellwasser anoxic facies, which are typically developed as two thin, bituminous limestone horizons in age-equivalent Frasnian sequences elsewhere (Walliser, 1996), including the Polar Urals (Yudina *et al*., 2002), are poorly developed in the Southern Urals. This is in part due to the frequent hiatuses at the level of the *linguformis* Zone. Bituminous facies are notably preserved in the uppermost Frasnian of the Lemezinsky section; like the Syviu River area studied by Yudina *et al*. (2002), this belongs to the Belsk–Elets zone. Upper Frasnian black shale and chert are also present in the upper part of the Mukas Formation, and partly in the Eginda and Ibragimovo formations.

CONCLUSIONS

The conodont-based biostratigraphic correlation of upper Frasnian and Famennian sections in the Southern Urals supports the concept of the general world-wide regression near the Frasnian-Famennian mass extinction boundary (*cf*. Johnson *et al*., 1985). The maximum of sea level fall, corresponding to the *triangularis* zones, is recorded as frequent hiatuses. Progress in dating has enabled reasonable exact palaeogeodynamic reconstructions and constraints on the timing of Late Devonian volcanic events. The beginning of specific ultra-potassic mantle volcanism was within the *linguiformis* Zone. The F-F transition was a time of exhumation of high-pressure low-temperature metamorphic rocks, intense olistostrome formation and an onset of flysch deposition.

Many of these geological events in the Southern Urals do not require a global mechanism, as they are readily explained by specific features of collision and a break-off of a subducting slab under the Magnitogorsk island arc. On the other hand, the idea of mantle superplume activity on a wider and longer scale, recorded in the time span of the Middle Devonian–Early Carboniferous on the East European Platform, Siberia, Kazakhstan, Gondwana and even Southern China cannot be excluded (see Veimarn and Milanovski, 1990; Nikishin, 2002; Veimarn *et al*., 2002*a*, *b*; Courtillot and Renne, 2003). The interaction and interference of the plate-tectonic and plume-tectonic processes (Puchkov, 2003) is well documented.

Acknowledgements. We thank G. Racki, the initiator of this publication, for his suggestions regarding the structure of this paper. We also thank D. J. Over for comments, suggestions and for improving the English text, and M. Narkiewicz for editorial comments. This work has been supported by the "Nauchnye Shkoly" NSh-326.2003.5 and RFBR 04-05-64503 programmes.

REFERENCES

ABRAMOVA A. N. (1999) — Franskiy yarus zapadnogo sklona Yuzhnogo Urala. IGG Ufimsky Nauchny Tcentr Ros. Acad. Nauk. Ufa.

ABRAMOVA A. N. and ARTYUSHKOVA O. V. (2002) — On the Frasnian/Famennian boundary in different facies on the western slope of the South Urals. In: Geology of the Devonian System. Proc. Internat. l Symp. Syktyvkar, Komi Republic: 126–130.

ABRAMOVA A. N. and ARTYUSHKOVA O. V. (2004) — The Frasnian-Famennian boundary in the Southern Urals. Geol. Quart., **48** (3): 217–232.

ABRAMOVA A. N., MASLOV V. A., ARTYUSHKOVA O. V. and BARYSHEV V. N (1998) — O nizhney granitse zilairskoy svity v razreze u d. Yaumbaevo. The Year-book 1996: 32–34. IGG Ufimsky Nauchny Tcentr Ros. Acad. Nauk. Ufa.

ARTYUSHKOVA O. V. and MASLOV V. A. (1998) — Paleontologicheskoye obosnovaniye stratigraficheskovo raschleneniya dofamenskikh vulkanogennykh kompleksov Verkhneuralskogo i Magnitogorskogo raiyonov. IGG Ufimsky Nauchny Tcentr Ros. Acad. Nauk. Ufa.

AKHMETSHINA L. Z., KONONOVA L. I. and KOROBKOV V. F. (2002) — Ob"yom famenskogo yarusa po konodontam na Yuzhnom Urale: 134–136. Syktyvkar. Geoprint.

ARZHAVITINA M. Yu. (1976) — The subdivision of the Zilair Formation of the Magnitogorsk Synclinorium by mineral components. Dok. Acad. Sc. USSR, **229** (3): 679–682.

AVDONIN V. V., ZAKHAROVA E. M. and YAKOVLEV G. F. (1968) — Ashchebutaksky rudnyy rayon. In: Palaeozoic Volcanism and Pyritic Deposits of the Southern Urals (ed. G. F. Yakovlev): 146–176. Moscow State Univ.

BEGUCHEV V. A. (1972) — Nizhnefamenskaya flora basseyna r. Suunduk (vostochny sklon Yuzhnogo Urala). Voprosy geologii Yuzhnogo Urala i Povolzhya, **8** (1): 3–7. Saratov Univ.

BELYAEVA N. V. (2000) — Model' sedimentatsyi fransko-turneyskikh otlozheniy na severo-vostoke Evropeyskoy platformy. Ph. D. thesis. Moskva.

BELYAEVA N. V. and STASHKOVA E. K. (1999) — A model of sedimentation of the Frasnian-Tournaisian sediments of the Kalinin basin in the system of Kama-Kinel troughs. IGG Ural. Otdel. Ros. Acad. Nauk. Ekaterinburg.

BIOSTRATIGRAFIYA POGRANICHNYKH OTLOZHENIY DEVONA I KARBONA (K KHARAKTERISTIKE POGRANICHNYKH OTLOZHENIY DEVONA I KARBONA MUGODZHAR) (1983) — Far East Sc. Cent., Acad. Sc. USSR. Magadan.

BOGOSLOVSKY B. I. (1971) — Devonian ammonoids. II. Goniatites. Trudy PIN, 127. Nauka. Moskva.

BOCHKAREV V. V. and YAZEVA R. G. (2000) — Subshchelochnoy vulkanizm Urala. IGG Ural. Otdel. Ros. Acad. Nauk. Ekaterinburg.

COURTILLOT V. E. and RENNE P. R. (2003) — On the ages of flood basalt events. C. R. Geosc., **335**: 113–140.

DEGTYAREV K. E., ARISTOV V. A. and STEPANOVA M. M. (2000) — The Upper Devonian cherty-tuffaceous-terrigenous Transuralian complexes. General and regional problems of geology, **2**. GEOS. Moskva.

FAUNA AND BIOSTRATIGRAPHY OF DEVONIAN-CARBONIFEROUS BOUNDARY SEDIMENTS OF THE BERCHOGUR (MUGODZHARS) (1987) — Nauka. Moskva.

GODDERIS Y. and JOACHIMSKI M. M. (2004) — Global change in the Late Devonian: modelling the Frasnian-Famennian short-term carbon isotope excursions. Palaeogeogr., Palaeoclimat., Palaeoecol., **202**: 309–329.

GOSUDARSTVENNAYA GEOLOGICHESKAYA KARTA ROSSIYSKOY FEDERATSYI MASSHTABA 1:200 000 (in press, the second edition) — The South-Urals series, sheet N-40-XXIV. An explanatory note (eds. V. M. Mosejchuk, A.V. Yarkova *et al.*).

ILYINSKAYA M. N. (1980) — On the sandstone composition of the Zilair series in the Southern Urals. Lithol. and Raw Mater., **6**: 32–44.

IVANOV K. S. (1989) — K stratigrafii kremnistyh porod Zaural'skoy zony. In: New Data on Geology of the Urals and Middle Asia: 20–36. IGG Ural. Otdel. Ros. Acad. Nauk. Sverdlovsk.

IVANOV K. S., PUCHKOV V. N. and PELEVIN I. A. (1992) — Novye dannye po stratigrafii i istorii razvitiya paleozoid vostochnykh zon Yuzhnogo Urala. In: Novye dannye po stratigrafii i litologii Urala i Sredney Azii: 3–10. Nauka. Ekaterinburg.

IVANOV K. S., PUCHKOV V. N. and PELEVIN I. A. (1996) — K geologii Ushchel'skikh gor Yuzhnogo Urala. Year-book 1995: 40–45. IGG Ural. Otdel. Ros. Acad. Nauk. Ekaterinburg.

IVANOV K. S., PILOSOVA O. E., PELEVIN I. A. and BIKBAEV A. Z. (1998) — "Pelel'chatye" izvestnyaki verkhnego devona na vostoke Urala. Year-book 1997: 37–40. IGG Ural. Otdel. Ros. Acad. Nauk. Ekaterinburg.

JOACHIMSKI M. M., PANCOST R. D., FREEMAN K. H., OSTERTAG-HENNING C. and BUGGISCH W. (2002) — Carbon isotope geochemistry of the Frasnian/Famennian transition. Palaeogeogr., Palaeoclimat., Palaeoecol., **181**: 91–110.

JOHNSON J. G., SANDBERG C. A. and KLAPPER G. (1985) — Devonian eustatic fluctuation in Euroamerica. Bull. Geol. Soc. Am., **96** (5): 567–586.

KELLER B. M. (1949) — Flishevaya formatsiya paleozoya v Zilairskom sinklinoriy na Yuzhnom Urale i skhodnye s nei obrazovaniya. Izd. Akad. Nauk SSSR. Moskva.

KONONOVA L. I. (1979) — Znachenie konodontov dlya stratigrafii famenskikh i turneyskikh otlozheniy Urala. In: Konodonty Urala i ikh stratigraficheskoe znachenie: 72–93. IGG Ural. Otdel. Ros. Acad. Nauk. Sverdlovsk.

KOCHETKOVA N. M., LUTFULLIN J. L., PAZUKHIN V. N. and ARZHAVITINA M. Yu. (1980) — Novye materialy k stratigrafii pogranichnykh otlozheniy devona i karbona rayona g. Verkhneural'ska. In: Stratigrafiya i paleontologiya paleozoya Yuzhnogo Urala: 26–33. IGG Bashkirian Otdel. USSR. Acad. Nauk. Ufa.

KOCHETKOVA N. M., PAZUKHIN V. N., REJTLINGER E. A. and SINITSYNA E. A. (1985) — Opornye razrezy pogranichnykh otlozheniy devona i karbona zapadnogo sklona Yuzhnogo Urala. North-East Complex Inst., Far East Sc. Cent., Ac. Sc. USSR. Magadan.

LEGENDA YUZHNOURAL'SKOY SERII LISTOV GOSGEOLKARTY RF MASSHTABA 1:200 000 (1998, the second edition) — All Russian Geological Inst. St. Petersburg.

MASLOV V. A. and ARTYUSHKOVA O. V. (2000) — Stratigrafiya paleozoyskikh obrazovaniy Uchalinskogo rayona Bashkirii. IGG Ufimsky Nauchny Tcentr Ros. Acad. Nauk. Ufa.

MASLOV V. A. and ARTYUSHKOVA O. V. (2002) — Stratigrafiya i korrelyatsiya devonskikh otlozheniy Sibay-Baymakskogo rayona Bashkirii. IGG Ufimsky Nauchny Tcentr Ros. Acad. Nauk. Ufa.

MASLOV V. A., ARTYUSHKOVA O. V. and NURMUKHAMETOV E. M. (1999) — Franskiye otlozheniya Magnitogorskogo megasinklinoriya. IGG Ufimsky Nauchny Tcentr Ros. Acad. Nauk. Ufa.

MASLOV V. A., CHERKASOV V. L., TISHCHENKO V. T. *et al*. (1993) — Stratigrafiya i korrelyatsiya srednepaleozoyskikh vulkanogennykh kompleksov osnovnykh mednokolchedannykh rayonov Yuzhnogo Urala. IGG Ufimsky Nauchny Tcentr Ros. Acad. Nauk. Ufa.

MIZENS G. A. (2002) — Sedimentatsionnye baseiny i geodinamicheskiye obstanovki v pozdnem devone-rannei permi yuga Urala. IGG Ural. Otdel. Ros. Acad. Nauk. Ekaterinburg.

MIZENS G. A. (2004) — Devonian palaeogeography of the Southern Urals. Geol. Quart., **48** (3): 205–216.

MOSEYCHUK V. M. and SURIN T. N. (1998) — Famen-turneyskaya bazal't-pikritovaya (sara-tyubinskaya) tolshcha Vostochno-Magnitogorskoy zony Yuzhnogo Urala: geologiya, geokhimiya, mineralogiya i paragenezis. IGG Ufimsky Nauchny Tcentr Ros. Acad. Nauk. Ufa.

NIKISHIN A. M. (2002) — Tectonic conditions. Intraplate and marginal plate processes. Moscow State Univ.

PAZUKHIN V. N., PUCHKOV V. N. and BARYSHEV V. N. (1996) — Novye dannye po stratigrafii zilairskoy serii zapadnogo sklona Yuzhnogo Urala. Year-book 1995: 34–41. IGG Ufimsky Nauchny Tcentr Ros. Acad. Nauk. Ufa.

PAZUKHIN V. N., PUCHKOV V. N. and KULAGINA E. I. (1998) — Novye dannye po stratigrafii kamennougol'nykh i pogranichnykh s nimi otlozheniy v rayone avtodorogi Ufa-Beloretsk. In: Nedra Bashkortostana. The Reports of the Branch of Earth Sciences and Environment Problems: 39–40. Acad. Sc. Bashkortostan Rpb. Ufa, Gilem.

PUCHKOV V. N. (1979) — Nakhodki devonskikh konodontov na zapadnom sklone Urala i ikh znachenie dlya strtigrafii paleozoya lemvinskogo tipa. In: Konodonty Urala i ikh stratigraficheskoe znachenie: 33–51. IGG Ural. Otdel. Ros. Acad. Nauk. Sverdlovsk.

PUCHKOV V. N. (2000) — Paleogeodinamika Yuzhnogo i Srednego Urala. Ufa. Dauriya.

PUCHKOV V. N. (2002) — Palaeozoic evolution of the East European continental margin involved in the Uralide orogeny. In: Mountain Building in the Uralides: Pangea to the Present (eds. D. Brown, C. Juhlin and V. Puchkov). AGU Geophys. Monogr. Ser., **132**: 9–31.

PUCHKOV V. N. (2003) — Plume and plate-tectonic mechanisms: mutual influence, interference, interaction and intertwining. Geophys. Res. Abstracts, EUG-EGS-AGU Assembly, Nice, **5**: 14251.

PUCHKOV V. N., BARYSHEV V. N. and PAZUKHIN V. N. (1998) — Novye dannye po stratigrafii terrigenno-kremnistogo devona na zapadnom sklone Bashkirskogo Urala. Year-book 1996: 24–31. IGG Ufimsky Nauchny Tcentr Ros. Acad. Nauk. Ufa.

PUCHKOV V. N. and IVANOV K. S. (1987) — K stratigrafii verkhnedevonsko-nizhnekamennougol'nykh tolshch Sakmarskoy zony. In: Novye dannye po geologii Urala: 84–93. IGG Ural. Otdel. Ros. Acad. Nauk. Sverdlovsk.

PERNA E. Ya. (1914) — Ammonoidea of the Upper Neo-Devonian of the eastern slope of the Urals. Transactions of the Geological Committee, New Ser., **99**.

RIKHTER Ya. A. (1968) — Devonskie otlozheniya verkhovyev r. Karaganki na vostochnom sklone Yuzhnogo Urala. In: Voprosy geologii Yuzhnogo Urala i Povolzhya. Saratov Univ., **3** (4): 101–116.

RIKHTER Ya. A. (1989) — Paleozoyskiy vulkanizm i geodinamika Yuzhnogo Urala. Ph. D thesis. IGG Ural. Otdel. Ros. Acad. Nauk. Sverdlovsk.

ROZMAN H. S. (1962) — Stratigrafiya i brahiopody famenskogo yarusa Mugodzhar i smezhnykh rayonov. USSR Acad. Nauk. Moskva.

RYAZANTSEV A. V., DUBININA S. V. and IVANOVA E. A. (2000) — Devonskie olistostromy i tektonicheskie pokrovy v Sakmarskoy zone

Urala i problemy vulkanogennogo kembriya. In: Obshchie voprosy tektoniki. Tectonics of Russia. GEOS. Moskva.

SALIKHOV D. N., YARKOVA A. V., SALIKHOVA R. N. and MOSEYCHUK V. M. (1987) — Vulkanizm pozdnego devona Magnitogorskogo megasinklinoriya (geologiya, petrokhimiya, geohimiya). Bashkirian Otdel. USSR Acad. Nauk. Ufa.

SANDBERG C. A. and ZIEGLER W. (1996) — Devonian conodont biochronology in geologic time calibration. Senckenbergiana lethaea, **76** (1/2): 259–265.

SMIRNOV G. A. and SMIRNOVA T. A. (1961) — Materialy k paleogeografii Urala. In: Ocherk III. Famensky vek. Trudy Geol. and Geophys. Inst., Ural. Odtel. USSR Acad. Nauk., **60**.

STRATIGRAFICHESKIE SKHEMY URALA (DOKEMBRIY, PALEOZOY) (1993) — Ekaterinburg.

TEVELEV Al. B. and KOSHELEVA I. A. (2002) — Geologicheskoe stroenie i istoriya razvitiya Yuzhnogo Urala (Vostochno-Ural'skoe podnyatie i Zaural'e). Moscow State Univ.

TCHIBRIKOVA E. V. (1997) — The age and subdivision of the Zilair sediments of the Urals. Domestic geology, **11**: 31–35.

VEIMARN A. B. and MILANOVSKY E. E. (1990) — Famennian riftogenesis in Kazakhstan and other regiones of Eurasia. Biul. Mosk. Obsch. Ispyt. Prirody, Otd. Geol., **65** (4): 34–47 (1), (6): 9–23 (2).

VEIMARN A. B., KUZ'MIN A. V., KONONOVA L. J., BARYSHEV V. N. and VORONTZOVA T. N. (1997) — Geological events at the Frasnian/Famennian boundary on the territory of Kazakhstan, Urals and adjacent regions of the Russian Plate. Cour. Forsch.-Inst. Senckenberg, **199**: 37–50.

VEIMARN A. B., NAYDIN D. P., KOPAEVICH L. F., ALEXEEV A. S. and NAZAROV M. A. (1998) — Metody analiza global'nykh stratigraficheskikh sobytiy pri detal'nykh issledovaniyakh. Metodicheskie rekomendatsyi. Moscow State Univ.

VEIMARN A. B., TEVELEV A. V. and DEGTYAREV K. E. (2002*a*) — The Late Devonian global riftogenesis and its display in the Urals. In: Rifts of the Lithosphere: Evolution, Tectonics, Magmatic, Methamorphic and Sedimentary Complexes, Minerals. Mat. Internat. Sc. Conference (VIIIth A. N. Zavaritsky Conference): 76–97. IGG Ural. Otdel. Ros. Acad. Nauk. Ekaterinburg.

VEIMARN A. B., ABRAMOVA A. N., ARTYUSHKOVA O. V., BARYSHEV V. N., DEGTYAREV K. E., KONONOVA L. I., MASLOV V. A., MOSEICHUK V. M., PAZUKHIN V. N., PUCHKOV V. N., TEVELEV A. V., SCHMELEV I. V. and YARKOVA A. V. (2002*b*) — Correlation of the Famennian sections of Southern Urals (in Russian with English summary). Bull. MOIP. Otdel Geologii, **77** (1): 32–42.

WALLISER O. H. (1996) — Global events in the Devonian and Carboniferous. In: Global Events and Event Stratigraphy in the Phanerozoic (ed. O. H. Walliser): 225–250. Springer Verlag, Berlin.

WILLNER A. P., ERMOLAEVA T., PUCHKOV V., ARZHAVITINA M. Yu. and GOROZHANINA Y. (2002) — Surface signals of an arc-continent collision: the detritus of the Upper Devonian Zilair Formation in the Southern Urals, Russia. In: Mountain Building in the Uralides: Pangea to the Present (eds. D. Brown, C. Juhlin and V. Puchkov). AGU Geophys. Monogr. Ser., **132**: 183–210.

YAZEVA R. G. and BOCHKAREV V. V. (1998) — Geology and geodynamics of the Southern Urals (in Russian with English summary). IGG Ural. Otdel. Ros. Acad. Nauk. Ekaterinburg.

YAKUPOV R. R., MAVRINSKAYA T. M and ABRAMOVA A. N. (2002) — Paleontologicheskoe obosnovanie skhem stratigrafii paleozoya severnoy chasti Zilairskogo megasinklinoriya. Year-book 1996: 24–31. IGG Ufimsky Nauchny Tcentr Ros. Acad. Nauk. Ufa.

YUDINA A. B., RACKI G., SAVAGE N. M., RACKA M. and MAŁKOWSKI K. (2002) — The Frasnian-Famennian events in a deep-shelf succession, Subpolar Urals: biotic, depositional and geochemical records. Acta Palaeont. Pol., **47** (2): 355–372.

YURINA A. L. (1988) — Flora srednego i pozdnego devona Severnoy Evrazii. Nauka. Moskva.