ISSN 1028-334X, Doklady Earth Sciences, 2017, Vol. 477, Part 1, pp. 1348–1352. © Pleiades Publishing, Ltd., 2017.
Original Russian Text © A.S. Biakov, N.A. Goryachev, I.L. Vedernikov, I.V. Brynko, E.V. Tolmacheva, 2017, published in Doklady Akademii Nauk, 2017, Vol. 477, No. 3, pp. 335–340.

GEOCHEMISTRY

New Results of U–Pb SHRIMP Dating of Zircons from Upper Wuchiapingian (Upper Permian) Deposits in Northeastern Russia

A. S. Biakov[a,b,c,*], **Corresponding Member of the RAS N. A. Goryachev**[a], **I. L. Vedernikov**[a], **I. V. Brynko**[a], **and E. V. Tolmacheva**[d]

Received January 31, 2017

Abstract—The first results are presented for U-Pb SHRIMP-II dating of zircons from the upper part of the Khivachian regional horizon (stage) of the Regional Stratigraphic Scale (RSS) of the Permian in northeastern Russia. The obtained isotope age of 255 ± 2 Ma is close to that of the present boundary between the Wuchiapingian and Changhsingian stages of the Permian system in the International Stratigraphic Scale (254.1 Ma). Based on the distribution of bivalves—*Intomodesma* spp. and *Claraioides* aff. *primitivus* (Yin)—in the sections considered, their relations to the stratigraphic positions of the samples considered and dated formerly, and in view of the interregional correlation of recent $\delta^{13}C_{org}$ data for clayey rocks, one may assume with certainty that most of the regional zone of *Intomodesma costatum* corresponds to the upper part of the Wuchiapingian stage. Here, the Changhsingian stage in northeastern Asia complies only with the uppermost part of this zone within the *I. postevenicum* subzone and, partially, of *Otoceras* layers within the *Otoceras concavum* zone.

DOI: 10.1134/S1028334X17110186

The correlation of Upper Permian deposits in northeastern Asia to the stages of the International Stratigraphic Scale (ISS) for the Permian system is one of the most intractable current problems of stratigraphy of the region. In solving this problem, a considerable role is played by the SHRIMP and TIMS techniques for absolute geochronological dating of zircons from tuff interlayers [1–3].

In this respect, the most promising are the sections containing sedimentation-synchronous tuffs of the Okhotsk, Ayan-Yuryakh, and Balygychan back-arc basins of the Okhotsk–Taigonos volcanic arc. The authors had formerly explored here the continuous Permian sections characterized well by fossil fauna. Some of the sections are typical for the zonal succession of bivalves revealed based upon the evolution of the representatives of two genera of *Inoceramus*-like bivalves: *Maitaia* and *Intomodesma* [4]. Hence, the dating, calibration, and correlation of the bivalve zones distinguished are important for solving the problem of the correlation of Upper Permian deposits in the region as a whole.

The authors have recently obtained substantial dating of isotope ages for the bottom part of the Khivachian regional horizon of the Upper Permian system in northeastern Asia [2]. The age came to 257 ± 3 Ma and corresponded to the lower part of the Wuchiapingian stage by the ISS. Moreover, two significant dates were obtained in parallel by the CA-IDTIMS technique at Boise State University (United States) for the samples for the upper part of the Gizhigian and the lower part of Khivachian regional strata (260.16 ± 0.4 and 258.14 ± 0.2 Ma, respectively) [3].

The present report considers the results of U–Pb SHRIMP II dating of zircons from the 3-cm interlayer of median-composition tuff from the section of the lower part of the Pautovaya series that we described formerly [5] (the upper part of the Khivachian regional horizon by the RSS of the Permian system in northeastern Russia).

The Pautovaya Formation of about 170 m in thickness in the section considered (Fig. 1) is presented by schistose mainly dark-gray to black silty argillites almost without lamination. The lower part contains interlayers (to 10 cm) of gray and light gray horizontally, lenslike, and obliquely laminated fine-grained feldspar–lithic sandstones and siltstones. Rare inter-

[a] *North-East Interdisciplinary Scientific Research Institute, Far East Branch, Russian Academy of Sciences, Magadan, 685000 Russia*
[b] *Kazan (Volga region) Federal University, Kazan, 420008 Russia*
[c] *North-Eastern State University, Magadan, 685000 Russia*
[d] *Institute of Precambrian Geology and Geochronology, St. Petersburg, 199034 Russia*
**e-mail: abiakov@mail.ru*

Table 1. Results of local U–Pb analyses of zircon from the tuff of the Pautovaya Formation

Grain nos.	$^{206}Pb_c$, %	U	Th	$^{232}Th/^{238}U$	$^{206}Pb^*$, ppm	Age, Ma, $^{206}Pb/^{238}U$		$^{207}Pb^*/^{235}U$	±%	$^{206}Pb^*/^{238}U$	±%	err corr
		ppm										
1	0.54	148	134	0.93	5.18	255	±2.7	0.272	6.6	0.0404	1.1	.166
2	1.00	70	135	1.99	2.41	251	±4.1	0.263	12	0.0396	1.6	.142
3	0.00	130	54	0.43	37.1	1854	±11	5.221	1.2	0.3331	0.7	.587
4	1.50	63	80	1.32	2.26	260	±4.9	0.247	20	0.0412	1.9	.098
5	0.28	35	22	0.65	10.1	1879	±22	5.33	2.7	0.3385	1.3	.496
6	0.00	62	98	1.64	2.17	258	±3.7	0.307	5.8	0.0409	1.4	.247
7	0.00	87	148	1.75	2.94	251	±3.7	0.335	12	0.0397	1.5	.126
8	0.00	23	37	1.66	0.786	254	±5.1	0.291	7.5	0.0401	2.0	.271
9	0.84	120	61	0.52	4.16	254	±3	0.285	9.5	0.0401	1.2	.125
10	1.20	82	81	1.02	2.85	252	±3.7	0.281	13	0.0399	1.5	.111
11	0.75	96	114	1.23	3.26	249	±3.1	0.262	9	0.0393	1.3	.139
12	1.87	34	14	0.43	1.17	252	±5	0.232	23	0.0398	2.0	.089
13	0.47	167	262	1.62	5.89	258	±2.1	0.268	5.6	0.0408	0.8	.148
14	0.00	295	142	0.50	82.9	1823	±8	5.008	0.93	0.3269	0.5	.539
15	0.00	177	120	0.70	6.23	259	±2.1	0.2892	3.4	0.0411	0.8	.244

The analysis point numbers coincide with those of grains; the errors are for 1σ range; Pb_c and Pb* are nonradiogenic and radiogenic lead, respectively; 1σ is the standard calibration error (0.29%); isotope ratios are corrected by the measured ^{204}Pb.

layers (1–3 cm) of gray and light gray litho-crystalloclastic tuffs of median composition are found. The sample for SHRIMP dating of zircons was collected from one of these layers at 58 m above the series basement (sample 5c/AB-16, 62°03′21.1″ N, 151°51′52.4″ E).

The fossil fauna at the lower part of the formation is represented by bivalves *Intomodesma* sp. indet., *I.* ex gr. *costatum* Popow, and gastropods *Straparolus* sp. Bivalves *Intomodesma postevenicum* Biakov and gastropods *Straparolus* sp. were found in the formation roof. These fossils allow us to ascribe the Pautovaya Formation to the top of the upper half of the Khivachian regional horizon in northeastern Russia (the Intomodesma costatum bivalve Zone) and to correlate the formation with the upper part of the Wuchiapingian and the lower part of the Changhsingian stages of the ISS [5–7]. The Pautovaya Formation is overlapped with gradual transition by the Gherba Formation. Late Changhsingian bivalve *Claraioides* aff. *primitivus* (Yin) was found at the base of the Gherba Formation [6]. The position of the modern Permian–Triassic boundary is assumed in the lower part (about 20 m above the base) of the Gherba formation on the basis of a characteristic negative excursion of the isotope $\delta^{13}C_{org}$ value in clayey rocks [8].

The sample selected for the separation of zircons consisted of highly modified litho-crystalloclastic median-composition tuff of thin horizontal layering (1–2 mm). The crystalloclasts of 0.2–0.3 mm in size constituting about 50% of the rock volume are presented by quartz and pelitized feldspar fragments. The lithoclasts of 0.5–0.7 mm in size are transformed into the pelitized matrix and presented by fragments of effusive rocks of median composition.

The zircons were separated using the standard procedure by means of heavy liquids. The zircons were examined by optic techniques with a Leica DMLP microscope at magnifications up to 1200×; the features of zircon morphology and inner structure were revealed in transmitted and reflected light, as well as under the conditions of cathode luminescence (Fig. 2). The inclusions of mineral-forming matter in zircons were also explored (Fig. 3).

The geochronology of separated zircons was studied at the Isotope Research Center under the Russian Geological Research Institute (St. Petersburg) by secondary-ion mass spectrometry (SIMS) on a SHRIMP II ion microprobe of high spatial resolution using the standard analytical procedures [9]. The results obtained were plotted into concordia diagrams using the Isoplot software [10].

To study the geochronology, 15 of 19 separated zircon grains were selected (Table 1) which were distinctly subdivided into two age groups: 12 and 3 grains of the first and the second group, respectively. Both the edge (predominantly) and central parts of the grains were treated.

The first group of zircons (grains 1.1, 2.1, 4.1, 6.1–13.1, and 15.1) is presented by a unified population of 255 ± 2.0 Ma in age (Fig. 4). The zircons are colorless, the idiomorphic faces of crystals are not smoothed, and the crystal surfaces sometimes show a trace of very

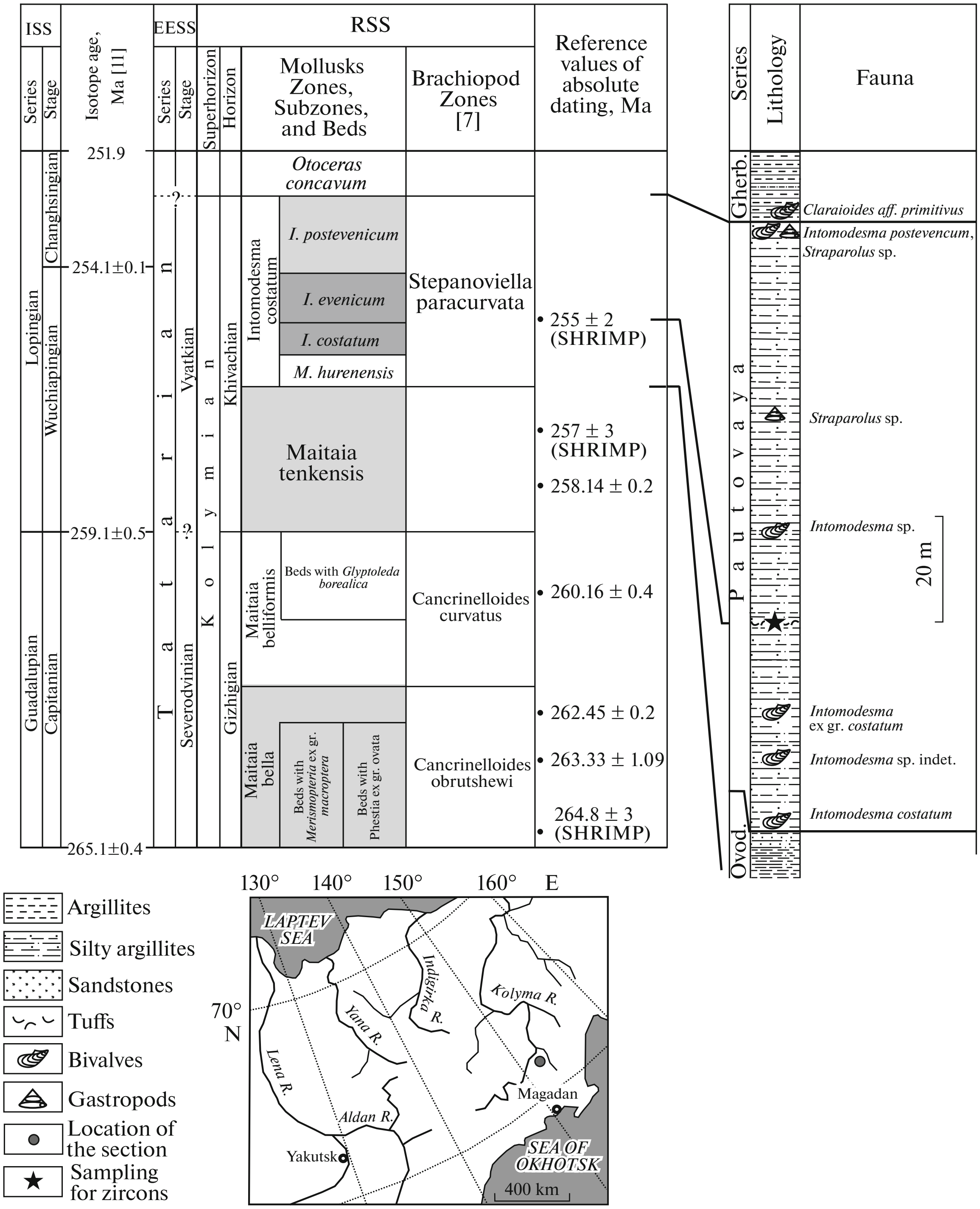

Fig. 1. Location of the section considered in northeastern Russia with correlation to regional, East-European, and international stratigraphic scales of the Permian system. Gherb. is the Gherba Formation; ISS, EESS, and RSS are the international, and regional stratigraphic scales, respectively.

weak corrosion. The length of crystals varies within 150–200 μm, and the elongation coefficient varies from 2 to 4. The zircons contain numerous melt, crystalline, and fluidal inclusions testifying to the magmatic genesis (see Fig. 3). The melt inclusions are presented by droplike isolates of partially decrystallized glass; the crystalline and fluidal inclusions are constituted of apatite and carbon dioxide, respectively. The occurrence of melt vitreous inclusions in zircons testifies uniquely to their igneous nature. A trend toward

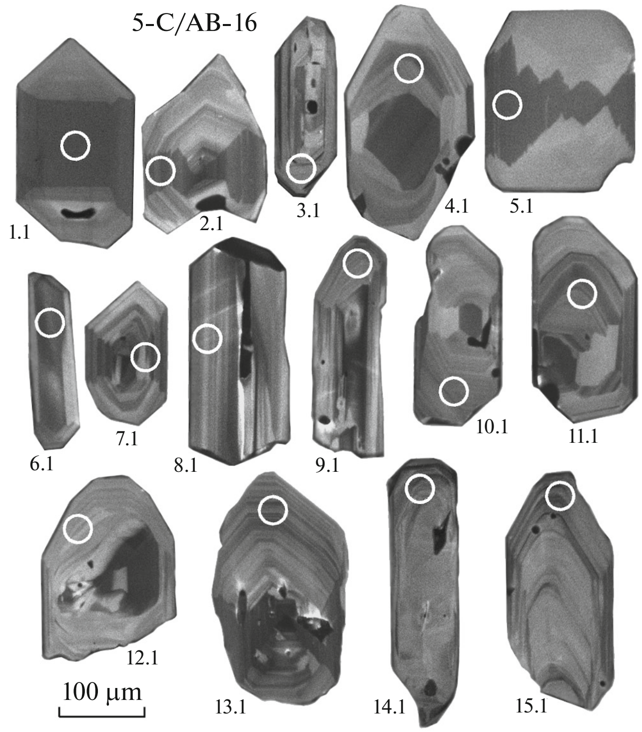

Fig. 2. Cathode-luminescent images of zircons from tuff of the Pautovaya Formation. The point numbers coincide to those in Table 1.

enrichment of the central parts of zircon crystals in inclusions is seen, with quite small amounts at the peripheries. Hence, the crystallization of zircons was fast at the initial step (probably when magma rose) and slow later on. The zircons contained 23–177 μg/g of U and 14–262 μg/g of Th, with a Th/U ratio of 0.43–1.99.

Zircons of the second group (grains 14.1, 3.1, and 5.1) are of the ages from 1818 ± 14 to 1868 ± 42 Ma. These zircons are of a light gray color and subidiomorphic habit, but with smoothed faces and signs of more intense corrosion of the surface. The outgrowths of the zircons of the first group are sometimes seen on the faces of bipyramids of zircons of the second group (grain 3.1). The dimensions are similar for zircons of both the first and second groups. The zircons contain rare melt (almost completely decrystallized) inclusions pointing to their intrusive and probably hypabyssal nature. These zircons contain 35–295 μg/g of U and 22–142 μg/g of Th; the Th/U ratio is within 0.43–0.65.

Under the conditions of cathode luminescence (see Fig. 2), all the zircons show magmatic zonality and moderate glow. Sectorial zonality is sometimes seen in zircons of both groups. Zircons of the first group are characterized by coarse and fuzzy magmatic zonality; those of the second group show thinner and more constant patterns.

The obtained isotope age of 255 ± 2 Ma is in good agreement with the stratigraphic position of the sample and with formerly obtained dates by CA–IDTIMS (260.16 ± 0.4 and 258.14 ± 0.2 Ma) and SHRIMP II (257 ± 3 Ma) for lower stratigraphic levels of the Khivachian regional horizon. The obtained age (255 ± 2 Ma) is close to that of the present boundary of the Wuchiapingian and Changhsingian stages of the Permian system by the ISS (254.1 ± 1 Ma) [11].

Based on the distribution of the remains of bivalves—*Intomodesma* and *Claraioides* aff. *primitivus* (Yin)—in the sections considered, the relationship to the stratigraphic positions of the dated samples, along with the interregional correlation of the recently

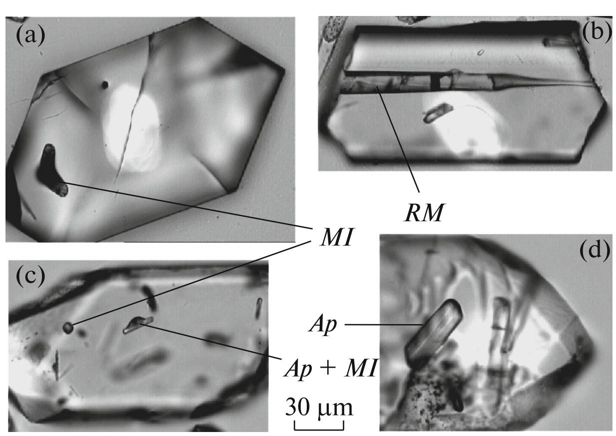

Fig. 3. The inclusions in zircons from the sample 5-C/AB of tuff of the Pautovaya Formation: *Ap* is apatite inclusion in a zone of zircon growth; *Ap* + *MI* is the inclusion of apatite (*Ap*) with a “sticking” melt inclusion (*MI*); *RM* is residual melt permeating along the crystal axis; and *MI* are primary melt inclusions.

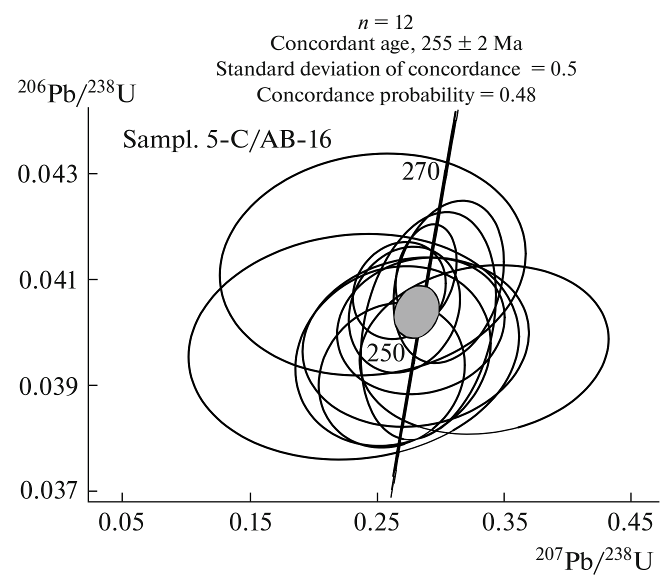

Fig. 4. Tera–Wasserburg diagram for the sample 5-C/AB of tuff of the Pautovaya Formation.

obtained record of $\delta^{13}C_{org}$ value in clayey rocks [8], one may assume with certainty that most of the *Intomodesma costatum* Zone (*Maitaia hurenensis*, *Intomodesma evenicum*, and *I. costatum* Subzones) corresponds to the upper part of the Wuchiapingian stage. The Changhsingian stage in northeast of Asia is correlated only with the uppermost part of the *Intomodesma costatum* Zone within the subzone of *I. postevenicum* and a part of *Otoceras* layers within the *Otoceras concavum* Zone (see Fig. 1).

Thus, the new data on U–Pb isotope dating of zircons allow us to date for the first time the upper part of the Khivach regional horizon by the RSS, as well as to perform anew and more substantially the correlation to the stages of the Permian system by the ISS.

ACKNOWLEDGMENTS

The authors are grateful to V.V. Akinin for his assistance in separating the zircons and for remarks in the course of writing. This study was supported by the Russian Foundation for Basic Research (project no. 17-05-00109) and by the Far East Branch of the Russian Academy of Sciences (project no. 17-I-1-021e), as well as according to the Russian Government Program of Competitive Growth of Kazan Federal University, and also at the expense of the subsidy allocated to the Kazan Federal University for the performance of the state task in the sphere of scientific activity no. 5.2192.2017/4.6. no. 5.2192.2017/4.6.

REFERENCES

1. V. I. Davydov, A. S. Biakov, J. L. Crowley, M. D. Schmitz, J. L. Isbell, and I. L. Vedernikov, Gondwana Res. **38**, 74–85 (2016).
2. A. S. Biakov, V. I. Shpikerman, I. L. Vedernikov, and E. V. Tolmacheva, Stratigr. Geol. Correl. **25** (3), 256–264 (2017).
3. V. I. Davydov, A. S. Biakov, M. D. Schmitz, and V. V. Silantiev, Earth-Sci. Rev. (2017) (in press).
4. A. S. Biakov, *Stratigr. Geol. Correl.* **15** (2), 161–184 (2007).
5. A. S. Biakov, *Permian Deposits of Balygychan Uplift* (Shilo North-Eastern Interdiscipl. Sci. Res. Inst. Far-Eastern Branch Russ. Acad. Sci., Magadan, 2004) [in Russian].
6. A. S. Biakov, Dokl. Earth Sci. **378** (4), 399–401 (2001).
7. V. G. Ganelin and A. S. Biakov, J. Asian Earth Sci. **26**, 225–234 (2006).
8. A. S. Biakov, M. Horacek, N. A. Goryachev, I. L. Vedernikov, and Yu. D. Zakharov, Dokl. Earth Sci. **474** (1), 591–594 (2017).
9. I. S. Williams, Rev. Econ. Geol. **7**, 1–35 (1998).
10. K. R. Ludwig, *User's Manual for Isoplot 3.00. A Geochronological Toolkit for Microsoft Excel. Berkeley Geochronological Center Special Publication No. 4* (Berkeley Geochronol. Center, Berkeley, CA, 2003), pp. 1–70.
11. "Permian Timescale," Permophiles **63**, 58 (2016).

Translated by A. Rylova