DOI 10.18454/PMI.2016.6.789

UDC 551.73:551.24

COMPOSITION, AGE AND TECTONIC MEANING OF GRANITE BOULDERS IN THE DEVONIAN CONGLOMERATES OF THE NORTH-WEST PART OF SPITZBERGEN

A.N.SIROTKIN[1], A.N.EVDOKIMOV[2]
[1] *Marine Arctic Geological and Prospecting Expedition JSC* (FSUE *MAGPE*), *City of Lomonosov*, *Russia*
[2] *Saint-Petersburg Mining University*, *Saint-Petersburg*, *Russia*

Identifying complexes of the early Proterozoic age in the composition of crystal foundation is a key task in studying pre-Cambrian formations of the whole of Spitzbergen and its northwestern part in particular. The territory of that region is formed by three deeply metamorphosed complexes that underwent the processes of migmatization and granitization in mid-Rifey and were broken through by granitoids of mid-Rifey and mid-Paleozoic. In their turn, the outbursts of the foundation are overlayed by terrigene rocks of the Devonian graben of Spitzbergen, conglomerates forming a large share among them. In the course of petrographic and chemical studies of such compositions, as well as isotopic characteristics of zircons from the boulders of basal conglomerates of Red Bay (D_1) series, the suite of Wolfberget at Cape Conglomeratodden the presence was identified of reddish (meat-red) granites of isotopic age of 1631±19 Mil years, which is comparable to late Karelian processes manifested actively across the archipelago. It is also proven that transformations of these rocks within the range of 380±42 Mil years are well associated with mid-paleozoic events, considerable restructuring of the foundation associated with them. The age range we defined is another proof of manifestation of early pre-Cambrian (late Karelian) processes in the northwestern Spitzbergen.
***Key words*:** zircon, absolute age, granitoid boulders, foundation, northwestern Spitzbergen.

How to cite this article: Sirotkin A.N., Evdokimov A.N. Composition, age and tectonic meaning of granite boulders in the devonian conglomerates of the north-west part of Spitzbergen. Zapiski Gornogo instituta. 2016. Vol. 222, p. 789-797. DOI 10.18454/PMI.2016.6.789

Introduction. Defining the age of forming of metamorphic complexes of northwestern Spitzbergen (NWS hereunder) is one of the main problems in geologic studies of the archipelago foundation. The initial assumption of Caledonian age of the regional metamorphism of these complexes [2, 12] was mainly based on the presence of reddish orogenic complex of Devonian graben, massifs of mid-Paleozoic granites, plus some scarce potassium-argon datings. S.A.Abakumov who gave many years of studies to that region has identified three series within its metamorphic complex: the lower-Proterozoic Smerenburg-Fjord, the Richarddalen and the Rifey Cross-Fjord [1], going by the differences in their composition and degree of metamorphism. Later isotopic techniques were used to demonstrate wide manifestations of the processes of mid-Rifey (Grenville) ultra-metamorphism in that region, observed, among other things, as bodies of anatectic granitoids (Fig. 1) [8]. Currently, wide use of zirconometry made it possible to identify a number of stages in tectonic-magmatic and tectonic-metamorphic activity in that region of the archipelago (AR_2 – PR_1 – R_2 – V – PZ_2), however no early Proterozoic rocks per se were found [6]. All the grains of zircon aged 1900-1650 Mil yr appear in association with grains (or rims) of other ages, which offers a reason to consider them detrital or scavenged [10, 11].

The only exclusion in that series is given by the age of pebbles and boulders of quartz porphyries in basal conglomerate of the Siktefjellet series (S_2-D_1) from the complex of the Devonian graben, that lay on the deeply metamorphosed rocks of the Richarddalen series. Fascial and lithologic characteristics of Siktefjellet series and the spatial localization of its outbursts make one claim that the carryover of material to form conglomerates and sandstones occurred from the west and north-west, that is from the side of anticlinoria elevation of NWS, while the mineral composition of these rocks points to their formation via the destruction of deeply metamorphosed rocks, according to our data. Taken together all that points to local origin of quartz porphyries that are native to this region. Therefore the age of about 1740 Mil yr [13] retrieved from the zircons of these rocks speaks unequivocally for the Karelian stage of foundation forming in this region. It is particularly important, since we are dealing not with hypothetic protolithic in this case, but with a certain specific material.

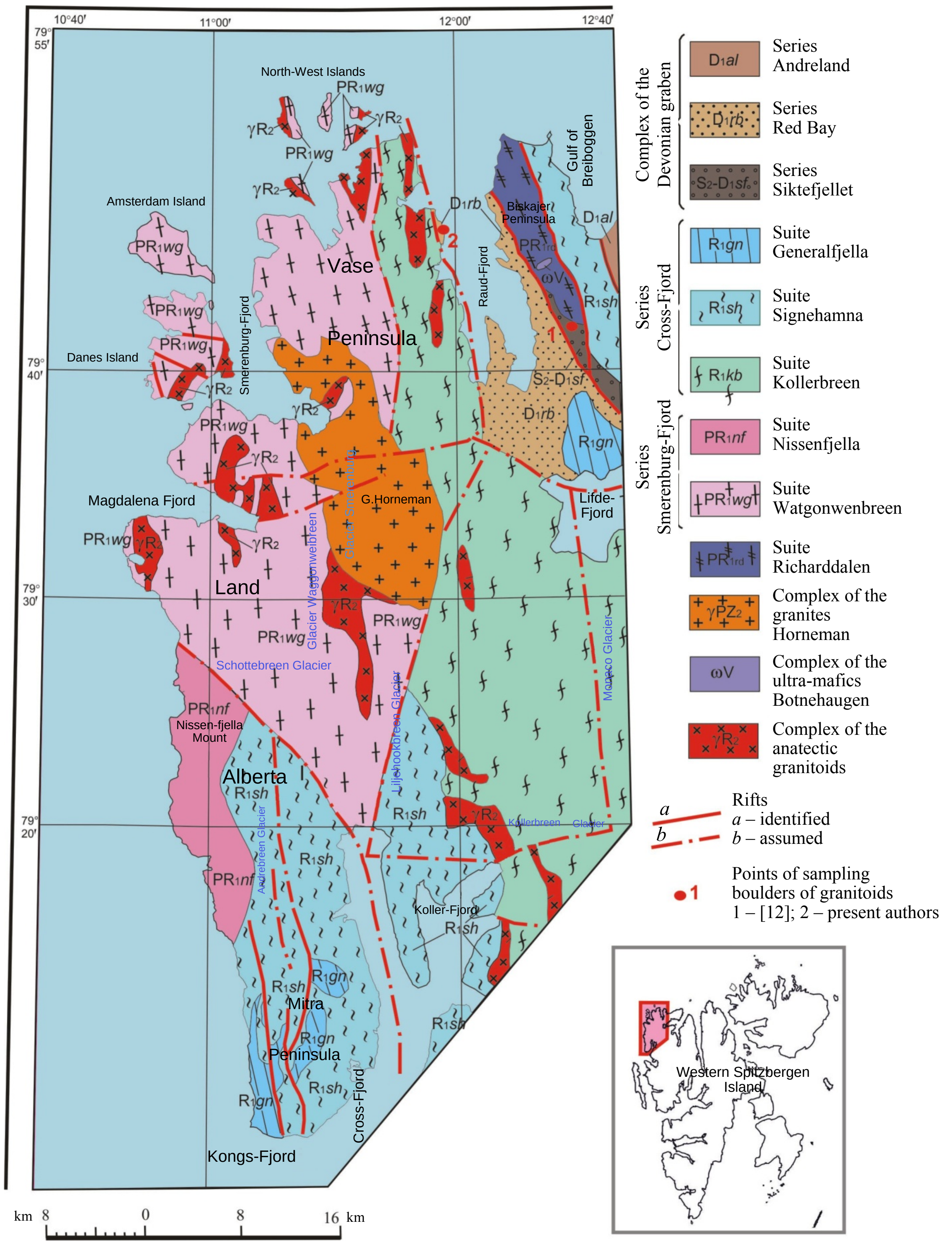

Fig.1. Scheme of geological structure of northwestern Spitzbergen

Northwestern part of the archipelago is tectonically characterized a zone of tectonic conjunction of two structures of Ist order: the anticlinoria protuberance of an ancient crystallic foundation and the Devonian graben of Spitzbergen (Fig.1). The NW protuberance of crystallic foundation features a stepwise joint with graben structures following a system of sub-parallel faults of different

DOI 10.18454/PMI.2016.6.789

amplitudes which form tectonic steps in the border of the graben with outbursts under the Devonian depositions of pre-Cambrian deeply metamorphosed rocks. The principal part of northwestern protuberance is formed by deeply metamorphosed rocks, among which one may expect blocks of early Proterozoic complexes (the Smerenburg-Fjord series) and early Rifey (the Cross-Fjord series) intensely processed by the mid-Rifey (Grenville) ultra metamorphism. The Southern part of the protuberance has major conjugated synclines and anti-synclines of sub-meridional stretching with joints gently sloping to the South and rock angles of incidence at the wings varying from 20 to 60° mapped. Syncline cores have lower-Rifey rocks outcropping, metamorphosed to the green shale fascia. Magmatic formations are presented by two complexes. The bodies of mid-Rifey anatectic granitoids tend to migmatization zones of lower-Proterozoic and lower-Rifey rocks. The mid-Paleozoic sub-base complex is presented by the Hornemantoppen major multi-phase granite massif and a series of smaller size bodies formed of granites, grano-syenites, monzonites, diorites and lamprophyres [1, 5, 9].

The structures of the Devonian graben stretch sub-meridionally across the whole central part of the Island of Western Spitzbergen. In the West they neighbor the northwestern protuberance of the crystallic foundation going via the Monacobreen – Breibogenoni system of deep faults; in the East they are limited by the Billefjord zone of abyssal fractures. The cross-section of the Devonian complex is represented by three series [3], separated by unconformity surfaces. The lower one of them, the Siktefjellet series (S_2-D_1) is represented by conglomerates and sandstones of the total depth up to 700 m. As mentioned earlier, in its basal horizons boulders of deeply metamorphosed rocks and boulders of quartz porphyries are present, aged around 1740 Mil yr. The middle Red Bay series (D_1) is represented by conglomerates, sandstones and aleurolites (of more than 2 km depth). Layers of acidic vulcanites are described among the sandstones of mid-part of the series [4]. The two lower series are only known in the western border of the graben within the western tectonic step; they are absent from the central part of the graben, but it is supposed that their analogs are present within the Billefjord zone at the base of the Devonian cross-section. The upper Andreland series (D_{1-3}) features a depth of 3500-4000 m and is represented by the reddish continental and grayish marine depositions. On the East the graben borders on the anticlinoria of the western Nu Frisland formed by the lower-Proterozoic rocks of the Atomfjella series and presents a protuberance of the Karelian crystallic foundation [2, 6].

To the East of Raud-Fjord, within the scope of the tectonic step in the western border of the Devonian graben, there jut out the deeply metamorphosed supposedly lower-Proterozoic rocks of the Richarddalen series [1] and the zonally metamorphosed rocks of the Cross-Fjord series (Fig.1). These rocks are bared in tectonic blocks and are overlapped by Devonian conglomerates with a certain angular discord. Bodies of mid-Rifey granitoids and Vendian metagabbroids and metahyperbasites are noted in blocks of pre-Cambrian rocks [6, 7].

During the field season of 2013 we studied the westernmost outcrops of Devonian rocks detected at the western shore of Raud-Fjord. They are represented by polymictic conglomerates of the Red Bay series (D_1) merged into the Wolfberget suite [3]. A block of conglomerates and gravelites with interlayers of sandstones spanning up to 300 m and limited on the west by the Monacobreen fault was described at Cape Conglomeratodden, where these rocks were tested. Brownish-greenish-gray polymictic conglomerates are recorded here, clearly layered and featuring major interlayers of brown and greenish-gray sandstones and gravelites (up to 2 m thick). Conglomerates feature numerous boulders and pebbles of gray marbles (1-1.5 m), and along with them there is a multitude of diverse metamorphic (shales, quartzites, gneiss) and magmatic rocks. Predominant among the magmatites are gray biotite granites; boulders are also found of metabasites and diorites (Fig.2). All these rocks are of local origin. Of most interest are boulders (up to 60 cm) of meat-red (Sample 3813-3) and

Fig.2. Basal conglomerates at the Cape Conglomeratodden, Red Bay series (D_1), Wolfberget suite

 DOI 10.18454/PMI.2016.6.789

greenish-gray (Sample 3813-4) granitoids, since no daylight surface outcrops of such rocks are known in this region.

Analytical studies. Zircon age is retrieved using the local uranium-lead technique (U-Pb) with the SHRIMP II ionic microprobe in the VSEGEI Center for Isotopic Studies following the standard methodology [14]. To select dating points in grains, optical (in transmitted and reflectedlight) and cathode luminiscence(CL) images ofzirconwere used. Heavy non-magnetic fractions(100-200 g) in

Table 1

Chemical composition of granitoids from the boulders of the Red Bay Devonian conglomerate series

Elements and indicators	Sample		Elements and indicators	Sample		Elements and indicators	Sample		Elements and indicators	Sample	
	3813-3	3813-4		3813-3	3813-4		3813-3	3813-4		3813-3	3813-4
SiO_2	71.2	72.9	Total	99.99	100.07	Zr	357	214	Gd	6.83	7.05
TiO_2	0.45	0.34	$K_ф$	0.71	0.63	Nb	15.8	9.72	Tb	0.93	1.0
Al_2O_3	13.8	13.9	*al'*	2.96	3.79	Ba	1190	850	Dy	5.53	4.82
Fe_2O_3	0.49	0.40	V	27.5	18.6	Hf	9.32	6.07	Ho	1.15	1.0
FeO	2.84	1.93	Cr	116	29.8	Th	13.9	22.2	Er	3.02	2.7
MnO	0.13	0.07	Co	4.4	4.08	Sc	3.03	3.0	Tm	0.53	0.43
MgO	1.33	1.34	Ni	16.7	6.49	La	53.7	60.2	Yb	3.68	2.77
CaO	0.8	0.34	Cu	12.9	9.82	Ce	108	131	Lu	0.55	0.43
Na_2O	2.48	2.52	Ga	15.3	12.7	Pr	13.9	16.2	ΣTR	250.34	291.4
K_2O	5.03	4.99	Rb	117	119	Nd	44	53.9	Eu/Eu*	0.59	0.66
P_2O_5	0.16	0.12	Sr	200	232	Sm	7.16	8.26			
Calcination losses	1.28	1.22	Y	27.3	26.3	Eu	1.36	1.64			

Comment. Samples from A.N. Sirotkin's collection. Analyses performed at the Central Analytic Laboratory of VSEGEI (A.P.Karpinsky Russian Geological Research Institute). Values for petrogenic oxides are given in mass per cent, microelements in grams per ton (ppm). $K_ф$ is fractionation coefficient; *al'* is the alumina coefficient; ΣTR is the cumulative content of rare earth elements; Eu/Eu* is the indicator of the Europian minimum.

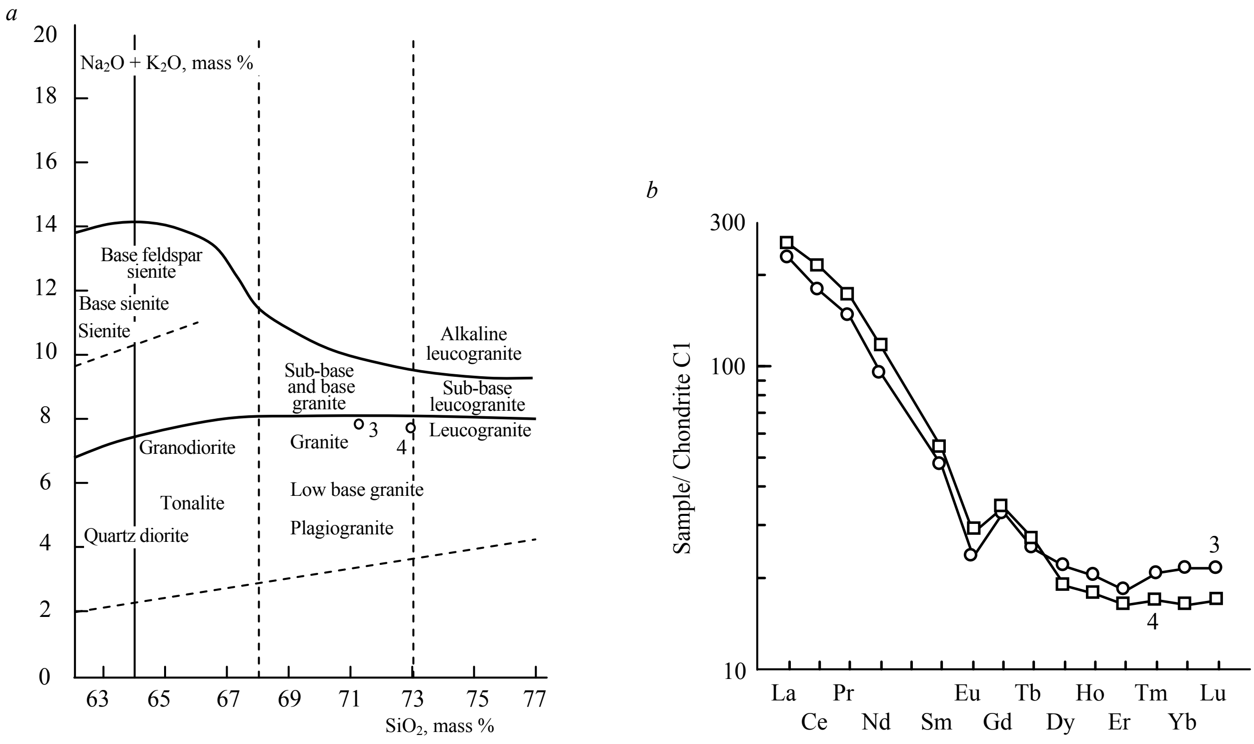

Fig.3. Diagrams SiO_2 – Na_2O+K_2O (*a*) and distributions of rare earth elements (REE) (*b*) in granitoids from boulders of the Devonian conglomerates

3 and 4 are samples 3813-3 and 3813-4, respectively

DOI 10.18454/PMI.2016.6.789

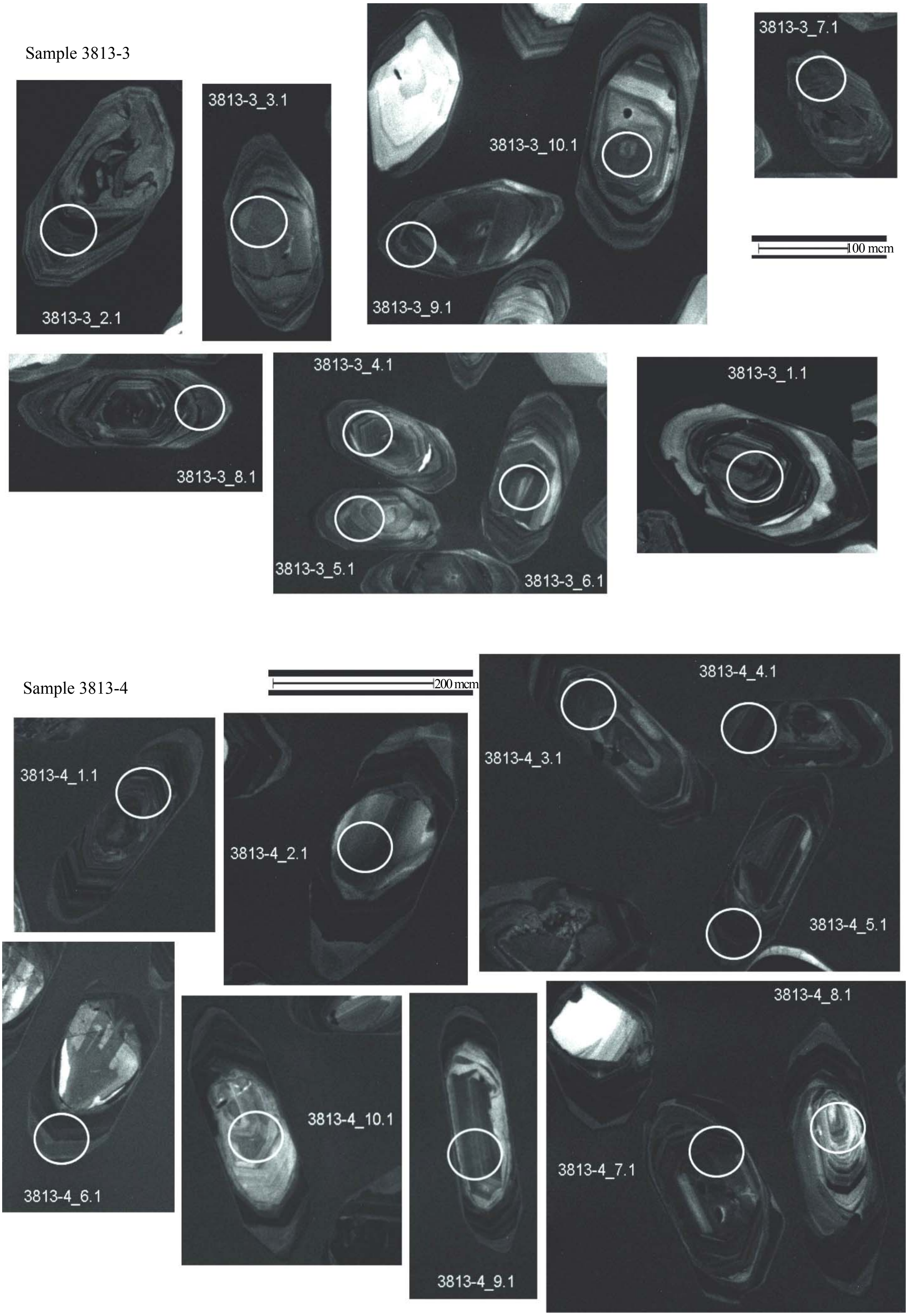

Fig.4. Grains of analyzed zircons, points of composition sampling indicated

DOI 10.18454/PMI.2016.6.789

which the zircon was located were obtained by means of electromagnetic separation and heavy fluids. Silicate analysis and ICP-MS-analysis of granites were also conducted at VSEGEI laboratories.

Sample 3813-3. Large grain granite, meat-red. Granite structure, grain size varying; mineral composition is microcline (55 %), oligoclase (20 %), quartz (20 %), biotite (5 %), zircon, chlorite, ore mineral. Quartz is sharply xenomorphic, forming aggregates between the larger grains of microcline; separate quartz grains are of elongated shape with serrated borders. Feldspars and biotite are noticeably altered (pelletized, saussuritized, carbonated, chloritized).

Sample 3813-4. Porphyraceous granitoid, greenish-gray. The structure is porphyric, coarse grain; mineral composition is microcline (65 %), oligoclase (10 %), quartz (15 %), biotite (10 %), zircon, fluorite, ore mineral, chlorite. Microcline forms large inclusions; plagioclase is found rarely, always as small rectangles. Quartz is present in the form of large grains, almost isometric. Secondary changes are expressed as chloritization of biotite.

Chemical composition (Table 1) demonstrates the rocks to be close to each other: figurative composition points on the SiO_2 – $Na_2O + K_2O$ diagram lie along the line separating granites of normal and moderate alkalinity, though the composition of sample 3813-4 is found at the boundary of the field of leucogranites (Fig. 3, *a*). Rocks are high in potassium and belong to the potassium-sodium series. Fractionation coefficient, $K_ф$ of these rocks varies noticeably; the same goes for the alumina coefficient, *al'*: its values of 2.96 and 3.79, respectively, point to noticeable differences in the amount of dark color minerals in these rocks. Recalculating the chemical composition into the composition of normativeminerals revealed their high alumina content (both samples have normative corundum present), while Sample 3813-4 hits the diagram (Or + Ab) – An – Q in the field of alkaline feldspar granite and Sample 3813-3 – the field of normal granite.

The granites manifest prominent differences in their microelement composition, first of all in their content of Cr and Ni (Table 1); differences are also quite visible in the concentrations of V, Zr, Nb, Ba, Hf, Th. The REE distribution indicates a considerable differentiation in mother magmas: Sample 3813-4 features higher REE in general and light REE in particular, while the granite from Sample 3813-3 has more heavy REE (Fig.3). All thee petro- and geochemical characteristics together point to different sources of the initial magmas as well as differences in the mechanisms of their crystallization.

By way of the initial conclusions one may note considerable differences in petrographic and petrochemical characteristics of these rocks so that they be viewed as representatives of separate stand-alone geological entities.

Zirconometry results and their interpretation. *Sample 3813-3*. Monofraction of zircon was separated from the meat-red granite sample of the boulder, represented by transparent and semi-transparent sub-idiomorphic crystals of prism and short prism shape. They measure 80-200 μm with an elongation factor of 2-3. Crystal faceting combines prismatic and di-pyramid facets. CL demonstrates all grains to be inhomogeneous: central and peripheral parts of the grains differ in the level of their bleaching, centers are always lighter and the character of zonality is always different. Peripheral parts always feature fine oscillating zonality parallel to the facets of di-pyramid; reaching the prism facets it thins out. Oscillational zonality is coarse in central parts of the grains, discordant with respect to the zonality of the peripheral parts of the grain, as a rule. Zircons shown in Fig.4 have demonstrated certain scattering in their individual ages ($^{206}Pb/^{238}U$) between 435 and 1713 Mil yr (Table 2). Note too that points taken in peripheral parts of zircon grains (measurements 7.1, 8.1, 9.1) have scattered widely within 435-896 Mil yr, while points taken from core crystals (measurements 1.1, 2.1, 3.1, 4.1, 5.1, 6.1, 10.1) composed into a tighter group of ages within 918-1713 Mil yr (Table 2). The discordia diagram for that

DOI 10.18454/PMI.2016.6.789

sample (Fig.5) yields the upper (1631 ± 19 Mil yr) and lower (380 ± 42 Mil yr) crossings to indicate early Proterozoic age of the magmatic event and the possible late Caledonian transformation age for the isotopic system of zircon grains.

Table 2

Local U-Pb-analysis results for zircons from granite boulders of the lower-Devonian conglomerates (western shore of Raud-Fjord, Spitzbergen archipelago)

Point of analysis	$^{206}Pb_c$, %	U, Mil^{-1}	Th, Mil^{-1}	$^{232}Th/^{238}U$	$^{206}Pb^*$, Mil^{-1}	Age $^{206}Pb/^{238}U$, Mil yr	Age $^{207}Pb/^{206}Pb$, Mil yr	D, %	$^{207}Pb/^{235}U$	Margin (±),%	$^{206}Pb/^{238}U$	Margin (±),%	K, relat. units
Sample 3813-3, boulder of meat-red granite													
1.1	0.00	341	281	0.85	44.9	918±12	903±23	–2	1.459	1.8	0.153	1.5	0.790
2.1	0.01	534	51	0.10	130	1604±21	1626±12	1	3.899	1.6	0.2825	1.5	0.922
3.1	0.04	197	76	0.40	34.1	1181±16	1131±26	–4	2.146	2	0.2011	1.5	0.756
4.1	0.06	278	271	1.01	70.8	1637±22	1628±16	–3	4.096	1.7	0.2964	1.5	0.868
5.1	0.00	136	79	0.60	31.5	1544±21	1495±23	–3	3.483	2	0.2076	1.5	0.783
6.1	0.12	210	290	1.43	55.0	1713±22	1649±24	–4	4.255	2	0.3044	1.5	0.749
7.1	0.40	443	52	0.12	43.5	695.3±9.7	1279±35	84	1.31	2.3	0.1139	1.5	0.636
8.1	0.17	405	18	0.05	24.3	435.8±6.3	434±54	–1	0.535	2.8	0.0699	1.5	0.528
9.1	0.05	410	87	0.22	52.6	896±12	1376±20	54	1.804	1.8	0.1492	1.5	0.817
10.1	0.12	242	220	0.94	62.2	1683±22	1659±18	–1	4.192	1.8	0.22984	1.5	0.838
Sample 3813-4, boulder of greenish gray granitoid													
1.1	0.20	725	247	0.35	85.1	824±11	1184±23	44	1.494	1.9	0.1363	1.4	0.744
2.1	0.16	349	214	0.63	69.7	1344±18	1377±19	2	2.804	1.8	0.2318	1.5	0.825
3.1	0.13	461	253	0.57	65.6	986±13	937±31	-5	1.603	2.1	0.1654	1.5	0.690
4.1	0.15	1191	196	0.17	71.1	432.5±6	423±30	-2	0.529	2	0.06939	1.4	0.729
5.1	0.07	1367	210	0.16	82.4	436.7±6.1	428±28	-2	0.535	1.9	0.0701	1.4	0.749
6.1	0.03	990	56	0.06	58.5	428.9±6	417±27	-3	0.5229	1.9	0.0688	1.4	0.766
7.1	0.01	609	532	0.90	159	1714±22	1673±11	-2	4.312	1.6	0.3047	1.4	0.926
8.1	3.36	212	128	0.62	25.6	818±12	898±140	10	1.286	7	0.1352	1.6	0.230
9.1	0.13	285	155	0.56	62.6	1464±19	1442±27	-2	3.192	2.1	0.255	1.5	0.723
10.1	0.12	140	138	1.02	34.4	1615±22	1599±25	-1	3.875	2.1	0.2848	1.6	0.753

Comment. The number of analytic point corresponds to the grain number and that of the crater within that grain. Errors are given for 1σ interval. Pb_c and Pb* are non-radiogenic and radiogenic lead. Standard calibration error for samples one and two are 0.44 % each (1σ). Isotopic ratios are adjusted by the measured ^{204}Pb. D is the discordance. K is the error correlation coefficient.

Sample 3813-4. Monofraction of zircon was separated from the greenish-gray granitoids of the boulder, represented by transparent and semi-transparent crystals of prism and elongated prism shape measuring 150-250 mcm with the elongation factor up to 5; rarely sub-isometric crystals are noticed with weakly expressed prism facets (see Fig.4). Crystals behave different in their CL-images; in particular, their central parts are characterized by both darker and lighter tones. Their oscillational zonality is well expressed in the peripheral parts of zircons, where it may be both fine- and coarse-striped. As a rule, the central parts of the grains have that zonality expressed very weakly. The studied zircons demonstrate quite a scatter of individual values of $^{206}Pb/^{238}U$-age from 428 to 1714 Mil yr (Table 2). The Ahrens – Wetherill diagram (Fig.6, *a*) has concordant points brought together for zircons from that age range. It may be seen clearly that the three points (measurements 4.1, 5.1, 6.1) coincide indicating the practically similar values (~ 432 Mil yr). These points characterize the outer part of zircon crystals (see Fig.4). Three points (measurements 2.1, 9.1, 10.1) describe crystal cores and yield the ages within 1344-1615 Mil yr. Three more points (measurements 1.1, 3.1, 7.1) feature large scatter at the concordia within 818-1714 Mil yr and are characterized by interim position in zircon crystals (when analyzing them material was picked from both the cores and the outer rims). Three first

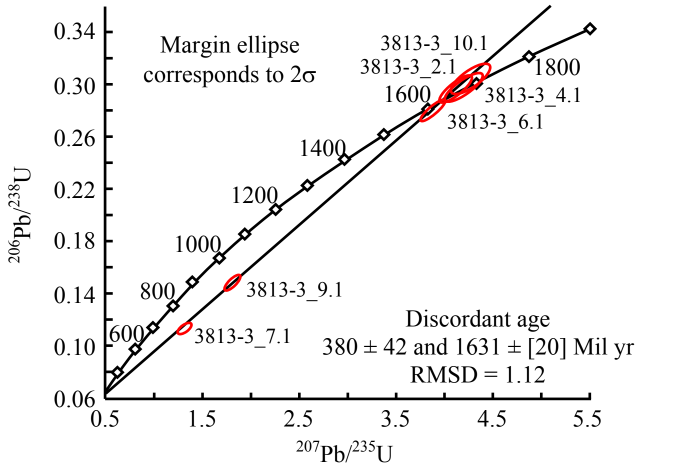

Fig. 5. Discordia diagram for zircons from the granite of Sample 3813-3, 6 measurements taken. RMSD – root mean square deviation

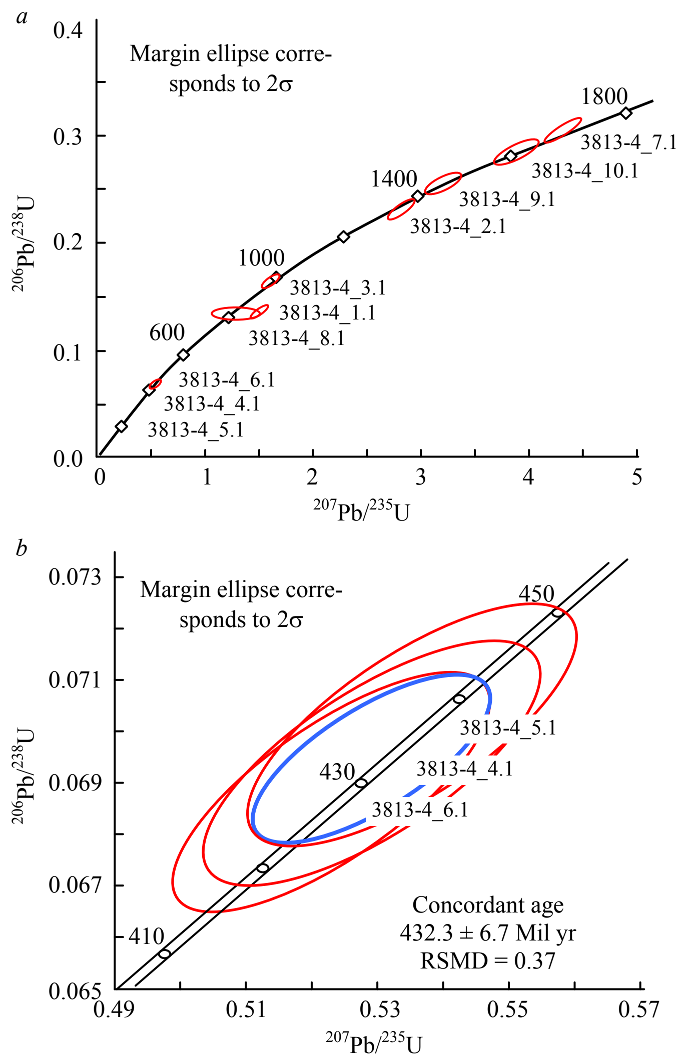

Fig. 6. Sample 3813-4: *a* – Ahrens – Wetherill diagram for 10 measurements; *b* – the Tera – Wasserburg diagram with concordia for 3 measurements; the concordia probability is 0.55

points considered at the Tera – Wasserburg concordia diagram (Fig.6, *b*) form a compact concordant cluster corresponding to the age of 432.3 ± 6.7 Mil yr, which points to Caledonian processes during which recrystallization of zircons took place. In their turn the cores of those zircons may be considered to be fragments of relic scavenged grains, their age possibly indicating the age of the ancient protolith.

Discussion of results. The petrographic and petrochemical materials presented on the granites from the boulders of Devonian conglomerate Red Bay series make it possible to view them as representatives of different stand-alone geological entities. At the same time one should note that the greenish-gray granites from Sample 3813-4 compare well in their characteristics with granitoids of the mid-Paleozoic complex, represented widely across the NWS. The structural-mineralogic characteristic of greenish-gray granites correlates directly with rocks from the Horneman massif; petrochemical characteristics of those granites permit one to rate them as sub-alkaline varieties close to leucogranites. It all makes possible comparing the granites from Sample 3813-4 with granitoids of the mid-Paleozoic complex [5]. Crystallization age of these rocks (432.3 ± 6.7 Mil yr) that we established is a weighty argument in favor of such an assumption so that they may be related to early phases of mid-Paleozoic magmatism in the NWS.

In their characteristics meat-red granites (Sample 3813-3) cannot be related to granitoids of any specific complex or massif in that region of the archipelago. Meanwhile their petrographic characteristics point to serious post-magmatic transformations (e.g., to metamorphism), which foreordains pre-Caledonian origin of these rocks. The age of the magmatic event for these granites that we retrieved is 1631 ± 19 Mil yr, which is comparable to late-Karelian processes, manifested actively in the archipelago. The possible-transformations of these rocks within the range of 380 ± 42 Mil years are well associated with mid-paleozoic events, considerable restructuring of the ancient archipelago foundation associated with them.

DOI 10.18454/PMI.2016.6.789

Conclusions

1. Meat-red granites present in the shape of boulders in the conglomerates of Red Bay series (D_1), also identified by us on the western shore of Raud-Fjord make it possible to date the age of the magmatic event at 1631 ± 19 Mil yr.

2. The character of the studied conglomerates points to the local origin of boulder material. Hence, the age range we defined is another proof of manifestation of early pre-Cambrian (late Karelian) processes in the northwestern Spitzbergen.

3. Impossibility to relate such granites with any known local complex should not preclude Conclusion 2, since outcrops of unknown rocks may be overlapped by glaciers, widely developed in this region or stay hidden in marine aquatoria.

4. Boulders of greenish-gray granites are related quite well in their characteristics with granitoids of the mid-Paleozoic complex. Crystallization age of these rocks (432.3 ± 6.7 Mil yr) that we established is a weighty argument in favor of such an assumption so that they may be related to early phases of mid-Paleozoic magmatism in the northwestern Spitzbergen archipelago.

REFERENCES

1. Abakumov S.A. The main features of geology and metamorphic of North-West Spitsbergen. Geologiya Sval'barda. Leningrad: NIIGA, 1976, p. 22-31 [in Russian].

2. Krasil'shchikov A.A. Stratigraphy and paleotektonics of precambrian – early paleozoik Spitsbergen. Leningrad: Nedra, 1973, p. 120 [in Russian]

3. Murashov L.G., Mokin Yu.I. Stratigraphic division of the Devonian of Spitsbergen Island. Geologiya Sval'barda. Leningrad: NIIGA, 1976, p. 78-92 [in Russian].

4. Murashov L.G., Pchelina T.M., Semevskii D.V. New data about the deposits of volcanism in the upper and lower Devonian formations of Western Spitsbergen. Geologiya Shpitsbergena. Leningrad: PGO «Sevmorgeologiya», 1983, p. 96-101 [in Russian].

5. Sirotkin A.N. Middle Paleozoic granitoid magmatism of Spitsbergen Geologiya i poleznye iskopaemye Kol'skogo regiona. Trudy Kh Vserossiiskoi Fersmanovskoi nauchnoi sessii. Apatity: Izd-vo K&M, 2013, p. 99-103 [in Russian].

6. Sirotkin A.N., Evdokimov A.N. Endogenous modes and evolution of metamorphic complexes of Spitsbergen infolded foundation (by the example of New Friesland). St. Petersburg: VNIIOkeangeologiya, 2011, p. 270. [in Russian].

7. Sirotkin A.N., Skublov S.G. U-Pb zircon age of metabasite crystalline foundation of Spitsbergen and the history of its formation. *Regional'naya geologiya i metallogeniya*. 2015. N 63, p. 47-58 [in Russian].

8. Teben'kov A.M., Krasil'shchikov A.A., Balashov Yu.A. The main geochronological boundaries and formation stages of Spitsbergen foundation *Doklady Akademii nauk*. 1996. Vol. 346. N 6, p. 786-789 [in Russian].

9. Balashov Ju.A., Peucat J.J., Tebenkov A.M., Ohta Y., Larionov A.N., Sirotkin A.N. Additional Rb-Sr and singl-grain zircon datings of Caledonian granitoid rocks from Albert I Land, northwest Spitsbergen. *Polar Research*. 1996. 15(2), p. 153-165.

10. Griffin W.L., Nikolic N., O'Reilly S.Y., Pearson N.J. Coupling, decoupling and metasomatism: Evolution of crust-mantle relationships beneath NW Spitsbergen. *LITHOS*. 2012. Vol. 149, p. 115-135.

11. Gasser D., Andresen A. Caledonian terrane amalgamation in Svalbard: Detrital zircon provenance of Mesoproterozoic to Carboniferous strata from Oscar II Land, western Spitsbergen. *Geophysical Research Abstracts*. 2012. Vol. 14, p. 41-42.

12. Harland W.B. An outline structural history of Spitsbergen. *Geol. Arctic*. 1961. Vol. 1, p. 34-42.

13. Hellmann F.J., Gee D.G., Gjelsvik T., Tebenkov A.M. Provenance and tectonic implications of Palaeoproterozoic (c. 1740 Ma) quartz porphyry clasts in the basal Old Red Sandstone (Lilljeborgfjellet Conglomerate Formation) of northwestern Svalbard's Caledonides. *Geol. Mag*. 1998. Vol. 135 (6), p. 755-768.

14. Williams I.S. U-Th-Pb geochronology by ion microprobe. *Rev. in Econom. Geol*. 1998. N 7, p. 1-35.

***Authors*: A.N.Sirotkin,** *Doctor of Geological and Mineral Sciences*, *Senior Geologist*, *sirfamily@front.ru* (*Polar Marine Geosurvey Expedition* (*FSUE PMGE*), *Lomonosov*, *Russia*) **A.N.Evdokimov,** *Doctor of Geological and Mineral Sciences*, *Professor*, *evdokimov48@list.ru* (*Saint-Petersburg Mining University*, *Saint-Petersburg*, *Russia*).

The paper was accepted for publication on 27 September, 2016.