U-Pb ages and tectonic setting of mid-Cretaceous magmatism in Chukotka (NE Russia)

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ABSTRACT

We present a brief review of recent research on the age of granitoid plutons of the Anuyi-Chukotka fold system, including Chaun fold zone, together with results of SHRIMP U-Pb zircon dating of two batholiths, Velitkenay and Moltykan. Despite structural differences, granitoids of both batholiths have similar isotopic ages, 105.3±1.2 and 107.0±1.0. Granitoids of Chaun fold zone including Velitkenay and Moltykan batholiths have characteristics that are similar to those of post-orogenic plutons formed in extensional tectonic settings. We suggest a transtensional stress regime for their formation. There are geochemical similarities between the lowermost Etchikun unit of the Okhotsk-Chukotka belt and the Velitkenay and Moltykan batholiths and other granitoids of the Chaun zone. These results indicate the existence of a significant Mid-Cretaceous (Albian) magmatic event in the region, preceding initiation of the northern segment of Okhotsk-Chukotka volcanic belt.

INTRODUCTION

The Alazei-Oloy fold belt, South-Anyui Suture Zone and Anuyi-Chukotka fold belt are the main tectonic elements of Chukotka (Fig. 1). They formed as a result of collision between an active North-Asian (Siberian) continent and the passive margin of the Chukotka-Alaska microcontinent (Parfenov, 1984; Zonenshain et al., 1990; Sokolov, 2007). Deformation on the Siberian continent was localized in the Alazei-Oloy fold system, and deformation of the passive margin of the Arctic Alaska-Chukotka microcontinent resulted in the Anyui-Chukotka fold belt. The South-Anyui suture zone formed as a result of an oceanic basin closure between these continental blocks (Seslavinsky, 1979; Natal'in, 1984; Sokolov et al., 2002). The South-Anyui suture zone is a large orogen with south- and north-vergent structures, complicated by strike-slip faults (Sokolov et al., 2001; Bondarenko, 2004).

Cretaceous granitic plutons are widespread across the Anyui-Chukotka fold system (nearly 10% of the area). They comprise several batholiths (up to 2000 km^2) and a number of smaller intrusions of granodiorites, quartz monzonites, granites, and leucogranites (Sadovsky,and Gelman, 1970; Samorukov and Matveenko, 1984; Varlamova et al., 2004; Tibilov and Cherepanova, 2001). Granitoids intrude folded Devonian-Carboniferous clastic and limestone sequences, Late Permian-Triassic clastic rocks, and weakly deformed Late Jurassic-Early

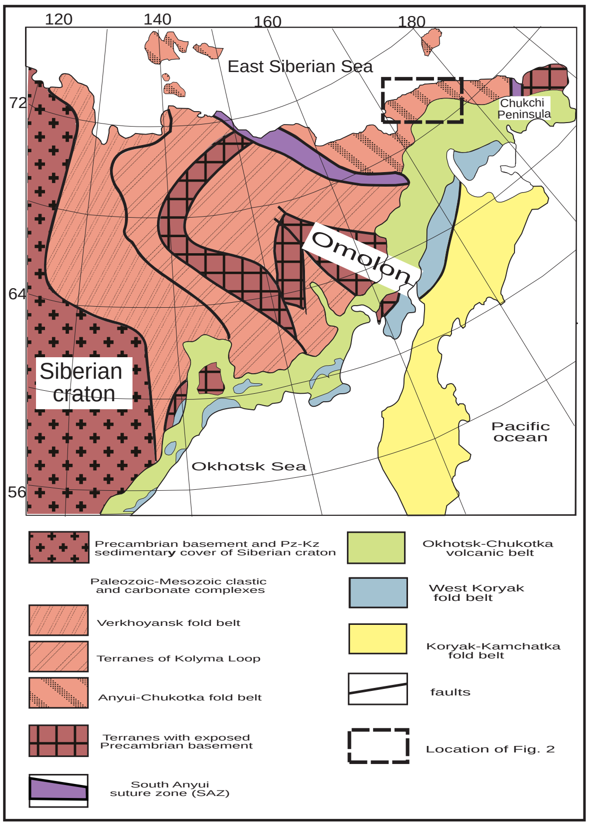


Fig. 1. Tectonic map of NE Russia (after Sokolov et al., 1999)

Cretaceous rocks, that formed in syn-collisional basins (Sadovsky and Gelman, 1970; Varlamova et al., 2004; Tibilov and Cherepanova, 2001). They are overlain by volcanic rocks of the Albian-Late Cretaceous Okhotsk-Chukotka belt (Fig. 2).

Here we present the results of SHRIMP U-Pb dating of zircons from two granitic plutons of the Chaun fold zone (CFZ), Velitkenay and Moltykan (V and M on Fig. 2). The shape and the spatial distribution of Chaun zone granitic bodies suggest their emplacement was controlled by faults of NW and NE strike (Fig. 2). The Velitkenay batholith includes gneissic granites, and some migmatites are present at its contact with Paleozoic metamorphic rocks. The Moltykan batholith consists of massive rocks and has sharp intrusive contacts with host rocks. The former may have formed in a granite-migmatite dome structure. The latter is similar to post-orogenic plutons formed in extensional tectonic settings. The observed structural diversity of the Chaun zone granitoids could result from their relation with at least two different tectonic events, though this suggestion needs to be verified by independent methods, including isotopic dating.

GEOLOGIC SETTING OF CHAUN FOLD ZONE

The Chaun fold zone (Fig. 2) is composed of Paleozoic-Mesozoic sedimentary deposits. Lower Mesozoic (Triassic) rock assemblages accumulated on the passive margin of the Chukotka microcontinent (Parfenov, 1984; Parfenov et al., 1993; Akimenko, 2000; Tibilov and Cherepanova, 2001; Tuchkova, 2011). The northern part of this zone exposes several uplifts with outcrops of Devonian to Carboniferous metasedimentary rocks, overlain by terrigenous clastic sequences of Permian–Triassic age. The structure of these uplifts is now considered as that of granite-metamorphic core complexes, and its formation took place in Early Cretaceous (Gelman, 1995, 1996; Bondarenko and Luchitskaya, 2003; Miller et al., 2009, Luchitskaya et al., 2010). Paleozoic and Early Mesozoic strata are folded, with NW-trending fold axes. The western part of the

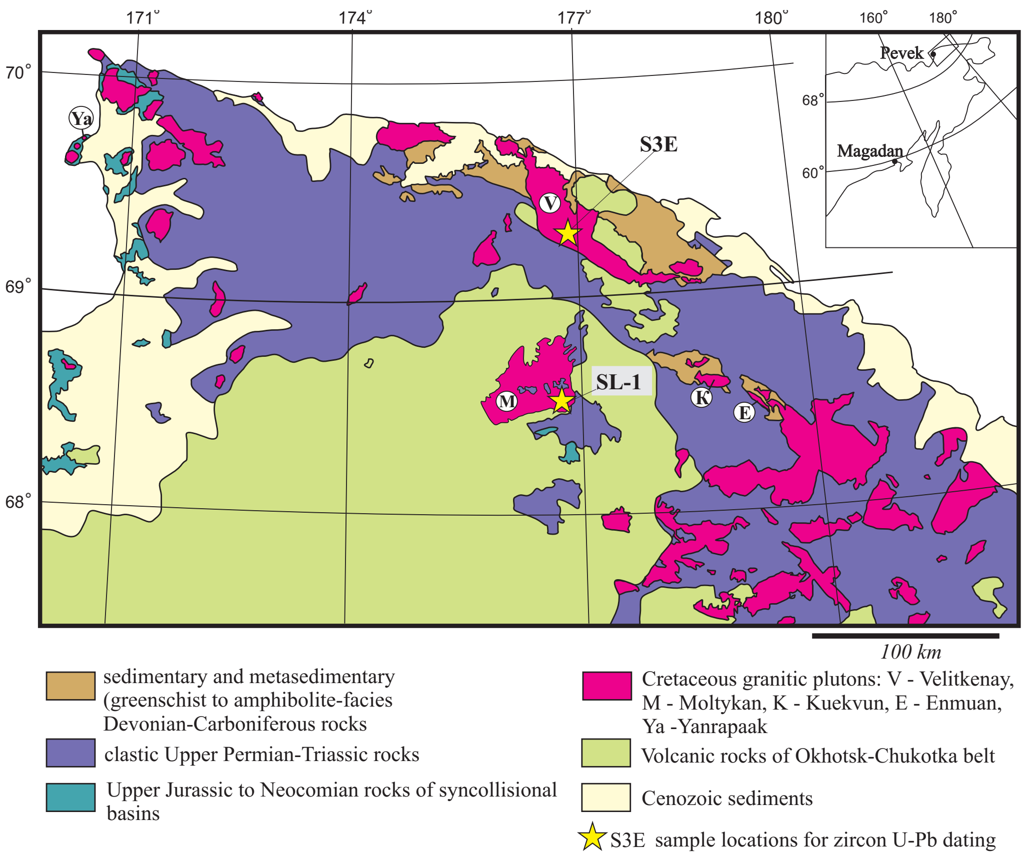


Fig. 2. Geological map of the Chaun tectonic zone (central part of Anyui-Chukotka fold system). Modified after Varlamova et al. (2004)

Chaun zone is overlain by slightly deformed Upper Jurassic to Lower Cretaceous clastic sediments of the Rauchua basin, probably of syn-collisional nature (Sokolov et al., 2002, Bondarenko, 2004, Miller et al. 2004, 2008, 2009).

To the south, structures of the Chaun zone are covered by thick (up to 3–4 km) undeformed sequences of the Okhotsk-Chukotka volcanic belt (OCVB). The OCVB was active from ~106–77 Ma (Belyui, 1977, Akinin and Miller, 2011), but the volcanic rocks which directly overlay the plutons are relatively young (89–80 Ma) (Tikhomirov et al., 2006). Granitic plutons of the Chaun zone form several linear belts with NW and NE strikes. They intrude both folded Triassic and weakly deformed Jurassic–Early Cretaceous sedimentary rocks, indicative of their emplacement during the post-orogenic stage (Miller et al., 2009).

K-Ar and Rb-Sr dating of granitoids of the Anyui-Chukotka fold system, including granitoids of Chaun fold zone, are predominantly Cretaceous, rarely Late Jurassic; single datings are Devonian (Sadovsky and Gel'man, 1970; Late Mesozoic granitoids of Chukotka, 1965; Petrology of magmatic formations of Chukotka, 1969; Milov, 1975; Zagruzina, 1977; Tibilov et al., 1986; Efremov et al., 2000; Tikhomirov, 1998; Zhulanova et al., 2007). On geological maps (Varlamova et al., 2004) all granitoid plutons are referred to as a single Early Cretaceous complex, which is called the Chukotka complex in western Chukotka and the Taureran complex in eastern Chukotka; in the central part of Chukotka the magmatic rocks are named the Telekay granitoid complex. Statistical peaks of the older K-Ar data reported from these rocks are 97 and 85 Ma (Gorbov et al., 1968; Akinin and Kotlyar, 1997; Zhulanova et al., 2007). Efremov et al., (2000) and Zhulanova et al., (2007) generalized existing K-Ar and Rb-Sr datings. The former distinguished three stages of granitoid magmatism based on a study of the granitoids of the Chaun fold zone (western part of Anyui-Chukotka fold system): 1) 144±14.4, 2) 126.8±9.6 and 3) 85±1.9 Ma (Efremov et al., 2000). The third stage is synchronous with Okhotsk-Chukotka volcanic belt activity. Efremov et al., (2010) noted that Rb-Sr dating of these rocks is not likely to be reliable because mixing of magmas with different initial $(^{87}Sr/^{86}Sr)_0$ values may have occurred.

According to Zhulanova et al., (2007) granitoid magmatism in the Chukotka, Taureran and Telekay complexes began in the Middle to Late Jurassic (164–152 Ma). However, the main volume of granodiorite magmas corresponds to Valanginian-Hauterivian, as the most precise date is 139±1.4 Ma (Zhulanova et al., 2007). Granites and leucogranites were intruded at 127 Ma (Zhulanova et al., 2007). These authors suggested that as a result of 109–106, 98–95, and 83–80 Ma thermal events, the isotopic systems of rocks of all three complexes were disturbed. More recently, U-Pb SHRIMP (Sensitive High-Resolution Ion Microprobe) dating on granitoids of the Anyui-Chukotka fold system (Natal'in et al., 1999; Miller et al., 2009; Miller and Verzhbitsky, 2009; Akinin, 2011, Akinin et al., 2012; Katkov et al., 2013), indicate both Cretaceous (Aptian-Albian, 117–100 Ma) and Devonian-Early Carboniferous (370–375 Ma, 363±44 Ma, 380 Ma, 353±5Ma, 352±6 Ma) ages.

The Moltykan batholith is one of the largest intrusive complexes of the Chaun zone; its outcrop area is 1,630 km^2. In map view, the intrusive body is slightly elongated in a northeasterly direction, across the strike of the principal fold structures of the region (Fig. 2). It intrudes Late Triassic clastic sequences and produced a hornfelsic aureole up to 200 m wide. The aureole is composed of quartz-biotite, quartz-biotite-diopside, quartz-biotite-cordierite and quartz-biotite-hornblende hornfels (Milov, 1975, Varlamova et al., 2004). To the NW and SW, the batholith is unconformably overlain by volcanic strata of the OCVB. Remnants of both Triassic sediments and Late Cretaceous volcanic rocks are present within the Moltykan granite, indicative of a relatively shallow depth of the erosional incision. Compositionally, the batholith is dominated by granodiorites and monzogranites. Between major rock types both sharp contacts and gradual transitions have been documented (Tikhomirov, 1998) so the batholith was likely produced by several major near-simultaneous intrusive pulses (Tikhomirov, 1998).

The Velitkenay batholith is elongated in a NE direction being 150 km in length and from 3–5 to 35 km in width and has S-shaped outlines; its outcrop area is nearly 2000 km^2 (Fig 2). The batholith intrudes Upper Devonian-Lower Carboniferous terrigenous and carbonate rocks, Triassic shales, siltstones and sandstones and is overlain by Upper Cretaceous volcanic rocks (Varlamova et al., 2004; Tibilov and Cherepanova, 2001). There is a migmatite zone along the contact with host rocks, varying in width from several to 250–300 meters and granitoids contain xenoliths of Paleozoic metasedimentary rocks (Milov, 1975, Akinin and Polzunenkov, 2013). Two intrusive phases are distinguished in the batholith (Milov and Ivanov, 1965): 1) coarse- and medium-grained porphyric biotite, biotite-amphibole and amphibole quartz diorite, monzonites, granodiorites and granites of the early phase; 2) fine- and medium-grained leucocratic granites of a later phase. Granites of the late phase form dikes and stocks.

RESULTS OF U-PB STUDIES

Analytical techniques

Zircons have been extracted from two samples: a gneissic quartz monzodiorite from the Velitkenay pluton and a massive granodiorite from the Moltykan pluton. U-Pb zircon dating was carried out by E.N.Lepekhina using the high-resolution multi-collector secondary ion mass spectrometer SHRIMP-II in the Center of Isotopic Studies of A.P.Karpinsky Russian Geological Research Institute (St.Petersburg).

Hand-picked zircons were mounted in epoxy together with standard zircons TEMORA and 91500. The zircons were ground to approximately half their original thickness and polished. To select the analysis locations optical (in transmitted and indirect light) and cathodoluminescence (CL) images were used to determine the inner structure and zoning of zircons.

Measurements of U-Pb ratios on SHRIMP-II were carried out by techniques described in Williams, (1998). The intensity of the primary beam of molecular negatively charged oxygen ions was 2 nA, and the beam diameter was 5 µm. The SQUID program (Ludwig, 2000) was used for data processing. U-Pb ratios were normalized to a 0.0668 value, attributed to standard TEMORA zircon, which corresponds to an age of 416.75 Ma age of this zircon (Black et al., 2003). Errors of single analyses (ratios

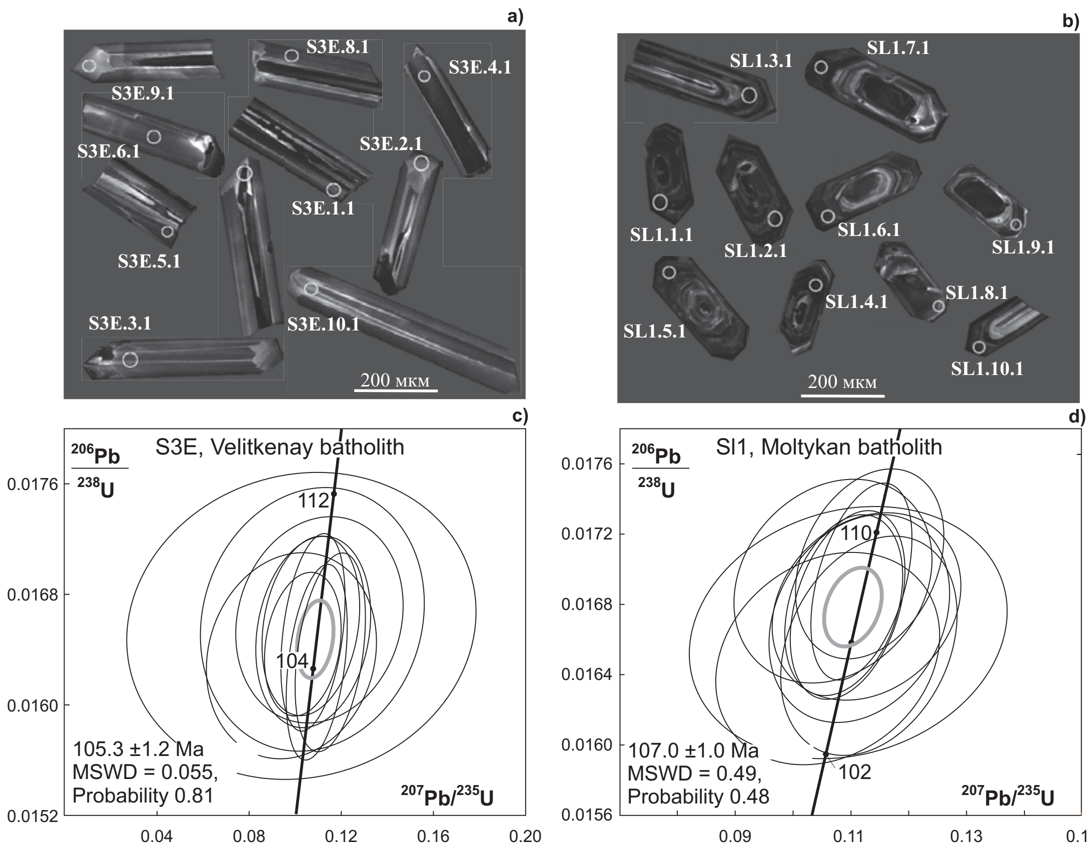


Fig. 3. CL images of zircons and concordia diagrams for granitoids of Velitkenay (a, c) and Moltykan (b, d) batholihs

Table 1.

spot	206 Pbc, %	U ppm	Th ppm	232Th /238U	206 Pb*, ppm	(1) 206Pb/ 238U age, Ma	1σ, ±%	238U/ 206Pb	1σ, ±%	207Pb/ 206Pb	1σ, ±%	207Pb* /235U	1σ, ±%	206Pb* /238U	1σ, ±%	Err corr
sample S3E (gneissic quartz monzodiorite, Velitkenay batholith, N 69°17’2.75’’, E 176°50’58.61”)																
S3E.1.1	0.44	932	44	0.05	13.2	105.1	0.79	60.56	1.2	0.0491	2.8	0.1033	6.5	0.01644	1.3	.198
S3E.2.1	0.00	383	129	0.35	5.43	105.7	1.09	60.50	1.8	0.0472	5.0	0.1076	5.3	0.01652	1.8	.334
S3E.3.1	0.00	378	231	0.63	5.32	104.7	1.10	61.00	1.8	0.051	5.1	0.1151	5.4	0.01638	1.8	.332
S3E.4.1	0.67	618	403	0.67	8.86	105.9	0.97	59.94	1.6	0.052	3.9	0.1068	8.1	0.01657	1.6	.199
S3E.5.1	0.81	508	314	0.64	7.27	105.7	1.03	60.01	1.6	0.0538	4.2	0.1080	9.5	0.01653	1.7	.180
S3E.6.1	1.21	465	292	0.65	6.61	104.6	1.16	60.40	1.7	0.0533	4.4	0.0980	15	0.01636	1.9	.121
S3E.7.1	1.58	365	198	0.56	5.29	106.3	1.38	59.20	2.1	0.0594	4.8	0.1070	18	0.01662	2.3	.127
S3E.8.1	1.16	506	301	0.61	7.31	106.2	1.08	59.48	1.7	0.0574	4.2	0.1100	13	0.01661	1.8	.137
S3E.9.1	0.00	416	201	0.50	5.83	104.3	1.10	61.30	1.8	0.0486	4.6	0.1093	5	0.01631	1.8	.358
S3E.10.1	2.54	225	102	0.47	3.29	106.0	1.63	58.80	2.2	0.0652	5.7	0.1030	30	0.01657	2.7	.091
sample SL1 (massive porphyric granodiorite, Mol’tykan batholith, N 68°30’35.70”, E 176°47’17.80”)																
SL1.2.1	0.21	1966	476	0,25	28.4	107.4	1.4	59.53	1.3	0,0472	2.7	0.1094	3.7	0.01680	1.3	.354
SL1.1.1	0.37	2153	514	0,25	31.6	108.9	1.4	58.72	1.3	0,0482	2.5	0.1132	4.6	0.01703	1.3	.282
SL1.3.1	0.70	2469	482	0,20	35.9	107.3	1.4	59.57	1.3	0,0487	2.3	0.1127	5.9	0.01679	1.3	.221
SL1.4.1	0.28	2889	1303	0,47	41.8	107.4	1.3	59.54	1.2	0,0470	2.2	0.1088	3.8	0.01679	1.3	.327
SL1.5.1	0.45	1593	523	0,34	23.3	108.2	1.5	59.05	1.4	0,0458	3.0	0.1070	6.5	0.01693	1.4	.214
SL1.6.1	0.00	937	286	0,32	13.3	105.9	1.6	60.37	1.5	0,0495	5.3	0.1130	5.5	0.01656	1.5	.280
SL1.7.1	0.00	1758	338	0,20	25.6	108.2	1.4	59.06	1.4	0,0479	2.9	0.1118	3.2	0.01693	1.4	.425
SL1.8.1	0.83	682	282	0,43	9.83	106.4	1.9	60.1	1.7	0,0478	4.3	0.1100	10	0.01664	1.8	.172
SL1.9.1	0.64	1416	524	0,38	20.5	106.9	1.5	59.81	1.4	0,0483	3.1	0.1114	5.7	0.01672	1.4	.253
SL1.10.1	0.48	1252	400	0,33	17.8	105.4	1.6	60.63	1.5	0,0466	4.6	0.1060	7.4	0.01649	1.5	.202

Notes. Errors are 1-sigma; Pbc and Pb* indicate the common and radiogenic portions, respectively. Error in Standard calibration was 0.68% (not included in above errors but required when comparing data from different mounts).
(1) Common Pb corrected using measured 204Pb. Analyst E.N.Lepekhina.

and ages) are at one sigma level, errors of calculated concordant ages and intersections with concordia are at two sigma levels. Concordia plotting (Wetherill, 1956) was carried out using ISOPLOT/EX program (Ludwig, 1999).

U–Pb SHRIMP data

Zircons from gneissic quartz monzodiorite (S3E, Velitkenay batholith) are represented by colorless or yellowish idiomorphic elongate-prismatic (1:4–1:10) crystals, with lengths ranging from 300–800 μm (Fig. 3a). CL zonation of the imaged crystals is predominantly oscillatory without apparent cores, suggesting a magmatic origin. All 10 analyses yield a weighted mean 206Pb*/238U concordant age of 105.3±1.2 Ma (MSWD=0.06, P=0.81) (Fig. 3c, Table 1). Nearly the same age (105–100 Ma) for the Velitkenay batholith was confirmed by V.V.Akinin et al., (2012).

Zircons from massive porphyric granodiorite (SL1, Moltykan batholith) are represented by colorless or yellowish idiomorphic short- and elongate-prismatic (1:2–1:5) crystals, with lengths ranging from 200–500 μm (Fig. 3b). CL zonation of the imaged crystals is predominantly oscillatory, suggesting their magmatic origin, and apparent cores are absent. All 10 analyses yield a weighted mean 206Pb*/238U concordant age of 107.0±1.0 Ma (MSWD=0.49, P=0.48) (Fig. 3d, Table 1).

Thus the age of both batholiths corresponds to Albian Stage of Cretaceous they are the same within the analytical error despite their structural difference.

GEOCHEMISTRY

The element analysis of rock's samples was made at the laboratory of the nuclear-physical and mass-spectrum method analysis involved in the Analytic Certification Testing Center of the Institute of Microelectronics Technology and High Purity Materials of Russian Academy of Science. The content of Li, Be, Na, Mg, Al, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Rb, Sr, Y, Zr, Nb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Pb, Th, and U in rocks was determined using inductively coupled plasma mass spectrometry (X-7, *Thermo Elemental*, USA) and inductively coupled plasma atomic emission spectrometry (ICAP-61, *Thermo Jarrell Ash*, USA).

Granitoids of Chaun fold zone including Velitkenay and Moltykan batholiths have characteristics that are similar to those of post-orogenic plutons formed in extensional tectonic settings. They fall in the field of post-collisional granites on Pearce (1996) discriminant diagram (Fig. 4) and in the same fields with Chaun zone granites of QAP diagram (Le Maitre, 1989) (Fig. 5). For comparison we included mid-Cretaceous granitoids of Kigluaik pluton of the Kigluaik gneiss dome, Seward Peninsula, Alaska (Amato and Wright, 1997). These granitoids are subalkaline, typical for all granitic complexes of the Chaun fold zone (Tikhomirov, 1998; Tikhomirov and Luchitskaya, 2006; Dudkinsky et al., 1993; 1997).

Granitoids of Velitkenay and Moltykan batholiths have identical fractionated chondrite-normalized patterns with negative Eu-anomalies (La_N/Yb_N=8.85; 10.71; Eu/Eu*=0.43; 0.55) (Fig. 6, Table 2). They are similar to those of granitoids of

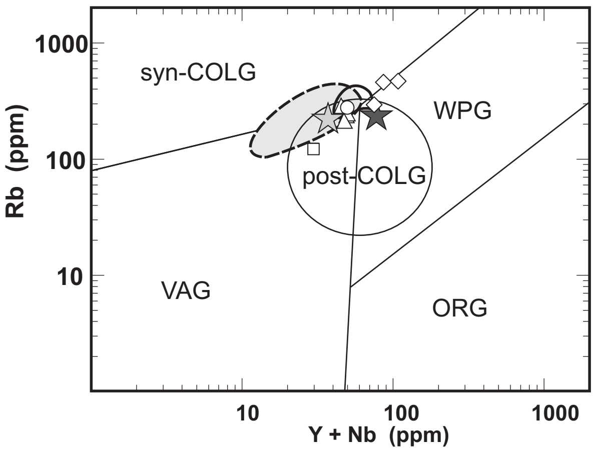
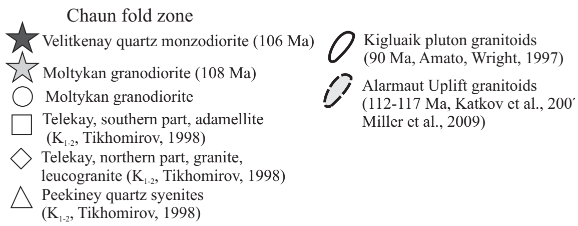


Fig. 4. Rb vs Y+Nb diagram (Pearce et al., 1984) for dated granitoids of Velitkenay and Moltykan batholiths, granites from other plutons of Chaun fold zone, Alarmaut Uplift granitoids (Chukotka) and granitoids of Kigluaik pluton, Seward Peninsula (Alaska)



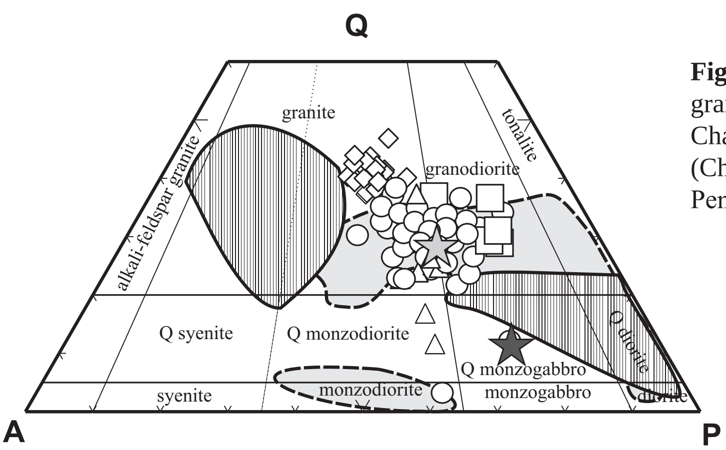


Fig. 5. QAP diagram (Le Maitre, 1989) for granitoids of Velitkenay and Moltykan batholiths, Chaun fold zone granites, Alarmaut Uplift granites (Chukotka) and granites of Kigluaik pluton, Seward Peninsula (Alaska). See fig. 4 for unit names

the other plutons of Chaun zone and Alarmaut Uplift. More differentiated leucogranites and granites of Telekay pluton (Chaun zone) and Kigluaik pluton have more pronounced negative Eu-anomaly (Fig. 6B).

Spidergrams of Velitkenay and Moltykan batholiths are characterized by enrichment of lithophile elements, light rare earths and negative Ta, Nb, Sr, Ti anomalies (Fig. 7). They are also similar to granitoids of other plutons of Chaun zone, Alarmaut Uplift and Kigluaik pluton.

DISCUSSION AND CONCLUSIONS

Comparison with other available U-Pb SHRIMP zircon data indicates that our ages are similar to those of Yanrapaak pluton near Pevek City (108.1±1.1 Ma, Miller and Verzhbitsky, 2009). Our ages are slightly younger than those of Aptian-Albian granitoids of the Alarmaut Uplift in more western part of Anyui-Chukotka fold system (116–112 Ma, Katkov et al., 2007, Miller et al., 2009). The latter are

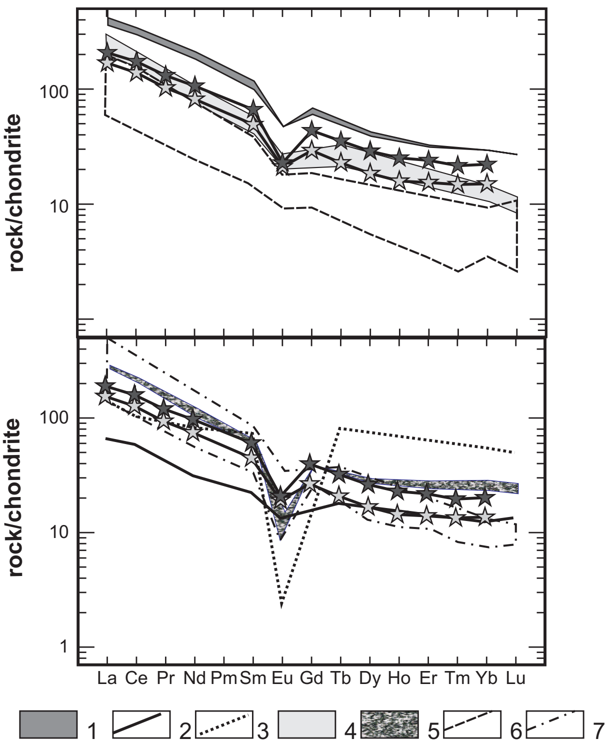


Fig. 6. Chondrite-normalized REE patterns for granitoids of Velitkenay, Moltykan batholiths and plutons of Chaun zone, Alarmaut Uplift and the Kigluaik pluton. Normalization to chondrite (Sun and Donough, 1989). For symbols see Fig. 4

Table 2. Major (wt.%) and trace elements (ppm) of granitoids of Velitkenay and Moltykan batholiths

	Velitkenay	Moltykan
Nosam.	S3E	SL-1
SiO_2	58.9	69.2
TiO_2	1.0	0.46
Al_2O_3	16.1	14.8
Fe_2O_3*	7.7	3.7
MnO	0.13	0.063
MgO	3.5	1.7
CaO	6.3	2.5
Na_2O	3.2	3.0
K_2O	2.8	4.4
P_2O_5	0.33	0.14
S	0.05	0.02
Total	99.97	99.99
Li	35.1	52.5
Be	5.2	4.7
Sc	16.9	11.7
V	85.6	60.3
Cr	36.3	47.7
Co	18.0	8.3
Ni	30.5	23.1
Cu	10.1	17.7
Zn	124	60.7
Ga	19.9	16.1
Rb	243	227
Sr	402	362
Y	40.4	23.0
Zr	109	173
Nb	25.2	13.1
Cs	12.7	11.8
Ba	505	900
La	48.6	39.5
Ce	105	83.7
Pr	12.3	9.6
Nd	49.0	37.6
Sm	10.0	7.4
Eu	1.3	1.2
Gd	8.8	5.9
Tb	1.3	0.84
Dy	7.2	4.6
Ho	1.4	0.88
Er	3.9	2.5
Tm	0.54	0.37
Yb	3.7	2.5
Lu	0.53	0.34
Hf	3.3	5.2
Ta	1.4	0.8
Pb	24.5	38.5
Th	16.9	23.7
U	3.0	4.3
Lan/Ybn	8.85	10.71
Eu/Eu*	0.43	0.55

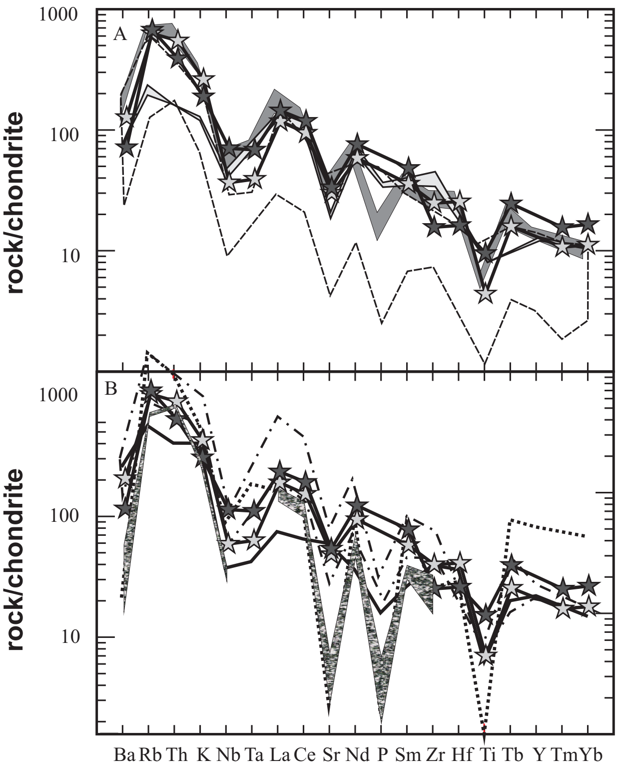


Fig. 7. Spidergrams for granitoids of Velitkenay, Moltykan batholiths and plutons of Chaun zone, Alarmaut Uplift and Kigluaik pluton. For symbols see Fig. 4 and 6.

undeformed granitoids associated with the central part of the granite-metamorphic core complex and are considered as extension-related post-collisional plutons, intruded the final stages of collision between active margin structures of North-Asian (Siberian) continent and Chukotka-Alaska microcontinent (Bondarenko and Luchitskaya, 2003, Miller et al. 2009, Miller and Verzbitksy, 2009; Luchitskaya et al., 2010). Extension might be associated with strike-slip movements (Bondarenko, 2004). The age of Moltykan and Velitkenay batholiths is similar to the age of metamorphism in the framework of Alarmaut Uplift granitoids (109–103 Ma), that is extensional in nature and post-dates collision (Miller et al., 2009) and the age of undeformed post-tectonic granitoid plutons of the South-Anuyi zone (109 Ma) (Miller et al., 2009; Luchitskaya et al., 2010). U-Pb zircon and monazite data of Koolen’ granite-metamorphic core complex of eastern part of Anyui-Chukotka fold system show that the age of metamorphism synchronous with extenstion (orthogneiss) (108 Ma) and deformation (deformed pegmatite) (104 Ma) coincides with the ages of Velitkenay and Moltykan batholiths (Bering Strait Geologic Field Party, 1997; Akinin, 2011). The age of non-deformed granites of Koolen’ complex is younger (94 Ma) (Bering Strait Geologic Field Party, 1997).

Many authors noted the interrelation between extension processes and the formation of plutonic belts and individual intrusions in northeastern Russia territory (e.g., Bering Strait Geologic Field Party, 1997; Layer et al., 2001, Toro et al., 2003; Miller and Verzhbitsky, 2009; Miller et al. 2009). Layer et al. (2001) used $^{40}Ar/^{39}Ar$ dating of magmatic complexes to distinguish two extensional events: an older one from 135–120 Ma and a younger one from 110–93 Ma. In their opinion the older event was probably related to post-accretionary northwest translation of the now-accreted Kolyma-Omolon terrane relative to North Asia. Subsequently the entire region was subjected to east-west extension resulting in the intrusion of plutonic belts that have within-plate characteristics. This extension could be the consequence of north-south closure of the South-Anyui suture. The age of the second younger extensional event coincides with our ages from the Velitkenay and Moltykan batholiths.

The shape and the spatial distribution of granitic bodies of the Chaun zone suggest their emplacement was controlled by faults of north-west and north-east strike. NS and NE average dike orientations and east-west, and north-west extension directions inferred from structural data in the region were proposed by Miller and Verzhbitsky, 2009. Our data support a model of northeast-southwest extension direction (Fig. 8). To explain the synchronous formation of both NE and NW-trending plutons, we use the tectonic model which implies the combination of NW-SE extension and right-lateral strike-slip deformations within the area north of the South Anyui zone (Miller et al., 2009). The gneissic structure of some granites and the observed manifestations of regional metamorphism may be associated with the formation of gneiss domes (Gel’man, 1996; Amato and Miller, 2004; Miller et al., 2009, Akinin et al., 2009; and references therein). Such complexes could have formed in a transtensional stress regime – a suggestion consistent with the S-shaped outlines of Velitkenay pluton (Fig. 2).

The SHRIMP U-Pb zircon dates obtained for the Velitkenay and Moltykan batholiths are similar to the

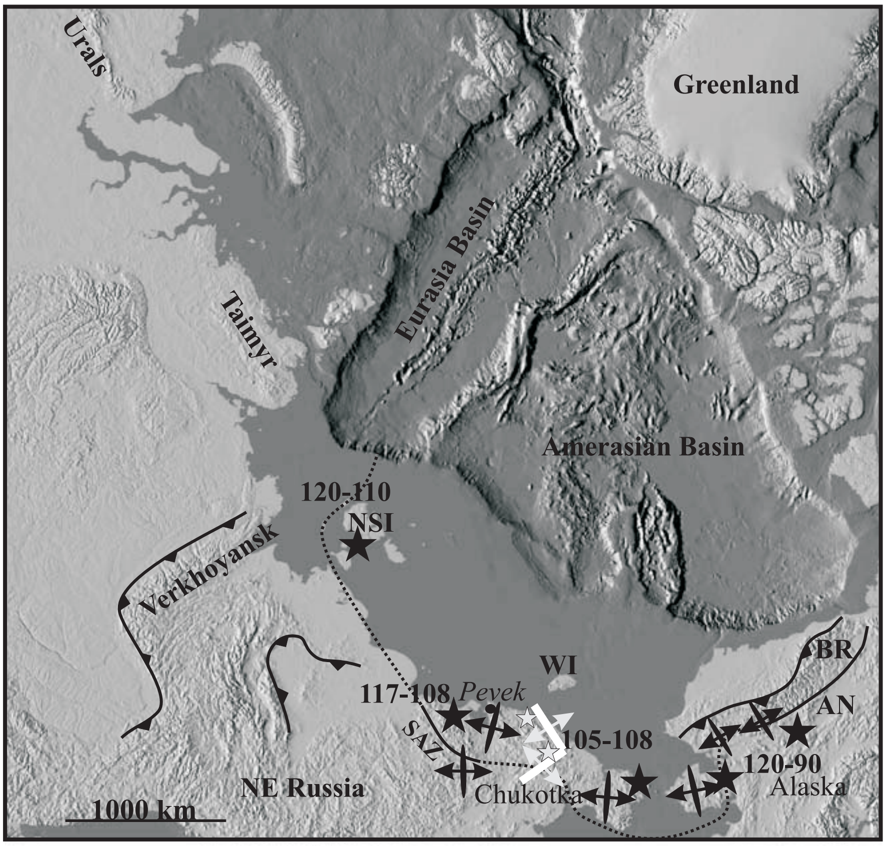


Fig. 8. Circum-Arctic map, modified after (Miller and Verzhbitsky, 2009). Black stars are Cretaceous magmatic activity and elongate ellipses are average dike orientations and inferred extension directions (thin lines) based on land geology (Miller and Verzhbitsky, 2009). White stars are Velitkenay and Moltykan batholiths and white sections are their orientations and inferred extension directions. Cretaceous extension directions in northern Alaska (south flank of Brooks Range and Seward Peninsula), the Bering Strait region and adjacent Chukotka are N-S oriented and are from Miller et al. (2002). AN – Angayucham belt, BR – Brooks Range, NSI – New Siberian Islands, WI – Wrangel Island

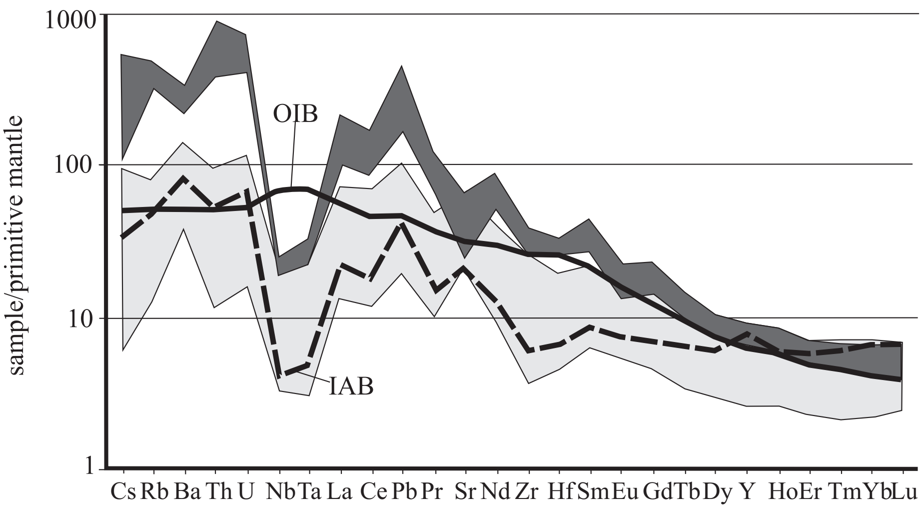


Fig. 9. Spidergrams for rocks of Etchikun Suite (dark grey), Okhotsk-Chukotka volcanic rocks, northern part (light grey). IAB, island arc basalt, OIB, oceanic island basalt (P.L.Tikhomirov, unpublished data). OIB, IAB normalization values are from Sun and Donough (1989)

age of the Etchikun suite (106 Ma – unpublished data of P.L.Tikhomirov). Within the study area this suite is considered as the lowermost unit of the Okhotsk-Chukotka volcanic belt. This suite is composed of trachybasalts, trachyandesites, latites and is shoshonitic series rocks, compositionally similar to subalkaline granitoids of Chaun zone. Spidergrams of Etchikun suite rocks are characterized by large-ion lithophile elements enrichment, depletion of high-field strength elements and pronounced Ta-Nb negative anomaly (Fig. 9). These facts, as well as a significant hiatus of about 15 m.y. at the top of the Etchikun suite, infer that the latter may be not linked to the Okhotsk-Chukotka belt. Instead, it could be related to the same mid-Cretaceous extensional event which that produced most of granitic bodies of the Chaun zone.

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