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Origin of the Early Mesozoic Bogd Uul granite pluton, Ulaanbaatar area, Mongolia

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Abstract

We present new isotopic age and geochemical data of the Bogd Uul granite pluton occurred in the margin of Khentey uplift, in the Ulaanbaatar area. The Bogd Uul granite pluton consists of slightly peraluminous, high-K, calc-alkaline series biotite and hornblende-biotite granite of A2-type. The Rb-Sr isochron age of the Bogd Uul granite pluton in this study confirm our former determined early Mesozoic age of the single zircon lead evaporation, and U–Pb isotopic analyses using a Laser Ablation Inductively Coupled Plasma Mass Spectrometer (LA-ICP-MS). The Bogd Uul granite pluton is formed in post-collisional environment, and granitic magma derived from continental crust contaminated with juvenile mantle-derived component due to geochemical analyses and Rb-Sr isotopic data which show the initial $^{87}Sr/^{86}Sr$=0.7005-0.7030, εNd(T)=(+0.7)–(+1.4), model ages of 826-1077 Ma. The topological analyses of zircon in the Bogd Uul granite pluton confirm the mixed sources which determined isotopic and geochemical data.

Key words: *Mongolia, Mesozoic, A2-type granite, Rb-Sr isotope*

1. Introduction

The Bogd Uul granite pluton occupies the eastern part of the Bogd Uul Mountain in south of the capital city of Ulaanbaatar, Mongolia (Fig.1). It is one of the numbers of small plutons surrounding the Khentey uplift of the western part of the Mongol-Okhotsk belt (Kovalenko et al., 1971) which named zone of Mesozoic granitoids in Central Asia. The Bogd Uul granite pluton previously dated by K-Ar method at 154 Ma (Bobrov et al., 1962) and 138 Ma (Koval et al., 1982), which relates to the Late Mesozoic granite belt. This age was controversial with other similar granite plutons of Early Mesozoic age near the Ulaanbaatar area. Mesozoic granitoids of the western part of Mongol-Okhotsk belt are well studied (Kovalenko et al., 1971; Khasin et al., 1973; Antipin, 1977; Kovalenko et al., 1984; Gerel, 1990; Koval, 1998), but the Bogd Uul granite pluton is poorly studied due to the lack of good outcrops that are covered by plants and boulders of fluvio-glacial processes. In addition, because the Bogd Uul granite pluton area is included in a protected area (recently it became the Bogdkhan Uul national Park), the Bogd Uul granite pluton area has been poorly studied. In this paper, we present new geochemical and isotope data that help to understand the origin of the Bogd Uul granite pluton.

2. Geologic setting

Tectonically, the Ulaanbaatar area belongs to the Khangay-Khentey basin (Sengor et al., 1993; Tomurtogoo, 1997) consisting mainly of the Bogd Uul granite pluton and an accretionary complex of the Gorkhi Formation and Late Paleozoic cover sequences (Kurihara et al., 2009). The Bogd Uul granite pluton is roughly oval-shaped, elongated and occupies an area of 200 km^2. The contact of granites with country rocks is sharp, tectonic in the west, southwest and southeast, intruded cover sequences in the north-west, and controlled by the north-east trending fault (Fig. 2). At the margins of the Bogd Uul gran-

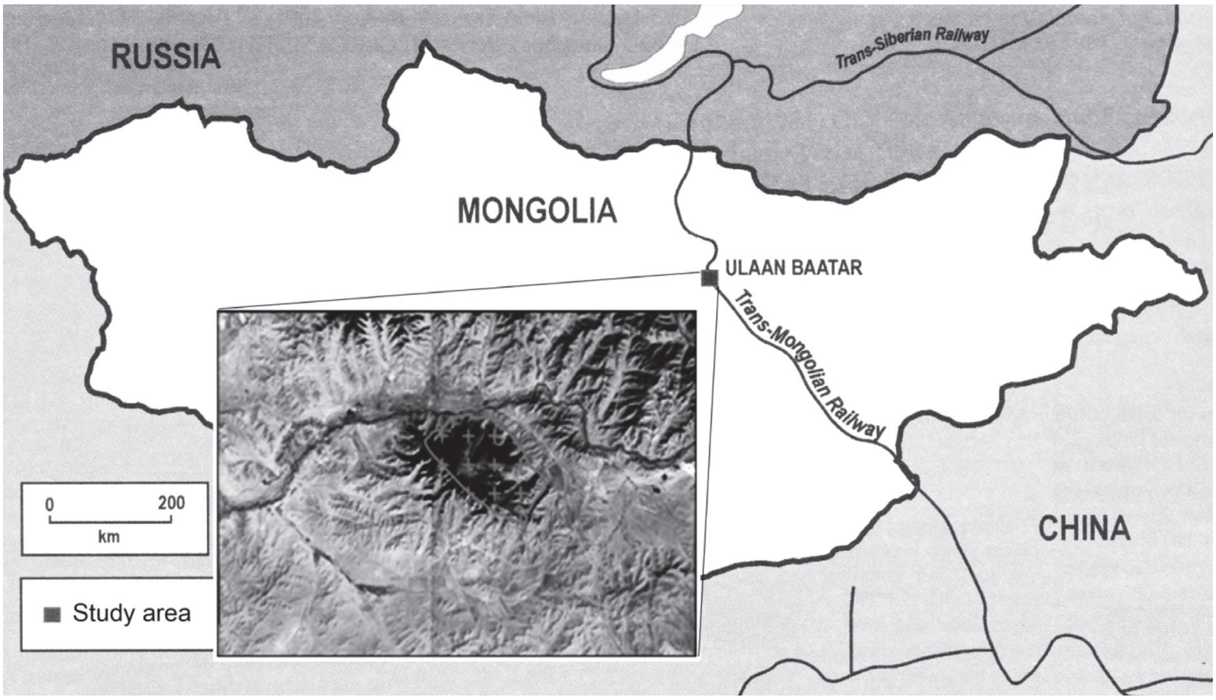

Fig. 1. Location map of the Bogd Uul granite pluton

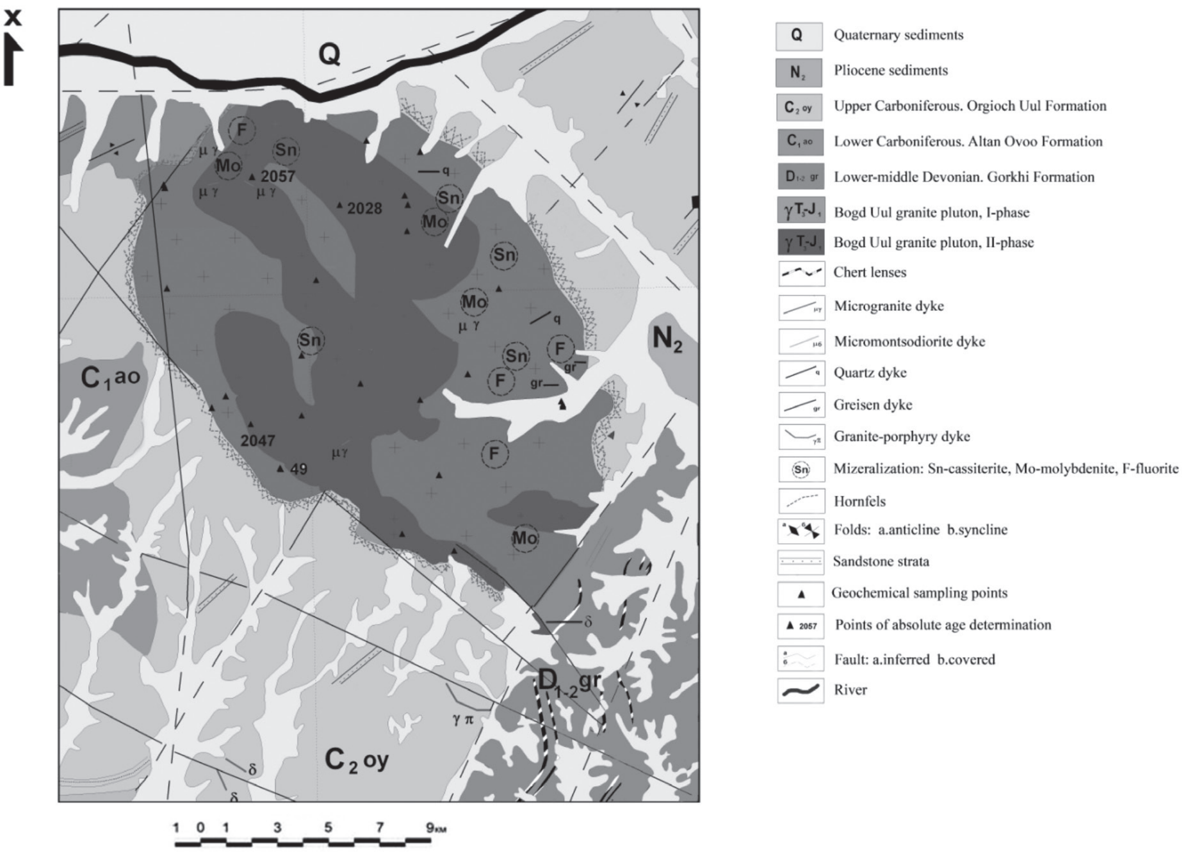

Fig. 2. Geologic map

ite pluton, hornfels formed contact with aureole in the host rocks.

The Bogd Uul granite pluton consists of biotite and biotite-hornblende granite (I phase) and porphyritic biotite granite (II phase). The biotite-hornblende granite (I phase) composed of mainly subhedral microcline-perthite (40-45%), quartz (25-30%), subhedral zoned plagioclase (10-15%), biotite (5-10%) and hornblende (1-5%). Interstitial minerals are quartz and microcline. Accessory minerals include apatite, zircon, R-zircon, ilmenite and sphene. Secondary minerals are sericite and chlorite. The biotite-granite (II phase) composed of mainly microcline-perthite (40-45%), quartz (25-30%), plagioclase (20-25%), and biotite (5-6%). The accessory minerals include zircon, R-zircon, sphene, apatite, fluorite, orthite, and tourmaline. The granites are altered to the chlorite, sericite, pellite. The Bogd Uul granite pluton intruded by little microgranite and aplite dykes. Microgranite consists of 45-50% microcline-perthite, 15-20% plagioclase, 25-30% quartz, and 5-6% biotite. It contains the accessory minerals of apatite, zircon, radio-active zircon and secondary minerals of pellite, albite, sericite, chlorite, and iron-oxide.

The host rocks of the Bogd Uul granite pluton are accretionary complex of the Gorkhi Formation and the Late Paleozoic cover sequences. The Gorkhi Formation is composed of disrupted oceanic-plate stratigraphy with Late Silurian to Late Devonian radiolarian cherts that are, in some parts, underlain by oceanic island basalt and overlain by siliceous shale and turbiditic clastic rock sequences (Kashiwagi et al., 2003; Tsukada et al., 2006; Kurihara et al., 2006; Kurihara et al., 2009). The clastic rock includes zircons of 339 Ma and older (Kelty et al., 2008), suggesting that the age of the clastic rock sequences, i.e. the age of accretion, is Early Carboniferous or a little younger. The cover sequences of the Khangay-Khentey basin contain Late Paleozoic Formations, such as the Altan Ovoo and Orgioch Uul. The Altan Ovoo Formation consists of flysch mudstone, sandstone and shale. The Orgioch Uul Formation is composed of coarse-grained sandstone, mudstone, siltstone, gravelstone, and conglomerate, and there are no remains of fauna. The accretionary complex and cover sequences of this area cut by fine-grained granite-porphyry dykes dated at 223.5±30.2 Ma (^{206}Pb); 294.2±51.4 Ma (^{207}Pb), and micromonzodiorite dyke could be of similar age with previous granite-porphyry dyke (Khishigsuren et al., 2009). According to the discrimination diagram of the Pearce et al. (1984), they are interpreted to be formed in the island arc and syn-collisional tectonic setting (Khishigsuren et al., 2006), except for the Bogd Uul granite pluton.

The Pliocene deposits, which are determined by the fauna, are developed in the eastern part of the pluton. The Pliocene deposits contain of medium-grained conglomerate, consisting essentially of rounded pebbles of locally derived sandstone in a red argillaceous matrix. The area has been strongly influenced by periglacial processes. The scattered granite blocks are distributed in northern part of the Bogd Uul granite pluton, which are probably relics of fluvio-glacial activity characteristic after the last glaciations. In the Tuul river basin, fluvial and aeolian deposits of Quaternary age are distributed.

3. Analytical methods

Chemical analyzes were conducted on representative samples from the Bogd Uul granite pluton using X-ray fluorescence (XRF) in geochemical laboratory of Federal Institute for Geosciences and Natural Resources, Germany. The REE element (ICP-MS) and Rb-Sr, Sm-Nd isotopic analyses were performed in the geochemical laboratory of Middle East Technical University of Turkey.

The ε_{Nd}(T) values and fractionation factor ($f_{Sm/Nd}$) were calculated using the present-day values for a chondritic uniform reservoir (CHUR) ^{143}Nd/^{144}Nd=0.512638 and (^{147}Sm/^{144}Nd)=0.1967.

$$\varepsilon_{Nd}(T) = \left[\frac{(^{143}Nd\,/\,^{144}Nd)_s)}{(^{143}Nd\,/\,^{144}Nd)_{CHUR})} - 1 \right] \times 10^4$$

$$f_{Sm/Nd} = \left[\frac{(^{147}Sm\,/\,^{144}Nd)_S)}{(^{147}Sm\,/\,^{144}Nd)_{CHUR})} \right] - 1$$

The decay constants used in age computation are ^{87}Rb= 0.0142 Ga^{-1} and ^{147}Sm=0.00654 Ga^{-1}. Sm-Nd model ages are calculated in two ways. The one stage model age (T_{DM1}) is calculated assuming a linear Nd isotopic growth of the depleted mantle reservoir from εNd=0 at 4.56 Ga to εNd=+10 at the present.

$$T_{DM1}=\frac{1}{②}\ln\left[\frac{(^{143}Nd/^{144}_{1}Nd)_S-(^{143}Nd/^{144}Nd)_{DM}}{(^{147}Sm/^{144}Nd)_S-(^{147}Sm/^{144}Nd)_{DM}}+1\right]$$

Where s=sample, ②=decay constant of ^{147}Sm (②=0,00654Ga^{-1}), and $(^{147}Sm/^{144}Nd)_{DM}$=0.2137, $(^{143}Nd/^{144}Nd)_{DM}$=0.51315 (Peucat et al., 1988).

The two stage model age is obtained assuming that the protolith of the granitic magmas has a Sm/Nd ratio (or ($f_{Sm/Nd}$) value) of the average continental crust.

$$T_{DM2}=T_{DM1}-(T_{DM1}-t)\frac{(f_{cc}-f_s)}{(f_{cc}-f_{DM})}$$

Where f_{cc}, fs, f_{DM}=$f_{Sm/Nd}$ values of the average continental crust, the sample and the depleted mantle, respectively. In our calculation f_{cc}=–0/4, f_{DM}=0.08592 are used, and t= the intrusive age of granite. Rb-Sr isochron ages were calculated using the regression programs of ISOPLOT (Ludwig, 2008). The estimation of the proportions of juvenile crust (X^m=%) were calculated using the εNd^m=+8 and Nd^m=15 ppm for the juvenile (basaltic) component, and εNd^c=-30 and Nd^c=25 ppm for the crustal component.

$$X^m=(\varepsilon^c\text{-}\varepsilon^r)\cdot Nd_c/[\varepsilon^r\cdot(Nd_m\text{-}Nd_c)–(\varepsilon^m\cdot Nd_m\text{-}\varepsilon^c\cdot Nd_c)$$

4. Results and discussions

4-1. Geochemistry

The results of chemical analysis on 26 samples of the Bogd Uul granite pluton are shown in Table 1. The principal major element characteristics may be summarized as follows: 1) In the Q vs. ANOR classification scheme of Streckeisen and Le Maitre (1979), most rocks belong to granite and K-feldspar granite (Fig. 3); 2) The total alkali contents are 7.95-10.46; 3) In terms of K_2O vs. SiO_2 diagram all samples are plotted in the field of high-K calc-alkaline series (Fig. 4); 4) In an A/NK vs. A/CNK plot, all

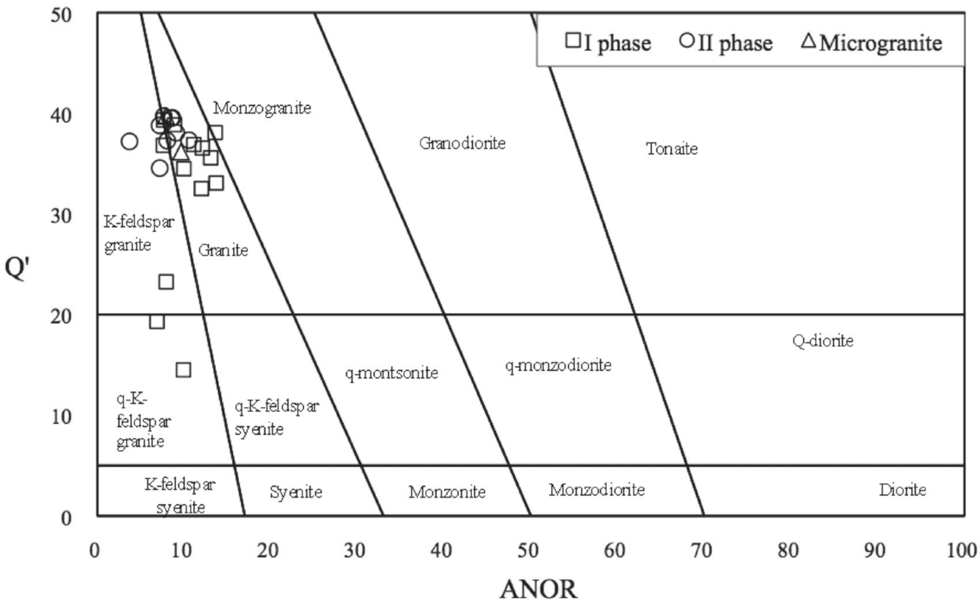

Fig. 3. Classification diagram (Streckeisen and Le Maitre, 1979) of the Bogd Uul granite pluton

Table 1. Chemical compositions of rocks from the Bogd Uul granite pluton

Rock type	I phase											II phase	
Sample No	**38**	**56**	**64**	**2003**	**2005**	**2028**	**2030**	**2051**	**2052**	**2053**	**2057**	**2064**	**29**
Longitude	47.86131	47.74389	47.85306	47.85889	47.83083	47.85583	47.85778	47.77528	47.80861	47.79083	47.51797	47.8816	47.82833
Latitude	106.9806	107.0615	107.0191	106.9421	107.0088	107.0476	107.0825	106.9929	107.0024	107.0024	106.5881	106.9763	107.0890
Major elements, %													
SiO_2	75.78	75.11	73.24	74.29	74.47	74.04	71.6	75.5	76.53	73.97	68.0	68.4	76.74
TiO_2	0.154	0.193	0.14	0.292	0.2	0.162	0.125	0.212	0.163	0.219	0.279	0.334	0.081
Al_2O_3	12.68	13.01	13.95	12.77	12.94	13.16	14.6	12.43	12.05	13.15	16.3	14.7	12.33
Fe_2O_3	1.64	1.77	1.65	2.22	1.93	1.89	1.38	1.9	1.74	1.99	2.27	3.03	1.23
MnO	0.03	0.026	0.033	0.036	0.038	0.039	0.03	0.038	0.038	0.043	0.04	0.06	0.026
MgO	0.08	0.1	0.07	0.22	0.13	0.07	0.08	0.18	0.11	0.17	0.30	0.29	0.01
CaO	0.682	0.468	0.546	0.92	0.65	0.796	0.82	0.755	0.466	0.882	1.05	1.63	0.503
Na_2O	3.79	3.75	3.94	3.53	3.9	3.96	4.15	3.82	3.57	4.06	4.40	4.19	3.51
K_2O	4.344	4.468	5.521	4.639	4.526	4.694	6.11	4.277	4.403	4.354	6.83	6.27	4.461
P_2O_5	0.029	0.025	0.026	0.074	0.044	0.029	0.012	0.046	0.027	0.05	0.130	0.145	0.007
(SO_3)	0.01	0.01	0.01	0.01	0.01	0.01		0.01	0.01	0.01	0.01	0.01	0.01
(Cl)	0.01	0.005	0.013	0.007	0.007	0.004	0.013	0.011	0.007	0.005	0.034	0.120	0.005
(F)	0.05	0.05	0.05	0.07	0.12	0.21	0.89	0.05	0.05	0.1	0.21	0.62	0.11
LOI	0.37	0.68	0.64	0.54	0.67	0.61	0.57	0.47	0.5	0.69	0.34	0.39	0.58
Σ	99.6	99.6	99.78	99.61	99.63	99.68	100.4	99.66	99.66	99.68	100.2	100.2	99.58
Trace elements, ppm													
(As)	3	2	13	19	5	15		2	4	2			4
Ba	181	213	201	354	189	193	40	199	157	253	484	388	32
Bi	3	3	3	3	4	4		3	3	3			3
Ce	101	88	147	173	125	151	99.35	102	90	118	104.95	90.89	
Co	3	4	3	3	4	3		3	3	3			3
Cr	3	3	4	3	3	3		3	3	3			3
Cs	11	6	21	8	9	19	12	10	12	10	11	17	15
Cu	10	10	15	10	10	10		10	10	10			10
Ga	25	24	33	25	19	30	28	21	23	25	25	25	31
Hf	5	10	8	9	8	7		5	9	10			6
La	39	78	70	104	83	58	44.61	71	47	61	46.92	32.85	104
Mo	2	3	3	2	2	2		2	3	2			2
Nb	15	23	32	17	24	25	27	19	18	21	15	18	44
Nd	55	60	43	87	57	50	39.17	55	50	69	45.31	44.66	64
Ni	3	3	3	3	3	3		3	3	3			4
Pb	35	30	36	27	46	42	60	25	30	30	26	59	21
Pr	50	50		50	50	50	11.17	50	50	50	12.02	11.67	50
Rb	294	249	546	233	326	440	499	288	270	299	274	284	522
Sb	5	5	6	8	5	6		8	5	5			5
Sc	2	3	2	4	2	2		2	2	3			2
Sm	50	50	14	50	50	50	8.48	50	50	50	8.97	10.36	50
Sn	3	10	15	7	4	24		4	47	5			9
Sr	53	44	37	110	42	51	16	59	37	72	120	112	12
Ta	5	5	7	5	5	5		5	5	5			5
Th	32	28	48	49	47	36	56	40	36	47	19	35	66
U	7	5	12	7	6	17	12	8	7	11			15
V	11	13	5	10	5	12		5	5	5			10
W	5	6	10	5	7	15		5	6	7			16
Y	63	31	77	78	54	88	78	32	14	32	35	60	113
Zn	54	60	47	51	32	43		45	47	35			35
Zr	201	229	217	355	264	250	176	221	217	243	106	178	224

Table 1. (Continued)

Rock type	II phase											Microgranite dyke	
Sample No	**33**	**34**	**43**	**47**	**48**	**65**	**2004**	**2018**	**2034**	**2038**	**2047**	**38/1**	**59/1**
Longitude	47.86872	47.79356	47.82839	47.79653	47.78833	47.84531	47.87203	47.50028	47.80028	47.80306	47.79306	47.86131	47.75139
Latitude	107.0545	107.1172	106.9432	106.9691	106.9800	107.0487	107.0309	107.1032	107.0282	107.0754	106.9629	106.9806	107.0440
Major elements, %													
SiO_2	76.02	76.55	75.62	75.02	76.69	76.93	76.22	77.04	77.18	77.14	75.25	76.57	77.58
TiO_2	0.096	0.092	0.206	0.206	0.15	0.089	0.096	0.097	0.063	0.082	0.219	0.091	0.075
Al_2O_3	12.57	12.21	12.38	12.76	12.2	12.5	12.34	12.03	12.11	12.26	12.91	12.52	12.29
Fe_2O_3	1.37	1.41	2.06	1.82	1.47	0.6	1.19	1.28	1.18	1.01	1.69	0.9	0.84
MnO	0.019	0.031	0.043	0.045	0.027	0.007	0.019	0.022	0.014	0.025	0.033	0.017	0.018
MgO	0.04	0.04	0.15	0.21	0.08	0.01	0.02	0.01	0.01	0.02	0.2	0.01	0.01
CaO	0.465	0.524	0.816	0.793	0.531	0.441	0.555	0.495	0.422	0.498	0.744	0.602	0.44
Na_2O	3.71	3.42	3.75	3.53	3.66	3.56	3.26	3.62	3.69	4.02	3.25	3.77	3.77
K_2O	4.87	4.772	4.043	4.734	4.348	4.609	5.192	4.334	4.259	4.069	4.922	4.865	4.183
P_2O_5	0.01	0.009	0.05	0.054	0.022	0.015	0.011	0.006	0.002	0.011	0.044	0.005	0.011
(SO_3)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
(Cl)	0.013	0.017	0.008	0.039	0.007	0.005	0.004	0.004	0.002	0.006	0.011	0.008	0.007
(F)	0.09	0.05	0.05	0.05	0.05	0.05	0.12	0.18	0.09	0.09	0.05	0.06	0.05
LOI	0.51	0.64	0.44	0.56	0.42	0.79	0.6	0.54	0.63	0.43	0.34	0.28	0.43
$\sum$	99.78	99.76	99.62	99.78	99.66	99.6	99.63	99.67	99.64	99.66	99.61	99.69	99.65
Trace elements, ppm													
(As)	2	19	6	6	2	7	5	10	2	8	2	2	2
Ba	65	117	202	238	124	117	88	17	5	58	320	42	17
Bi	2	4	3	2	3	3	3	3	3	3	3	3	3
Ce	134	102	120	112	95	91	111	128	91	66	108	35	29
Co	3	3	3	3	4	3	8	3	3	3	3	3	3
Cr	4	4	3	5	3	3	3	3	3	11	3	3	3
Cs	17	16	11	18	10	8	15	14	10	16	10	7	5
Cu	5	6	10	10	10	10	10	10	10	10	10	10	10
Ga	33	29	25	19	25	28	28	28	34	24	22	26	23
Hf	10	10	5	7	8	6	8	8	8	6	9	5	5
La	67	62	90	56	87	61	54	63	55	29	71	20	40
Mo	3	3	2	3	2	2	3	2	2	2	2	2	2
Nb	44	32	15	14	10	27	24	27	47	26	19	16	17
Nd	45	39	66	32	80	56	51	83	63	50	57	50	50
Ni	2	3	3	3	3	3	3	3	4	3	3	3	3
Pb	32	30	25	35	34	22	32	26	23	28	34	45	29
Pr			50		50	50	50	50	50	50	50	50	50
Rb	517	509	279	336	271	419	469	444	516	380	179	317	261
Sb	6	6	5	6	6	6	5	5	5	5	5	5	5
Sc	1	1	2	2	2	2	2	2	2	2	2	2	2
Sm	14	14	50	14	50	50	50	50	50	50	50	50	50
Sn	5	14	8	7	6	23	10	20	23	13	3	3	2
Sr	17	24	64	73	31	39	25	6	4	14	112	21	10
Ta	7	7	7	5	5	5	5	5	5	5	5	5	5
Th	57	47	41	43	47	51	45	49	45	54	28	45	38
U	12	3	11	6	3	8	8	6	3	13	7	6	4
V	5	5	12	8	5	5	5	6	5	5	5	5	5
W	16	6	5	5	5	16	11	8	10	5	17	5	5
Y	99	83	44	39	10	79	99	109	109	57	53	69	3
Zn	81	64	54	39	27	81	57	40	67	26	34	28	22
Zr	237	161	201	181	206	193	195	212	195	155	253	133	78

rocks plotted in the slightly peraluminous field (Fig. 5); 5) The Harker diagrams indicate that the SiO_2 contents are negative correlation with other major elements, and Sr, Zr, Ce, and Ba (Khishigsuren et al., 2006). Rb/Sr ratios of the Bogd Uul granite pluton are ranging from 1.6 to 43.5. The distinct negative anomalies in Ba, Sr, Ti and P in primitive mantle normalized spiderdiagrams (Fig. 6). Their REE patterns are almost similar to granitic and, with little Eu anomalies and rich in heavy REE (Table 2, Fig. 7).

Almost all the samples of the Bogd Uul granite pluton are plotted in the uppermost part of the WPG field on the Y vs. Nb diagram, and between the WPG and syn-COLG field on the Y+Nb vs. Rb discrimination diagrams of Pearce et al. (1984). Rocks of the Bogd Uul granite pluton were different from I-type and S-type granites and plotted in the A-type granite field on the diagrams of Walen et al., 1987 (Fig. 8). The Bogd Uul granite pluton show A2 type granite post collisional, anorogenic tectonic setting on the discrimination diagrams of Eby (Fig. 9).

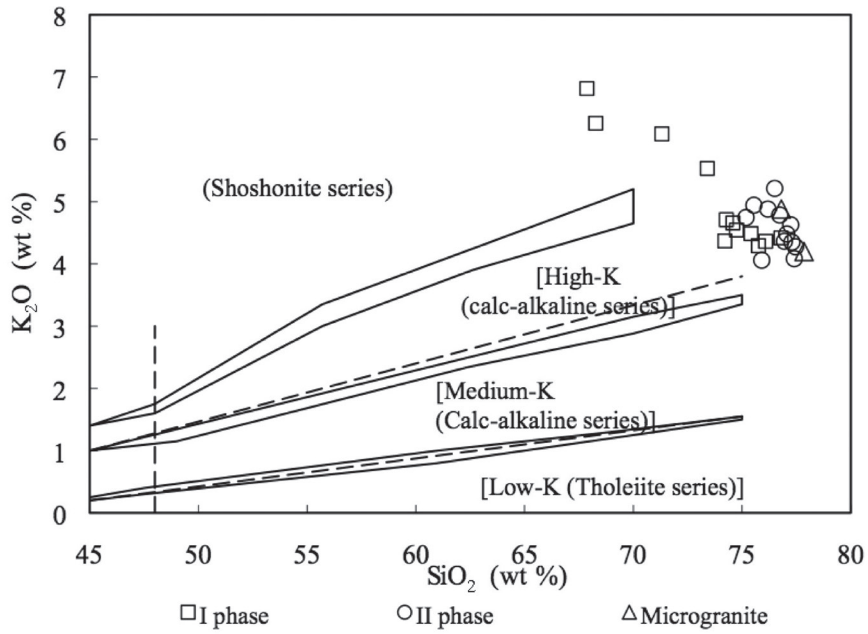

Fig. 4. The SiO_2 vs. K_2O diagram (Le Maitre et. al., 1989) of the Bogd Uul granite pluton.

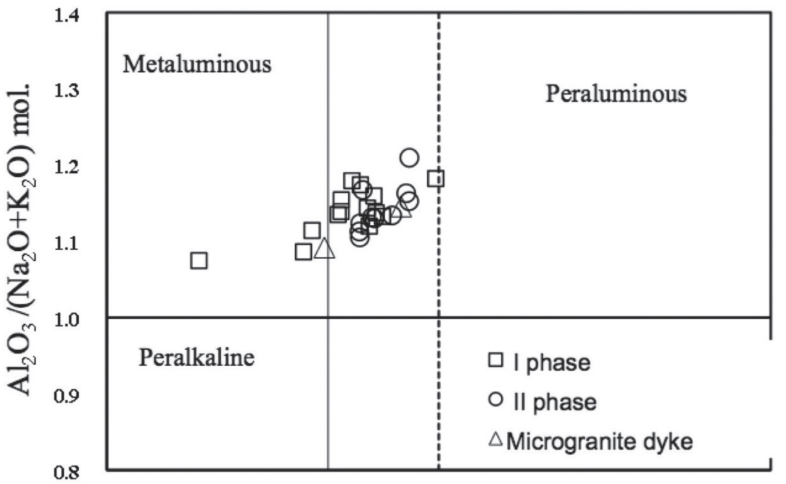

Fig. 5. The A/CNK-A/NK diagram of the Bogd Uul granite pluton. It shows the granites are slightly peraluminous.

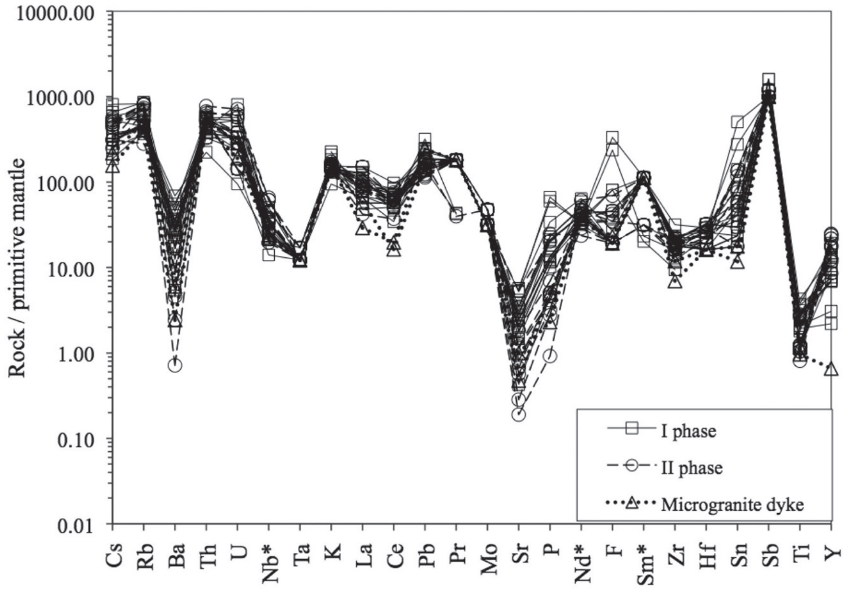

Fig. 6. Primitive mantle normalized (S.s. Sun and W.F. McDonough, 1992) trace element spider diagram of the Bogd Uul granite pluton

Table 2. REE compositions of rocks from the Bogd Uul granite pluton

Elements, ppm	33	2030	2034	2053	2057	2064
La	43.61	44.61	30.64	38.8	46.92	32.85
Ce	96.99	99.35	64.36	81.41	104.95	90.89
Pr	10.96	11.17	7.04	8.83	12.02	11.67
Nd	35.08	39.17	22.55	31.22	45.31	44.66
Sm	8.5	8.48	4.13	5.24	8.97	10.36
Eu	0	0.16	0.24	0.7	1	0.86
LREE	195.14	202.94	128.96	166.2	219.17	191.29
Gd	8.44	9.17	4.23	4.99	8.87	9.61
Tb	1.82	1.82	0.72	0.86	1.47	1.81
Dy	13.03	12.13	5.09	5.82	8.7	12.18
Ho	2.88	2.67	1.17	1.18	1.64	2.28
Er	10.03	8.86	3.35	3.75	5.72	7.64
Tm	1.7	1.57	0.64	0.74	0.88	1.13
Yb	12.36	11.09	4.38	4.47	5.45	7.63
Lu	1.69	1.65	0.67	0.78	0	1.2
HREE	51.95	48.96	20.25	22.59	32.73	43.48
REE total	247.09	251.9	149.21	188.79	251.9	234.77
La/Yb	3.53	4.02	7	8.68	8.61	4.31
LREE/HREE	3.76	4.15	6.37	7.36	6.7	4.4

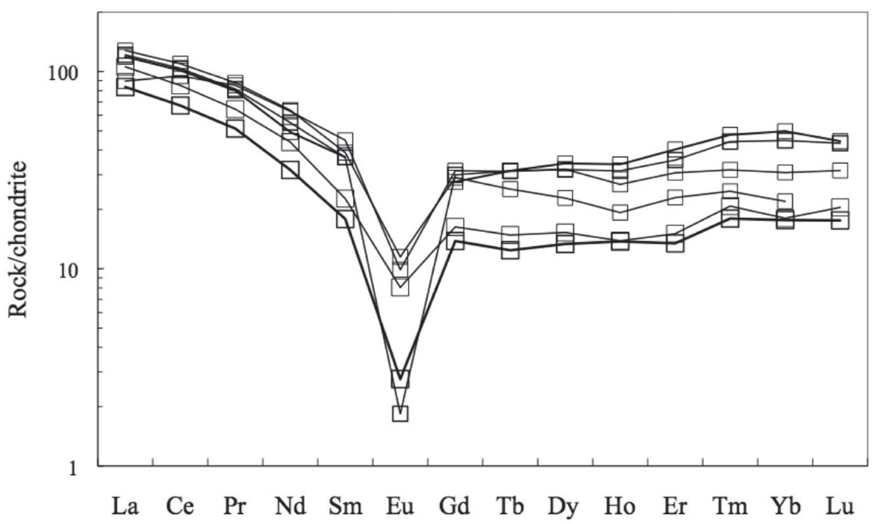

Fig. 7. Chondrite normalized (Taylor and McLennan, 1985) REE spider diagram of the Bogd Uul granite pluton

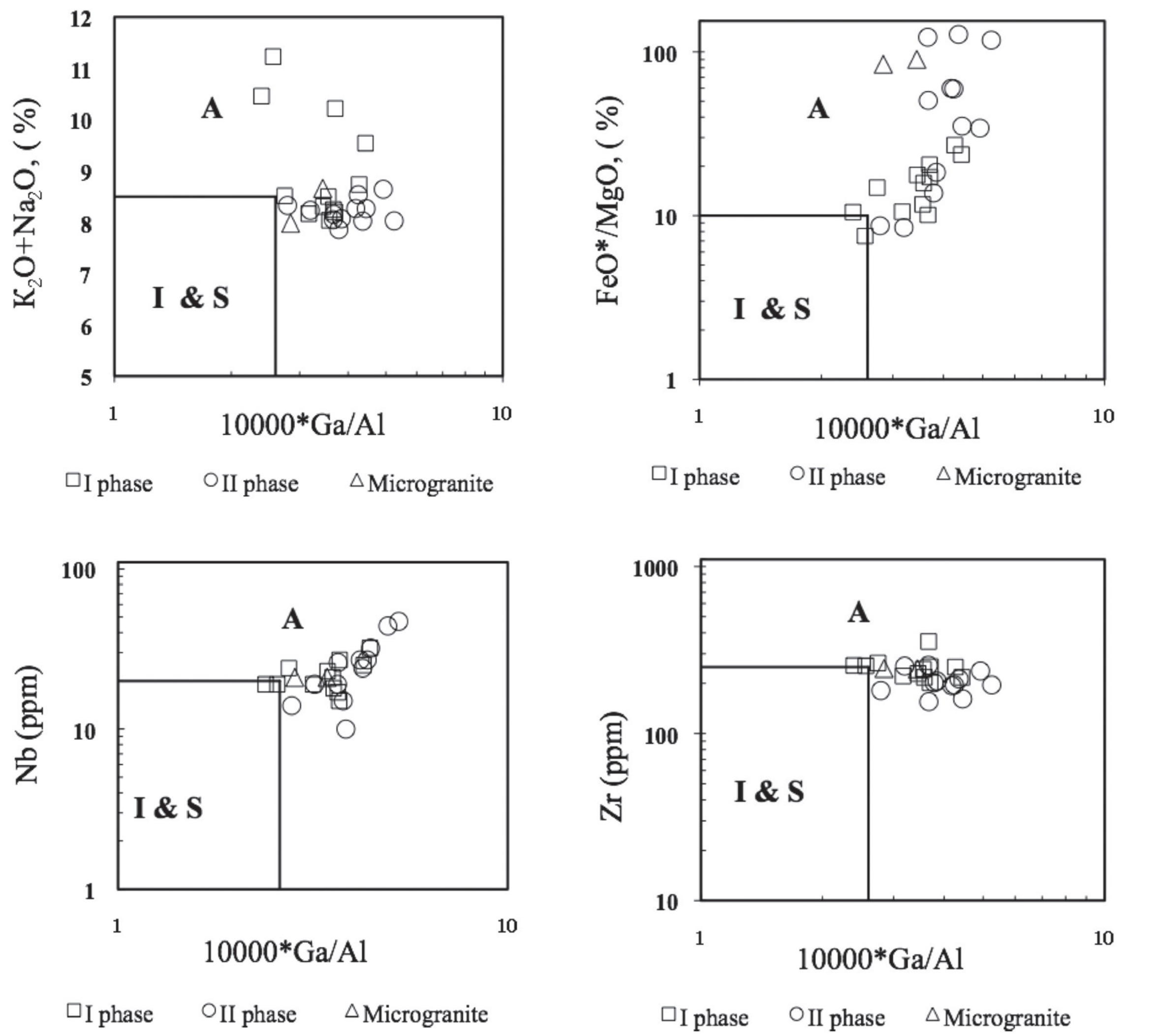

Fig. 8. The 10000 Ga/Al vs. K_2O+Na_2O, FeO*/MgO, Nb, and Zr diagram of the Bogd Uul granite pluton (Whalen et al., 1987). All the diagrams show that the Bogd Uul granite pluton different from I-type and S-type granite.

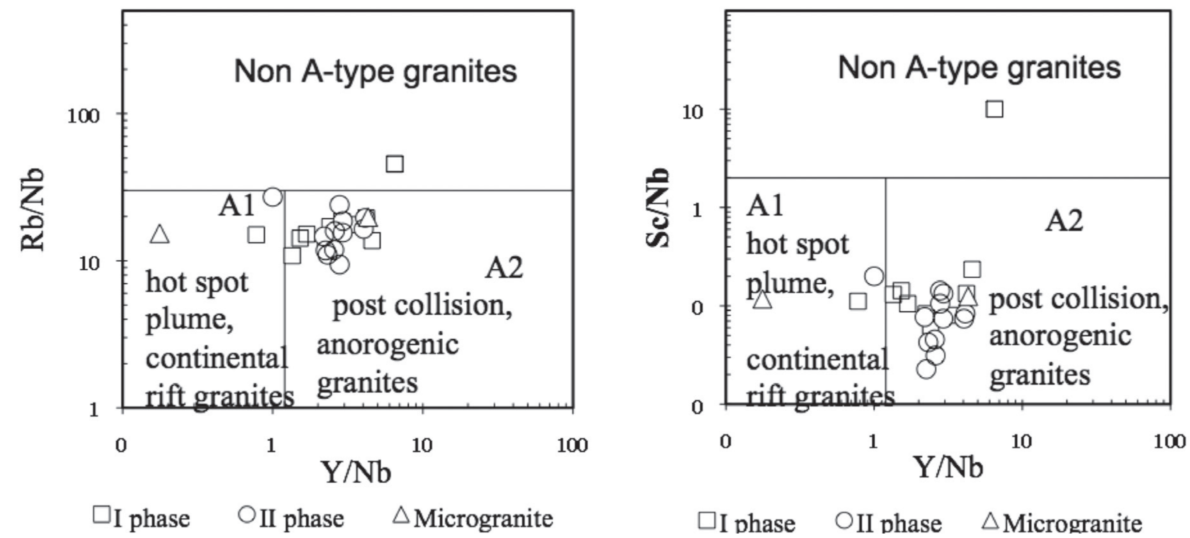

Fig. 9. Rb/Nb vs.Y/Nb and Rb/Nb vs. Y/Nb diagrams (Eby, 1992) of the Bogd Uul granite pluton. All two diagrams of Eby show that rocks of the Bogd Uul granite pluton are similar to the A2-type granite.

4-2. Geochronology

The Rb-Sr isotope data of 4 samples of the Bogd Uul granite pluton define an isochron age of 211 Ma with Sr*I* = 0.7025±0.0022 which shows the early Mesozoic age in this study. This result confirms our previously determined single zircon lead evaporation and U–Pb isotopic ages of early Mesozoic. Our previously determined ages of the Bogd Uul granite pluton range from 205.7±4.1 to 208.4±9.1 Ma by the single zircon lead evaporation analyses in the Freiberg University, Germany (Khishigsuren et al., 2003), and from 181.4±7.7 to 212.5±10.8 Ma by the single zircon age of $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$ ratios, obtained in the Tokyo Institute of Technology, Japan (Khishigsuren et al., 2009). These 3 results of our studies show the Bogd Uul granite pluton formed in Early Mesozoic time and reveal the older formation age than the previously determined Late Mesozoic K-Ar age by Bobrov et al., (1962) and Koval et al., (1982).

4-3. Zircon morphology

The topological distribution determined on the basis of the examination of 638 unbroken zircon crystals which were selected from 28 samples (Khishigsuren, 2007). The zircon crystals are dark reddish, dominantly yellowish-brown to brown, radiation-damaged (up to 60%), mainly euhedral normal prismatic, sometimes stubby. Typological analyses of zircons from the Bogd Uul granite pluton dominantly show D, P5 field (about 60%) and P4, P3, J5, S25 types (Fig. 10). It reflects on the crystallization environment with dominance of {101} pyramids and {110} prisms, shows that the Bogd Uul granite pluton was derived from subalkaline magma with mixed materials. The temperature of the zircon morphology diagram is almost the same (750-900°C) on the binary diagram Zr vs. (Na+K+2Ca)/(Al*Si) after Watson and Harrison, 1983 (Fig. 11).

4-4. Sr-Nd isotope

The calculated Sr*I* given in Table 3 provides the most of the Sr initial isotope ratio of rocks have low

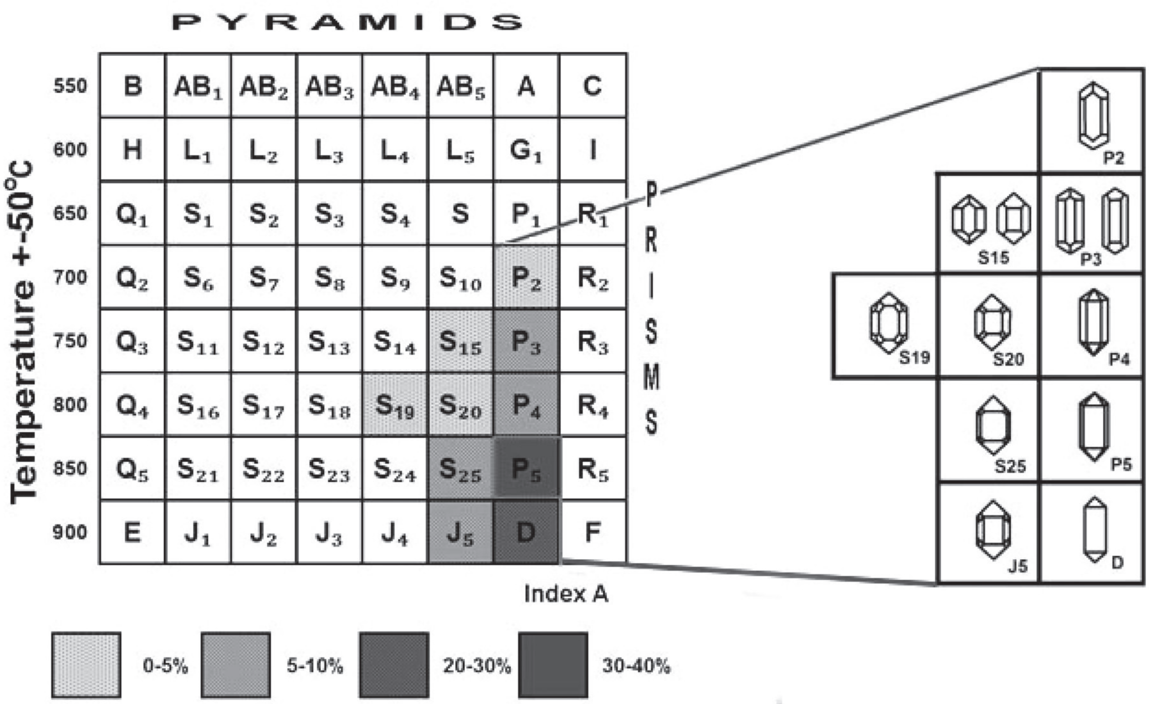

Fig. 10. Zircon morphology, and their estimation of the Bogd Uul granite pluton. Zircon typological classification and corresponding geothermometric scale proposed by Pupin (1980). Index A reflects the Al/alkali ratio controlling the development of zircon pyramids, whereas temperature affects the development of different zircon prisms. 50-70 % of the zircon crystals of the Bogd uul granite pluton are belongs to the D and P5 field.

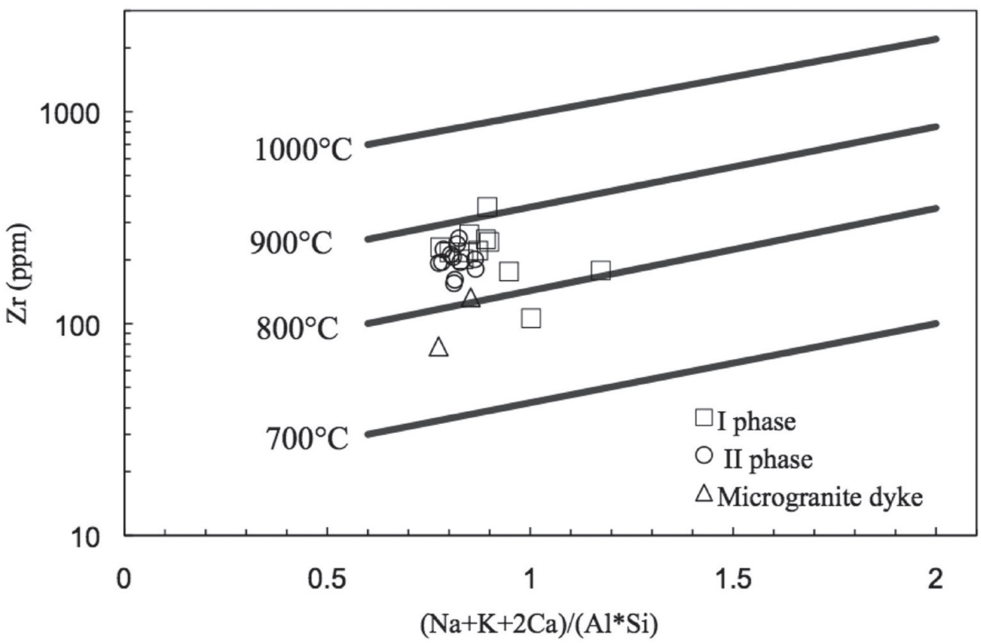

Fig. 11. The Zr vs. M=(Na+K+2Ca)/(Al*Si) binary diagram of the Bogd Uul granite pluton (Watson and Harrison, 1983)

Sr*I* isotope ratios between 0.7005-0.7030, except for one sample (0.7101). Sm-Nd analyses revealed that ε_{Nd}(T) values are ranging from +0.7 to +1.4. The model age (T_{DM1}) of the Bogd Uul granite pluton is 826-1077 Ma (Fig. 12) and they are plotted in the field of Caledonian mobile belt of Central Asia. The tectonics and magmatism of the Caledonian mobile belts, which coincide with the Caledonian isotope province of the Central Asian Mobile belt, are described by Kovalenko et al. (2004). They showed significant effect of contamination by Precambrian basement rock.

The Bogd Uul granite pluton isotopic characteristics are quite similar to those observed in Mesozoic granitoids of Khentey uplift. The slightly positive ε_{Nd}(T) values and Neo-Mesoproterozoic Nd model ages of the Bogd Uul granite pluton are similar to Mesozoic granitoids related to the collision of the North Asia and Sino-Korean continents and intraplate igneous activity. The Bogd Uul granite pluton occurred on the correlation line for the Caledonian province and between the fields of Nd isotope evolution for the island arc felsic igneous rocks and terrigenous metasediments of the microcontinental blocks of the ε_{Nd}(T)-age plot (Fig. 13). It indicates that parental melts of the Bogd Uul granite pluton most probably were formed from mixed sources consisting of relatively juvenile Caledonian and long-lived crustal materials.

Assuming a fixed depleted mantle component and variable crustal end-members, the result of the isotopic mass balance calculation is shown on Fig. 14. It suggests that the granitoids were derived from source composed of mixed materials with juvenile mantle-derived component.

Table 3. Sr-Nd isotope data of the rocks from the Bogd Uul granite pluton

Sample	Pb age	Sr (ppm)	Rb (ppm)	$^{87}Sr/^{86}Sr$	$^{87}Rb/^{86}Sr$	SrI	Nd (ppm)	Sm (ppm)	$^{143}Nd/^{144}Nd$	$^{147}Sm/^{144}Nd$	Nd*I*	ε_{Nd}(T)	$f_{(Sm/Nd)}$	T_{DM1}, Ma	T_{DM2}, Ma	Xm
2034	208	29.1	476.31	0.852470	48.02755	0.71013	22.55	4.13	0.512584	0.1107225	0.512433	1.2	–0.4371	838	886	88.5
2053	208	80.98	348.26	0.737508	12.47891	0.70053	31.22	5.24	0.512542	0.1014674	0.512404	0.7	–0.484152	826	933	87.4
2057	206	120	274.14	0.722326	6.621849	0.70296	45.31	8.97	0.512606	0.1196832	0.512445	1.4	–0.391545	882	870	88.8
2064	206	111.9	283.85	0.724504	7.349232	0.70301	44.66	10.36	0.512631	0.1402421	0.512442	1.3	–0.287026	1077	874	88.7

The calculation of $\varepsilon_{Nd}(T)$ values, fractionation factor ($f_{Sm/Nd}$), one stage model age (T_{DM1}), two stage model age (T_{DM1}), and estimation of the proportions for juvenile crust (X^m=%) used equation and constants in the analytical methods of this paper.

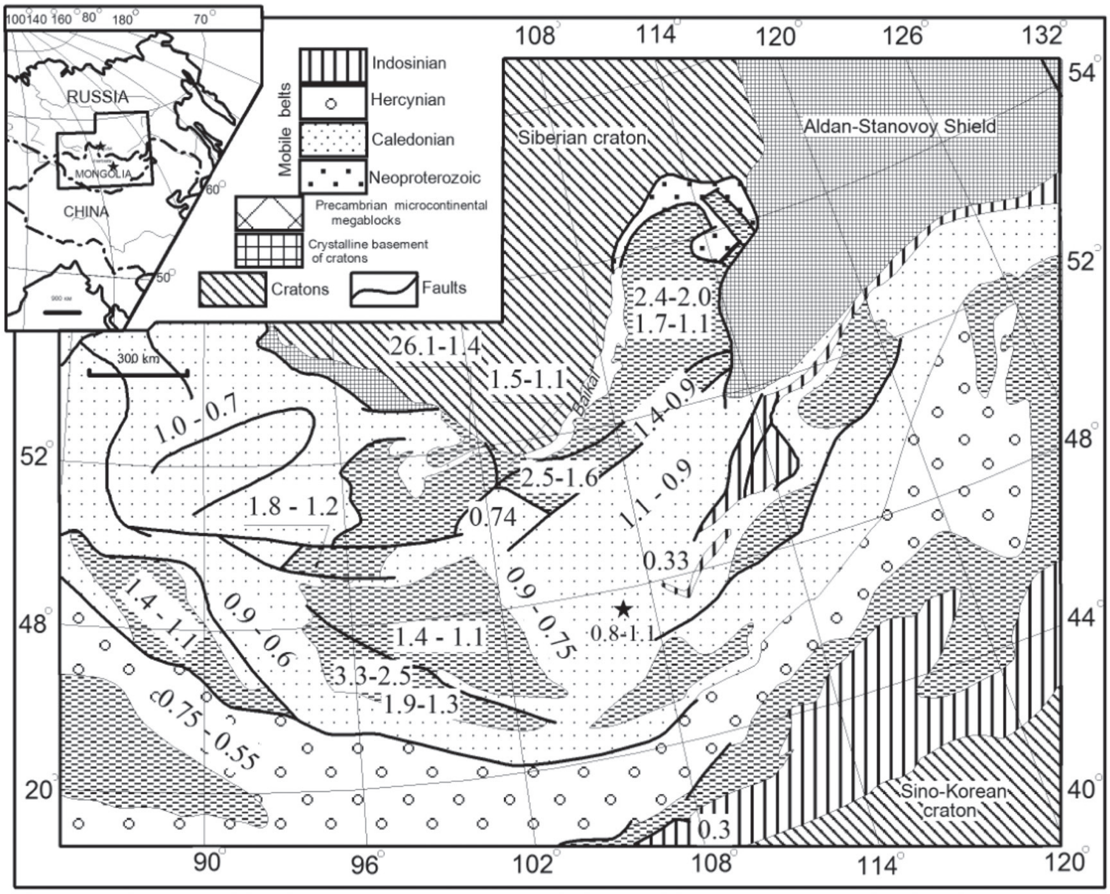

Fig. 12. Map of isotopic provinces of the Central Asian Orogenic Belt. (Kovalenko et al., 2004). Black star on the map shows the location of the Bogd Uul granite pluton in the Caledonian isotopic province (Caledonian mobile belt) of the Central Asian Orogenic belt. The model age (0.8-1.1 Ga) of the Bogd Uul granite pluton coincides with the Caledonian isotopic province near the Khentii uplift.

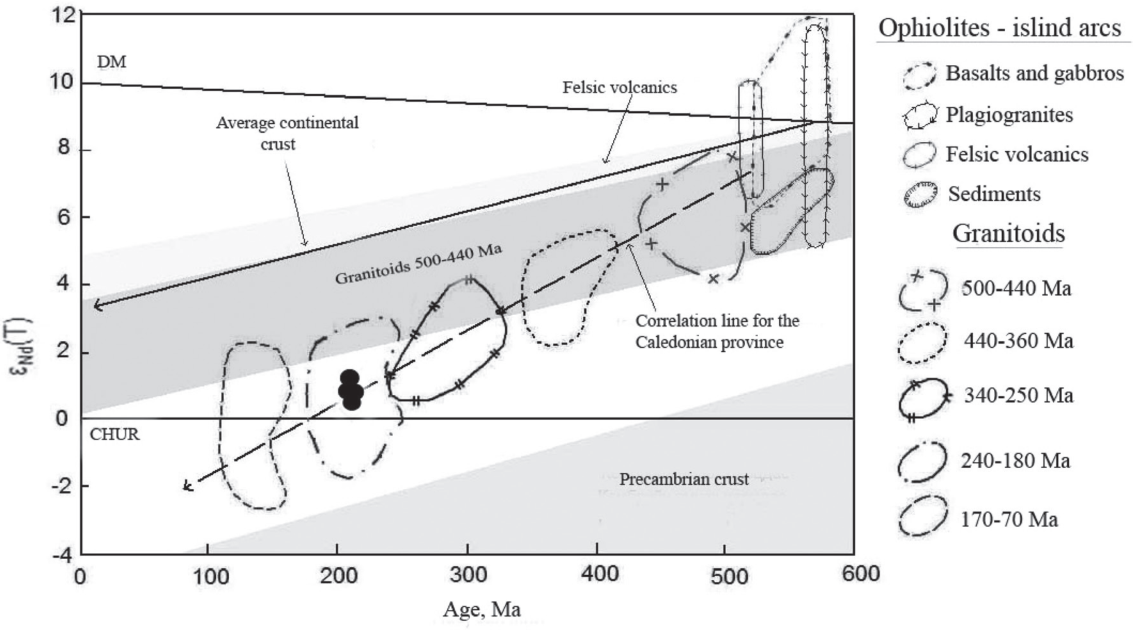

Fig. 13. Bogd Uul granite pluton on the diagram $\varepsilon_{Nd}(T)$ vs. primary age for rocks of the Central Asian Orogenic Belt. (*Kovalenko et al.*, 2004)

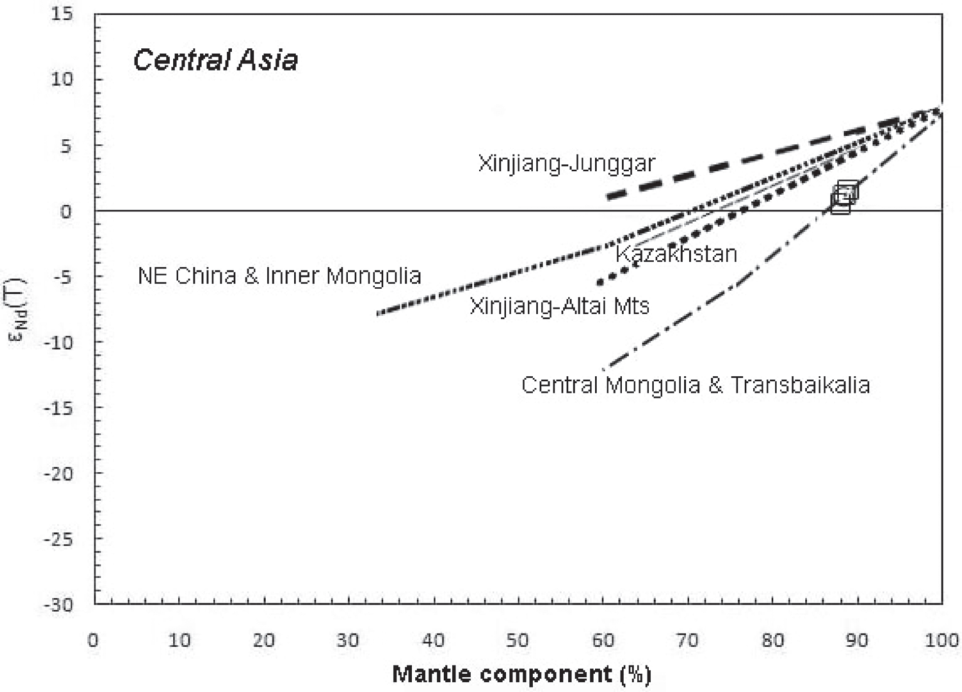

Fig. 14. Estimate of proportions of the mantle or juvenile component in the generation of Central Asian granitoids (Jahn et al., 2004). The equation used is: $X^m=(\varepsilon^c-\varepsilon^r)\cdot Nd_c/[\varepsilon^r\cdot(Nd_m-Nd_c)-(\varepsilon^m\cdot Nd_m-\varepsilon^c\cdot Nd_c)$ where X^m=% mantle component (represented by basalt). ε^c, ε^r, ε^m = N_d isotope compositions of the crustal component, rock measured, and mantle component, respectively. Nd_m, Nd_c =Nd concentrations in the crustal and mantle components, respectively. Parameters used: ε^m=+8, ε^c=–30 (Central Mongolia), –12 (NE China), –15 (Altai and Kazakhstan), –4 (Junggar), –18 (Tianshan), Nd_m=15 ppm, Nd_c=25ppm. The estimation proportion of rocks in the Bogd Uul granite pluton is similar to the Central Mongolia and Transbaikalia granitoids.

5. Summary

Mesozoic magmatism is occurred eastern part of Mongolia and structurally correlated with Mongol-Okhotsk belt. The origins of the Mesozoic granitoids are controversial still now. So, researchers involved a lot of models of this belt (Nagibina, 1967; Zonenshain et al., 1976; Kovalenko et al., 1984; Kuzmin, 1985, and Koval, 1998). They explained that the origin of the Mesozoic magmatism is correlated with magmatic activization, hot spot, and contamination of crust and mantle plume.

The major element analyses indicate that almost all the granitoids of the Bogd uul granite pluton are slightly peraluminous, which can be classified as granites including K-feldspar granites based on the Q vs. ANOR classification scheme (Streckeisen and Le Maitre, 1979), and belong to the high-K calc-alkaline series granite (K_2O vs. SiO_2). REE patterns of the Bogd Uul granite pluton are almost similar to granitic and, with little Eu anomalies and rich in heavy REE.

The Rb-Sr isochron age of early Mesozoic coincide our previously determined age of the Bogd Uul granite pluton ranging from 181.4±7.7 to 212.5±10.8 Ma.

Rocks of the Bogd Uul granite pluton is similar to A2-type granite that is formed in post-collision tectonic setting, and granitic magma derived from continental crust contaminated with juvenile mantle-derived component, due to geochemical analyses and Rb-Sr isotopic data which show the Sr*I*=0.7005-0.703, εNd(T)=(+0.7)-(+1.4), model ages of 826-1077 Ma. These results show that the Bogd Uul granite pluton has same origin as other granites formed Early Mesozoic time. The Sr*I* of largest Early Mesozoic plutons in the Khentey uplift are 0.705-0.708 and for the rare metal granitoids 0.710-0.715 (Koval, 1998; Odgerel et al., 2008).

T_{DM} of the Khentey-Daurian batholite is 820-1100 Ma and positive $\varepsilon_{Nd}(T)$ values (Yarmolyuk and Kovalenko, 2003; Kovalenko et al., 2004) are similar to the Bogd Uul granite pluton. It manifests a significant effect of contamination of juvenile crust. Nevertheless, mass balance and zircon morphology suggests that the Bogd Uul granite pluton was derived from source composed of juvenile mantle derived materials.

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