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Original article

Age, origin and tectonic setting of Dulaankhan granitic pluton in northern Mongolia

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ABSTRACT

Dulaankhan granitic pluton, which is situated in northern Mongolia, the southern portion of the Mongolian-Transbaikalian belt (MTB), is petrographically composed of fine to medium-grained peralkaline granite and is intruded by a small body of quartz syenite. Geochemical data show the Dulaankhan granite and the intruding quartz syenite are both slightly peraluminous and high-K calc-alkaline, and are enriched in LREEs relative to the HREEs, with negative Eu anomaly, and in large ion lithophile elements (LILEs; such as K, Cs and Rb) with respect to high field strength elements (HFSEs; e.g., Nb, Ta and Ti). In terms of relations of Nb, Zr and Y to Ga/Al, however, the Dulaankhan granite and quartz syenite show geochemical features of A-type granites and can be classified into the A2-sub type granite, implying that the pluton formed in an post-collision extensional environment. LA-ICPMS zircon U-Pb dating results suggest that the Dulaankhan granite crystallized at 198±1 Ma, whereas the intruding quartz syenite at 180±1 Ma, consistent with our field observation that the quartz syenite intrudes the granite, attesting that the two granitic bodies were emplaced at different times although both of them formed during the Early Jurassic period. According to these new data, as well as regional ones, we propose that the Dulaankhan granitic pluton was likely generated in the post-collision setting related to the orogenesis of the Mongol-Okhotsk belt that seems to occur prior to Early Jurassic in the northern Mongolian segment.

Keywords: A-type granite, Mongolia-Transbaikalian belt, U-Pb dating

INTRODUCTION

Since "A-type granite" was first recognized about 40 years ago (Loiselle and Wones, 1979; Collins et al., 1982), a spectrum of alkali-rich granitic rocks has been included in this type, from syenogranite through peralkaline granite, rapakivi granite and charnockite, to fluorine-rich topaz granite (Collins et al., 1982; Whalen et al., 1987; Eby, 1992; Patiño Douce, 1997; Wu et al., 2002; Bonin, 2007). Such a wide range of composition is likely to be one of the important factors that lead to the debate regarding the origin of A-type granites (e.g., Whalen et al., 1987; Bonin et al., 2004; Whalen, 2005; Bonin, 2007). Consequently, a unified model for the generation of A-type granitoids seems not to have reached.

It is widely accepted that A-type granites are

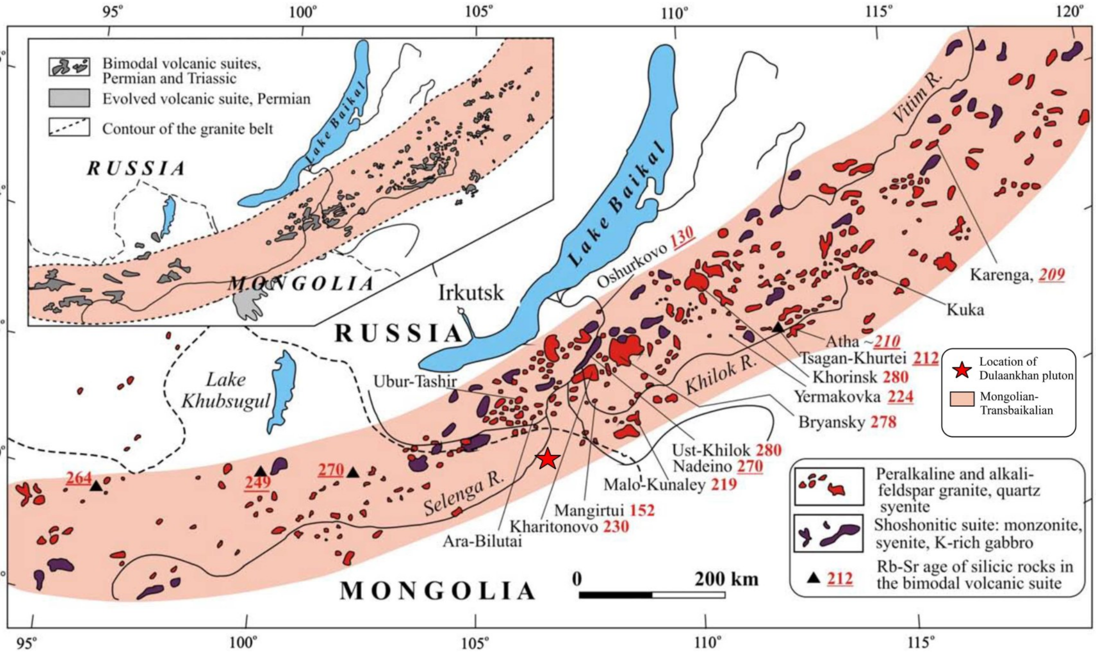

Fig. 1. Distribution of the Late Paleozoic and Mesozoic peralkaline and alkali feldspar granitoids in the Mongolian-Transbaikakalian Belt (Jahn et al., 2009)

produced in extensional settings although the geodynamic mechanisms causing the extensions are not unique, including within-plate extension, rifting extension, post-collision extension, and back-arc extension, etc. Alkaline granitoids are widespread in the Central Asian Orogenic Belt (CAOB) (Jahn et al., 2009), especially within the Mongolia-Transbaikalian belt (MTB; Fig. 1), which contains abundant peralkaline and alkali feldspar granitoids (Fig. 1). However, the age, origin, and tectonic setting of these alkaline granitoids, particularly those in the Mongolian section, are poorly constrained, which hampers understanding of crustal and tectonic evolution of the region. The purpose of this study is to determine the emplacement age(s), to discuss the origin of the Dulaankhan granitic pluton, a typical composite pluton in the Mongol-Transbaikalian magmatic belt (Fig. 1), and to constrain the tectonic and crustal evolution of the northern Mongolia.

GEOLOGICAL SETTING

The Dulaankhan area is located in the northern Mongolia, belongs to the MTB, also known as the Mongolian-Transbaikalian rift Province (Zanvilevich et al., 1985). The MTB extends in a NE-SE direction over a distance of >2500 km from northern Mongolia to Russia, and varies in width from 150 to 250 km (Fig. 1). The main part of the MTB is situated in Russia, and the northern Mongolia constitutes its southwestern extension. The MTB has been mapped at scale of 1:50,000 since 1950's (Zanvilevich et al., 1985) and more than 350 alkali-feldspar plutons have been delineated within it so far (Fig. 1; Jahn et al., 2009). Compared with the alkaline plutons in the Russian part, those in the Mongolian segment are relatively less voluminous. Of these, the Dulaankhan pluton is one of the representatives of the alkaline plutons (Fig. 2).

The intrusions of these alkali-feldspar granitoids are contemporaneous (Jahn et al., 2009). Meanwhile, the order of emplacement these alkaline plutons generally starts from alkali feldspar syenite, followed by granite to peralkaline syenite (nordmarkite), finally to peralkaline granite, and the proportion of quartz in syenites increased from 3–6 vol.% in the earlier to 10–15 vol.% in the latest phases. The structures of the plutonic bodies are depended on their sizes (Jahn et al., 2009).

In the MTB, the alkali feldspar granites are normally considered as A-type granite and syenites are closely associated with syenite, both

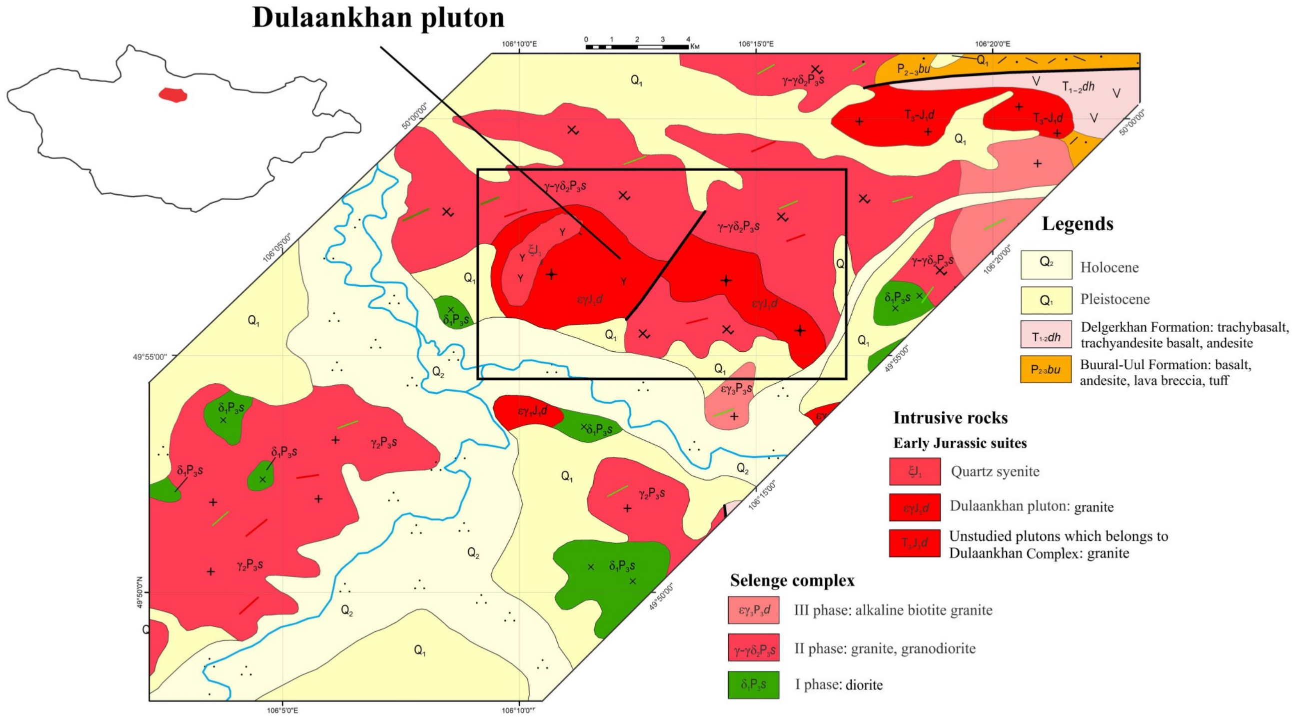

Fig. 2. Geological map of Dulaankhan pluton at 1:100000 scale (Gendenjamts, 2018)

of which were commonly emplaced at the early stages of the granitoid magmatism. Geochemical and Sr-Nd isotopic data demonstrated that A-type granite and syenite are cogenetic (Litvinovsky et al., 2015). This means that the syenite and granite magmas were produced from the same source, which insists of juvenile crustal material (Litvinovsky et al., 2015).

The Dulaankhan pluton occurs in the northern Mongolia, about 310 km north of Ulaanbaatar, the capital of Mongolia. This pluton occupies an exposure area of 47.6 km^2 and intrudes into the Middle-Upper Permian Buural-Uul Formation containing basalts, andesite basalts, andesites, lava breccias, tuffs, conglomerates, sandstones, and siltstones, and into the Triassic Delgerkhan Formation comprising trachybasalt, basaltic trachyandesite and andesite. Additionally, it also intrudes the granitoid bodies of the Selenge Complex (Permian). Petrographically, the Dulaankhan pluton is a alkaline granite and is intruded by a small body of quartz syenite (Fig. 2). The intrusive relationships of the granite and the quartz syenite were observed in the field.

ANALYTICAL METHODS

Samples of the Dulaankhan pluton were analyzed for petrography, major and trace element geochemistry, and radiogenic isotopic age dating. For the petrographic study, thin-sections were comprehensively examined by using a microscopy at the Institute of Geology, Mongolian Academy of Sciences (IGMAS). For geochemical analysis, whole-rock samples after removal of altered surfaces were crushed and grilled in an agate mill to ~200 meshes at the IGMAS. The geochemical analyses were carried out at the SGS Mongolia LLC company (invested by Switzerland) and Field Research Center (FRC) of Mongolian University of Science and Technology (MUST) following the standard procedure. The major and some trace-element (As, Ba, Cr, Cu, V, Zn, Ba, Mo, Nb, Sn, Ta and W) concentrations were determined by using the X-Ray Fluorescence analyzer (XRF76V) and other trace elements and rare earth elements (REE, Th, U, Sr, Rb and Hf) by the Inductively-Coupled Plasma Mass Spectrometry (IC90A and IC90M).

For the U-Pb dating, zircon grains were contracted using heavy mineral contracting methods, and were analyzed by using the LA-

ICPMS at the Guangzhou Institute of Geochemistry, Chinese Academy of Sciences and at the Geological Institute of Siberian Branch of the Russian Academy of Sciences, Ulan-Ude.

RESULTS

Petrographic characteristics

In this study, 24 thin-sections from the Dulaankhan pluton, its country rocks and dykes were examined. As mentioned above, the pluton is a composite body, comprising mainly of granites and a minor mount of quartz syenite. Microscopic observations demonstrate that the granite is coarse to medium-grained and shows a hypidiomorphic to equigranular texture. The mineral assemblage is dominated by K-feldspar (65-69%), quartz (25-30%) plagioclase (3-5%) and biotite (1-2%), with minor amount of opaque minerals. The K-feldspar in this granite displays gridiron twinning, indicating that it is microcline (Fig. 3). So, the Dulaankhan granitic rock is named as K-feldspar granite .

The quartz syenite intruding the granite are porphyritic, with K-feldspar phenocrysts (3.2-4.1 mm) in a fine-grained groundmass, which is composed mainly of K-feldspar (60-65%), plagioclase (20-25%), quartz (10-20%), biotite and hornblende (<5%). Minor amounts of opaque minerals are also observed in this

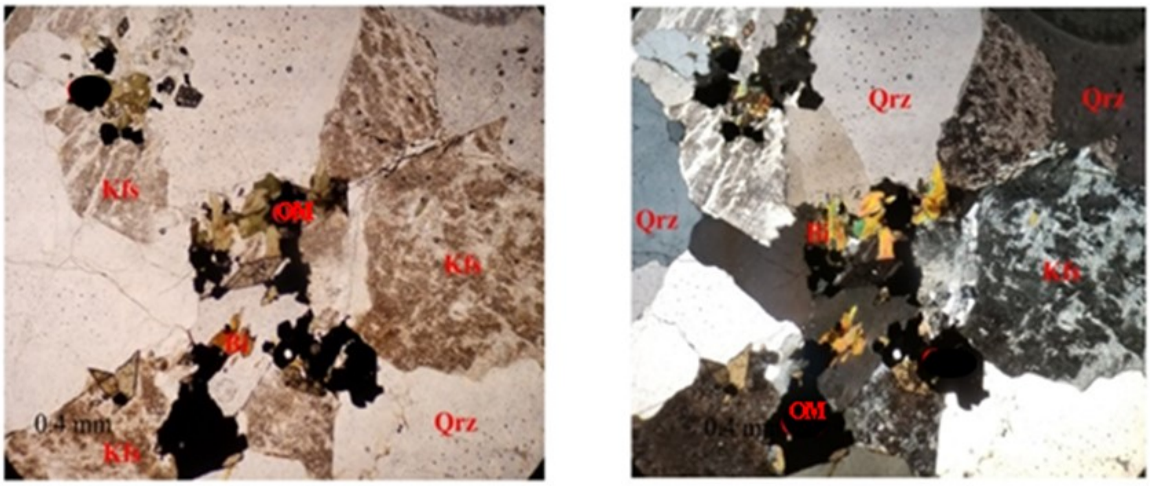

Fig. 3. Microphotographs of the Dulaankhan K-feldspar granite (Dul-02-17) in northern Mongolia (left: plane polarized light picture; right: XPL-cross polarized light image)

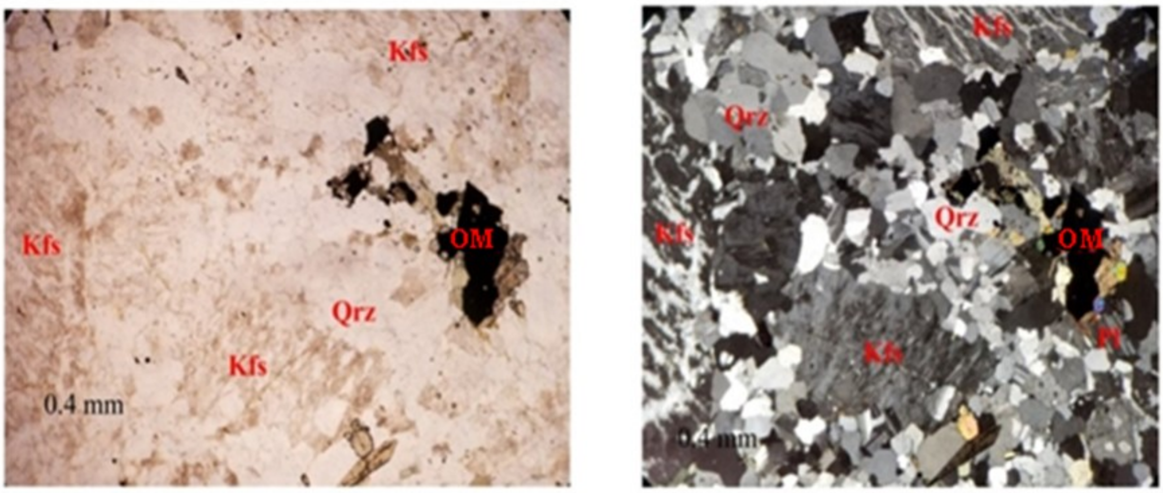

Fig. 4. Microphotographs of a quartz syenite (Dul-01-17) intruding the Dulaankhan granitic pluton in northern Mongolia (left: plane polarized light picture; right: XPL-cross polarized light image)

syenite. The phenocrystal K-feldspar shows a stria structure, suggesting that it is perthite (Fig. 4).

Geochemistry results

Eight samples were analyzed for major and trace elements, of which 6 samples from the the Dulaankhan pluton and 2 samples from the quartz syenite intruding the granite. The Dulaankhan K-feldspar granite has 77.1-78.13 wt.% SiO_2, 12.45-13.79 wt.% Al_2O_3, 0.04-0.2 wt.% MgO, 0.13-0.34 wt.% CaO, 3.54-4.89 wt.% Na_2O, and 4.44-4.6 wt.% K_2O. Compared with the granites, the quartz syenite is relatively low in SiO_2 (~69 wt.%) but relatively high in Al_2O_3 (15.1-15.36 wt.%), Na_2O (5.03-5.19 wt.%) and K_2O (5.3-5.7 wt.%), as well as CaO (0.45-0.5 wt.%) (Table 1).

In (Na_2O+K_2O)-SiO_2 diagram (Cox, 1979; Wilson, 1989), all the 6 samples of the K-

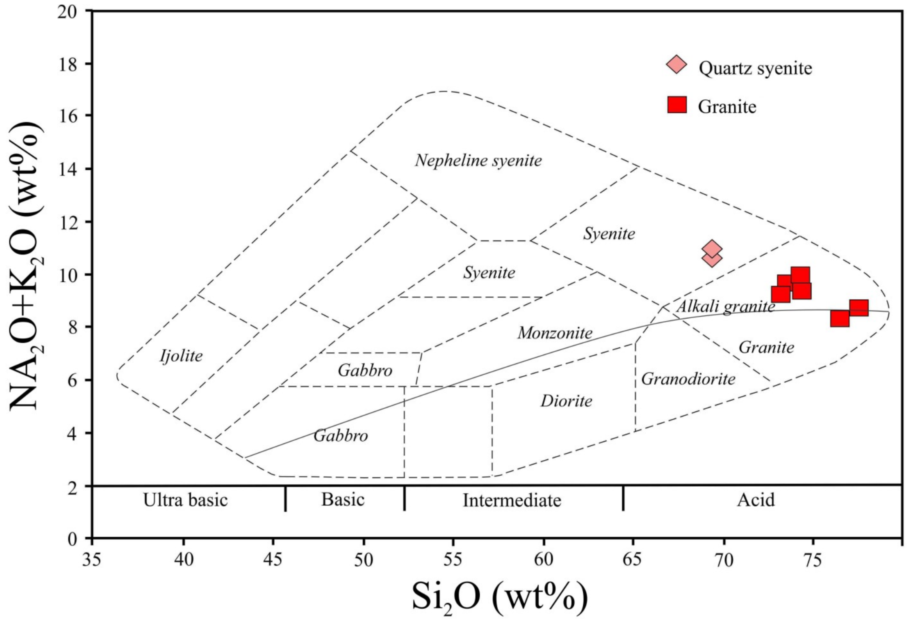

Fig. 5. (Na_2O+K_2O)-SiO_2 diagram (Cox, 1979, Wilson, 1989)

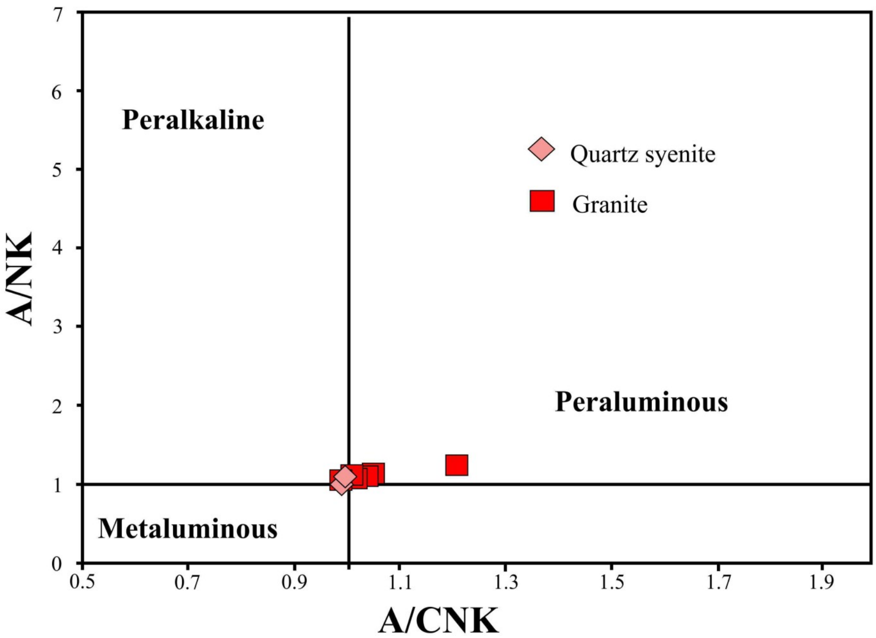

Fig. 6. A/CNK-A/NK diagram (Shand, 1943)

Table 1. Chemical composition of rocks from the Dulaankhan granitic pluton

Sample no.	Dul-1-17	Dul-06-17	Dul-02-17	Dul-03-17	Dul-04-17	Dul-05-17	Dul-09-17	G-1
Rock type	Quartz syenite		Dulaankhan pluton					
Major elements (%)								
SiO2	69.91	69.94	74.15	74.2	74.79	77.11	78.13	74.18
TiO2	0.303	0.25	0.18	0.19	0.19	0.07	0.116	0.18
Al2O3	15.136	15.36	13.17	13.79	13.69	13.34	12.45	13.44
Fe2O3	1.698	1.53	1.38	1.34	1.27	0.39	0.879	1.49
MnO	0.083	0.05	0.08	0.05	0.06	0.01	0.082	0.11
MgO	0.137	0.25	0.24	0.19	0.2	0.1	0.041	0.12
CaO	0.455	0.5	0.34	0.29	0.31	0.13	0.305	0.23
Na2O	5.198	5.03	4.8	4.7	4.69	3.54	4.193	4.89
K2O	5.376	5.73	4.44	4.48	4.45	4.6	4.341	4.6
P2O5	0.03	0.04	0.03	0.03	0.01	0.01	0.01	0.03
LOI	0.3	0.32	0.32	0.29	0.15	0.57	0.25	0.61
Total	98.329	98.98	99.08	99.52	99.76	99.8	100.554	99.98
Trace elements (in ppm)								
Al		7.62	6.67			5.85	6.41	5.96
Ba	57	246	153	139		30	50	168
Be		5	9			5	6	11
Ca		0.32	0.3			0.13	0.27	0.28
Cr	89	73	148	64		142	113	132
Cu	0	10	0	0		0	1	10
Fe		1.25	1.17			0.39	0.71	0.92
K		4.23	3.45			3.24	3.54	3.41
Li		10	40			32	44	47
Mg		0.09	0.08			0.01	0.03	0.06
Mn		385	657			21	629	747
Ni	2	5	3	4		5	4	5
P		0.02	0.01			0.01	0.01	0.02
Sc		5	5			5	5	5
Sr	26	80	57	55		10	16	44
Ti		0.14	0.1			0.04	0.07	0.08
V		5	5			5	5	5
Zn	46	36	53	45		20	32	46
Co	0	0.6	0.7	0		1	0	1.7
Ga	20	21	21	22		25	19	20
Ge		2	2			2	2	2
As		5	5			5	5	5
Rb	133	163	250	292		229	217	238
Y	32	16.1	13.7	19		39.4	9.2	14.1
Zr	438	189	144	246		84.9	78.1	332
Nb	25	17	24	31		11	17	24
Mo	21	2	10	9		2	2	2
Cd		0.2	0.3			0.2	0.2	0.2
In		0.2	0.2			0.2	0.2	0.2
Sn		2	2			4	1	3
Sb		0.1	0.6			0.2	0.2	0.2
Cs		2.5	5.4			6.2	2.6	8.4
La		52	47.5			16.8	34.4	34.4
Ce		74.8	54			39	41.7	58.1
Pr		8.42	5.33			4.83	3.91	5.05
Nd		30	16.7			20.9	12	15.2
Sm		5	2.8			7.1	1.9	2.5
Eu		0.58	0.29			0.07	0.16	0.43
Gd		3.08	1.84			6.67	1.24	2.58
Tb		0.42	0.26			1.06	0.14	0.41
Dy		2.85	1.89			6.89	1.23	1.94
Ho		0.53	0.4			1.4	0.24	0.45
Er		1.78	1.34			4.05	1.03	1.48
Tm		0.25	0.19			0.58	0.13	0.26
Yb		1.8	1.7			3.7	1.2	1.8
Lu		0.32	0.32			0.56	0.21	0.33
Hf		5	4			2	3	7
Ta		0.8	1			0.5	0.7	1.5
W		18	68			15	18	1
Tl		0.7	0.9			1	0.9	1.2
Pb	18	24	22	27		25	26	22
Bi		0.1	0.1			3.4	0.1	0.1
Th	22	18.3	17.9	34		15.2	15.4	18.5
U		1.39	2.53			3.64	2.85	2.56

feldspar granite plot in the “granite” field, straddling the boundary line between the alkaline and subalkaline series, whereas the 2 samples of the quartz syenite in the “syenite” field, belonging to alkaline series (Fig. 5). However, in terms of the K_2O-SiO_2 relation (Rickwood, 1989), both granitic rocks belongs to high–K and calc-alkaline series (Fig. 6). In the A/CNK-A/NK diagram and all samples plot in an area transitional from the metaluminous to peraluminous fields (Fig. 7).

Primitive mantle-normalized spider diagram shows that the Dulaankhan pluton is enriched in large ion lithophile elements (LILEs), such as

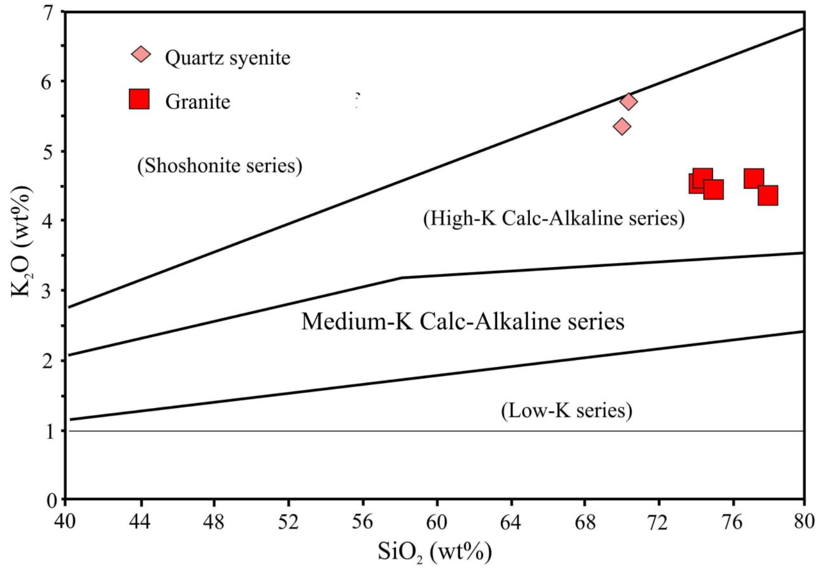

Fig. 7. K_2O-Si_2O diagram (Rickwood, 1989)

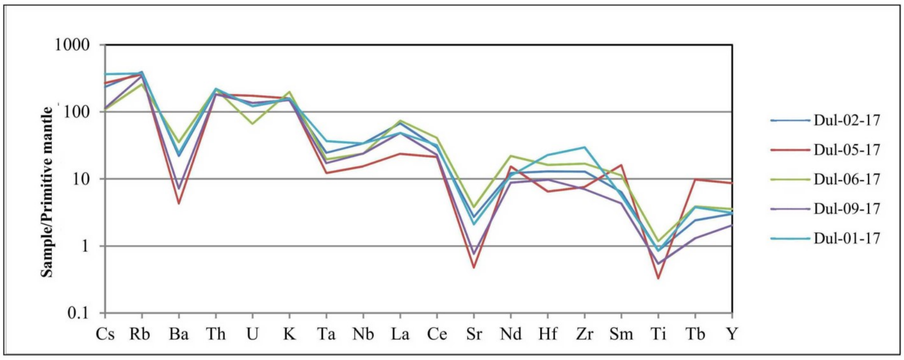

Fig. 8. Primitive-mantle-normalized (Sun and McDonough, 1989) spider diagram

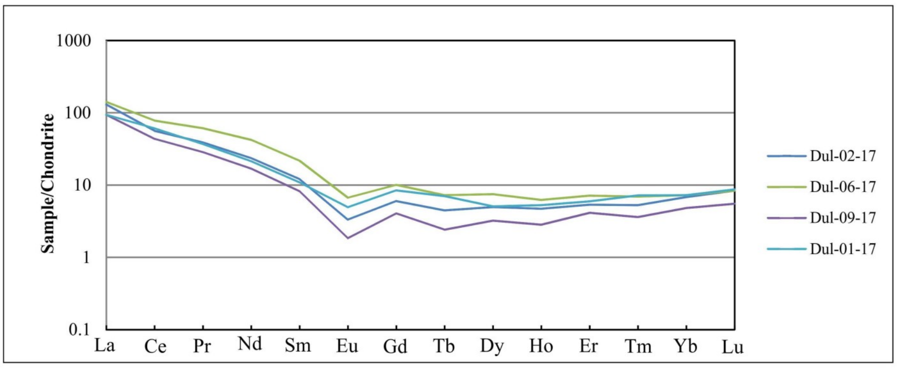

Fig. 9. Chondrite –normalized (Taylor and McLennan, 1985) REE spider diagram

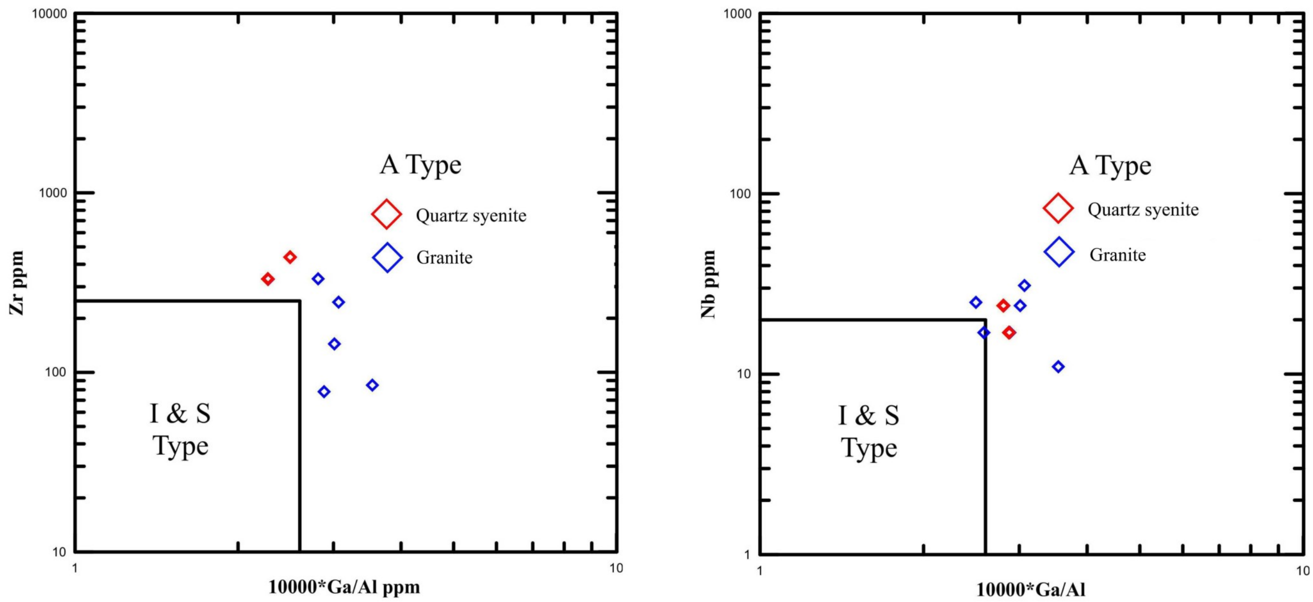

Fig. 10. 10,000*Ga/Al vs. Zr and Nb diagram (Whalen et al., 1987) showing the A-type granite natures of the Dulaankhan pluton in northern Mongolia

Rb, K and Cs relative to high field strength elements (HFSEs; e.g. Nb, Ta and Ti). Moreover, negative anomalies of Sr and Ba in this diagram are evident, which is consistent with the observation that no or minor amounts of plagioclase exists in the rocks. This pattern of the trace element distribution is similar to that of A-type granites (Fig. 8). The chondrite-normalized REE patterns (Taylor and McLennan, 1985) are characterized by enrichment in LREE with respect to HREE, with some extents of negative Eu anomaly (Fig. 9).

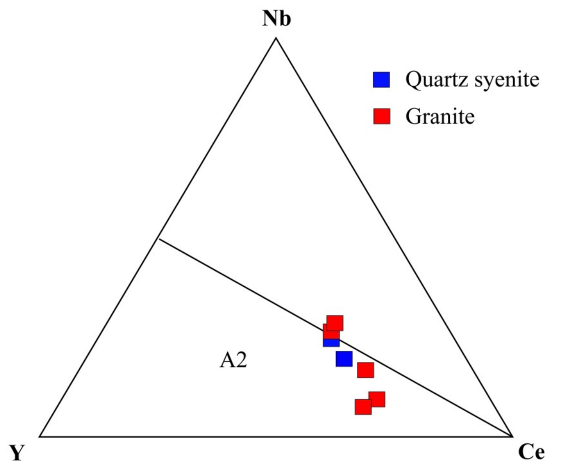

Fig. 11. Y-Nb-Ce diagram showing the A2-type characteristics of the Dulaankhan pluton in northern Mongolia

In the 10,000*Ga/Al vs Zr, Nb diagrams (Whalen et al., 1987), all the Dulaankhan samples and 2 samples of quartz syenite plot into the "A-type granite" field (Fig. 10). The Dulaankhan pluton with samples of quartz syenite show A2-type characteristics in terms of Y-Nb-Ce diagram (Fig. 11).

Geochronology

Two samples Dul-03-17 (N 49°56'30.4", E 106° 09'53,2") and Dul-06-17 (N 49°57'45,6", E 106° 10'57,7"), which were respectively collected from the Dulaankhan K-feldspar granite and the quartz syenite intruding the granite, were selected for LA-ICPMS zircon U-Pb dating. Zircon grains from the 2 samples display similar morphological and inner textural features; they are light brownish or colorless, subhedral to prismatic, and generally 50-200 μm long, and show well-developed oscillatory zoning, indicating a magmatic origin for the zircon.

Totally 23 analyses were made on 23 zircon grains of the granite (Dul-03-17). Of these, 21 analyses yield a weighted mean $^{206}Pb/^{238}U$ age of 198±1 Ma (MSWD = 0.05) (Fig. 12). The remaining 2 analyses were omitted from the age calculation due to their high discordance. The age of 198±1 Ma is interpreted to be the emplacement age of the granite.

For the quartz syenite (Dul-06-17), 30 analyses were done on 30 zircon grains, of which 27 analyses give a weighted mean $^{206}Pb/^{238}U$ age of 180±1 Ma (MSWD = 0.07) (Fig. 13). Similarly, the remaining three analyses were excluded from the calculation due to high discordance. As a consequence, the age of 180±1 Ma is interpreted as the formation age of the small body of quartz syenite. These new results indicate that the two generations of magmatism of the Dulaankhan composite pluton have a ~10 Ma difference though both of them occurred in Early Jurassic.

DISCUSSION

The Dulaankhan pluton is geochemically characterized by high silica and alkalis and belongs to high-K calc-alkaline series (Figs. 5 and 6), which is common in Phanerozoic orogenic belts. On the other hand, the Dulaankhan granite resembles A-type granites in

Table 2. Isotope data of sample (Dul-03-17) from Dulaankhan pluton

Samples	ratio	1sigma	ratio	1sigma	ratio	1sigma	ratio	1sigma	age	1sigma	age	1sigma	age	1sigma	age	1sigma	
Analysis	$^{207}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{207}Pb/^{235}U$	$^{207}Pb/^{235}U$	$^{206}Pb/^{238}U$	$^{206}Pb/^{238}U$	$^{208}Pb/^{232}Th$	$^{208}Pb/^{232}Th$	$^{207}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{235}U$	$^{208}Pb/^{232}Th$	$^{208}Pb/^{232}Th$	Concordance
DOI03-17-1	0.053	0.0022	0.23	0.009	0.031	0.0004	0.0100	0.0002	328.1	93.07	197.7	2.39	208.1	7.69	201.7	2.97	95.00
DOI03-17-11	0.051	0.0013	0.22	0.005	0.031	0.0003	0.0093	0.0001	224.5	56.81	198	1.84	199.9	4.31	187.8	2.4	99.05
DOI03-17-12	0.050	0.0009	0.21	0.003	0.031	0.0003	0.0095	0.0001	196.3	40.21	197.9	1.66	197.7	2.9	190	1.53	100.10
DOI03-17-13	0.049	0.0008	0.21	0.003	0.031	0.0003	0.0092	0.0001	163.7	35.09	198.2	1.61	195.5	2.43	184.9	1.4	101.38
DOI03-17-15	0.049	0.0010	0.21	0.004	0.031	0.0003	0.0094	0.0001	129.5	48.4	198.6	1.74	193.2	3.45	188.6	1.9	102.80
DOI03-17-16	0.049	0.0009	0.21	0.003	0.031	0.0003	0.0095	0.0001	163.7	40.54	197.8	1.67	195.1	2.88	190.6	1.86	101.38
DOI03-17-17	0.049	0.0008	0.21	0.003	0.031	0.0003	0.0095	0.0001	154.7	39.52	198.5	1.67	195	2.79	190.8	1.52	101.79
DOI03-17-18	0.049	0.0014	0.21	0.006	0.031	0.0003	0.0098	0.0001	170.1	63.99	198.4	1.94	196.1	4.77	197	2.24	101.17
DOI03-17-19	0.055	0.0019	0.24	0.008	0.031	0.0004	0.0095	0.0001	409.2	75.63	198.4	2.2	215.6	6.52	190.9	2.35	92.02
DOI03-17-2	0.050	0.0008	0.22	0.003	0.031	0.0003	0.0093	0.0001	194.9	38.35	198.2	1.62	197.9	2.73	186.6	1.59	100.15
DOI03-17-20	0.049	0.0013	0.21	0.006	0.031	0.0003	0.0094	0.0001	133.8	63.51	197.7	1.92	192.7	4.63	188.2	1.84	102.59
DOI03-17-21	0.050	0.0010	0.21	0.004	0.031	0.0003	0.0094	0.0001	192.8	45.49	197.9	1.73	197.3	3.33	188.3	1.59	100.30
DOI03-17-24	0.054	0.0013	0.23	0.005	0.031	0.0003	0.0057	0.0001	383.3	51.52	197.3	1.84	212.2	4.24	114.6	1.11	92.98
DOI03-17-25	0.048	0.0010	0.21	0.004	0.031	0.0003	0.0100	0.0001	118.3	47.52	199	1.76	192.7	3.38	201.6	1.84	103.27
DOI03-17-26	0.049	0.0007	0.21	0.003	0.031	0.0003	0.0094	0.0001	127.1	33.59	198	1.64	192.4	2.28	189.2	1.46	102.91
DOI03-17-28	0.043	0.0040	0.18	0.016	0.030	0.0006	0.0093	0.0004	0.1	50.3	193.5	4.03	168.6	14.06	187.7	8.19	114.77
DOI03-17-29	0.048	0.0009	0.21	0.004	0.031	0.0003	0.0097	0.0001	118	45.07	198.6	1.74	192.3	3.18	194.8	2.12	103.28
DOI03-17-3	0.050	0.0016	0.21	0.006	0.031	0.0003	0.0090	0.0002	174.8	71.48	197.9	2	196	5.36	181.3	3.4	100.97
DOI03-17-30	0.051	0.0009	0.22	0.004	0.031	0.0003	0.0094	0.0001	219.1	41.46	199.1	1.73	200.4	3.08	190	1.65	99.35
DOI03-17-5	0.050	0.0007	0.22	0.003	0.031	0.0003	0.0095	0.0001	204.2	33.75	198.1	1.58	198.5	2.36	190.6	1.49	99.80
DPI03-17-6	0.050	0.0007	0.21	0.002	0.031	0.0003	0.0095	0.0001	182	30.31	198.4	1.56	197.1	2.04	191.5	1.25	100.66
DPI03-17-7	0.050	0.0009	0.21	0.003	0.031	0.0003	0.0093	0.0001	191.5	39.97	198.3	1.65	197.6	2.87	187.7	1.52	100.35
DPI03-17-8	0.049	0.0009	0.21	0.003	0.031	0.0003	0.0096	0.0001	133.8	41.07	198.9	1.66	193.8	2.87	192.8	1.67	102.63

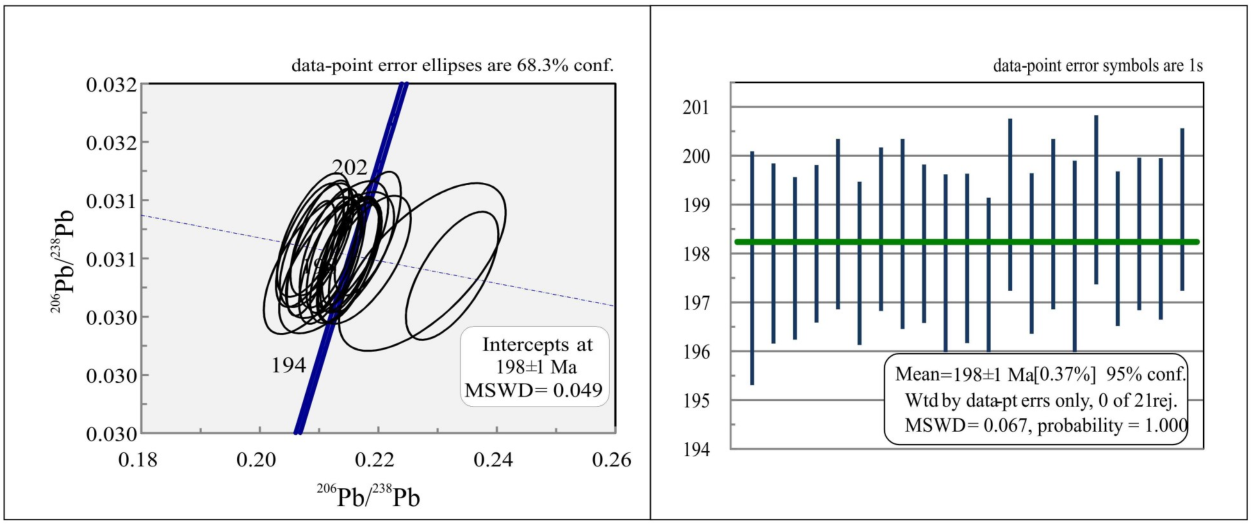

Fig. 12. Concordia and histogram diagrams of the Dulaankhan pluton (sample Dul-03-17)

Table 3. Isotope data of sample (Dul-06-17) from Dulaankhan

Samples	Age		Signals, cps				
Analysis	$^{206}Pb/^{238}U$	1σ	^{206}Pb	^{207}Pb	^{208}Pb	^{206}Th	^{238}U
PRB5	169.0	4.5	15730	939	5711	299043	457895
PRB1	316.3	16.7	1706806	842011	2779874	3258629	11963807
PRB10	193.8	4.7	340290	16069	259012	1351556	8813267
PRB11	174.5	4.4	43742	2199	18206	982307	1258402
PRB12	179.9	4.5	43451	2297	16406	864405	1208425
PRB13	178.9	4.6	37306	1872	13657	755078	1048092
PRB14	174.2	5.0	9117	505	3606	193737	261556
PRB15	180.4	4.7	21978	1001	7725	405543	616504
PRB16	174.7	4.7	13981	778	4882	271816	400972
PRB17	179.8	4.6	40479	2076	11095	612307	1135291
PRB18	173.0	4.7	14824	722	4293	245984	433881
PRB19	180.5	4.7	28497	1386	12110	663634	799981
PRB2	173.2	4.4	34901	1766	8531	444408	1000116
PRB20	178.5	4.6	39931	2007	12530	686687	1132004
PRB21	231.9	5.8	142939	7579	34383	1402300	3109452
PRB22	229.0	5.8	101348	5160	21779	909710	2240276
PRB23	172.0	4.5	29867	1662	14687	803376	876510
PRB24	170.5	4.5	21905	1239	10206	544866	648531
PRB25	173.3	4.6	28793	1525	8357	438012	842770
PRB26	176.0	4.7	23292	1239	5780	322335	673044
PRB27	174.2	4.9	13358	722	4806	270838	389945
PRB28	175.1	4.9	13575	748	4455	242983	393799
PRB29	176.0	4.6	32351	1585	11686	625455	941423
PRB3	183.5	4.4	285769	15314	215811	1263106	7702172
PRB30	175.0	4.6	30865	1542	9827	548783	903042
PRB4	183.6	4.5	69442	3628	51740	2752507	1875499
PRB6	177.2	4.6	23786	1254	9756	517554	667817
PRB7	178.6	4.5	58575	3032	34139	1921941	1634330
PRB8	173.2	4.3	46724	2414	15821	849097	1346267
PRB9	185.3	4.5	270551	13292	193008	1020348	7308768

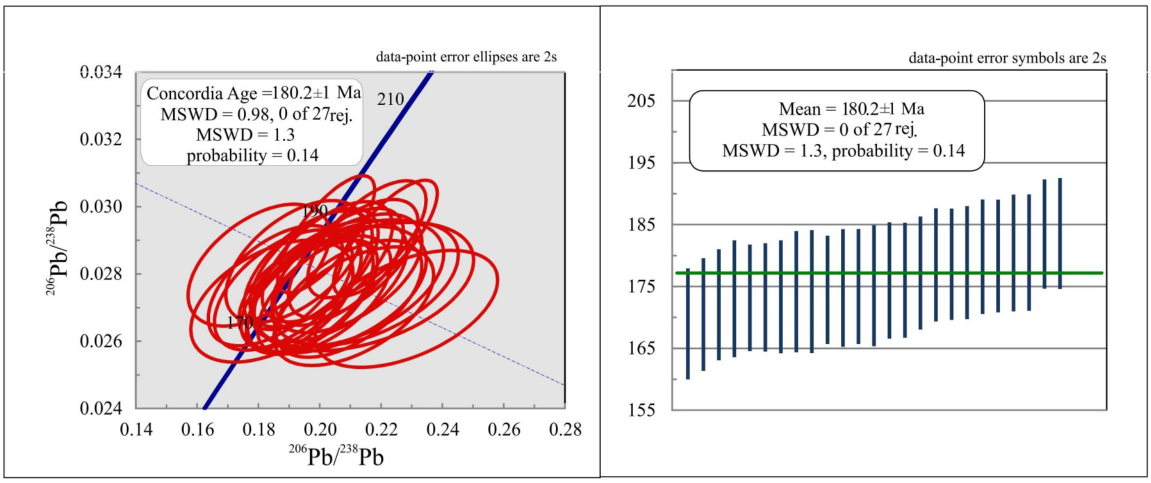

Fig. 13. Concordia and histogram diagrams of the small body of quartz syenite (sample Dul-06-17)

terms of trace elemental signatures (Fig. 10). These features suggest that the granitic body was produced in an extensional environment.

It is widely accepted that A-type granites can be divided into 2 groups: the A1 group, which is considered to be generated in anorogenic settings and A2 group formed in post-collision/orogenic settings. The Dulaankhan pluton shows distinct features of A2-type granites (Fig. 12), indicating that this pluton was generated in a post-orogenic setting. Our new age data testify that the Dulaankhan granite was emplaced at the earliest Jurassic at ca. 198 and was in intruded by quartz syenite during Early Jurassic at ca.180 Ma. Considering the regional data, we urge that the post-orogenic environment in which the Dulaankhan A2-type granite generated is related to the orogenesis of the Mongol-Okhotsk belt because this belt is situated to the immediate southeast of the MTB and the orogenesis of the northern Mongolia segment of this belt is confirmed to occur prior to Jurassic.

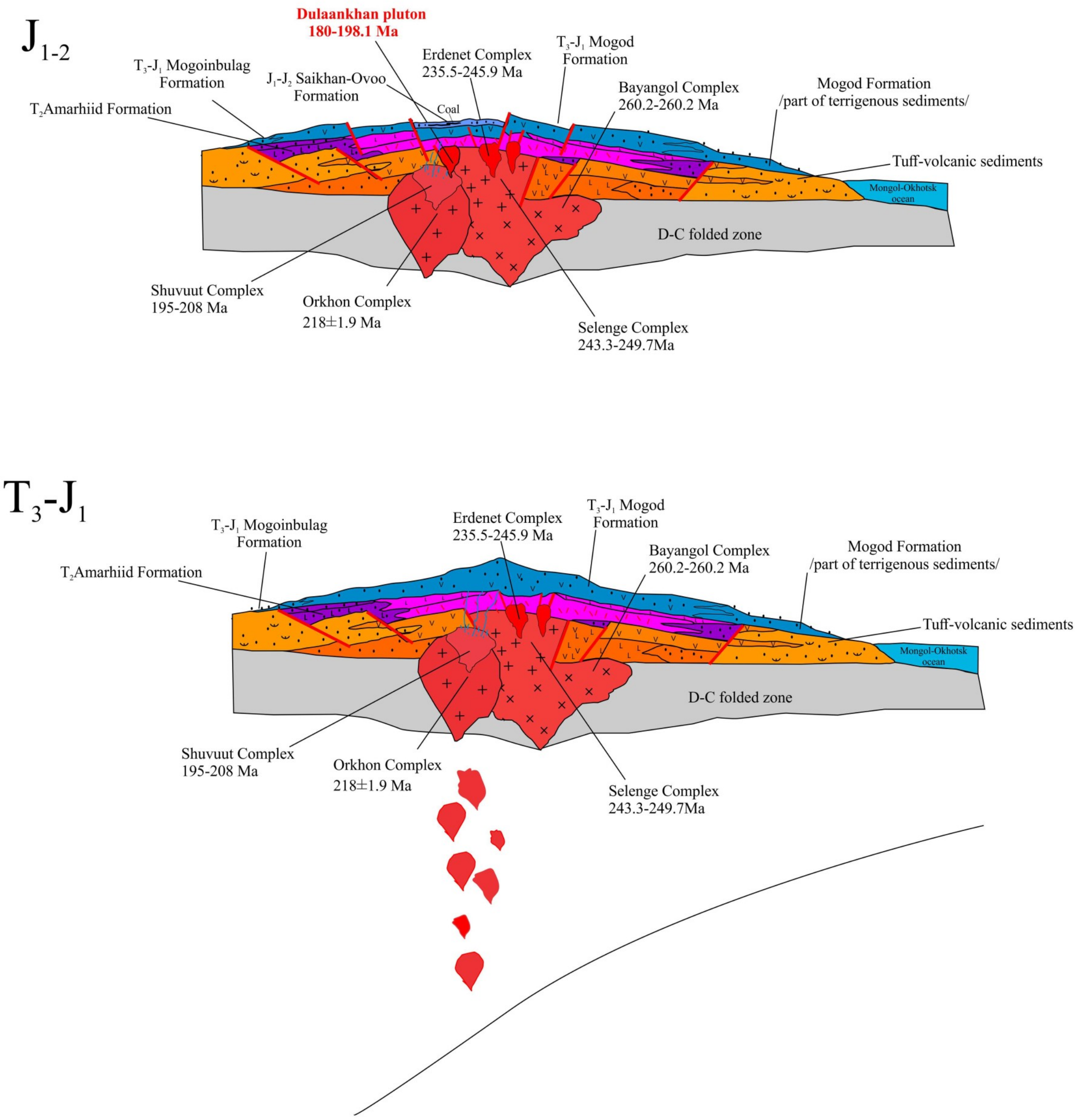

Fig. 14. Cartoon sketches showing the late Triassic (a) and early-middle Jurassic (b) geodynamic setting in which corresponding granitic intrusions formed at the Dulaankhan area in northern Mongolia (based on idea of A.Chimedtseren, unpublished data)

Regarding the petrogenesis of the Dulaankhan pluton, we believe that it should be generated from partial melting of crustal materials because of its high silica content and its large scale nature in dimension. The magmas have experienced relatively strong plagioclase fractional crystallization, as attested by the lack, or very low contents, of plagioclase in the mineral assemblages of the pluton (Figs. 3 and 4) and the negative anomalies of Eu, Sr, and Ba (Figs. 8 and 9). It is noted that the negative anomalies of these elements can also be produced when plagioclase is as a residual phase during partial melting in the source region, meaning that the partial melting likely took place under the condition of plagioclase stability, i.e. a low pressure condition. An extension setting can provide this condition.

On the basis of the data available, we illustrate Paleozoic-Early Mesozoic to Jurassic tectonic and crustal evolution of the Dulaankhan area in northern Mongolia in Fig. 14. From late Triassic to early Jurassic period, the Shuvuut and the Orkhon complexes, which show arc magmatic features, formed probably by the latest northward subduction of the Mongol-Okhotsk oceanic plate (Fig. 14a; Chimedtseren, unpublished data), which led to the closure of the Mongol-Okhotsk Ocean. Following the Mongol-Okhotsk orogenesis, the high-K calc-alkaline Dulaankhan A2-type granite formed in the post-collision extensional setting during early-middle Jurassic (Fig. 14b).

CONCLUSIONS

From current study, following conclusions can be reached:

(1) The Dulaankhan pluton in northern Mongolia is a composite intrusive body, fine to medium grained peralkaline granites and intruded by small body of quartz syenite as well as both two belongs to high-K calc-alkaline series.

(2) Geochemical data shows small body of quartz syenite and peralkaline granites of Dulaankhan magmas were produced singly or together from the same source. But the Dulaankhan pluton formed during Early Jurassic at 198±1 Ma, and quartz syenite is generated at 180±1 Ma, respectively, suggesting that pre-dominantly Jurassic in age.

(3) The Dulaankhan pluton belongs to A2-type granite and was likely generated from partial melting of crustal materials in the post-orogenic/ collision extensional setting related to the orogenesis of the Mongol-Okhotsk belt, which is believed to occur prior to Jurassic in the northern Mongolian segment.

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REFERENCES

Bonin, B., Ethien, R., Gerbe, M.C., Cottin, J.Y., Féraud, G., Gagnevin, D., Giret, A., Michon, G., Moine, B. 2004. The Neogene to Recent Rallier-du-Baty nested ring complex, Kerguelen Archipelago (TAAF, Indian Ocean): stratigraphy revisited implications for cauldron subsidence. In: Breitkreuz, C., Petford, N. (Eds.), Physical Geology of High-Level Magmatic Systems: Geological Society, London, Special Publication, 234, 125-149. https://doi.org/10.1144/GSL.SP.2004.234.01.08

Bonin, B. 2007. A-type granites and related rocks: Evolution of a concept, problems and prospects: Lithos, 97, 1-29. https://doi.org/10.1016/j.lithos.2006.12.007

Collins, W.J., Beams, S.D., White, A.J.R., Chappell, B.W. 1982. Nature and Origin of A-Type Granites with Particular Reference to Southeastern Australia: Contributions to Mineralogy and Petrology, 80, 89-200. https://doi.org/10.1007/BF00374895

Cox, K.G., Bell, J.D, Pankhurst, R.J. 1979. The interpretation of igneous rocks. p. 450. https://doi.org/10.1007/978-94-017-3373-1

Eby, G.N. 1992. Chemical subdivision of the A-type granitoids: Petrogenetic and tectonic implications: Geology, 20(7), 641. https://doi.org/10.1130/00917613(1992)

020<0641:CSOTAT>2.3.CO;2

Gendenjamts, B. 2018. Geochemistry and geochronology of Dulaankhan massif, Khentii uplift MSc thesis, Mongolian University of Science and Technology, Ulaanbaatar, 60 p. (in Mongolian).

Jahn, B.M., Litvinovsky, B.A., Zanvilevich, A.N., Reichow, M. 2009. Peralkaline granitoid magmatism in the Mongolian-Transbaikalian Belt: evolution, petrogenesis and tectonic significance: Lithos, 113, 521-539. https://doi.org/10.1016/j.lithos.2009.06.015

Litvinovsky, B.A., Jahn, B.M., Eyal, M. 2015. Mantle-derived sources of syenites from the A-type igneous suites - New approach to the provenance of alkaline silicic magmas: Lithos, 232, 242-265. https://doi.org/10.1016/j.lithos.2015.06.008

Loiselle, M.C., Wones, D.R. 1979. Characteristics and origin of anorogenic granites: Abstracts of papers to be presented at the Annual Meetings of the Geological Society of America and Associated Societies, San Diego, California, November 5-8, 11, 468 p.

Patino Douce, A.E. 1997. Generation of metaluminous A-type granites by low-pressure melting of calc-alkaline granitoids: Geology, 25, 743-746. https://doi.org/10.1130/0091-7613(1997)025<0743:GOMATG>2.3.CO;2

Rickwood, P.C. 1989. Boundary lines within petrologic diagrams which use oxides of major and minor elements: Lithos, 22(4), 247-263. https://doi.org/10.1016/0024-4937(89)90028-5

Shand, S.J. 1943. The eruptive rocks: 2nd edition, John Wiley, New York, 444 p.

Sun, S.S., McDonough, W.F. 1989. Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. In: Saunders, A.D., Norry, M.J. (Eds.), Magmatism in Ocean Basin Geological Society of Special Publication, London, 313-345. https://doi.org/10.1144/GSL.SP.1989.042.01.19

Taylor, S.R., McLennan S.M. 1985. The Continental Crust: Its Composition and Evolution. Blackwell, Oxford.

Whalen, J.B., Curie, K.L., and Chappell, B.M. 1987. A-type granites: geochemical characteristics, discrimination and petrogenesis: Contributions to Mineralogy and Petrology, 95, 407-419. https://doi.org/10.1007/BF00402202

Whalen, J.B. 2005. A-type granites: N25 years later. Abstracts of the Annual V.M.Goldschmidt Conference, 15th, Moscow, Idaho, May 2005, Geochimica and Cosmochimica Acta 69, A84 Special Supplement.

Wilson, M. 1989. Igneous petrogenesis: A global tectonic approach. Chapman Hall, London, 466 p. https://doi.org/10.1007/978-1-4020-6788-4

Wu, F.Y., Sun, D.Y., Li, H.M., Jahn, B.M., Wilde, S.A. 2002. A-type granites in Northeastern China: age and geochemical constraints on their petrogenesis: Chemical Geology, 187, 143-173. https://doi.org/10.1016/S0009-2541(02)00018-9

Zanvilevich, A.N., Litvinovsky, B.A., Andreev, G.V. 1985. The Mongol-Transbaikalian alkali-granitoid province. Nauka, Moscow (in Russian).