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
produced in extensional settings although the
godynamic mechanisms causing the extensions
are not unique, including within-plate extension,
ripping 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)

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$_2$O$_3$, 0.04-0.2 wt.% MgO, 0.13-0.34 wt.% CaO, 3.54-4.89 wt.% Na$_2$O, and 4.44-4.6 wt.% K$_2$O. Compared with the granites, the quartz syenite is relatively low in SiO$_2$ (~69 wt.%) but relatively high in Al$_2$O$_3$ (15.1-15.36 wt.%), Na$_2$O (5.03-5.19 wt.%) and K$_2$O (5.3-5.7 wt.%), as well as CaO (0.45-0.5 wt.% (Table 1).

In (Na$_2$O+K$_2$O)-SiO$_2$ diagram (Cox, 1979; Wilson, 1989), all the 6 samples of the K-
Table 1. Chemical composition of rocks from the Dulaankhan granitic pluton

| Sample no. | Dal-1-17 | Dal-02-17 | Dal-03-17 | Dal-04-17 | Dal-05-17 | Dal-06-17 | Dal-09-17 | G-1 |
|------------|----------|-----------|-----------|-----------|-----------|-----------|-----------|-----|
| Rock type  | Qtz mylonite | Dulaankhan pluton | Dulaankhan pluton | Dulaankhan pluton | Dulaankhan pluton | Dulaankhan pluton | Dulaankhan pluton | Dulaankhan pluton |
| Major elements (%) | | | | | | | | |
| SiO2       | 69.91 | 69.94 | 74.15 | 74.2 | 74.79 | 77.11 | 78.13 | 74.15 |
| 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 | 13.41 |
| Fe2O3      | 1.698 | 1.53 | 1.38 | 1.34 | 1.27 | 0.39 | 0.879 | 1.49 |
| Na2O       | 0.083 | 0.05 | 0.08 | 0.05 | 0.06 | 0.01 | 0.082 | 0.11 |
| MgO        | 0.117 | 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 |
| K2O        | 5.198 | 5.03 | 4.8 | 4.79 | 4.69 | 3.54 | 4.195 | 4.89 |
| P2O5       | 5.376 | 5.73 | 4.44 | 4.68 | 4.45 | 4.6 | 4.341 | 4.6 |
| LOI        | 0.03 | 0.04 | 0.03 | 0.03 | 0.01 | 0.01 | 0.01 | 0.03 |
| Total      | 98.329 | 98.98 | 99.08 | 99.52 | 99.76 | 99.8 | 100.554 | 99.98 |
| Trace elements (in ppm) | | | | | | | | |
| Al          | 7.62 | 5.87 | 5.95 | 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 |
| Cs          | 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 |
| 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 | 1 | 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 | 259 | 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 |
| Cs          | 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          | 0.1 | 0.5 | 0.2 | 0.2 | 0.2 |
| Hf          | 0.25 | 0.19 | 0.2 | 0.2 | 0.2 |
| 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          | 0.33 | 0.4 | 1.4 | 0.24 | 0.45 |
| Er          | 1.78 | 1.34 | 4.05 | 1.03 | 1.48 |
| Tm          | 0.28 | 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 |
| Ce          | 4 | 2 | 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 K₂O-SiO₂ 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...
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. 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

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 $^{206}\text{Pb}/^{238}\text{U}$ 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.

Fig. 11. Y-Nb-Ce diagram showing the A2-type characteristics of the Dulaankhan pluton in northern Mongolia
For the quartz syenite (Dul-06-17), 30 analyses were done on 30 zircon grains, of which 27 analyses give a weighted mean $^{206}\text{Pb}/^{238}\text{U}$ 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 | $\delta^{18}O$ | ratio | $\delta^{18}O$ | ratio | $\delta^{18}O$ | ratio | $\delta^{18}O$ | ratio | $\delta^{18}O$ | ratio | $\delta^{18}O$ | ratio | $\delta^{18}O$ | ratio | $\delta^{18}O$ |
| D083-17-1 | 0.05 | 0.0082 | 0.23 | 0.009 | 0.01 | 0.0001 | 0.0100 | 0.0002 |
| D083-17-11 | 0.05 | 0.0013 | 0.22 | 0.003 | 0.01 | 0.0001 | 0.0003 | 0.0001 |
| D083-17-12 | 0.05 | 0.0009 | 0.21 | 0.003 | 0.01 | 0.0001 | 0.0005 | 0.0001 |
| D083-17-13 | 0.04 | 0.0006 | 0.21 | 0.003 | 0.01 | 0.0001 | 0.0002 | 0.0001 |
| D083-17-15 | 0.04 | 0.0010 | 0.21 | 0.004 | 0.01 | 0.0001 | 0.0004 | 0.0001 |
| D083-17-16 | 0.04 | 0.0009 | 0.21 | 0.003 | 0.01 | 0.0001 | 0.0005 | 0.0001 |
| D083-17-17 | 0.04 | 0.0008 | 0.21 | 0.003 | 0.01 | 0.0001 | 0.0005 | 0.0001 |
| D083-17-18 | 0.04 | 0.0001 | 0.21 | 0.006 | 0.01 | 0.0001 | 0.0008 | 0.0001 |
| D083-17-19 | 0.05 | 0.0019 | 0.24 | 0.008 | 0.01 | 0.0004 | 0.0095 | 0.0001 |
| D083-17-20 | 0.05 | 0.0008 | 0.22 | 0.003 | 0.01 | 0.0003 | 0.0001 | 0.0001 |
| D083-17-21 | 0.04 | 0.0013 | 0.21 | 0.006 | 0.01 | 0.0001 | 0.0004 | 0.0001 |
| D083-17-22 | 0.05 | 0.0010 | 0.21 | 0.004 | 0.01 | 0.0001 | 0.0004 | 0.0001 |
| D083-17-24 | 0.05 | 0.0013 | 0.23 | 0.005 | 0.01 | 0.0001 | 0.0007 | 0.0001 |
| D083-17-25 | 0.04 | 0.0011 | 0.21 | 0.003 | 0.01 | 0.0001 | 0.0010 | 0.0001 |
| D083-17-26 | 0.04 | 0.0007 | 0.21 | 0.003 | 0.01 | 0.0003 | 0.0004 | 0.0001 |
| D083-17-28 | 0.04 | 0.0040 | 0.18 | 0.016 | 0.00 | 0.0006 | 0.0093 | 0.0004 |
| D083-17-29 | 0.04 | 0.0009 | 0.21 | 0.004 | 0.01 | 0.0003 | 0.0097 | 0.0001 |
| D083-17-30 | 0.05 | 0.0016 | 0.21 | 0.006 | 0.01 | 0.0003 | 0.0002 | 0.0002 |
| D083-17-31 | 0.05 | 0.0009 | 0.22 | 0.004 | 0.01 | 0.0001 | 0.0004 | 0.0001 |
| D083-17-33 | 0.05 | 0.0007 | 0.22 | 0.003 | 0.01 | 0.0003 | 0.0005 | 0.0001 |
| D083-17-34 | 0.05 | 0.0009 | 0.21 | 0.003 | 0.01 | 0.0001 | 0.0005 | 0.0001 |
| D083-17-35 | 0.05 | 0.0009 | 0.21 | 0.003 | 0.01 | 0.0003 | 0.0006 | 0.0001 |

**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 (Ma) | $^{206}$Pb/$^{238}$U | $^{206}$Pb (cps) | $^{207}$Pb (cps) | $^{208}$Pb (cps) | $^{206}$Th (cps) | $^{238}$U (cps) |
|---------|----------|---------------------|----------------|----------------|----------------|----------------|----------------|
| PRB5    | 169.0    | 4.5                 | 15730          | 939            | 5711           | 299043         | 457895         |
| PRB1    | 316.3    | 16.7                | 1708606        | 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          | 788            | 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          | 686867         | 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-Okhtotsk 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 predominantly 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.

ACKNOWLEDGEMENTS

The study was supported by “Geodynamic settings and mineralization (W, Sn and REE) of Mesozoic Granitoid Magmatism, Mongolia: Prospective”, project (№ SSA 009/2016) of Institute of Geology, MAS. First author is very grateful to colleagues at Institute of Geology, MAS and Professors at the Department of Geology and Hydrogeology, MUST for their continuous support during his MSc study.

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