Paleozoic and Mesozoic granitic rocks in the Hotont area, central Mongolia

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Abstract: The granitic rocks of the Hotont area were classified into the Late Paleozoic Delgerhaan batholithic complex and Mesozoic Egiindavaa stocks, the latter of which is further divided into normal granitoids and Sn-rich granitoids. The Delgerhaan granitoids are weakly magnetic, their oxygen fugacity being at QMF buffer, while the Egiindavaa granitoids are more reduced belonging generally to ilmenite series. The Sn-rich granites are completely magnetite free and most reduced.

The Delgerhaan granitoids are shoshonitic, whereas the Egiindavaa granitoids are shoshonite to high-K series. Both the granitoids are similar in most of chemical components in the Harker’s diagrams, but the Delgerhaan granitoids are richer in P₂O₅ and poorer in Fe₂O₃, TiO₂ and MgO than the Egiindavaa granitoids. Both the granitoids seem to be generated within continental crust in island-arc setting, and well fractionated.

Weak Au-mineralizations are related to the Late Paleozoic Delgerhaan granitic complex. The Late Paleozoic granitoids are too well exposed to have primary base-metal deposits, and the Mesozoic granitoids are not oxidized enough to have base metal mineralizations. Sn and W mineralizations and some Ti-Ta-Nb occurrences are possibly associated with reduced granitoids of the Mesozoic age, particularly with the Sn-rich granites, which may have formed in anorogenic setting.

Keywords: Hotont area, granitoids, Late Paleozoic, Early Mesozoic, chemical compositions, tin granite

1. Introduction

The Hotont area (102° 00’E to 102° 30’E and 47° 10’N to 47° 40’N) is located in Tüvshruuleh and Hotont sums of Arhangai Aimag in central Mongolia, which is geologically divided into Harhorin and Tsetserleg terranes. The area was mapped at a scale of 1:50,000 by geologists and students of the School of Geology, Mongolian University of Science and Technology (MUST) during the years of 2002 - 2004.

One of the authors (S.O.) visited the area in the 2002 - 2003 field season, and studied the magnetic susceptibility and the mode of occurrence of the granitic rocks. Petrographical description including the modal analyses was later carried out at the laboratories of the MUST. Chemical analyses were performed jointly with the Geological Survey of Japan. In this paper, we report petrographical and chemical characteristics of the granitoids in the Hotont area and discuss mineral resources potentiality of the granitoid affinity.

2. Geologic setting

The Hotont area has been geologically studied by many geologists (Semeikhan and Bold, 1970; Khosbayar et al., 1987; Davaa et al., 1996; Chuluunsüh et al., 1996). The area was originally divided into Harhorin uplift block and Hangai Zone. Recently, Chuluun and Javkhlanbold (2004) geotectonically reclassified the region into Harhorin and Tsetserleg terranes, based upon the terrane map of Mongolia by Tomurtogoo (2004). Geological map of the studied area is given in Fig. 1.

The Harhorin terrane (formerly the Harhorin uplift, e.g., Semeikhan and Bold, 1970) is composed of Lower to Middle Ordovician Hotont Formation (O₁-2ht), Lower to Middle Silurian Mongontseej Formation (S₁-2mj) and Middle to Upper Silurian Jashil Formation (S₃-4jl). The Hotont Formation consists of epidote-chlorite schist, sericite-chlorite schist, muscovite schists and quartzite. The Yashil Formation, which is subdivided into Serven and Hangai Members, is composed of two-mica schists, siltstone and quartzite. The Yashil Formation consists of epidote-chlorite schist, sericite-chlorite schist, muscovite schists and quartzite. The Yashil Formation, which is subdivided into Serven and Hangai Members, is composed of two-mica schists, siltstone and quartzite.

The Tsetserleg terrane is composed of Middle to Upper Devonian Erdenetsogt Formation, Lower Carboniferous Tsetserleg Formation and Upper Carboniferous Jargalant Formation. The Erdenetsogt Formation consists of sandstone, siltstone and quartzite. The Lower Carboniferous
Tsetserleg and Upper Carboniferous Jargalant Formations are mainly composed of conglomerate and sandstone. An Ordovician dioritic stock (Od3) occurs in the Harhorin terrane. Granitic and minor dioritic rocks intrude abundantly in the sedimentary rocks of the Tsetserleg terrane. By cross-cutting relationship in field, intrusive stage of these granitic rocks must be later than the Carboniferous formations, and is considered as Late Paleozoic and Early Mesozoic in referring to the radiometric age data (e.g., Amar-amgalan, 2004), although we still need additional age determination. Cretaceous to Neogene pyroxene and olivine-pyroxyene basalts are distributed mainly in the central part of the Tsetserleg terrane.

3. Geology and petrography of the granitic complexes

The granitic rocks of the Hotont area are divided into Late Paleozoic Delgerhaan complex and Early Mesozoic Egiindavaa complex (Fig. 1). The Delgerhaan granitoids intrude discordantly into the Erdenetsogts sandstones and siltstone of the Middle to Upper Devonian age, and also concordantly into the sediments of the Lower Carboniferous Jargalant Formation and the Upper Carboniferous Tsetserleg Formation. The intrusive age is therefore later than the Upper Carboniferous geologically, and the granitoids are considered intrusion complex of Late Permian to Early Triassic age, based on reconnaissance Rb-Sr isotopic studies of Amar-Amgalan (2004). On the other hand, small stocks of the Egiindavaa granitic complex intrude into the Devonian Erdenetsogt Formation and also into the Late Paleozoic granitoids. The intrusive ages are considered Late Triassic to Early Jurassic (Amar-Amgalan, 2004).

3.1 Delgerhaan granitic complex

This granitic complex occurs along the top and slope of mountains (Fig. 2A) with adomen-like relief. It is a large batholith occupying Tsagduul, Tsohiot, and Tsagaan Asga massifs. The batholith consists mainly of quartz monzodiorite, granodiorite, quartz monzonite and monzogranite (Figs. 3, 4). The mafic silicates are generally biotite with various amounts of hornblende with or without magnetite (Oyungerel and Nyamsuren, 2003).

A number of fine-grained mafic enclaves rich in biotite, 3 cm to 35 cm in size, occur in endocontact zone of the granitoids. Hornfelsic sandstones with schistose textures (Fig. 2B), 10 cm to 1 m in diameter, are also observed in the endocontact zone. A variety of dikes, up to 5 m in the width, occur in the granitoids,
Paleozoic and Mesozoic granitic rocks in the Hotont area, central Mongolia (Oyungerel and Ishihara)

Field measurement of magnetic susceptibility by KT-5 Kappameter (Fig. 2A) indicates that the coarse- to medium-grained, biotite quartz monzodiorite (O-26, 102° 17’ 21”E, 47° 19’ 56”N) range from 4.65 to 12.5 x 10⁻³ SI unit, which is the values of magnetite series (>3.0 x 10⁻³ SI). The medium-grained, biotite-hornblende quartz monzonite (O-71, 102° 22’ 89”E, 47° 15’ 06”N) varies from 0.03 to 2.39 x10⁻³ SI, which is the values of ilmenite series (<3.0 x 10⁻³ SI). The fine- to medium-grained, hornblende-biotite monzogranite (O-72, 102° 22’ 89”E, 47° 14’ 63”N) show the magnetic susceptibility of 2.2 - 5.0 x 10⁻³ SI and porphyritic fine- to medium-grained hornblende-bearing biotite monzogranite (O-74, 102° 21’ 08”E, 47° 13’ 43”N) reveals the magnetic susceptibility of 1.4 - 4.5

Fig. 2 Field photographs and samples pictures of the Hotont area.
A. Measured outcrop of magnetic susceptibility in field.
B. Sedimentary xenolith at margin of the Late Paleozoic granitoids, Bulamtolgoi Mtn. The magnetic susceptibility is low (0.12-0.52 x 10⁻³ SI).
C. Amazonitic Sn-rich granite (right, 23G) and aplite (left, 23A).
x 10^{-3} \text{SI} \ (\text{Oyungerel et al., 2003}). \ Therefore, \ overall \ values \ are \ intermediate \ between \ typical \ values \ of \ the \ magnetite- \ and \ ilmenite-series \ granitoids.

Rock-forming minerals are represented by plagioclase, K-feldspar, quartz, biotite, sometimes hornblende, opaque minerals, and zircon with various degrees of radioactive haloes and apatite. If primary titanite appears among accessory minerals, its magnetic
Paleozoic and Mesozoic granitic rocks in the Hotont area, central Mongolia (Oyungerel and Ishihara)

susceptibility is usually high, and the rock belongs to magnetite-series.

Modal analyses indicate that granitoids of the Delgerhaan complex are plotted mostly in the monzogranite field and some plotted in the quartz monzogranite and quartz monzodiorite field (Fig. 3).

Contents of the mafic minerals are generally low (Fig. 4) but vary from 1.2 to 18.0 %. Panning of the stream sediments at Tagtolgoi Au-occurrence indicates magnetite contents of 90 - 200 grams/ton and ilmenite contents of 30 - 70 grams/ton, implying both magnetite and ilmenite are contained in the original granitoids. The chemical compositions are given in Tables 2 and 3.

3.2 Egiindavaa granite complex

The Egiindavaa granitic complexes occur as stock-like small bodies controlled by deep faults with north-
easterly trends. They show strongly sheared and slightly weathered outcrops caused by recent uplifting and NW-SE shearing along the Harhorin and Hanhar faults. Therefore it is difficult to obtain fresh rock samples for geochemical studies.

The Egiindavaa granites are granodiorite to monzogranite (Figs. 5, 6), containing biotite universally and some hornblende as major mafic silicates, which may be enriched in endogranitic zone when the bulk composition is granodioritic. Mafic enclaves are rare. There occur a few dikes of granite-pegmatite, aplite, biotite syenite porphyry and amazonite porphyry. The chemical compositions are given in Tables 2 and 3.

At one place near the Tsagduul massif, fine to medium grained mica granites with green amazonitic K-feldspar and dark quartz (Fig. 2C) occur in the Delgerhaan batholith. These rocks may be a later...
Table 3  Trace element and REE compositions of selected granitoids from the Hotont area.

<table>
<thead>
<tr>
<th>Age</th>
<th>Paleozoic granitoids</th>
<th>Mesozoic granitoids</th>
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<td>P13</td>
<td>M14</td>
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<tr>
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</tr>
<tr>
<td>Th</td>
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<td>20.2</td>
<td>52.6</td>
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<tr>
<td>U</td>
<td>3.4</td>
<td>2.5</td>
<td>7.6</td>
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<td>0.98</td>
<td>0.55</td>
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<tr>
<td>Sr/Y</td>
<td>15.5</td>
<td>18.5</td>
<td>13.4</td>
</tr>
<tr>
<td>La/Yb</td>
<td>24.0</td>
<td>25.6</td>
<td>25.7</td>
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<tr>
<td>LREE/HREE</td>
<td>5.7</td>
<td>4.8</td>
<td>5.9</td>
</tr>
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</table>

Analyst: Actlabs, Ltd. (ICP-MS)
Mesozoic intrusion, although the field relationship is ambiguous for the poor exposure. The granites are very high in the trace amounts of tin (see geochemistry chapter), and therefore called tentatively Sn-rich granites in this paper.

Field measurement of magnetic susceptibility on the representative rock types are as follows: coarse- to medium-grained, biotite quartz syenite (O-63, 102° 13′ 50″ E, 47° 24′ 50″ N) ranging from 1.14 up to 2.29 x 10⁻³ SI; hornblende-bearing biotite quartz syenite (O-69, 102° 24′ 50″ E, 47° 17′ 24″ N) measured at 2.89, 3.37, 3.71 x 10⁻³ SI; fine- to medium-grained, two-mica, leucocratic monzogranite (O-16, 102° 26′ 25″ E, 47° 12′ 50″ N) with low values as 0.47, 0.34, 0.44, 0.36 x 10⁻³ SI; medium-grained, biotite-bearing monzogranite (O-56, 102° 06′ 51″ E, 47° 26′ 05″ N) with 0.44 - 2.11 x 10⁻³ SI, and cataclastic, coarse-grained, biotite-bearing syenogranite (O-66; 102° 26′ 37″ E, 47° 15′ 53″ N) with magnetic susceptibility of 0.11 - 0.27 x 10⁻³ SI).

The Mesozoic granitoids are therefore composed mostly of ilmenite series, represented by either biotite or biotite-muscovite assemblages, which are common in Sn-mineralized terrains, such as Japan and Malay Peninsula (Ishihara, 1977; Ishihara et al. 1979). Only some hornblende-bearing phase of the Egindavaa complex belongs to magnetite series. The Sn-rich granite seems to be most reduced granite in the Hotont area.

Rock-forming minerals of the Egindavaa complex are K-feldspar, plagioclase, quartz, biotite, rarely hornblende, opaque minerals, radiogenic zircon and apatite. By modal analyses, the granitoids are mostly plotted in monzogranite and syenogranite-quartz syenogranite fields (Fig. 5). Contents of the mafic minerals are generally low varying from 0.8 to 10.0 % (Fig. 6). Therefore, granitoids of the Egindavaa complex are more leucocratic and alkaline than those of the Delgerhaan complex.

### 3.3 Sn-rich granite

This granite, containing pale green color K-feldspar (amazonite, Fig. 2C), is found in a prospecting shaft of Ulaanbulag valley near the Tsagduul massif of the Late Paleozoic Delgerhaan complex. This is so different from the other rocks that they may belong to younger, Mesozoic age. The quartz is dark transparent which is due to radioactive decay. The biotite is platy crystals and is really black in color, indicating Fe⁺⁺ rich variety, because of lack of magnetite shown by very low degree of the magnetic susceptibility (less than 0.1 x 10⁻³ SI). The rocks are so different from the surrounding granodiorite and the chemistry is also clearly different as mentioned later, and are therefore considered as a Mesozoic stock intruded into the Late Paleozoic granitoids.

The granite consists of microcline (45 - 50%), plagioclase (20 - 25%), quartz (25 - 30%) and biotite (2 - 3%) with small amounts of opaque minerals. Microcline is anheal and it shows grid twinning. Microcline is partly corroded by quartz. Albite rim is developed along contact with the microcline. The plagioclase is euheudral to subhedral, and shows polysynthetic twinnings. The anorthite contents are 8 - 10 %. Plagioclase is sometimes replaced by microcline. Biotite is subhedral and includes accessory minerals of apatite, radioactive zircon and opaque minerals. Quartz microveinlets, 0.04 - 0.4 mm wide, may be seen in the granite.

### 4. Mineralizations in the Hotont area

In the Hotont area, Tagtolgoi (102° 00′ 43″ N, 47° 26′ 55″ E) and Baahanbulag (102° 12′ 17″ N, 47° 25′ 53″ E) Au-occurrences, and Hanhar (102° 03′ 29″ N, 47° 28′ 22″ E), Namdava (102° 10′ 55″ N, 47° 14′ 09″ E) and Barunganga Au-mineralized points (102° 01′ 37″ N, 47° 24′ 54″ E) are found in the Late Paleozoic Delgerhaan complex, which is weakly magnetic and can be an intermediate series of Ishihara et al. (1984). Gold mineralizations with similar oxidation state have been reported in eastern Australia (Blevin, 2004).

On the contrary, the Egindavaa granitoids are associated with tin-tungsten mineralizations, e.g., Ulaanbulag tin-mineralized point (102° 22′ 22″ N, 47° 16′ 38″ E), Tomorhairhan Sn-W occurrence (102° 03′ 34″ N, 47° 12′ 07″ E), Tömört scheelite (W)-occurrence (102° 05′ 12″) and Ulaanbulag Ti-Ta-Nb placer occurrence (102° 21′ 22″ N, 47° 13′ 52″ E). Within the Sn-rich granitic body, there occur cassiterite-greisen mineralizations, and cassiterite is also found in the stream sediments in this area.

This spatial relationship between the ilmenite-series granitoids and Sn-W mineralizations is widely recognized in the other Phanerozoic terrains of the Circum-Pacific region (Ishihara, 1977).

### 5. Geochemistry of the granitoids

Chemical analyses were made on representative samples from the Paleozoic Delgerhaan complex (P1-13, 13 samples) and the Mesozoic Egindavaa granitoids (M14 - 25, 12 samples). Their localities are given in Table 1 and Fig. 1, and the results are listed in Tables 2 and 3. The Mesozoic granitoids are divided into normal granitoids (M14 - 21) with Sn contents of 0.7 - 4.9 ppm and Sn-rich granite (M22 - M25) with Sn contents of 6.7 - 1,158 ppm. The analytical results are plotted with these categories in the Harker’s diagrams of Figs. 7 to 12.

5.1 Feldspar components

Al₂O₃ contents decrease with increasing of SiO₂ (Fig. 7),
Paleozoic and Mesozoic granitic rocks in the Hotont area, central Mongolia (Oyungerel and Ishihara)

and Mesozoic granitoids have the least amount of Al₂O₃, because they are rich in SiO₂. However, the alumina saturation index (ASI, Zen, 1992) of both Paleozoic and Mesozoic granitoids is mostly above 1.0, i.e., peraluminous, but below 1.1, implying all the rocks belong to I type of Chappell and White (1974). In the Na₂O vs. K₂O diagram, all the granitoids are also plotted in the I-type field (Fig. 7).

In the K₂O-SiO₂ diagram, most of the Paleozoic granitoids are plotted in the shoshonite field, but the Mesozoic granitoids are plotted in both the shoshonite and high-K calc-alkaline-series field (Fig. 8). Na₂O contents are generally higher in the Paleozoic granitoids than in the Mesozoic granitoids. Very high value of the O23A Sn-rich granite (6.4 % Na₂O) may be due to late magmatic albition.

The total alkali contents are high in the Paleozoic granitoids, being 8.2 - 11.1% Na₂O+ K₂O, but their Rb/Sr ratios are low ranging from 0.3 to 1.9, implying that they are not fractionated before the emplacement. The Mesozoic granitoids have also low ratios of 0.5 - 2.0, except for the M21 granite with the Rb/Sr of 7.7. Therefore, these granitoids have disadvantage in concentrating the metals associated with magmatic fractionation, such as Mo and Pb-Zn.

The Sn-rich granites are high in Rb (Fig. 9), Rb/ (1.57A) is larger than K+ (1.46A), thus substituting K+ of K-bearing minerals in a late crystallizing...
stage for the larger ionic size. The Sn-rich granite must be also high in Pb\(^{2+}(1.02\text{Å})\), which is expected to substitute K position in an early crystallizing stage for the smaller ionic radius and higher electron charge. These granites are also high in Cs\(^+\)(1.78\text{Å}), which may be concentrated in the latest phase of K-feldspar.

Ba\(^{2+}(1.44\text{Å})\), replacing an early crystallized K-bearing minerals, is generally abundant in low SiO\(_2\) rocks, but the contents are very variable on the early Mesozoic granites (Fig. 10). Some of the high SiO\(_2\) granites are very high being over 1,000 ppm, but the Sn-rich granites are less than 28 ppm (Table 2).

Ga, not shown in Fig. 10 and replacing Al\(_2\)O\(_3\) in feldspars, is generally higher than 20 ppm in A-type granite (Collins \textit{et al.}, 1988). Here the element is below 21 ppm for most of the rocks (Table 2), except the Sn-rich granites which vary from 22 to 43 ppm. Zr is higher in the Paleozoic granitoids than in the Mesozoic granitoids (Fig. 10).

5.2 Mafic components

The Harker diagrams (Fig. 11) indicate that the Paleozoic granitoids are plotted generally lower than the Mesozoic granitoids in the total FeO\(_x\), TiO\(_2\) and MgO. MgO is less than 1.7% throughout the granitoids implying a little or no mantle components involved in these granitoids.

Vanadium is low, below 52 ppm (Table 2). The element (V\(^{2+}(0.87\text{Å}; V^{3+}(0.72\text{Å})\)) may substitute Fe\(^{3+}(0.71\text{Å})\)
and Fe$^{3+}$ (0.57Å) of rock-forming magnetite. Chromium (Cr$^{2+}0.81$Å; Cr$^{3+}0.70$Å, Cr$^{4+}0.52$Å) and Zn$^{2+}$ (0.68Å) may replace iron in the rock-forming silicate. P$_2$O$_5$ contents are more in the Paleozoic granitoids than in the Mesozoic granitoids (Fig. 10). There is no microscopic evidence of monazite occurring in the Paleozoic granitoids; thus the element must be present as apatite. The Paleozoic granitoids are richer in apatite than the Mesozoic granitoids.

Nb is less than 18 ppm in the normal granitoids but high as 13 - 67 ppm in the Sn-rich granite. Ta is lower than 6 ppm in most granitoids but high in the Sn-rich granite as 4 - 15 ppm. Y is much higher in the Sn-rich granite (19 - 108 ppm) than the normal granites (9 - 31 ppm, Table 2).

5.3 REE components

REE components are analyzed by ICP-MS method on representative samples and listed in Table 3. The Paleozoic granitoids have the total REE of 100 and 310 ppm, and the Mesozoic granitoids of 174 and 330 ppm. The Sn-rich granites have lower values as 172 and 292 ppm, but the Rb-rich granite of the sample M25 has the lowest LREE/HREE ratio, implying this rock is very rich in HREE (e.g., La/Yb ratio=0.74), with a typical bird-flying REE pattern (Fig. 13).

On the chondrite normalized REE patterns (Fig. 13), the studied granitoids show similar patterns, high in LREE but low in HREE with weak Eu negative anomalies, except for one of the Sn-rich granites. The granodiorite P3 of the Paleozoic Delgerhaan granitoids is
richest in REE and the granite P13 is least in REE. Among the Mesozoic Egiindavaa complex, the granodiorite M14 and the granite M18 are plotted between the two values.

The Sn-rich aplitic granite M24 has strong concentration of HREE, which may be contained in accessory minerals. Eu is strongly depleted, which is due to plagioclase fractionation. This aplitic granite should be formed from the final fractional melt of the Sn-rich granites.

5.4 Discrimination diagrams

The analytical data are plotted in the discrimination diagram of Pearce et al. (1984). Almost all the granitoids are plotted in the uppermost part of the volcanic arc granites (VAG), except for the Sn-rich granites, which are plotted in the syn-collisional granite field (syn-COLG) because of the high contents of Rb (Fig. 14). No granitoids are plotted in the within-plate granite field (WPG), although three of the Sn-rich granites are plotted in the WPG field of the Nb-Y diagram, which is not shown here. Therefore, most of the granitoids are considered generated under an island-arc setting.

The Sn-rich granites are high in F, Rb, Cs, Nb, Ta, Y, Zn, Pb, Ga and Sn, which are characteristics of anorogenic (A-type) granites. The Sn-rich granites may have been originated locally along structural weakness within the continental crust. These anatectic melts may have possibly intruded as a younger small stock in the Late Paleozoic granitoids.
Paleozoic and Mesozoic granitic rocks in the Hotont area, central Mongolia (Oyungerel and Ishihara)

6. Concluding Remarks

The granitic rocks of the Hotont area, composed of the Late Paleozoic Delgerhaan batholith complex and Mesozoic Egiindavaa stocks, are mostly biotite monzogranite and some hornblende-biotite granodiorite, associated with little mafic rocks. The Delgerhaan granitoids contain generally small amounts of magnetite, and can be considered crystallization around the QMF buffer. The Egiindavaa granitoids are more reduced belonging mostly to ilmenite series, thus they can be formed below the NNO buffer (Ishihara, 1977). The Sn-rich granites are completely magnetite free and most reduced.

The Delgerhaan granitoids are shoshonitic, whereas the Egiindavaa granitoids are shoshonite to high-K series. Both the granitoids are similar in most of chemical components in the Harker’s diagrams, but the Delgerhaan granitoids are richer in P2O5 and poorer in Fe2O3, TiO2 and MgO than the Egiindavaa granitoids. Both the granitoids seem to be generated within continental crust with K-rich I-type sources under an island-arc setting.

The Sn-rich granites are high in F, Rb, Cs, Nb, Y, Zn, Pb, Ga and Sn, which are characteristics of A-type granites. They may be a Mesozoic intrusion and generated in anorogenic tectonic setting. The granites should have been formed by remelting of an older reduced granitic materials in anorogenic environment, and carried Sn and rare metal mineralizations.

The Delgerhaan granitoids are too well exposed to have metallic mineral deposits, which tend to occur generally associated with small plugs or stocks. The granitoids are not oxidized enough to concentrate sulfur-combined ore minerals. Placer gold and weak Au mineralizations can be expected with the granitoids. Sn and W mineralizations and some Ti-Ta-Nb occurrences are possibly associated with reduced granitoids of the Mesozoic age, particularly with the Sn-rich granitoids.

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