Tungsten and tin deposits of Mongolia

by N. Tungalag*, S. Jargalan** and O. Odbayar*

Abstract: Tungsten and tin are very abundant and economically important metals of Mongolia. There are more than 160 primary and placer deposits of these metals, of which only 20 are primary deposits. The tin and tungsten deposits of Central and Eastern Mongolia are genetically associated with Mesozoic granitoids. These granitoids occur widely in the zone of Mesozoic tectonic and magmatic activity. Most of the tin and tungsten deposits are genetically associated with both "normal" and lithium-fluorine types of granitoids. Greisen and quartz-vein type wolframite and cassiterite deposits are associated with the granites of normal composition. Tantalum-bearing lepidolite-albite and amazonite granites are genetically associated with lithium-fluorine granites, ongonites, rare-earth microclinites and rare-element zwitters. The tin-tungsten mineralization of Mongolia is very diverse, and includes hydrothermal and pegmatitic shows as well as skarns. The most commercially viable hydrothermal deposits containing wolframite and quartz and cassiterite, wolframite and quartz. The highest value in the economy have deposits of tungsten and tin, represented mostly by quartz vein, greisen and placer types, although detailed ore genesis studies of the mineralization have not yet been conducted.

1. Introduction

Mongolia is rich in mineral deposits including copper, iron, precious metals and rare and rare earth elements (Dejidmaa et al., 2001). The current scientific and industrial revolution is making our social and technical development increasingly dependent on very specific properties of certain metals used in special alloys and products in various fields of modern technology. One of these metals that has wide application in the most advanced technology are tungsten and tin. It are becoming more and more important in many branches of industry, especially in the production of metalworking machinery, turbines, rocket nozzles, tool steels, drill bits, tin cans, soft solder, pewter, bronze and phosphor bronze etc. Geological analysis shows that tungsten and tin mineralization of the rift zones occurs at late Mesozoic metallogenic zone coinciding with the late Mesozoic igneous province.

Gundsambuu (1978, 2004) reported the geochemical characteristics of rare-metal granitoids to a close genetic relation between tin and tungsten ore deposits and acid magmatism. This relation is more clearly found for the zwitter type of ore deposition in the territory of the Mongolia. This type of deposition is an intermediate member between pegmatites and greisens. The most interesting geological facts showing the relationship of the zwitter ore deposition to acid magmatism are illustrated in the form of isolated schlieren of zwitter segregations and greisens in the granites of supplementary intrusions of the hypabyssal massifs. Thus for example in the granites of the supplementary intrusions of Baga-Gazryn, isolated schlieren and segregations of simple pegmatites are encountered.

The ore deposition in the quartz bodies of the tungsten deposit Tumen-Tsogto is localised in isolated lens-like quartz-mica greisens which occur along a contact zone of fine-grained granites with coarse-grained porphyritic granites of the normal type. The enrichment of granites in rare elements and ore metals, their general geochemical features, and also the schlieren segregations of pegmatites, zwitters and microclinites underline concepts concerning the genetic unity of granites with pegmatites, microclinites, and other postmagmatic formations (Gundsambuu, 1978).

This article reports just introducing of previous studies proceedings of tin and tungsten mineralization in Mongolia.

2. Geology and mineralization features of Tin and Tungsten in Mongolia

Most of the known tin-tungsten deposits and ore shows...
in Mongolia are described in: Khasin and Marinov (1977); Shcherbakov (1986); Sotnikov (1986); Obolensky (1986); Kovalenko (1986). Tin-tungsten deposits in central and eastern Mongolia are genetically closely associated with granitoids of Mesozoic age, especially with the normal and lithium-fluorine types (Kovalenko et al., 1970). These granitoids are widely developed in the zone of Mesozoic tectonic and magmatic activity.

Joint Mongolian and Soviet expeditions in 1967–1971 and in following years under the supervision of V. I. Kovalenko established several geochemical types of Mesozoic granitoids of Mongolia. Some of the granitoids include rare-metal, lithium-fluorine and appaïtic types. Most of the tin and tungsten deposits are genetically associated with both normal and lithium-fluorine types of granitoids. Thus greisen and quartz-wolframite types (Ikh-Khairkhan, Tumen-Tsogt, Chulun-khorot, Ikh-Nartyn-khid, Tsagan-daba), and tin deposits (Modoto, Khuchzhikhan) are associated with the granites of normal composition. Tantalum-bearing lepidolite-albite and amazomite granites are genetically associated with lithium-fluorine granites, ongonites (Ongon-Khairkhan, Baga-Gazryn), rare-earth microclinites and rare-element zwitters (Baga-Gazryn). In addition greisen deposits (Baga Gazryn), quartz-ore and tin (Zhanchivlan) and tungsten deposits (Barun-Tsogto) are also encountered (Gundsambuu, 1978).

The tin-tungsten mineralization of Mongolia is very diverse, and includes hydrothermal and pegmatitic shows as well as skarns (Kovalenko et al., 1995). The most commercially viable are hydrothermal deposits containing wolframite and quartz and cassiterite, wolframite and quartz. Tungsten predominates over tin, and the proportion of tungsten is higher in the first of ore: the wolframite-quartz type. Tin and tungsten mineralization is represented by the tungsten-quartz, tungsten-cassiterite-quartz, and cassiterite-quartz (Dergunov, 2001).

3. Geochemical characteristics of Tungsten and Tin ore-bearing granitoids

Multi-element average contents of tungsten-tin bearing granitoid rocks including normal and lithium-fluorine types as well as dykes in the Mongolia are presented in Table 1 (Gundsambuu, 1978). The normal granite composition in its late phases there is an increase in Rb and Be and decrease of Li, Sn, Zn, Ba and Sr. The concentration of Be remains constant or is slightly increased. In pegmatites of the granitoids with normal composition an accumulation of Rb, K and Pb occurs accompanied by a decrease in Sn, W, Ba and Sr. In the greisened granites, greisens and muscovite micacites the contents of K, Rb, Li, Sn, Zn, W, Ba, and Sr are considerably increased along the selvedges of quartz veins whereas those of Na and Pb are lower (Table 1).

The contents of Li, Rb, W, Sn, Zn, Tl, F and T a are increased in the lithium-fluorine type granitic rocks, whereas the contents of Ba and Sr are decreased. Pegmatites of the lithium-fluorine granites are characterized by relatively high contents of K, W, P and Be, and by relatively low Rh, Zn, Sn, Pb and Ba contents by comparison with the granitoids of the supplementary intrusions.

The dykes of ongonites are characterized by strongly increased contents of Li (60 times), Rb (15 times), Sn (10 times), Be (10 times), tungsten (5 times), fluorine (30 times) as compared with granite averages. The contents of Ba and Sr in ongonites are usually lower by one order of magnitude whereas those of Zn and Pb are near those of granite averages. When comparing the lithium-fluorine granites with normal granites, differences are also found in the distribution of lithium, rubidium and strontium.

Biotite zwitters show an accumulation of F up to 4.1 %, an increase of Rb, Li, Sn, T a, W and Zn along with strong depletion of K and Na and a decrease in the K/Rb ratios (to 27). In quartz-topaz zwitters a strong decrease of K, Na, Rb, Li, W, T a, Be, Ba and Sr is observed by comparison with biotite zwitters and this is accompanied by a strong increase of F (4.7 %) and Sn. In greisens and greisenized granites with the wall rock micacites there are increased contents of Li, Rb, Pb, Sn, Zn, W, Mo and Be, and low contents of Sr. When comparing the greisens and micacites of the lithium-fluorine and normal types the metasomatites of the lithium-fluorine granites are relatively more enriched in Pb, Zn, Sn and W whereas the metasomatites of normal granites are higher in Ba and Sr.

Thus a characteristic feature of the ore-bearing granites (normal and lithium-fluorine ones) and their postmagmatic products in Eastern and Central Mongolia is a strong enrichment in rare elements as shown from the data given above.

4. Tungsten and Tin deposits of Mongolia

The tungsten and tin, that has wide application in the most advanced technology and substantial economic importance. Currently in Mongolia, there are more than 160 primary and placer deposits of these metals, of which only 20 primary deposits (Fig. 1).
Table 1  Average contents of potassium, sodium, fluorine in % and rare elements in ppm in granitoids and ore formations of Mongolia (Gundsambuu, 1974; 1978).

<table>
<thead>
<tr>
<th>Rock types</th>
<th>K</th>
<th>Na</th>
<th>Li</th>
<th>Rb</th>
<th>Pb</th>
<th>Sn</th>
<th>Zn</th>
<th>Te</th>
<th>WO₃</th>
<th>Mo</th>
<th>Be</th>
<th>F</th>
<th>Ba</th>
<th>Sr</th>
<th>B</th>
<th>Sample Number</th>
</tr>
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<tr>
<td><strong>Normal type</strong></td>
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</tr>
<tr>
<td>Granites of the main intrusion phase</td>
<td>3.9</td>
<td>2.7</td>
<td>88</td>
<td>277</td>
<td>30</td>
<td>11</td>
<td>32</td>
<td>1.1</td>
<td>4.1</td>
<td>1.5</td>
<td>5.9</td>
<td>0.1</td>
<td>641</td>
<td>200</td>
<td>10</td>
<td>57</td>
</tr>
<tr>
<td>granites of the supplementary intrusions</td>
<td>3.6</td>
<td>2.7</td>
<td>33</td>
<td>304</td>
<td>30</td>
<td>8.9</td>
<td>25</td>
<td>1.2</td>
<td>2</td>
<td>1.5</td>
<td>9</td>
<td>0</td>
<td>245</td>
<td>109</td>
<td>11</td>
<td>39</td>
</tr>
<tr>
<td>pegmatites</td>
<td>5</td>
<td>2.9</td>
<td>30</td>
<td>440</td>
<td>51</td>
<td>5</td>
<td>25</td>
<td>0.9</td>
<td>1.6</td>
<td>1.5</td>
<td>6.2</td>
<td>16</td>
<td>40</td>
<td>3</td>
<td>9</td>
<td></td>
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<tr>
<td>graisen and greisenized granites</td>
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<td>788</td>
<td>1161</td>
<td>134</td>
<td>131</td>
<td>50</td>
<td>1.1</td>
<td>15</td>
<td>5.3</td>
<td>1361</td>
<td>200</td>
<td>17</td>
<td>10</td>
<td>3</td>
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<td>muscovite micacites</td>
<td>8.8</td>
<td>0.47</td>
<td>1900</td>
<td>1900</td>
<td>19</td>
<td>500</td>
<td>42</td>
<td>4.3</td>
<td>175</td>
<td>16</td>
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<tr>
<td>alaskites</td>
<td>3.8</td>
<td>2.8</td>
<td>194</td>
<td>538</td>
<td>40</td>
<td>9.8</td>
<td>59</td>
<td>2</td>
<td>4</td>
<td>1.6</td>
<td>8.1</td>
<td>0.3</td>
<td>25.9</td>
<td>6.6</td>
<td>10</td>
<td>68</td>
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<tr>
<td>granites of the supplementary intrusions / alaskites, amazonite albite, lepidolite-albite</td>
<td>3.6</td>
<td>3.6</td>
<td>379</td>
<td>814</td>
<td>58</td>
<td>40</td>
<td>94</td>
<td>3.6</td>
<td>4</td>
<td>1.3</td>
<td>6.6</td>
<td>0.4</td>
<td>16.4</td>
<td>4.6</td>
<td>10</td>
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<td>ongonite</td>
<td>3</td>
<td>4</td>
<td>2376</td>
<td>2268</td>
<td>38</td>
<td>44</td>
<td>38</td>
<td>10.2</td>
<td>42.8</td>
<td>2.2</td>
<td>6.2</td>
<td>10</td>
<td>12</td>
<td>14</td>
<td>14</td>
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<tr>
<td>amazonite-albite pegmatite</td>
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<td>2.7</td>
<td>379</td>
<td>782</td>
<td>34</td>
<td>75</td>
<td>48</td>
<td>4</td>
<td>17.3</td>
<td>1.3</td>
<td>9.2</td>
<td>0.8</td>
<td>11.7</td>
<td>5</td>
<td>10</td>
<td>11</td>
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<tr>
<td>biotite zwitters</td>
<td>1.53</td>
<td>0.09</td>
<td>830</td>
<td>578</td>
<td>8</td>
<td>72</td>
<td>57</td>
<td>1.6</td>
<td>98</td>
<td>3.3</td>
<td>2.3</td>
<td>4.1</td>
<td>26</td>
<td>14</td>
<td>26</td>
<td>24</td>
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<tr>
<td>quartz-topaz zwites</td>
<td>0.35</td>
<td>0.03</td>
<td>57</td>
<td>84</td>
<td>9</td>
<td>338</td>
<td>42</td>
<td>0.6</td>
<td>82</td>
<td>1.8</td>
<td>0.8</td>
<td>4.8</td>
<td>10</td>
<td>3</td>
<td>10</td>
<td>17</td>
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<tr>
<td>quartz-lepidolite greisens</td>
<td>4</td>
<td>1.7</td>
<td>1315</td>
<td>1639</td>
<td>14</td>
<td>81</td>
<td>52</td>
<td>6.9</td>
<td>3.9</td>
<td>1.8</td>
<td>4.7</td>
<td>1.4</td>
<td>12</td>
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<td></td>
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<tr>
<td>quartz-muscovite greisens and greisened granites</td>
<td>3.39</td>
<td>1.1</td>
<td>127</td>
<td>790</td>
<td>189</td>
<td>507</td>
<td>457</td>
<td>3.6</td>
<td>400</td>
<td>4.1</td>
<td>6.5</td>
<td>0.3</td>
<td>30</td>
<td>8</td>
<td>22</td>
<td>36</td>
</tr>
<tr>
<td>muscovite micacites</td>
<td>8.7</td>
<td>0.1</td>
<td>270</td>
<td>2187</td>
<td>299</td>
<td>1900</td>
<td>78</td>
<td>4.7</td>
<td>1787</td>
<td>4.4</td>
<td>21.7</td>
<td>1</td>
<td>120</td>
<td>3</td>
<td>25</td>
<td>6</td>
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</table>
The Modotin ore deposit is confined to the Modotin granitic massif, located near the western margin of the Khentei batholith (1 on Fig. 1). A group of placer and primary deposits with combined tin-tungsten mineralization has been discovered within a relatively small area (Khasin and Marinov, 1977). Its primary shows are concentrated within two sites: the Modotin site itself and also at Khuchzhikhan, 16 km away.

The Modotin Massif tapers in a north-westerly direction, and cuts across the strike of the surrounding Palaeozoic structures. Its area is about 500 km². The northern contact of the massif is steeply dipping and rectilinear. The southern contact dips more gently and is sinuous. The massif cuts across Upper Proterozoic metamorphic beds, Lower- and Upper Palaeozoic granitoids and Upper Permian marine deposits. The massif has been dated, using the K-Ar method as between 175 and 199 Ma (Upper Triassic-Lower Jurassic (Zaitsev and Tauson ed., 1971).

The rocks of two intrusive phases are involved in the structure of the massif. The major phase is presented by medium- and coarse-grained, rarely porphyritic granites, which occupy more than 95% of the area of the massif. These granites show increasing amounts of biotite and scarce hornblends at the endocontacts of the massif. Granites with a gneissoid structures have been observed within the northwestern contact zone.

The granites of the major intrusive phase are cross-cut by dykes of fine-grained, often pegmatoid, second-phase granites (the second phase is also known as the phase of extra-intrusions): Zaitsev and Tauson ed., 1971). Biotite-bearing, two-mica and muscovite granite units predominate among these intrusions. Dykes of second-phase granites are observed within both the massif and the enclosing rocks. They vary in thickness from tens of centimetres < 10 m, while their length along the strike is up to a few hundred metres.

Zones of greisenization make up the later formations of the Modotin Massif. Greisenization occurs within the coarse-grained granites of the main phase of intrusion and also in the fine-grained and pegmatoid granites of the second phase. The greisenized rocks form long, thin zones, striking in a similar direction to the granite dykes. These zones vary in thickness from several centimetres up to several metres thick, while their length is up to tens and even hundreds of metres.

The greisen bodies have a zonal structure, with the
following pattern from the periphery to the centre:
1) granite;
2) two-mica or muscovitic granites;
3) greisenized granites;
4) quartz-muscovitic greisens;
5) quartz rocks (veins).
The rocks of all of these zones are cross-cut by very thin muscovitic streaks. Thin bodies of lamprophyres, which cross-cut the greisens, are very scarce within the massif.

The Modoto deposit is confined to the margin of the massif, characterized by widespread ore-bearing greisens and quartz veins. The latter are commonly accompanied by greisenization adjacent to the vein. Wolframite, cassiterite, arsenopyrite, chalcopyrite, galena, and sphalerite are developed within the greisens and quartz veins.

Wolframite, with a MnW0 4 content varying from 32 to 42%, forms thick- columnar or thin-tabular crystals. Clusters of these crystals form nest-like accumulations (Khasin and Marinov, 1977). They are concentrated in both the centres and on the edges of the veins. In the thicker veins, wolframite occurs in much higher concentrations than cassiterite. Cassiterite is represented by euhedral crystals, from 0.1mm to ≤ 1-2 cm in size. The cassiterite tends to occur on the edges of the quartz veins and streaks, and less frequently forms trace disseminations on the edges and in the centres of the veins. Generally, cassiterite and wolframite do not occur adjacent to each other, but when they do occur together, their ratios indicate that they formed simultaneously.

At Bine-Mod, located west of the Modoto deposit, there is an unusual type of ore-bearing vein. The mineralization occurs as thin streaks of quartz and topaz, containing abundant disseminated cassiterite and occasionally fluorite and feldspar. The streaks vary in thickness from fractions of a millimetre up to 10 cm. They occur within both the granites and their roof rocks, and occasionally saturate them (this is a stockwork type of mineralization).

**The Baga-Gazryn deposit,** which is confined to the granitic massif of the same name, is represented by primary and placer ore shows.

The Baga-Gazryn granitic massif is located at the southwestern end of the Khenti uplift, in the eastern part of the transition zone between the Khentai and Khangai mountain chains ((2) on Fig. 1). It occurs within Permian and probably Triassic basic and acid lavas and their tuffs inside sedimentary rocks. The massif was formed in the early Mesozoic. Potassium-argon dating gave an age of between 200 and 236 Ma (Zaitsev and Tauson ed., 1971).

In plan, the massif is oval (Fig. 2) and has an E-W strike. The outcrop is about 120 km² in area. Judging from the strike of the contact surface, the massif is nearly dome shaped. The contact surface of the massif slopes gently from the north, west and south towards the country rocks, roughly concordant with their strike. The eastern contact of the massif is discordant relative to the country rocks.

The structure of the massif involves rocks of two intrusive phases. The central part of the massif (Fig. 2) is made up of coarse-grained, biotite-bearing Li-F granites, which belong to the main phase of intrusion.

The rocks of the second phase of intrusion form veined bodies confined to the gently dipping main-phase granite. These tend to occur within the endocontact zone of the massif, and also around the margins of the main-phase granites to the west, south, and east, and are represented by fine-grained Li-F granites containing biotite and topaz.

All these rocks are cross-cut by zwitter (biotite-bearing greisens containing topaz). These bodies have a distinct zonal structure involving:
1) biotite-bearing granites;
2) microcline granite;
3) biotite-bearing zwitter;
4) topaz zwitter;
5) quartz.

The zwitter are characterized by later streaks of lithium biotite or zinnwaldite, topaz, or occasionally by a mixture of topaz and mica. The late streaks, which contain mica, are common within the zone of biotite-bearing zwitter, and those without mica can also be found within the zone of quartz-topaz-bearing rocks. The streaks often contain rich cassiterite mineralization.

The tin mineralization of the deposit is associated with thick (1 to 20 m) quartz-topaz-bearing zwitter, both veins and stocks, located within the endocontact zone of the granitic massif. Numerous quartz-topaz streaks are also recorded from within the sandstones/shales of the exocontact zone. The ore bodies consist mostly of quartz and topaz. Fluorite, beryl, cassiterite, wolframite, and molybdenite, are present in smaller amounts. The exocontact zones where the streaks occur are richer in cassiterite compared with the veins and thus are of major interest to prospectors.

**The Ikh-Khairkhan deposit** is located in central Mongolia ((3) on Fig. 1), within a structural zone of the western boundary of the Khentei Uplift. The deposit is associated with the granitic massif of the same name (Zaitsev and Tauson ed., 1971). This oval-shaped massif is about 100 km² in area. The massif occurs within Upper Permian-Lower Triassic beds and is made up mainly of medium- and coarse-
grained biotite-bearing leucogranites. They are cross-cut by veined bodies of fine-grained leucocratic biotite-bearing granites, represented by pegmatoid units. The massif is dated by the Rb-Sr age method as 121 Ma old (Dergunov, 2001).

The Ikh-Khairkhan deposit contains mainly tungsten-type mineralization (Khasin and Marinov, 1977). Ore-bearing quartz veins were formed at the hydrothermal stage, preceded by a stage of granite greisenization.

The ore-bearing quartz veins are confined to the contact zone between the granites and the enclosing andesitic porphyries. As the quartz veins pass into the granites, the veins decrease markedly in thickness. The quartz veins infill fractures that roughly parallel the main fault zones and have north-westly 300-340° and north-easterly 40-70° strikes. The veins are steeply dipping, and average 0.65-3.25 m thick and 60-260 m long. The ore-bearing veins were recorded by prospecting boreholes down to a depth of 200 m. The wolframite is thought to be distributed as ore chute in the quartz veins as a whole.

The veins are made up mainly of an aggregate of quartz and wolframite. Orthoclase, muscovite, fluorite, sulphides (pyrite, chalcopyrite, and bismuthine) and very scarce cassiterite, beryl, and scheelite have also been recorded from the veins. The secondary minerals are hydrous ferric oxides, malachite, azurite, tungstite, and basobismuthine. The muscovite usually forms thin streaks within the quartz veins and the enclosing rocks.

**The Ongon-Khairkhan deposit** is located some 60 km north-west of the Ikh-Khairkhan deposit ((4) on Fig. 1), and as a whole shows similar characteristics.

The Ongon-Khairkhan Massif forms the geological setting for the deposit. Its area is about 200 km². The massif is made up of main-phase, medium-grained biotitic granites, fine-grained, second-phase granites, and the pegmatoid granites and pegmatites cross-cutting them. This massif is similar in composition to the Ikh-Khairkhan Massif, and is probably similar in age.

The Ongon-Khairkhan deposit contains quartz veins with wolframite, which are concentrated near the eastern margin of the massif. The mineralization is cross-cut by dykes of topaz-bearing rhyolites (ongonites) (Zaitsev and Tauson ed., 1971). They have been Rb-Sr dated as 121 Ma. Therefore the geological relationships observed within the Ongon-Khairkhan deposit indicate that magmatism and mineralization processes are coeval here. It should also be noted that the ongonites are cross-cut by thin quartz-mica-
Topaz streaks with wolframite, which form a stockwork within the enclosing Palaeozoic sedimentary rocks. The presence of minerals such as lithium mica, topaz and cassiterite distinguishes this type of mineralization from the pre-ongoonitic type. In these terms, the mineralization of the Ongon-Khairkhan deposit is believed to consist of two stages (Zaitsev and Tauson ed., 1971). The first is a quartz-wolframitic veined stage. It is associated with leucocratic granites, and is identical to the mineralization of the Ikh-Khairkhan deposit. The stockwork mineralization, which is combined wolframite-cassiteritic, with Li and T a minerals was formed during the second phase of ore formation. We can draw a parallel between this type of mineralization and the stockwork, (mainly Sn) mineralization of the Baga-Gazryn deposit.

As evidenced by the above examples, most of the commercial tin and tungsten deposits of Mongolia contain a combination of these elements. Tungsten commonly predominates over tin in the ores; however, the concentrations of tin did increase during particular stages in the process of ore formation (Dergunov, 2001).

5. Summary

With regard to the prospects in the territory of Mongolia for industrial tungsten and tin mineralization, it should specify the following sources.

1. Cassiterite-wolframite-quartz (tungsten-tin) and wolframite-quartz formations.
2. Occurences known, but is non-industrial types (skarn, cassiterite-silicate, cassiterite-sulfide, rare-metal albite granites).

References


