Short course SC4:
Exploration for skarn deposits of the world

Presenter:

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Former Professor of Economic Geology – Washington State University

Date: Tuesday, April 2, 2019; one day pre-conference 9 am-5 pm

Included:
- Lunch, morning and afternoon teas
- Hard-copy print out of short course manual

Minimum number of participants: 10

Cost: To be notified.
Short Course Description

Skarn deposits have been mined for a variety of metals, including Fe, W, Cu, Pb, Zn, Mo, Ag, Au, U, REE, F, B, and Sn. They are particularly abundant in the circum-Pacific region with large, high-grade examples at Ertsberg, Indonesia (2.8 Gt @ 1.12% Cu, 0.78g/t Au), Las Bambas, Peru (2.12 Gt @ 0.6% Cu), and Antamina, Peru (2.0 Gt @0.86% Cu, 0.54% Zn, 0.02% Mo, 10.5 g/t Ag). They are found adjacent to plutons, along faults and major shear zones, in shallow geothermal systems, on the bottom of the seafloor, and at lower crustal depths in deeply buried metamorphic terrains. What links these diverse environments, and what defines a rock as skarn, is the mineralogy which includes a wide variety of calc-silicate and associated minerals but is usually dominated by garnet and pyroxene.

Mineralogy is the key to recognizing and defining skarns, and is key to distinguishing economically important deposits from interesting but uneconomic mineral localities. Skarn mineralogy is mappable in the field and serves as the broader "alteration envelope" around a potential ore body. Because most skarn deposits are zoned, recognition of distal alteration features can be critically important in the early exploration stages. Details of skarn mineralogy and zonation can be used to construct deposit-specific exploration models as well as more general models useful in developing grass roots exploration programs or regional syntheses. In addition, igneous petrogenesis and tectonic setting provide a framework for regional exploration or classification. This workshop will develop an understanding of skarns in general with particular emphasis on field identifiable characteristics that are useful in exploration.

Course Outline

1) Introduction, definitions, processes, and classification
2) Evolutionary stages of skarn formation, depth of formation, oxidation state
3) Skarn mineralogy, petrogenesis, and tectonic setting
4) Characteristics and examples of major Fe, Cu, Au, Zn, W, and Sn skarn systems
5) Skarn zonation - General models and processes
6) Skarn exploration strategies
World distribution of skarn deposits
Ertsberg District, Indonesia (Skarn - 2.8 Gt @ 1.12% Cu, 0.78g/t Au)

Antamina, Peru (2.0 Gt @ 0.86% Cu, 0.54% Zn, 0.02% Mo, 10.5 g/t Ag)
Las Bambas, Peru (2.12 Gt @ 0.6% Cu)
Evolutionary stages of pluton-associated skarn deposits

“Ground preparation” during skarn formation

Skarn zonation
Retrograde alteration

Distal features – fluid escape structures
Effect of wall rocks

Tectonic Setting

- Oceanic Subduction
  - Dip 60°
  - Deposits: Fe-Cu (Co, Au), Au (Co, Fe, Cu)
  - Plutonic: Diorite, Granite

- Continental Subduction
  - Dip 40°
  - Deposits: W (Mo, Cu), Zn-Pb (Cu, Ag), Ca (Pb, Mo)
  - Plutonic: Granodiorite, Granite

- Shallow Subduction
  - Dip <30°
  - Deposits: Porphyry Mo, Mo-WB
  - Plutonic: Monzonite, Granite

- Moderate Subduction
  - Dip <60°
  - Deposits: F (Li, Be, Sn, U), Sn (W, B)
  - Plutonic: Granite

Rising associated with upwelling mantle lithosphere
Zn skarn zonation model

<table>
<thead>
<tr>
<th>Feature</th>
<th>Proximal</th>
<th>Intermediate</th>
<th>Distal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garnet-pyropeone</td>
<td>&gt; 1:1</td>
<td>1:20</td>
<td>No garnet</td>
</tr>
<tr>
<td>Max Jo in pyroxene</td>
<td>&lt; 25%</td>
<td>25-50%</td>
<td>&gt; 50%</td>
</tr>
<tr>
<td>Fe oxides</td>
<td>mt &gt; hm</td>
<td>hm ~ mt</td>
<td>hm &gt; mt</td>
</tr>
<tr>
<td>Ore sulfides</td>
<td>sl &gt; gl &gt; cp</td>
<td>sl &gt; gl &gt; cp</td>
<td>sl &gt; gl &gt; cp</td>
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<tr>
<td>Skarnmantle core</td>
<td>&gt; 10</td>
<td>1-10</td>
<td>&gt; 1</td>
</tr>
<tr>
<td>Temperature</td>
<td>&gt; 400°C</td>
<td>320° - 400°C</td>
<td>&lt; 320°C</td>
</tr>
<tr>
<td>Salinity (NaCl eq. wt.%)</td>
<td>&gt; 15%</td>
<td>7.5-15%</td>
<td>&lt; 7.5%</td>
</tr>
<tr>
<td>Zn/Cu</td>
<td>&lt; 10</td>
<td>10-20</td>
<td>&gt; 20</td>
</tr>
<tr>
<td>Zn/Pb</td>
<td>&gt; 5</td>
<td>2-5</td>
<td>&gt; 2</td>
</tr>
<tr>
<td>Pb/Cu</td>
<td>&lt; 5</td>
<td>5-10</td>
<td>&gt; 10</td>
</tr>
</tbody>
</table>

Skarn exploration strategies

1. [Image 1]
2. [Image 2]
3. [Image 3]
4. [Image 4]
5. [Image 5]