SKARNS: ZONING PATTERNS AND CONTROLLING FACTORS

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WHY SKARNS?

- Au, Cu, Sn, W, Pb, Zn, Mo, Fe, minor Ag, B, Be, Bi, Co, F, REE and U
- Common: >1630 skarn deposits described in literatures

Zhaoshan Chang, unpub.
WHY SKARNS?

• Major source of W and Sn

• Significant source of base metals and Au, e.g., Antamina, Peru (2,968 Mt @ 0.89% Cu, 0.77% Zn, 11 g/t Ag and 0.02% Mo; 2015)
WHY SKARNS?

Ertsberg-Grasberg district, Indonesia (0.5% Cu cut-off)

- Skarn: 2.8 Gt @ 1.12% Cu, 0.78 g/t Au
- Porphyry: 2.3 Gt @ 1.14% Cu, 1.09 g/t Au

OK Tedi, PNG
Cananea, Mexico
Bingham, Utah, US
Mission, Arizona, US

... Einaudi, 1982; Meinert et al., 1997; 2005; Leys et al., 2012

- High grade “sweetener” in porphyry deposits
SKARN AND RELATED DEPOSITS

Zoning pattern:
1. Find out where you are and vector towards other parts of the system
2. Determine the causative intrusion
SKARNS ARE TYPICALLY ZONED

Transfer of heat and mass from intrusions or fluid conduits

- Intrusion
- Endoskarn
- Massive/metamorphic skarn
- Calcareous wall rock
- Garnet/pyroxene ratio decreases
- Garnet colour lighter
- Pyroxene colour darker
- Mn in pyroxene/amphibole increase
- Mn minerals
- Bleached marble
-大理石
- Limestone
- Ca-Si Hornfels
- Reaction skarn
- Fluid escape structures
- Mn minerals
ZONATION IN A CU SKARN

Carr Fork, Bingham, USA

Meinert, 1997; based on Atkinson and Einaudi, 1978

gar: garnet; pyx: pyroxene; cp: chalcopyrite; wo: wollastonite; ves: vesuvianite; bn: bornite; po: pyrrhotite; py: pyrite

% Cu
Sulfides
Skarn
Garnet color

1.5% cp>bn>po-py
gar>>pyx
red-brown

3.0% cp>po-py
gar=pyx
brown

2.0% cp>po-py
gar=pyx
brown-green

0.5-1.5% po-py<cp
pyx>gar
yellow-green

<0.5%
py-po<st>cp.bn.gl
wo-ves>pyx-gar
green-yellow

Calc-silicate hornfels
Sandstone
Limestone
Shale
Pluton

200 m

Sulfide-Fe oxide manto
Zoning away from intrusion in a Cu skarn
Zonation in a Zn skarn

Groundhog, USA;
Meinert, 1987
Gar: garnet; Pyx: pyroxene; Hd: hedenbergite; Jo: Johannsenite

Zonation in a Au skarn – Fortitude, USA

Meyer and Meinert, 1991
Zonation at marble front in a Au skarn, Mexico

- Dark marble
- Garnet
- Wollastonite
- Bleached marble
Fluid escape structures – distal features beyond skarn

Meinert et al., 2005
50-100m away from skarn

Meinert et al., 2005

Fluid escape structures
200m away from skarn

Fluid escape structures

Meinert et al., 2005
FLUID ESCAPE STRUCTURES – DISTAL FEATURES BEYOND SKARN

Yaojialing Zn-Au skarn, China
Fe-Mn oxides veins

Meinert et al., 2005
Cryptic hydrothermal signals in marble: C-O isotopes

El Mochito Zn-Pb skarn, Honduras
O isotope halo: 300-400 m wide, up to 4km along fault
C isotope halo: up to 30 m wide
Summary – skarn zonation

Chang et al., 2019
Factors affecting the formation of skarns

Redox state gradient between magma and wall rock

Causative magma
  Volatiles
  Degree of fractionation*
  Redox state*

Wall rock
  Composition
  Redox state
  Permeability

Depth of formation

Distance from magma
The zoning pattern is based on:

**Oxidizing** ➤ Garnet/pyroxene ratio decrease ➤ Garnet colour lighter ➤ Pyroxene colour darker ➤ Fe$^{3+}$ ➤ garnet

**Reducing**

Calcereous wall rock ➤ Massive/metamasomatic skarn ➤ Marble ➤ Limestone ➤ Bleached marble ➤ Hornfels ➤ Fluid escape structures ➤ Fe$^{2+}$ ➤ pyroxene

- Intrusion
- Endoskarn

**Redox state gradient**

- Grossular: Ca$_3$Al$_2$(SiO$_4$)$_3$
- Andradite: Ca$_3$Fe$^{3+}$$_2$(SiO$_4$)$_3$
- Diopside: CaMgSi$_2$O$_6$
- Hedenbergite: CaFe$^{2+}$Si$_2$O$_6$
If both the magma and the wall rocks are reducing ...

Nickle Plate, Hedley District, Canada

\[ \frac{\text{Fe}_2\text{O}_3}{(\text{Fe}_2\text{O}_3 + \text{FeO})} = 0.15 \]

Ilmenite-bearing

Toronto Stock

Ettlinger, 1990; Ray et al., 1996

Courtesy of Larry Meinert
If both the magma and the wall rocks are oxidizing ...

A Cu skarn prospect, Philippines
If both the magma and the wall rocks are oxidizing ...
Effect of magmatic volatiles - F

Empire Cu-Zn skarn, USA

Unusual features: 1) Abundant endoskarn, > exoskarn
2) Proximal Zn minearlisation
Effect of magmatic volatiles - F

Empire Cu-Zn skarn mine, USA

High F content in the magmatic-hydrothermal system as indicated by:

- 1.53-2.46 wt% F in magmatic hornblende
- 1.43-3.87 wt% F in magmatic biotite
- Fluorite as igneous accessory mineral
- Fluorite as daughter mineral in fluid inclusions
- 1.29-2.42 wt% F in hydrothermal vesuvianite
- Fluorite in skarns

Chang and Meinert, 2004, 2008
Effect of magmatic volatiles - F

Empire Cu-Zn skarn mine, USA

Reasons for these unusual features:

- F greatly facilitates the dissolution of silicates

- F decreases the solidus temperatures of magmas. When the late-stage fluids exsolved from them, the fluids were already at low temperatures, therefore only short transportation distance was needed for the fluids to be cool enough to deposit sphalerite

Chang and Meinert, 2004, 2008
Textures indicating high F

Chang and Meinert, 2004, 2008
Effect of wall rocks

Composition – Ca skarn vs. Mg skarn

Redox

CaCO₃ + SiO₂(aq) = CaSiO₃ + CO₂

C + O₂ = CO₂

Porosity, composition

"Receptive" lithology

Fracture

W: wollastonite; P: pyroxene; G: garnet

Courtesy of Larry Meinert
Effect of wall rocks

Geometry

- Massive/irregular vs. stratabound
DEPTH OF FORMATION

- Ambient temperature
- Metamorphism
- Retrograde alteration
- Permeability

W skarn vs. Cu skarn

Meinert, 1992
Musc - hm - chl - qtz
Bio - sill - alm - ilm ± cord ± ksp ± qtz
Bio - adl - sill - ilm
Bio - sill - ilm ± cord

W Skarn Locality

Granodiorite

Isabella Lake Quad
Southern Sierra Nevada
California

W skarn

Courtesy of Larry Meinert
Granodiorite porphyry

Skarn

Cu skarn

Massive skarn

Granodiorite porphyry

Santa Rita Porphyry Cu deposit, New Mexico (after Nielsen, 1968)

Outer limit of bleaching

Outer limit of marble, hornfels, and calc-silicate minerals

1 km

Courtesy of Larry Meinert
Metal association based on skarns in China

- 386 deposits reported, 24% of world skarns (1627)
  - Traditionally resources of all metals calculated under planned economy
  - good for metal association studies

Chang et al., 2019
- Mo – Sn, Mo – Au and Au – Sn are rare associations
- 162 deposits
- 90%: No association between any of the elements

N=162

Chang et al., 2019

2; a few ton Au

4; byproducts

9; byproducts
Redox and fractionation of causative magmas

- Sn$^{4+}$ : Ti$^{4+}$ and Fe$^{3+}$ in biotite, hornblende, titanite, ilmenite, and magnetite → Sn is dispersed in igneous rocks in oxidized environment.
- Needs reduced environment so that Sn as Sn$^{2+}$ is enriched in fractionated magmas.

Both Au-only skarn and Sn skarn are related to reduced magmas. But Au is related to more mafic magmas whereas Sn & Mo related to felsic magmas. → Mo-Au and Sn-Au associations rare.

- Mo$^{4+}$ can substitute for Ti$^{4+}$
- Mo$^{6+}$ is incompatible

Lehmann, 1990

Chang et al., 2019
Redox and fractionation of causative magmas

Blevin, 1998
- W-Sn are not that common. Only 10 out of the 184 deposits contain both Sn and W.
- W-Cu association moderate
- Sn-Cu association: 13/33 Sn-bearing skarns contain Cu; 13/133 Cu-bearing skarns contain Sn
1. Classic W skarns, even the reduced ones associated with S-type granite, contain little Sn and Sn-associated elements including Be, Li, Rb, F and Cs

2. Reduced W skarns and Sn skarns have low Mo (4-76ppm). Oxidized W skarns and W-F skarns have higher Mo (135-8400ppm)

Newberry, 1998
- Close association between Cu-Au, Cu-Mo
- Very weak Au-Mo association
  - Similar to porphyry deposits

Chang et al., 2019
Cu-Mo:

- Both related to oxidized magmas; Cu magmas more oxidized
- Cu: less fractionated magmas; Mo: highly fractionated magmas

*Chang et al., 2019*

*Shu et al., 2019*
Redox indicated by zircon trace element

Cheng et al., 2017
- Strong W-Mo association
- In the 1st, 5th and 9th largest Mo-bearing skarns, Mo is subordinate to W
- Note Zn-Pb: distal to both

Chang et al., 2019
Zn-Pb:
- Both oxidized and reduced magma
- Magmas of various degrees of fractionation
- Association with Au: Not commonly known; only a few deposits outside of China
May contain Ag, Au, Fe, Cu, Sn, Cd, As, Sb, Mo, Cr
May be subordinate in Sn, W, Au, Fe, Cu, and Ag skarns. The largest ones mostly subordinate metal of Sn, W and Au deposits.
Fe:

- Moderate association with Cu, Au, Mo, Zn-Pb
- Weak association with W and Sn (e.g., Damoshan, Gejiu; Makeng; Xianghualing)

Chang et al., 2019
METAL ASSOCIATIONS

4 sets:

1. Mo-W-Cu-Zn-Pb: oxidized; moderate to strong fractionation
2. Fe-Cu (± W)-Au-Zn-Pb: oxidized; weak to moderate fractionation.
3. Sn (± Fe, Cu?, W) – Zn-Pb: Reduced; strong fractionation
4. Au-Zn-Pb: Reduced; weak to moderate fractionation

Chang et al., 2019
Zn-Pb being distal is well known.

What do you expect to find at the proximal locations of a Zn-Pb skarn? Cu?

Gejiu:
3 Mt Sn
5 Mt Cu
28 Mt Zn-Pb

Cheng et al., 2013;
Chang et al., 2019
Zn-Pb being distal is well known. But distal mineralization is not limited to Zn-Pb

Distal W skarn

- Caojiaba

Xie et al., 2019; Chang et al., 2019
Distal mineralization is not limited to Zn-Pb

Metal Zoning

Distal Cu in a W skarn

• Zhuxi: 2.7 Mt W, 0.22 Mt Cu

Other metals at distal locations: Sn, Mo, Au

No. 912 Team, 2013; Pan et al., 2017
# Metal zonation

**Chang et al., 2019**

## Table 5. Skarn Position and Metal Zonation of Selected Deposits

<table>
<thead>
<tr>
<th>Deposit number</th>
<th>Deposit name</th>
<th>Resources</th>
<th>Bank</th>
<th>Inside intrusion</th>
<th>At contact</th>
<th>Distal veins, mantos, and chimney</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>27-15</td>
<td>Gejiu</td>
<td>3 Mt Sn, 28 Mt Zn + Pb, 5 Mt Cu</td>
<td>Sn1, Cu2, Zn-Pb1</td>
<td>Minor; W</td>
<td>Some; Cu (Sn)</td>
<td>Major; Sn-Cu, to Sn-Pb, to Pb-Zn in pipes; Cu at Kafang in mantos</td>
<td>Y.-M. Zhao et al. (1990); Chang et al. (2012, 2013)</td>
</tr>
<tr>
<td>24-07</td>
<td>Dachang</td>
<td>1.5 Mt Sn, 5.6 Mt Zn-Pb, 0.27 Mt Cu</td>
<td>Sn2, Zn-Pb2</td>
<td>Little</td>
<td>Major; Cu, Zn</td>
<td>Major; Sn, Zn-Pb</td>
<td>Fe et al. (1991, 1993); W.-H. Huang et al. (2012); Shuang et al. (2006)</td>
</tr>
<tr>
<td>23-20</td>
<td>Furong</td>
<td>1.7 Mt Sn</td>
<td>Sn3</td>
<td>Major</td>
<td>Major</td>
<td>Minor</td>
<td>Some; vei; Sn-Zn-Pb</td>
</tr>
<tr>
<td>23-04</td>
<td>Xitian</td>
<td>0.59 Mt Sn, 0.037 Mt W</td>
<td>Sn4</td>
<td>Some; gresen W-Sn</td>
<td>Major; Sn- minor W</td>
<td>Minor</td>
<td>Sn-Be veilets</td>
</tr>
<tr>
<td>23-10</td>
<td>Shizhuyuan</td>
<td>0.63 Mt W, 0.49 Mt Sn, 0.2 Mt Mo</td>
<td>W2, Sn5, Mo6</td>
<td>Some; W-Sn-Mo-Bi gresen</td>
<td>Major; W-Sn-Mo-Bi skarn and overprinting vei</td>
<td>Minor; Sn-Bi</td>
<td>Sn-Bi skarn and overprinting vei; Sn-Bi skarn and overprinting vei</td>
</tr>
<tr>
<td>05-08</td>
<td>Huanggang-liang</td>
<td>0.46 Mt Sn, 150 Mt Fe ore, 0.047 Mt W, 0.12 Mt Zn-Pb, 0.016 Mt Cu</td>
<td>Sn6</td>
<td>Little</td>
<td>Major; Cu, Fe</td>
<td>Major; Sn, Fe, + minor W</td>
<td>Z.-H. Zhao et al. (2010)</td>
</tr>
<tr>
<td>23-18</td>
<td>Bailiashui</td>
<td>0.42 Mt Sn, 0.03 Mt W, 0.12 Mt Cu</td>
<td>Sn7</td>
<td>Major</td>
<td>Major</td>
<td>Minor</td>
<td>Shuang et al. (2005)</td>
</tr>
<tr>
<td>27-19</td>
<td>Daling</td>
<td>0.4 Mt Sn, 4 Mt Zn-Pb, 4,000 t In</td>
<td>Sn8, Zn-Pb3</td>
<td>Little</td>
<td>Little</td>
<td>Major; Sn, Zn</td>
<td>B. Xu et al. (2015)</td>
</tr>
<tr>
<td>18-08</td>
<td>Pongshan</td>
<td>0.3 Mt Sn, 1.5 Mt Zn-Pb</td>
<td>Sn9</td>
<td>Minor; Sn</td>
<td>Minor; Sn</td>
<td>Major; Sn to Zn-Pb to Zn-Pb in mantos</td>
<td>B. Xu et al. (2017)</td>
</tr>
<tr>
<td>23-17</td>
<td>Xiang-hualing</td>
<td>0.17 Mt Sn, 0.005 Mt Zn-Pb</td>
<td>Sn10</td>
<td>Minor; gresen Nb, Ta, W, Sn</td>
<td>Minor; Be, W</td>
<td>Major; Sn to Zn-Pb</td>
<td>Du (1968)</td>
</tr>
<tr>
<td>22-06</td>
<td>Dalin</td>
<td>0.17 Mt Sn, 125 Mt Fe ore, 0.014 Mt Zn-Pb</td>
<td>Sn10</td>
<td>No info</td>
<td>No info</td>
<td>No info</td>
<td>NA</td>
</tr>
<tr>
<td>28-28</td>
<td>Jiana</td>
<td>7.4 Mt Cu, 208 t Au, 0.62 Mt Mo, 1.4 Mt Zn-Pb</td>
<td>Cu1, Au2, Mo4</td>
<td>Some Mo, minor Cu</td>
<td>Major; Cu, Mo, Au</td>
<td>Major Zn-Pb, some Cu</td>
<td>W.-B. Zheng et al. (2010, 2016); Z.-L. Wang (1991)</td>
</tr>
<tr>
<td>18-06</td>
<td>Chengmaochang</td>
<td>3.1 Mt Cu, 44 t Au</td>
<td>Cu5</td>
<td>Major, porphyry and skarn Mo to Cu-Mo</td>
<td>Major, Cu-Fe</td>
<td>Major Zn-Pb, Cu-Cu (No.1)</td>
<td>Chengmaochang (1996)</td>
</tr>
<tr>
<td>18-02</td>
<td>Wuxian</td>
<td>2.5 Mt Cu, 67 t Au</td>
<td>Cu4, Au7</td>
<td>Some; Mo-Cu</td>
<td>Major; Cu</td>
<td>Major; Cu to Zn-Pb (north zone)</td>
<td>J.-W. Li et al. (2007)</td>
</tr>
<tr>
<td>15-16</td>
<td>Shizhuan-Dongjia-shan</td>
<td>2 Mt Cu, 50 t Au</td>
<td>Cu5, Au8</td>
<td>Minor</td>
<td>Major; Cu, Au, minor Mo</td>
<td>Major; Cu to Zn-Pb (north zone)</td>
<td>X.-C. Xu et al. (2011)</td>
</tr>
<tr>
<td>27-03</td>
<td>Hongjing-Hongshan</td>
<td>1.8 Mt Cu, 0.006 Mt W, 0.006 Mt Mo, 0.035 Mt Zn-Pb</td>
<td>Cu6</td>
<td>Minor; Mo-Cu</td>
<td>Major; Cu, Mo-Cu</td>
<td>Major; Cu to Zn-Pb (north zone)</td>
<td>Peng et al. (2016)</td>
</tr>
<tr>
<td>27-01</td>
<td>Yangla</td>
<td>1.5 Mt Cu</td>
<td>Cu7</td>
<td>Minor</td>
<td>Minor</td>
<td>Minor</td>
<td>Major</td>
</tr>
<tr>
<td>18-14</td>
<td>Yonggang</td>
<td>1.5 Mt Cu, 0.024 Mt W</td>
<td>Cu8</td>
<td>Little</td>
<td>Some</td>
<td>Minor</td>
<td>Major</td>
</tr>
<tr>
<td>17-11</td>
<td>Tonglinshan</td>
<td>0.69 Mt Au, 1.1 Mt Cu, 57 Mt Fe ores</td>
<td>Au6, Cu9</td>
<td>Minor</td>
<td>Major</td>
<td>Minor</td>
<td>Xie et al. (2011)</td>
</tr>
<tr>
<td>09-07</td>
<td>Muxingou</td>
<td>1.1 Mt Cu</td>
<td>Cu10</td>
<td>No info</td>
<td>No info</td>
<td>No info</td>
<td>No info</td>
</tr>
<tr>
<td>18-11</td>
<td>Zhongde</td>
<td>2.7 Mt Cu, 0.22 Mt Cu</td>
<td>W1</td>
<td>Some; W</td>
<td>Major; W-Cu</td>
<td>Major W-Cu to distal Cu-only</td>
<td>Pan et al. (2015)</td>
</tr>
<tr>
<td>14-14</td>
<td>Sandao-zhuan</td>
<td>0.44 Mt W, 0.75 Mt Mo</td>
<td>Mo1, W3</td>
<td>Major, porphyry</td>
<td>Some; W-Mo</td>
<td>Major; W-Mo</td>
<td>Xiang et al. (2012)</td>
</tr>
</tbody>
</table>
# Metal Zonation

Chang et al., 2019

<table>
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<tr>
<th>Deposit number</th>
<th>Deposit name</th>
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<th>Rank¹</th>
<th>Inside intrusion</th>
<th>At contact</th>
<th>Distal veins, mantos, and chimneys</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>02-01</td>
<td>Xiaoliangou</td>
<td>0.20 Mt W, 0.31 Mt Mo</td>
<td>Mo5, W5</td>
<td>Some; porphyry Mo</td>
<td>Some; Mo</td>
<td>Major; proximal Mo-W to distal W-Cu 600 m above intrusion contact</td>
<td>T.-C. Zhou et al. (2002); X.-M. Zhao et al. (2014)</td>
</tr>
<tr>
<td>15-23</td>
<td>Baizhangyan</td>
<td>0.02 Mt W, 0.01 Mt Mo</td>
<td>Medium W</td>
<td>Little Major; porphyry style Mo</td>
<td>Some</td>
<td>Major</td>
<td>C.-X. Song et al. (2012a)</td>
</tr>
<tr>
<td>14-13</td>
<td>Shangzhangou</td>
<td>0.72 Mt Mo, 80 Mt Fe ore</td>
<td>Mo5</td>
<td>Major; porphyry style Mo</td>
<td>Minor; Mo-Fe</td>
<td>Minor</td>
<td>Y. Yang et al. (2013)</td>
</tr>
<tr>
<td>06-03</td>
<td>Yangjia-zhangzi</td>
<td>0.26 Mt Mo</td>
<td>Mo6</td>
<td>Minor; porphyry style Mo</td>
<td>Some; garnet-dominant to distal pyroxene-dominant, Mo</td>
<td>Minor</td>
<td>Wu et al. (1990); X.-L. Liu et al. (2009)</td>
</tr>
<tr>
<td>27-11</td>
<td>Bentiya</td>
<td>300 t Au, 4.4 Mt Zn-Pb</td>
<td>Au1, Zn-Pb8</td>
<td>Miner</td>
<td>Major; Fe-Cu-An</td>
<td>Major</td>
<td>He et al. (2015); Miao et al. (2017)</td>
</tr>
<tr>
<td>12-04</td>
<td>Luoshang</td>
<td>78 t Au</td>
<td>Au4</td>
<td>Not found yet</td>
<td>Not found yet</td>
<td>Major</td>
<td>Sun et al. (2011)</td>
</tr>
<tr>
<td>23-06</td>
<td>Kangjiaowan</td>
<td>71 Mt Au, 1.5 Mt Zn-Pb</td>
<td>Au5, Zn-Pb10</td>
<td>Not found yet</td>
<td>Not found yet</td>
<td>Major; carbonate replacement deposit</td>
<td>Zuo et al. (2014)</td>
</tr>
<tr>
<td>27-13</td>
<td>Luoyuan</td>
<td>2.5 Mt Zn-Pb, 0.024 Mt Cu</td>
<td>Zn-Pb4</td>
<td>Not found yet</td>
<td>Not found yet</td>
<td>Major; deeper; Fe; shallower Zn-Pb, orebodies up to 3 km long</td>
<td>Jiang et al. (2015)</td>
</tr>
<tr>
<td>05-07</td>
<td>Baijinnan’er</td>
<td>2.4 Mt Zn-Pb</td>
<td>Zn-Pb5</td>
<td>Miner; carbonate xenoliths</td>
<td>Major</td>
<td>Major</td>
<td>Shu et al. (2017)</td>
</tr>
<tr>
<td>23-14</td>
<td>Huang-shaping</td>
<td>2.3 Mt Zn-Pb, 0.12 Mt W, 0.045 Mt Mo</td>
<td>Zn-Pb6</td>
<td>Minor; Cu</td>
<td>Major; Cu to Zn-Pb, to up to 1.2 km away from intrusion contacts</td>
<td>Major; Cu to Zn-Pb, up to 1.2 km away from intrusion contacts</td>
<td>Y.-M. Zhao et al. (1990); S.-F. Dong (1997)</td>
</tr>
<tr>
<td>09-01</td>
<td>Caijiaying</td>
<td>2.2 Mt Zn-Pb, 25 t Au</td>
<td>Zn-Pb7</td>
<td>Not found yet</td>
<td>Not found yet</td>
<td>Major; Zn-Pb-Au; in a belt ~2.3 km long</td>
<td>Chang et al. (2013)</td>
</tr>
<tr>
<td>14-15</td>
<td>Chitoukuan</td>
<td>1.9 Mt Zn-Pb</td>
<td>Zn-Pb9</td>
<td>None</td>
<td>Not found yet</td>
<td>Major; distal skarn: minor Mo, ±Zn; to CRD Zn-Pb; up to 4.5 km long and → 15 km away from the intrusion</td>
<td>Duan et al. (2011)</td>
</tr>
<tr>
<td>06-04</td>
<td>Baijia</td>
<td>0.37 Mt Zn-Pb, 0.012 Mt Cu</td>
<td>Medium-size Zn-Pb</td>
<td>None</td>
<td>Miner; Mg-skarn + Fe-Cu, 20–50 m wide</td>
<td>Major; along faults, up to ~4 km from contact; proximal Fe-Cu to distal Zn-Pb</td>
<td>Y.-M. Zhao et al. (1990)</td>
</tr>
<tr>
<td>15-20</td>
<td>Yaojiating</td>
<td>1.4 Mt Zn-Pb, 32 t Au, 0.13 Mt Cu, 382 t Ag</td>
<td>Large-size Zn-Pb and Au Zn-Pb-An</td>
<td>Major; roof pendants</td>
<td>Some</td>
<td>Major</td>
<td>Zhong et al. (2015)</td>
</tr>
<tr>
<td>12-08</td>
<td>Laiwu</td>
<td>206 Mt Fe ore</td>
<td>Fe1</td>
<td>Minor</td>
<td>Minor</td>
<td>C.-B. Yang et al. (2006)</td>
<td></td>
</tr>
</tbody>
</table>
## Metal zoning patterns

<table>
<thead>
<tr>
<th>Magma</th>
<th>Intrusion</th>
<th>Proximal</th>
<th>Distal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced; strong fractionation</td>
<td>Greisen Sn ± W</td>
<td>Sn ± Cu ± Fe</td>
<td>Sn: distal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Zn-Pb: far distal</td>
</tr>
<tr>
<td>Oxidized; week to moderate fractionation</td>
<td>Porphyry and/or endoskarn Mo and/or Cu</td>
<td>Cu and/or Fe, ± Au, ± Mo</td>
<td>Cu: distal; locally Zn-Pb ± Au: far distal</td>
</tr>
<tr>
<td>Oxidized; strong fractionation</td>
<td>Porphyry Mo, greisen W</td>
<td>Mo and/or W, ± Fe, ± Cu</td>
<td>Mo or W, ± Cu</td>
</tr>
<tr>
<td>Reduced; week to moderate fractionation</td>
<td>?</td>
<td>Au?</td>
<td>Zn-Pb-Au</td>
</tr>
</tbody>
</table>

- **Au:**
  - Proximal to distal; Oxidized to reduced

_Chang et al., 2019_
Mineral Deposits of China

Many deposits:

- 1303 deposits reported in public literature and summarized in SEG SP No. 22. + some new deposits with not publically described yet + some deposits not summarized

To order: https://www.segweb.org/Store/detail.aspx?id=SP22
Final Remarks

- Not one metal zoning pattern can fit all skarns
- Many examples of continuous transition from distal to proximal skarn alteration and mineralization proves distal systems are part of a skarn (up to 4.5 km; Chitudian Zn-Pb skarn)
- Large deposits have all parts discovered
- Be aware of skarns replacing igneous rocks, particularly mafic-intermediate rocks
- Tectonic control at large scale; tectonic reconstruction important for older terranes
Professional Master degree in Mineral Exploration at CSM

- Focus on mineral exploration
- Coursework only. No thesis.
- 30 credits; ~10 courses; could be done in 2 semesters.
- Certificates as steps towards the degree (4 courses)
- No GRE requirement
- Block mode courses (~12 days)
- Industry career

Websites:
https://cmrs.mines.edu/professional-master-in-mineral-exploration/
https://geology.mines.edu/graduate-programs/graduate-certificates-in-mineral-exploration/
https://www.mines.edu/graduate-admissions/international-applicants/

Enquiries: mineralexploration@mines.edu
Thanks!
Additional Questions

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