Ore deposits related to intermediate to felsic intrusions – Porphyry Base Metal (Cu-Mo) Deposits

- GLY 361 -
Lecture 7
Ore deposits related to intermediate to felsic intrusions

- Deposits associated with the great calc-alkaline orogenic belts of the world:
  - Diorite-monzonite-granite intrusive rocks
  - Andesite-latite-rhyolite extrusive rocks
  - Porphyritic equivalents of both
Porphyry base-metal deposits

- Igneous metamorphic-metasomatic deposits:
  - Porphyry copper deposits
  - Porphyry molybdenum deposits

- commonly found where porphyry systems cut sedimentary (carbonates) sections:
  - Skarns or tactites

- 40% of total metal-mine value output around the world
Main Mo-bearing Minerals

- Molybdenite – MoS$_2$
- Wulfenite – PbMoO$_4$
Molybdenum - Uses

- **Utilized by Steel Manufacturers to**
  - Increase Metal Strength (construction)
  - Increase Corrosion Resistance (pipelines, boats, desalinization plants)
  - Increase Heat Resistance (aircraft)

- **Utilized by Oil & Gas Companies to**
  - Remove Sulphur from Fuels (diesel fuel, refining of crude oil)
  - Build Oil & Gas Pipelines (Alaska Oil Pipeline)
Molybdenum - Resources

**World Mine Production and Reserves:** Reserves for Armenia and Chile were revised based on new information from those countries.

<table>
<thead>
<tr>
<th></th>
<th>Mine production</th>
<th>Reserves&lt;sup&gt;5&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2011</td>
<td>2012&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>United States</td>
<td>63,700</td>
<td>57,000</td>
</tr>
<tr>
<td>Armenia</td>
<td>4,500</td>
<td>4,600</td>
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<tr>
<td>Canada</td>
<td>8,400</td>
<td>9,400</td>
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<tr>
<td>Chile</td>
<td>40,900</td>
<td>35,300</td>
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<tr>
<td>China</td>
<td>106,000</td>
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<td>Iran</td>
<td>3,700</td>
<td>4,000</td>
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<tr>
<td>Kazakhstan</td>
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<td>___</td>
</tr>
<tr>
<td>Kyrgyzstan</td>
<td>250</td>
<td>250</td>
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<tr>
<td>Mexico</td>
<td>10,900</td>
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<tr>
<td>Mongolia</td>
<td>1,960</td>
<td>1,950</td>
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<tr>
<td>Peru</td>
<td>19,100</td>
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<tr>
<td>Russia</td>
<td>3,900</td>
<td>3,900</td>
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<tr>
<td>Uzbekistan&lt;sup&gt;e&lt;/sup&gt;</td>
<td>550</td>
<td>550</td>
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<tr>
<td>World total (rounded)</td>
<td>264,000</td>
<td>250,000</td>
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</table>

- **World Resources:** 14Mt resources - adequate to supply world needs for the foreseeable future.
Molybdenum - Market

- **Demand and Consumption:** China’s high level of steel production and consumption continues to generate strong internal consumption of Mo.

- In elastic demand (not price sensitive).

- Slow supply, resilient demand, high prices.
  - 30% growth in demand since 1997.
  - Market remained in deficit through 2009.
  - Projected demand growth between 4.5% - 6% going forward.
Terminology of porphyrytic ore bodies

- “Very large hydrothermal-petrogenic systems that influence cubic kilometres around them and include the intrusive stock or dike systems that cause their emplacement.”
Terminology of porphyritic ore bodies

• “Large, low- to medium-grade deposits in which primary (hypogene) ore minerals are dominantly structurally controlled and which are spatially and genetically related to felsic to intermediate porphyritic intrusions in island arc and continental margin settings.”
General Description

Petrography

- Hosted by acidic to intermediate intrusives such as granite, granodiorite, tonalite, diorite.
- Multiple intrusive events are common in areas of porphyry Cu mineralisation, with the host intrusions being the youngest and most differentiated plutons.
- Breccia zones with angular or locally rounded fragments are commonly associated with the intrusives. The sulphide mineralization typically occurs between or within fragments.
- Usually emplaced passively rather than forcefully, i.e. in an extensional rather than compressive regime.
Porphyry Samples
Porphyry-hosted deposits

- Low-grade (0.4-1% Cu), large tonnage (50-500 Mt) Cu/Mo/Sn/W/Au/Ag mineralization
- Associated with intermediate (Cu/Au) to acid (Mo/Sn/Cu) plutonic rocks and associated alteration
- Ore minerals occur as:
  A) disseminated sulfides, or
  B) stockwork – quartz veinlets
- Provide ~50% of world Cu supply and 70% Mo
- Require bulk mining methods – open pit
The metal content of porphyry deposits is diverse:

- Cu (±Au, Mo, Ag, Re, PGE)
- Cu-Mo (±Au, Ag)
- Cu-Mo-Au (±Ag)
- Cu-Au (±Ag, PGE)
- Au (±Ag, Cu, Mo)
- Mo (±W, Sn)
- W-Mo (±Bi, Sn)
- Sn (±W, Mo, Ag, Bi, Cu, Zn, In)
- Sn-Ag (±W, Cu, Zn, Mo, Bi)
- Ag (±Au, Zn, Pb)
Commodities

Cu, Mo - quantities range from insufficient for economic recovery to major ore constituents.

Minor Ag, Au in most deposits; Re.
Deposit comparison

Types of deposit:
- Porphyry copper
- Stratiform
- Massive sulphide
Tectonic Setting of Porphyries

- compressional orogenic environments above subducting oceanic lithosphere along plate convergent, destructive plate margins

  generally along linear calc-alkaline volcano-plutonic arcs related to subduction zones
Tectonic Setting of Porphyries

- Most porphyry deposits occur within Mesozoic and Cenozoic orogenic belts associated with either island-arcs and convergent continental margins.

- Some porphyries occur in Paleozoic orogenic belts in Central Asia, Australia, and US.

- Few are found in Precambrian rocks due to their low preservation potential (erosion).
Tectonic Setting of Porphyries

Partial melting of asthenospheric mantle due to presence of water derived from subducting slab.
Tectonic Setting of Porphyries

• Deposits related to melting of oceanic crust, which gives rise to metal and water-rich calc-alkaline magma

  ➢ magma rises to shallow crustal environments
  ➢ crystallization in magma chambers

• most famous deposits occur within strongly deformed, faulted and uplifted regions of the Pacific Rim

  ➢ deposits here are episodic corresponding with periods of calc-alkaline magmatism
    ➢ rate of spreading or convergence.
Series of extensive, relatively narrow, linear metallogenic provinces.
<table>
<thead>
<tr>
<th>Country</th>
<th>Deposit</th>
<th>Tonnage(^a) (Mt)</th>
<th>Grade(^b)</th>
<th></th>
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<tr>
<td>USA</td>
<td>Bingham (Utah)</td>
<td>2733</td>
<td>0.71</td>
<td>0.053</td>
<td>—(^c)</td>
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<tr>
<td></td>
<td>Morenci (Arizona)</td>
<td>848</td>
<td>0.88</td>
<td>0.007</td>
<td>—</td>
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<tr>
<td></td>
<td>Ray (Arizona)</td>
<td>172</td>
<td>0.85</td>
<td>—</td>
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<tr>
<td></td>
<td>San Manuel—Kalamazoo (Arizona)</td>
<td>980</td>
<td>0.74</td>
<td>0.015</td>
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<tr>
<td></td>
<td>Santa Rita (New Mexico)</td>
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<td>0.97</td>
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<td>Canada</td>
<td>Lornex (British Columbia)</td>
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<td>0.374</td>
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<td></td>
<td>Valley Copper</td>
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<tr>
<td>Mexico</td>
<td>Cananea</td>
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<td>Panama</td>
<td>Cerro Colorado</td>
<td>2000+</td>
<td>0.6</td>
<td>0.015</td>
<td>0.062</td>
<td>4.35</td>
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<td>Chile</td>
<td>Chuquicamata</td>
<td>9423</td>
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<td></td>
<td>El Salvador</td>
<td>283</td>
<td>1.17</td>
<td>0.033</td>
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<td>Papua New Guinea</td>
<td>Ok Tedi</td>
<td>543</td>
<td>0.6</td>
<td>—</td>
<td>0.5</td>
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<td></td>
<td>Panguna</td>
<td>1085</td>
<td>0.48</td>
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<td>0.55</td>
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<tr>
<td>UK</td>
<td>Coed-y-Brenin</td>
<td>200</td>
<td>0.3</td>
<td>0.003+</td>
<td>0.082</td>
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<tr>
<td>Yugoslavia</td>
<td>Bor</td>
<td>383</td>
<td>0.428</td>
<td>~0.1</td>
<td>0.065</td>
<td>~4.26</td>
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</tbody>
</table>

\(^a\) Past production plus reserves.

\(^b\) For present reserves, often higher grade worked in the past.

\(^c\) Gold by-product is important, grade figures not available.

(Data from Gilmour 1982 and other sources)

Evans, 1993
Host/ associated rock types

- Intrusions range from coarse-grained phaneritic to porphyritic stocks, batholiths and dyke swarms; rarely pegmatitic.

- Compositions range from calc-alkaline quartz diorite to granodiorite and quartz monzonite.

- Commonly multiple emplacement of successive intrusive phases and a wide variety of breccias.
Mineralogy

ORE MINERALOGY (Principal and subordinate):

• **Ore minerals**: chalcopyrite, molybdenite, lesser bornite and rare (primary) chalcocite.

• py is the predominant sulphide mineral; in some deposits the Fe oxide minerals magnetite, and rarely hm, are abundant.

• *Tetrahedrite/tennantite, enargite and minor Au, electrum and arsenopyrite.*

• In many deposits late veins commonly contain galena and sphalerite in a gangue of quartz, calcite and barite.
Mineralogy

GANGUE MINERALOGY (Principal and subordinate):

• in mineralized veins: quartz

• lesser *biotite, sericite, K-feldspar, magnetite, chlorite, calcite, epidote, anhydrite and tourmaline*

• many of these minerals are also alteration products of primary igneous mineral grains
Mineralogy

TEXTURE/STRUCTURE:

- quartz, quartz-sulphide and sulphide veinlets and stockworks; sulphide grains in fractures and fracture selvages

- minor disseminated sulphides commonly replacing primary mafic minerals

- quartz phenocrysts can be partially resorbed and overgrown by silica
Associated Structures and Mineralization Styles

- associated structures can result in a variety of mineralization styles:
  - veins, vein sets
  - stockworks
  - fractures
  - 'crackled zones'
  - breccia pipes, etc.

In large, complex, economic porphyry deposits, mineralized veins and fractures typically have a very high density.
Associated Structures and Mineralization Styles

- Orientations of mineralized structures can be related to local stress environments around the tops of plutons or can reflect regional stress conditions.

- Where they are superimposed on each other in a large volume of rock, the combination of individual mineralized structures results in higher grade zones and the characteristic large size of porphyry deposits.
Examples of different mineralization styles associated with porphyry deposits.

- (A) bn-bearing quartz veins cutting highly sericitized Bethsaida granodiorite.
- (B) cpy- and bn-rich quartz-apatite veins and veinlets cutting biotite-feldspar porphyry.
- (C) Quartz-molybdenite stockwork in sericitized granodiorite porphyry; cross-cutting and offset relationships of molybdenite-bearing fractures and quartz veinlets indicate multiple stages of mineralization.
- (D) Stockwork of wolframite-bearing fractures cutting intensely altered breccia.
• (E) Mineralized breccia containing granite clasts with wolframite-bearing fractures that are truncated at the margins of the clasts, indicating that the granite was mineralized prior to the incorporation of the clasts in the breccia; wolframite (wf) also occurs as disseminated grains in breccia matrix.

• (F) cpy disseminated along foliation planes and in a crosscutting quartz vein in deformed biotite-rich mafic breccia.
Examples of inter-mineral dykes and breccias associated with porphyry deposits.

- (A) Older porphyry with magnetite and quartz-magnetite veins and associated biotite and K-feldspar (potassic) alteration (1) truncated by an intermineral porphyry dyke with a chilled margin (2); both the older porphyry and the intermineral porphyry are cut by a bn- and cpy-bearing quartz vein (3).

- (B) Quartz-molybdenite veins in altered porphyry (1) terminate at contact of intermineral dyke (2); a younger quartz-molybdenite (3) vein cuts the altered porphyry, earlier veins and the intermineral dyke. A late quartz-base metal vein (4) cuts all other features.

- (C) Intermineral intrusive breccia with a partly digested chalcopyrite fragment (1) and a chalcopyrite-bearing quartz vein fragment (2). The matrix porphyry is cut by later cpy-bearing fractures and quartz veins.
Three types of Porphyry Deposits

• Classic Deposits
• Volcanic Deposits
• Plutonic Deposits
Classic Deposits

- Occur in high-level, post orogenic stocks that intrude unaltered host rocks.
- Multiple emplacements at shallow depth (1 to 2 km) of generally equant, cylindrical porphyritic intrusions.
- Mineralization may occur entirely within the stock, the country rock or in both.
- Numerous dykes and breccias of pre-, intra-, and post-mineralization age modify stock geometry.
- E.g. Bingham (Utah, USA).
Model of Classic-Type Porphyry Cu Deposits
Bingham Mine, USA

- First developed porphyry copper mine in the world.

- Disseminated Cu and contact metasomatism (skarn) between limestone and porphyry of Cu, Pb, Zn and Ag.

- The ore body forms zonal distribution, from intruded porphyry toward outside:
  - Cu → Cu-Pb-Zn → Pb-Zn-Ag → Ag-Au.
Volcanic Deposits

• Multiple intrusions in subvolcanic settings (roots of volcanoes) of small stocks, sills, dykes and diverse types of intrusive breccias.

• Reconstruction of volcanic landforms, structures, vent-proximal extrusive deposits and subvolcanic intrusive centres is possible in many cases, or can be inferred.

• Mineralization in both volcanic rocks and associated comagmatic plutons; at depths of 1 km, or less, associated with breccia development or as lithologically controlled preferential replacement in host rocks with high primary permeability.

• e.g. Panguna (Papua New Guinea).
Model of Volcanic-Type Porphyry Cu Deposits
Panguna mine, Papua New Guinea
Plutonic Deposits

- Occur in large plutonic to batholithic intrusions immobilized at relatively deep levels (2 – 4 km).

- Intrusions can display internal compositional differences - result of differentiation.

- Mineralization in one or more phases of the plutonic rocks. Local swarms of dykes, many with associated breccias, and fault zones are sites of mineralization.

- Orebodies around silicified alteration zones tend to occur as diffuse vein stockworks carrying cpy, bn and minor py in intensely fractured rocks but, overall, sulphide minerals are sparse.

- e.g. Chuquicamata and La Escondida (Chile).
Model of Plutonic-Type Porphyry Cu Deposits

For detail see figure 7c

Detail area outlined in figure 7a

- Porphyry Dykes
- Quartz Monzonite
- Granodiorite
- Quartz Diorite
- Volcanic Rocks
- Country Rock
- Ore Zone
- Pyrite Zone
- Breccia
La Escondida, Chile

- The world's largest porphyry copper mine started its operation in 1990.
- Represented by Zaldivar deposit and El Salvador deposit, a lot of other deposits of Au, Ag and Cu exist in the area.
- Open pit and mining facilities can be clearly identified in the image.
- No vegetation - ideal place to develop extraction technology of alteration mineral, by applying remote sensing technology.