PORPHYRY COPPER MINERALISATION OF WESTERN USA

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Porphyry copper deposits of western USA are very large low grade deposits dominated by disseminated Cu mineralisation but commonly with appreciable Mo and Au. Many deposits began as gold camps. Mineralisation is centred on, and mostly within, near surface quartz monzonite intrusions in which there is inner and deeper concentric Mo-rich shells. Mo shells are followed by Cu-rich shells, then pyrite and there may be an outermost Pb-Zn-Ag zone as in the country rock skarns of the Bingham deposit (John 1978). Cu-Mo mineralisation occurs within a “potassic” alteration zone characterised by secondary biotite (e.g. Moore 1978). Extensive outer sericitic (phylllic), argillic and propylitic alteration zones do not necessarily conform to the concentric pattern. Large scale bulk mining of a porphyry deposit was first carried out at Bingham.

There is a belt of economic deposits extending from Butte Montana, through Bingham Utah, to Arizona where deposits are most abundant, and New Mexico. This review is based on visits to many deposits along the whole length of the belt and various petrological observations at Butte, Bingham, Bagdad, Miami-Globe and Sierrita.

Most deposits are Laramide (approx. 70 Ma), a notable exception being Bingham (40 Ma). The Laramide belt is inboard up to 1200 km from the Pacific coast of the US where there are Recent to Mesozoic subduction related rocks. It is suggested that the Laramide igneous rocks were not formed as a result of subduction but as a result of rifting within the Precambrian basement.

At Butte Montana (references in Miller 1978) where the rich “main” veins (e.g. Anaconda Vein) cut typical shells of the porphyry system, the host rock is quartz monzonite. Two suites of associated rocks have been recognised within the Boulder Batholith. Rocks of the high-K, mineralised suite range from mafic monzonites or high-K diorites through quartz monzonites to low quartz granites. Associated volcanic rocks include voluminous latites. Latites are high-K, acid to intermediate SiO₂ rocks in which there are virtually no quartz phenocrysts. The original quartz monzonite was described from Walkerville (a northern suburb of Butte) more than 100 years ago, but the significance of this rock has been lost, mainly because many later petrologists referred to the rock type as granite or adamellite (now “monzogranite”) probably because the Butte sample is on the borderline between quartz monzonite and granite. A sample, collected near the type locality, is described. It consists of plagioclase, K-feldspar, quartz, biotite, hornblende (commonly with pyroxene cores), relatively abundant magnetite and very small amounts of titanite and apatite. Quartz is lower than in typical granite and magnetite is more abundant. Magnetite is commonly seen as aggregates along with apatite, suggestive of crystallisation from an immiscible Fe-P melt phase!

Monzonites very low in quartz are very common at Bingham. At Miami-Globe (Peterson 1962) there are typical quartz monzonites and very low quartz granites, and at Sierrita (Anthony & Titley 1988) rocks range from high-K diorites (and high-K andesites) through quartz monzonites (and latites) to low quartz granites (and rhyolites). Bagdad (Anderson
1950) is a high-K diorite lower in $K_2O$ than most other igneous rocks of the Laramide belt.

The quartz monzonite host rocks for the US deposits reviewed here have high $K_2O + Na_2O$. As in host rocks of other economic porphyry Cu deposits, $K_2O$ is high but normally less than $Na_2O$. Gerel (1995) says Cu-Au porphyry systems have $K_2O/Na_2O = 0.7$ to $1.3$ whereas the porphyry Cu-Mo deposits are associated with rocks with $K_2O/Na_2O = 0.3 – 0.7$. Bingham and Butte both have $K_2O/Na_2O = 1.2$ to $1.3$ but have produced about 1000 and 100 tonnes of Au respectively. Bingham has produced appreciable Mo. Higher alkalis in the quartz monzonite magma produced higher feldspar in the rock and consequently lower quartz. Another characteristic geochemical feature is high Ba commonly amounting to 1000 ppm or more. Oscillatory zoning within K-feldspar seen in the field and in thin section is indicative of high Ba. Oxygen fugacity is extremely high. Values of $\Delta NNO > +2$ can be calculated from more reliable rock analyses in which FeO and Fe$_2$O$_3$ have been recorded, and from biotite compositions (e.g. Anthony & Titley 1988).

The following features indicate that host rocks were intruded close to the surface at pressures near 50 MPa (500 bars):

1. There are associated volcanic rocks.
2. Some intrusions are porphyries that are pressure-quenched rocks.
3. There are acid rocks with miarolitic cavities (crystals of copper and molybdenum sulfide have been reported in some cavities).
4. Granophyric intergrowths of quartz and alkali feldspar are seen in thin section.
5. Occurrence of hydrothermal breccias.
6. Quartz monzonites have closely spaced vertical joints.

It is concluded that economic porphyry copper systems of the western USA are associated with, and probably derived from, high temperature monzonitic suites in which the variety of rock types are the result of fractional crystallisation. Mineralised rocks are near-surface quartz monzonites similar to I-type granites but with lower quartz contents. Many are on the borderline between quartz monzonite and granite. Some deposits are only economic if there has been secondary enrichment.

References
Porphyry copper deposits visited
Porphyry copper deposits mainly in Arizona.

After Titley (1982)
Advances in the geology of the porphyry copper deposits.
Characteristics of US porphyry-Cu deposits

Deposits are mostly Laramide (Late Cretaceous to Early Tertiary) around 70 Ma.

Notable exceptions are Bingham, Utah - late Tertiary, and Bisbee, Arizona - Jurassic.
Continental rift may be a more appropriate setting for the laramide rocks!!

After Titley (1982)
Advances in the geology of the porphyry copper deposits.
CHARACTERISTICS OF US PORPHYRY-CU DEPOSITS

Large low-grade, disseminated and stockwork deposits

Generally associated with intermediate to acid intrusive rocks that may be porphyritic. Mineralisation commonly centred on a quartz monzonite intrusion.

Host rocks are highly fractured with pervasive wall rock alteration
CHARACTERISTICS OF US PORPHYRY-CU DEPOSITS

- Some are very large

Bingham pit from the air
CHARACTERISTICS OF US PORPHYRY-CU DEPOSITS

• So large I have not seen the bottom of this pit

Bingham pit from top west side. 1978.
CHARACTERISTICS OF US PORPHYRY-CU DEPOSITS

• Generally associated with intermediate to acid intrusive rocks that may be porphyritic. Mineralisation commonly centred on a quartz monzonite intrusion.

• Host rocks are highly fractured with pervasive wall rock alteration
CHARACTERISTICS OF US PORPHYRY-CU DEPOSITS

Generally associated with intermediate to acid intrusive rocks that may be porphyritic.

Mineralisation commonly centred on a quartz monzonite intrusion.

e.g. Bingham is centred on a quartz monzonite porphyry.

The igneous rocks the main focus of this paper are discussed later.
CHARACTERISTICS OF US PORPHYRY-CU DEPOSITS

Host rocks are highly fractured and veined.

Based on notebook sketch
BAGDAD Az

hornblende replaced by biotite
chalcopyrite + quartz
quartz

quartz + pyrite + feldspar
chalcopyrite + quartz
quartz

15 mm

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Characteristics of US porphyry-Cu Deposits - Mineralisation features

- Ore types: Cu-only: Cu-Au; Cu-Mo; Cu-Au(-Mo) (many deposits began as gold camps)
- Main primary ore minerals: chalcopyrite and bornite.
- Gangue minerals: quartz, K-feldspar, anhydrite, magnetite, biotite ± sericite ± pyrite

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Characteristics of US porphyry-Cu Deposits - hypogene mineral zoning

Hypogene mineralisation tends to occur in concentric zones or shells with a spatial relationship to wall rock alteration.

- Mo-rich shells
- Cu-rich shells (chalcopyrite, bornite)
- Outer pyrite-rich halo.
- Pb-Zn-Ag outer zone may be present as in skarns at Bingham.

Inner and deeper

Zoning of primary mineralization at Bingham.

From: John, 1978. Econ. Geol. 73, 1250-1259.

Map of zoning - primary molybdenum mineralisation at eastern Butte, Montana.

From: Miller, 1978, Bute Field Meeting Guidebook. (Anaconda Co. Butte)
Characteristics of US porphyry-Cu Deposits – generalised hydrothermal alteration zones.

Stockwork and disseminated mineralisation generally associated with potassic alteration.

Modified from Lowell & Guilbert 1970, Econ Geol 65, 373-408.
### Characteristics of US porphyry-Cu deposits - Hypogene alteration assemblages

<table>
<thead>
<tr>
<th>Type</th>
<th>Assemblage</th>
</tr>
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<tbody>
<tr>
<td>Potassic</td>
<td>- biotite, magnetite, K-feldspar, quartz, anhydrite, chalcopyrite</td>
</tr>
<tr>
<td>Phyllic</td>
<td>- sericite, quartz, pyrite</td>
</tr>
<tr>
<td>Argillic (intermediate)</td>
<td>- sericite, chlorite, kaolinite or illite, pyrite, calcite</td>
</tr>
<tr>
<td>Argillic (advanced)</td>
<td>- alunite, kaolinite, pyrophyllite, quartz, dickite, gibbsite, pyrite, enargite, covellite</td>
</tr>
<tr>
<td>Propylitic</td>
<td>- chlorite, epidote, calcite, pyrite</td>
</tr>
</tbody>
</table>
Characteristics of US porphyry-Cu deposits - Potassic alteration

Potassic - biotite, magnetite, K-feldspar, quartz, anhydrite, chalcopyrite.

Biotite replacing hornblende is most characteristic
Characteristics of US porphyry-Cu deposits - Potassic alteration

Introduction of K over emphasised - original rocks were K-rich. (see table)

Note that sericitisation increases K.

Data from Moore 1978, Econ Geol 73, 1267
Characteristics of US porphyry-Cu deposits - supergene mineralisation

Supergene enrichment commonly occurs as a blanket. Many porphyry Cu deposits around the world would not be economic but for supergene enrichment.

Chalcocite (Cu$_2$S) is the most prevalent supergene mineral

Minerals of the oxidation zone include:

1. goethite
2. jarosite (K,H)Fe$_3$(SO$_4$)$_2$
3. hematite
4. chrysocolla (Cu,Al)$_2$H$_2$Si$_2$O$_5$(OH)$_4$.nH$_2$O
5. malachite [Cu$_2$CO$_3$(OH)$_2$] and azurite [Cu$_2$(CO$_3$)$_2$(OH)$_2$]
“pre main stage” at Butte is a typical porphyry copper deposit.

Randomly oriented veins (up to 250 mm thick) and veinlets (1-5 mm) of quartz, biotite, chalcopyrite, bornite, and magnetite (EDM veins) occur within a dome “one mile” across. Veins are within potassic alteration envelopes.

Quartz-molybdenite veinlets occur at deeper levels.

Data from Guidebook, Butte Field Meeting 1978 reprint. The Anaconda Company.
Three sets of intersecting “main stage” veins cut across the typical porphyry copper deposit.

These produced the “richest hill on earth”. The E-W Anaconda system is best known - the Anaconda Vein is legendary. These veins were dominated by chalcocite group minerals (chalcocite, djurleite, digenite) and enargite and hence very rich.

Butte produced 9 million tons of copper 3 million oz gold and 7 million oz silver as well as Pb, Zn and Mn.
BUTTE MONTANA

Berkeley Pit showing Anaconda veins (red) and other main veins.
BUTTE MONTANA

Berkeley Pit Section showing supergene enrichment – chalcocite blanket. Rocks are sooty with coating of chalcocite
Boulder Batholith intrudes Late Cretaceous Elkhorn Volcanics. Laramide batholith. Largely Butte Quartz Monzonite (bqm).

Early mafic rocks south and north include olivine monzonites (olivine opx biotite plagioclase alkali feldspar apatite and magnetite).

Pre bqm Radar Creek pluton contains "lamprophyric" Bodies, dykes of vuggy "syenite’ and some auto breccias.

Post bqm Donald pluton contains miarolitic cavities some with MoS,FeS$_2$ and CuFeS$_2$.
BUTTE MONTANA -Igneous rocks
Butte Quartz Monzonite

Most of the US porphyry copper deposits associated with quartz monzonites – quartz monzonites are therefore examined in detail.

The original quartz monzonite described from Walkerville (a northern suburb of Butte) more than 100 years ago, but the significance of this rock has been lost, mainly because many later petrologists referred to the rock type as granite or adamellite (now “monzogranite”).
**BUTTE MONTANA – Igneous rocks**

**Butte Quartz Monzonite**

Chemical analyses and modes

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<tr>
<th></th>
<th>64.92</th>
<th>64.34</th>
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<tbody>
<tr>
<td><strong>SiO₂</strong></td>
<td>64.92</td>
<td>64.34</td>
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<tr>
<td><strong>TiO₂</strong></td>
<td>0.53</td>
<td>0.53</td>
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<tr>
<td><strong>Al₂O₃</strong></td>
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<td><strong>Fe₂O₃</strong></td>
<td>1.81</td>
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<tr>
<td><strong>FeO</strong></td>
<td>2.70</td>
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<td><strong>MnO</strong></td>
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<tr>
<td><strong>MgO</strong></td>
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<td><strong>CaO</strong></td>
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<tr>
<td><strong>Na₂O</strong></td>
<td>3.06</td>
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<tr>
<td><strong>K₂O</strong></td>
<td>3.94</td>
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<tr>
<td><strong>P₂O₅</strong></td>
<td>0.18</td>
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<tr>
<td><strong>H₂O⁺</strong></td>
<td>0.59</td>
<td>0.76</td>
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<tr>
<td><strong>H₂O⁻</strong></td>
<td>0.12</td>
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<tr>
<td><strong>CO₂</strong></td>
<td>0.06</td>
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<tr>
<td><strong>BaO</strong></td>
<td>0.09</td>
<td>0.06</td>
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</table>

Total 99.85 99.72

**Note**
- Low SiO₂ and quartz
- High K₂O
- High Ba


**Modes of Butte quartz monzonite**

<table>
<thead>
<tr>
<th>Mineral</th>
<th>1</th>
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<tbody>
<tr>
<td>Plagioclase</td>
<td>38.5</td>
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<tr>
<td>K-feldspar</td>
<td>22.6</td>
<td>21</td>
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<tr>
<td>Quartz</td>
<td>23.7</td>
<td>23</td>
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<tr>
<td>Biotite</td>
<td>9.0</td>
<td>11</td>
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<tr>
<td>Hornblende</td>
<td>5.0</td>
<td>4</td>
</tr>
<tr>
<td>Magnetite</td>
<td>1.0</td>
<td>4*</td>
</tr>
<tr>
<td>Others (titanite)</td>
<td>0.2</td>
<td>-</td>
</tr>
</tbody>
</table>

2. Tröger 1969 * includes apatite
BUTTE MONTANA - Igneous rocks

Gerel (1995) when discussing deposits at Ulaan, Mongolia, pointed out that rocks associated with Cu-Au porphyry systems have $K_2O/Na_2O = 0.7 - 1.3$.

Butte quartz monzonite has $K_2O/Na_2O = 1.35$. Butte produced about 100 tonnes gold.

Bingham quartz monzonites have $K_2O/Na_2O = 1.18$ has produced about 1000 tonnes of gold as well as producing Mo.

Porphyry Cu/Mo deposits Gerel says are associated with rocks with $K_2O/Na_2O = 0.3 - 0.7$. Bagdad fits into the latter category - it has low gold.

BUTTE MONTANA - Igneous rocks
Butte Quartz Monzonite

A sample, collected near the type locality, is described.

Butte sample is on the borderline between quartz monzonite as now defined and granite.
BUTTE MONTANA - Igneous rocks
Butte Quartz Monzonite

Plagioclase, K-feldspar, quartz, biotite, hornblende (commonly with pyroxene cores), relatively abundant magnetite and very small amounts of titanite and apatite.

Quartz is lower than in typical granite and magnetite is more abundant. Magnetite is commonly seen as aggregates with apatite, suggestive of crystallisation from an immiscible Fe-P melt phase!

Oxygen fugacity high. $\Delta$ NNO > 2.
**BUTTE MONTANA** - Igneous rocks

Butte Quartz Monzonite

Quartz is lower than in typical granite.

Note the even texture of the rock

100 mm
NB There are no low-Si granites. Most are quartz monzonites as presently defined.

Oxygen fugacity high. Δ NNO > 2.
NB There are some low-Si granites but on the borderline of the quartz monzonite field.
IGNEOUS ROCKS - Miami - Globe low-Si granite

Schultze low-Si granite from Globe.

Although relatively felsic there is an abundance of magnetite - upper centre of picture. This is a result of the high oxygen fugacity.

Rare large K-feldspar crystals up to 30 mm long, are zoned as a result of high barium.
IGNEOUS ROCKS – Modes of Sierrita rocks

The suite ranges from high-K diorite to low Si granites. But the chemical analysis of the diorite is more like a monzonite.

Oxygen fugacity high. \( \Delta \text{NNO} = 2 \).

IGNEOUS ROCKS – evidence for near-surface intrusion

1. There are associated volcanic rocks.

e.g. Laramide volcanic rocks of Arizona

2. Some intrusions are porphyries - pressure-quenched rocks and latite dykes common.

e.g. Bingham
3. Rocks with miarolitic cavities (crystals of copper and molybdenum sulfide have been reported in some cavities).
4. Granophyric intergrowths of quartz and alkali feldspar are seen in thin section.
5. Occurrence of hydrothermal breccias.
6. Quartz monzonites have closely spaced vertical joints.
SUMMARY AND CONCLUSIONS regarding associated igneous rocks

Rock type – quartz monzonites or low Si-granites are ubiquitous.

Igneous rocks emplaced near surface

Associated with high temperature suites fractionated from monzonites or high-K diorites.

Very high oxidation state $\Delta$ NNO = +2 to +3. Quartz monzonites and low-Si granites have aggregates of magnetite commonly with apatite, even in felsic rocks.