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 (phyllic), 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 SiO_2 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 ΔNNO > +2 can be calculated from more reliable rock analyses in which FeO and Fe_2O_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.

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GRANITIC ROCKS ASSOCIATED WITH WESTERN USA PORPHYRY COPPER DEPOSITS

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DISTRIBUTION

Map Western USA

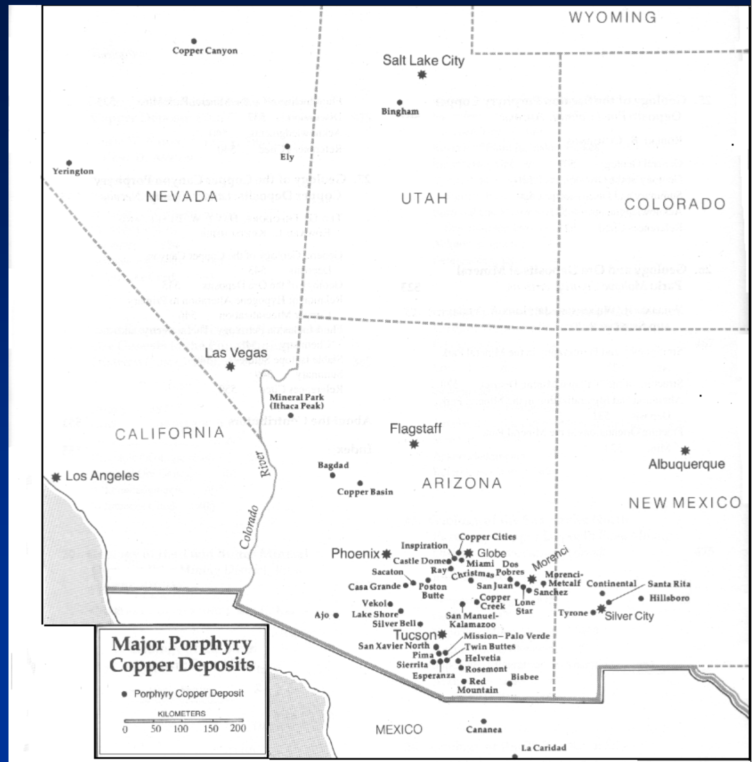
Porphyry copper deposits visited

DISTRIBUTION

Map Southwestern USA

Porphyry copper deposits mainly in Arizona.

After Titley (1982)
Advances in the geology of the porphyry copper deposits.



MAP MODIFIED FROM TITLEY 1982
Advances in Geology of the Porphyry Copper Deposits
University of Arizona Press

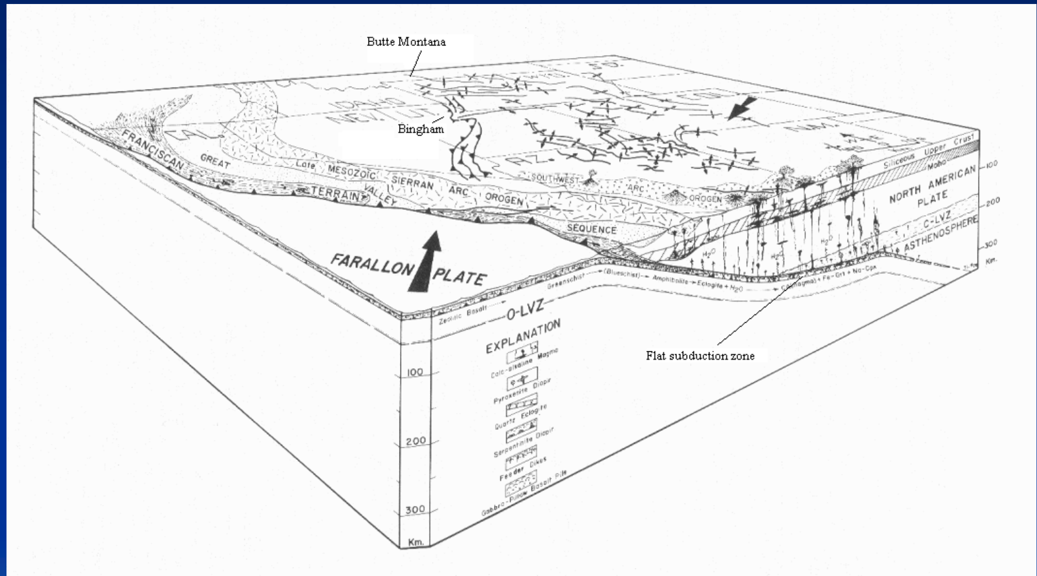
Characteristics of US porphyry-Cu deposits

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

Notable exceptions are Bingham, Utah - late Tertiary, and Bisbee, Arizona - Jurassic.

DISTRIBUTION – TECTONIC INTERPRETATION

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

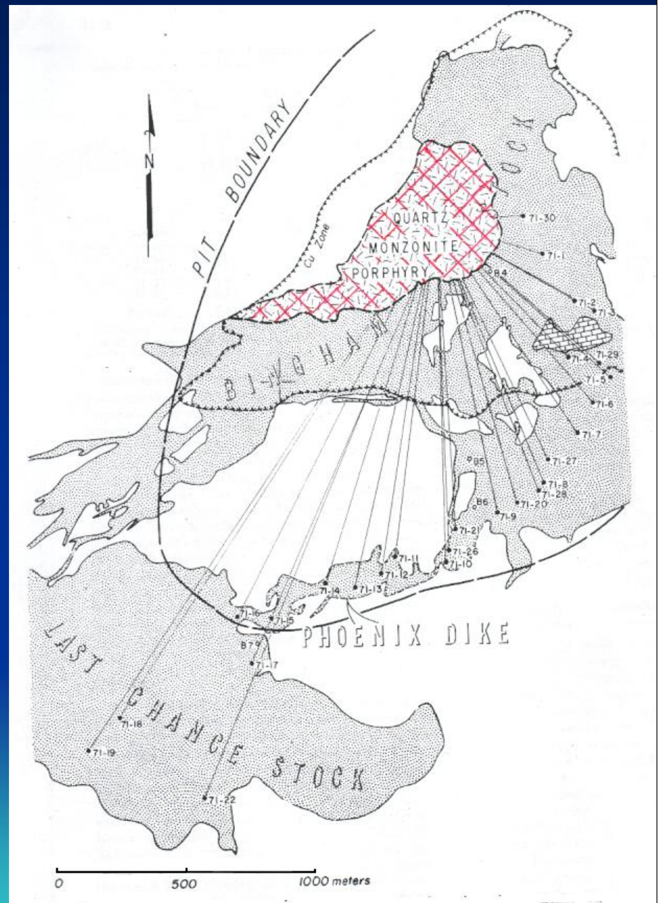
CHARACTERISTICS OF US PORPHYRY-CU DEPOSITS

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

Mineralisation commonly centred on a quartz monzonite intrusion.

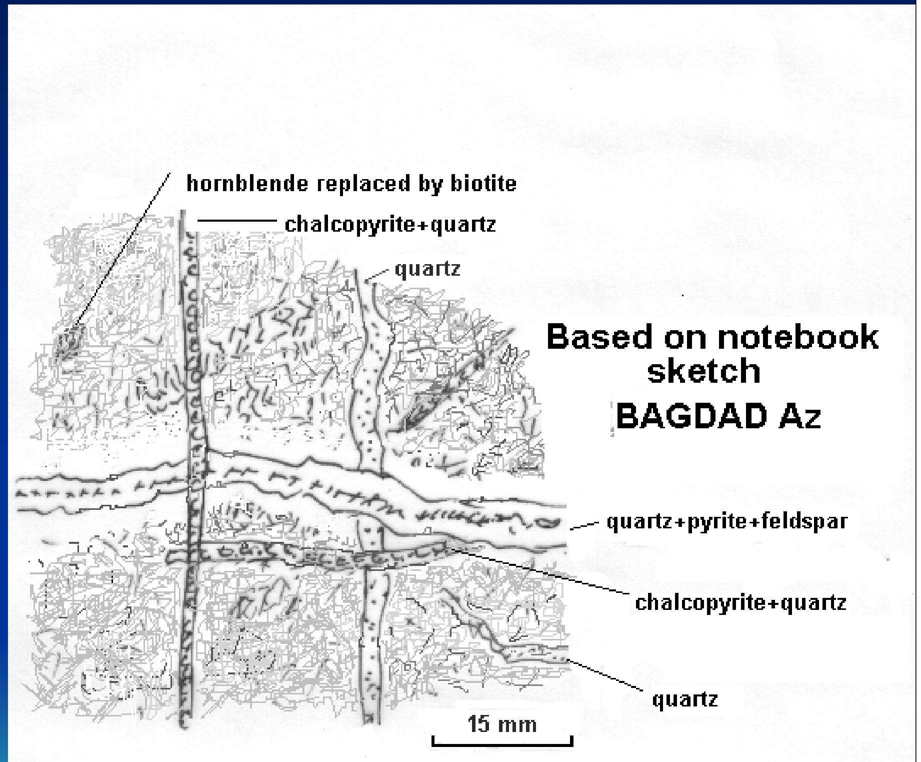
e.g. Bingham is centred on a quartz monzonite porphyry.

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.



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**

Characteristics of US porphyry-Cu Deposits – hypogene mineral zoning

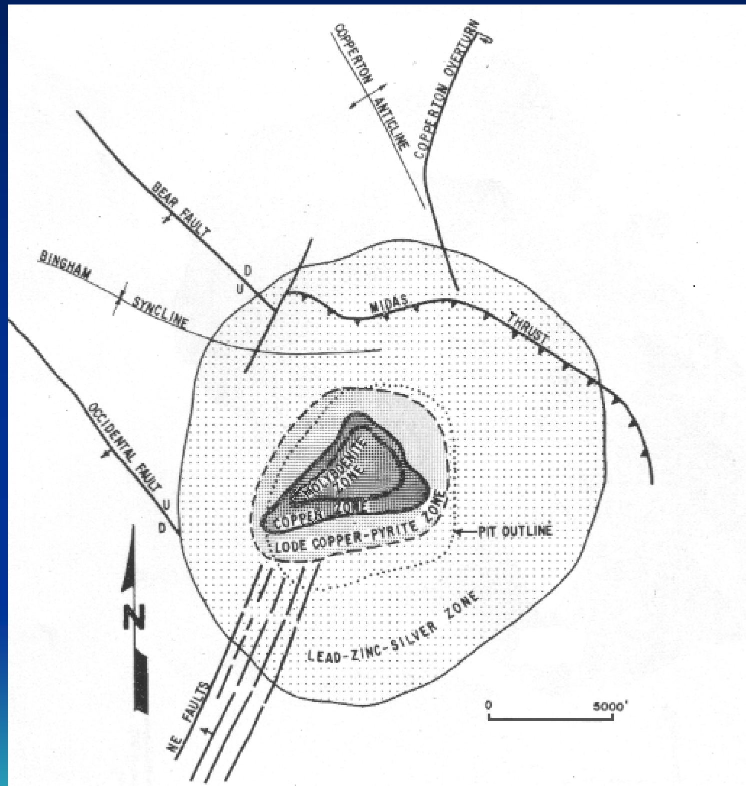
Hypogene mineralisation tends to occur in concentric zones or shells with a spatial relationship to wall rock alteration.

Inner and deeper ↑

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.

Characteristics of US porphyry-Cu Deposits – hypogene mineral zoning.

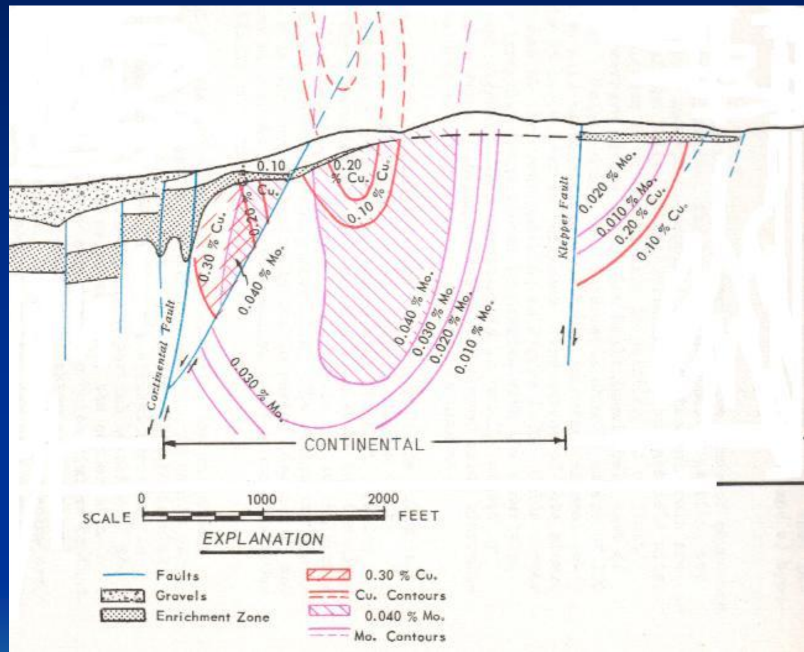
Zoning of primary mineralisaton at Bingham.



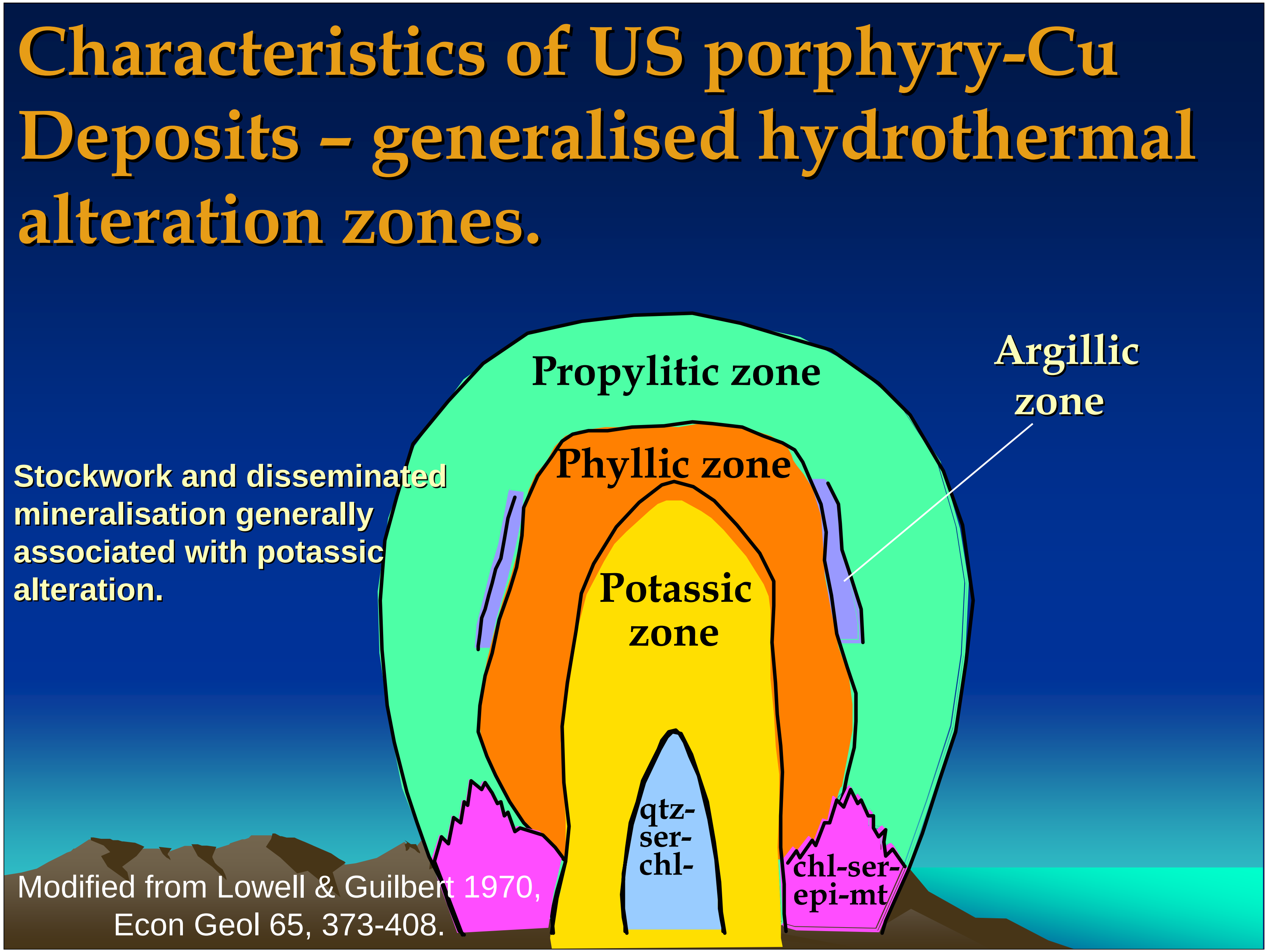
From: John, 1978. Econ. Geol. 73, 1250-1259.

Characteristics of US porphyry-Cu Deposits – hypogene mineral zoning.

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.
Propylitic zone
Argillic zone
Phyllic zone
Stockwork and disseminated mineralisation generally associated with potassic alteration.
Potassic zone
qtz-ser-chl-
chl-ser-epi-mt
Modified from Lowell & Guilbert 1970, Econ Geol 65, 373-408.

Characteristics of US porphyry-Cu deposits - Hypogene alteration assemblages

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

Phyllic - sericite, quartz, pyrite

Argillic (intermediate) - sericite, chlorite, kaolinite or illite, pyrite, calcite

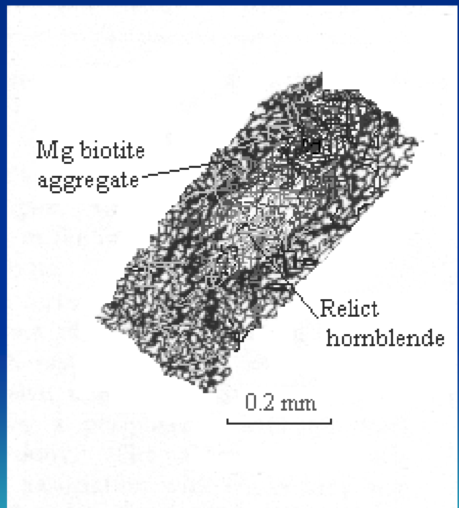
Argillic (advanced) - alunite, kaolinite, pyrophyllite, quartz, dickite, gibbsite, pyrite, enargite, covellite

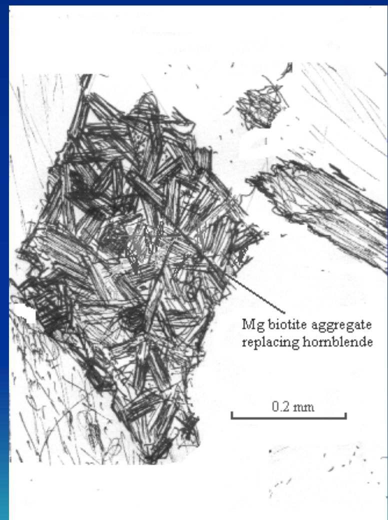
Propylitic - chlorite, epidote, calcite, pyrite

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

	Quartz monzonite		
	Unaltered	Biotitized	Biotitized and sericitized
	A	B	C
	Weight percent		
SiO_2	58.9	61.1	61.4
$A._2O_3$	15.6	14.9	15.6
Fe_2O_3	3.2	2.2	3.2
FeO	3.8	3.6	2.6
MgO	3.9	4.6	4.4
CaO	3.8	1.6	0.90
Na_2O	3.4	2.0	1.0
K_2O →	4.8	5.5	5.8
H_2O (total)	1.79	2.2	3.6
TiO_2	0.90	0.90	0.83
CO_2	0.07	0.15	0.01
P_2O_5	0.59	0.62	0.44
MnO	0.04	0.01	0.03
S	0.19	0.58	1.38
Specific gravity	2.67	2.63	2.60
	Grams per 100 cubic centimeters		
SiO_2	157.3	160.7	159.6
Al_2O_3	41.7	39.2	40.6
Fe_2O_3	8.5	5.8	8.3
FeO	10.1	9.5	6.8
MgO	10.4	12.1	11.4
CaO	10.1	4.2	2.3
Na_2O	9.1	5.3	2.6
K_2O →	12.8	14.5	15.1
H_2O (total)	4.8	5.8	9.4
TiO_2	2.4	2.4	2.2
CO_2	0.2	0.4	
P_2O_5	1.6	1.6	1.1
MnO	0.1		0.1
S	0.5	1.5	3.6

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_2S) is the most prevalant supergene mineral

Minerals of the oxidation zone include:

(1) goethite
(2) jarosite $(K,H)Fe_3(SO_4)_2$
(3) hematite
(4) chrysocolla $(Cu,Al)2H_2Si_2O_5(OH)_4.nH_2O$
(5) malachite $[Cu_2CO_3(OH)_2]$ and azurite $[Cu_2(CO_3)_2(OH_2]$

BUTTE MONTANA

"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.

BUTTE MONTANA

Three sets of intersecting "main stage" veins cut across the typical porphyry copper deposit.

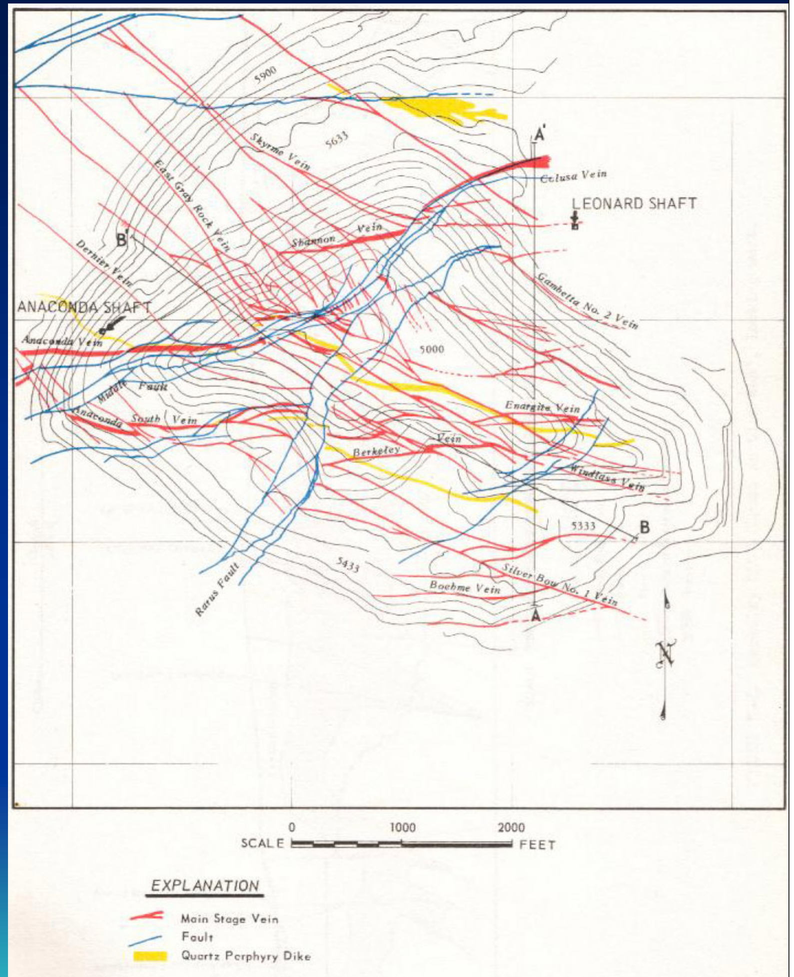
These produced the "richest hill on earth". The E-W Anaconda system is best known - the Anaconda Vein is legendary. These veins were dominated by chalcocite group minerals (chalcocite, djurleite,digenite) and enargite and hence very rich.

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

Data from Guidebook,Butte Field Meeting 1978 reprint. The Anaconda Company.

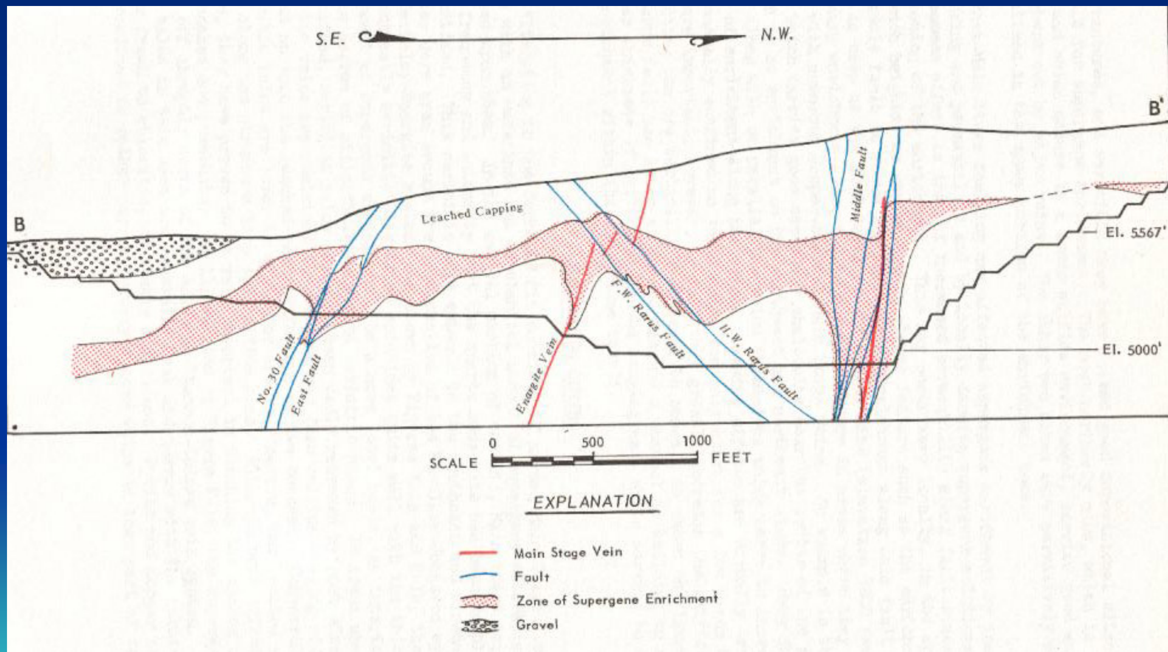
BUTTE MONTANA

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

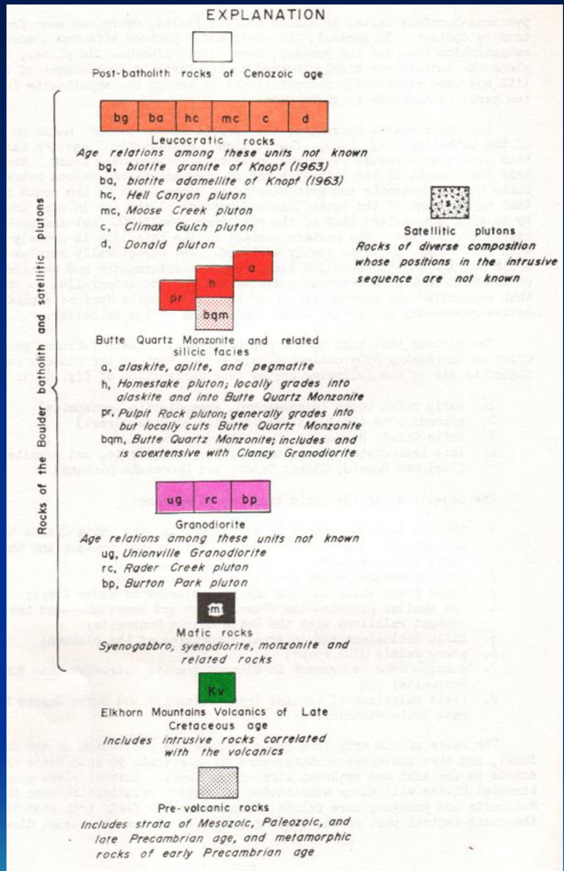


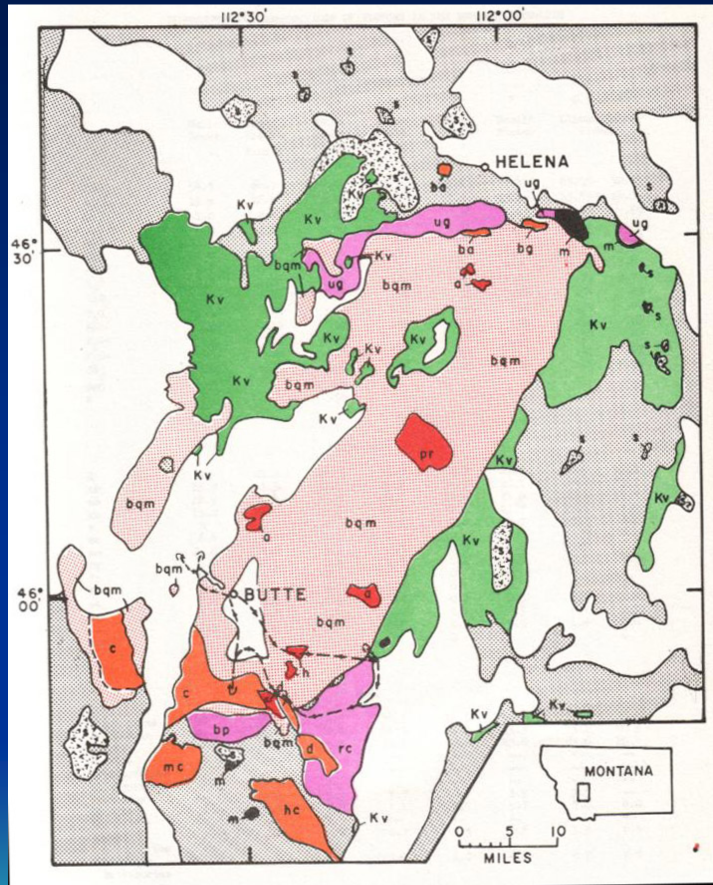
BUTTE MONTANA

Berkeley Pit Section showing supergene enrichment – chalcocite blanket. Rocks are sooty with coating of chalcocite



BUTTE MONTANA Igneous rocks





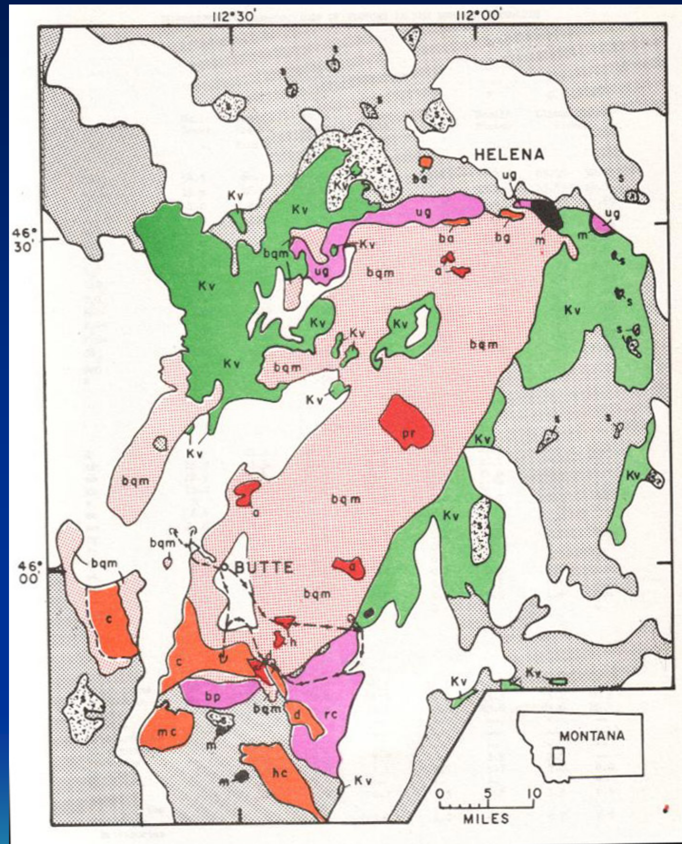
BUTTE MONTANA Igneous rocks

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

Note Low SiO_2 and quartz
High K_2O
High Ba

SiO2	64.92	64.34
TiO2	0.53	0.53
Al2O3	15.46	15.72
Fe2O3	1.81	1.62
FeO	2.70	2.94
MnO	0.09	0.12
MgO	2.05	2.17
CaO	4.24	4.24
Na2O	3.06	2.76
K2O	3.94	4.04
P2O5	0.18	0.14
H2O+	0.59	0.76
H2O-	0.12	0.25
CO2	0.06	0.03
BaO	0.09	0.06
Total	99.85	99.72

1 Quartz monzonite. Butte. Smedes et al. In Miller, 1978
2 Quartz monzonite. Walkerville, Butte. J. Geol 7, 1899.

Modes of Butte quartz monzonite

Plagioclase	38.5	37
K-feldspar	22.6	21
Quartz	23.7	23
Biotite	9.0	11
Hornblende	5.0	4
Magnetite	1.0	4*
Others (titanite	0.2	-

1 Smedes et al. In Miller 1978
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 producedabout 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.

Gerel, O., 1995, In Ishihara S & Czamanske G.K. eds. Resource Geology Special Issue No18, 151 – 157

BUTTE MONTANA –Igneous rocks
Butte Quartz Monzonite

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

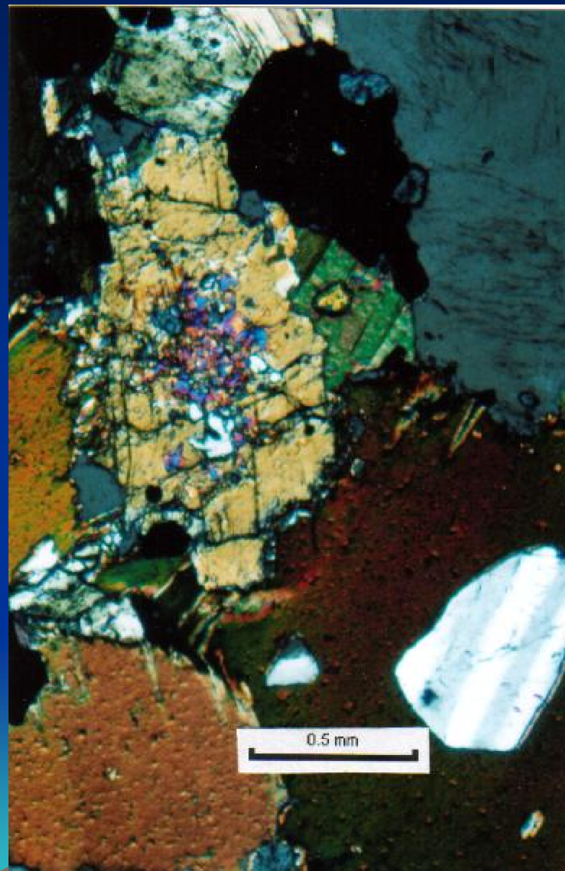
Butte sample is on the borderline between quartz monzonite as now defined and granite.

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. Δ NNO > 2.



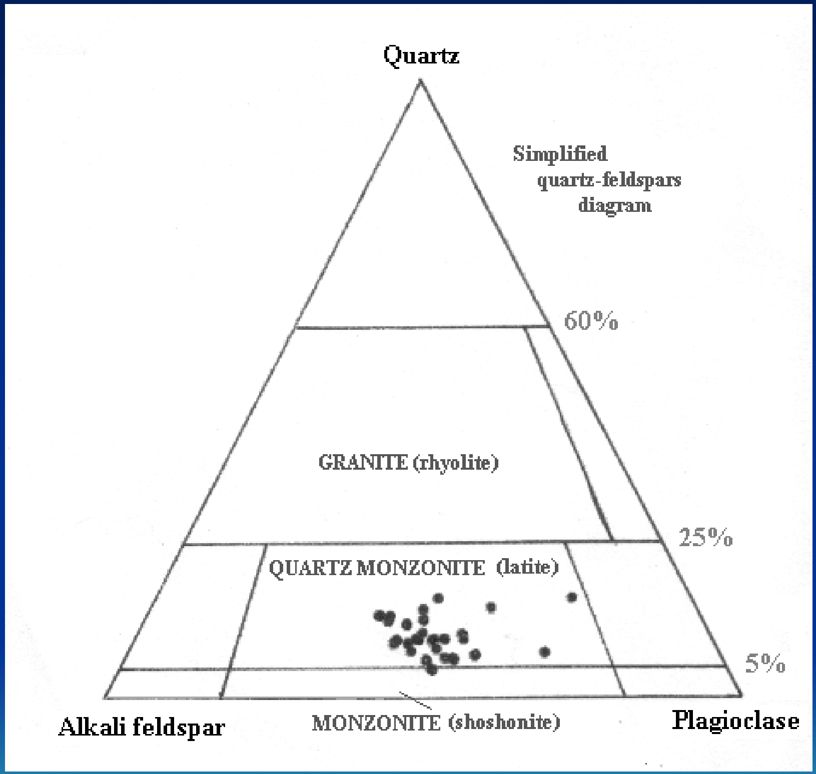
BUTTE MONTANA –Igneous rocks
Butte Quartz Monzonite

Quartz is lower than in typical granite.

Note the even texture of the rock

100 mm

IGNEOUS ROCKS – Modes of Bingham rocks

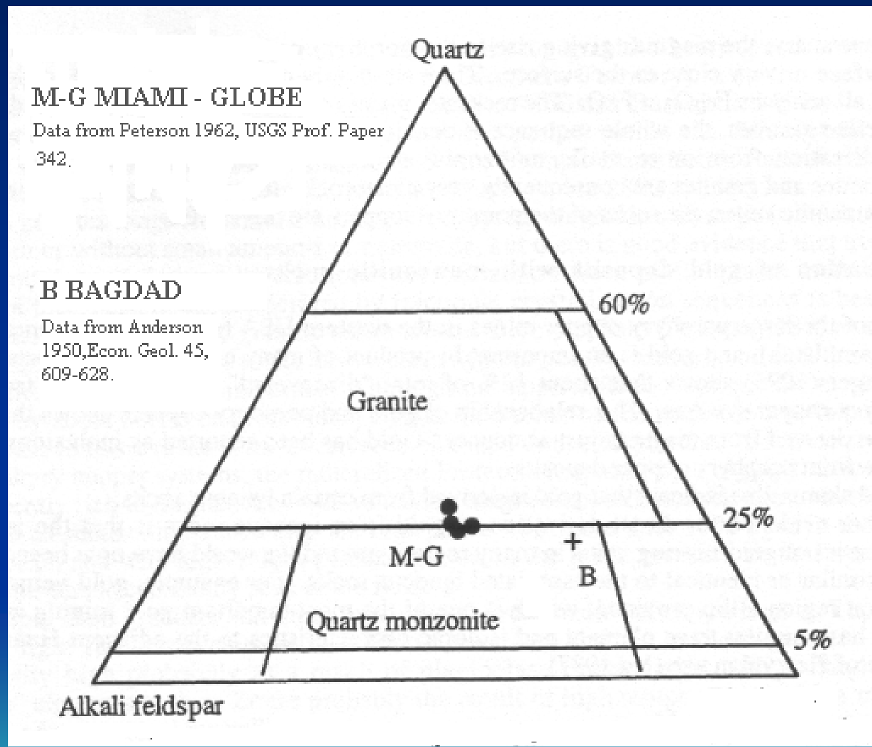


NB There are no low-Si granites. Most are quartz monzonites as presently defined.

Oxygen fugacity high.
Δ NNO > 2.

IGNEOUS ROCKS – Modes of Miami- Globe and Bagdad rocks

NB There are some low-Si granites but on the borderline of.the quartz monzonite field.



IGNEOUS ROCKS –Miami-Globe low-Si granite

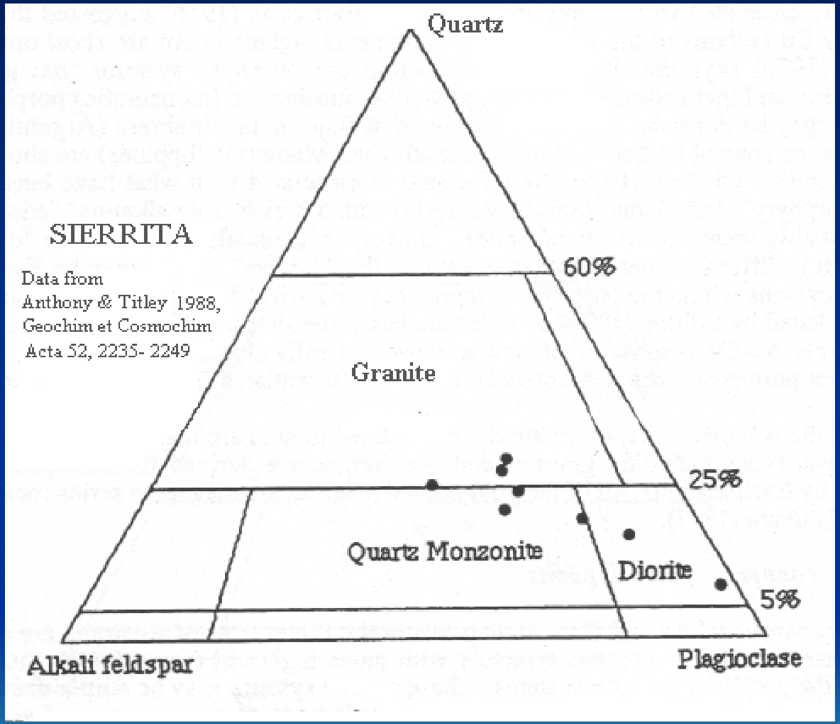
Schultze low-Si granite from Globe.

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



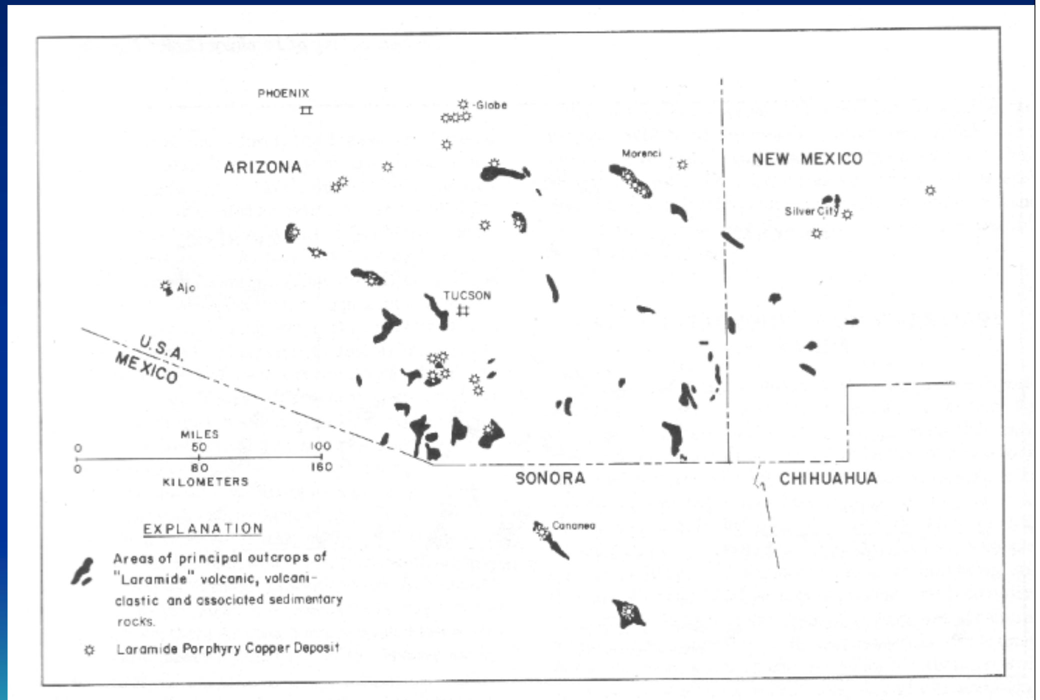
Oxygen fugacity high.
Δ NNO = 2.

Data from Anthony & Titley 1988. Geochim et Cosmochim Acta 52, 2235

IGNEOUS ROCKS – evidence for near-surface intrusion

1. There are associated volcanic rocks.

e.g. Laramide volcanic rocks of Arizona

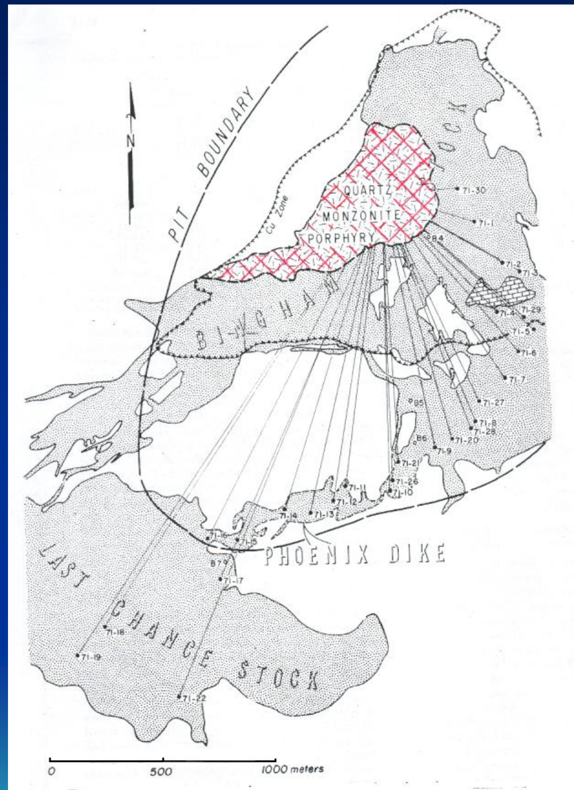


After Titley 1982. Advances in Geology of porphyry copper deposits. Univ Ariz. Press

IGNEOUS ROCKS – evidence for near-surface intrusion

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

e.g. Bingham



IGNEOUS ROCKS – evidence for near-surface intrusion

3. Rocks with miarolitic cavities (crystals of copper and molybdenum sulfide have been reported in some cavities).

20 mm

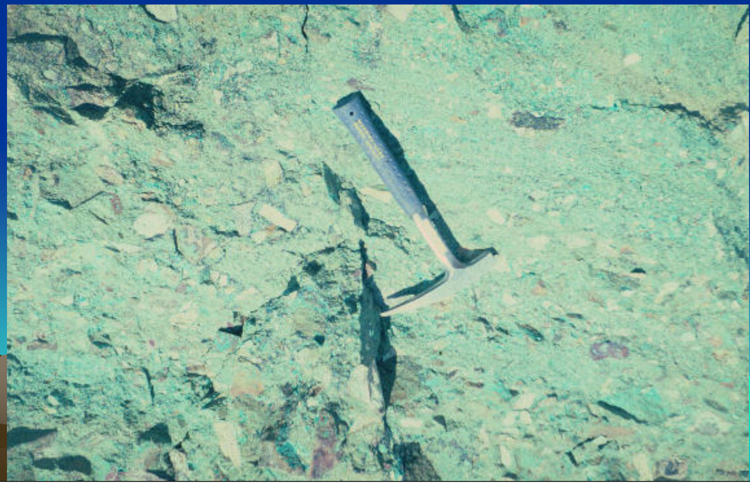
IGNEOUS ROCKS – evidence for near-surface intrusion

4. Granophyric intergrowths of quartz and alkali feldspar are seen in thin section.

IGNEOUS ROCKS – evidence for near-surface intrusion

5. Occurrence of hydrothermal breccias.

Pictures from Bagdad Az



IGNEOUS ROCKS – evidence for near-surface intrusion

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 Δ NNO = +2 to +3. Quartz monzonites and low-Si granites have aggregates of magnetite commonly with apatite, even in felsic rocks.