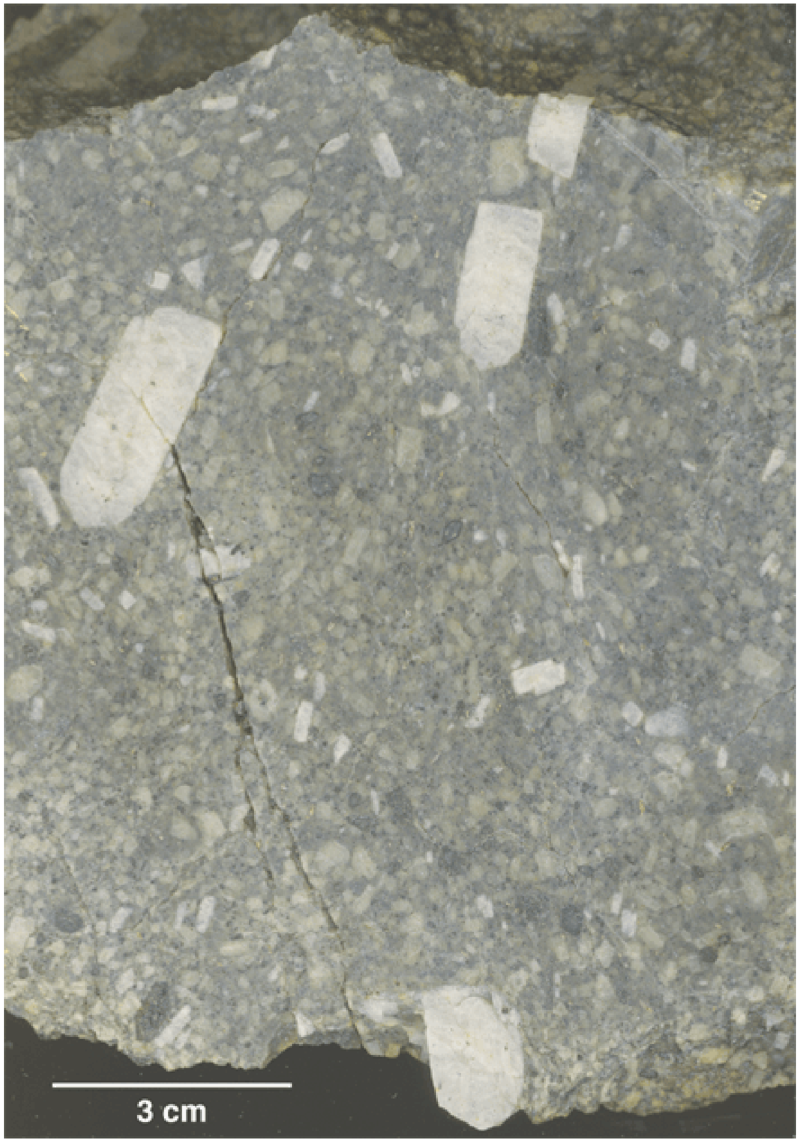
Porphyry copper deposit

Porphyry copper deposits are copper ore bodies which are **associated with porphyritic intrusive rocks**.

The ore occurs as disseminations along hairline fractures as well as within larger veins, which often form a stockwork.

The orebodies typically contain between **0.4 and 1 % copper** with smaller amounts of other metals such as **molybdenum, silver and gold**.

They are formed when large quantities of hydrothermal solutions carrying small quantities of metals pass through fractured rock within and around the intrusive and deposit the metals.
Porphyry copper deposits are the largest source of copper, and are found in North and South America, Europe, Asia, and Pacific islands. None are documented in Africa. **The largest examples are found in the Andes in South America**.



Typical porphyry from an economic copper deposit.

Quartz monzonite porphyry associated with economic copper mineralization at the Robinson Mining District, Nevada.

The porphyritic rock contains coarse crystals of orthoclase feldspar, plagioclase feldspar, and quartz set in a finely crystalline ground mass generated during decompression and quenching of the melt.

The largest orthoclase crystal (white) is 3.0 cm in diameter.

Characteristics of porphyry copper deposits include:

- The orebodies are associated with multiple intrusions and **dikes of diorite to quartz monzonite** composition with porphyritic textures.

- **Breccia zones** with angular or locally rounded fragments are commonly associated with the intrusives. The sulfide mineralization typically occurs between or within fragments.

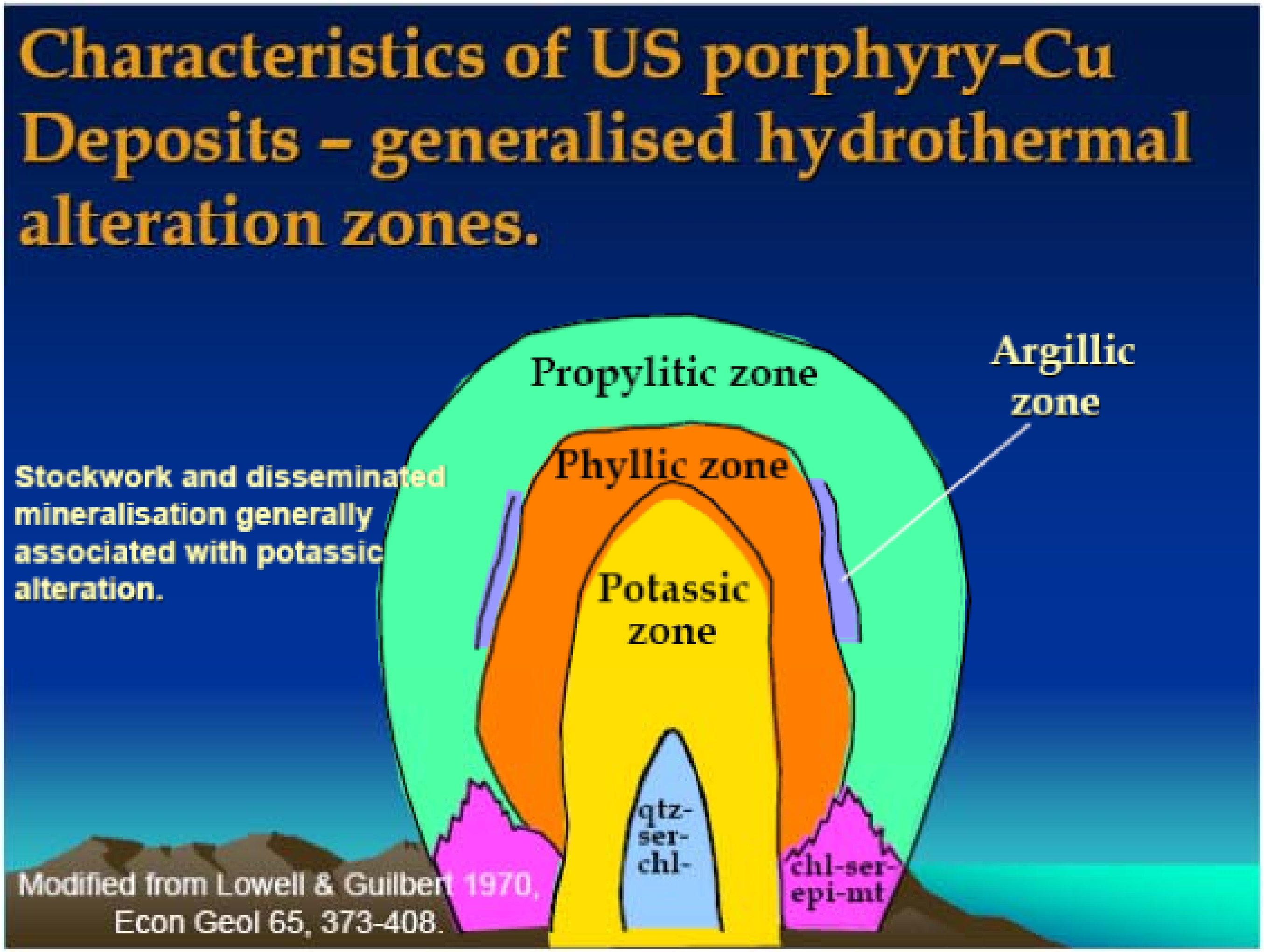
- The deposits typically have an **outer epidote - chlorite mineral alteration zone.**

- A **quartz - serite alteration zone** typically occurs closer to the center and may overprint.

- A central ***potassic* zone** of secondary biotite and orthoclase alteration is commonly associated with most of the ore.

- Fractures are often filled or coated by sulfides, or by quartz veins with sulfides. Closely spaced fractures of several orientations are usually associated with the highest grade ore.

Porphyry copper deposits are typically **mined by open-pit methods**.


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

MINERALIZATION

Original sulphide minerals in these deposits are **pyrite, chalcopyrite, bornite and molybdenite**.

Gold is often in native found as tiny blobs along borders of sulphide crystals.

Most of the sulphides occur in veins or plastered on fractures; most are intergrown with quartz or sericite.

In many cases, the deposits have a central very low grade zone enclosed by **'shells' dominated by bornite**, then **chalcopyrite**, and finally **pyrite**, which may be up to 15% of the rock.

Molybdenite distribution is variable, Radial fracture zones outside the pyrite halo may contain **lead-zinc veins with gold and silver values**.

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.

DISTRIBUTION AND AGE

Porphyry copper provinces seem to coincide, worldwide, with **orogenic belts**.

This remarkable association is clearest in **Circum-Pacific Mesozoic to Cenozoic deposits** but is also apparent in North American, Australian and Soviet Paleozoic deposits within the orogenic belts.

Porphyry deposits occur in **two main settings** within the orogenic belts; in **island arcs** and at **continental margins**.

Deposits of Cenozoic and, to a lesser extent, Mesozoic age predominate. Those of **Paleozoic age are uncommon** and only **a few Precambrian deposits** with characteristics similar to porphyry coppers have been described.

Deformation and metamorphism of the older deposits commonly obscured primary features, hence they are difficult to recognize.

Distribution of porphyry copper deposits world-wide

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 $[Cu_2(CO_3)_2(OH_2)]$

Porphyry-type ore deposits for metals other than copper

Copper is not the only metal that occurs in porphyry deposits. There are also porphyry ore deposits mined primarily for molybdenum, many of which contain very little copper.

Some porphyry copper deposits in oceanic crust environments, such as those in the **Phillippines, Indonesia, and Papua New Guinea**, are sufficiently rich in gold that they are called **copper-gold porphyry deposits**.

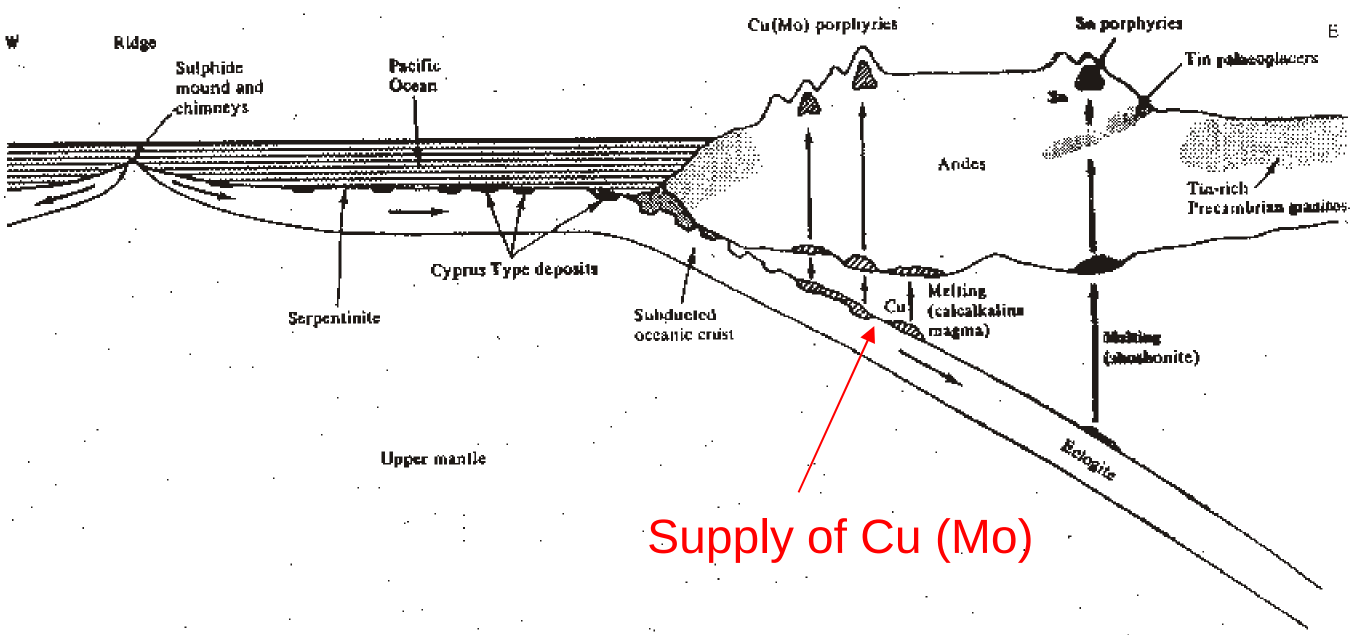


Figure 11.7 Diagram showing how ocean floor sediments with Cyprus Type copper sulphide deposits overlying serpentinised oceanic crust begin to melt as they are carried down to high-temperature zones in the mande at a depth of 100–300 km. The subsequent melts contribute to sulphur and copper-bearing calcalkaline magmas. At greater depths alkaline magmas are produced which rise through the mantle and then the crust to digest Silurian quartzites bearing cassiterite within the orogenic prism. Tin as well as copper porphyries crystallise in the hearths of volcanoes. Not to scale.

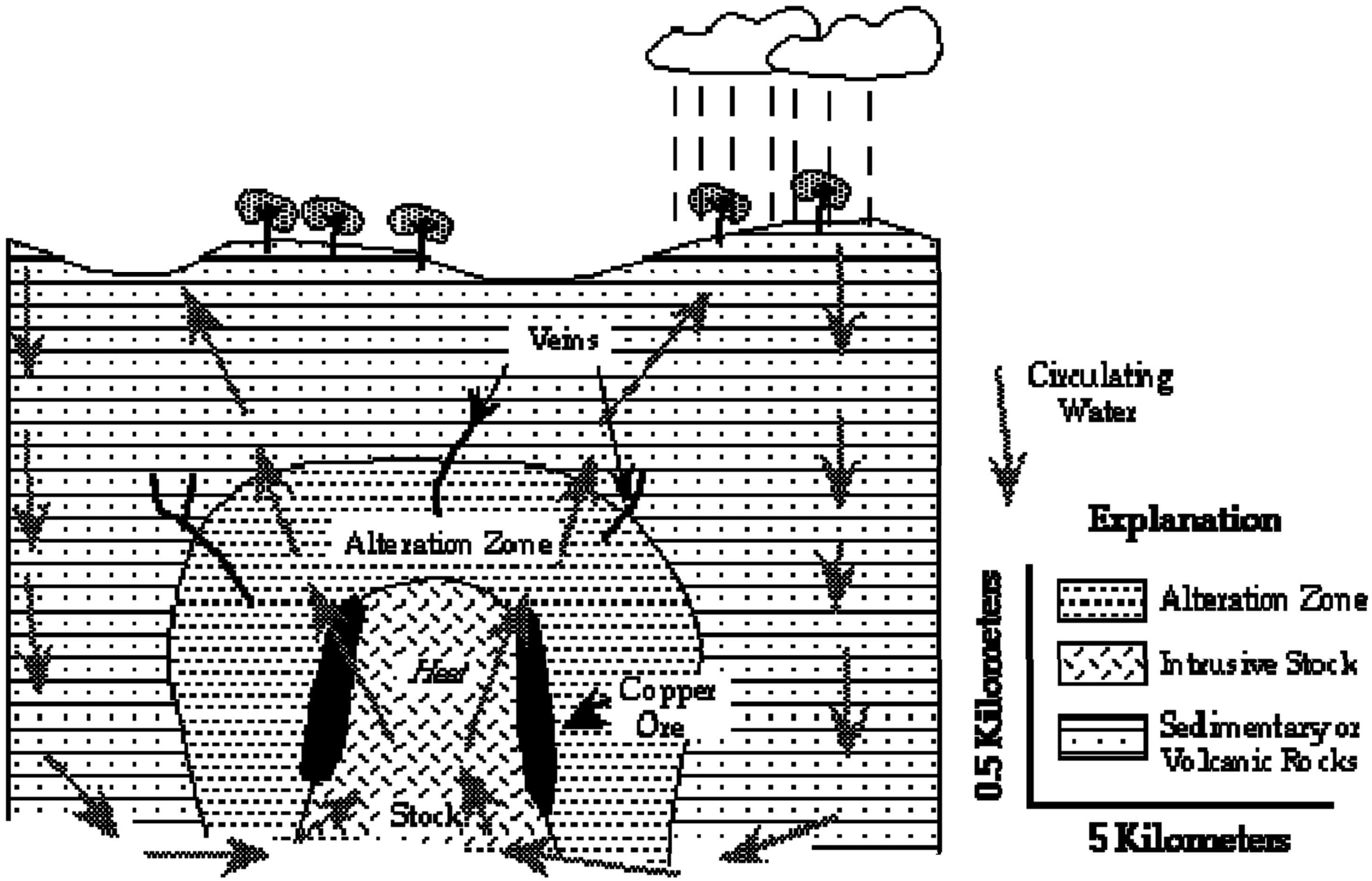


Figure 1. Vertical cross section showing a porphyry copper deposit as it occurs deep within the earth. (Modified from Evans, 1980)

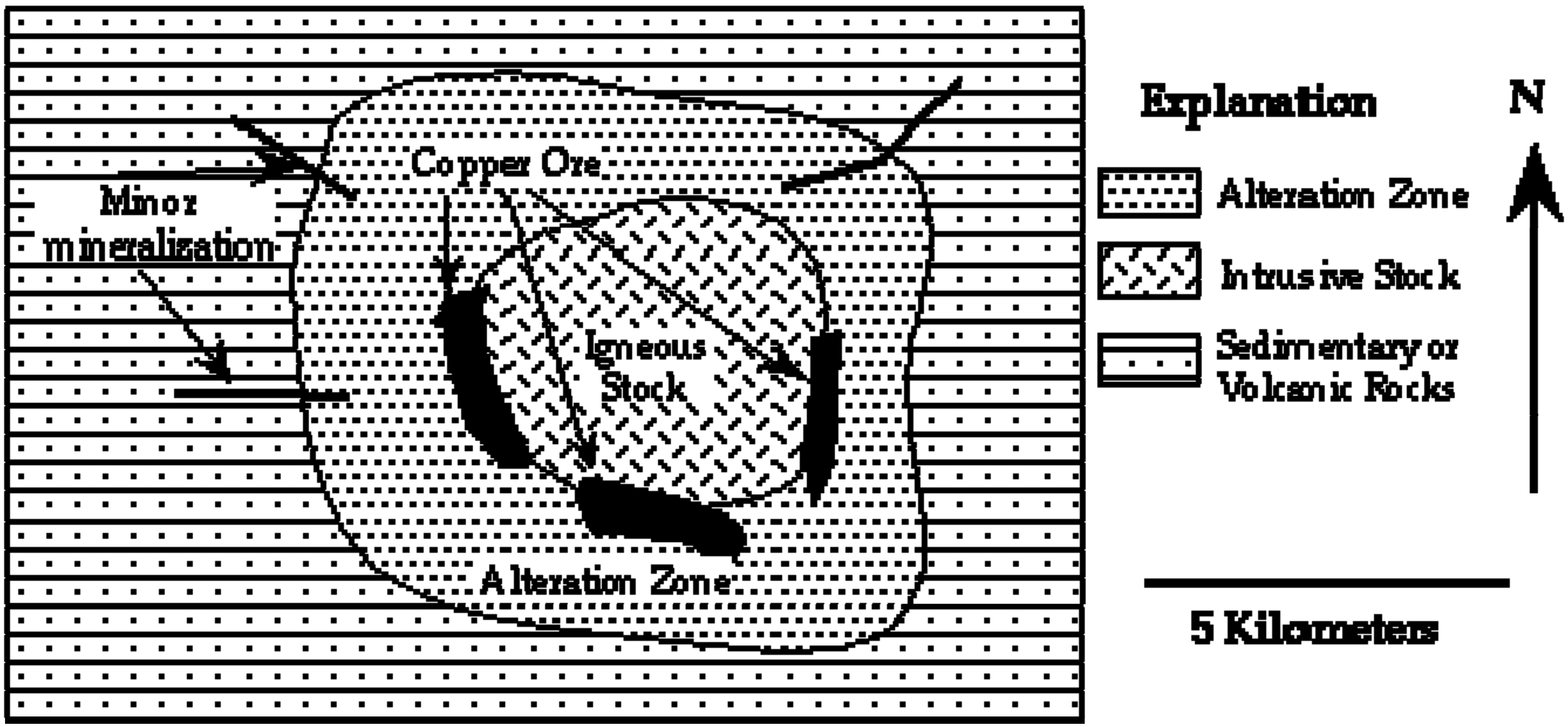


Figure 2. Geologic map showing the aerial view of a porphyry copper deposit

Geochemical Exploration

Such a map may look like Figure 3. The circles along the streams are locations at which **gold (Au)** has been panned.
The numbers refer to the number of gold grains that were found at these locations.
The arrows point in the direction that the stream is flowing (the "v's" formed by the joining streams always point downstream).

After studying the map, geologists would predict that gold deposits may occur upstream from the two highest gold values (35 and 21). Unusually high concentrations such as these are termed **geochemical anomalies** by exploration geologists. The number of grains decreases downstream from these anomalous values. Upstream from the predicted gold deposit, there are few gold grains in the sediments. This is because the stream can only carry the gold grains downstream from the deposit, not upstream.

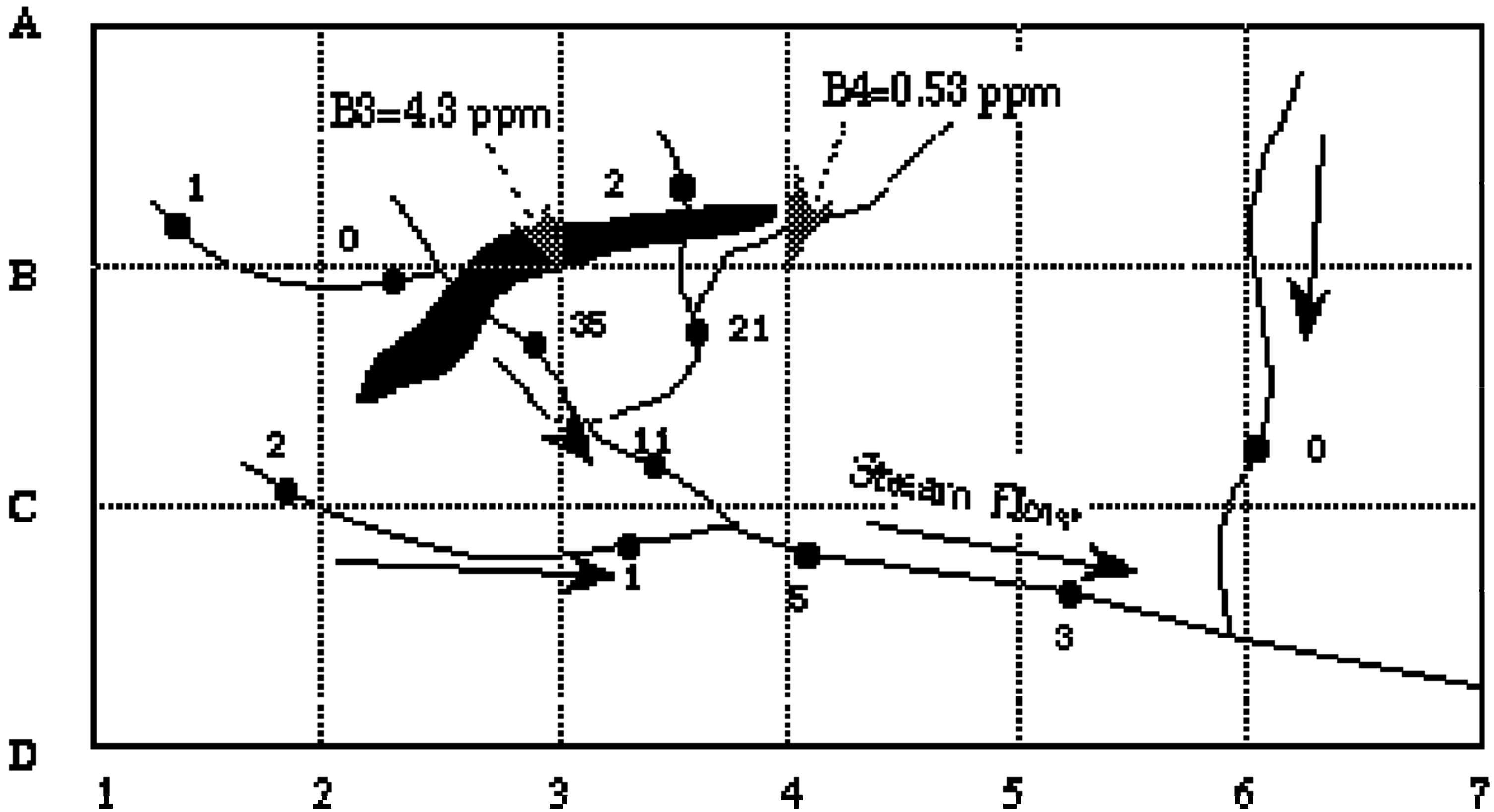


Figure 3. Map showing a stream and sediment survey

Black dots: the place where Au has been panned and shown with gold value

Another commonly used geochemical exploration technique is **soil geochemistry**. Geologists establish a **sampling grid** over an area of interest. Figure 3 shows such a grid. It is defined by the letters A through D on the north-south axis, and the numbers 1 through 5 are on the east-west axis. Geologists analyze soil samples at each node of the grid (where the lines cross). They then construct a map showing the concentration of gold at each location. On this map, the highest value of **gold (4.3 ppm)** occurs at node B3. Node B4 has a lower gold value than **B3 (0.53 ppm),** but higher than all of the other soil samples in the area. Geologists could use these anomalous values, together with the anomalous stream sediment values to predict that an ore body was present below the soil somewhere in the blackened area.

Porphyry Deposits-summary

A large body of rock, typically a porphyry of granitic to dioritic composition, that has been **fractured on a fine scale** and through which **chalcopyrite and other copper minerals are disseminated**.

Porphyry copper deposits commonly contain hundreds of millions of metric tons of ore that averages a fraction of 1 percent copper by weight; although they are low-grade.

The major products from porphyry copper deposits are **copper and molybdenum** or **copper and gold**.

The term porphyry copper now includes engineering as well as geological considerations; **It refers to large, relatively low grade, epigenetic, intrusion-related deposits that can be mined using mass mining techniques**.

Geologically, the deposits occur close to or in granitic intrusive rocks that are **porphyritic** in texture.

There are usually **several episodes of intrusive activity**, so expect swarms of dykes and intrusive breccias. The country rocks can be any kind of rock, and often there are **wide zones of closely fractured and altered rock surrounding the intrusions**.

This country rock alteration is distinctive and changes as you approach mineralization. Where sulphide mineralization occurs, surface weathering often produces rusty-stained bleached zones from which the metals have been leached; if conditions are right, these may redeposit near the water table to form an enriched zone of secondary mineralization.

PORPHYRY COPPER CLASSIFICATION

Porphyry copper deposits comprise three broad types: plutonic, volcanic, and "classic".

Plutonic porphyry copper deposits occur in batholithic settings with mineralization principally occurring in one or more phases of plutonic host rock.

Volcanic types occur in the roots of volcanoes, with mineralization both in the volcanic rocks and in associated comagmatic plutons.

Classic types occur with high-level, post-orogenic stocks that intrude unrelated host rocks; mineralization may occur entirely within the stock entirely in the country rock, or in both. The earliest mined deposits, as well as the majority of Cenozoic porphyry copper deposits, are of the classic type.

Intrusions Associated with Porphyry Copper Deposits

Intrusions associated with porphyry copper deposits are diverse but generally felsic and differentiated. Those in island arc settings have primitive strontium isotopic ratios (**87Sr/86Sr of 0.702 to 0.705**) and, therefore, are **derived either from upper mantle material or recycled oceanic crust**. In contrast, ratios from intrusions associated with deposits in continental settings are generally higher.

WHAT TO LOOK FOR IN THE FIELD

1. Dykes and granitic rocks with porphyritic textures.

2. Breccia zones with angular or locally rounded fragments; look for sulphides between fragments or in fragments.

3. Epidote and chlorite alteration.

4. Quartz and sericite alteration.

5. Secondary biotite alteration - especially if partly bleached and altered.

6. Fractures coated by sulphides, or quartz veins with sulphides. To make ore, fractures must be closely spaced; generally grades are better where there are several orientations (directions).

STRUCTURAL FEATURES

Mineralization in porphyry deposits is mostly on **fractures or in alteration zones adjacent to fractures**, so ground preparation or development of a 'plumbing system' is vitally important and grades are best where the rocks are closely fractured. Porphyry-type mineral deposits result when **large amounts of hot water that carry small amounts of metals pass through permeable rocks and deposit the metals**.

Strong alteration zones develop in and around granitic rocks with related porphyry deposits. Often there is early development of a wide area of secondary biotite that gives the rock a distinctive brownish colour. Ideally, mineralized zones will have **a central area** with secondary biotite or potassium feldspar and **outward 'shells'** of cream or green quartz and sericite (phyllic), **then greenish** chlorite, epidote, sodic plagioclase and carbonate (**propylitic) alteration**. In some cases white, chalky clay (argillic) alteration occurs.

THEORY

The spectrum of characteristics of a porphyry copper deposit reflects the various influences of four main and many transient stages in the evolution of the porphyry hydrothermal system. Not all stages develop fully, nor are all the stages of equal importance.

Various **factors**, such as **magma type, volatile content, the number, size, timing and depth of emplacement of mineralizing porphyry plutons, variations in country rock composition and fracturing**, all combine to ensure a wide variety of detail. As well, **the rate of fluid mixing, density contrasts in the fluids, and pressure and temperature gradients** influence the end result. Different depths of erosion alone can produce a wide range in appearances even in the same deposit.

No single model can adequately portray the alteration and mineralization processes that have produced the wide variety of porphyry copper deposits. However, **volatile-enriched magmas emplaced in highly permeable rock are ore-forming processes** that can be described in a series of models that represent successive stages in an evolving process.

End-member models of hydrothermal regimes attempt to show contrasting conditions for systems dominated by **magmatic** (waters derived from molten rock) and **meteoric waters** (usually groundwater), respectively.

Both end-members are depicted after enough time has elapsed following emplacement for water convection cells to become established in the country rock in response to the magmatic heat source.

The convecting fluids transfer metals and other elements, and heat from the magma into the country rock and **redistribute elements in the convective system**.

The two models represent end-members of a continuum. The fundamental difference between them is the **source** and **flow path** of the hydrothermal fluids.

CONCLUSION

The search for porphyry copper deposits, especially buried ones, must be founded on detailed knowledge of their tectonic setting, geology, alteration patterns, and geochemistry. Sophisticated genetic models incorporating these features will be used to design and control future exploration

The Bingham Canyon open pit stretches for 2.5 miles across the rim and is the largest manmade excavation on Earth

CHARACTERISTICS OF US PORPHYRY-CU DEPOSITS

- Some are very large

Bingham pit from the air