

Alteration Basics

- Hydrothermal alteration is a common feature around ore bodies of hydrothermal origin and is a repetitious subject in the ore deposit literature.
- The alteration may appear to be simply a color change or it may involve major textural, mineralogical and/or chemical changes.
- The extent of the alteration may be measured in millimeters or kilometers. Some alteration assemblages are of sufficient scale and predictability that they can be used to increase the target size when exploring for new ore deposits.
- It should also be recognized that while metallization is likely to be accompanied by alteration, there are plenty of rocks in the world that are altered but are not associated with metallization.

- Wallrock alteration has been recognized for many years as a valuable tool in exploration. The alteration halos around many deposits are more widespread and much easier to locate than the ore bodies within them.

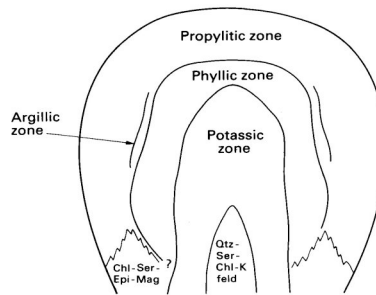
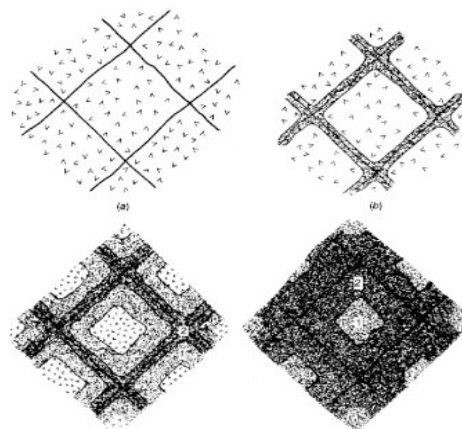


Fig. 14.4 Hydrothermal alteration zoning pattern in the Lowell-Guilbert model of porphyry copper deposits. (After Lowell & Guilbert 1970.)

- The development of sequential alteration packages or zones is analogous to metamorphic facies as they develop in response to changes in composition, temperature and pressure.
- We will start by considering 'hypogene' effects - those that are caused by ascending hydrothermal solutions. We will return to some of the 'supergene' effects caused by descending groundwater later in the context of those deposit types which have been most effected by this process.

- Most hydrothermal solutions are weakly acidic and thus react with rocks by **hydrolysis** - the addition of hydrogen ion and the removal of other cations.
- Variables: host rock
 - Composition, grain size, physical condition, permeability.
- Variables: fluid
 - Chemistry, pH, Eh, T, and P.
- Pressure gradients likely to be minor
 - (unless lithostatic to hydrostatic fluctuations are attending intermittent faulting)
- Temperature also is only likely to vary a small amount
 - (although it will likely evolve in one direction or another)
- Compositional gradients must be an important variable.

Progression of Alteration



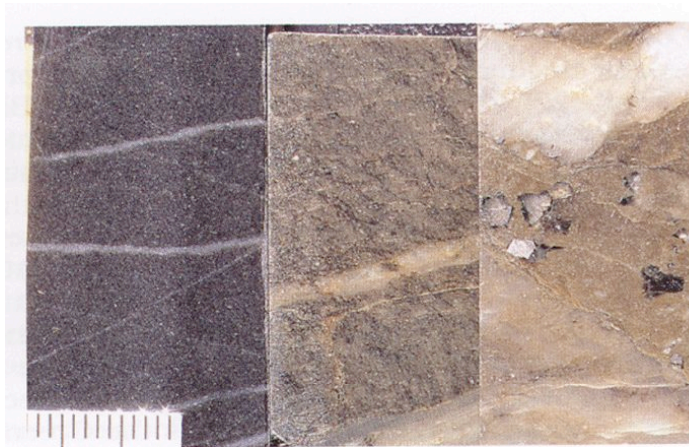


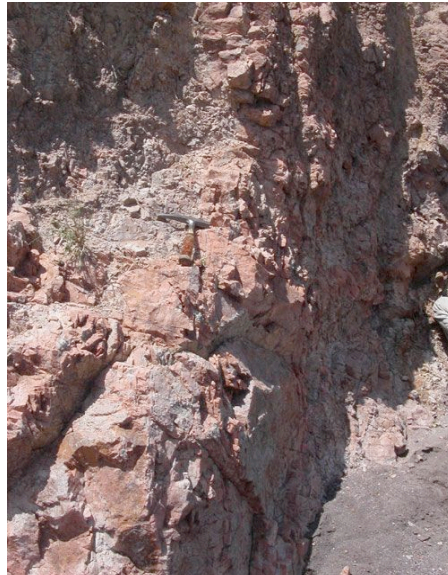
Figure 23 Left to right: distal (calcite-chlorite), intermediate (dolomite-chlorite±sericite) and proximal (dolomite-sericite) alteration in fine-grained metasedimentary rock in the Twin Peaks deposit, Edjudina, Keith-Kilkenny shear zone. No bleaching in distal zone, partial bleaching in intermediate zone, and complete bleaching in proximal zone. Note the increase in volume of veins towards ore. Yellow surface is due to initial weathering of Fe-bearing dolomite in the intermediate and



Figure 53 Abundant pyrrhotite (bronze) and arsenopyrite-loellingite (white) dissemination near mineralised quartz vein (on right) in the lower-granulite facies metasedimentary host rock at Griffin's Find. Silicates are plagioclase, quartz, diopside and hypersthene. Yellow specks are reflections of light from

Potassic

- Formation of secondary k-feldspar and/or biotite.
 - Clays are absent, minor chlorite may be present.
 - Anhydrite is often important in porphyry copper deposits.
 - Magnetite and hematite are common.
 - Sulfides are usually pyrite, molybdenite, chalcopyrite.





Sericitization (Phyllic)

- One of the most common alteration types characterized by sericite, quartz and pyrite.
 - If K is introduced, this alteration can be developed in initially low-K rock types.
 - Primary quartz in the rock is basically unchanged.
 - Shearing can lead to schistose textures.
 - At higher temperatures with development of secondary K-feldspar or biotite this grades into potassic alteration.
 - If fluorine is present topaz and zunyite may develop yielding a greisen.



Advanced Argillic

- Fairly intense alteration characterized by
 - (dickite, kaolinite) $\text{Al}_4\text{Si}_4\text{O}_{10}(\text{OH})_8$,
 - pyrophyllite $\text{Al}_2\text{Si}_4\text{O}_{10}(\text{OH})_2$ and
 - quartz with sericite, pyrite and one or more of alunite, tourmaline and topaz.
- Associated sulfides are sulfur-rich.
- Major leaching of alkalis and calcium.
- If aluminum is also leached, the advanced argillic zone can't form and silicification results.



Intermediate Argillic

- Also known in the older literature as simply argillic alteration, characterized by kaolin and montmorillonite-group minerals as alteration of plagioclase.
 - Other ‘amorphous’ clays may be present.
 - Sulfides are usually absent.
 - Montmorillonite is lower grade/intensity than kaolinite.

Propylitic

- Complex low intensity alteration characterized by chlorite, epidote, albite and carbonate.
 - Sericite, magnetite, pyrite, and zeolites may be present.
 - Commonly widely developed around ore systems - **good exploration target.**
 - If one of the main minerals is strongly developed, propylitic alteration may grade into chloritization, carbonatization, etc.

Chloritization

- Chlorite +/- quartz, tourmaline, anhydrite.
 - Chlorite may show Fe:Mg zoning with proximity to the ore. (Why?)
 - Chlorite may result from alteration of mafic minerals or introduction of Fe and/or Mg.
 - Very common surrounding plumbing of sea-floor massive sulfides.

Carbonatization

- Dolomite is the most common hydrothermal carbonate.
 - Common in carbonate rocks (introduction of Mg).
 - Ankerite common in iron-bearing silicate hosts.
 - 2 or more carbonates can occur in the same alteration zone. (Why?)
 - Think about the difference between what is added in the carbonatization of carbonate hosts versus silicate country rocks.

Silicification

- Addition of quartz, chert, or opaline silica.
 - Silica may be introduced or be the by-product of in-situ leaching of other elements (see above).
 - Commonly a good guide to mineralization.
 - Addition of silica (and other elements) to carbonates leads to the development of skarns.



Tourmalinization

- Medium to high temperature alteration.
 - Associated with many tin and gold deposits.
 - Quartz-sericite-tourmaline veins and alteration common.



Fenitization

- Associated with carbonatites (igneous carbonates).
 - Addition of ferric iron (Fe^{+3}), Na^+ and K^+ leading to growth of nepheline (NaAlSiO_4), aegirine ($\text{NaFe}^{+3}\text{Si}_2\text{O}_6$), sodic amphiboles and alkali feldspars ($(\text{Na,K})\text{AlSi}_3\text{O}_8$).

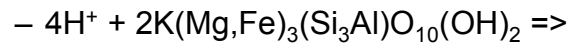
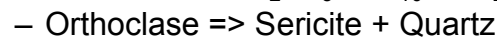
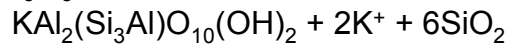


Types of Reactions-1

- **Simple Hydration:** (rare)
 - $\text{Fe}_2\text{O}_3 + \text{H}_2\text{O} \Rightarrow 2\text{FeOOH}$
- **Oxidation:**
 - $2\text{Fe}_3\text{O}_4 + \text{H}_2\text{O} \Rightarrow 3\text{Fe}_2\text{O}_3 + 2\text{H}^+ + 2\text{e}^-$
- **Reduction:**
 - $2\text{H}^+ + 6\text{HS}^- + \text{Fe}_3\text{O}_4 \Rightarrow 3\text{Fe}^{+2}\text{S}_2 + 4\text{H}_2\text{O} + 4\text{e}^-$
- **Base Exchange:**
 - $\text{Na}^+ + \text{KAlSi}_3\text{O}_8 \Rightarrow \text{NaAlSi}_3\text{O}_8 + \text{K}^+$

Types of Reactions-2

- **Hydrolysis:**



Mineralogic Manifestation?

- Acidic rocks most commonly show sericitization, argillization, silicification, pyritization.
- Intermediate and basic rocks show chloritization, carbonatization, sericitization, pyritization and propylitization.
- Carbonates show skarnification.

Alteration Assemblages - ACFK

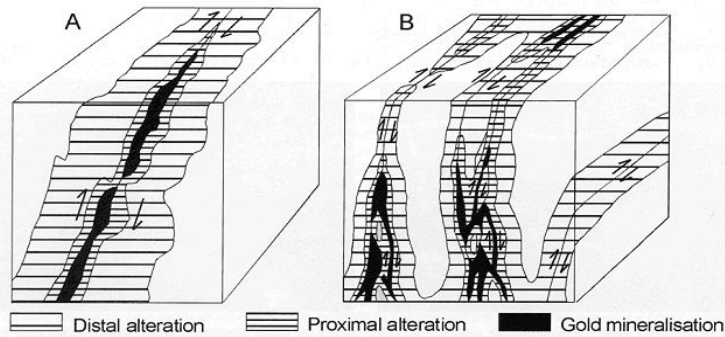
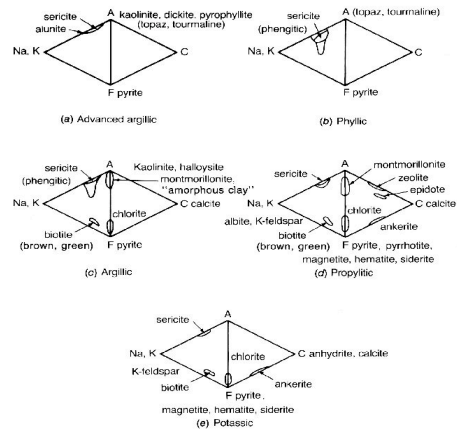


Figure 9 Extent of alteration around a lode-gold deposit. A. A simple case with one quartz vein or shear zone. B. A complex case with several subparallel veins or shear zones adjacent to each other. Based on Colvine et al. (1988), Mikucki et al. (1990) and Ridley & Barnicoat (1990).

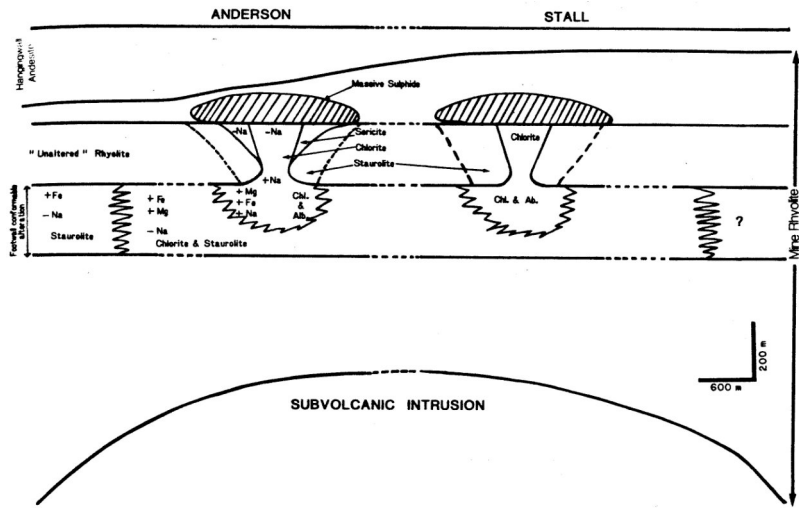
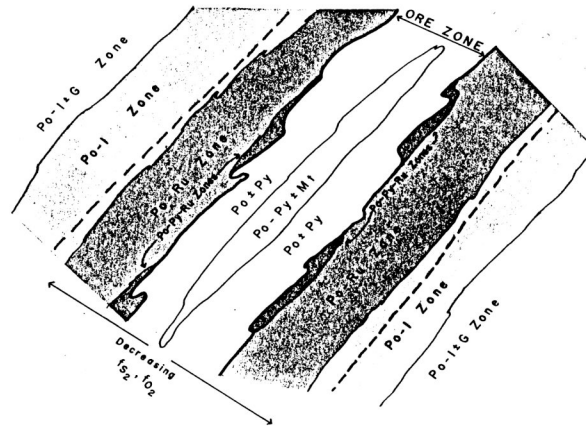
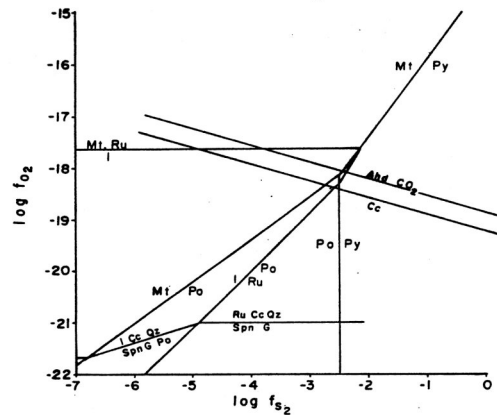


FIG. 67. Schematic reconstruction of the pipe and lower conformable alteration zones at the Anderson Lake mine, Snow Lake, Manitoba, showing the principal mineralogical and chemical characteristics. (After Walford and Franklin, in press.)

Ducktown: Zoning



Ducktown: 550°, 6kb

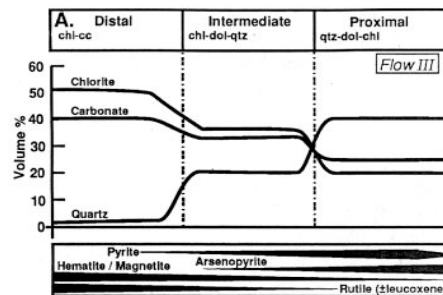


Zoning

- The study of the systematics of internal ore-deposit variation is the study of zoning, defined as the spatial distribution patterns of major or trace elements, mineral species, mineral assemblages, or textures in ore deposits
 - Ore deposit zoning can extend from veinlet, to vein systems, to single ore shoots and to regional scale zoning.
 - Zoning may be obvious as with the dramatic changes in mineral species and assemblages:
 - assemblage zoning
 - mineral zoning or phases zoning

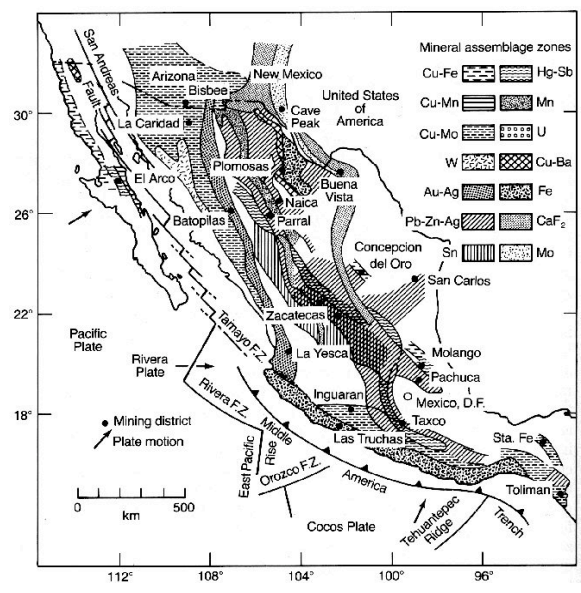
Zoning (cont)

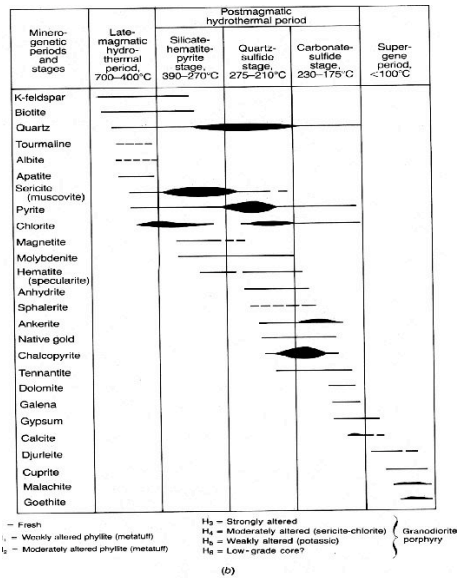
- or it may take the form of minor chemical changes that are invisible to the eye
 - cryptic zoning or chemical zoning
- or it may take the form of changes in the texture of a rock or vein
 - textural zoning
- Overall zoning deals with arrays of ore deposit components and characteristics in three dimensions



A.

FLOW III	Least altered	Distal		Intermediate		Proximal	
		Wallrock/Vein	Vein/lets	Wallrock/Vein	Vein/matrix	Wallrock/Vein	Vein/matrix
SILICATES							
Clinopyroxene							
Amphibole							
- Actinolite							
Olivine							
Epidote							
Plagioclase							
Albite An<1							
Quartz							
Chalcedony							
Chlorite							
Brunsvigite							
Sericite							
CARBONATES							
Dolomite							
Ankerite							
Calcite							
OXIDES							
Hematite							
Magnetite							
Ilmenite							
Rutile							
(=Leucocoxene)							
Titanite							
TUNGSTATES							
PHOSPHATES							
Scheelite							
Apatite							
SULFIDES							
Pyrite							
Arsenopyrite							
Chalcopyrite							
Gersdorffite							
Chalcostibnite							
ELEMENTS							
Gold							
Graphite							



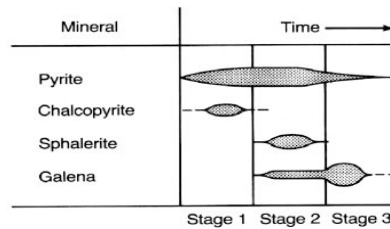


Paragenesis

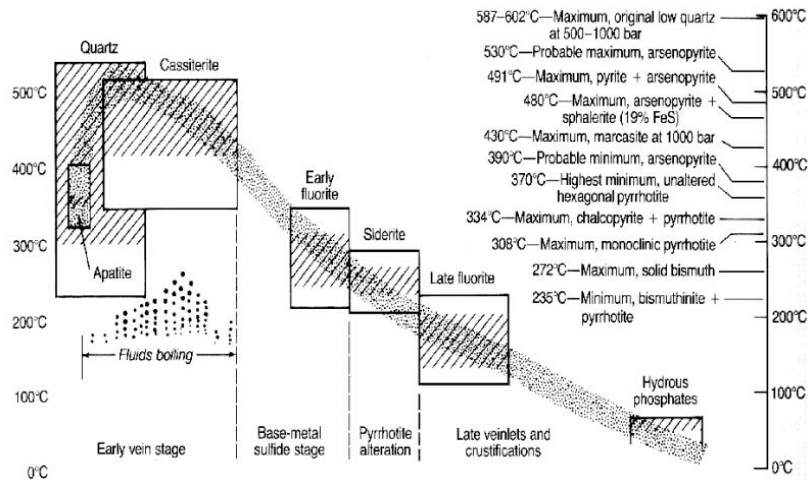
- Paragenesis is used to describe any assemblage of ore minerals with or without gangue, formed at the same time and normally in equilibrium
 - temporal changes in a volume of rock undergoing mineralization can result in different apparent timing of mineral assemblages from place to place in an ore body or a district.
 - the chronological order of mineral deposition - the sequence of deposition of minerals, or assemblages - in a rock or ore deposit is known as the paragenetic sequence of a deposit, and again variations in the spatial distribution of paragenesis is known as zoning

Simple Paragenesis

- Paragenesis is determined by mineral studies that commonly focus upon microscopic textural features, but that can and should include megascopic features visible in outcrop or core, such as crosscutting, offsetting vein types with different mineralization or alteration complements. Zoning patterns are manifested by changes along both vertical and horizontal traverses of mineralized areas.



- Ore-bearing fluid gradually changes as it migrates from its source.
- Typically it reacts with the wallrocks, and its chemical composition, Eh, pH, sulfur fugacity, and other properties change as it travels into regions of lower fluid pressure and loses heat to cooler country rocks.
- As these physical and chemical changes take place, the solubility products of the ore and gangue minerals are reached, and they can be sequentially deposited. They thus can leave a detailed record in time and space of the evolutionary trends in an ore-forming solution.



General order of deposition

- General paragenetic sequences have been established for hydrothermal deposits.
 1. silicates
 2. magnetite, ilmenite, hematite
 3. cassiterite, wolframite, molybdenite
 4. pyrrhotite, loellingite, arsenopyrite, pyrite, cobalt and nickel arsenides
 5. chalcopyrite, bornite, sphalerite
 6. galena, tetrahedrite, lead sulphosalts, tellurides, cinnabar