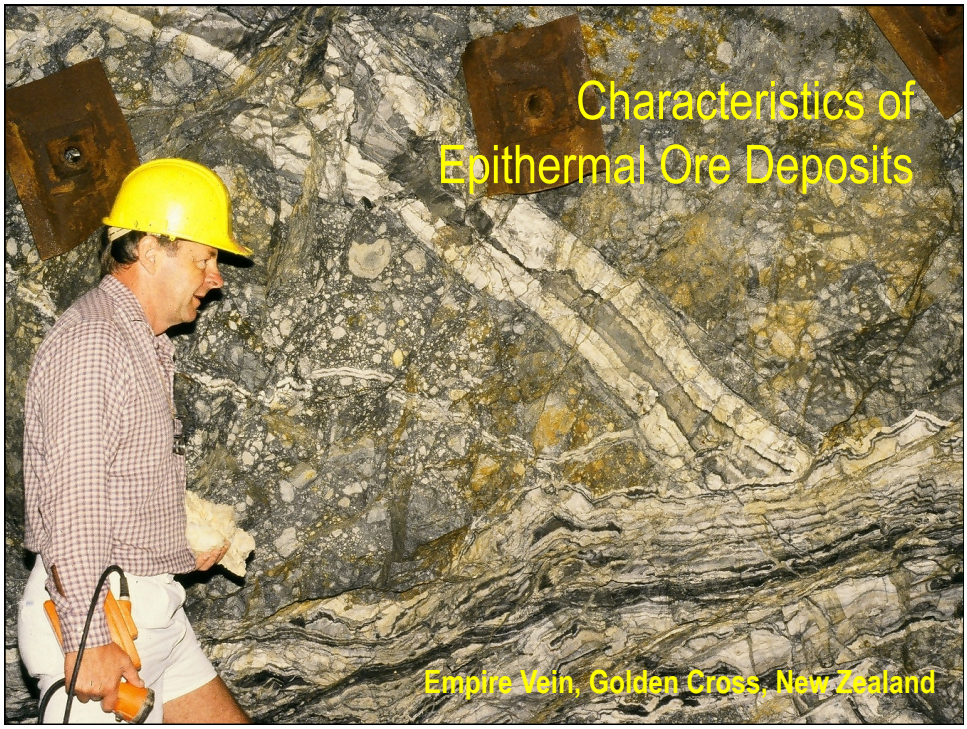


Epithermal Deposits: Summary Characteristics

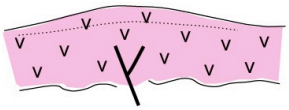
Metals	Au, Ag (Hg, Cu, Pb, Zn, Sn)	
Ore bodies	veins, stockwork, breccias, disseminations	
Dimensions	horizontal	<500 to ~2000 m
	vertical	<500 m
Grades	Au 2 to >100 g/t	
	Ag 100 to > 500 g/t	
Global	~6% of gold	
	16% of silver	(Singer, 1995)

Epithermal Deposits-Summary Characteristics

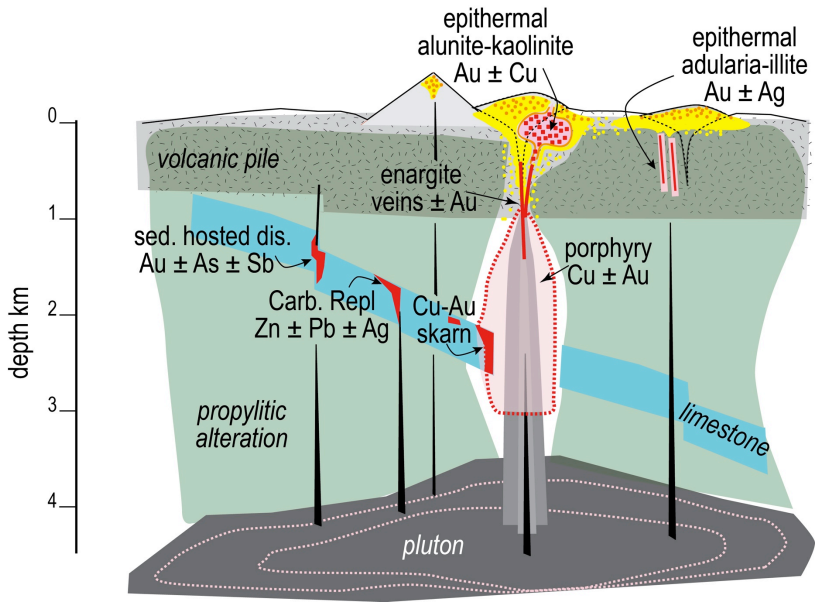
Host rocks	andesite to rhyolite (basalt) volcanic "basement"
Exploration	commonly blind zoned alteration patterns structure (paleo-permeability)
Environment	<300° C, <1 km depth boiling (mixing?)

volcanic rocks

basement



Intrusion-related hydrothermal ore deposits



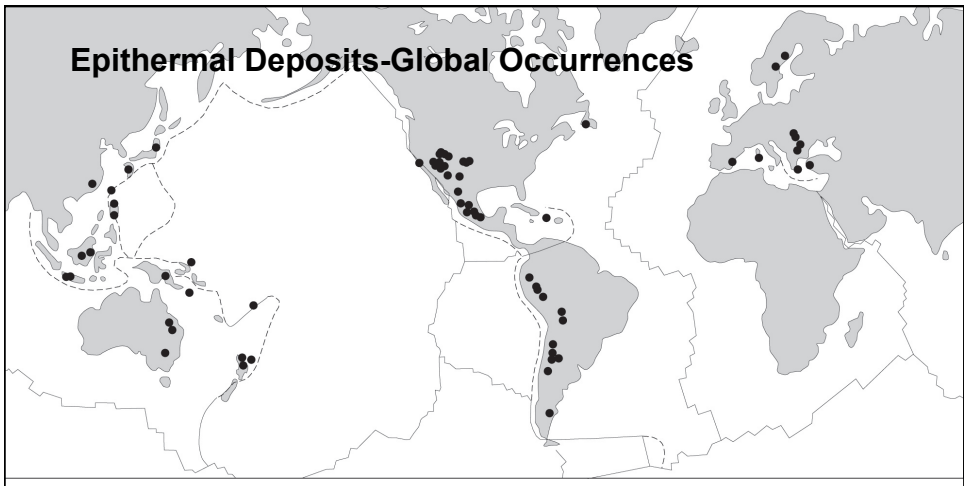
Modified from Sillitoe, 2010

The term “epithermal” was defined by Lindgren (1933) based on *observations* of

- mineralogy of ores and alteration
- textures of ores and alteration

and *inferences* about

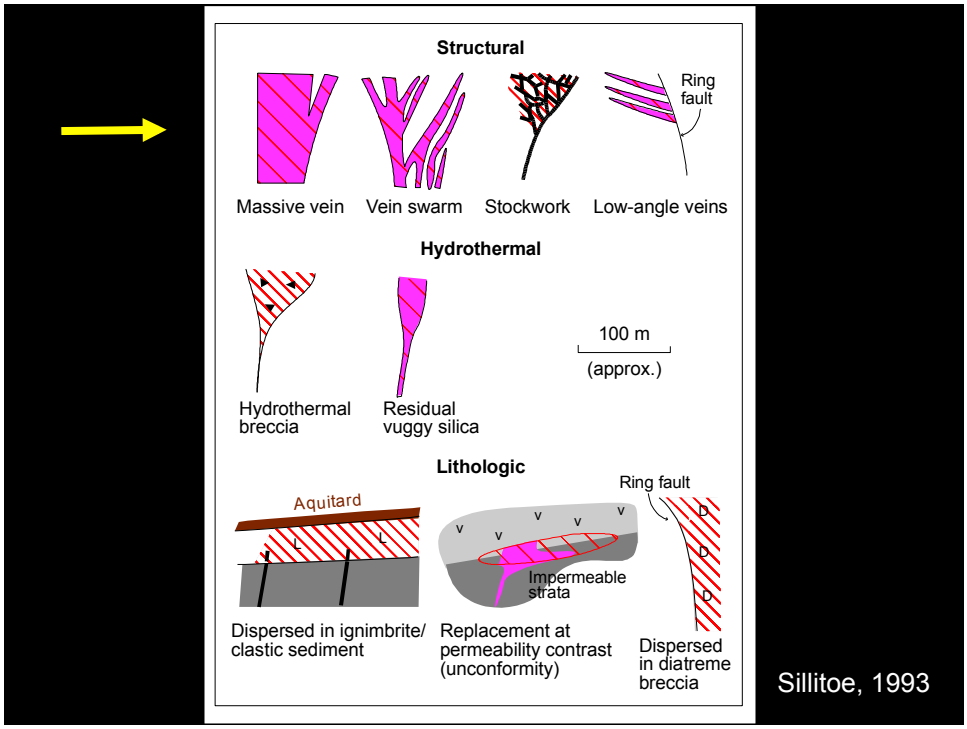
- temperature of deposition
- depth of formation

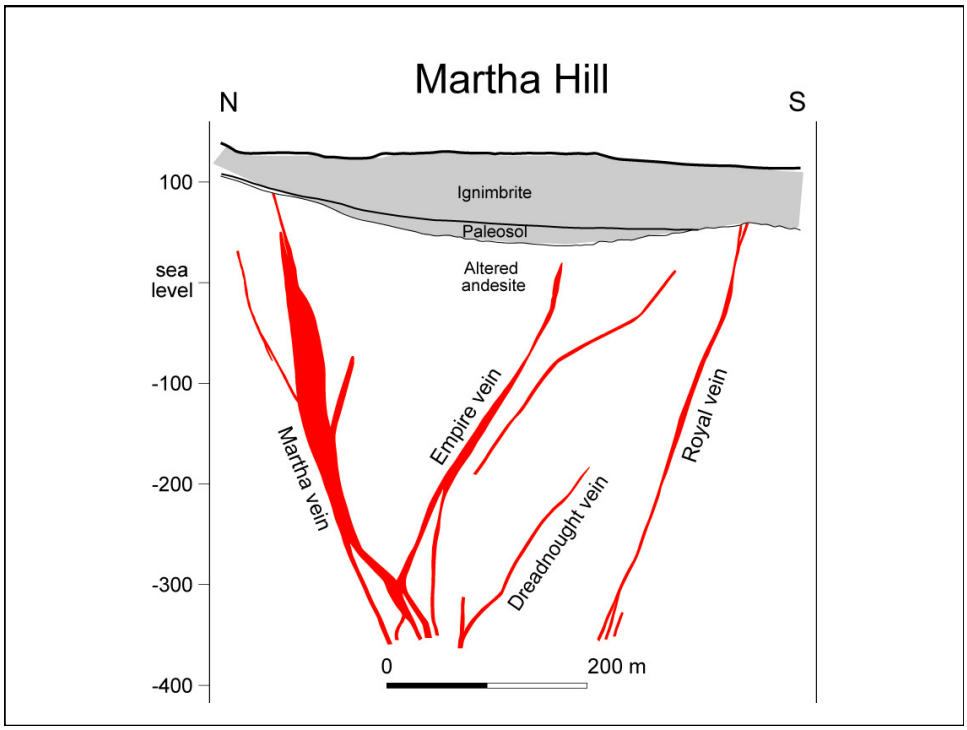


•epithemal deposits occur in isolation or clustered in provinces and metallogenic belts

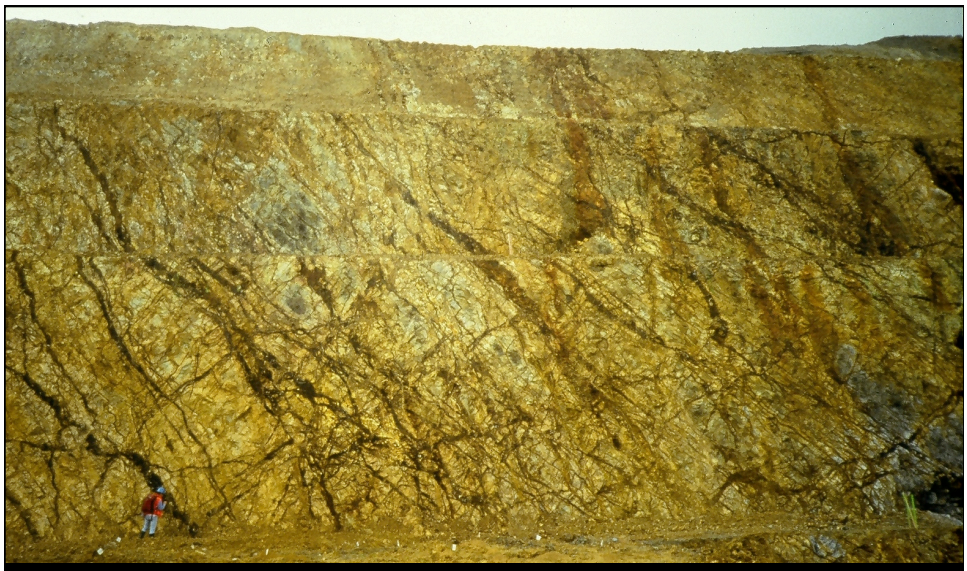
•they are associated with convergent plate boundaries-arcs and post-collisional belts in neutral to extensional stress regimes

•generally Tertiary and younger, but older examples known (some significant)


Structural
Ring fault
Massive vein
Vein swarm
Stockwork
Low-angle veins
Hydrothermal
100 m
(approx.)
Hydrothermal breccia
Residual vuggy silica
Lithologic
Ring fault
Aquitard
Impermeable strata
Dispersed in ignimbrite/ clastic sediment
Replacement at permeability contrast (unconformity)
Dispersed in diatreme breccia
Sillitoe, 1993

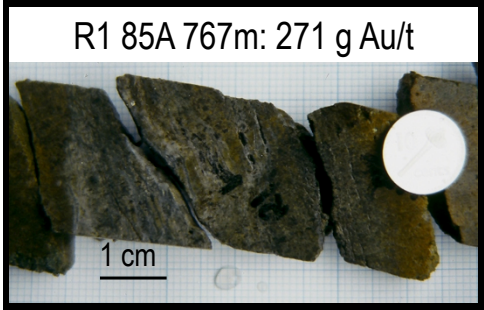

Martha Hill
N
S
100
sea level
-100
-200
-300
-400
Ignimbrite
Paleosol
Altered andesite
Martha vein
Empire vein
Dreadnought vein
Royal vein
0
200 m

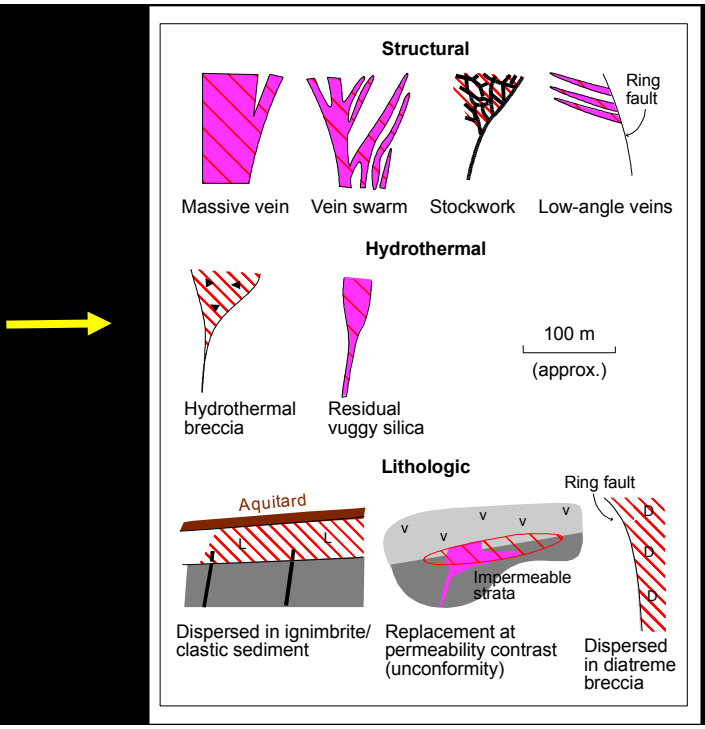
Martha Hill, NZ



Golden Cross, NZ

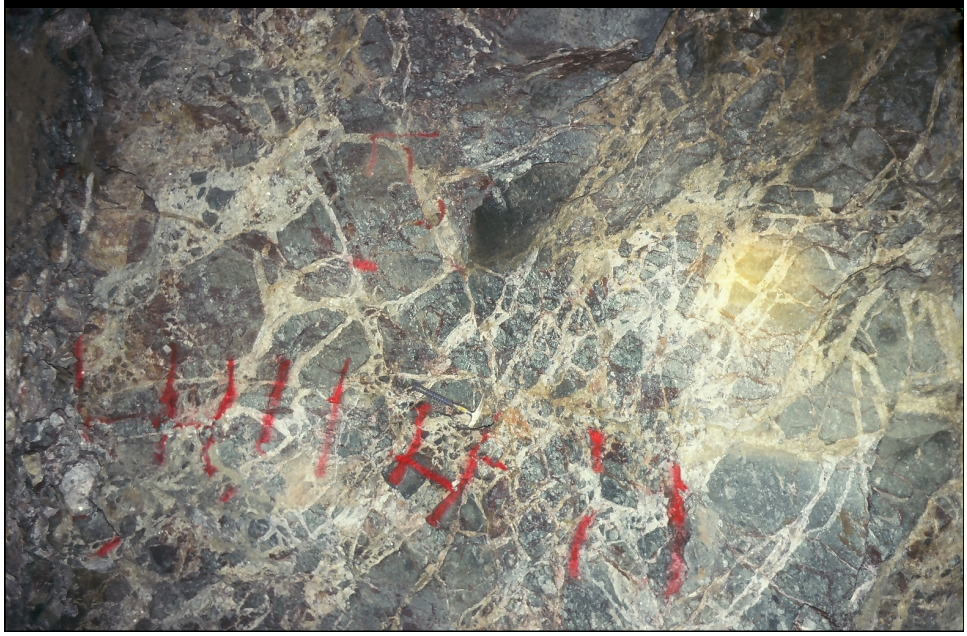
Emperor, Fiji



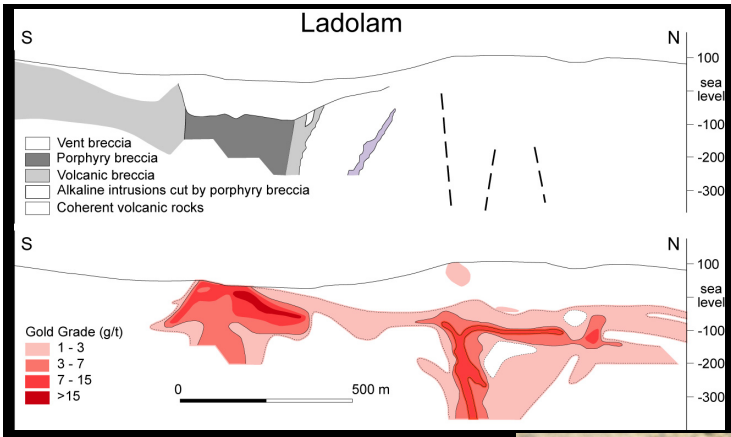


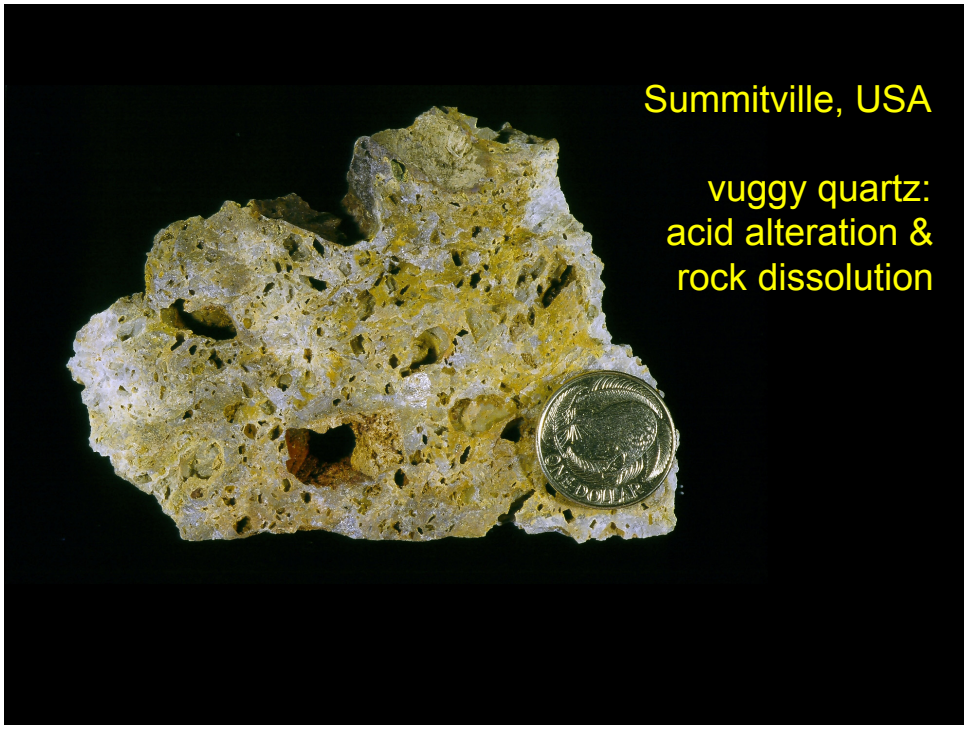
Sillitoe, 1993

Los Torres, Guanajuato



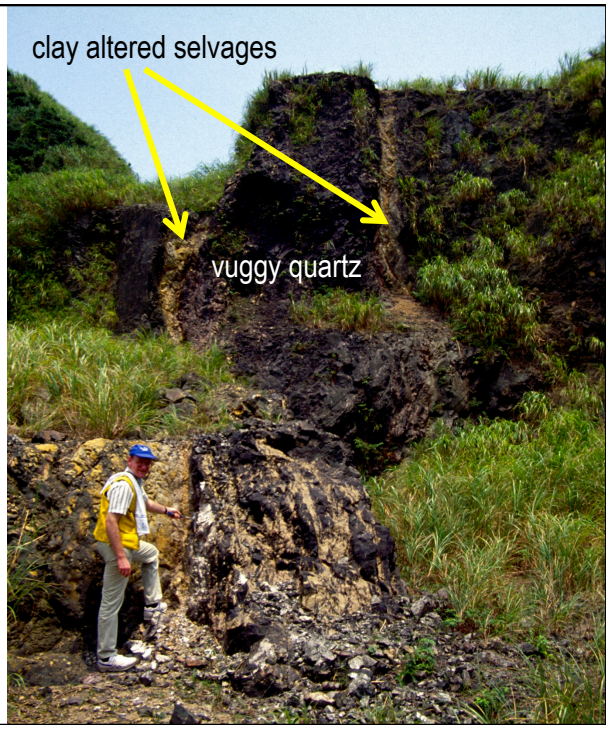
Lihir, PNG

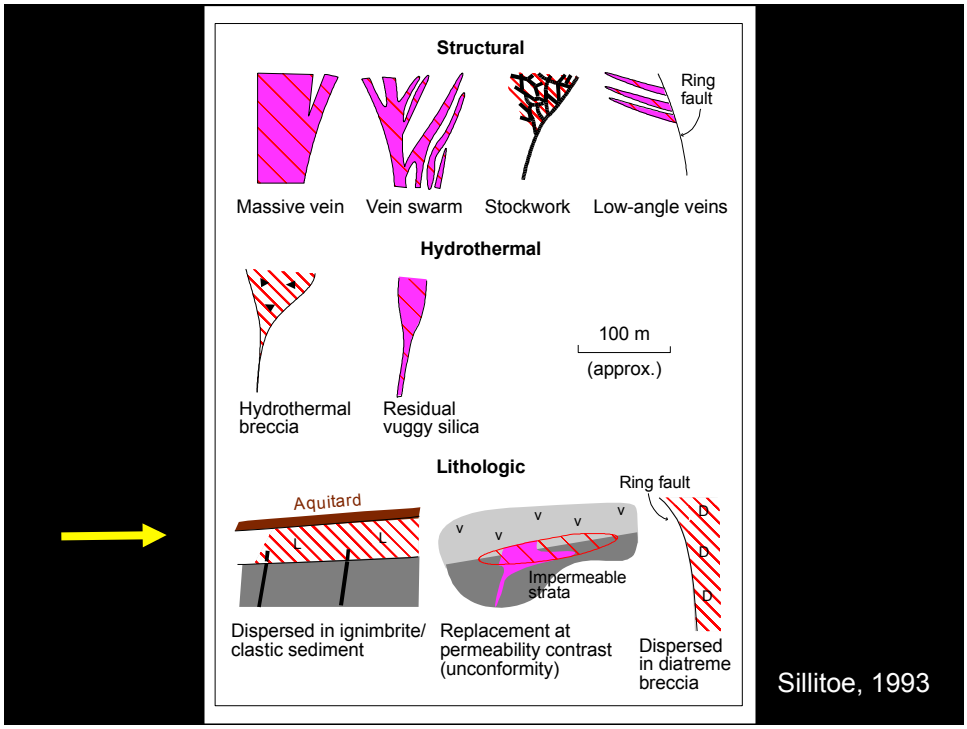




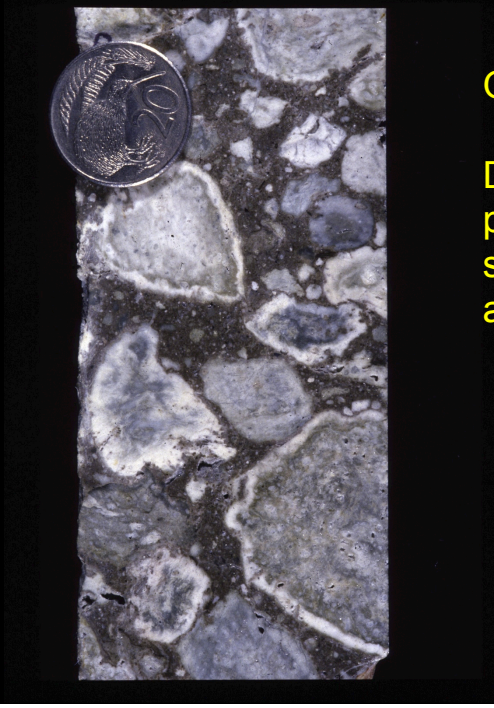
Chinkhuashih, Taiwan

Au-bearing vuggy quartz in structurally in structurally controlled zone with well defined alteration selvage





Sillitoe, 1993



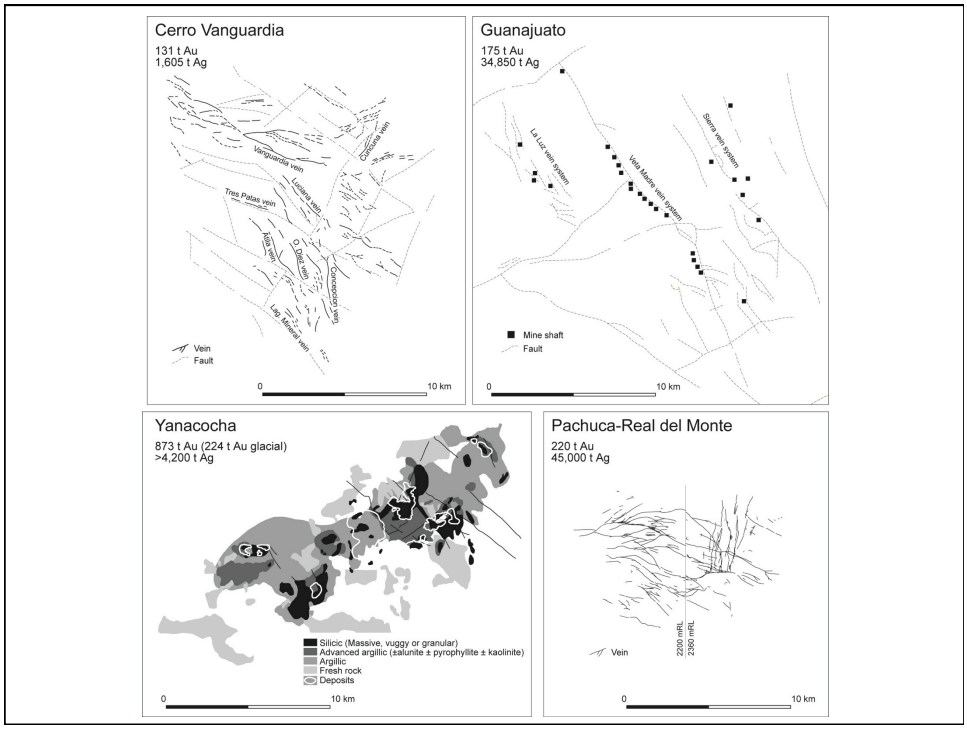
Ohakuri, NZ

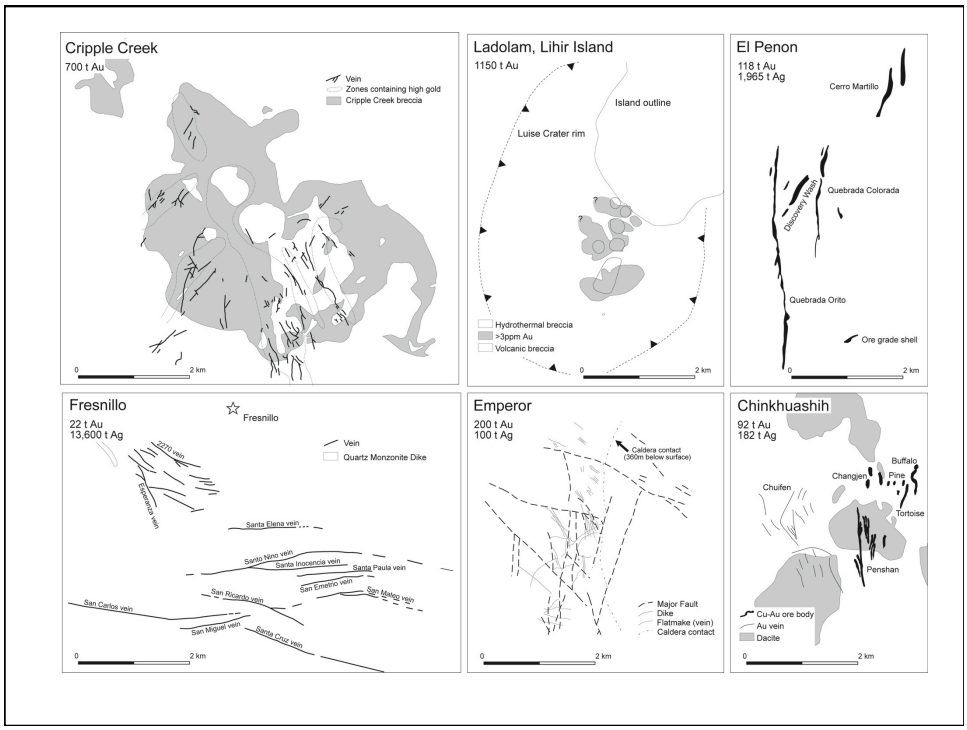
Disseminated Au in pumice breccia-silicified and adularia-bearing

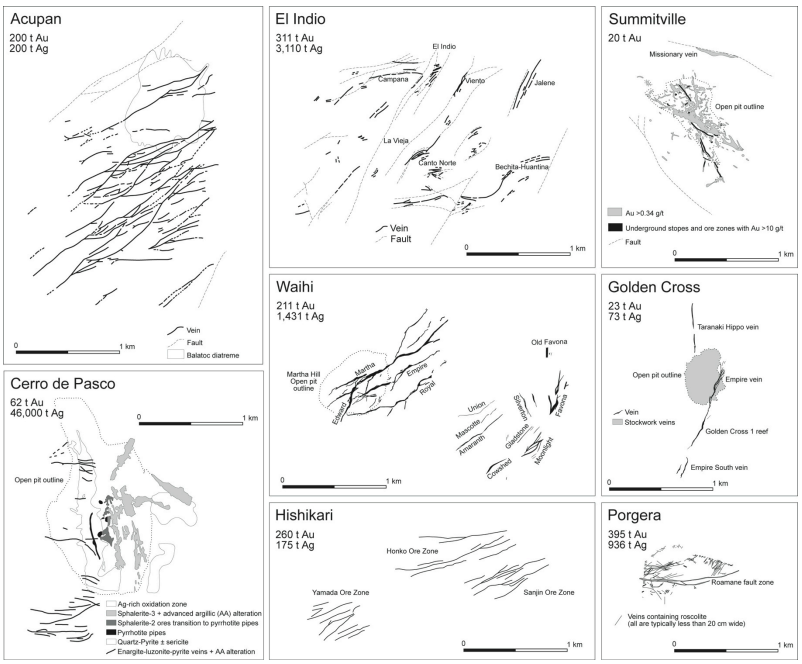
Plan views of epithermal districts from around the world.

Note:

- dimensions of districts (wide variation)
- diverse geometry of ore bodies
- no correlation between resource and district size


Cerro Vanguardia
131 t Au
1,605 t Ag
Vanguardia vein
Cristina vein
Tres Patas vein
Luciana vein
Aqua vein
O Diaz vein
Concordia vein
Las Mercedes vein
Vein
Fault
0
10 km
Guanajuato
175 t Au
34,850 t Ag
La Luz vein system
Veta Madre vein system
Sierra vein system
Mine shaft
Fault
0
10 km
Yanacocha
873 t Au (224 t Au glacial)
>4,200 t Ag
Silicic (Massive, vuggy or granular)
Advanced argillic (±alunite ± pyrophyllite ± kaolinite)
Argillic
Fresh rock
Deposits
0
10 km
Pachuca-Real del Monte
220 t Au
45,000 t Ag
2200 mRL
2300 mRL
Vein
0
10 km


Cripple Creek
700 t Au
Vein
Zones containing high gold
Cripple Creek breccia
0
2 km
Ladolam, Lihir Island
1150 t Au
Island outline
Luise Crater rim
Hydrothermal breccia
>3ppm Au
Volcanic breccia
0
2 km
El Penon
118 t Au
1,965 t Ag
Cerro Martillo
Quebrada Colorada
Discovery Vein
Quebrada Orito
Ore grade shell
0
2 km
Fresnillo
22 t Au
13,600 t Ag
Fresnillo
Vein
Quartz Monzonite Dike
2270 vein
Esperanza vein
Santa Elena vein
Santo Nino vein
Santa Inocencia vein
Santa Paula vein
San Ricardo vein
San Ernesto vein
San Mateo vein
San Carlos vein
San Miguel vein
Santa Cruz vein
0
2 km
Emperor
200 t Au
100 t Ag
Caldera contact
(950m below surface)
Major Fault
Dike
Flatmake (vein)
Caldera contact
0
2 km
Chinkhuashih
92 t Au
182 t Ag
Buffalo
Changjen
Pine
Chuifen
Tortoise
Penshan
Cu-Au ore body
Au vein
Dacite
0
2 km



Ore bodies terminate upward

Blind mineralization

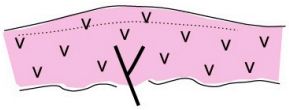
Hishikari, Japan
Veins hosted in Shimanto Group metasediments & overlying andesitic volcanic rocks

Epithermal Deposits: Common Characteristics

Ore bodies	zones of paleo-permeability <10 to >100 km^2 limited vertical extent-commonly blind zoned alteration patterns
Environment	<300° C, <1 km depth boiling (mixing?)
Host rocks	volcanic rocks (mafic to felsic) "basement"

volcanic rocks

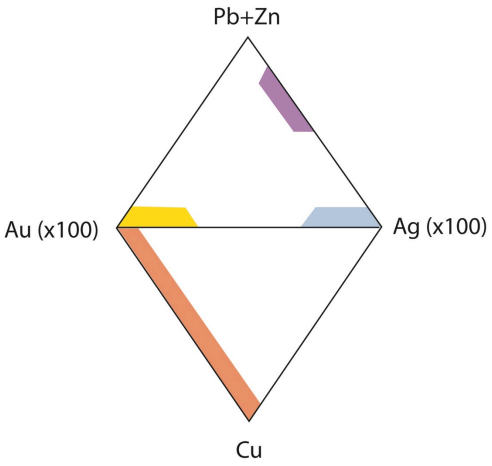
basement



Epithermal Deposits: Diverse Characteristics

Metals	Au, Ag (Hg, Sb, Cu, Pb, Zn, Sn)
Sulfide Minerals	variable concentration (nil to high) low & intermediate sulfidation intermediate & high sulfidation
Gangue Minerals	Quartz-Calcite-Adularia-Illite Quartz-Alunite-Kaolinite-Pyrophyllite
Fluids	neutral and acid pH dilute and saline meteoric and magmatic
Magmas	mafic, intermediate, and felsic

Diverse Metal Contents:
Au, Ag (Hg, Cu, Pb, Zn, Sn)



Classification of sub-types

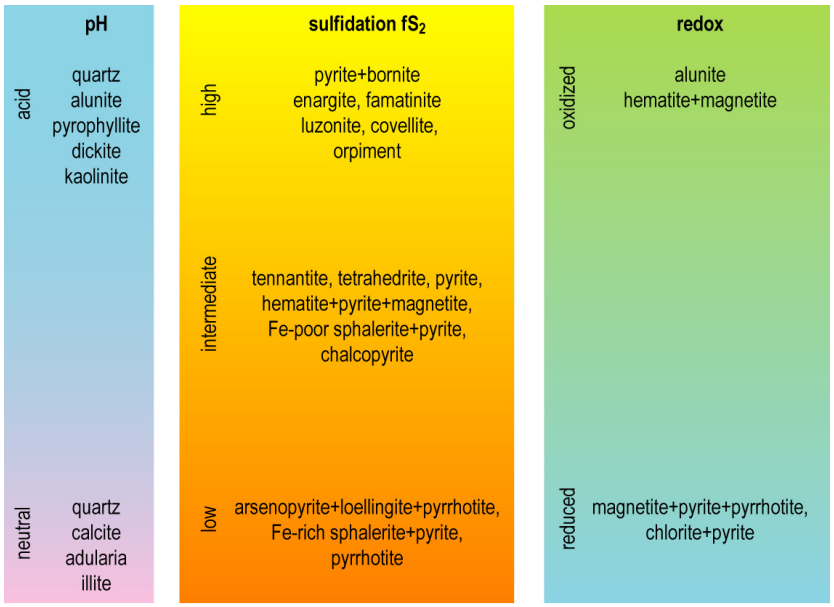
- there are two major sub-types of epithermal deposits
- different names have been used for them:

Low sulfur/high sulfur – Bonham, 1986
Low sulfidation/high sulfidation – White & Hedenquist, 1990
Adularia-sericite/acid sulfate – Heald *et al.*, 1987
Adularia-sericite/kaolinite-alunite – Berger and Henley, 1989
Low, intermediate & high sulfidation –
Einaudi et al. 2003, Sillitoe & Hedenquist, 2003

sulfidation state: refers to fS_2 and the stability of sulfide minerals

Lindgren recognized diversity among epithermal deposits and originally classified 9 sub-types.

Epithermal Indicator Minerals: Chemical Conditions



Two sub-types based on common gangue minerals

Quartz + Alunite ± Pyrophyllite ± Dickite ± Kaolinite

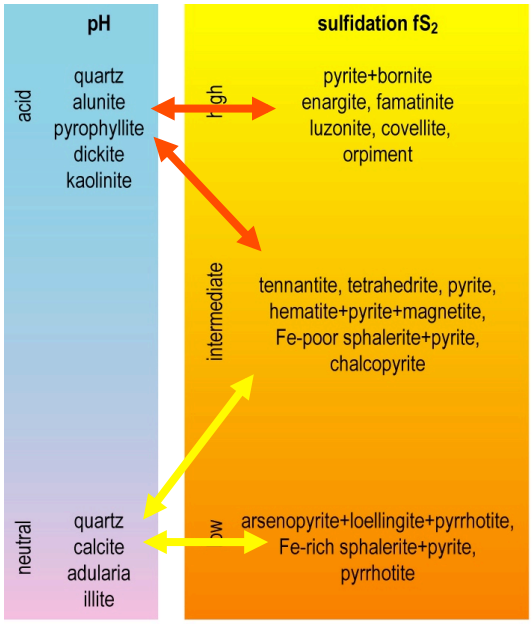
Indicates: Acid pH -- oxidizing conditions (H_2SO_4)

Quartz ± Calcite ± Adularia ± Illite

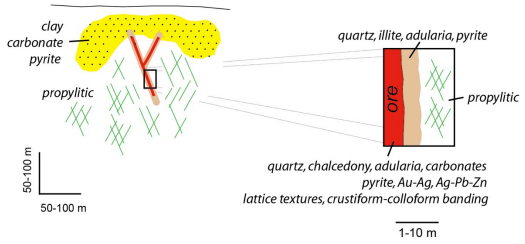
Indicates: Neutral pH -- reducing conditions (H_2S)

Follows classification scheme proposed by Hedenquist, 1987 and White & Hedenquist, (1990, 1995)

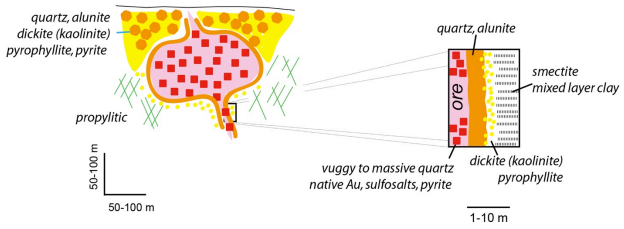
Hybrid terminology combining gangue & sulfide mineralogy



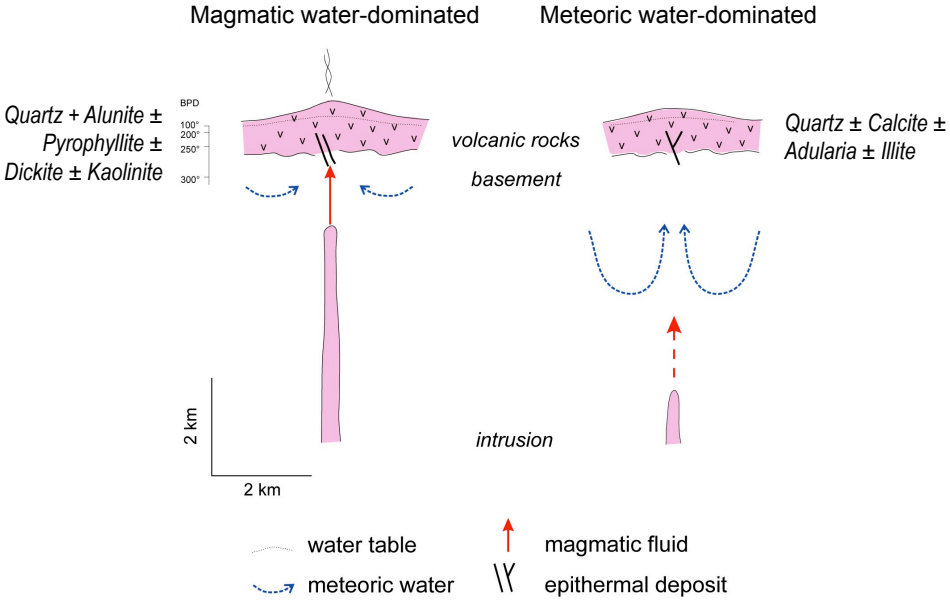
Quartz ± Calcite ± Adularia ± Illite *(intermediate to low sulfidation)*



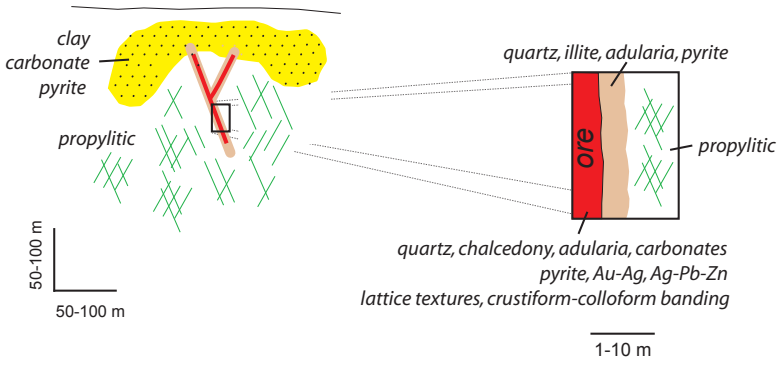
Quartz + Alunite ± Pyrophyllite ± Dickite ± Kaolinite *(high to intermediate sulfidation)*



Hydrothermal systems hosting epithermal environments



Quartz ± Calcite ± Adularia ± Illite *(intermediate to low sulfidation)*

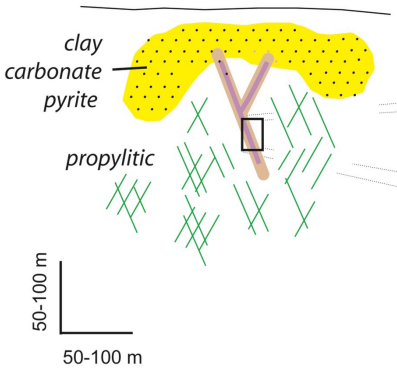


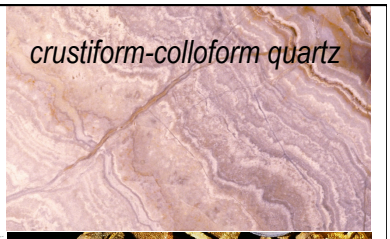
Examples

Hishikari, Japan
Acupan, Philippines
Martha Hill, New Zealand
Cerro Vanguardia, Argentina

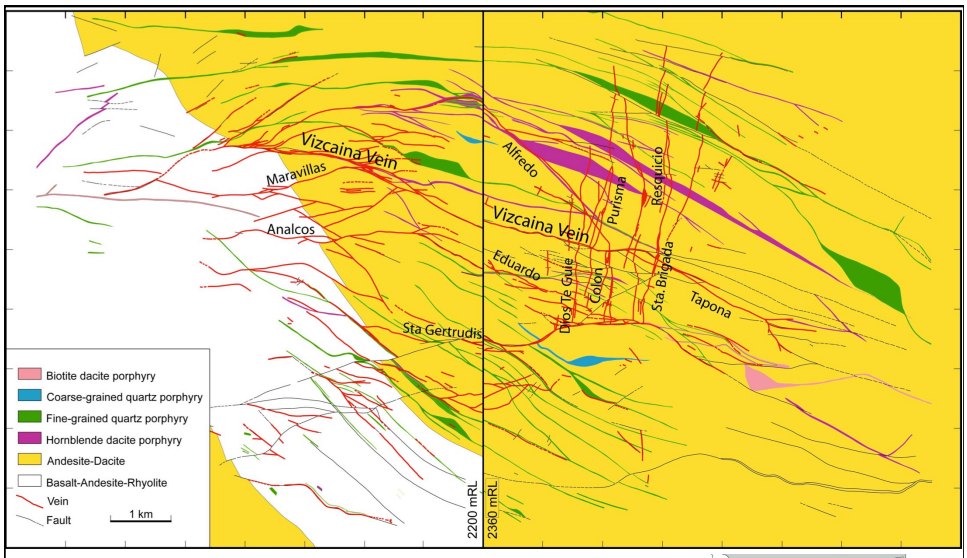
Round Mtn, USA
Fresnillo, Mexico
El Peñon, Chile
Pajingo, Australia

Quartz ± Calcite ± Adularia ± Illite

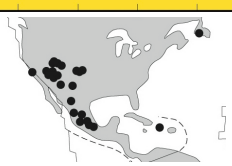




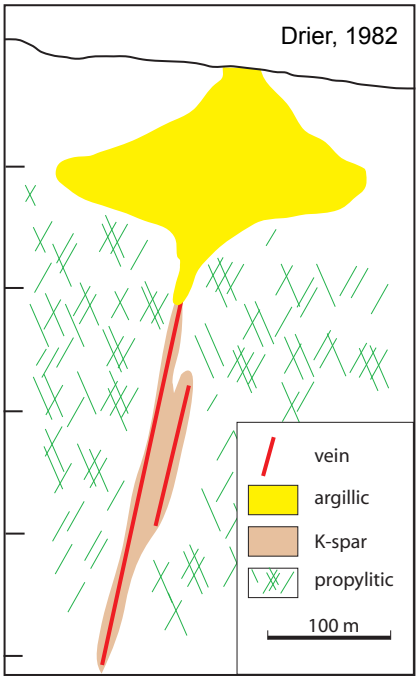
Ore textures-minerals



Pachuca-Real del Monte, Mexico;
quartz-adularia-sulfide Ag-Au ores



Pachuca-Real del Monte: Vizcaína Vein Surface Expression



Pachuca, Mexico

Blind epithermal quartz-adularia veins capped by argillic alteration

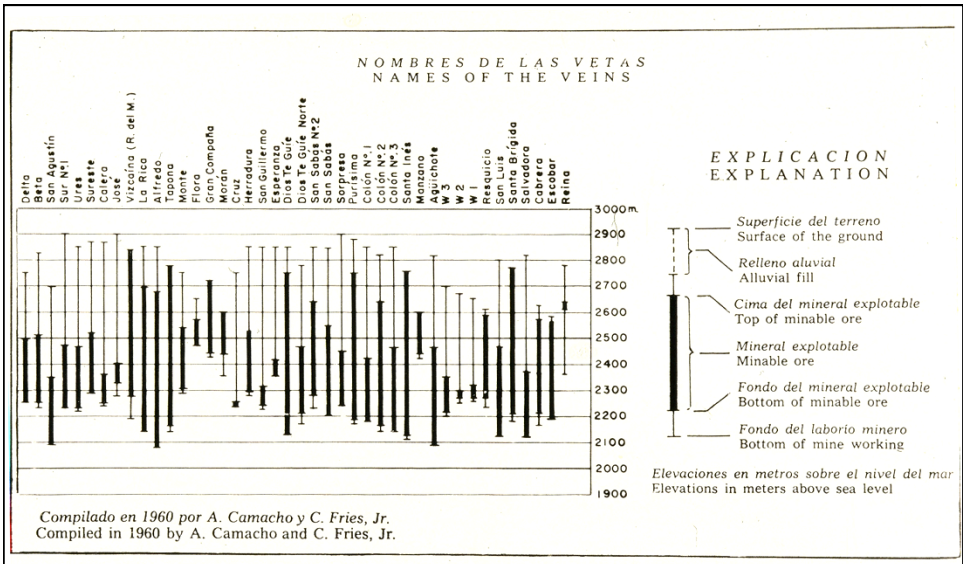


FIGURE 38. *Diagram showing the vertical productive ranges of most of the veins in the Pachuca-Real del Monte district.*

Variable depth intervals of vein ores Pachuca-Real del Monte, Mexico (Geyne et al. 1963)

Digression: Alkalic sub-type

Emperor, Fiji *Cripple Creek, USA*
Porgera, PNG *Ladolam, PNG*

Tellurides common (not always, e.g. Ladolam)

Intense K-feldspar (adularia) alteration

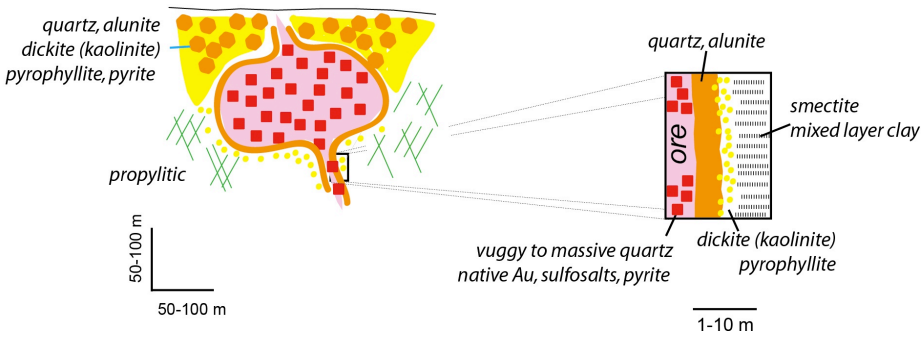
Subordinate quartz (e.g., narrow veins, Emperor)

Magmatic water isotopic signature

High grade ores; world-class deposits (only 4)


Emperor, Fiji

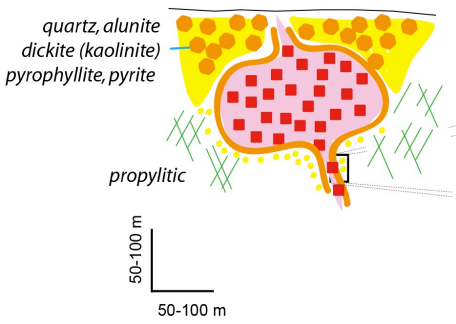
Quartz + Alunite ± Pyrophyllite ± Dickite ± Kaolinite



Examples

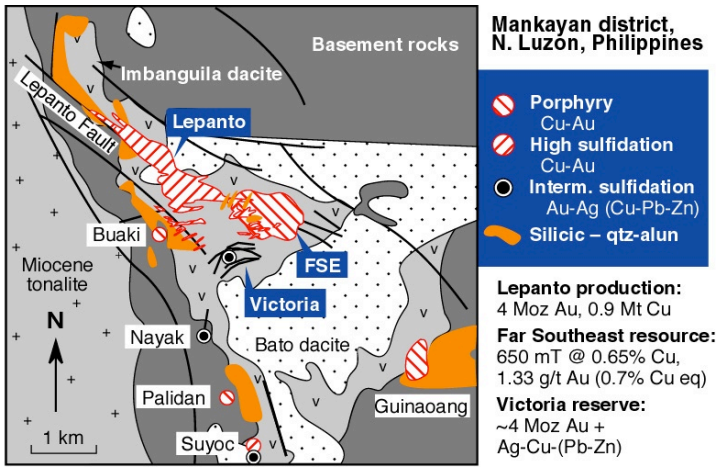
Nansatsu, Japan	Summitville, USA
Lepanto, Philippines	Chinkhuashih, Taiwan
Yanacocha, Peru	El Indio, Chile
La Mejicana, Argentina	Pascua-Lama, Chile-Argentina

Quartz + Alunite ± Pyrophyllite ± Dickite ± Kaolinite



Ore textures-minerals

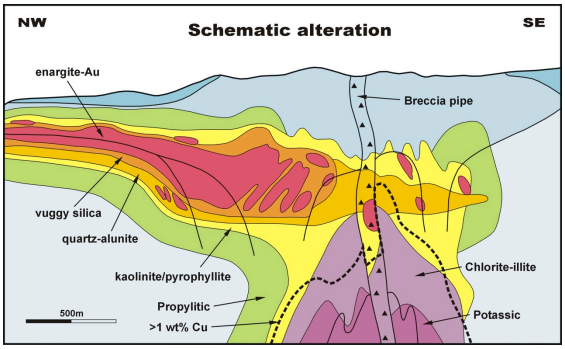
Lepanto-Philippines (Cu-Au)

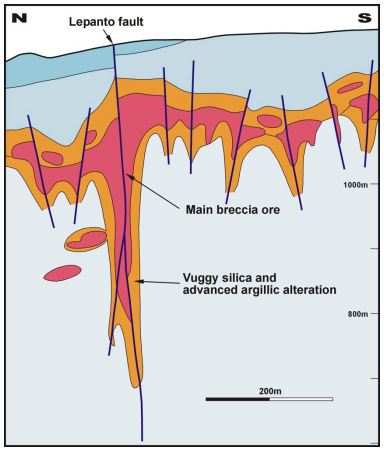


Hedenquist et al. 1998; 2001 (Pro Explo Abstract)

Co-temporal (1.4 to 1.1 Ma)

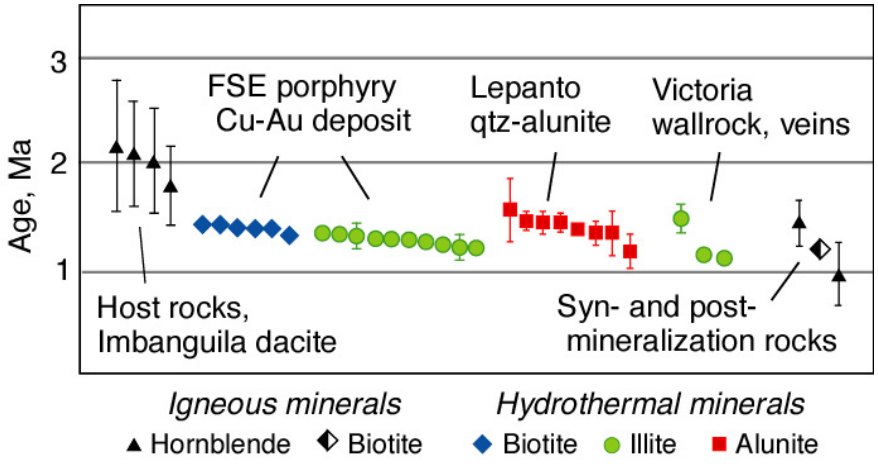
Lepanto, Philippines





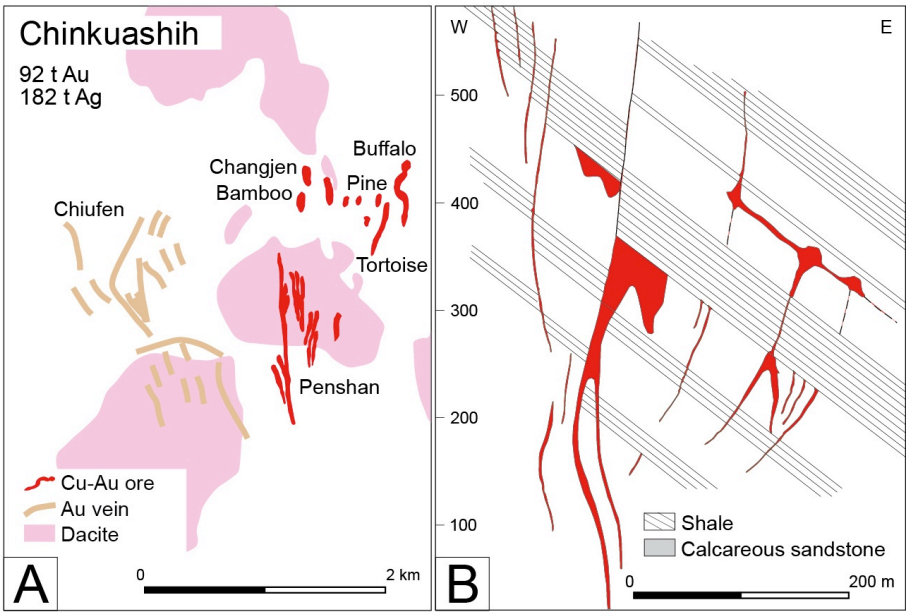
Arribas et al., 1995; Hedenquist et al. 1998

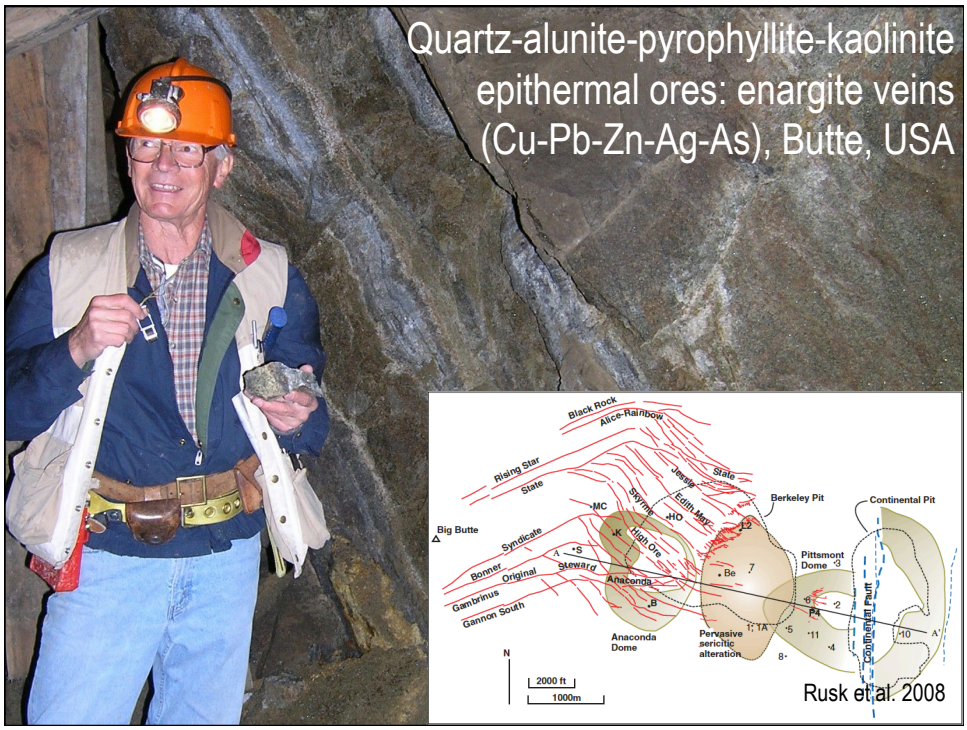
Lepanto, Philippines

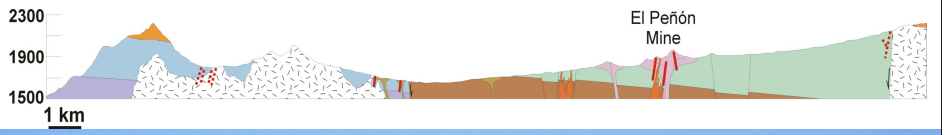


Arribas et al., 1995; Hedenquist et al. 1998; 2001 (Pro Explo Abstract)

Chinkhuashih, Taiwan

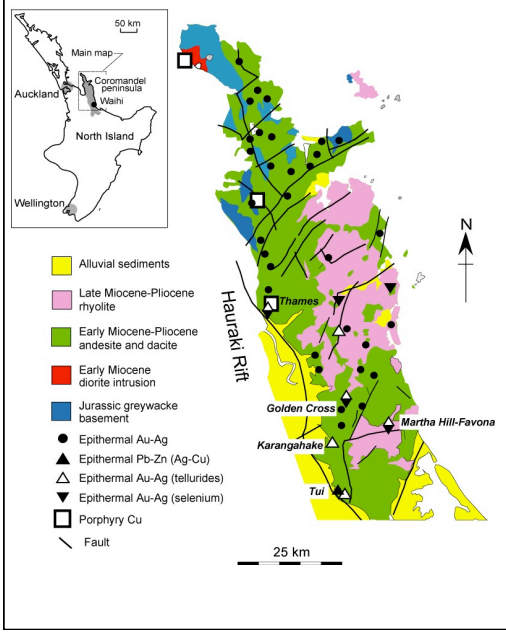




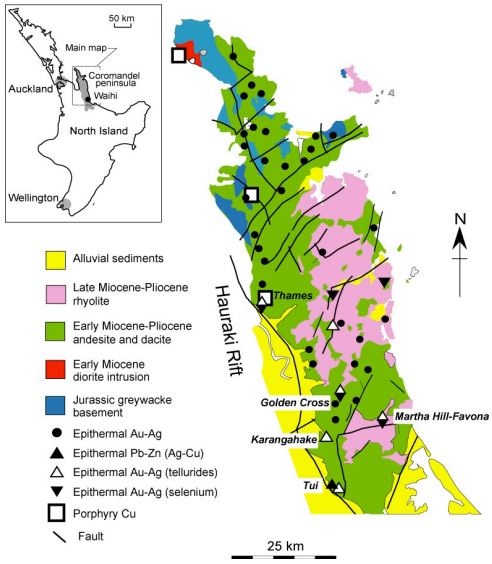


Coexisting quartz-alunite-pyrophyllite and quartz-calcite-adularia epithermal mineralization styles rarely occur in the same deposit: Examples include: Lepanto, Baguio District, Chinkhuashih, and El Peñon (shown below with barren quartz-alunite alteration in foreground).

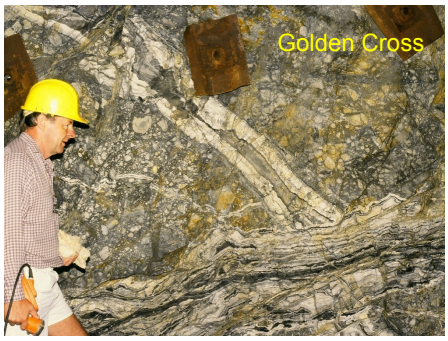
Coromandel epithermal province, New Zealand



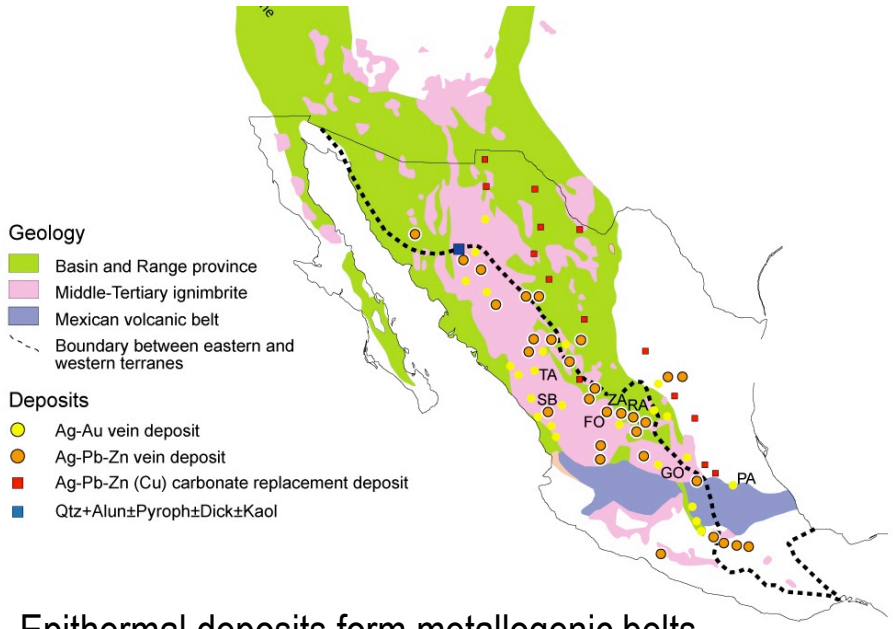
Coromandel epithermal province, New Zealand



Martha Hill	Au-Ag
Karangahake	Au-Ag
Golden Cross	Au-Ag
Thames	Au-Te
Tui	Pb-Zn



Guanajuato, Mexico—Spanish colonial city

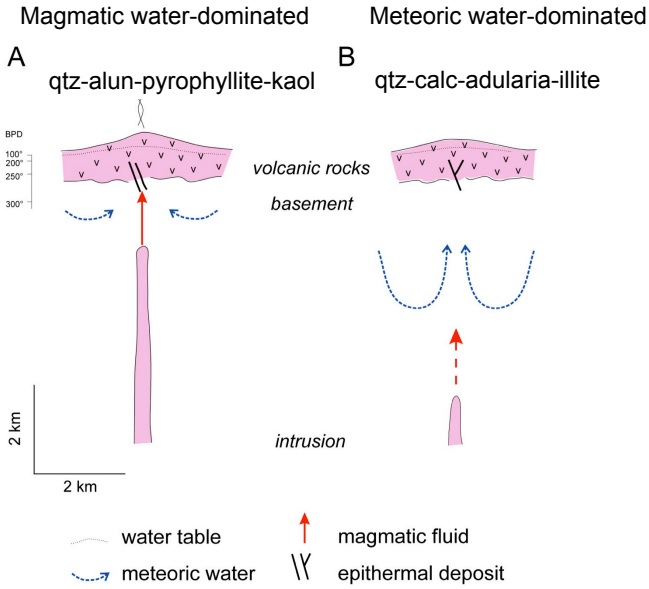


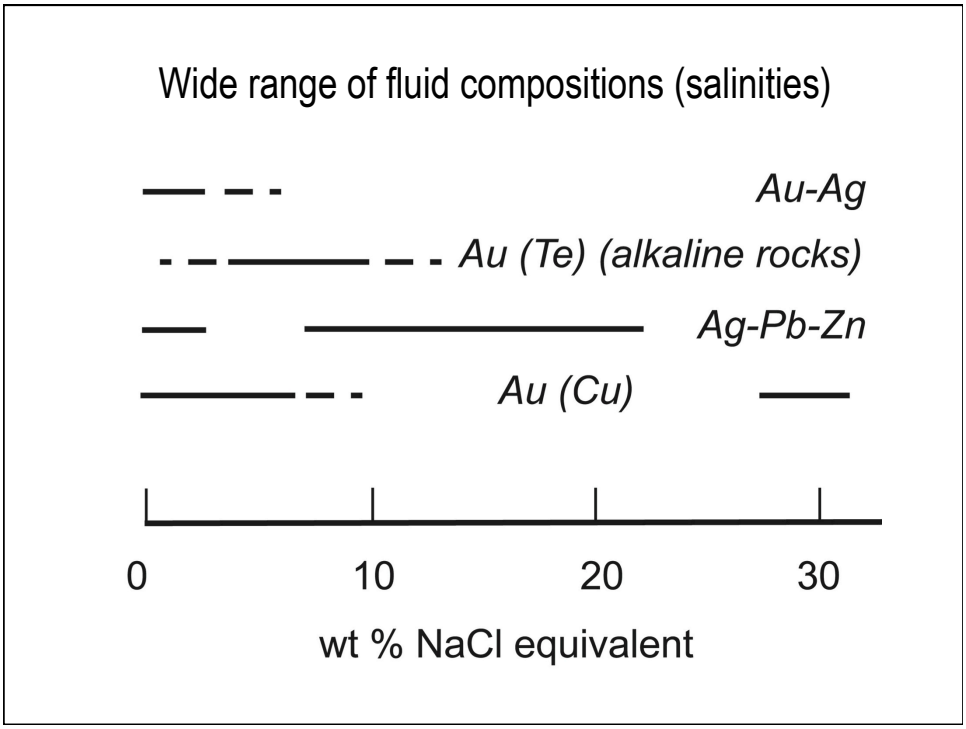
Epithermal deposits form metallogenic belts

Genetic Factors

•Water table
•Mineralizing Processes
-boiling, mixing, cooling

•Depth of Intrusion, path length to epithermal environment



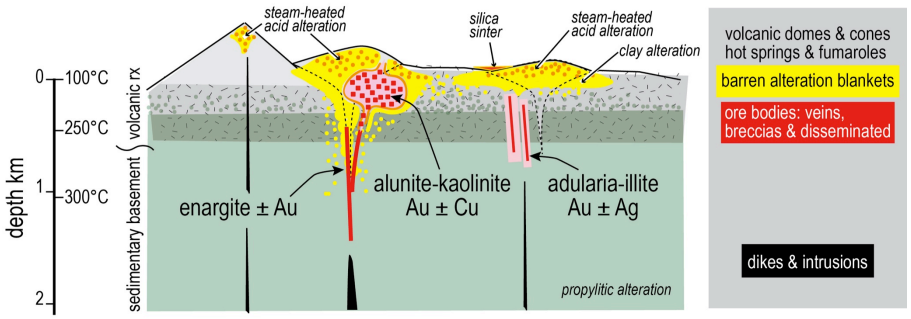


Exploration Considerations

- Depth level of exposure
- Mineralogical-chemical signature of ore
- Lithological-structural controls that localize ores
- Potential footprint of ore mineralization
- Telescoped ore zones (blind mineralization)
- Ore vs sub-economic mineralization

Answers found in mineralogy, mineral textures, mineral zonation, alteration extents, structure-stratigraphy, and rock geochemistry.

Depth level zonation-epithermal deposits

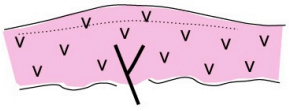


Epithermal Deposits: Common Characteristics

Ore bodies	zones of paleo-permeability <10 to >100 km^2 limited vertical extent-commonly blind zoned alteration patterns
Environment	<300° C, <1 km depth boiling (mixing?)
Host rocks	volcanic rocks (mafic to felsic) "basement"

volcanic rocks

basement



Epithermal Deposits: Diverse Characteristics

Metals	Au, Ag (Hg, Sb, Cu, Pb, Zn, Sn)
Sulfide Minerals	variable concentration (nil to high) low & intermediate sulfidation intermediate & high sulfidation
Gangue Minerals	Quartz-Calcite-Adularia-Illite Quartz-Alunite-Kaolinite-Pyrophyllite
Fluids	neutral and acid pH dilute and saline meteoric and magmatic
Magmas	mafic, intermediate, and felsic