Geology, Hydrology, Geochemistry, and Biology of Mine Sites

Geologic Aspects

STRATUS CONSULTING

Geologic Aspects

Outline

- Minerals
- Lithology and Wall-rock Alteration
- Mineral Deposits of California
  - Gold-Silver
  - Base Metals (Cu, Zn, Pb)
  - Mercury

Figure A1 Map of California showing locations of past and present mines with recorded mineral production, including metallic commodities, industrial minerals, and some construction commodities. Fuel minerals are not included. Data primarily from U.S. Geological Survey, Mineral Resource Data System (MRDS) database, supplemented with selected data from Mineral Industry Location System (MILS) database (formerly maintained by U.S. Bureau of Mines, now maintained by U.S. Geological Survey). Data set depicted does not include all small and intermittent producers, and is known to be incomplete with respect to sand and gravel, aggregate, and stone.

Minerals (see handout)

- Sulfides
- Sulfosalts
- Sulfates
- Native Elements
- Carbonates
- Silicates
- Oxides / Hydroxides
- Halides
- Arsenates and Antimonates
- Other (Fluorides, Arsenides, Tellurides)

MINERALS COMMONLY ASSOCIATED WITH ORE DEPOSITS AND MINE WASTES

		Solubility*			
		High	Low	Supergene	Hypogene
Sulfides					
Pyrite	FeS_2	O	R		✓
Marcasite	FeS_2	O	R	✓	✓
Pyrrhotite	$Fe_{(1-x)}S$ (x = 0 to 0.17)	O	R		✓
Chalcopyrite	$CuFeS_2$	O	R		✓
Bornite	Cu_5FeS_4	O	R		✓
Chalcocite	Cu_2S	O	R	✓	✓
Covellite (covelline)	CuS	O	R	✓	✓
Gersdorffite	NiAsS	O	R		✓
Arsenopyrite	FeAsS	O	R		✓
Arsenian pyrite	$Fe(S,As)_2$	O	R		✓
Realgar	AsS	O	R		✓
Orpiment	As_2S_3	O	R		✓
Molybdenite	MoS_2	O	R		✓
Cinnabar, metacinnabar	HgS	O	R	✓	✓
Argentite, acanthite	Ag_2S	O	R	✓	✓

Relative solubility

O = Oxidizing conditions

R = Reducing conditions

MINERALS COMMONLY ASSOCIATED WITH ORE DEPOSITS AND MINE WASTES

		Solubility*			
		High	Low	Supergene	Hypogene
Carbonates					
Calcite	$CaCO_3$	A	B	✓	✓
Aragonite	$CaCO_3$	A	B	✓	
Dolomite	$Ca(Mg,Fe)(CO_3)_2$	A	B	?	✓
Ankerite	$Ca(Fe,Mg)(CO_3)_2$	A	B	?	✓
Siderite	$FeCO_3$	A	B	✓	✓
Magnesite	$MgCO_3$	A	B	✓	✓
Rhodochrosite	$MnCO_3$	A	B	✓	✓
Azurite	$Cu_3(CO_3)_2(OH)_2$	A	B	✓	
Malachite	$Cu_2(CO_3)(OH)_2$	A	B	✓	
Cerussite	$PbCO_3$		B	✓	✓
Smithsonite	$ZnCO_3$	A	B	✓	✓

Relative solubility

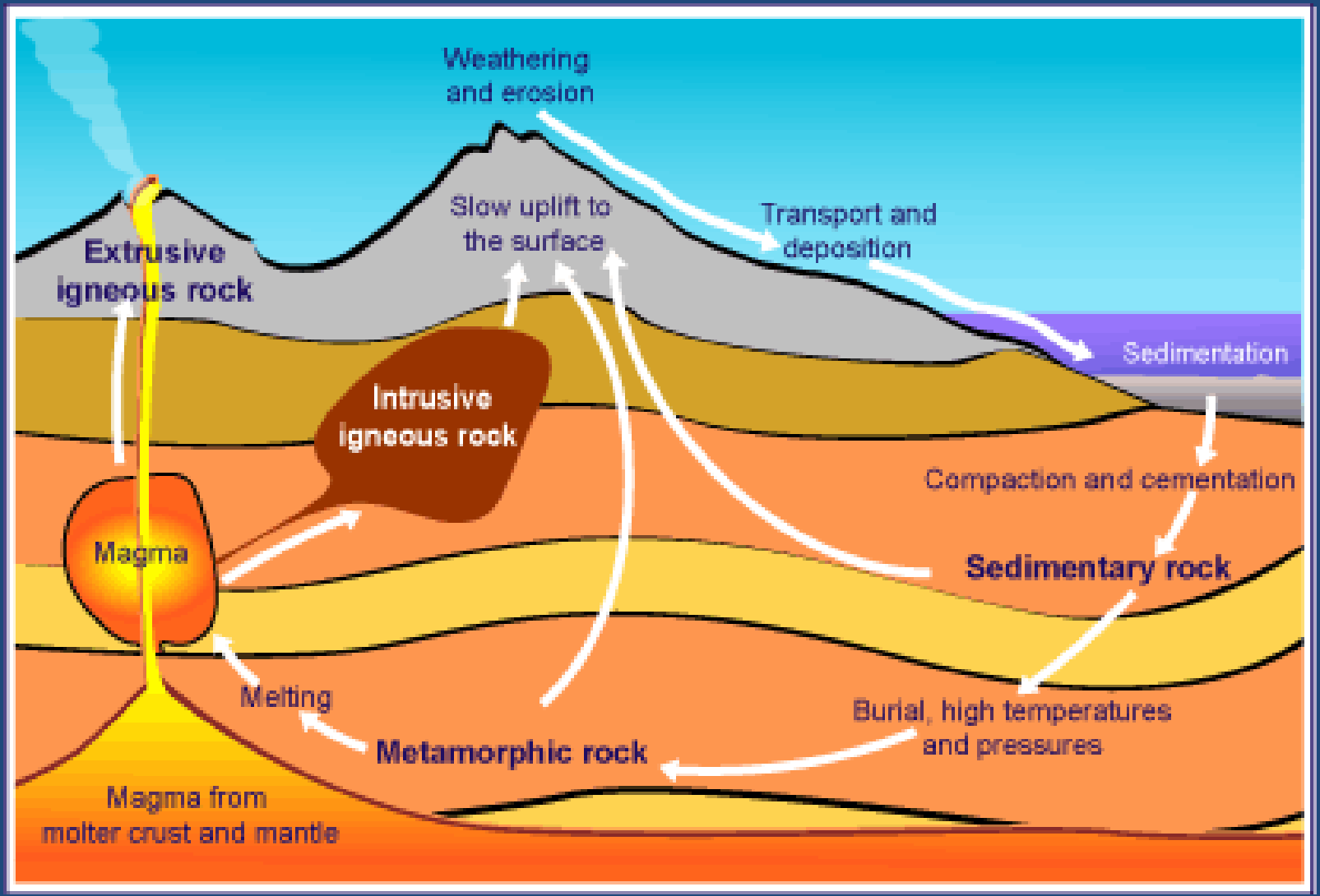
A = Acidic conditions

B = Basic conditions

Lithology and Wall-rock Alteration

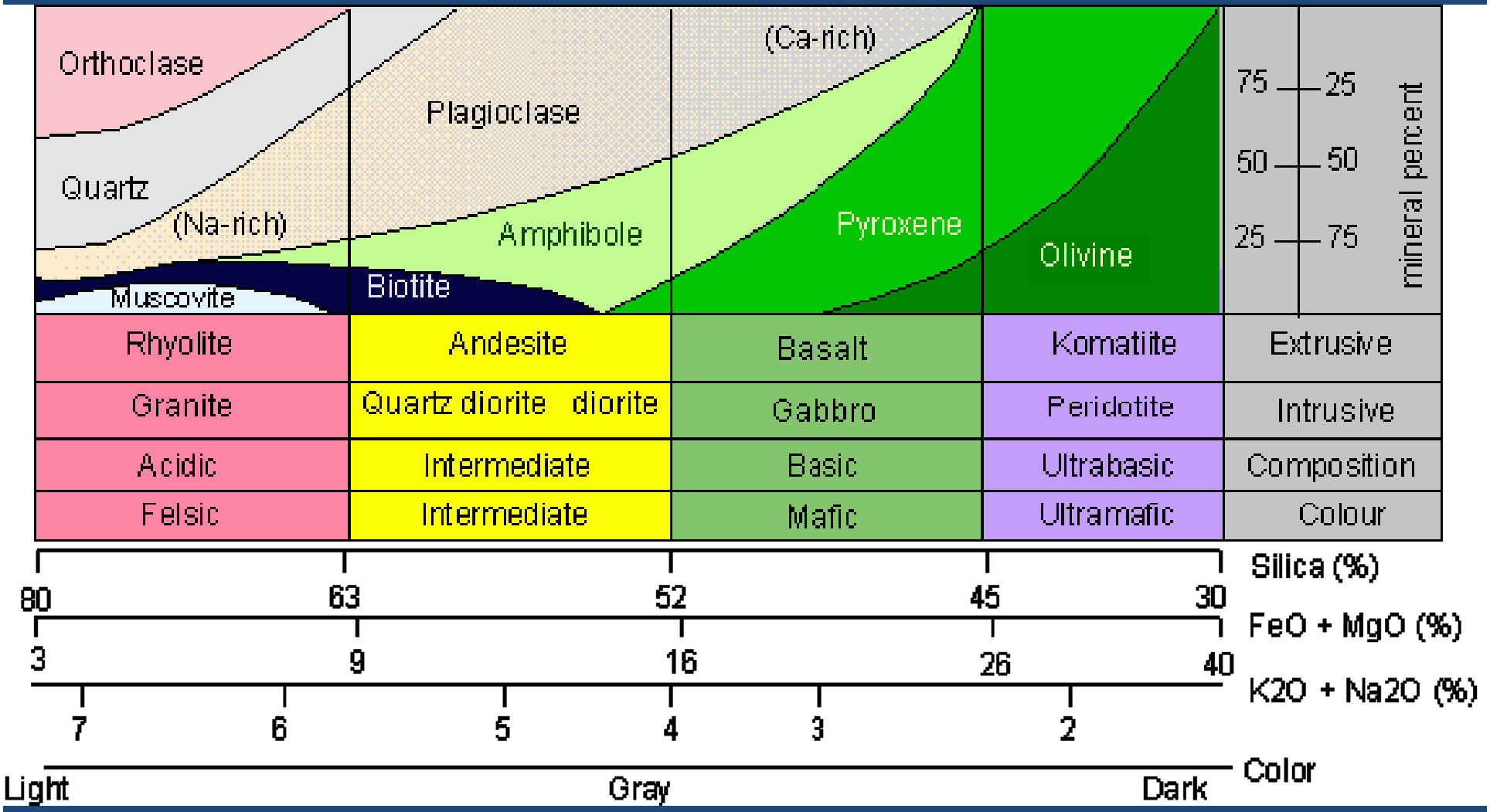
- The Rock Cycle
- Unaltered Rocks
  - Igneous
  - Metamorphic
  - Sedimentary
- Altered Rocks
  - Key alteration types
  - Importance to environmental behavior

The Rock Cycle



Source: http://www.bbc.co.uk/schools/ks3bitesize/science/chemistry/rock_cycle_9.shtml

Igneous Rocks



Source: http://www.eos.ubc.ca/courses/eosc221/rock_cycle/igneousrx.html

Sedimentary Rock Classification

Clastic & Bioclastic textures

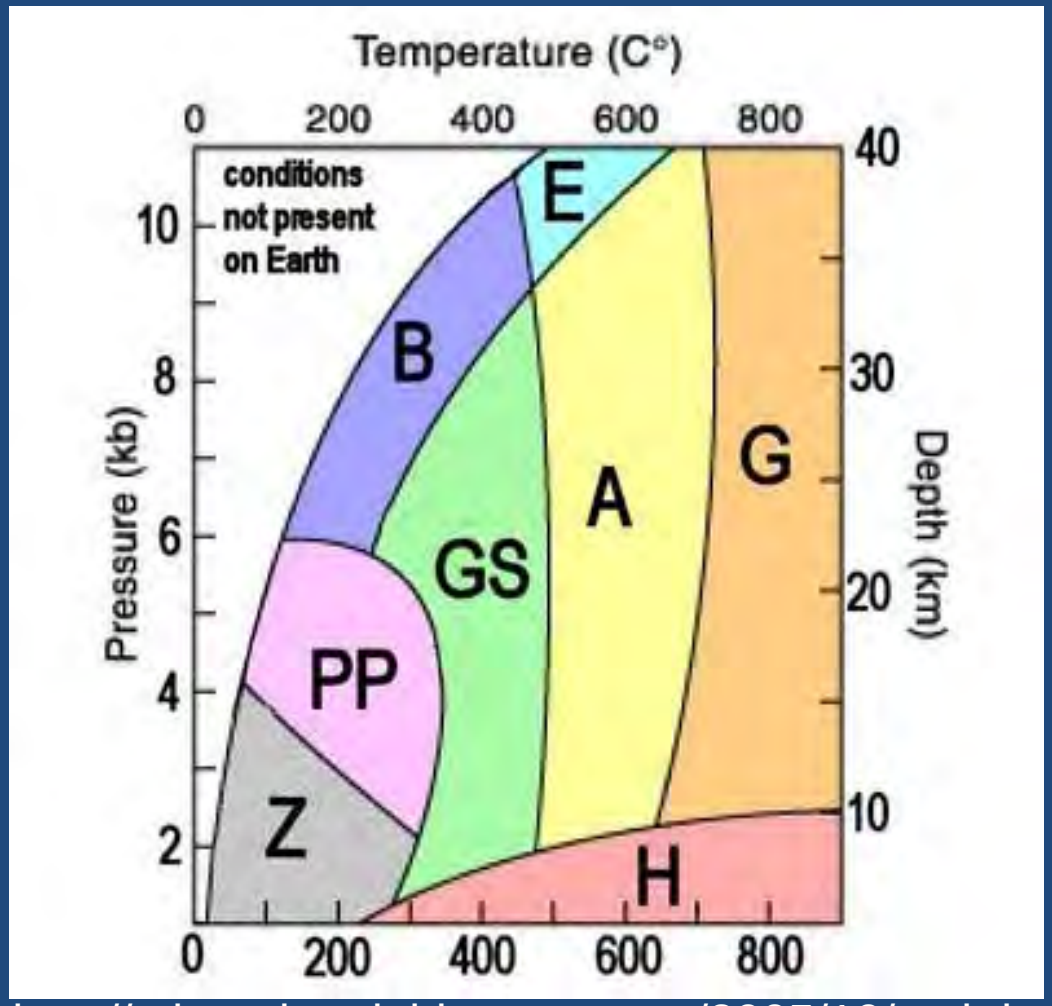
Texture	Size		Clast Composition	Rounding	Sorting	Rock Name	Comments	Depositional Environment
Clastic	>2 mm	gravel	variable	angular	poor	**sedimentary breccia**	large angular clasts - less transport	alluvial fan
	>2 mm	gravel	variable	rounded	poor	**conglomerate**	large rounded clasts - more transport	alluvial fan, stream, beach
	2-1/16 mm	sand	quartz	rounded	well	**quartz sandstone**	"clean" sandstone - more transport	dunes, stream
	2-1/16 mm	sand	feldspar, quartz, etc.	angular	mod-poor	**arkose**	"dirty" sandstone - less transport	alluvial fan, stream
	<1/16 mm	mud	-	-	well	**mudstone**	may split apart along bedding; may or may not "fizz"; easily scratched	floodplain, delta, shallow & deep marine
Bioclastic	>2 mm	gravel	shells	poor	poor	**coquina**	poorly-cemented shell fragments	beach
	<1/16 mm	mud	shells	-	well	**chalk**	microscopic shells; "earthy"	shallow-deep marine

Chemical & Biochemical textures

Texture	Composition	Hardness	Color	Rock Name	Comments	Depositional Environment
Chemical	calcite / $CaCO_3$	H=3	variable	**limestone**	will "fizz"; can be scratched by a nail	shallow marine, lake
	dolomite / $CaMg(CO_3)_2$	H=3	variable	**dolomite**	will <u>not</u> "fizz" unless scratched; can be scratched by a nail	nearshore marine
	silica / SiO_2	H=7	variable	**chert**	will <u>not</u> "fizz"; <u>not</u> scratched by a nail	deep sea
	halite / NaCl gypsum / CaSO4*2H2O	H=2.5 H=2	clear-variable white-variable	**evaporites**	soft, non-metallic minerals; halite is "salty"	playa
Bio	altered organic remains	soft	brown-black	**coal**	light in weight	swamp

http://www.mc.maricopa.edu/dept/d43/glg/Study_Aids/sedimentaryrkID1.JPG

Metamorphic Facies



http://mineral-rock.blogspot.com/2005/10/rock-index-metamorphic.html

Z = zeolite

PP = prehnite – pumpellyite

B = blueschist

E = eclogite

GS = greenschist

A = amphibolite

G = granulite

H = hornfels

Altered Rocks

TABLE 3.7—The environmental characteristics of various wallrock alteration types common to hydrothermal mineral deposits. See discussion in Guilbert and Park (1986) for discussion of alteration origins.

Alteration type	Alteration products	Chemical effects	Physical effects
Acid-sulfate (advanced argillic)	Vuggy silica (+pyrite), quartz-alunite, kaolinite, ± pyrophyllite, dickite	Greatly decreases acid-buffering capacity of host rocks, and increases acid-generating capacity	Vuggy silica zones highly permeable. Surrounding clay alteration zones impermeable
Argillic	Kaolinite, illite, montmorillonite, ± pyrite, ± chlorite	Decreases acid-buffering capacity	Substantially decreases rock and fracture permeability
Phyllic	Quartz, sericite, pyrite	Increases acid-generating capacity	Slightly decreases rock and fracture permeability
Potassic	Potassium feldspar, biotite, anhydrite	Coarse grain size of feldspars decreases rock reactivity	Shifts permeability to fracture permeability
Propylitic	Epidote, chlorite, calcite, albite, ± pyrite	Increases acid-buffering capacity of rock	Chlorite-rich alteration somewhat decreases fracture permeability
Silica	Silica, quartz addition to rock and replacement of rock minerals	Decreases acid-buffering capacity of rock	Decreases rock permeability, porosity. Increases susceptibility of rocks to fracturing
Jasperoid	Silica, quartz replacement of carbonate sedimentary rocks	Greatly decreases acid-buffering capacity	Can increase porosity, permeability of rock; also increases susceptibility of rocks to fracturing
Greisen	Quartz, muscovite, topaz, fluorite, cassiterite, magnetite	Some decrease in acid-buffering capacity, reactivity	Moderate rock permeability, fracture permeability
Skarn	Carbonate rocks alter to calc-silicates, magnetite	Decrease acid-buffering capacity; increase acid-generating capacity	May decrease rock permeability
Dolomitization	Alteration of limestones to dolomites	May decrease acid-buffering capacity	May decrease or increase rock porosity, permeability
Carbonatization	Alteration of rock minerals to carbonates	Substantially increases acid-buffering capacity	Negligible effect
Sulfidation	Alteration of Fe minerals to Fe sulfides	Increases acid-generating capacity	Negligible effect
Decalcification (decarbonatization)	Removal of carbonate from rocks, some replacement by silica	Decreases acid-buffering capacity	Substantially increases porosity, permeability

Source: Plumlee (1999)

Altered Rocks

TABLE 3.7—The environmental characteristics of various wallrock alteration types common to hydrothermal mineral deposits. See discussion in Guilbert and Park (1986) for discussion of alteration origins.

Alteration type	Alteration products	Chemical effects	Physical effects
Acid-sulfate (advanced argillic)	Vuggy silica (+pyrite), quartz-alunite, kaolinite, ± pyrophyllite, dickite	Greatly decreases acid-buffering capacity of host rocks, and increases acid-generating capacity	Vuggy silica zones highly permeable. Surrounding clay alteration zones impermeable
Argillic	Kaolinite, illite, montmorillonite, ± pyrite, ± chlorite	Decreases acid-buffering capacity	Substantially decreases rock and fracture permeability
Phyllic	Quartz, sericite, pyrite	Increases acid-generating capacity	Slightly decreases rock and fracture permeability
Potassic	Potassium feldspar, biotite, anhydrite	Coarse grain size of feldspars decreases rock reactivity	Shifts permeability to fracture permeability
Propylitic	Epidote, chlorite, calcite, albite, ± pyrite	Increases acid-buffering capacity of rock	Chlorite-rich alteration somewhat decreases fracture permeability
Silica	Silica, quartz addition to rock and replacement of rock minerals	Decreases acid-buffering capacity of rock	Decreases rock permeability, porosity. Increases susceptibility of rocks to fracturing
Jasperoid	Silica, quartz replacement of carbonate sedimentary rocks	Greatly decreases acid-buffering capacity	Can increase porosity, permeability of rock; also increases susceptibility of rocks to fracturing
Greisen	Quartz, muscovite, topaz, fluorite, cassiterite, magnetite	Some decrease in acid-buffering capacity, reactivity	Moderate rock permeability, fracture permeability
Skarn	Carbonate rocks alter to calc-silicates, magnetite	Decrease acid-buffering capacity; increase acid-generating capacity	May decrease rock permeability
Dolomitization	Alteration of limestones to dolomites	May decrease acid-buffering capacity	May decrease or increase rock porosity, permeability
Carbonatization	Alteration of rock minerals to carbonates	Substantially increases acid-buffering capacity	Negligible effect
Sulfidation	Alteration of Fe minerals to Fe sulfides	Increases acid-generating capacity	Negligible effect
Decalcification (decarbonatization)	Removal of carbonate from rocks, some replacement by silica	Decreases acid-buffering capacity	Substantially increases porosity, permeability

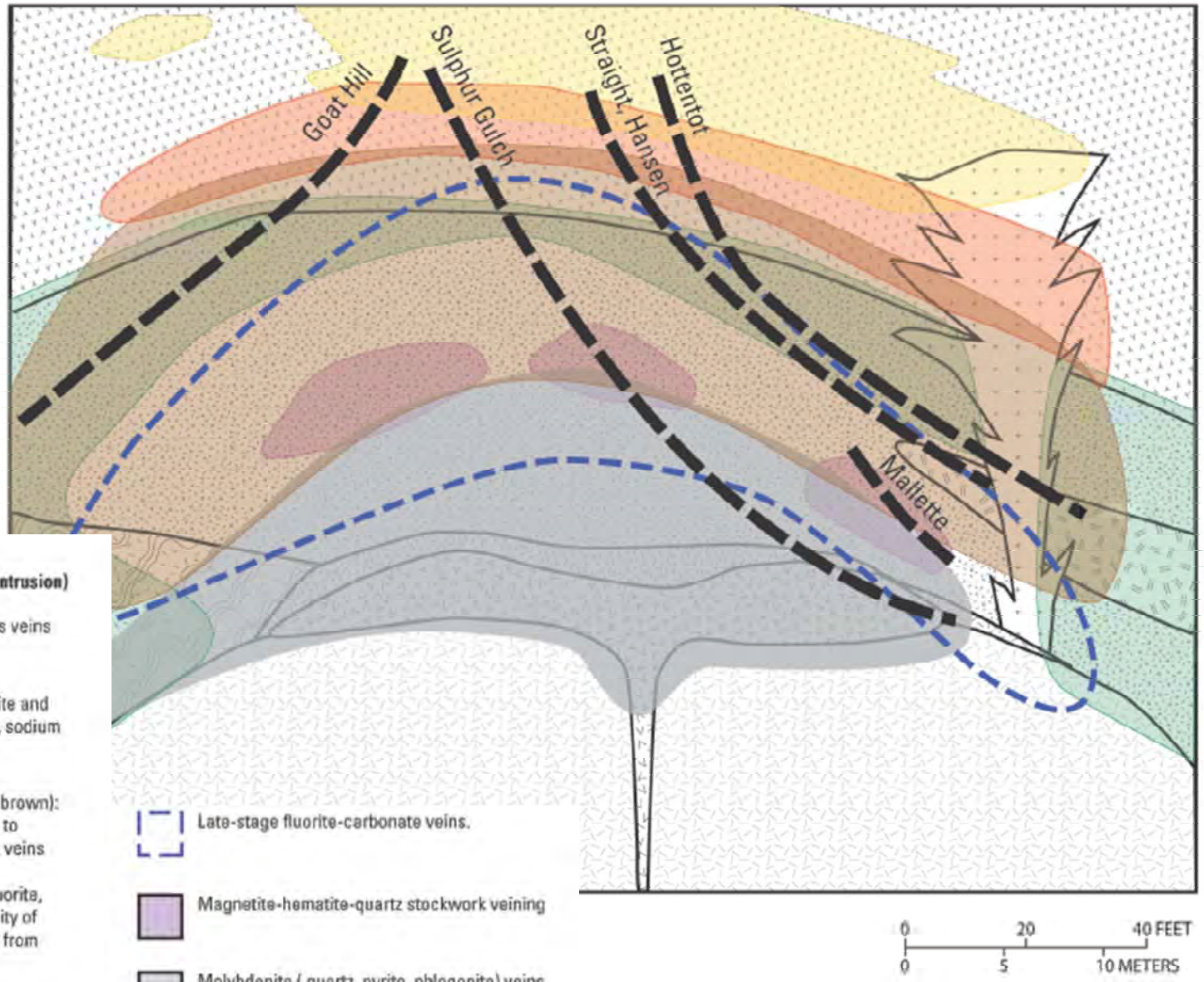
Source: Plumlee (1999)

Key Alteration Types – Chemical Effects

Alteration type	Alteration products	Chemical effects
Acid-sulfate (advanced argillic)	Vuggy silica (+pyrite), quartz-alunite, kaolinite, ± pyrophyllite, dickite	Greatly decreases acid-buffering capacity of host rocks, and increases acid-generating capacity
Argillic	Kaolinite, illite, montmorillonite, ± pyrite, ± chlorite	Decreases acid-buffering capacity
Phyllic	Quartz, sericite, pyrite	Increases acid-generating capacity
Potassic	Potassium feldspar, biotite, anhydrite	Coarse grain size of feldspars decreases rock reactivity
Propylitic	Epidote, chlorite, calcite, albite, ± pyrite	Increases acid-buffering capacity of rock
Silica	Silica, quartz addition to rock and replacement of rock minerals	Decreases acid-buffering capacity of rock
Jasperoid	Silica, quartz replacement of carbonate sedimentary rocks	Greatly decreases acid-buffering capacity

Plumlee (1999)

Alteration and mineralization at Questa, NM (molybdenum porphyry)



Hydrothermal Alteration
(listed in order of increasing proximity to source intrusion)

- Alunite and kaolinite of unknown age as veins and partial alteration of Amalia Tuff.
- Propylitic alteration, primarily of andesite and quartz latite porphyry rocks, to chlorite, sodium plagioclase, epidote, and calcite.
- Quartz-sericite-pyrite (QSP) alteration (brown): Generally incomplete alteration of rock to quartz, pyrite, and illite, with stockwork veins containing quartz, pyrite, and lesser chalcopyrite, pyrrhotite, carbonates, fluorite, barite, phosphates, Fe-Ti oxides. Intensity of alteration and veining diminishes away from source intrusions.

  Quartz-sericite (QS) alteration (orange): Distal, sulfide-poor facies of QSP alteration in rhyolitic intrusions and Amalia Tuff.

- Late-stage fluorite-carbonate veins.
- Magnetite-hematite-quartz stockwork veining
- Molybdenite (quartz, pyrite, phlogopite) veins in rock potassically altered to contain phlogopite, potassium feldpsar, topaz, and other minerals

Ludington et al. (2005)

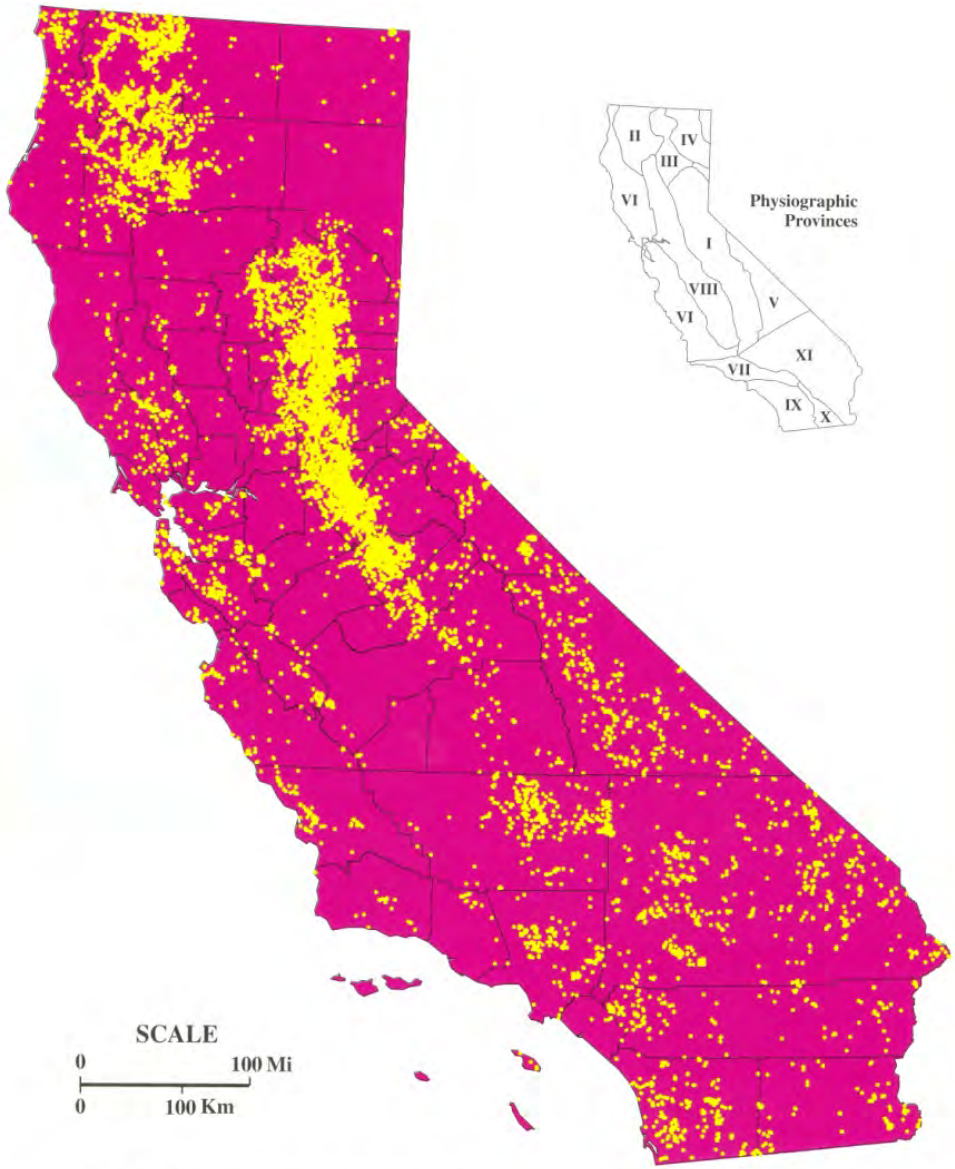


Figure A1. Map of California showing locations of past and present mines with recorded mineral production, including metallic commodities, industrial minerals, and some construction commodities. Fuel minerals are not included. Data primarily from U.S. Geological Survey, Mineral Resource Data System (MRDS) database, supplemented with selected data from Mineral Industry Location System (MILS) database (formerly maintained by U.S. Bureau of Mines, now maintained by U.S. Geological Survey). Data set depicted does not include all small and intermittent producers, and is known to be incomplete with respect to sand and gravel, aggregate, and stone.

Locations of Past and Present Mines in California

Approx. 47,000 abandoned mines (Calif. Dept. of Conservation and USGS databases)

From Ashley (1998) in DTSC Preliminary Assessment Handbook

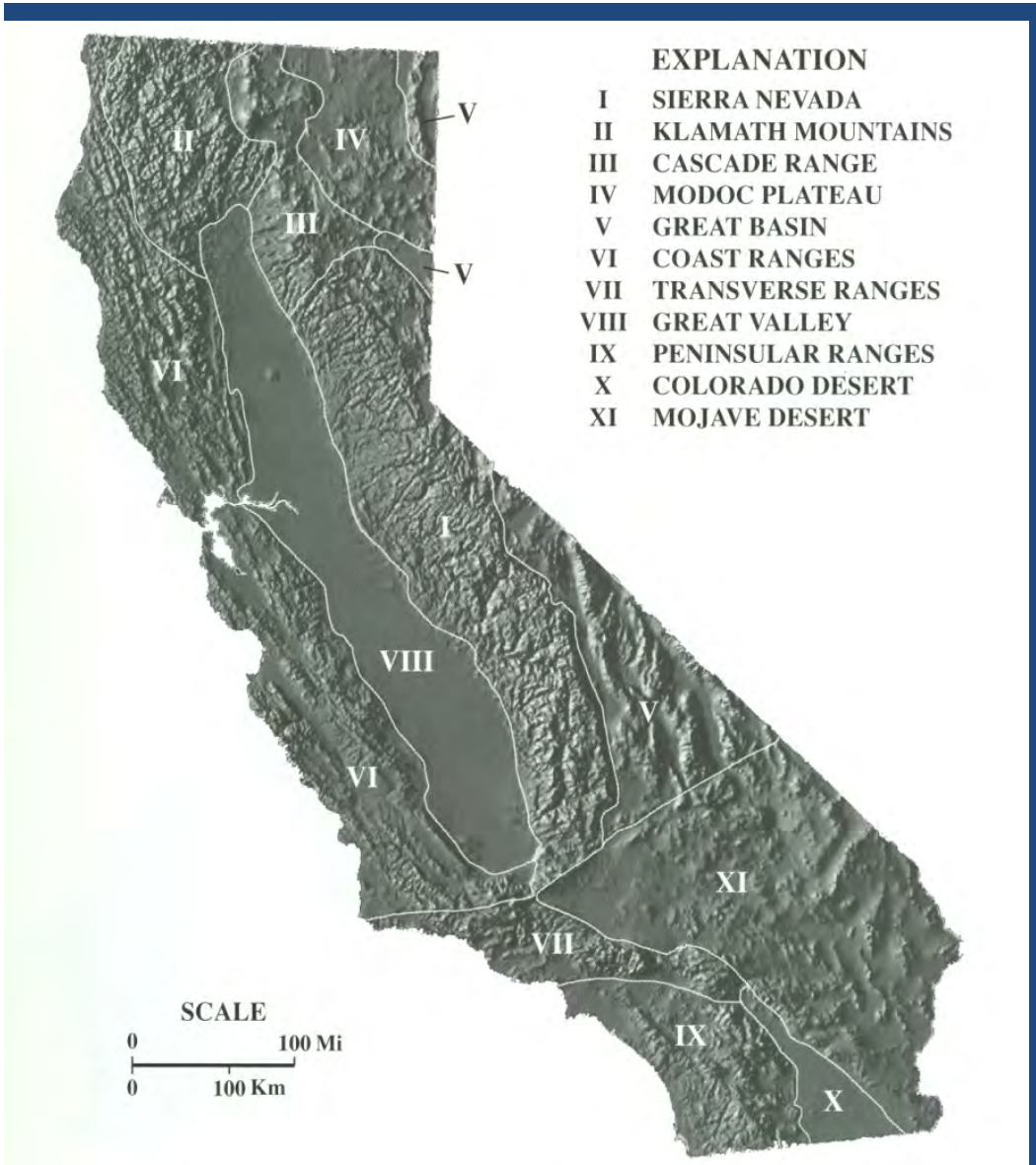


Figure A2. Physiographic provinces of California. Provinces include: I, Sierra Nevada; II, Klamath Mountains; III, Cascade Range; IV, Modoc Plateau; V, Great Basin (Basin and Range); VI, Coast Ranges; VII, Transverse Ranges; VIII, Great Valley; IX, Peninsular Ranges; X, Colorado Desert; XI, Mojave Desert. Base from Thelin, G.P., and Pike, R.J. 1991, Landforms of the conterminous United States—a digital shaded-relief portrayal: U.S. Geological Survey Miscellaneous Investigations Series Map I-2206, scale 1:2,500,000.

Physiographic Provinces of California

From Ashley (1998) in DTSC Preliminary Assessment Handbook

Gold and Silver Deposit

Deposit type	Common sulfide minerals	% sulfide in ore	Acid-buffering minerals
Low-sulfide gold-quartz veins	py, asp, stib, sl, cp, gn, pyr	1-10	dol, ank, mag, sid, cal
Epithermal veins	py, arg, Ag-sulfo, gn, sl, cp, mc, asp	<1-5	cal, rdc
Quartz-alunite gold	py, sulfo, cc, cv, mc, sl, gn	2-30	none
Hot spring	py, stib, real	<1-10	none
Polymetallic vein	py, sl, cp, gn, asp, sulfo, arg	5-20	none
Sediment-hosted disseminated gold	py, asp, real, orp, stib	<1-5	cal

Modified from Ashley (1998) in DTSC Preliminary Assessment Handbook

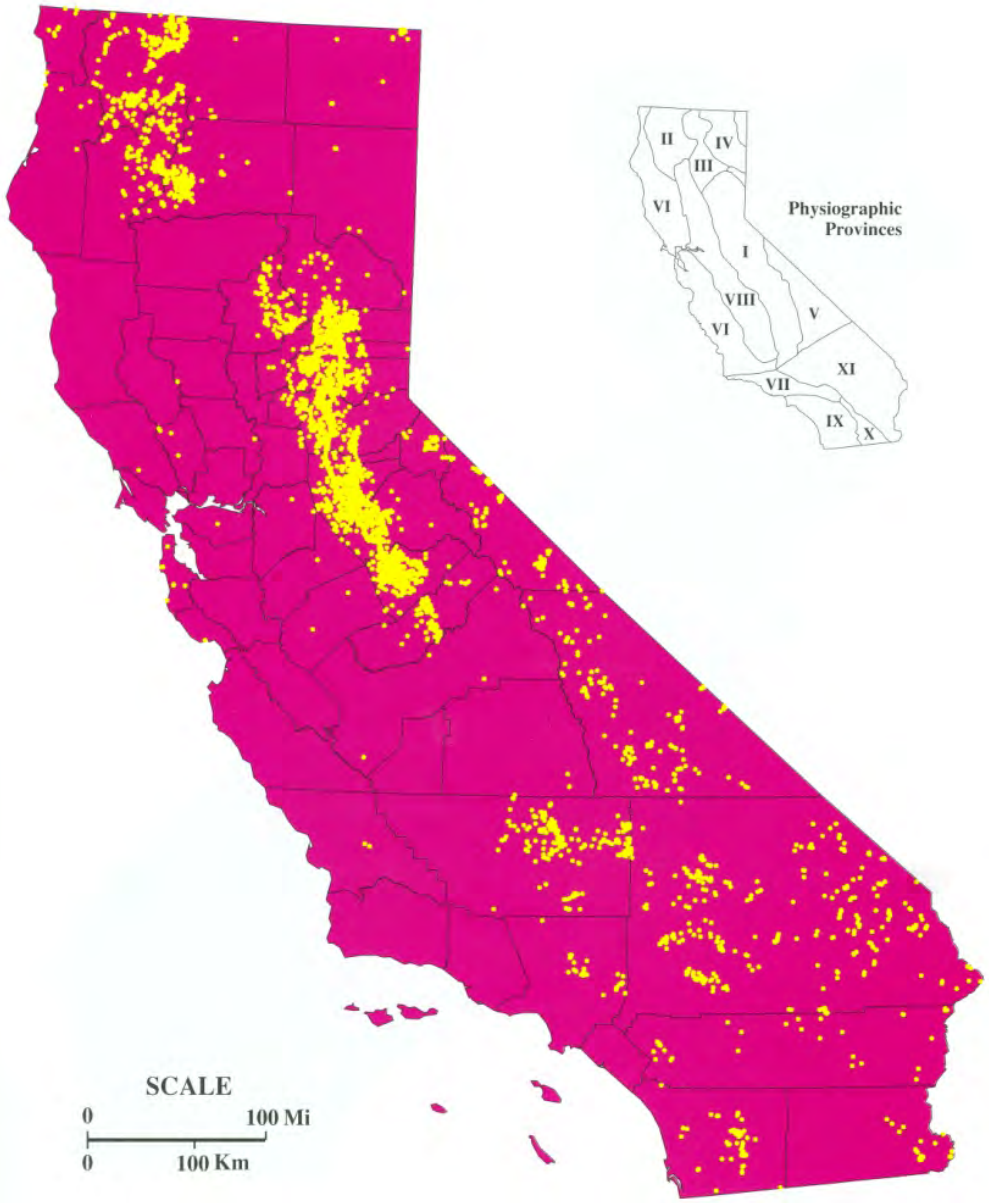


Figure A3. Map of California showing locations of lode gold mines with recorded production. Data from U.S. Geological Survey, Mineral Resource Data System (MRDS) database.

Distribution of Lode Gold Mines

Photo: Oriental Mine, CA http://www.gold-classics.com/Gold12.htm

Map: Ashley (1998) in DTSC Preliminary Assessment Handbook

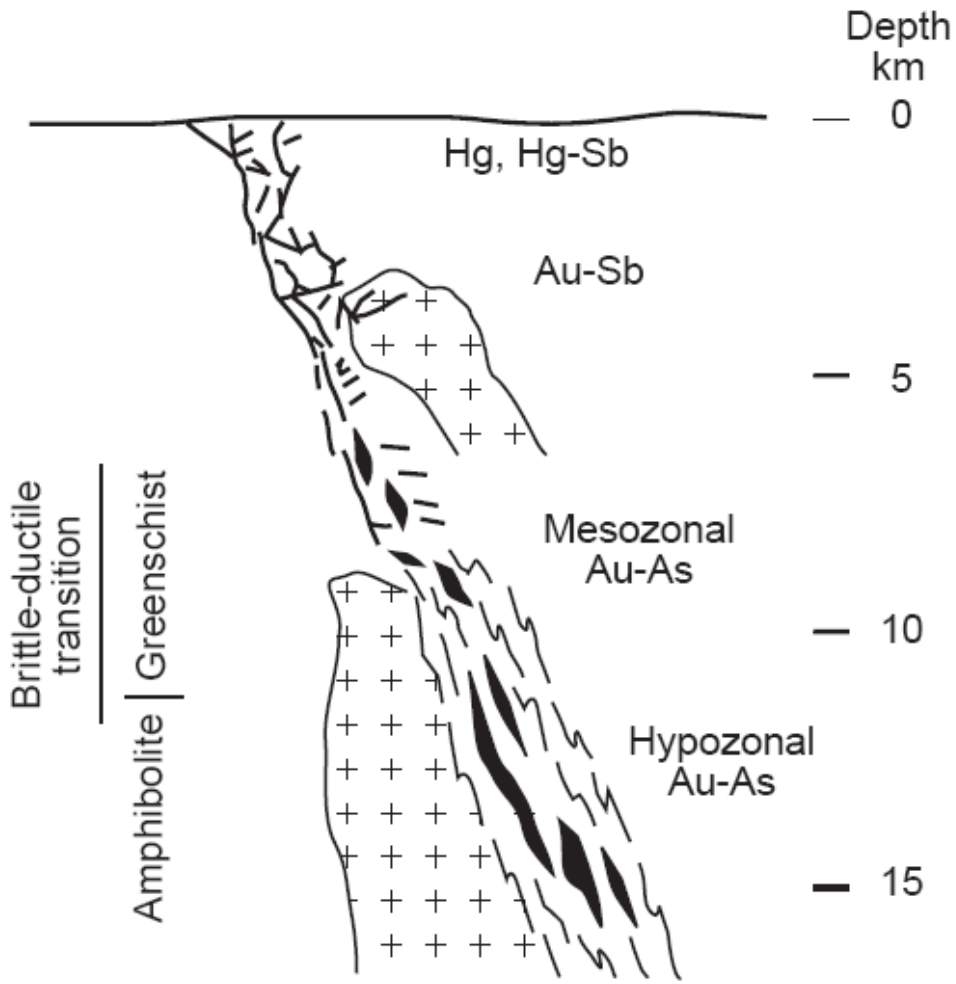
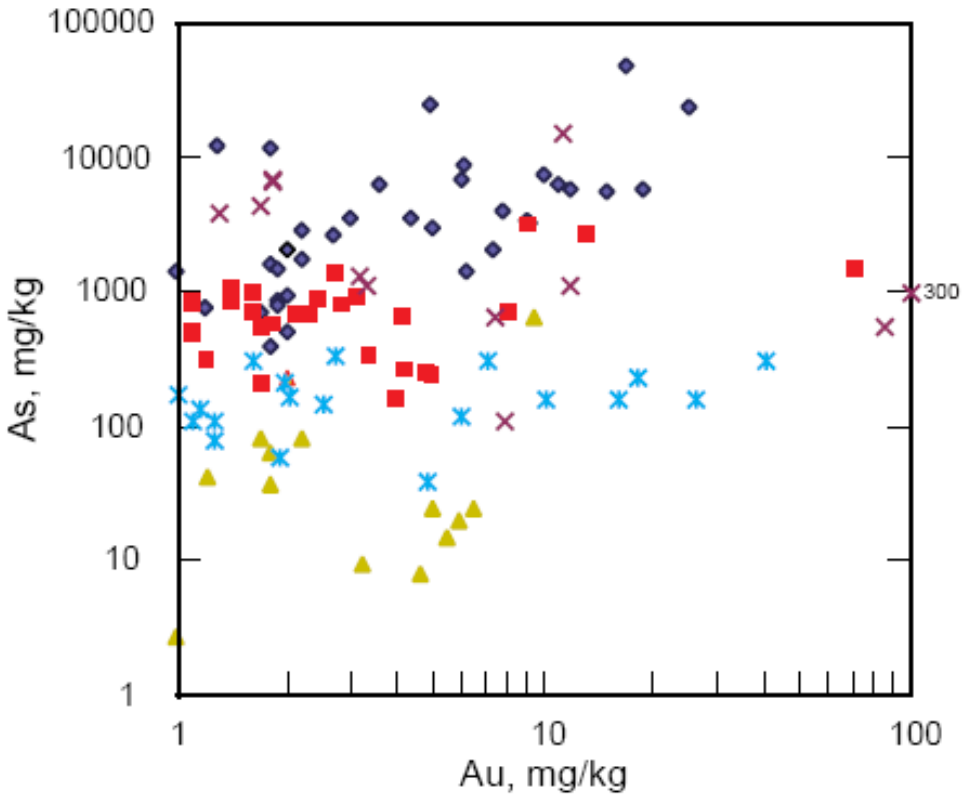


Figure 1. Schematic representation of shear-zone setting of low-sulfide gold-quartz veins and related deposits. Mod-ified from Groves and others (1998), and McCuiag and Kerrich (1998).

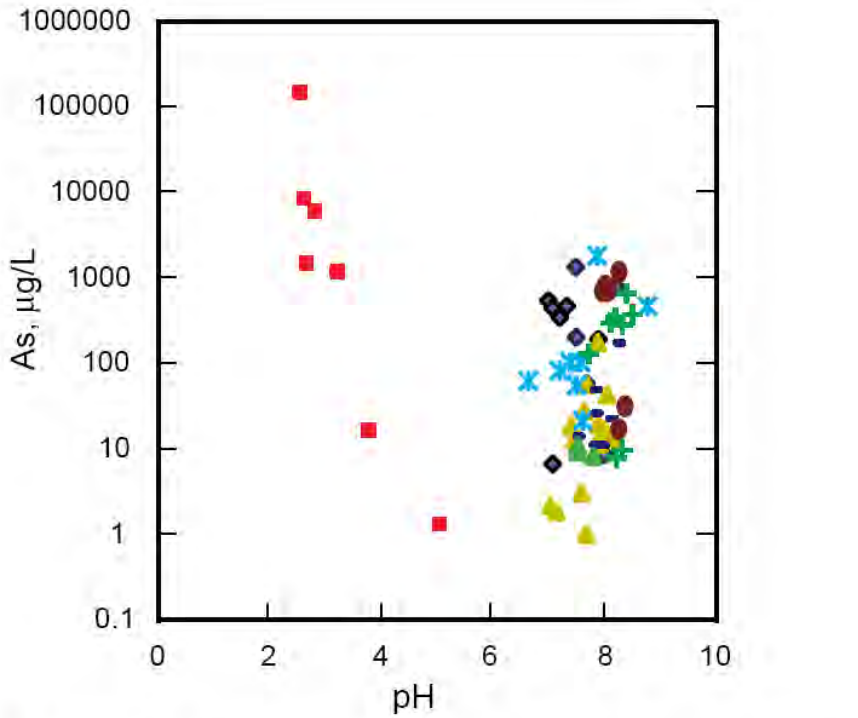
From: Ashley (2002) USGS OFR 02-195



- Alleghany district (Böhlke, 1986)
- Shingle Springs district (Nash, 1988)
- Hodson district (Chaffee and Sutley, 1994)
- Harvard mine, Jamestown district (Ashley, unpub. data)
- N. Mother Lode districts (Sutter Cr., Nashville, Kelsey, Spanish Flat; Ashley, unpub. data)

Figure 2. Arsenic concentrations in ores from selected gold districts, Sierra Nevada region, California.

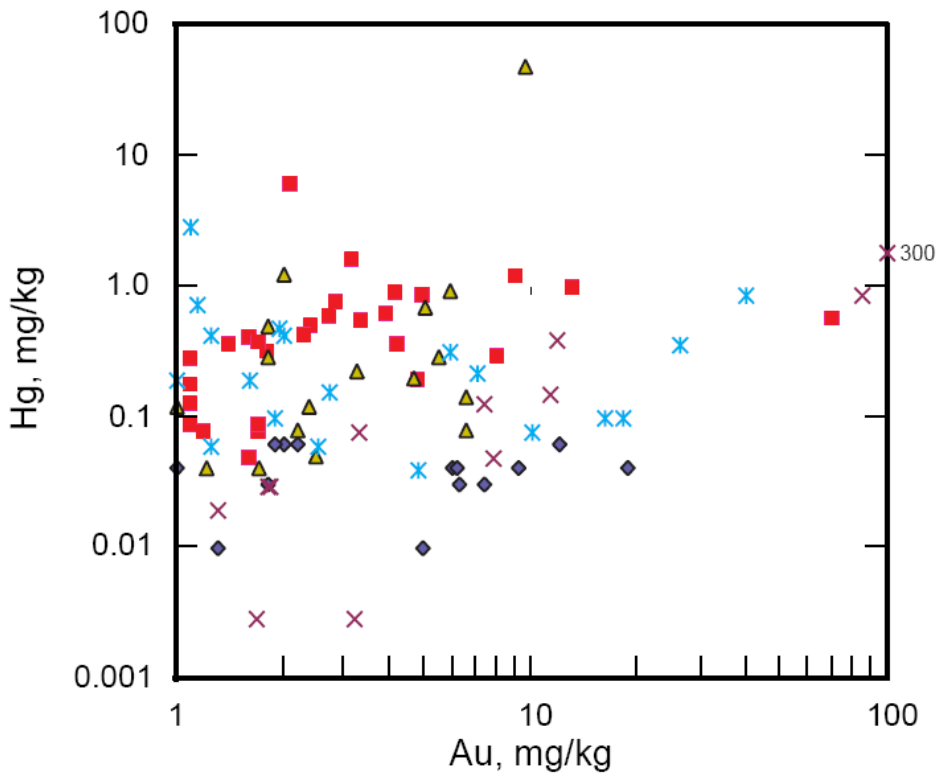
From: Ashley (2002)
USGS OFR 02-195



- Mine drainage, several N. Mother Lode mines (Ashley, unpub. data)
- Argonaut mine, Jackson district, concentrates (Ashley, unpub. data)
- Argonaut mine, Jackson district, tailings (Ashley, unpub. data)
- Kennedy mine, Jackson district, tailings (Dames & Moore, 1995)
- Lava Cap mine, Nevada City district, tailings (Ashley, unpub. data)
- Harvard mine pit lake, Jamestown district (County of Tuolumne, 1998)
- Skyrocket pit lake, Hodson district (Meridian Gold Company, 1997)
- North pit lake, Hodson district (Meridian Gold Company, 1997)

Figure 4. pH and arsenic concentrations of mine drainage, drainage from mill tailings and concentrates, and pit lake waters from low-sulfide gold-quartz deposits, Sierra Nevada region, California.

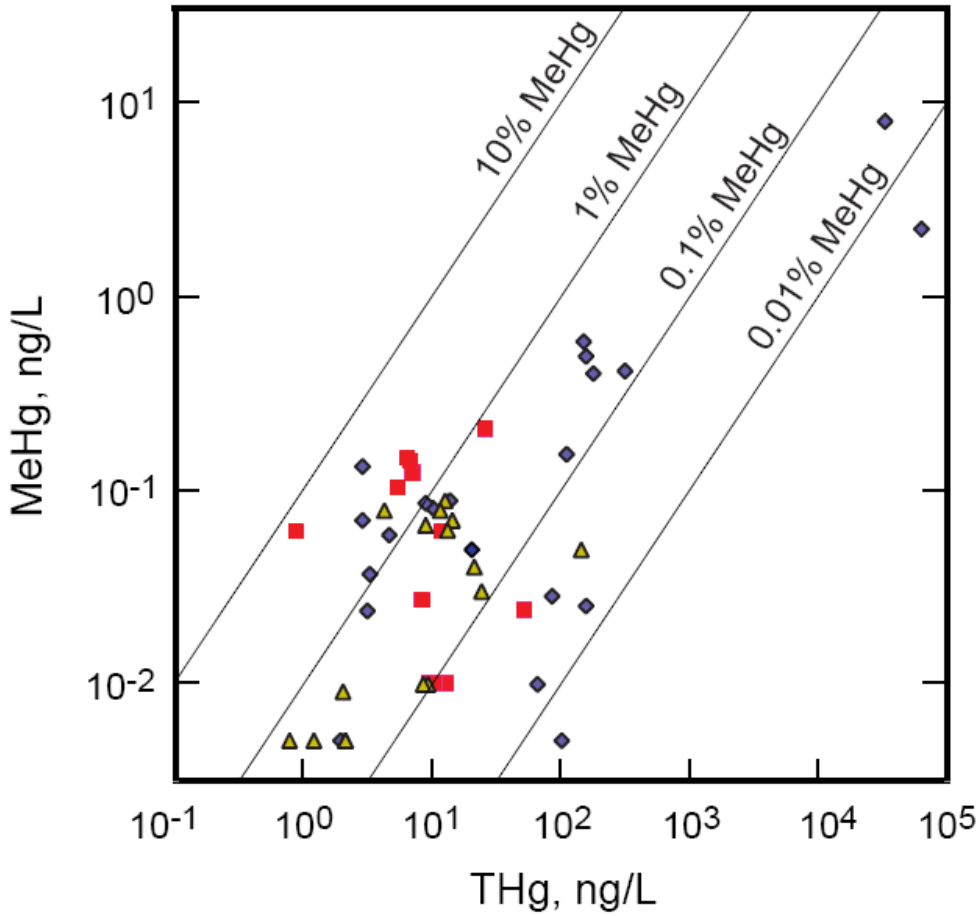
From: Ashley (2002)
USGS OFR 02-195



- Alleghany district (Böhlke, 1986)
- Northern Mother Lode districts (Sutter Creek, Jackson, Nashville, Kelsey, Spanish Flat, Nevada City; Ashley, unpub. data)
- Shingle Springs district (Nash, 1988)
- Hodson district (Chaffee and Sutley, 1994)
- Harvard mine, Jamestown district (Ashley, unpub. data)

Figure 3. Mercury concentrations in ores from selected gold districts, Sierra Nevada region, California.

From: Ashley (2002)
USGS OFR 02-195



- Drainage, Argonaut mine mill tailings (Ashley, unpub. data)
- Mill tailings impoundment and drainage, Lava Cap mine (Ashley & Ziarkowski, 1999, Ashley, unpub. data)
- Mine drainage, 6 sites in 5 Sierra Nevada districts (Ashley, unpub. data)

Figure 8. Methylmercury vs. total mercury in mine drainage and drainage from mill tailings, low-sulfide gold-quartz deposits, Sierra Nevada region, California.

From: Ashley (2002)
USGS OFR 02-195

Hot-Spring Gold-silver

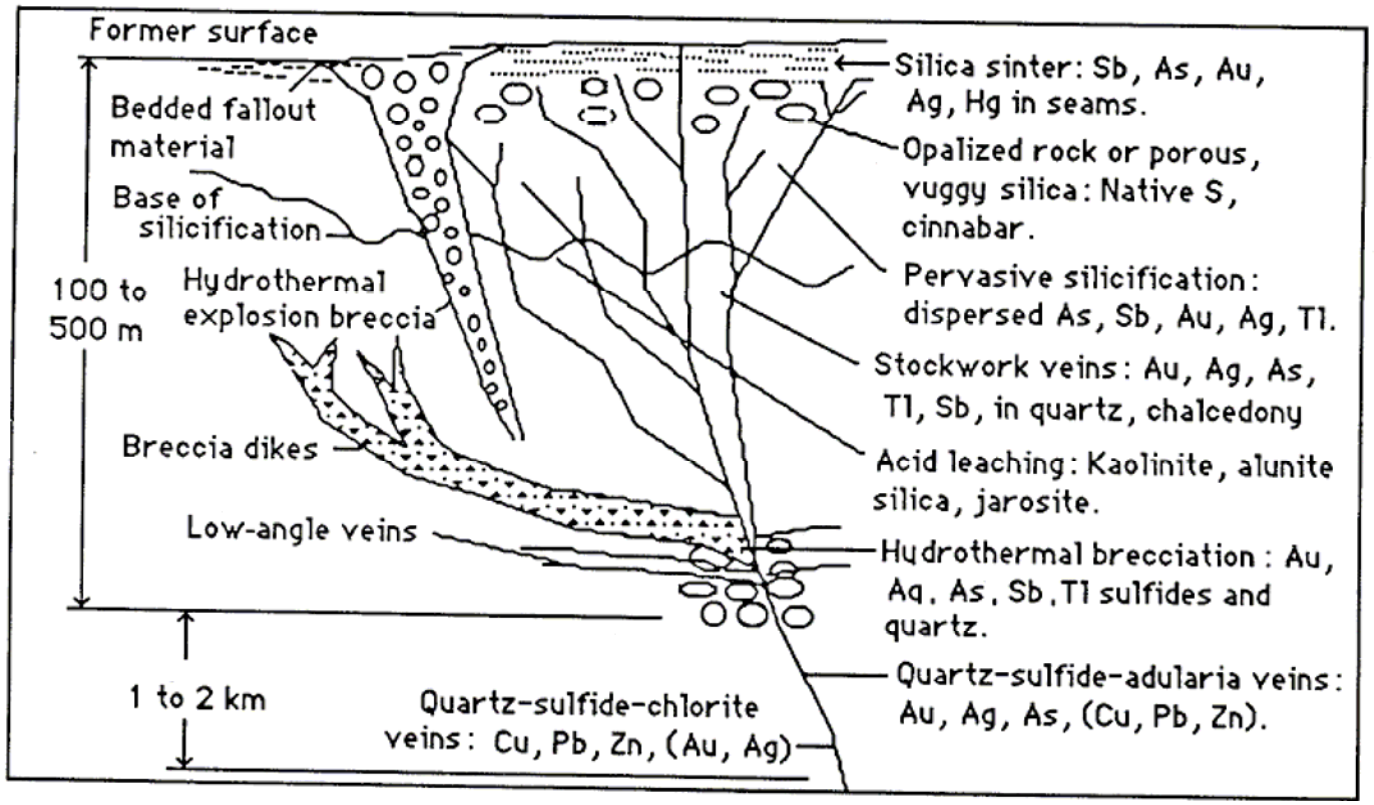


Figure 105. Cartoon cross section of hot-spring Au-Ag deposit.

Berger (1986) USGS Bulletin 1693

Mineral Deposit Types Related to Intrusion of Igneous Stock into Sedimentary Sequence

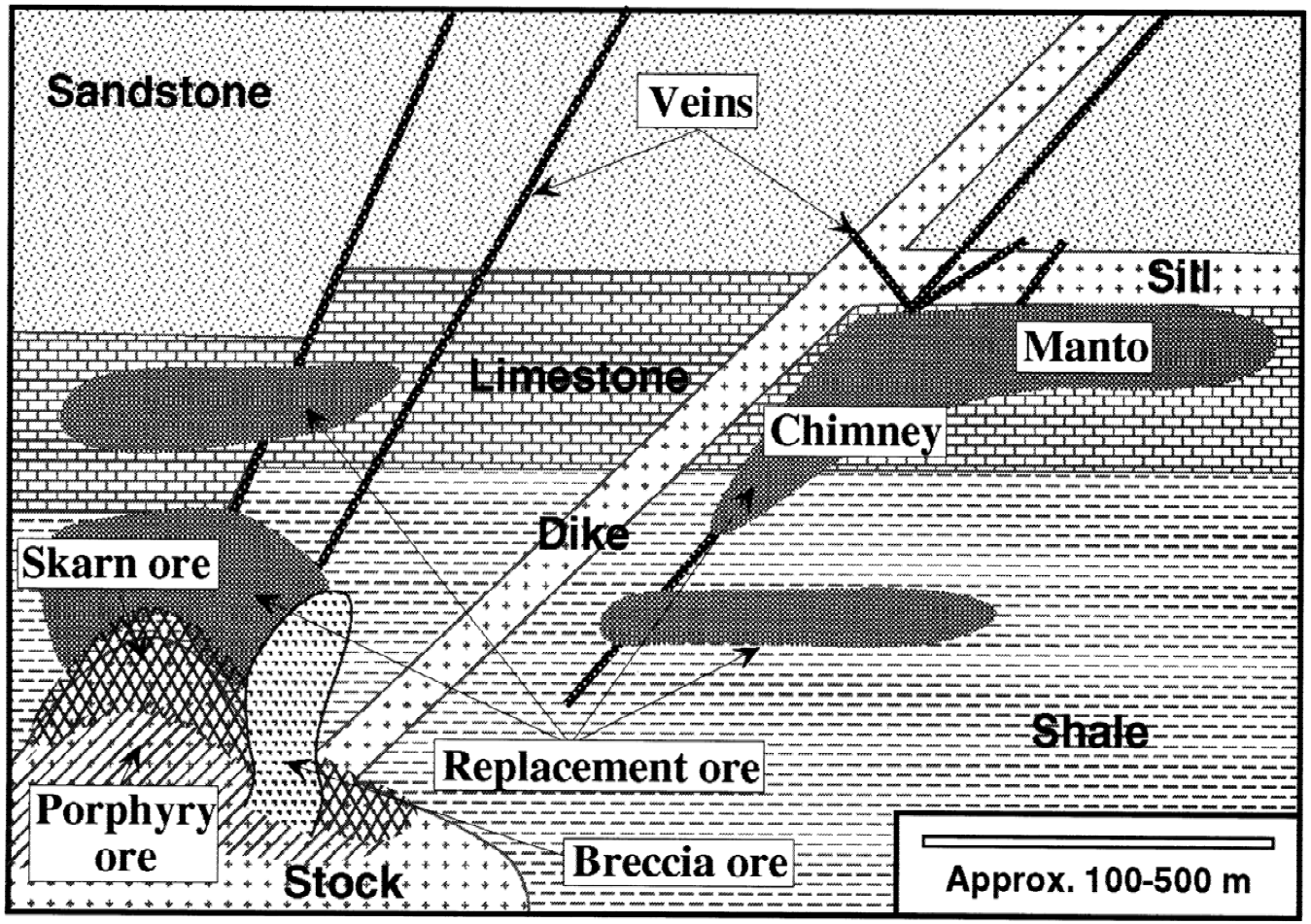


FIGURE 3.15—Schematic cross section of mineral-deposit types that may form from the intrusion of a magmatic stock into a sedimentary-rock sequence containing carbonates, shales, and sandstones.

Plumlee (1999)

Base Metal and Silver Deposit Types

Deposit type	Common sulfide minerals	% sulfide in ore	Acid-buffering minerals
Volcanogenic massive sulfide	Py,sl,cp,pyr,gn	5-90+	Few (cal, silicates)
Polymetallic vein	Py,sl,cp, gn, asp, sulf,arg	10-50+	Cal, dol, ank, sid, rdc
Polymetallic replacement	Py, gn, sl, cp, arg, mc, sulfo	10-50+	Cal, dol, sid, rdc
Skarn (copper)	Cp, py, bn, pyr	10-50+	Cal, dol
Skarn (zinc-lead)	Sl, gn, pyr,py, cp, bn, asp	10-50+	Cal, dol, rdc

Modified from Ashley (1998) in DTSC Preliminary Assessment Handbook

Figure A4. Map of California showing locations of mines that produced base metals (primarily copper, lead, or zinc), with or without silver. Either base metals or silver may account for the majority of production value. Many mines shown here produced gold as a byproduct; mines in which gold value predominates, however, are shown on Figure A3. Data from U.S. Geological Survey, Mineral Resource Data System (MRDS) database.

Distribution of Base Metal Mines (Pb, Zn, Cu)

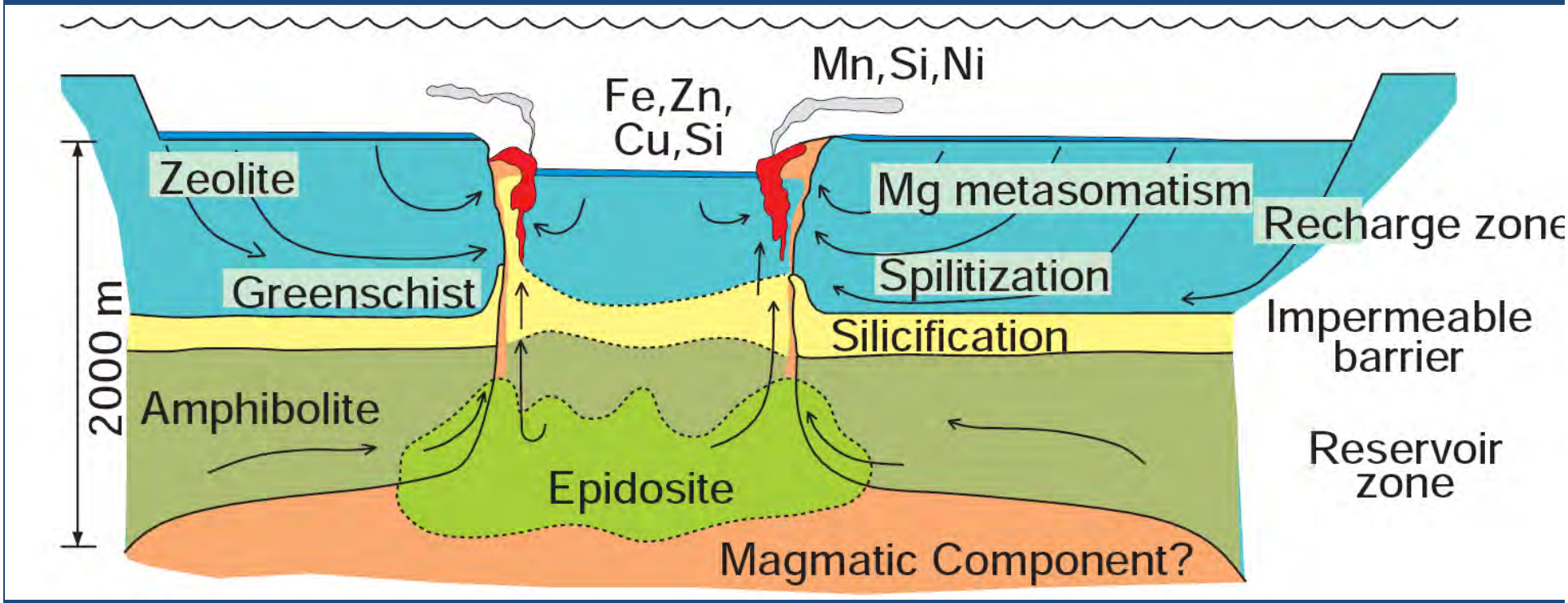
Largest are VMS deposits in Klamath Mtns. (West Shasta mining district) and western Sierra Nevada (Foothill Zn-Cu Belt)

From Ashley (1998) in DTSC Preliminary Assessment Handbook

Iron Mountain, Shasta County, CA
Volcanogenic Massive Sulfide (VMS) deposit

STRATUS CONSULTING

Volcanogenic Massive Sulfide



Galley et al., 2007, Geol. Assn. Canada, Mineral Deposits Div., Spec. Pub 5.

Table 2. Mineralogical and metal associations of massive sulfide deposits

	Noranda	Kuroko	Cyprus	Besshi	Bathurst	Sed-Ex
Major metals	Fe, Cu, Zn, (Al)	Fe, Zn, Pb, Cu, (Al)	Fe, Cu	Fe, Cu, Zn, (Al)	Fe, Zn, Pb, (Al)	Fe, Zn, Pb, (Al)
Minor metals	Pb, Cd, As, Ag, Au	Cd, As, Ag, Au	Zn, Cd, Pb, Ag, Au	Pb, Cd, Ag, Ag	Cu, Cd, As	Cu, Cd, Ag
Dominant Fe sulfide	py≥po	py	py	po≥py	py	py≥po
Major ore Sulfides	cpy, sph	sph, gn, cpy	cpy	cpy, sph	sph, gn	sph, gn
Minor sulfide	apy, td	apy, cs, cb, po, td	po, sph	apy, cb, gn, td	cpy, po, apy	apy, cpy, st, td
Primary sulfates	ba	ba, anh			ba	ba
Minor carbonates	sd, cal	cal, dol, sd	cal	ank, cal	cal	cal, dol
Secondary sulfides	en, cv, cc-dg, mc	ac, cv, en	bn	mc, cv, cc-dg		mc
Secondary alkaline earth sulfates	ba, anh	ba, anh		ba, anh		ba, anh
Secondary metal sulfates	ang, gos, hal-pk, mel, roz, cop	ang, gos, aln, chc, eps, hal-pk, mel, roz, cop	chc, eps, Cu-Mg mel, gos	ang, aln, gos, hal-pk, mel, roz, cop		ang, gos, hal-pk, mel, roz
Secondary ferric hydroxide-hydrates	fer, goe, hm, sch, jar	fer, goe, sch, sc	fer, goe, sch	fer, goe, jar, sch		fer, goe

Abbreviations: py: pyrite; po: pyrrhotite; cpy: chalcopyrite; sph: sphalerite; gn: galena; apy: arsenopyrite; td: tetrahedrite-tennantite; cs: cassiterite; cb: cubanite; st: stannite; en: enargite; cv: covellite; cc-dg: chalcocite-digenite; mc: marcasite; bn: bornite; cal: calcite; dol: dolomite; ank: ankerite; sd: siderite; ba: barite; anh: anhydrite; ang: anglesite; gos: goslarite; hal-pk: halotrichite-pickeringite; mel: melanterite; roz: rozenite; cop; copiapite; aln: alunogen; chc: chalcanthite; eps: epsomite; fer: ferrihydrite; goe; goethite; hm: hematite; sch: schwertmannite; sc: scorodite; jar: jarosite.

Seal et al. (2002) USGS OFR 02-195

	Noranda	Kuroko
Major metals	Fe, Cu, Zn, (Al)	Fe, Zn, Pb, Cu, (Al)
Minor metals	Pb, Cd, As, Ag, Au	Cd, As, Ag, Au
Dominant Fe sulfide	py≥po	py
Major ore Sulfides	cpy, sph	sph, gn, cpy
Minor sulfide	apy, td	apy, cs, cb, po, td
Primary sulfates	ba	ba, anh
Minor carbonates	sd, cal	cal, dol, sd

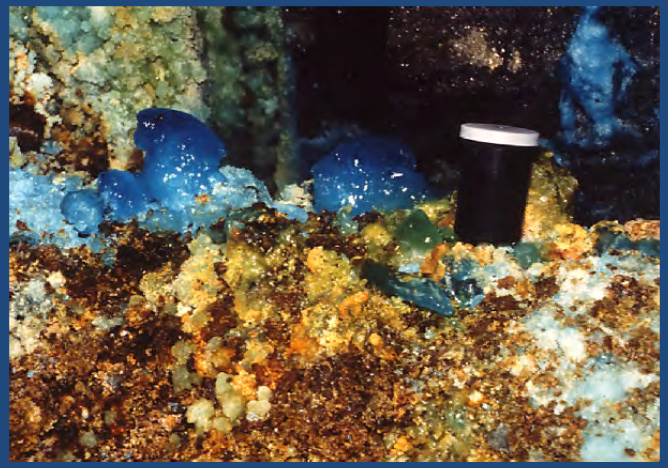
Seal et al. (2002)
USGS OFR 02-195

	Noranda	Kuroko
Secondary sulfides	en, cv, cc-dg, mc	ac, cv, en
Secondary alkaline earth sulfates	ba, anh	ba, anh
Secondary metal sulfates	ang, gos, hal-pk, mel, roz, cop	ang, gos, aln, chc, eps, hal-pk, mel, roz, cop
Secondary ferric hydroxide-hydrates	fer, goe, hm, sch, jar	fer, goe, sch, sc

Seal et al. (2002) USGS OFR 02-195

Secondary Sulfate Minerals, Iron Mtn., CA

Copiapite



Melanterite

Halotrichite

Seafloor Massive Sulfide Deposits – Associated Water Quality (1 of 2)

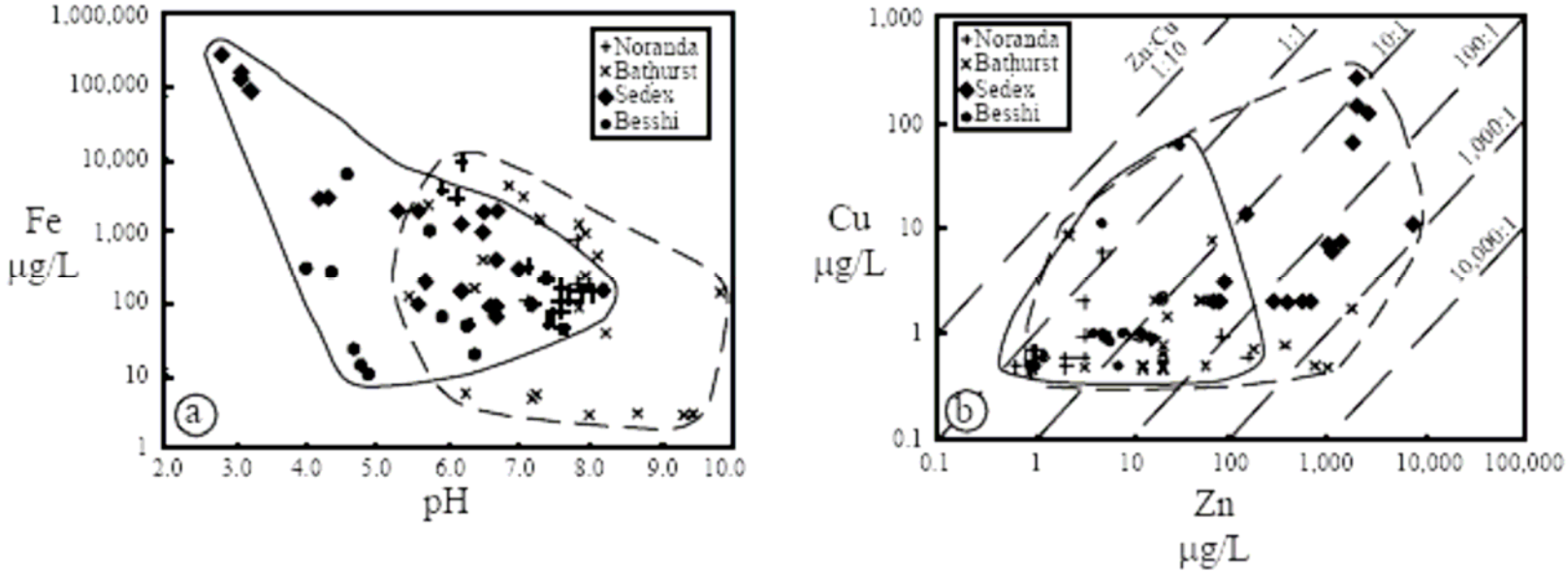


Figure 3. Natural background geochemical data for filtered ground and surface waters around massive sulfide deposits. a. Fe vs. pH. Data outlined by solid line are from deposits exposed at the surface; data outlined by dashed line are from buried deposits. b. Cu vs. Zn. Dashed lines represent Zn:Cu ratios (mass basis). Note that waters from Zn-rich deposits (Sedimentary-exhalative and Bathurst) range to higher Zn:Cu ratios than Cu-rich deposits (Noranda and Besshi).

Seal et al. (2002) USGS OFR 02-195

Seafloor Massive Sulfide Deposits – Associated Water Quality (2 of 2)

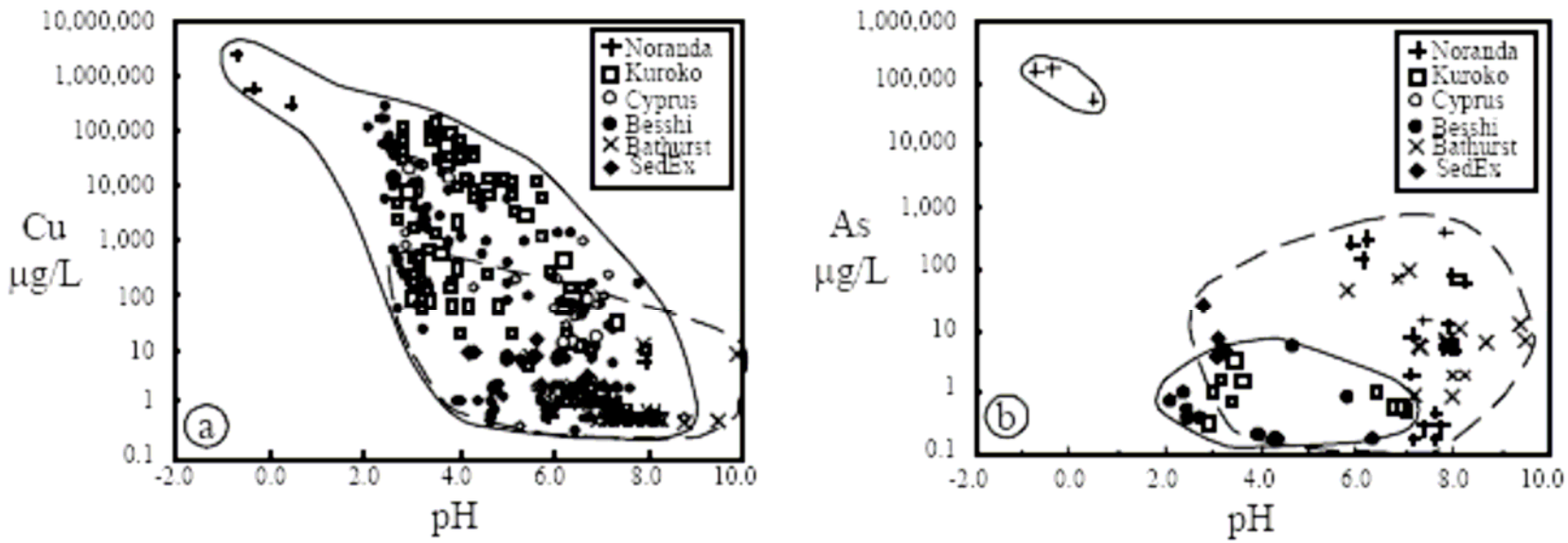


Figure 4. Comparison of filtered mine drainage waters with natural background waters. Data outlined by solid lines are mine drainage; data outlined by dashed lines are natural backgrounds. a Cu vs. pH. The general negative slope of the data is typical of most divalent metals. b. As vs. pH. Note that many of the natural background samples have higher As concentrations than the mine drainage samples.

Seal et al. (2002) USGS OFR 02-195

Figure A5. Map of California showing locations of mines that produced mainly mercury. Data from U.S. Geological Survey, Mineral Resource Data System (MRDS) database. Data set depicted is known to be incomplete with respect to small producers.

Distribution of Mercury Mines

Calif. Coast Range mines account for approx. 75% of Hg production in North America (1850s -1960s) (Rytuba, 2003)

From Ashley (1998) in DTSC Preliminary Assessment Handbook

Mercury Deposit Types

Deposit type	Common sulfide minerals	% sulfide in ore	Acid-buffering minerals
Silica-carbonate	cin, py, marc, stib, cp, sl	2-10	mag, dol, cal, serp
Hot spring	cin, marc, py	<1-5	none

Modified from Ashley (1998) in DTSC Preliminary Assessment Handbook

Mercury ore, cinnabar and native Hg

Altoona Mine, Trinity County, CA