

Geology of the Jamestown mine, Mother Lode gold district, CA, and geochemistry of the Harvard mine pit lake

By

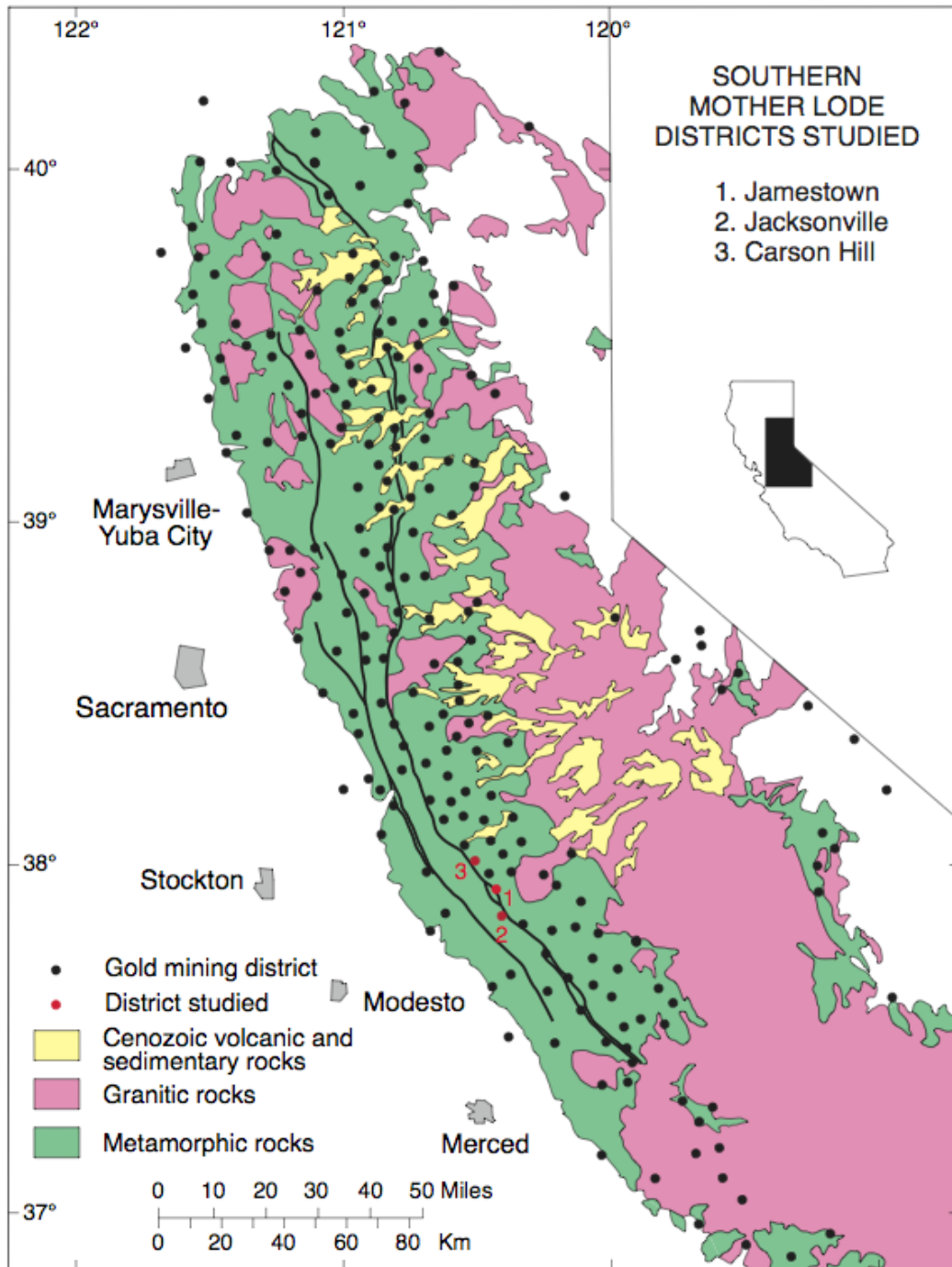
Kaye Savage, Roger Ashley, & Dennis Bird

Presenter: Roger Ashley

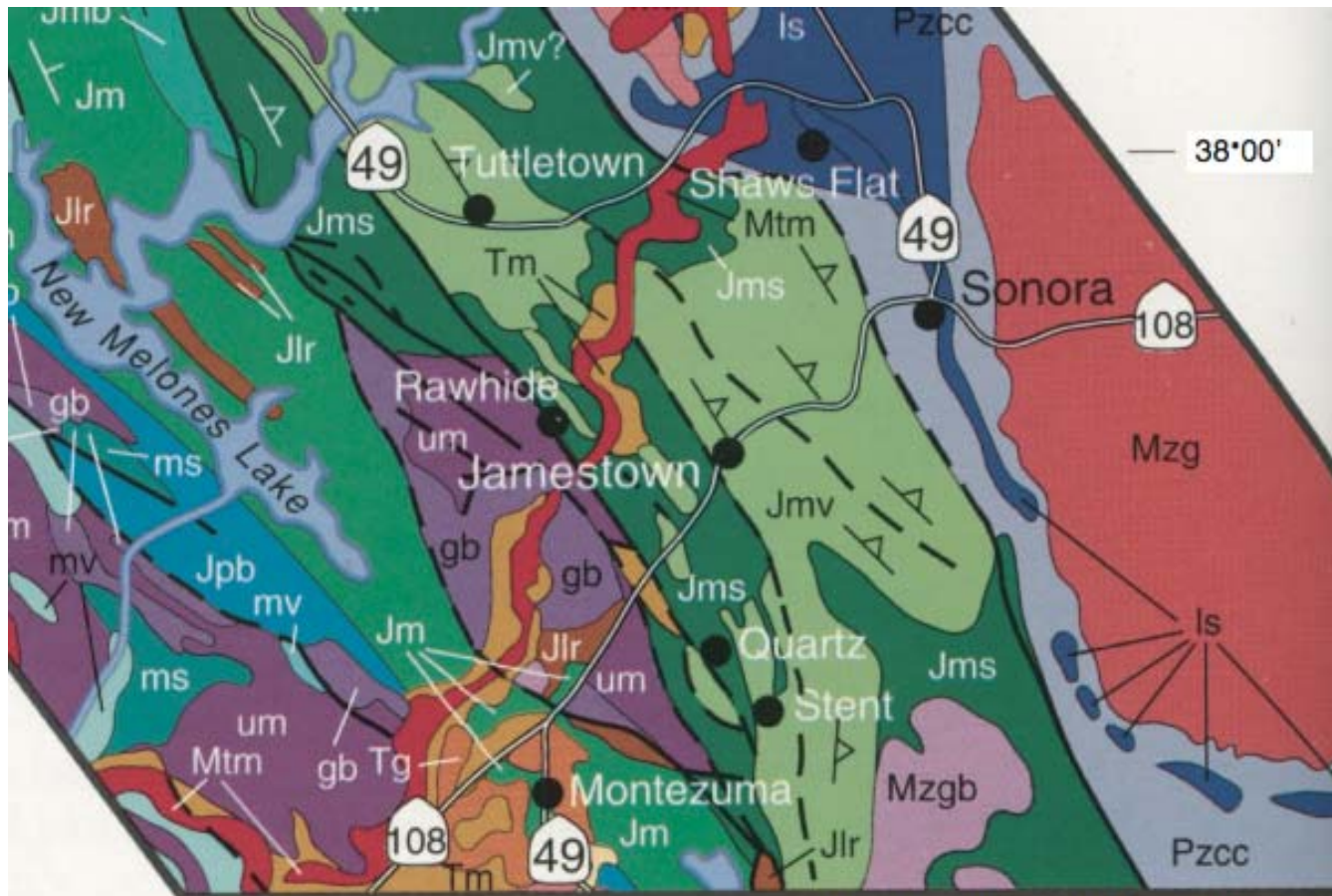


Outline

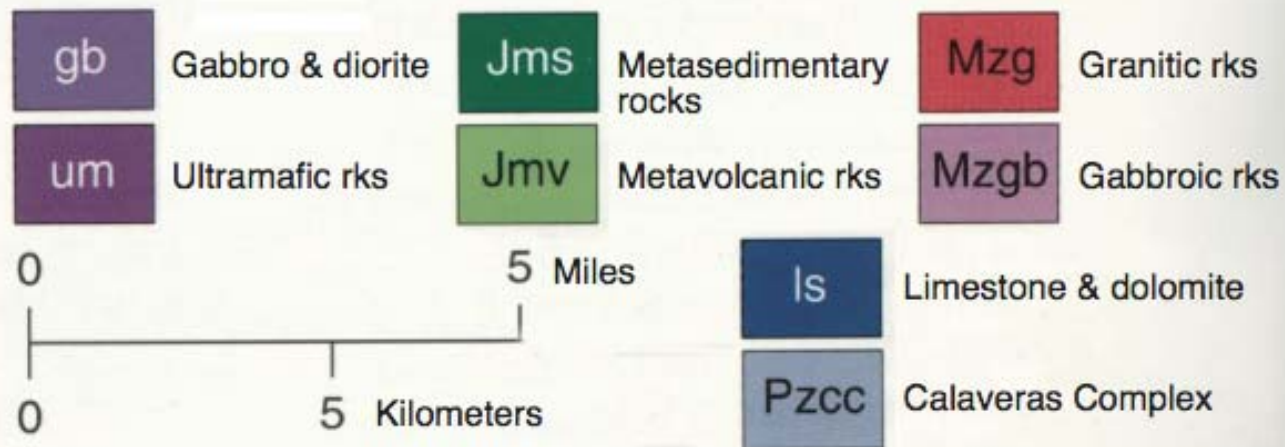
- Geologic setting
- Site geology
- Mineralogy of mined and processed materials
- Composition of pit lake water and major features of water chemistry
- Water chemistry modeling



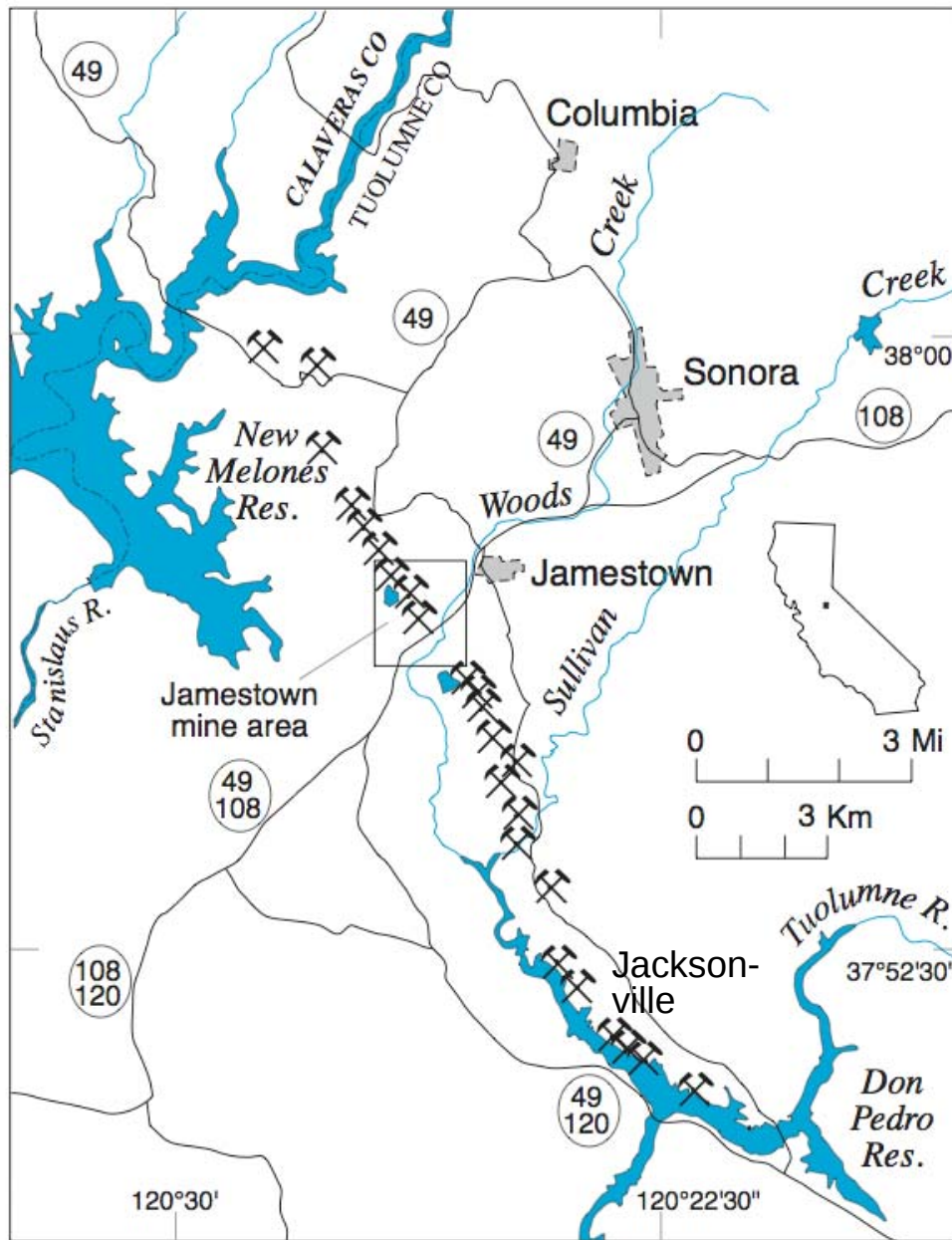
Geologic map
of the
Sierra Nevada
gold region,
California



From Bowen & Crippen, 1997



Geologic map
of the
Mother Lode
belt in the
Jamestown
area



Area map of
Jamestown and
Jacksonville
gold mining
districts,
Tuolumne County,
California

MINING HISTORY

Harvard, Crystalline, and Alabama mines

Discovery: 1848 (placers), 1859 (lodes)

Main mining period: 1890-1916

Production: 110,000-160,000 Toz (3.4-4.9 t) gold

Approximate amount ore processed:

330,000-1,100,000 tons (300,000-1,000,000 t)

Jamestown mine

Exploration-development periods: 1938-1942,
1974-1985

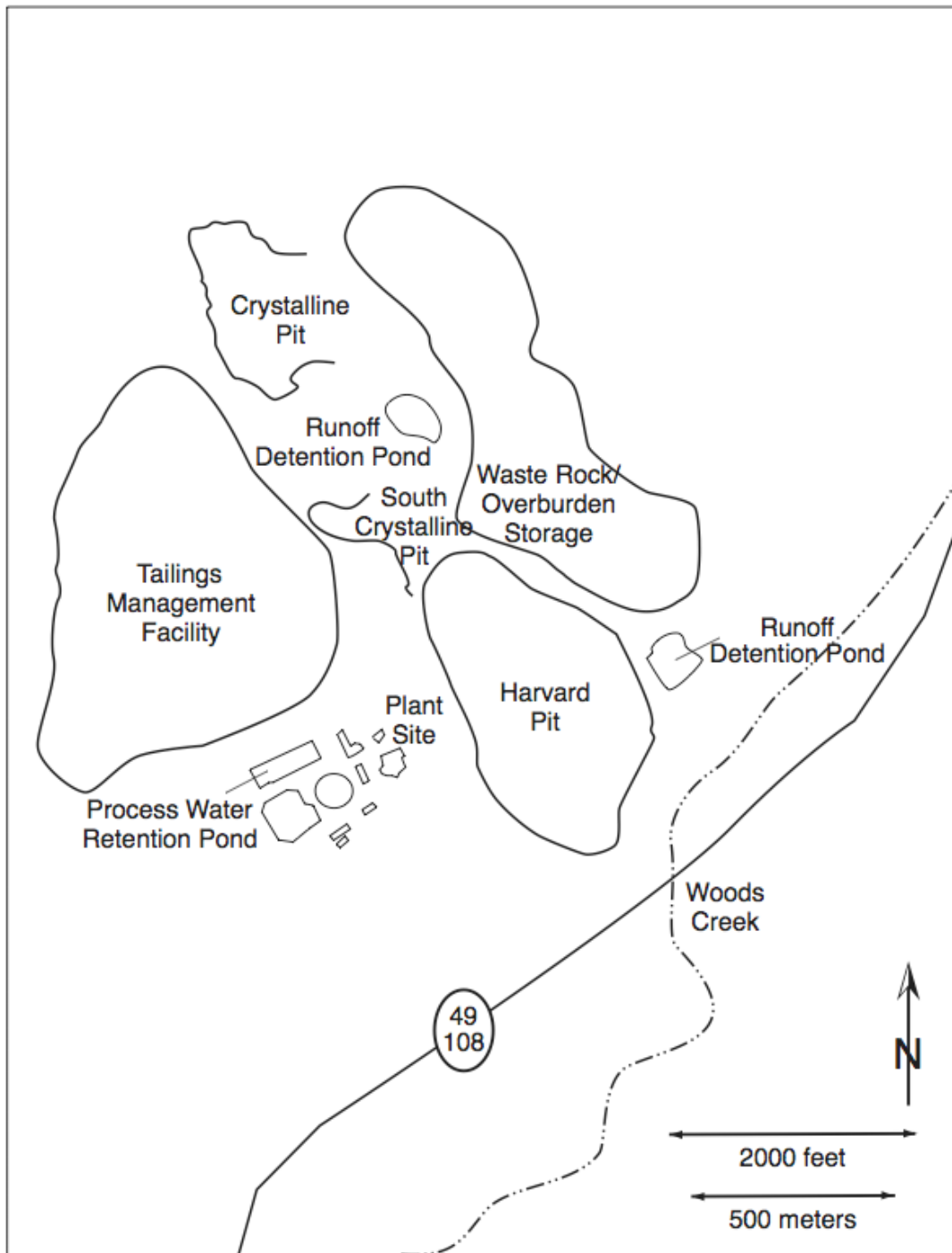
Mining period: (1986) 1987-1994

Production: 660,000 Toz (20.5 t) gold

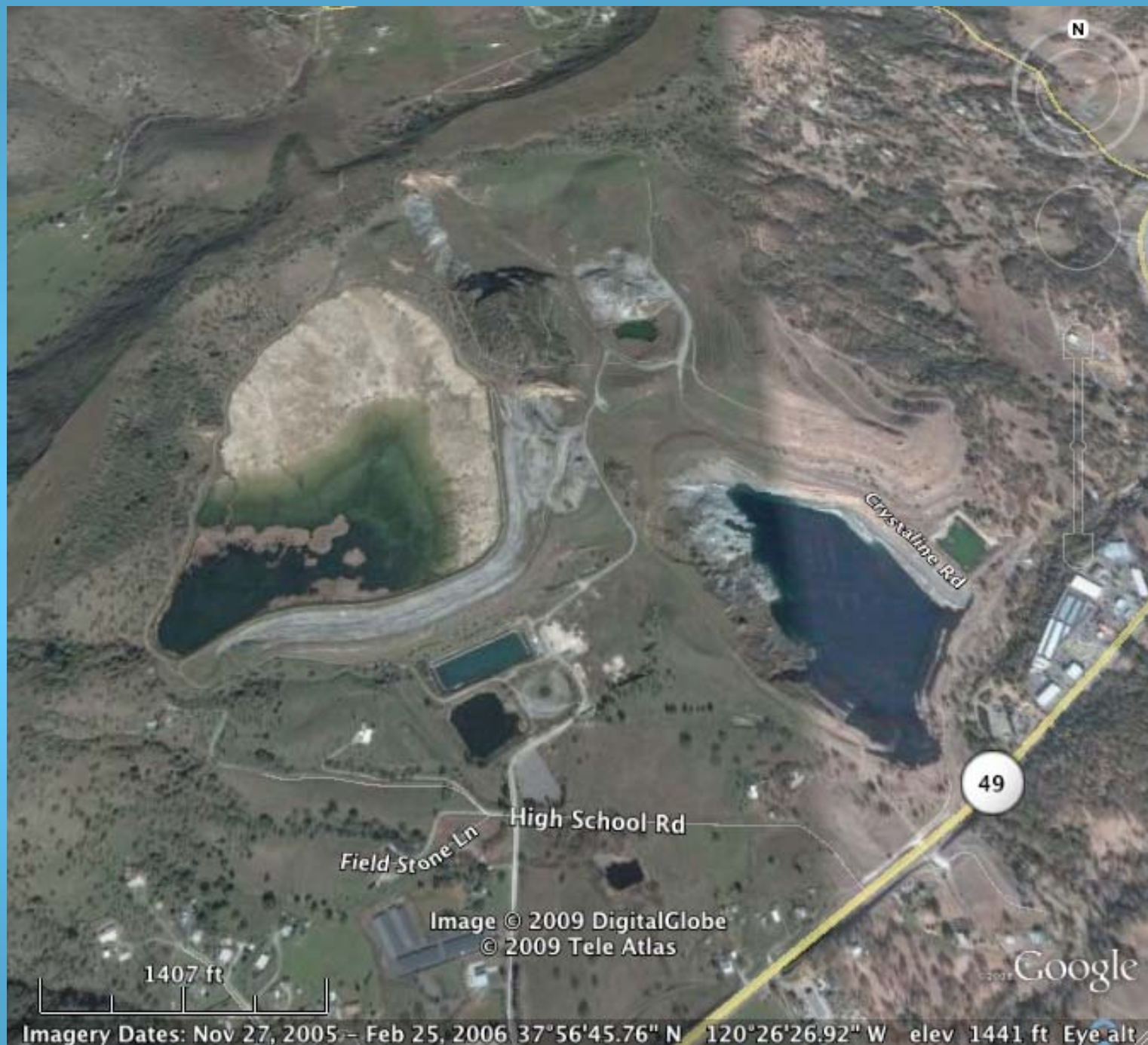
Ore processed: 10,500,000 tons (9,500,000 t)

Stripping ratio: > 4.15:1

Largest mass of gold recovered: 876 Toz (27 kg)

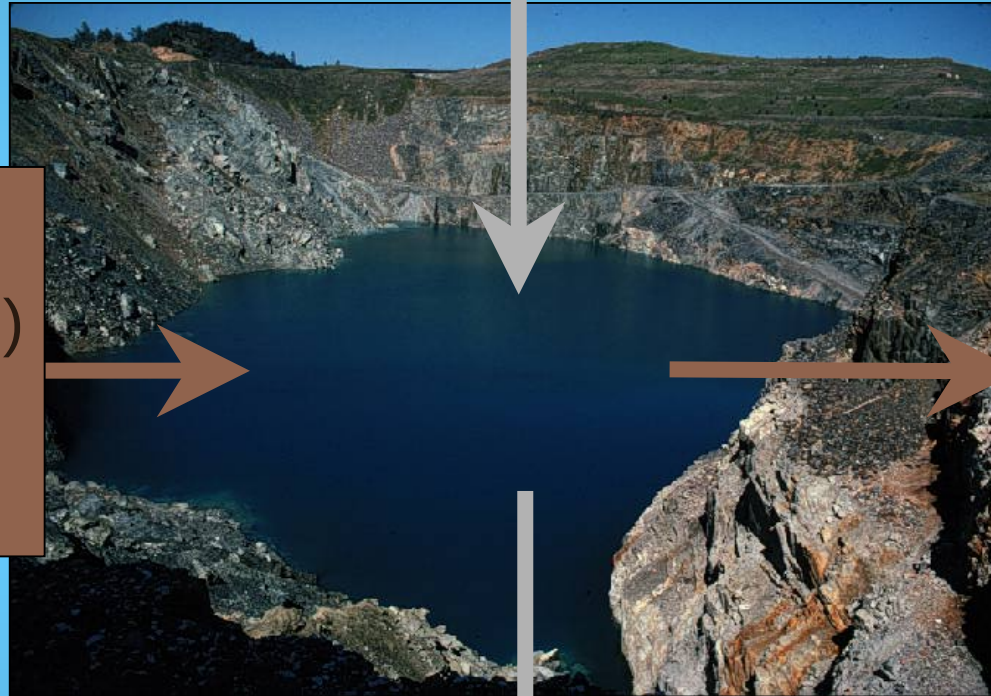


Jamestown
mine site
map,
Jamestown
district



- Water transfer
- Chemical mass transfer

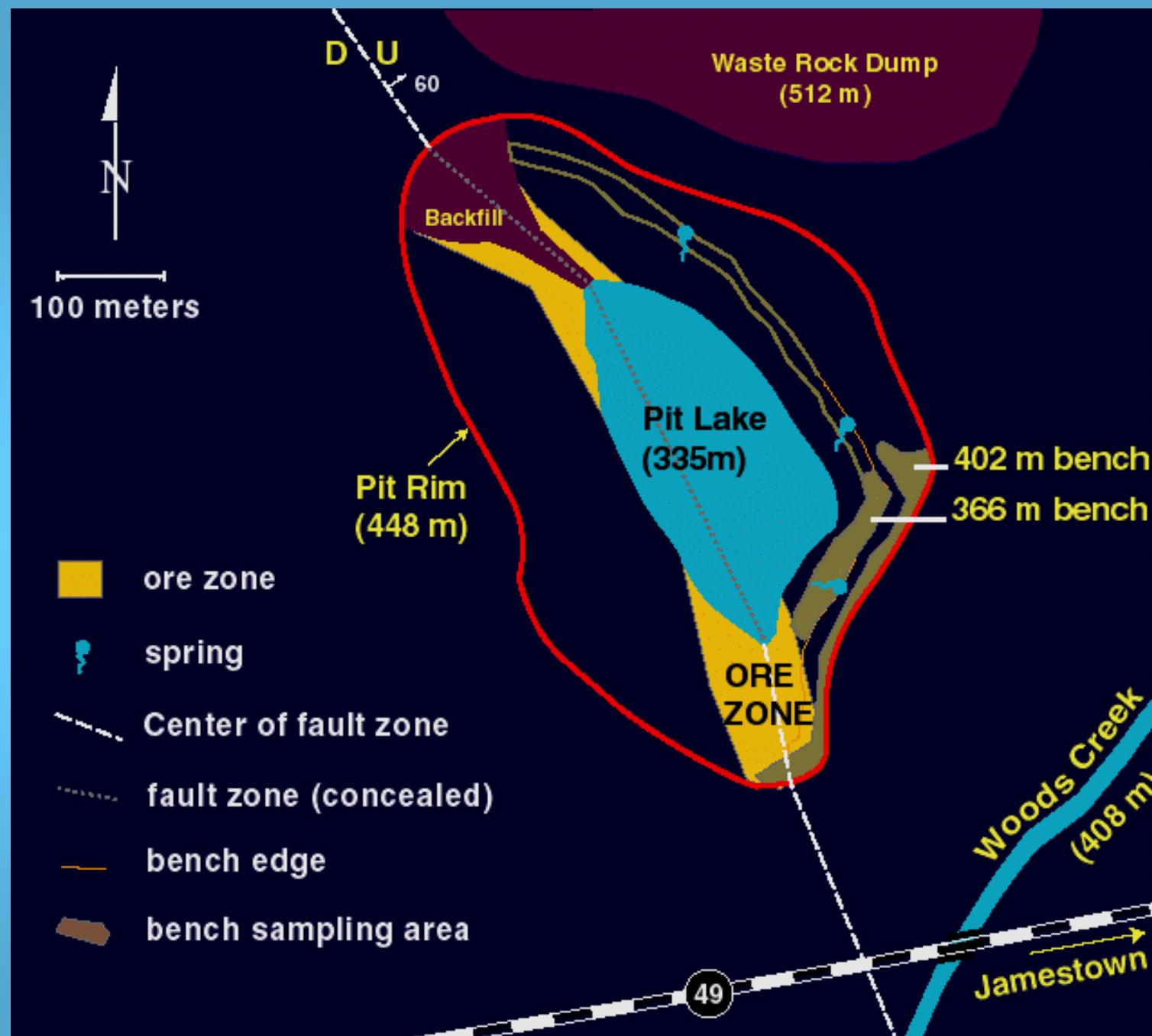
Precipitation
Runoff
Ground Water/Springs



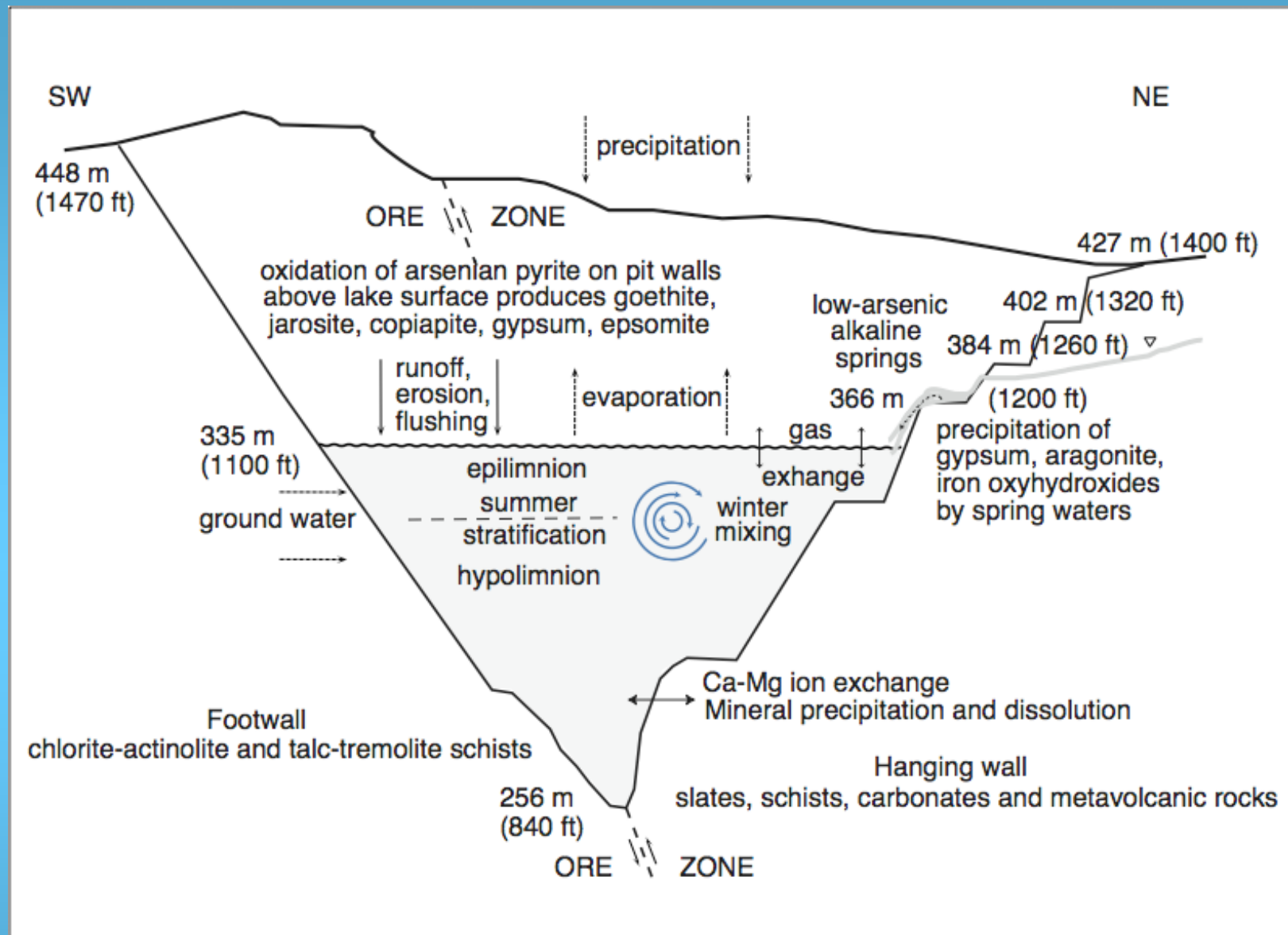
Pit Wall (direct)
Pit Wall (erosive)
Ground Water
Transfer Water

Settling
Sorption
Mineral
Precipitation
(Ground Water)

Evaporation
(Ground Water)



Harvard
pit



Schematic showing predominant influences on pit lake chemistry (from Savage et al, in press)



Pit wall mineralogy-major rock units

MINERALOGY

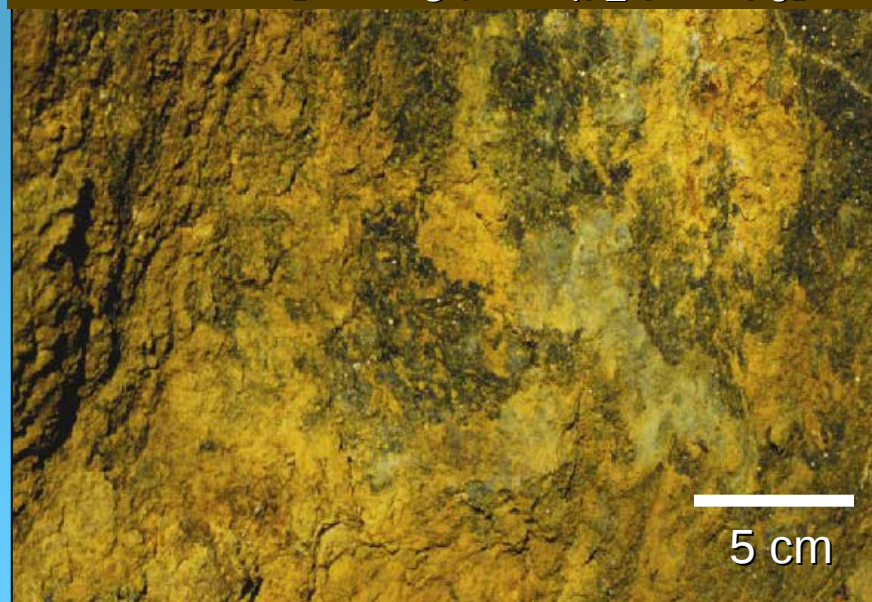
	Rock type	Silicates/other	Carbonates	Sulfides/metals
Hanging wall	Graphitic slate Metavolcanic Metavolcaniclastic	Quartz Albite Chlorite Sericite (Graphite)	Ferroan dolomite $\text{Ca}(\text{Mg,Fe})(\text{CO}_3)_2$ (Calcite CaCO_3)	Pyrite FeS_2
Footwall	Altered serpentine Diorite/gabbro	Talc Tremolite Actinolite Chlorite (Chromite)	Magnesite MgCO_3	Gersdorffite NiAsS (Niccolite NiAs) (Millerite NiS) (Cobaltite CoAsS)
Ore zone	Intermixed h.w. & f.w. rocks Quartz veins	Quartz Albite Mariposite Chlorite Sericite Talc	Ferroan dolomite Magnesite (Calcite)	Arsenian pyrite $\text{FeS}_{2-x}\text{As}_x$ Gold (Sulfosalts Cu-As,Sb-S) (Au-Ag tellurides)
Gossan	Ore zone & hanging wall	Goethite FeOOH Magnesiocopiapite $(\text{Mg,Fe})_4(\text{SO}_4)_6(\text{OH})_2 \cdot 20\text{H}_2\text{O}$ Jarosite $\text{KFe}_3(\text{SO}_4)_2(\text{OH})_6$ Gypsum $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ Hexahydrate $\text{Mg}(\text{SO}_4) \cdot 6\text{H}_2\text{O}$ (epsomite, pentahydrate, starkeyite) (Halotrichite, loewite, slavikite, weilite- CaHAsO_4)		



Magnesiocopiapite

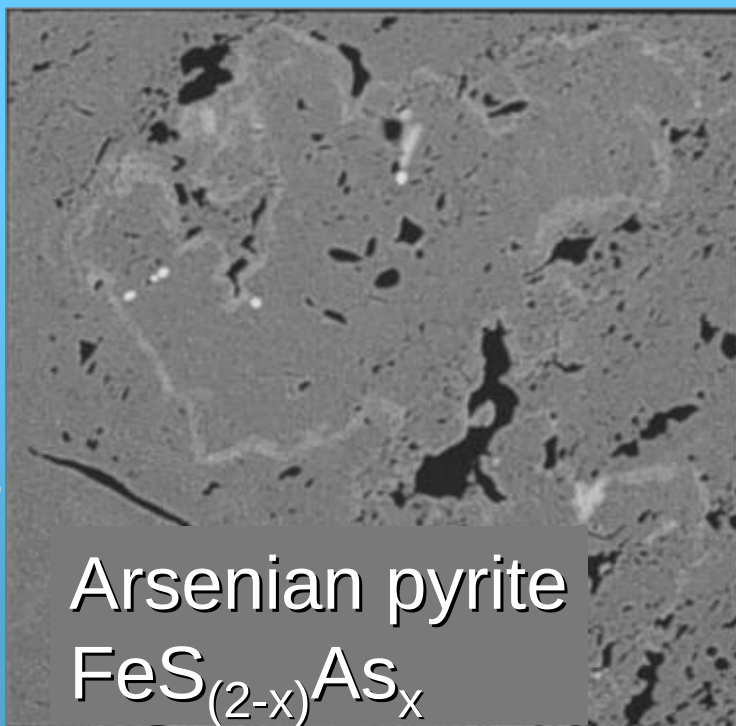


Jarosite: $[\text{KFe}_3(\text{SO}_4)_2(\text{OH})_6]$



5 cm

Mineral
sources
of
arsenic



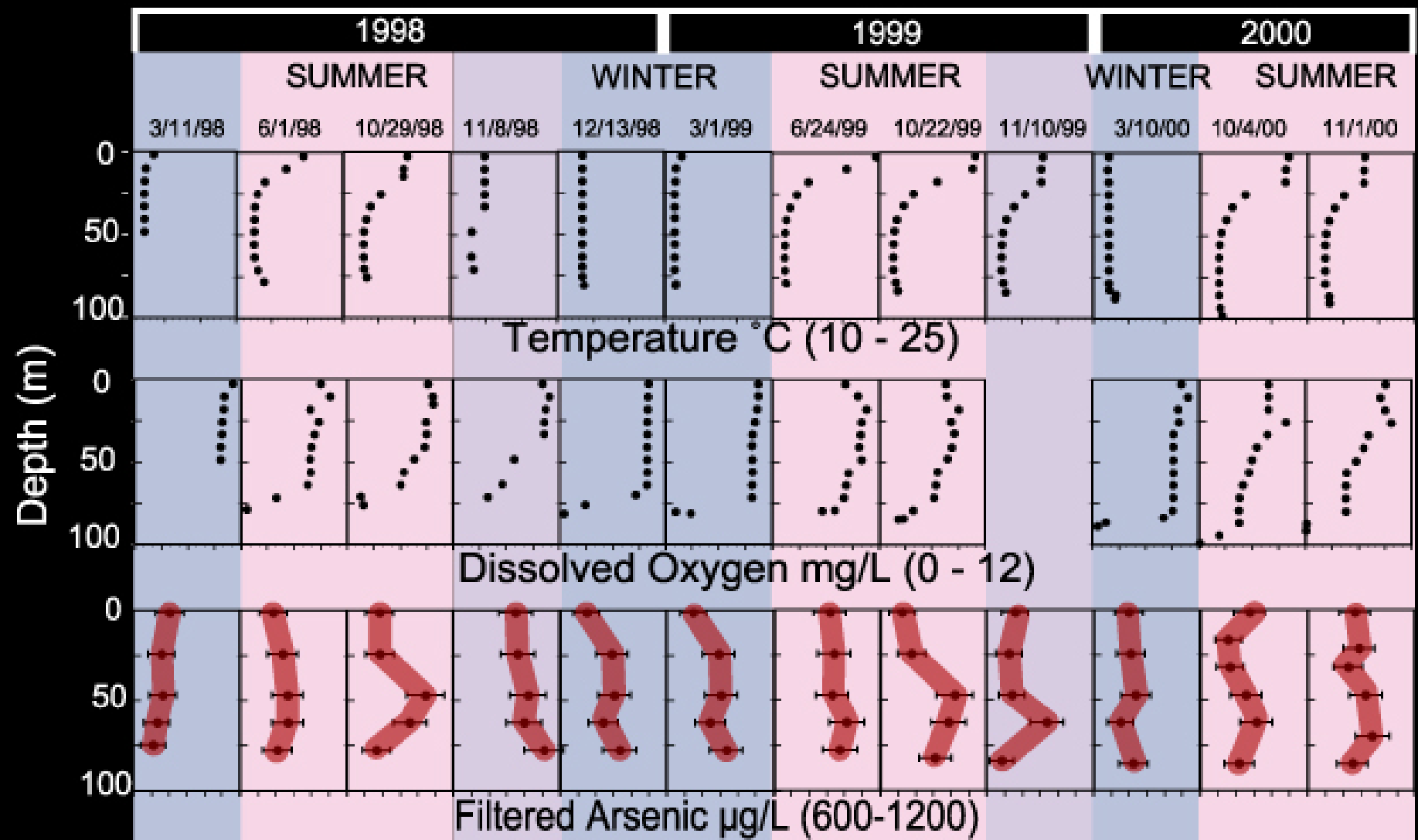
Arsenian pyrite
 $\text{FeS}_{(2-x)}\text{As}_x$

Goethite $[\alpha\text{-FeOOH}]$

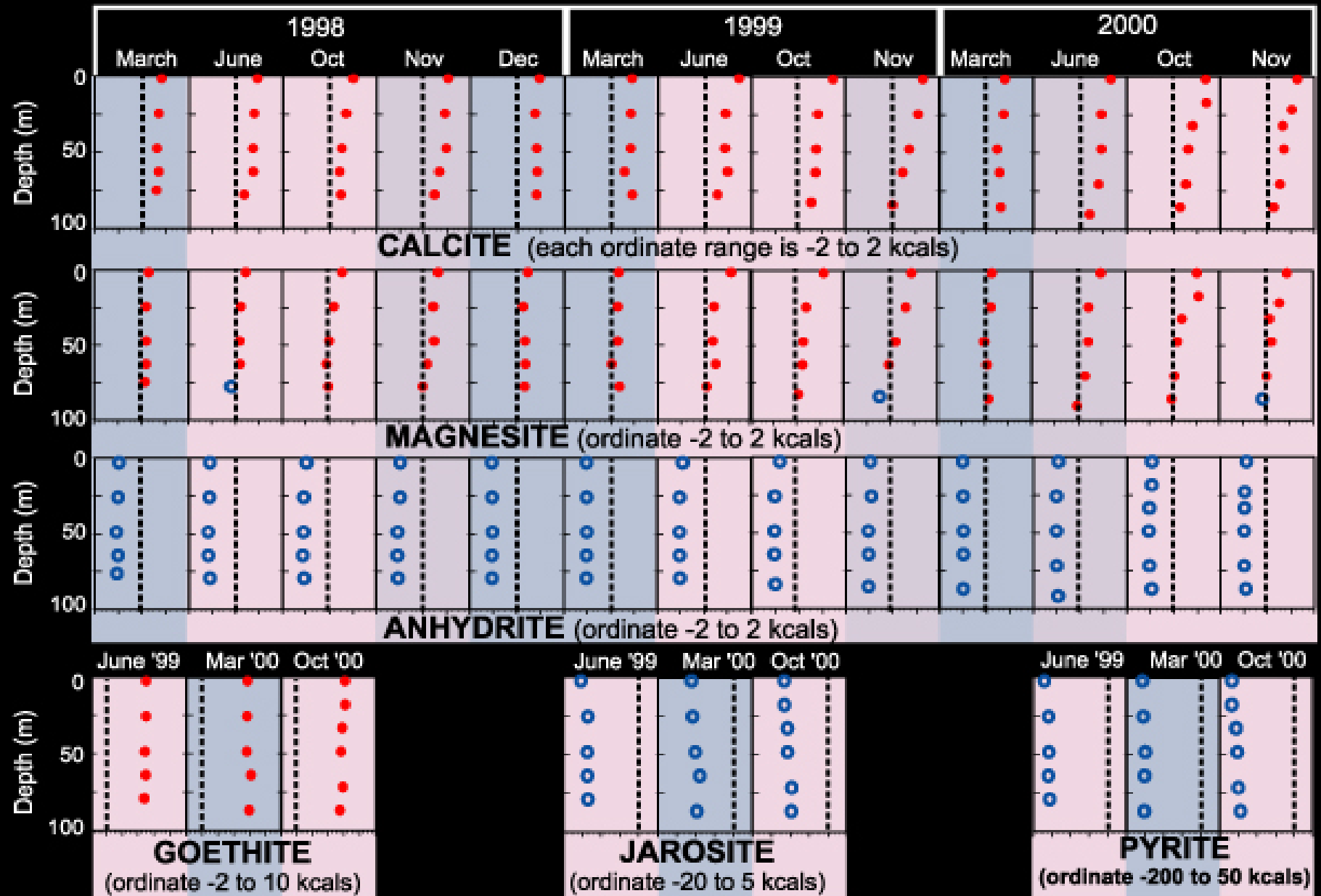


20 cm

Depth profiles: Temperature, dissolved oxygen and dissolved arsenic



Depth Profiles: Mineral saturation states



SUMMARY

1. Deep groundwater and weathering of arsenian pyrite along fracture zones extending away from the ore zone are the most likely sources of pit lake arsenic.
2. Calcite and magnesite are saturated or supersaturated. Pyrite, jarosite, anhydrite and arsenic phases are undersaturated. Arsenic mobility in the pit lake is promoted by the alkaline pH, buffered by carbonate wall rocks.
3. Arsenic from arsenian pyrite in the Harvard Mine ore zone is transferred into weathering products, including jarosite, goethite and copiapite. Seasonal winter storms wash soluble arsenic-bearing phases into the Harvard Mine pit lake, causing seasonal arsenic concentration spikes.

Hydrogeochemical modeling

Conditions and composition evaluated for each seasonal period:

$$V_{t+sp} = V_t - E_{sp} + P_{sp} + S_{sp} + G_{sp}$$

- V_{t+sp} = ending volume, from Arcview model derived from 1995 mine map
- V_t = starting volume (Arcview model)
- E_{sp} = evaporation, from New Melones Lake Station (daily), surface area of lake from Arcview model
- P_{sp} = precipitation, from Sonora RS gauge (daily); proportions of runoff and direct addition to lake surface unknown
- S_{sp} = springs, flows from field observations
- G_{sp} = ground water, unknown
- Optimization calculation to determine values for unknowns: volume of precipitation per inch rain, volume of ground water per day

Hydrogeochemical modeling

Water compositions used in model runs

- Precipitation: analysis of rainwater collected 4 km SE of pit
- Spring water: analysis of a selected spring water sample having major element composition close to median for all spring samples (24)
- Ground water: could not be sampled directly; samples near lake bottom may be dominated by influent ground water but extent of mixing with overlying lake water unknown
 - Initial composition from computationally dissolving calcite (80 mol%), magnesite (18 mol%) and siderite (2 mol%) incrementally in pure water to calcite saturation, reacting it with 5:1 pyrite-arsenian pyrite mixture and O_2 , equilibrating with atmospheric O_2 and amorphous $FeOOH$, and setting pCO_2 to that of hypolimnion calculated from measured water compositions.
 - Adjusted composition (Ca, Mg, CO_2) in response to tests of forward mixing models.

PHREEEQC used for geochemical calculations

- Inputs facilitated by using Excel spreadsheets (seasonal epilimnion and hypolimnion volumes and water fluxes, reaction rates, etc.) copied to text files for the actual runs

Lake chemistry modeling stages

1. Consider only processes directly related to gain or loss of water mass:
 - Direct precipitation
 - Runoff
 - Evaporation
 - Ground water flow, spring water
2. Add processes that affect chemical composition of pit lake water with little mass change:
 - Wall rock reactions (mineral precipitation, dissolution, ion exchange)
 - Chemical weathering and erosion, resulting in transport of dissolved and suspended materials into the lake
 - Dissolved gas fluxes

Modeling stages, continued

3. Apply results of Stage 2 model to predict evolution of composition
 - Repeat the annual seasonal cycle (stratification-evaporation-flush-mixis-rain)
 - Implement forward modeling by using results at the end of each seasonal event as input for the next step
 - Model adjusted to simulate 1998-2000 observed trends
 - Starting condition: March 1998
 - Model calculations carried forward through October 2004 for comparison with water sampled at that time

Modeling results

Performance of forward model carried through four seasonal cycles

- Detailed results shown in two figures included in field trip handouts
- Model predicts concentrations of major components reasonably well, but depends upon charge balance adjustments
- Not so good for arsenic concentrations, which probably depend mainly upon arsenic supply
- Departures of calculated from actual values may be related to:
 - Event timing, especially for the epilimnion?
 - Inadequate hydrologic model?