

19.7 grams



36 grams

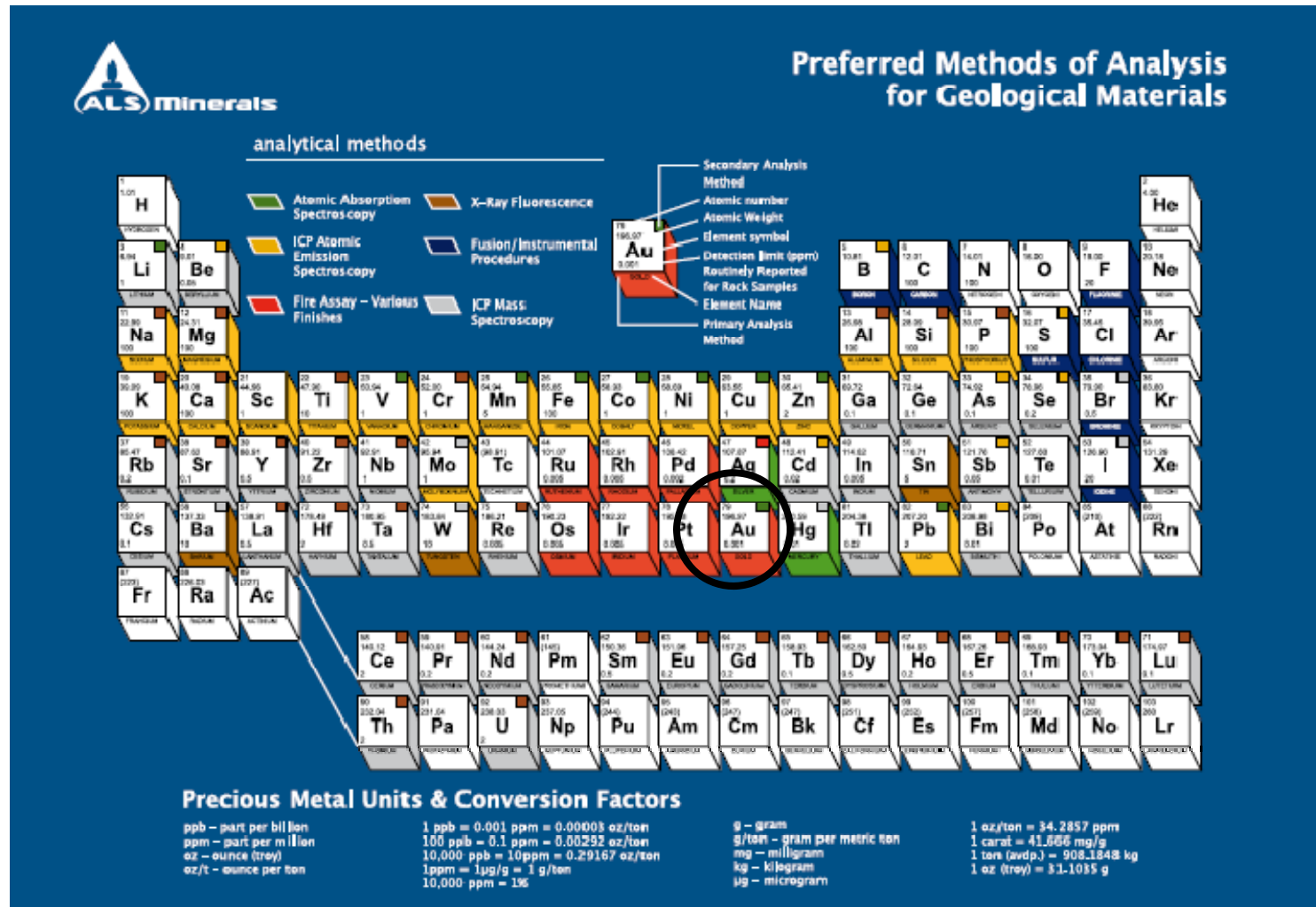
Gold Nuggets

Evidence of past climates and former landscapes.



*Odin Christensen – Hardrock Mineral Exploration
April 2014*

GOLD!



Atomic Number: 79
Specific Gravity: 19.32

Average crustal abundance: ~2.5 ppb
Average fresh water abundance: ~0.03 ppb

Units and conversions used when speaking of gold

1 gram/tonne = 1 ppm

(typical grade of many large-scale gold deposits!)

1 troy ounce = 31.1 grams

1 oz (troy) per short ton = 34.287 grams/tonne

1 troy ounce gold is valued ~\$1300

1 gram gold is valued ~\$42

“Large” gold deposit = 100 tonnes = 3.2 million ounces Au

“Giant” gold deposit = 1000 tonnes = 32 million ounces Au

“Fineness” is the amount of elemental Au in native Au metal, per mil.





*Gold nugget, about 6" long
American Museum Natural History.*



*Welcome Stranger Nugget
2284 oz ~71 kg*

“With gold nuggets like this, there has to be one heckava giant lode deposit upstream in this valley”



or maybe not.....



12 pounds

“Common Knowledge”

- Gold nuggets that are rounded, hammered and worn are far traveled;
- Gold nuggets with delicate crystal forms or attached quartz are close to their bedrock source.



or maybe not.....

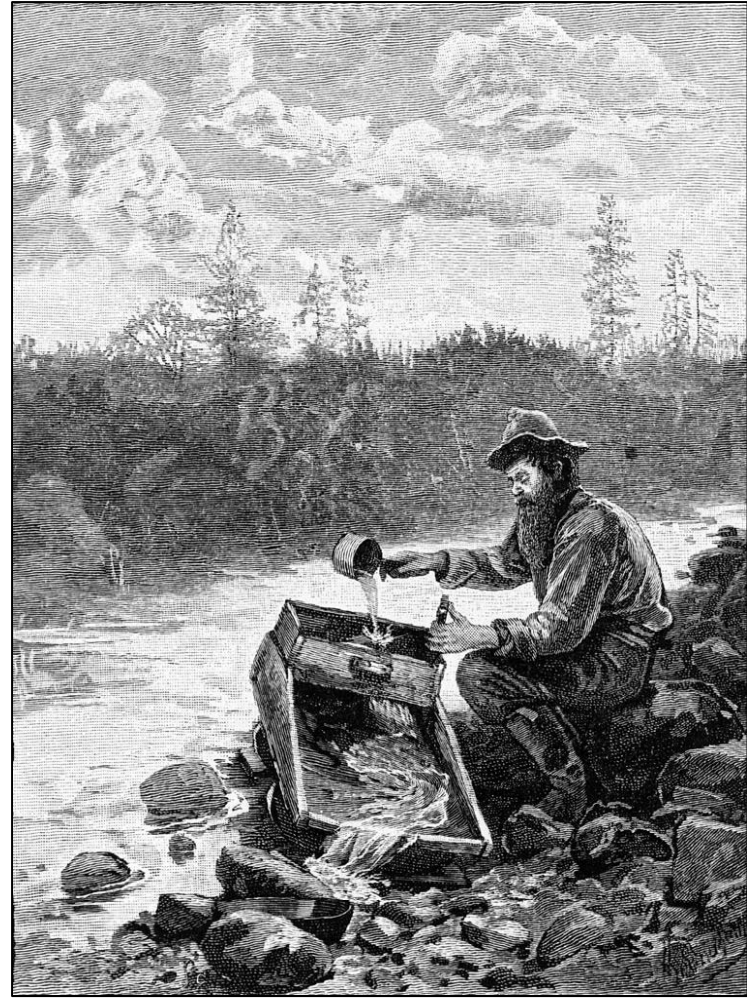


*Residual or eluvial gold placer – in place
Bolivia*

*Alluvial gold placer – transported
California*



The California Gold Rush ~1849

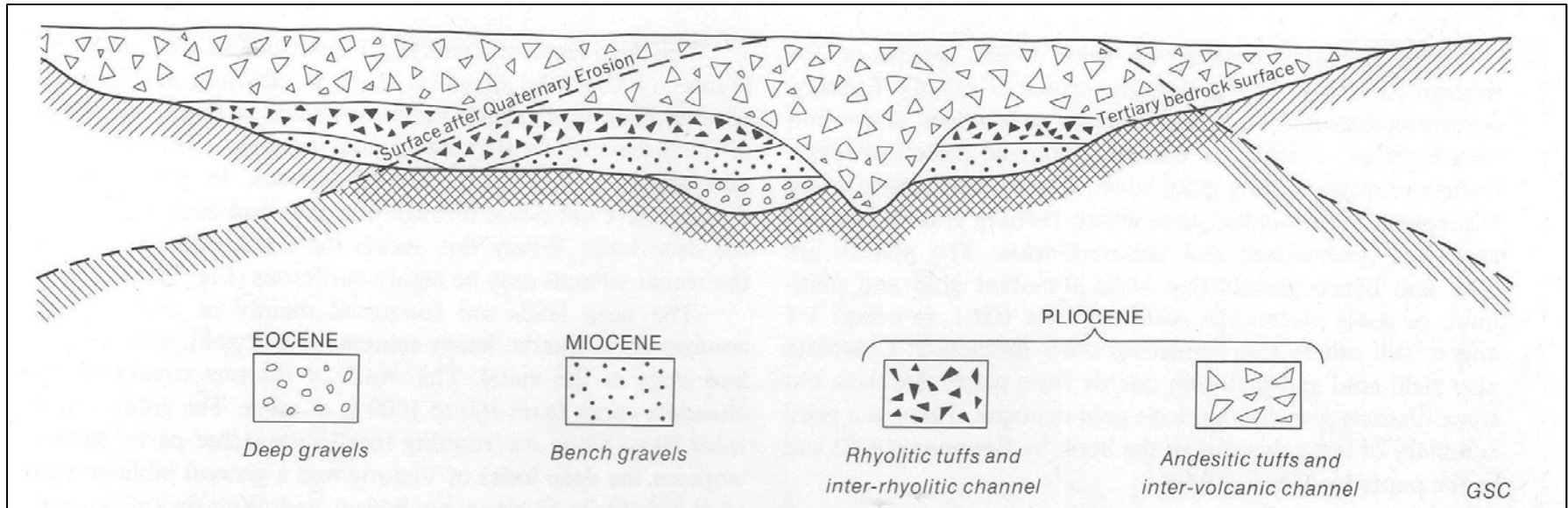




Hydraulic mining ~1870's

*Yuba dredge and aerial view
of Yuba Goldfields - 1990's*





Schematic presentation of the principal epochs of Tertiary gravels in the Sierra Nevada, California (Lindgren, 1911)



Malakoff Diggings State Park

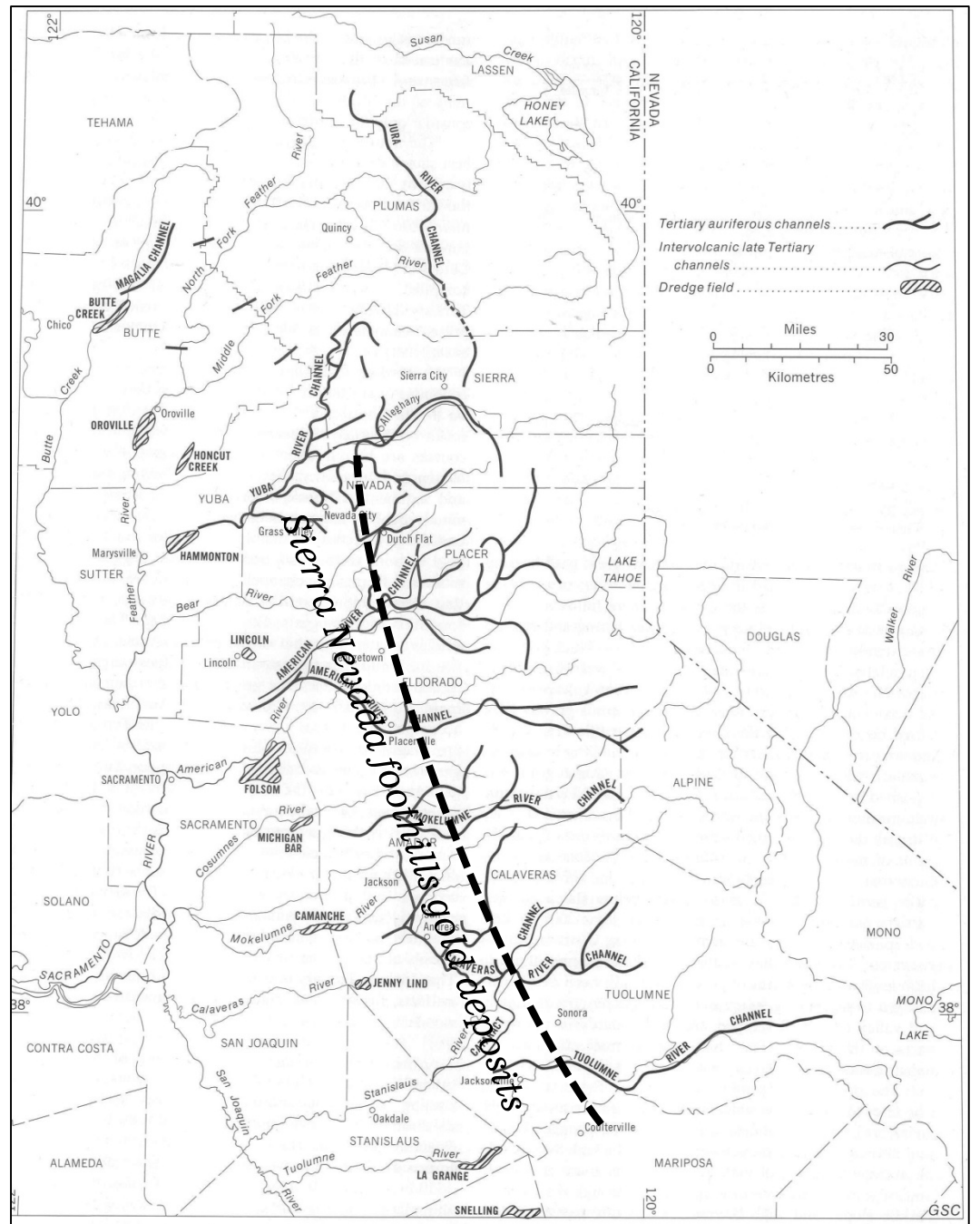


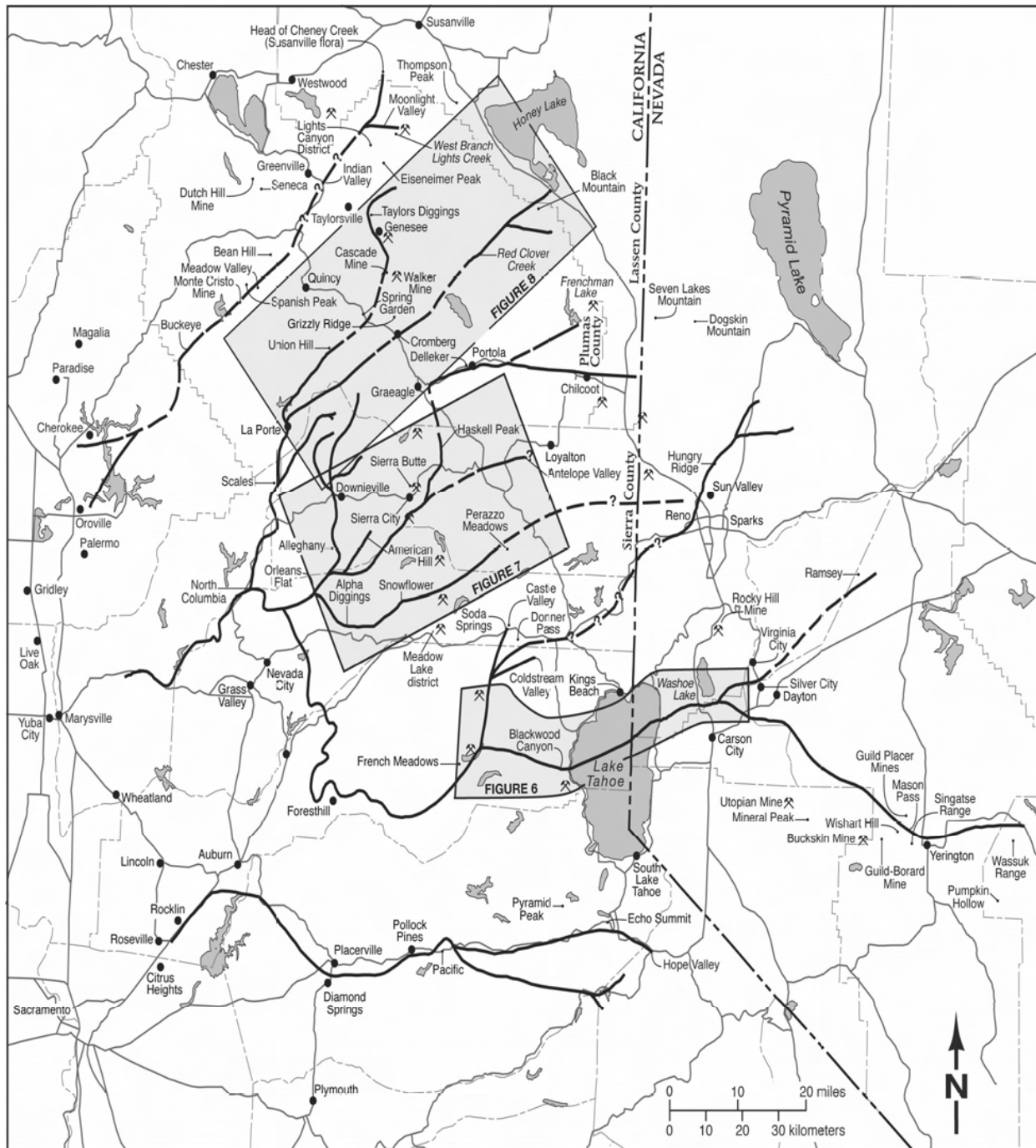
Auriferous channel gravels
and recovered gold nuggets
Ruby Mine, Sierra County, CA



Map of Tertiary channels and dredge fields, Sierra Nevada, California.
(Lindgren, 1911)

Total placer gold production ~55 million troy oz
Total lode gold production ~ 32 million troy oz





Traces of known and interpreted Eocene paleovalleys in eastern California and western Nevada.

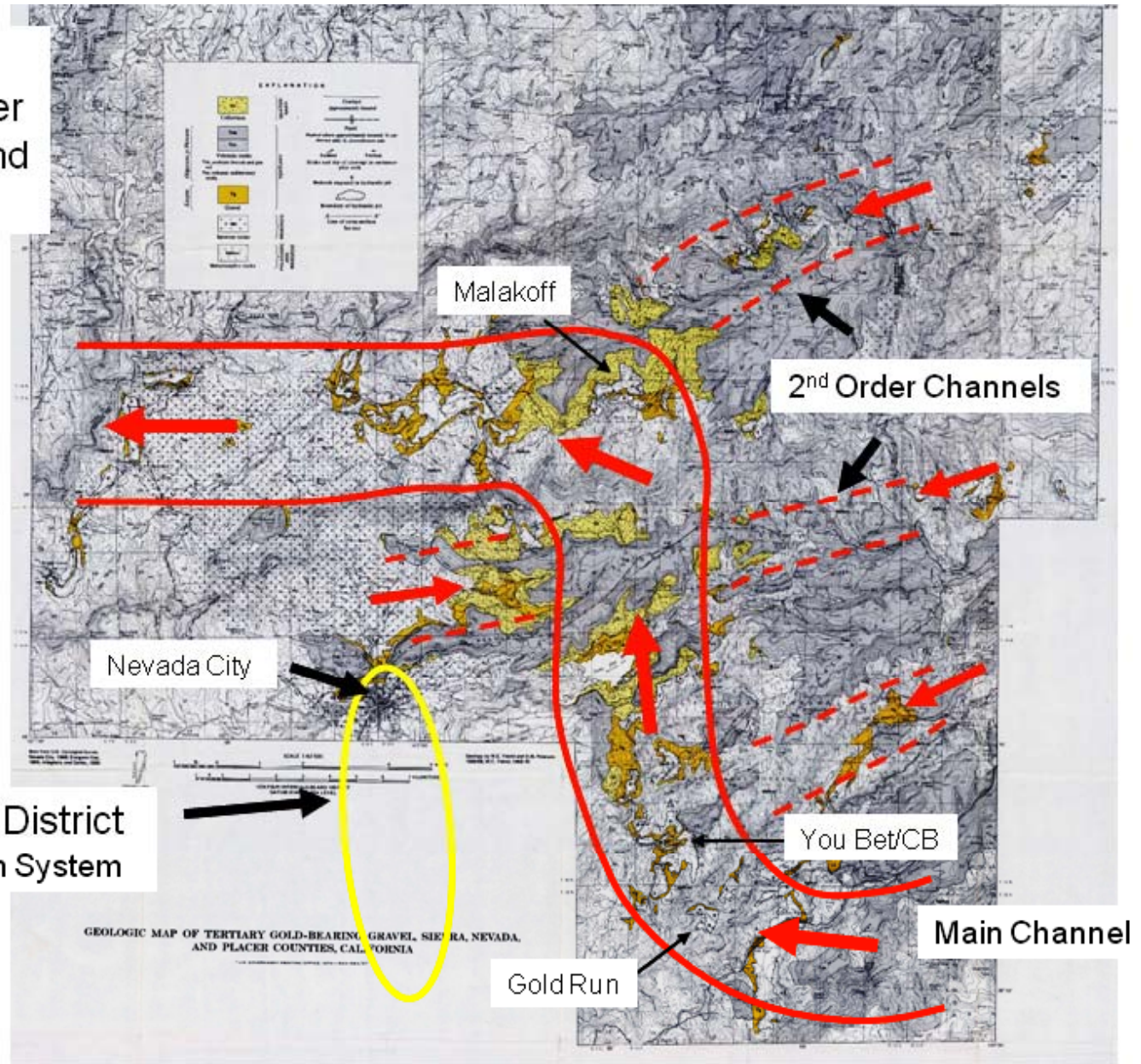
from Garside and others, 2005. GSN Window to the World.

Early Tertiary Ancestral Yuba River System in Placer and Nevada Counties

1st Order and 2nd
Order channel
trends
popularized by
others

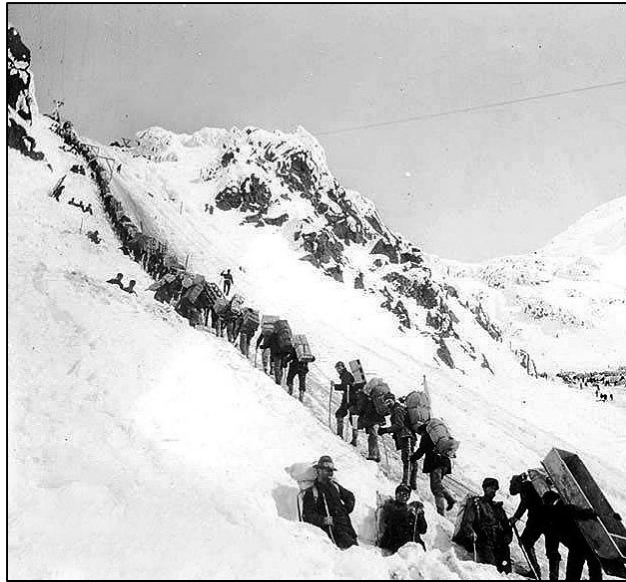
Grass Valley Mining District
ie., Mother Lode Gold Vein System

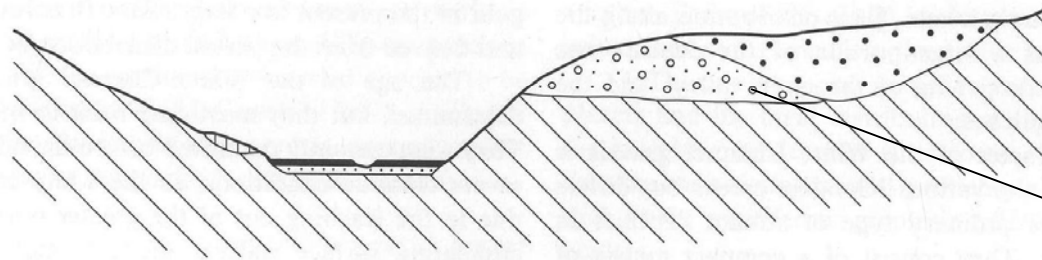
Base Map
Yeend, 1972



Interpretive map by Jim Woods, 2014

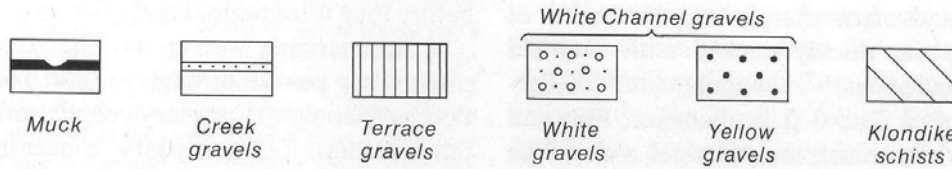
The Klondike Gold Rush ~1898



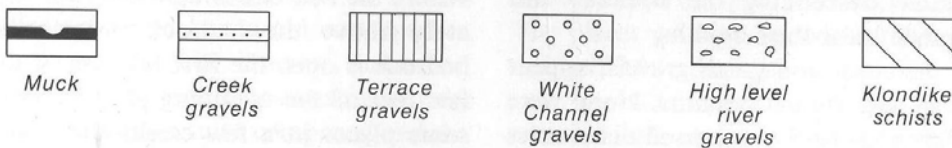
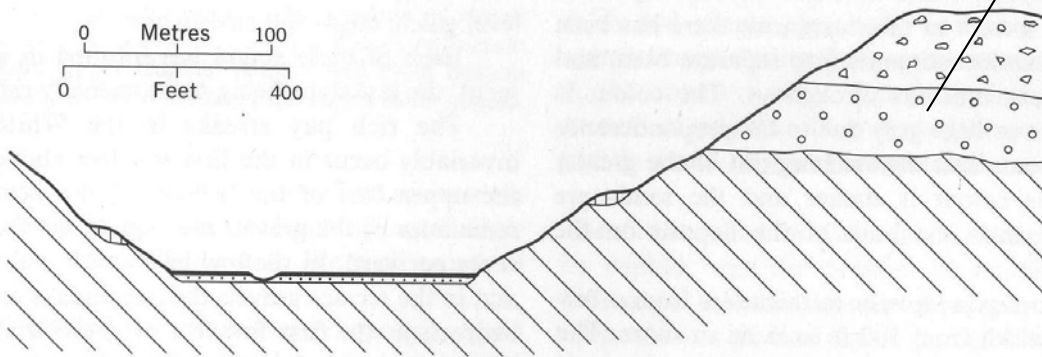
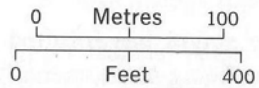


*White Channel
Gravels – Tertiary
gravels >3Ma*

*May have
contained 60
million ounces Au.*



Section across Bonanza Creek valley below Eldorado Forks



Section across the lower part of Bonanza Creek valley


G S C


Figure 77 Generalized sections across the placer deposits of Bonanza Creek, Klondike (Dawson) district, Yukon (after McConnell, 1907).


139° 35'
64° 07'


138° 15'
64° 07'


LEGEND


 Mainly stream, river bottom and low-level bench placers (productive)


 Mainly stream, river bottom and low-level bench placers (marginal)


 High bench placers (mainly in the White Channel gravels)


 Mainly Tertiary river and stream deposits: includes the auriferous high-level White Channel gravels and some younger high-level gravels and sands

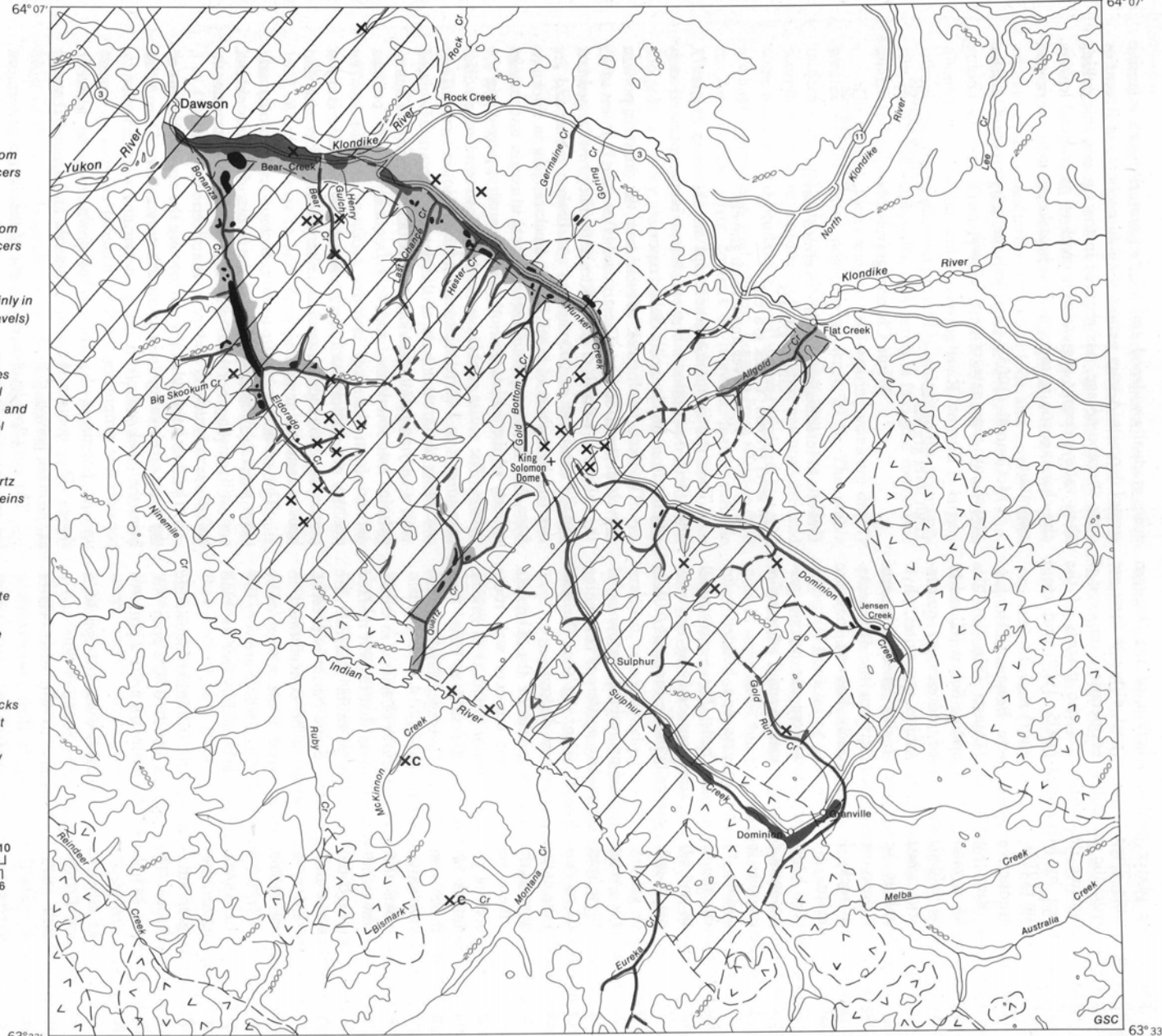
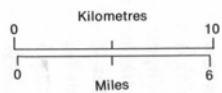
 Zones of auriferous quartz veins and polymetallic veins

 Tunnels, etc. in Tertiary conglomerates

 Klondike gneissic granite

 Klondike schist: sericite schist, chlorite schist, graphitic schist

 Mainly Yukon Group rocks (gneiss, quartzite, schist and slate) overlain by Tertiary and Quaternary alluvial deposits



63° 33'
139° 35'

63° 33'
138° 15'

GSC



Twin Creeks Mine – Humboldt Co. NV – Newmont Mining Corp. - 2012

Sedimentary rock-hosted disseminated gold deposits ("Carlin-type" deposits)

"Replacement-type deposit". Probably better described as a trace residue of gold left in rock following passage of hydrothermal fluid and rock alteration.

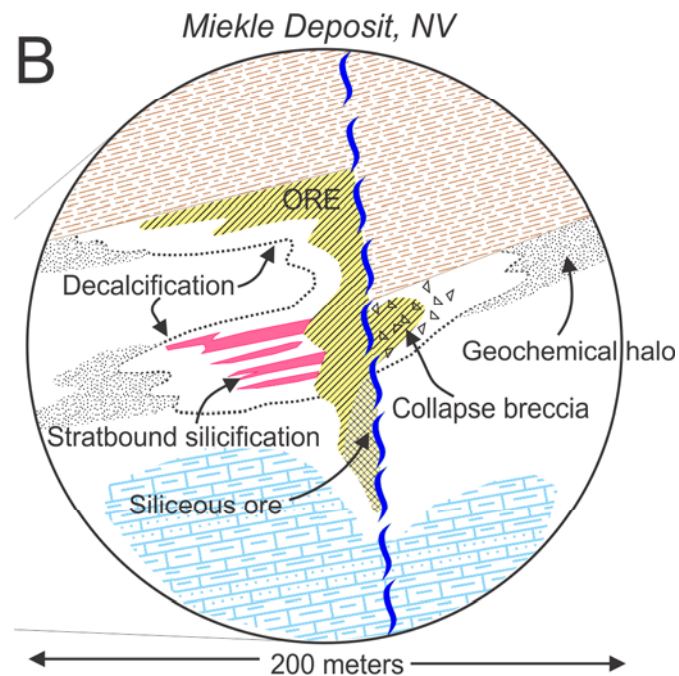
Host Rock: Carbonate sedimentary rocks, esp. thin-bedded silty limestone and marl.

Feeders and Traps: Thrust fault aquitard, anticlinal hinge zones, sedimentary breccia, fault breccia.

Alteration: Carbonate dissolution, argillization, sulfidation (pyrite), silicification

Geochemistry: *Added:* S, As, Au, Sb, Hg, Tl. *Removed:* CO₃, Ca, Mg, Sr, Mn, Na

Age: In Nevada 42-36 Ma (Eocene)



Perhaps the most distinctive attribute of Carlin-type gold deposits around the world is the occurrence of gold within arsenical rims on fine-grained pyrite.

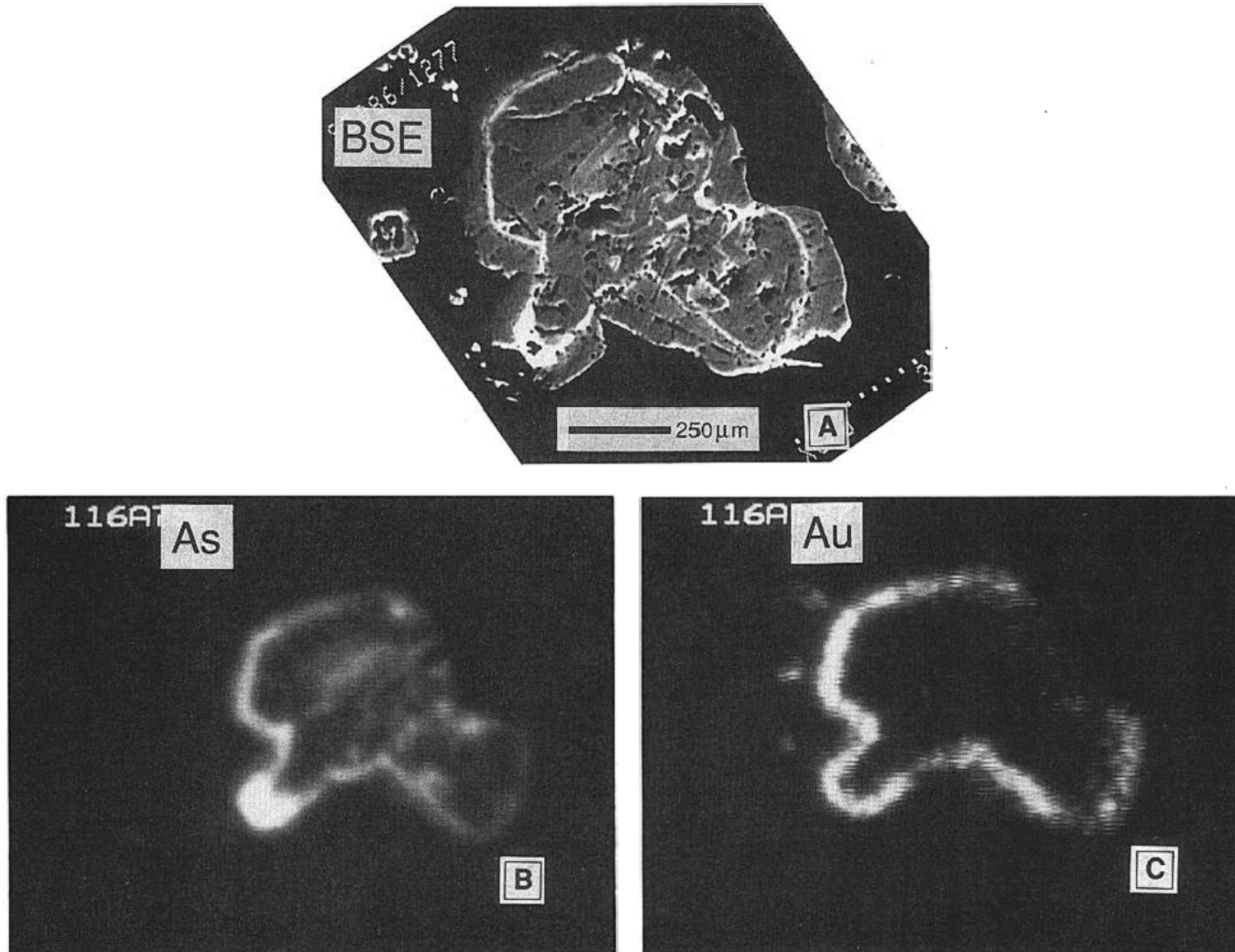
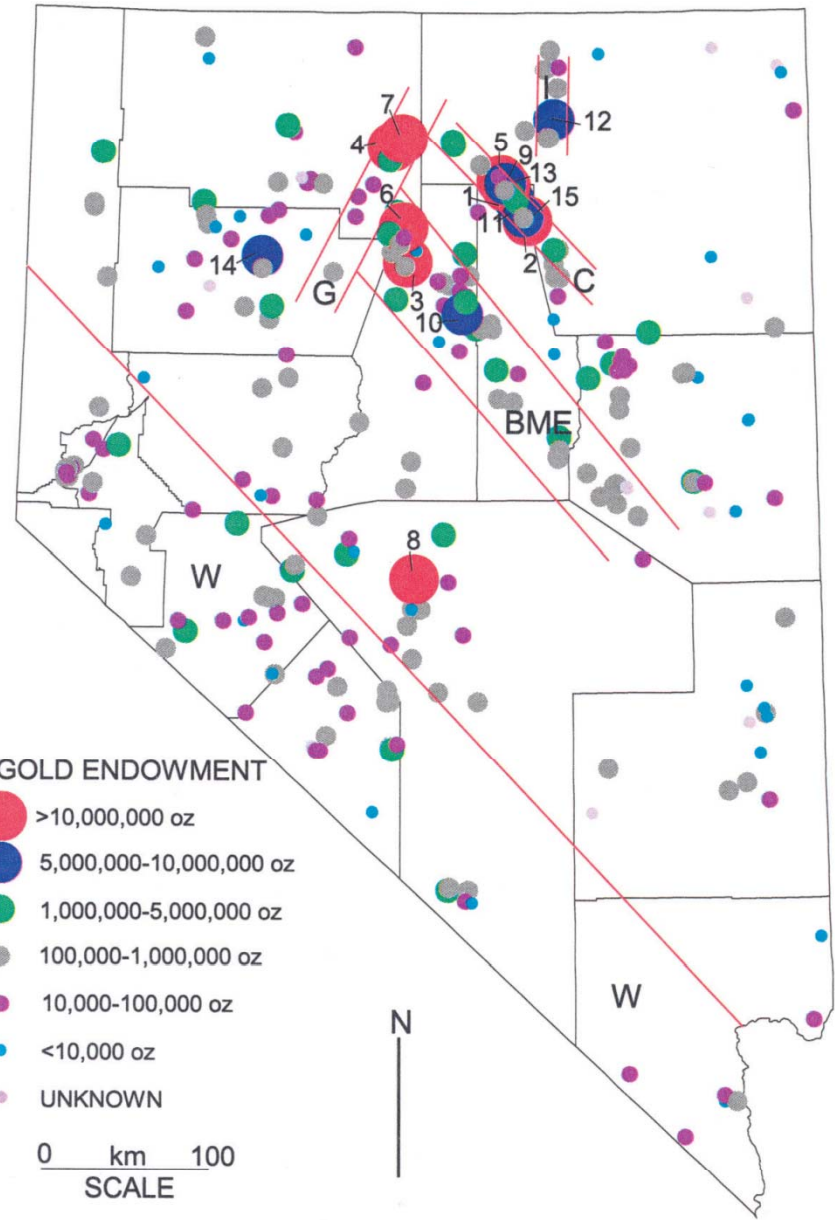
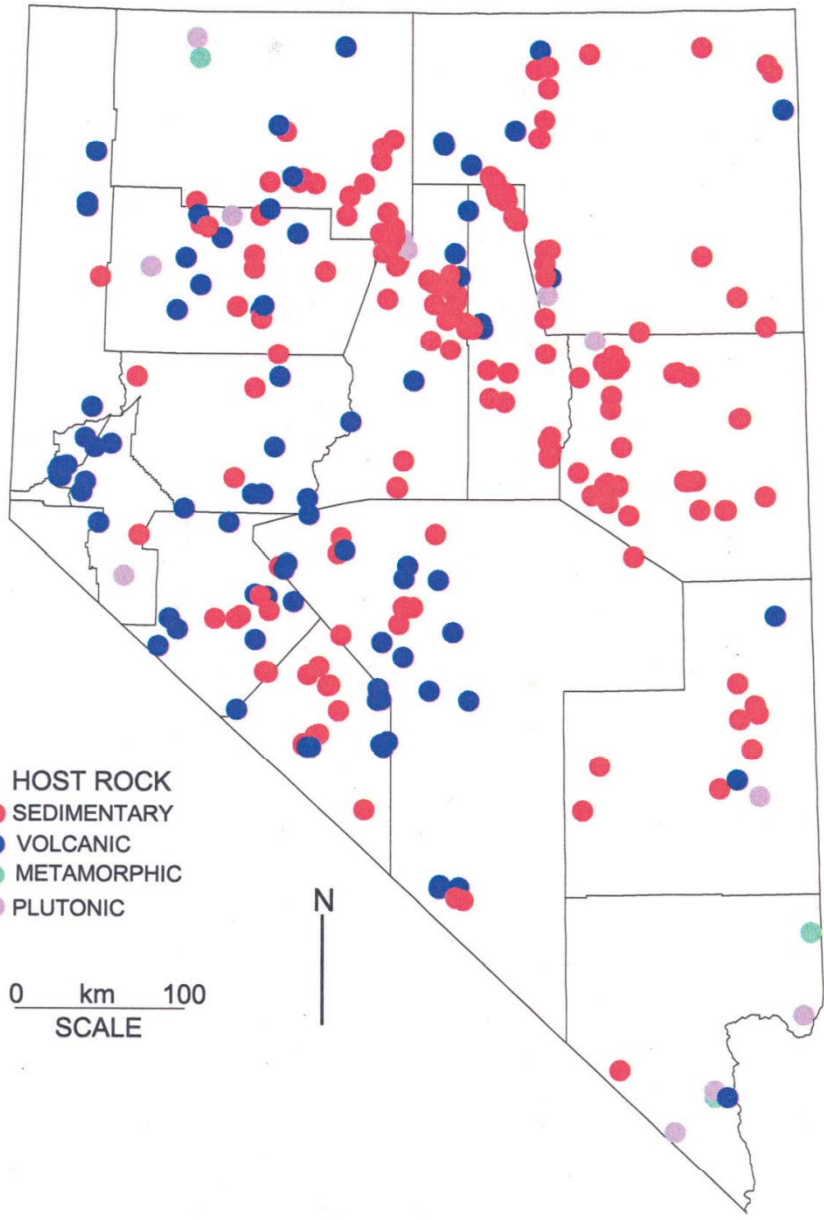


FIG. 5. Backscattered electron image and secondary ion mass spectrometry images of pyrite from Chimney Creek (sample SED86/1277). A. Backscattered electron image showing the concentration of As in the earliest overgrowth material. B. Secondary ion mass spectrometry mass map for mass 75 (As) of the same grain as A. C. Secondary ion mass spectrometry mass map for mass 197 (Au) of the same grain as A.

(Arehart et al, 1993)



*Typical drill core in a Carlin-type carbonate-rock hosted gold deposit: subtle to boring
"No-see-um gold"*

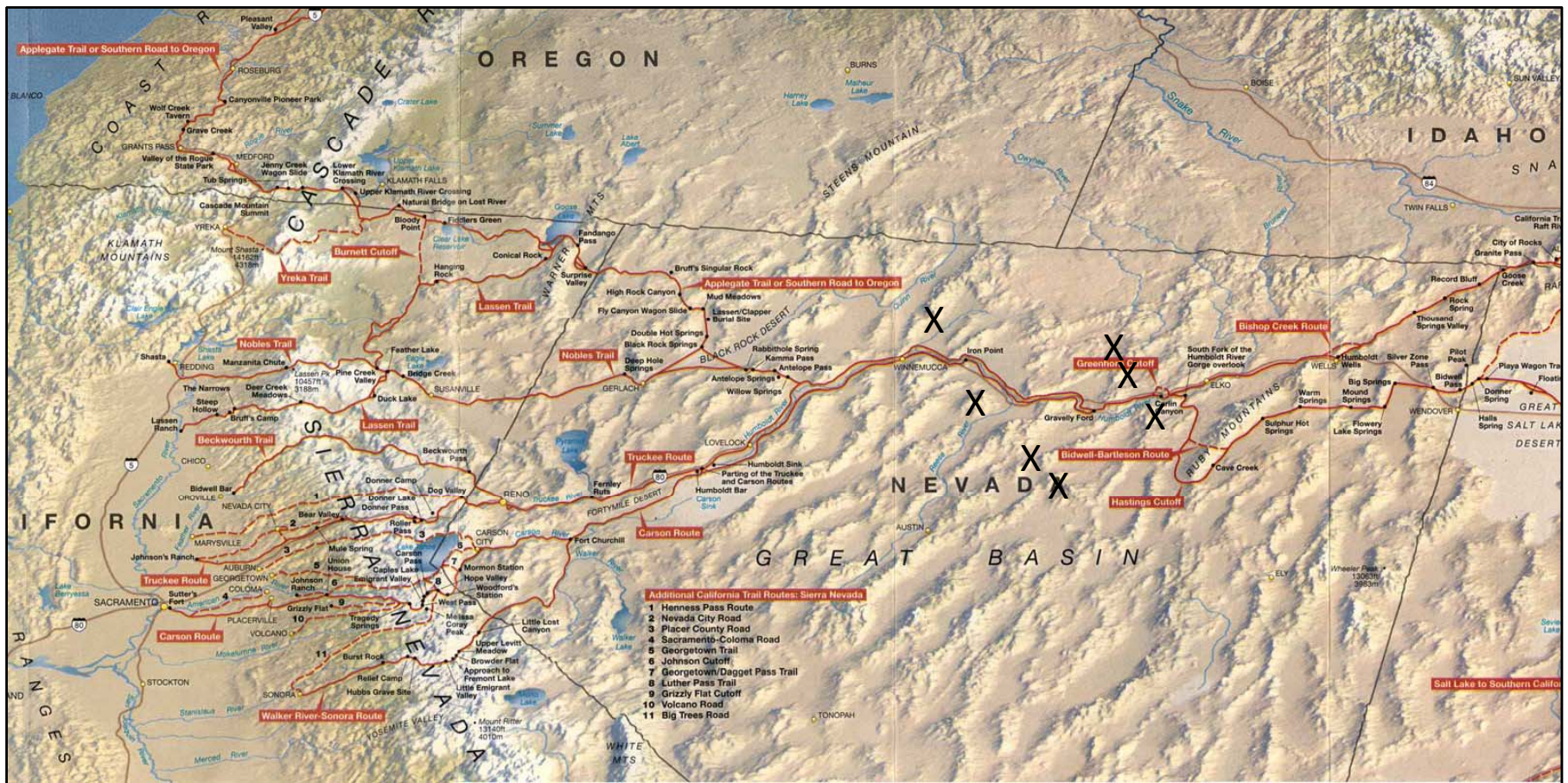


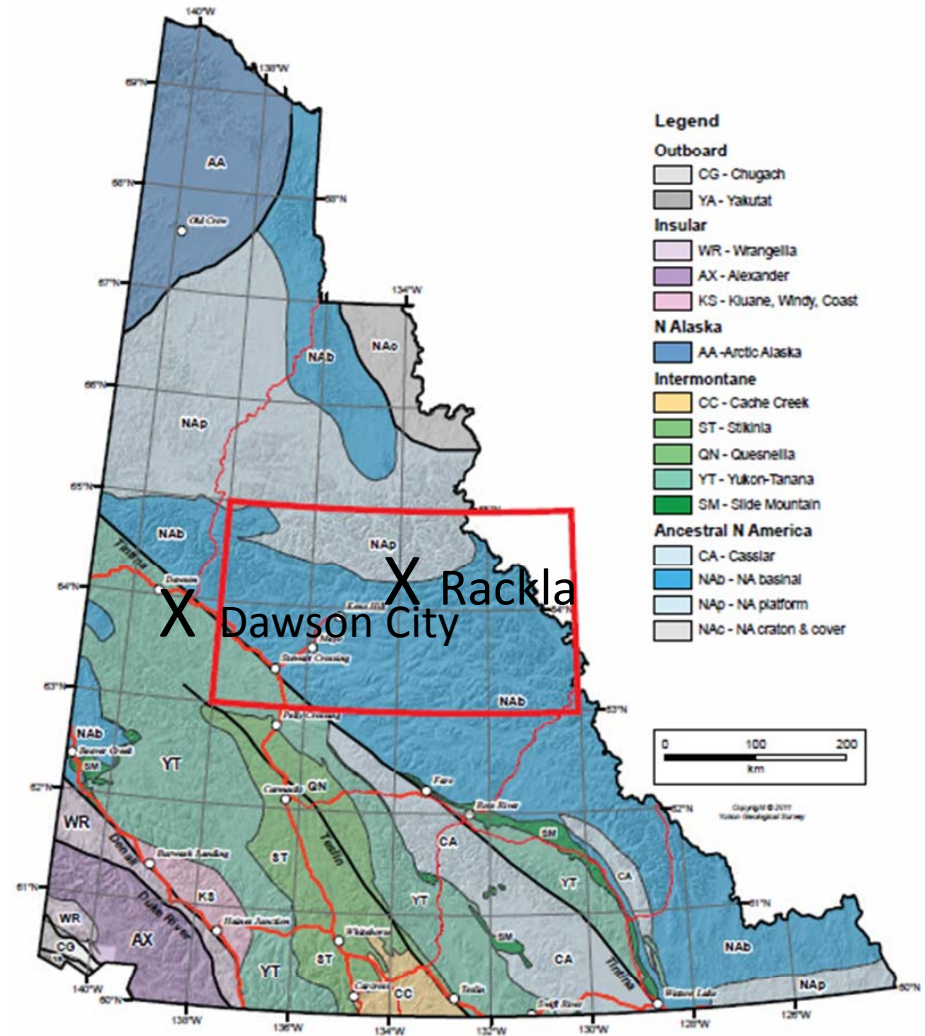
Precious Metal Deposits of Nevada.

(Davis and Tingley, 2005, GSN Volume)

None of the Carlin-type gold deposits in Nevada have significant proximal associated placer gold deposits, nor is gold visible in outcrop.

Most were not discovered until more than a century after the California gold rush.





*Rackla River area – Yukon Ty
Significant new discoveries of Carlin-type
gold mineralization*



Photos of drill core from Rackla gold district, showing decalcified Proterozoic limestone with disseminated orpiment. Typical grades for this type of rock are 10-30 ppm Au

Rackla gold discoveries are Carlin-type gold deposits, and the first major bedrock gold deposits discovered in the Yukon -a century after the Klondike gold rush:

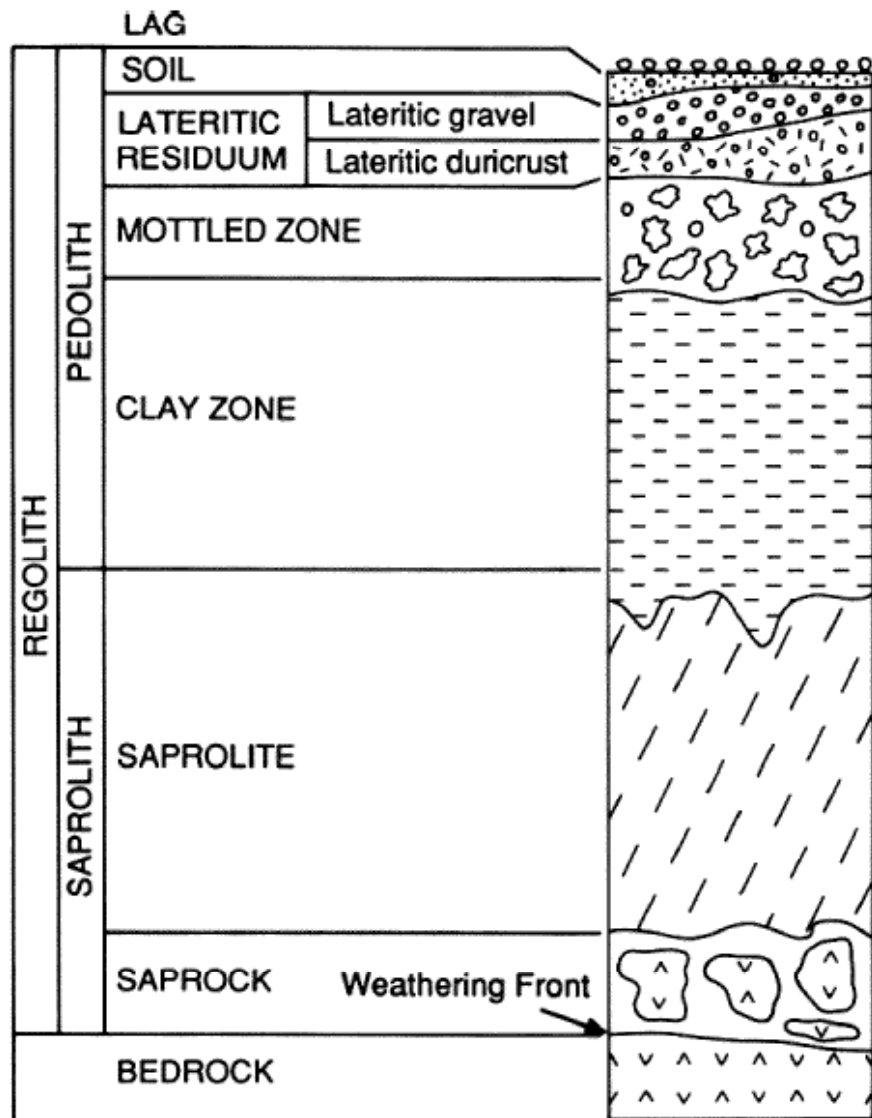
- ***Hosted in impure carbonate rocks deposited along a continental margin;***
- ***Gold is contained in rims on arsenical pyrite;***
- ***Alteration is dominantly carbonate dissolution;***
- ***Trace element geochemistry: As, Tl, Sb, Hg;***
- ***No associated placer gold deposits.***

There have never been any large Yukon lode gold deposits discovered that could have shed great chunks of native gold to the rivers of the Klondike!

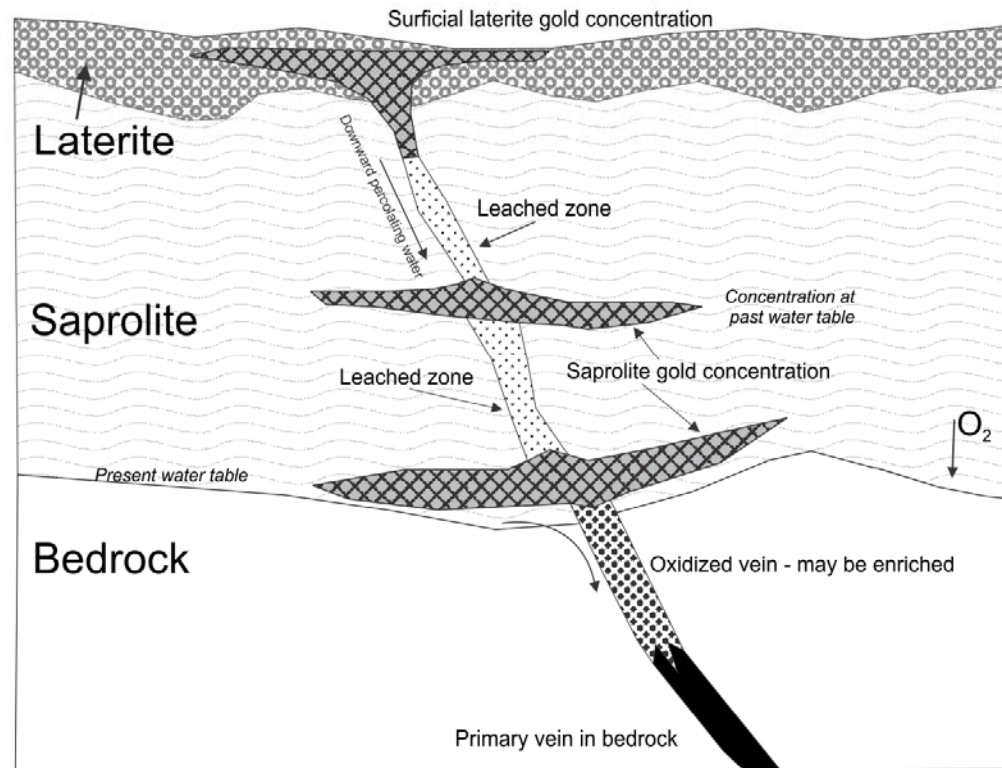


Garimpos, Mato Grosso, Brasil ~2006





Regolith terminology used for deeply weathered laterite profile (Smith et al. 1997)



Schematic diagram showing Au distribution in laterite supergene Au deposits

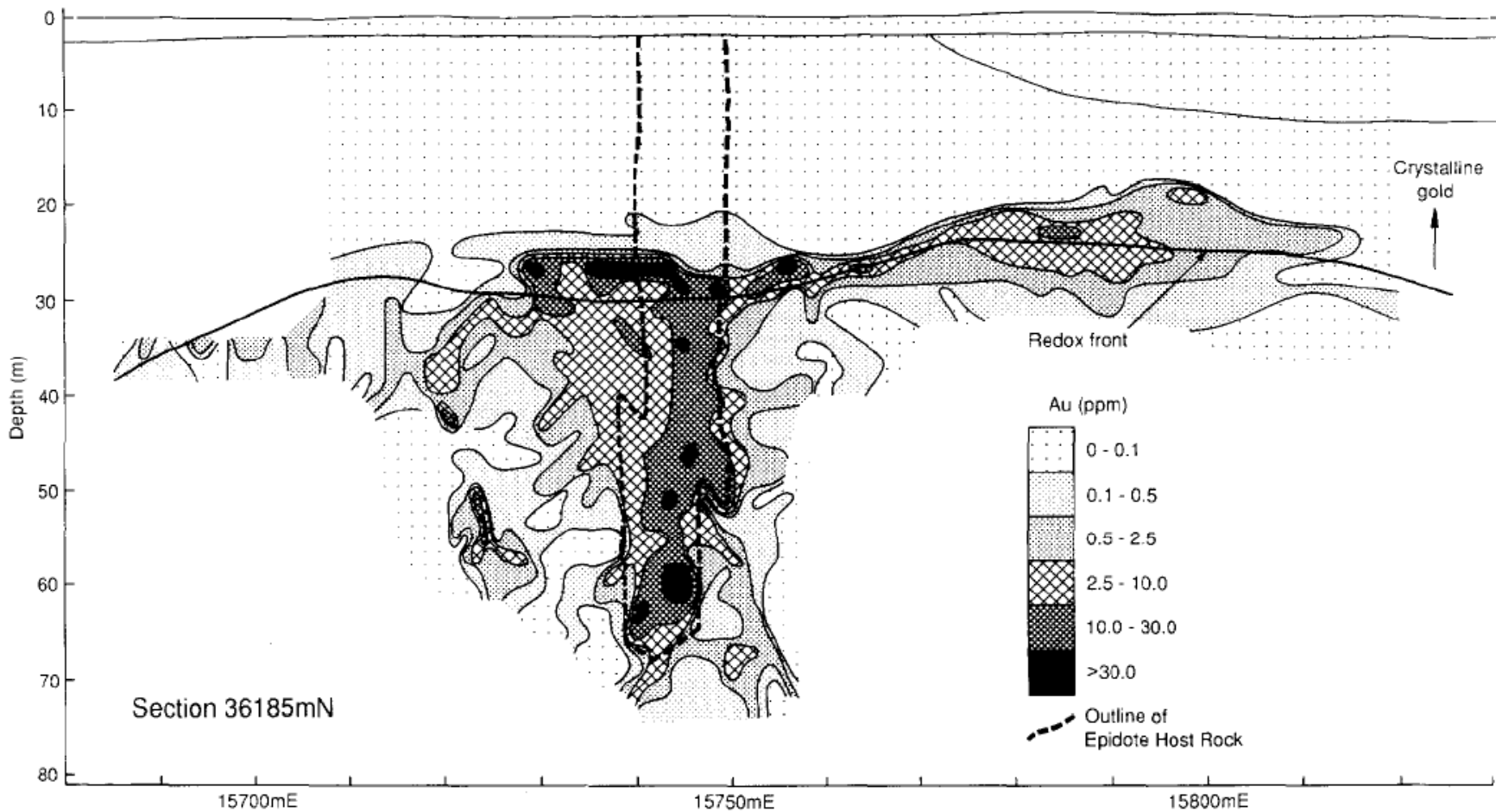
Two distinct types of supergene gold deposits are recognized:

Laterite supergene gold deposits are nearly flat-lying enrichment zones coincident with a ferricrete or mottled zone. Gold is usually fine-grained, but nuggets are found. Gold may occur as complex intergrowths in duricrust.

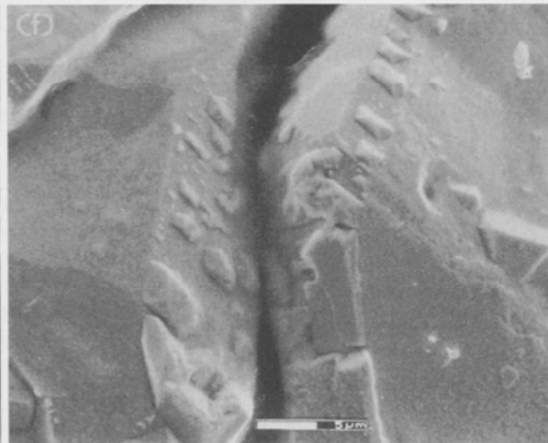
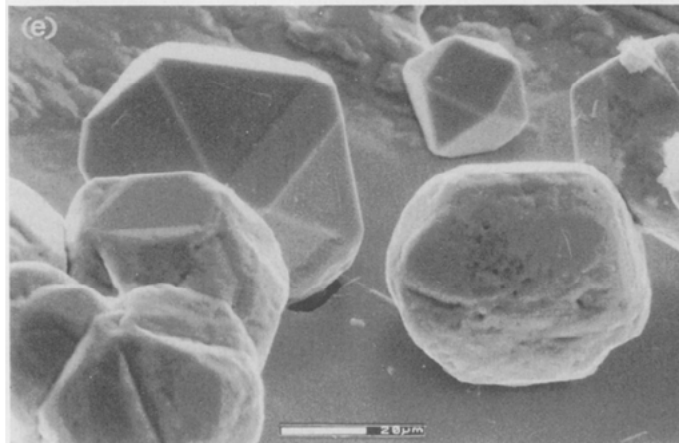
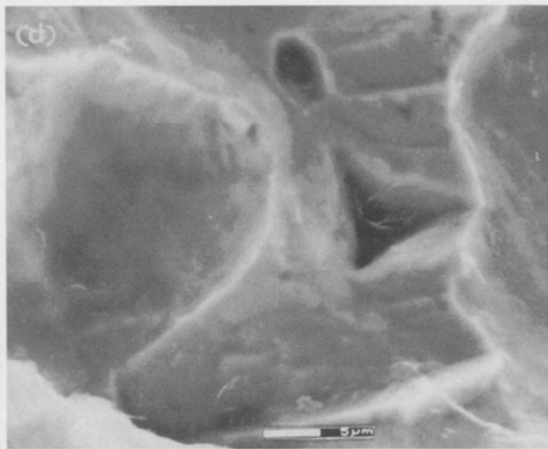
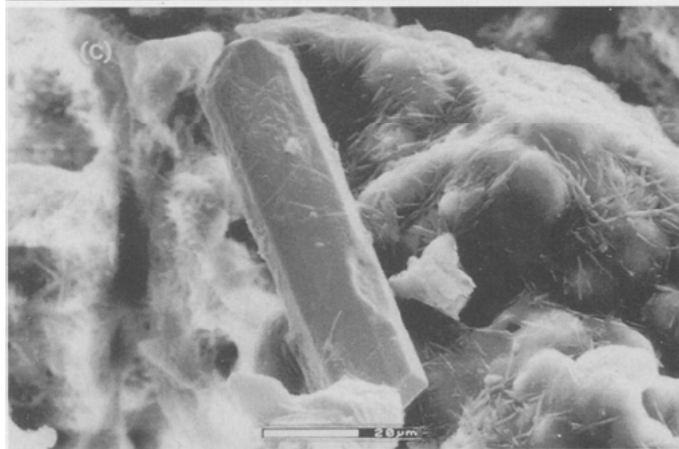
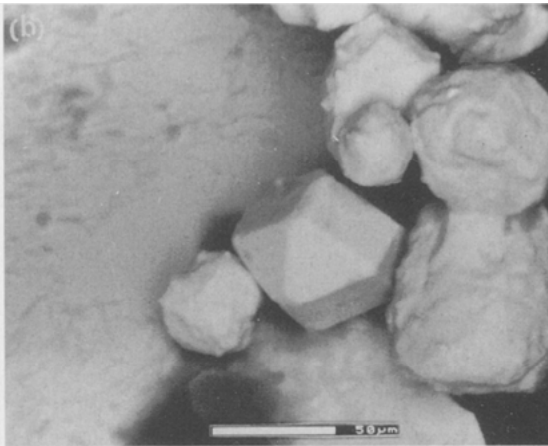
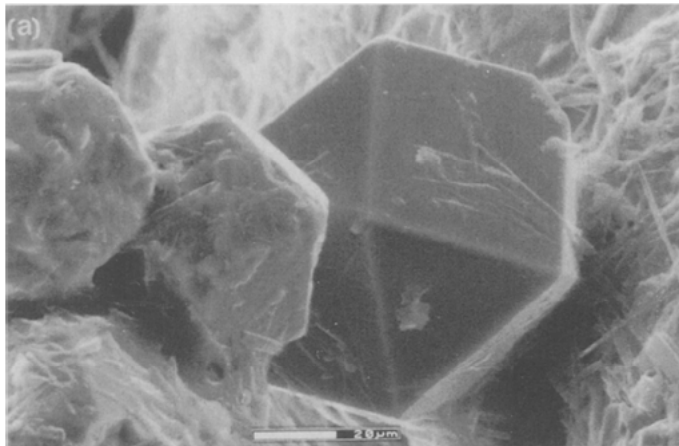
Saprolite supergene gold deposits are deeper and may form more than one sub-horizontal layer, often near bedrock. Euhedral gold crystals are common.

Ouro Preto Minas Gerais, Brasil ~1995

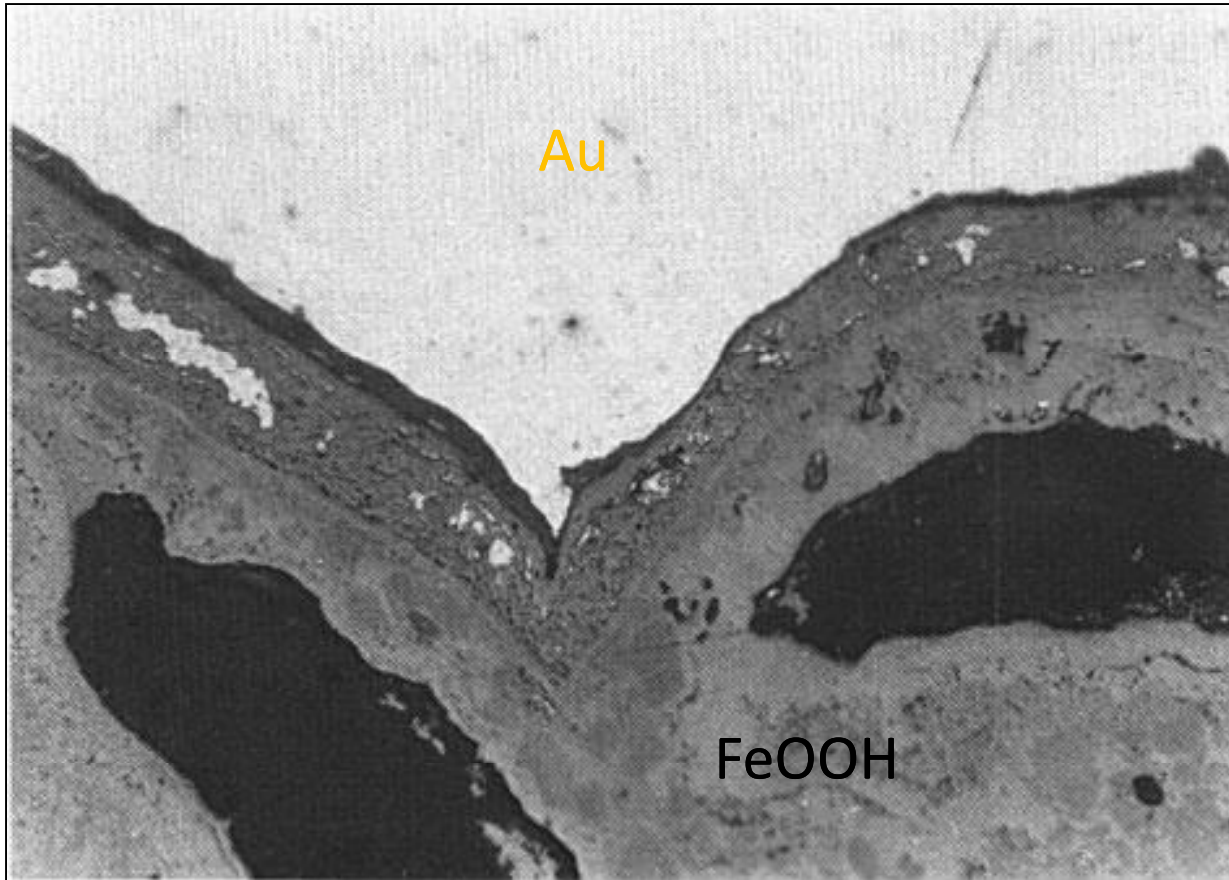




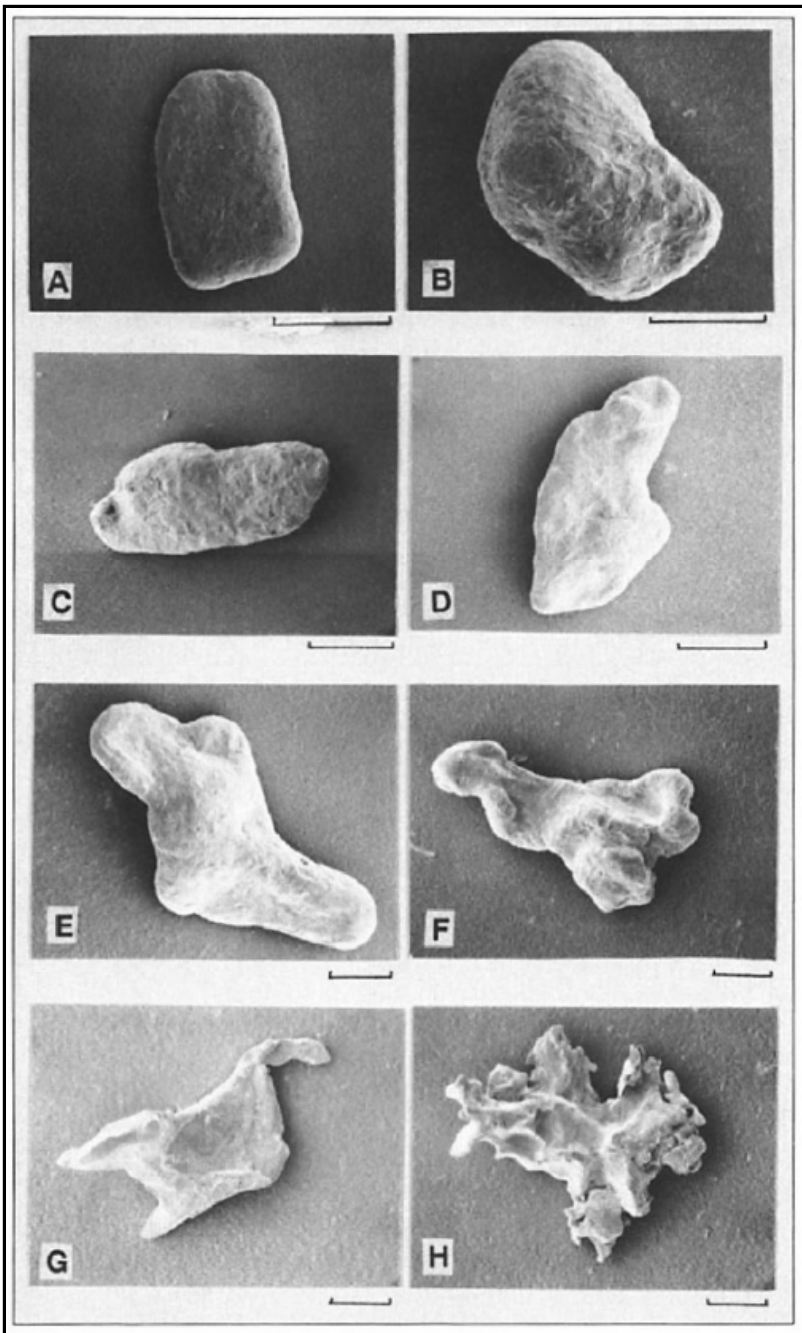
Sections through the Hannan South mineralization showing location of secondary gold crystals in saprolitic enrichment zone. (Lawrance and Griffin, 1994)



SEM Photomicrographs of secondary Au crystals in saprolite: Hannan South gold deposit. (Lawrance and Griffin, 1994)



Optical micrograph of the polished edge of a gold nugget intergrown with iron-oxide laterite from WA. The micrograph is 20 microns across. (Mann 1984)



Scanning electron micrographs of gold grains recovered from various zones of weathering profile from Nilambur, India. Gold separated from top (A) to bottom (H) of soil profile. Bar scales = 100 µm.

Detailed images show corrosion pits in grains from upper profile and growth dendrites from grains in lower profile.

Primary gold grains contain 82.5% Au, while secondary grains have fineness 991-999: almost pure gold.

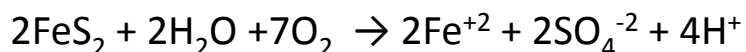
Gold grains are often found within or coated by iron-oxide.

(Santosh and Omana, 1991)

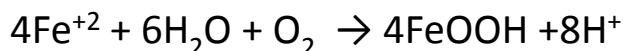
Some Critical Reactions:

Oxidation of pyrite:

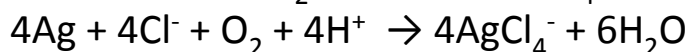
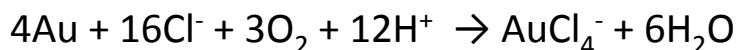
The first step occurs at the weathering front:



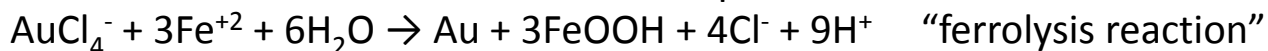
The second step occurs at the water table:



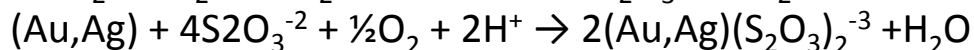
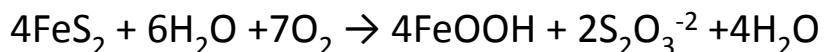
Dissolution of Au and Ag in acidic saline conditions:



Precipitation of Au by reduction of AuCl_4^- , increase in pH, or dilution:



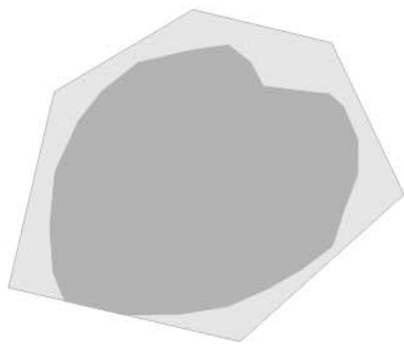
In an alkaline environment, thiosulfate may be the important ligand:



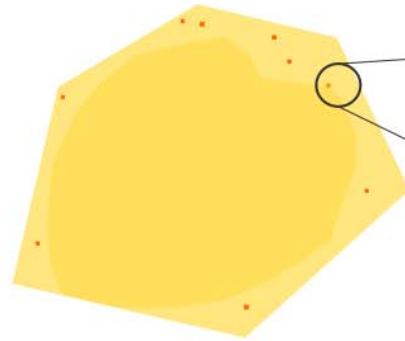
Other important aqueous gold species include:

chloride, bisulfide, thiosulfate, cyanide, organic acids (fulvic and humic substances)

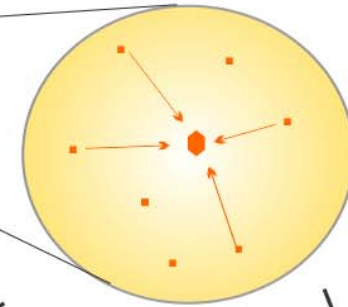
Formation of secondary gold crystals



Pyrite with arsenical rim enriched in gold

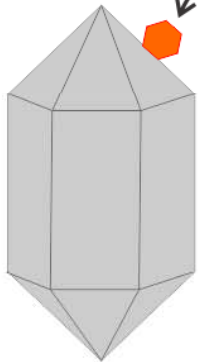


Oxidation of pyrite leaves gold in extremely fine particles

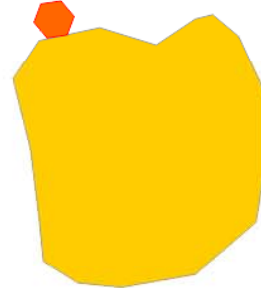


Gold accretes to form "micronuggets" ~20µm

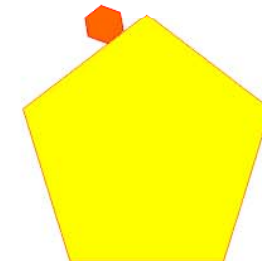
Intense chemical weathering
 $S_2O_3^-$, Cl^- , Humate



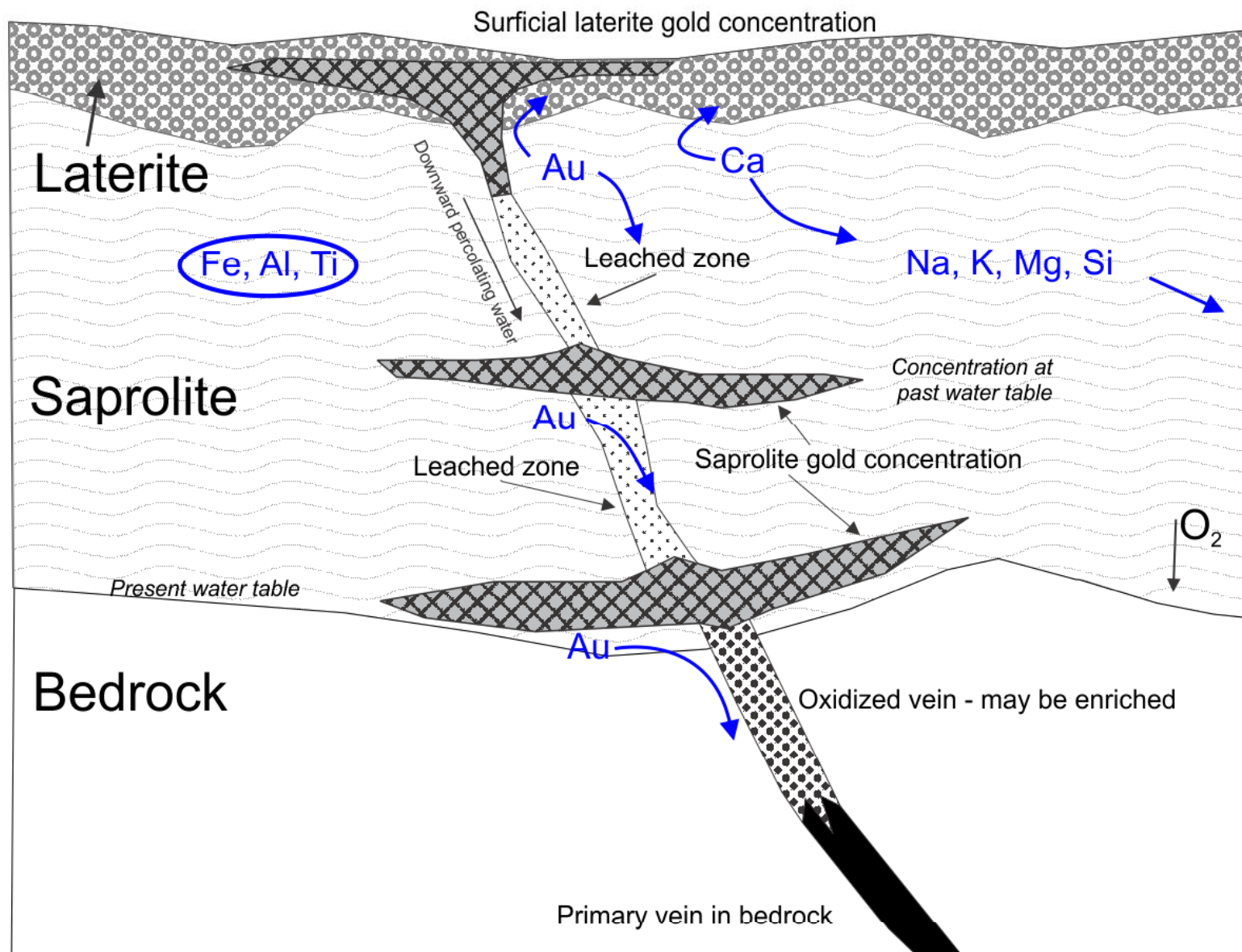
Epitaxial gold nucleation and growth on quartz



Gold accretion to nuggets - lower surface energy



Gold precipitation on pyrite or marcasite (reduction)



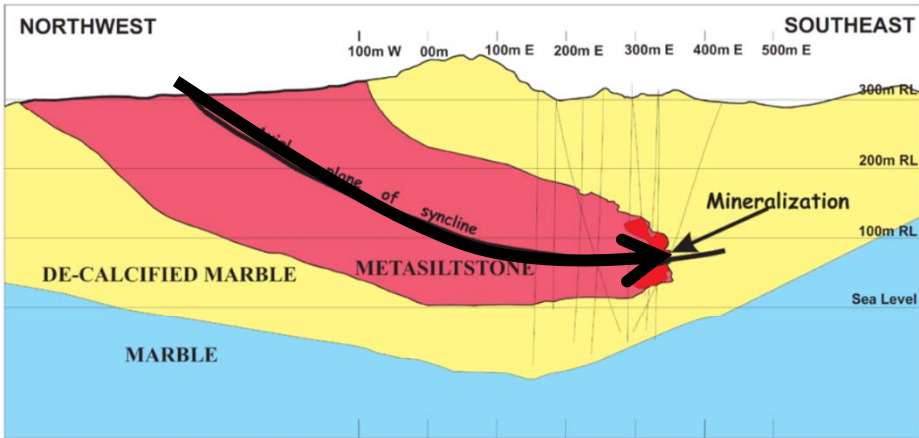
Schematic diagram showing Au distribution in laterite supergene Au deposits



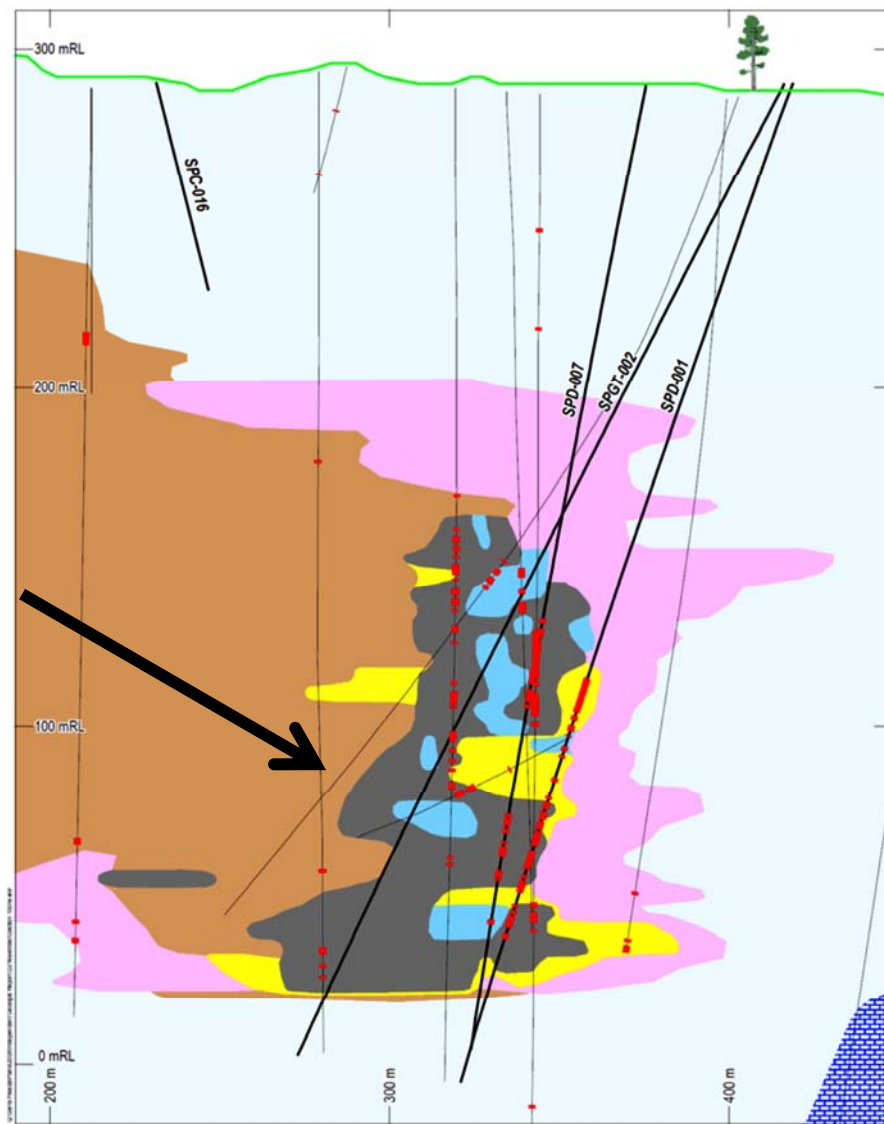
Gold prospect in Mato Grosso, Brasil. The gold-bearing laterite has been stripped away. Garimpeiros extracted gold-rich iron-oxide extending down a bedrock fracture. Gold concentrations fell dramatically about 10 meters from the top of bedrock.

Serra Pelada, Pará, Brasil ~1981





Serra Pelada –
current exploration



FACT: Gold is indeed mobile in the natural environment.

- *Field evidence suggests that oxidation of sulfide minerals releases gold in a chemically active state to the environment.*
- *Where groundwaters are oxidizing and halide-rich, gold is readily taken into solution as a chloride complex.*
- *Under more basic conditions, gold may be solubilized as thiosulfate complex.*
- *Because silver is more soluble than gold, the two metals are parted during weathering and secondary concentration, removing silver in solution and leaving a gold enriched residue behind.*

Bacteria !

Local Equilibrium

Plants

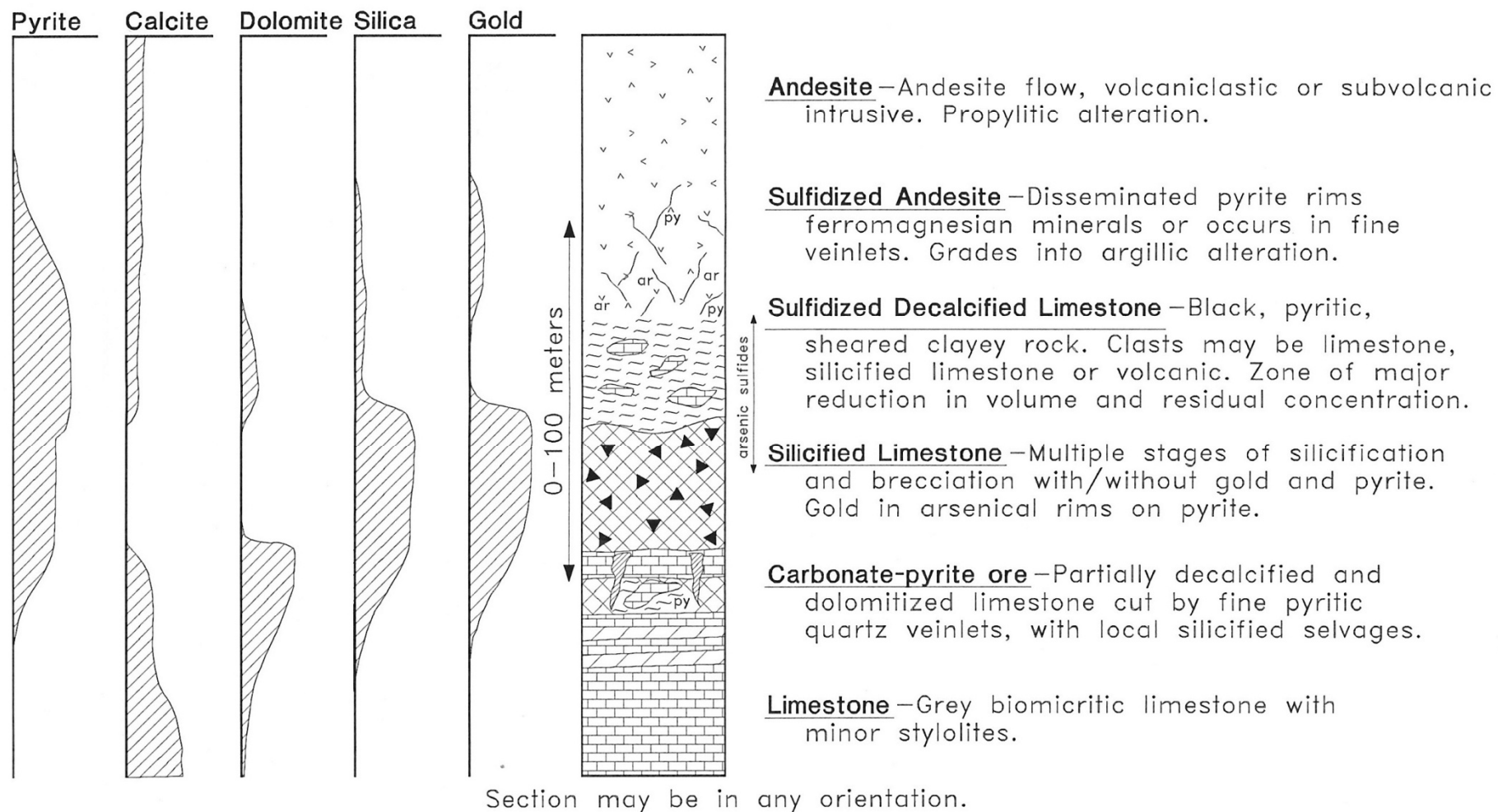
Laterite soils cover 1/3 of the exposed land surface of the earth

Mesel Gold Deposit – Sulawesi Indonesia

7.8 Mt @ 7.3 g/t = 1.8 million oz Au



MINAHASA DISTRICT MESEL-STYLE PRIMARY GOLD MINERALIZATION



Andesite—Andesite flow, volcanoclastic or subvolcanic intrusive. Propylitic alteration.

Sulfidized Andesite—Disseminated pyrite rims ferromagnesian minerals or occurs in fine veinlets. Grades into argillic alteration.

Sulfidized Decalcified Limestone—Black, pyritic, sheared clayey rock. Clasts may be limestone, silicified limestone or volcanic. Zone of major reduction in volume and residual concentration.

Silicified Limestone—Multiple stages of silicification and brecciation with/without gold and pyrite. Gold in arsenical rims on pyrite.

Carbonate-pyrite ore—Partially decalcified and dolomitized limestone cut by fine pyritic quartz veinlets, with local silicified selvages.

Limestone—Grey biomicritic limestone with minor stylolites.

Figure 1 Mesel-style primary gold mineralization at limestone-andesite contact. Some variation is observed in individual sections, but most exhibit general relationships illustrated here.

MINAHASA DISTRICT HAI-PASOLO-STYLE SECONDARY OXIDE GOLD CONCENTRATION

Soil over andesite is barren of gold. Soil over carbonate is gold-enriched

Oxidation of pyritic aureole at andesite-limestone contact promotes solution-contact appears to be vertical at zone of solution collapse.

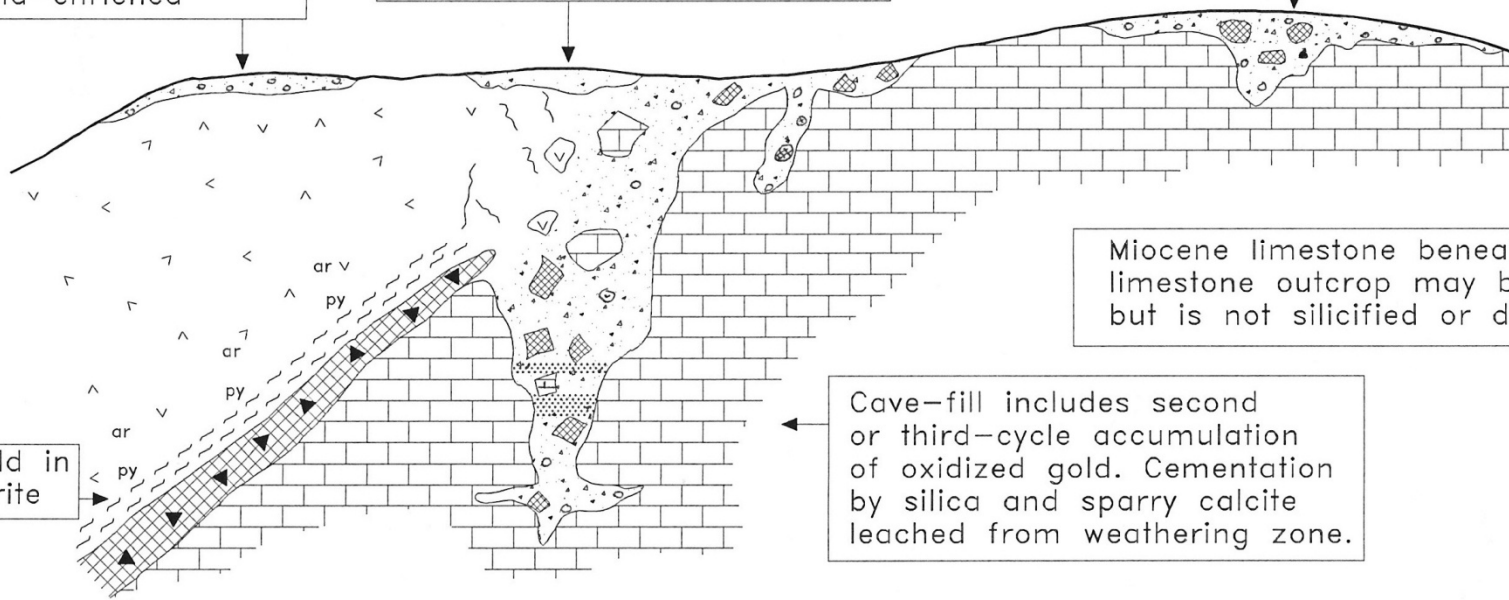
Pasolo-style eluvial gold concentration on irregular karst surface. Free gold.

Miocene limestone beneath limestone outcrop may be karsted but is not silicified or decalcified.

Cave-fill includes second or third-cycle accumulation of oxidized gold. Cementation by silica and sparry calcite leached from weathering zone.

Gold in pyrite

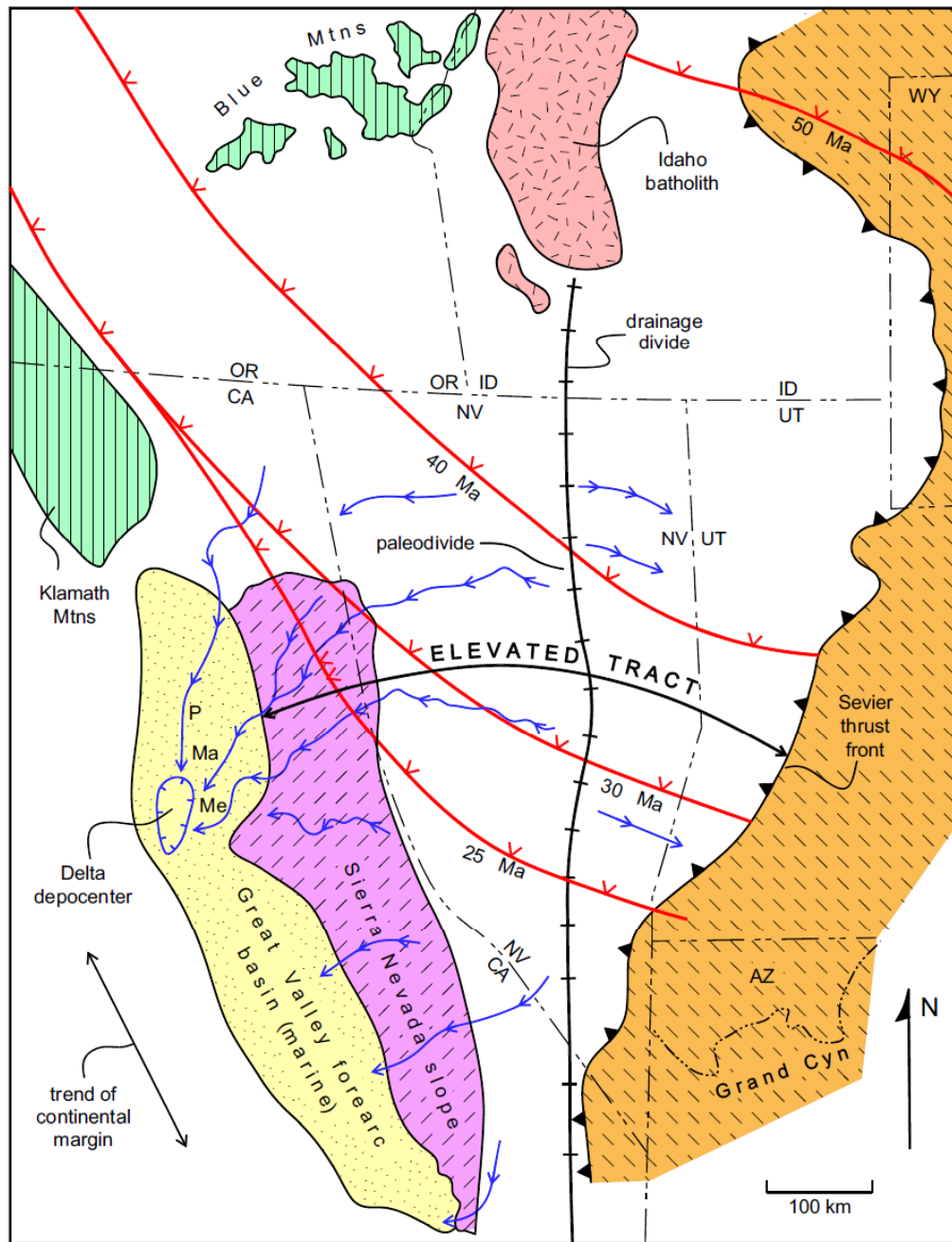
Primary Mesel-style silica-sulfide-gold mineralization at limestone-andesite contact. Limestone is decalcified and silicified at contact.



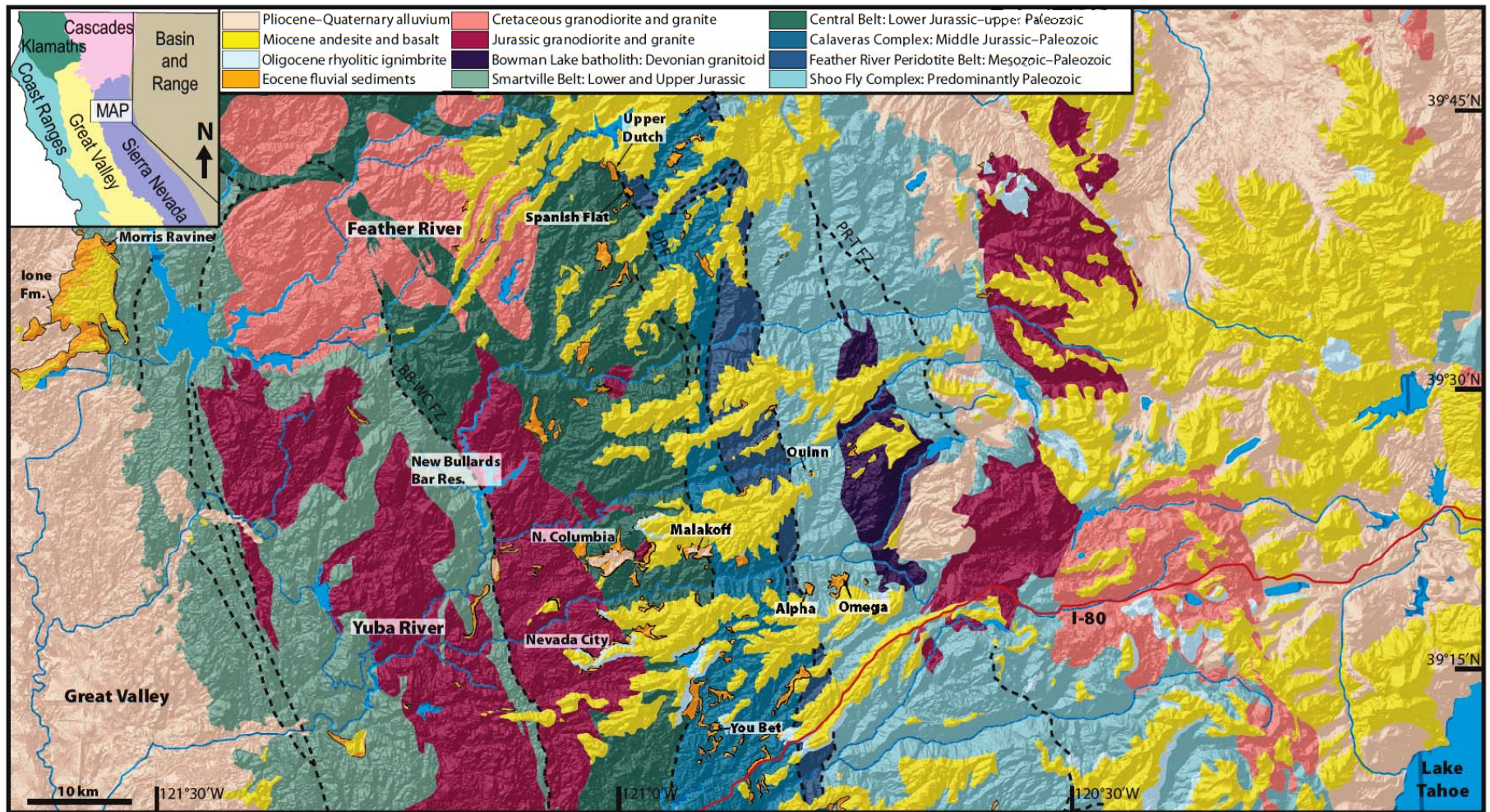


Interesting related observations:

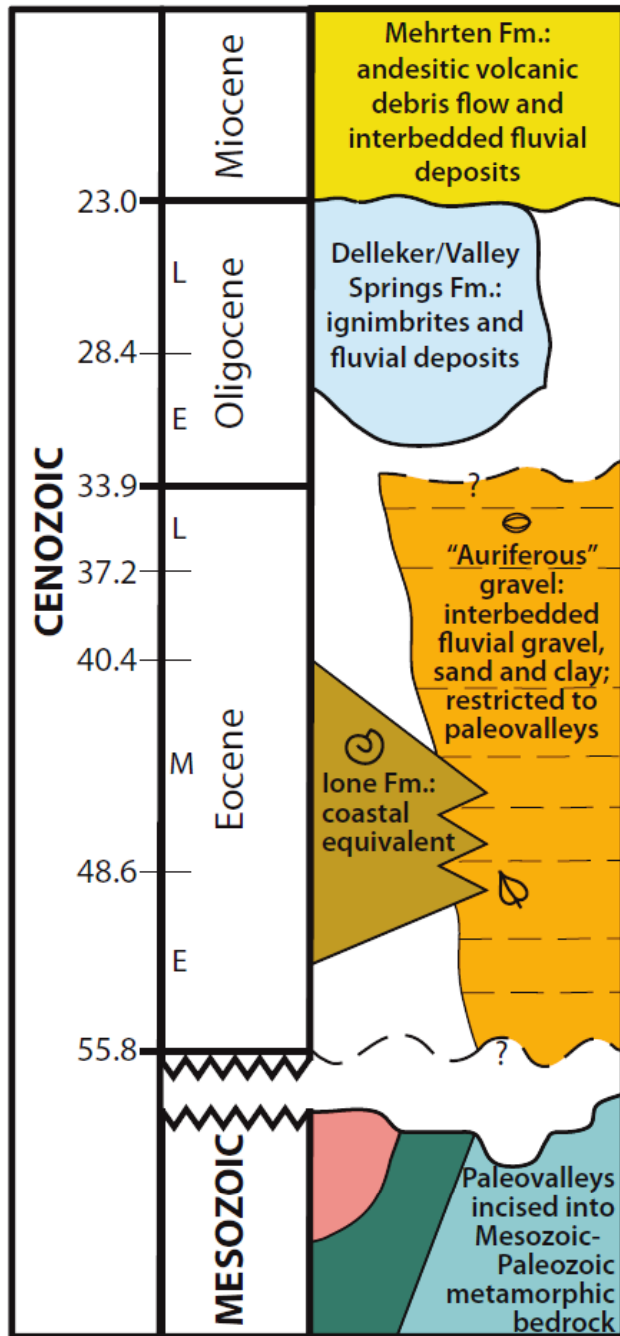
- Gold on cleats in anthracite in Wales – no possible detrital source.
- Gold common in moss-mats in Alaska
- Drift and placer miners observe nugget growth on historic debris
- Deeply oxidized specularite deposits after BIF have “jacutinga” – gold nuggets



Early Eocene to Early Miocene (50–20 Ma) tectonomagmatic relations across the site of the younger Great Basin prior to Neogene Basin and Range extension. Elevated tract (curving double-headed arrow) included the Sierran slope, Nevadaplano, and Sevier thrust belt. Barbed blue lines denote principal paleodrainages including terrestrial paleovalleys of the linked to submarine canyons leading into the Delta depocenter of the Great Valley forearc basin. Red lines are successive volcanic fronts. (Dickinson, 2013)



Distribution of geologic units in the northern Sierra Nevada of California. Eocene fluvial sediments are shown in orange. (Cassell et al., 2012)



Chronostratigraphic column showing ages and depositional relationships of Cenozoic units in the Sierra Nevada.
(Cassell et al., 2012)

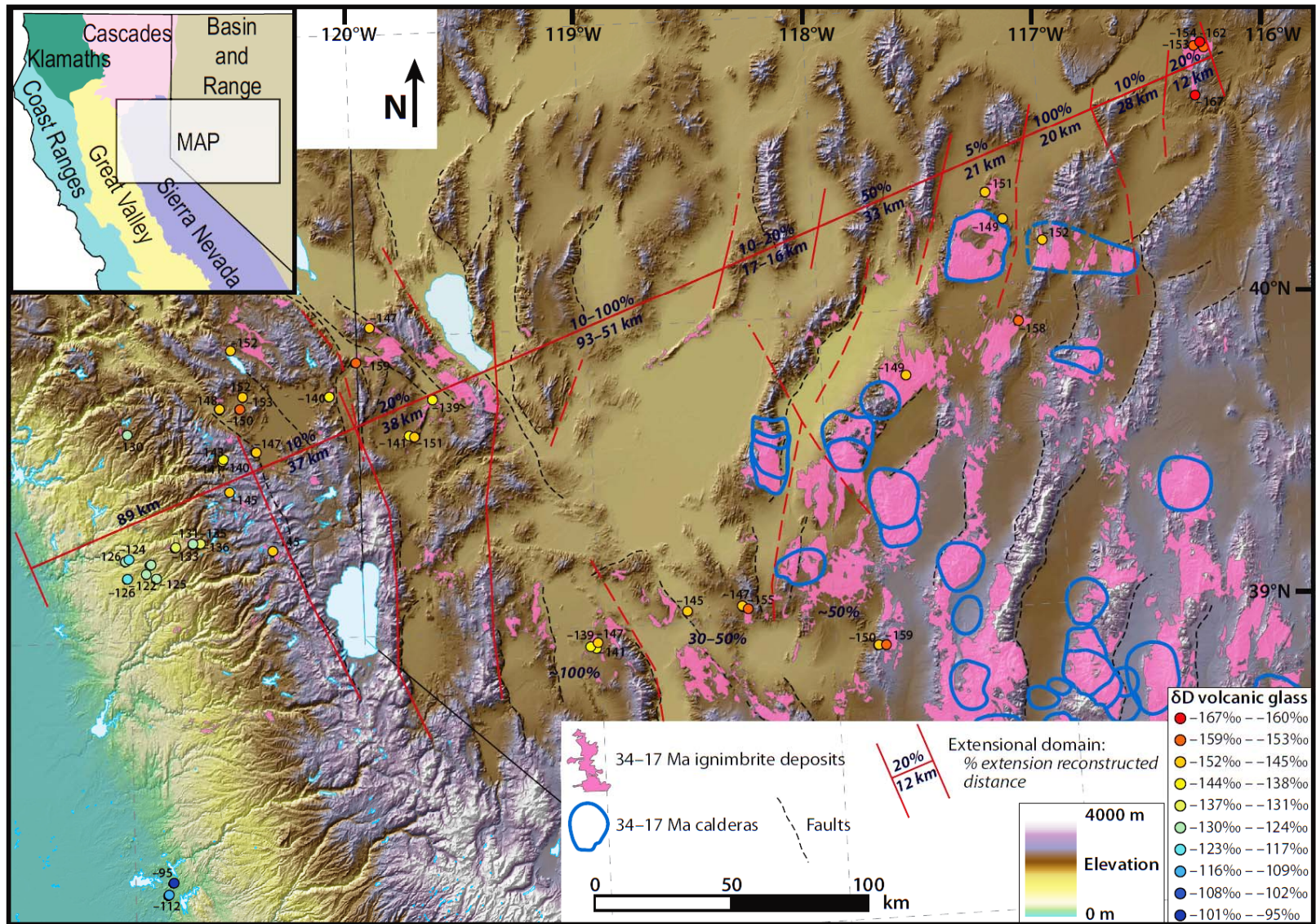


Photos showing characteristics of Sierra Nevada Eocene stream deposits.

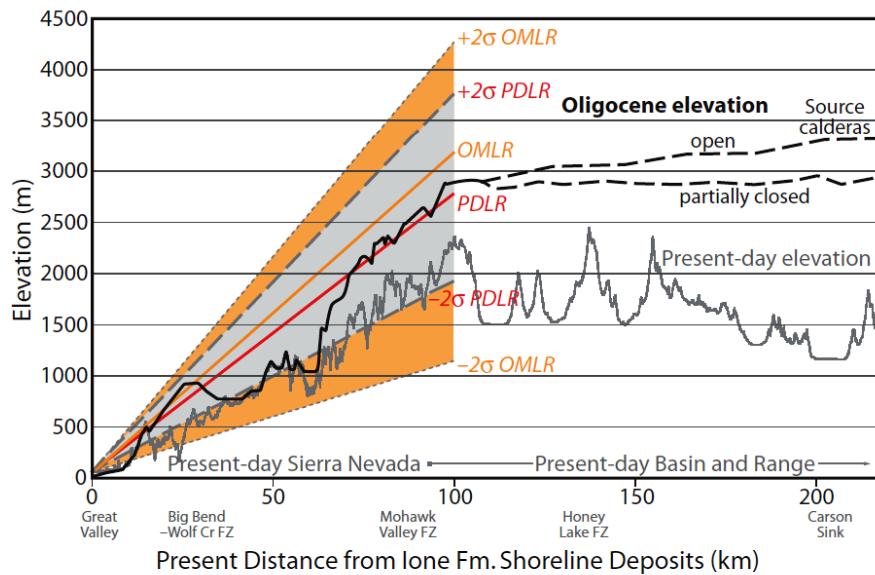
Left is boulder conglomerate: clasts were argillized in-situ in the Eocene.

Right is oxisol with ferric nodules, color mottling, and burrowing: features of tropical soils.

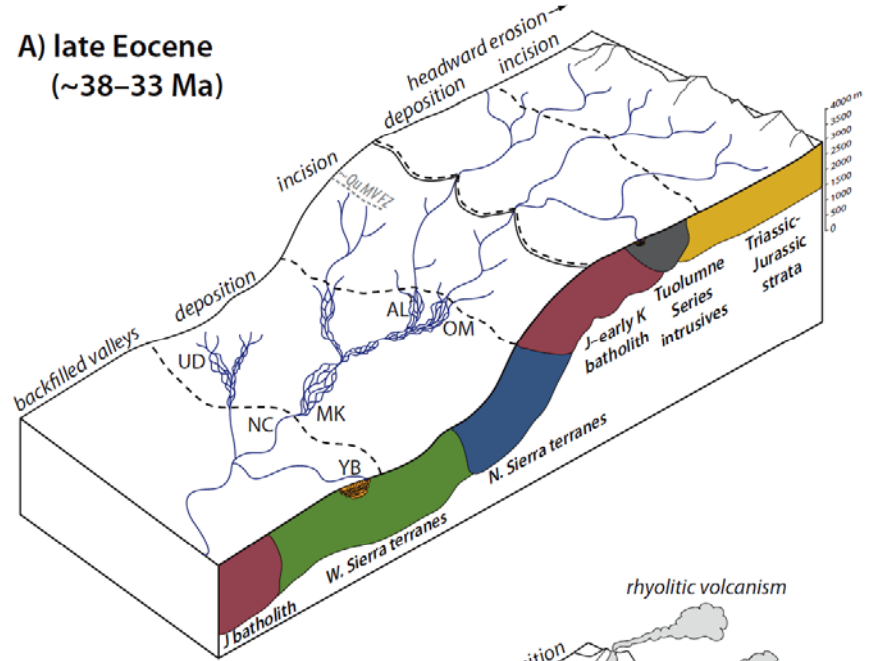
(Cassell et al., 2012)



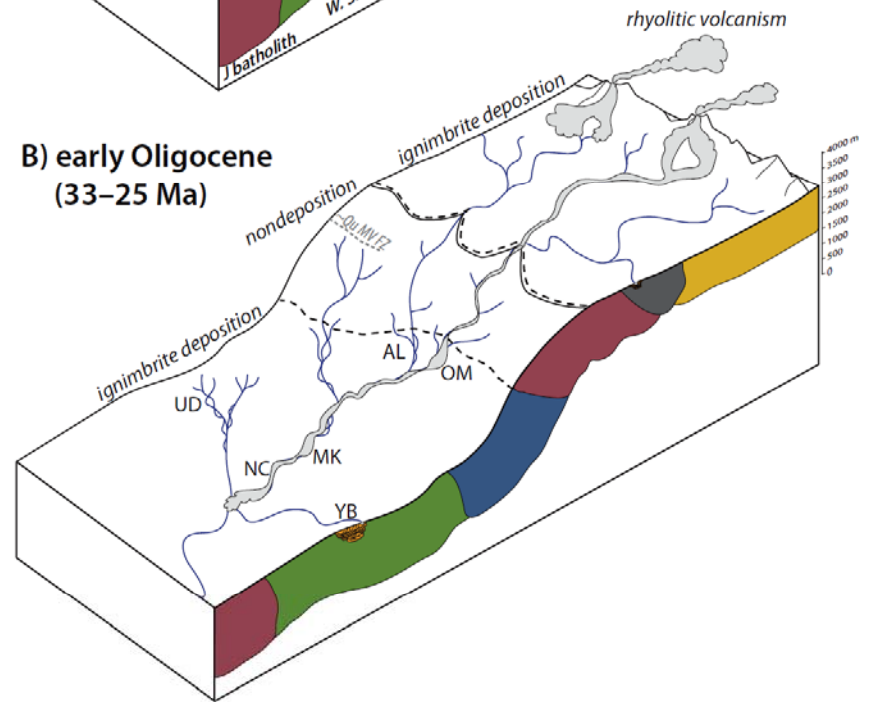
Digital elevation model of the Sierra Nevada and western Basin and Range, showing distribution of 34-17 Ma ignimbrites, mapped calderas, and volcanic glass samples. Extensional domains shown. (Cassell et al., 2012)



A) late Eocene (~38–33 Ma)



B) early Oligocene (33–25 Ma)



Above: Topographic profile comparison of present day and Oligocene elevations based on stable isotope paleoaltimetry.

Right: Proposed landscape reconstructions of the area that is now the northern Sierra Nevada and western Basin and Range.

(Cassell et al., 2012, *Geosphere*, 8, 229.)

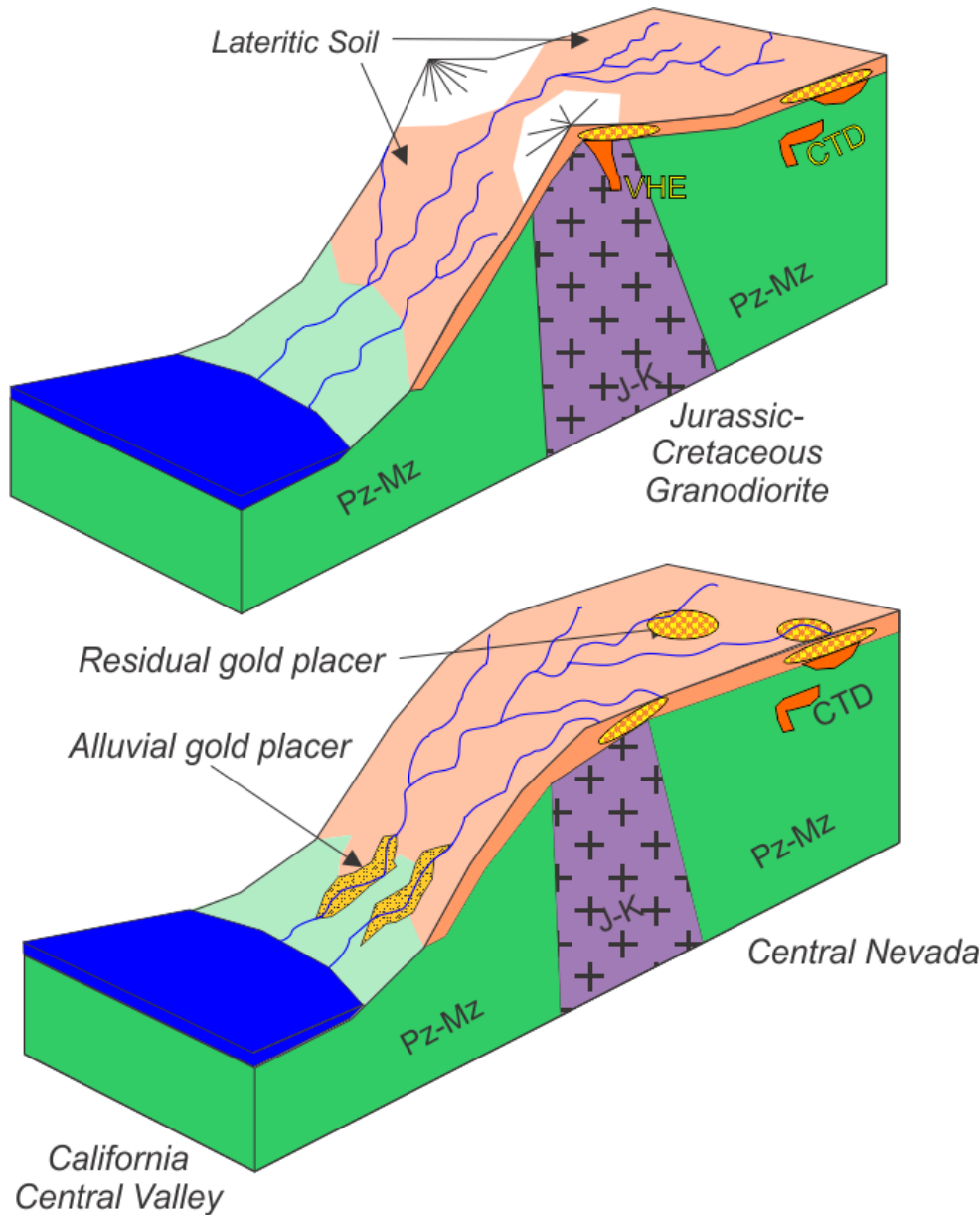
The drainage basin for the great California placer gold deposits included the Sierra Nevada and most of northern Nevada – one of the world's largest gold provinces.

Gold deposits known in this province are non-vein disseminated gold deposits, with neither quartz veins nor visible native gold.

The age of the California placer deposits is early Tertiary. The climate in western North America during the Cretaceous and early Tertiary was warmer and wetter than at present. Remnants of a Cretaceous peneplane with laterite soils remain in northern California.



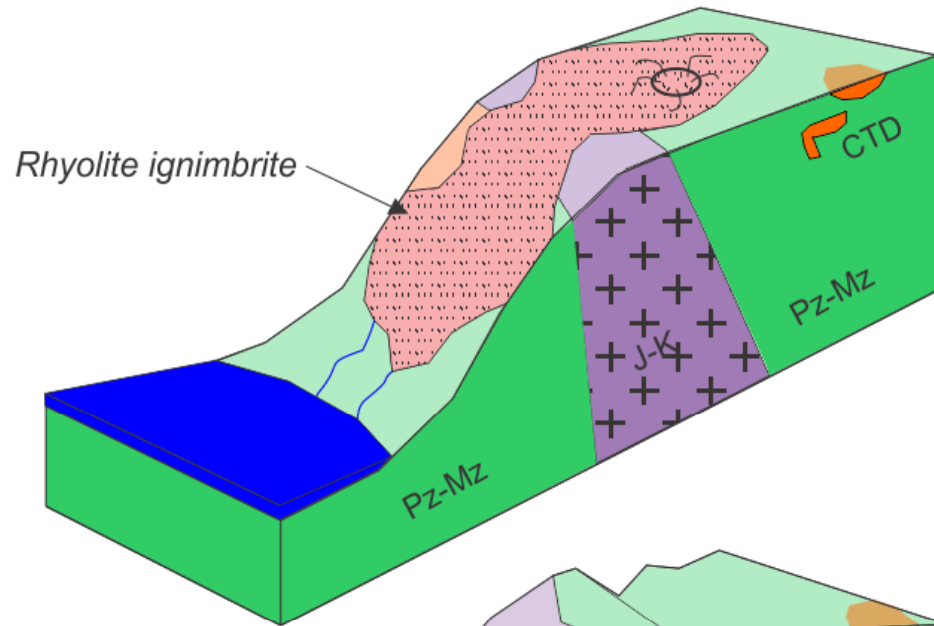
Simplified conceptual model for development of the auriferous gravels of California (1)



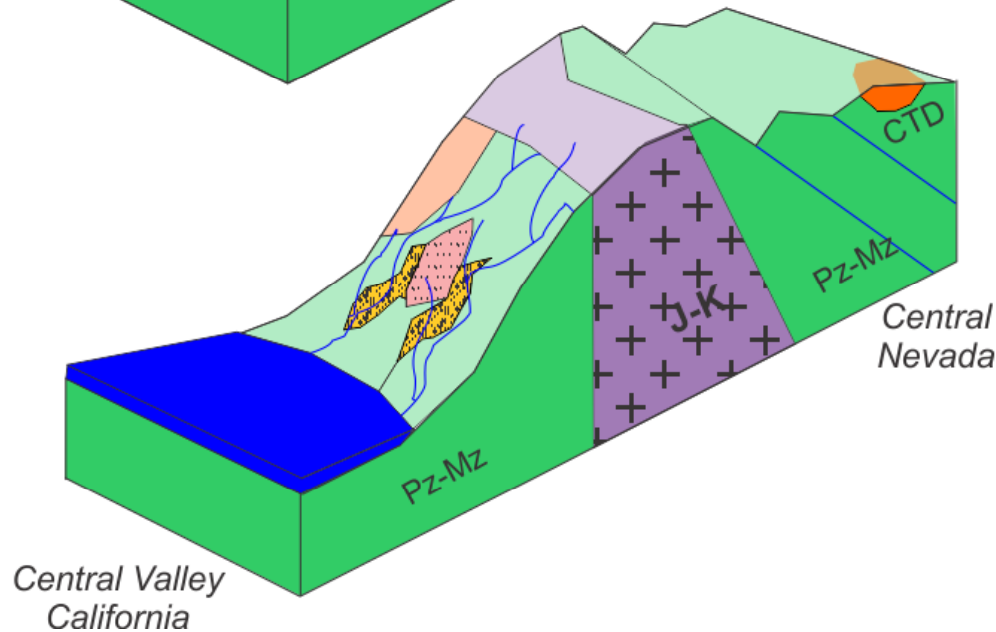
Cretaceous - Eocene: Remnants of the Sierran magmatic arc remain with the high Nevadplano behind. Intense chemical weathering in a tropical climate create residual gold placers over Carlin Type Deposits in Central Nevada, and perhaps over Volcanic-Hosted Epithermal deposits in Sierra arc volcanic rocks.

Eocene: Changing climate or tectonics result in increased physical erosion. Residual placer gold nuggets and underlying white quartz are eroded, transported westward in major rivers, and deposited at the slope break on the western flank of the Sierra. These are the Tertiary auriferous gravels.

Simplified conceptual model for development of the auriferous gravels of California (2)



Oligocene: Rhyolite volcanism in central Nevada spreads ignimbrite sheets as far as 200 km westward, filling Tertiary river valleys, and burying the auriferous gravels west of the Sierran crest.



Late Tertiary - Quaternary: Extensional collapse of the high Nevadaplano cuts westward drainage from Nevada. Erosion removes much of the volcanic cover from auriferous gravels. Modern streams erode and remobilize gold from Tertiary placer channels. No further development of residual gold nuggets in Nevada due to arid climate.

Back to the Yukon.

Gold in the Klondike rivers is recycled from Tertiary placer deposits – the White Gravels.

Climate in the Yukon during the Cretaceous-Paleogene was warmer and wetter than today.

Basins in the Yukon and Alaska contain Cretaceous and Tertiary coal.

Most evidence of Tertiary chemical weathering have been removed by physical weathering following renewed tectonism, and by glaciation.



Usibelli Coal Company

- Alluvial placer deposits in North America contained tens of millions of ounces of gold – quantities equal to the total contained gold of several “giant” bedrock gold deposits.
- Very few bedrock gold deposits contain significant amounts of visible gold: most is contained as little more than a trace geochemical impurity within sulfide minerals. Large pieces of gold metal are exceedingly uncommon.
- Gold is mobile in the weathering environment.
- Gold nuggets are forming today in locations where chemical weathering exceeds physical weathering. Sizeable gold deposits have been formed where weathering has continued for long periods of geological time (like tens of millions of years).
- Once formed, gold nuggets are both physically and chemically resistant. The significant placer deposits of California, Yukon and Alaska all represent recycled placer accumulations.
- The Earth’s climate and physiography have and continue to change.
- Chemical weathering was much more significant in western North America in the warmer, wetter climate of the Cretaceous and early Tertiary.

The story that placer gold deposits tells is that the earth has a long history, and the landscape and climate was different in the past than it is today.



Sorry my friend: there are no great lodes of metallic gold waiting at the head of this creek.



Thanks for your attention