Ore Deposits Associated with Weathering and Mass Wasting

DR. GREGG WILKERSON

I ❤ weathering and Mass Wasting

Discuss with a friend:

1. . What kind of class of mineral deposits do you think Form from weathering and erosion?

Industrial or Metallic minerals?

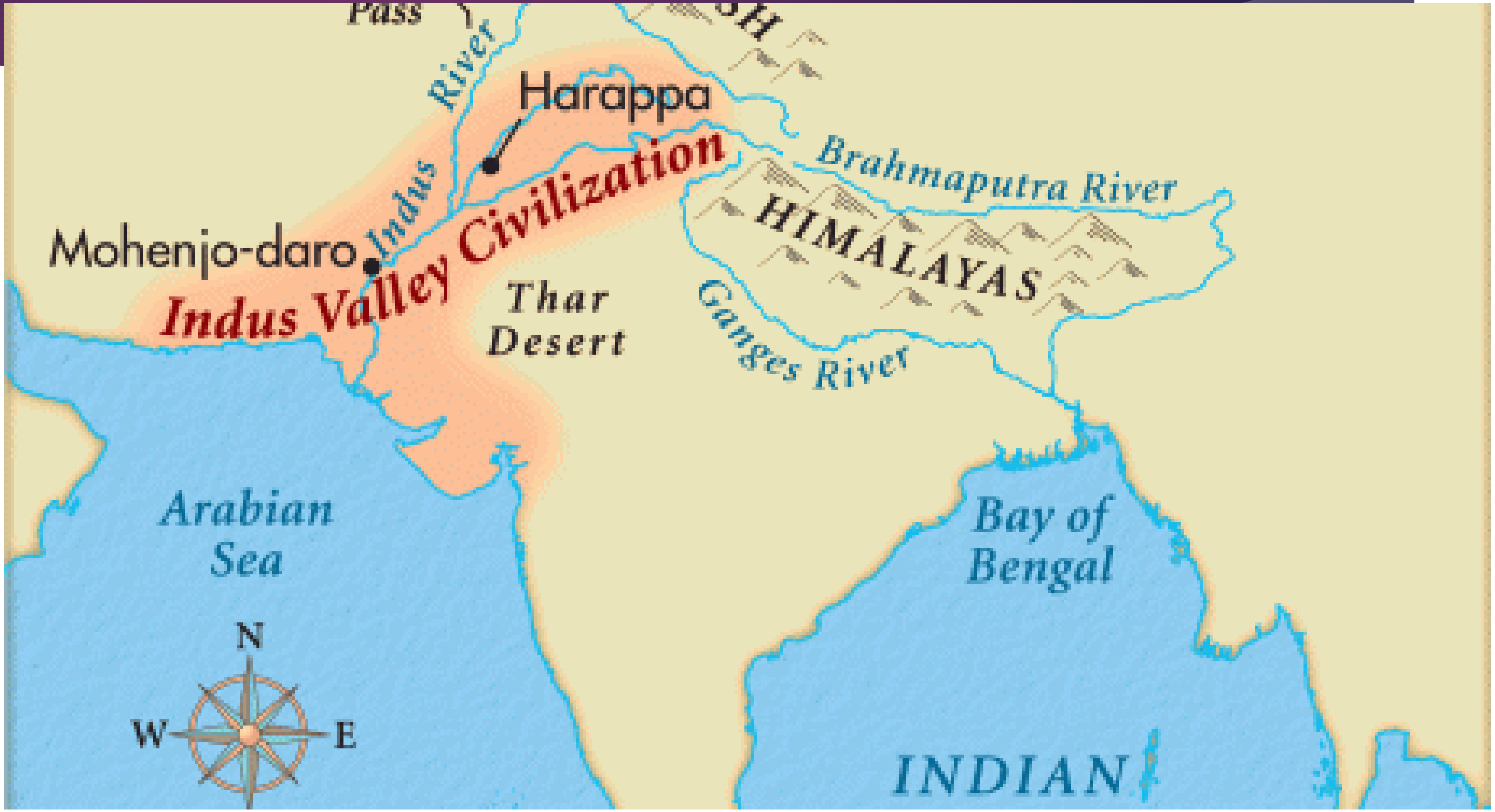
I will get an A on my exams and quizzes

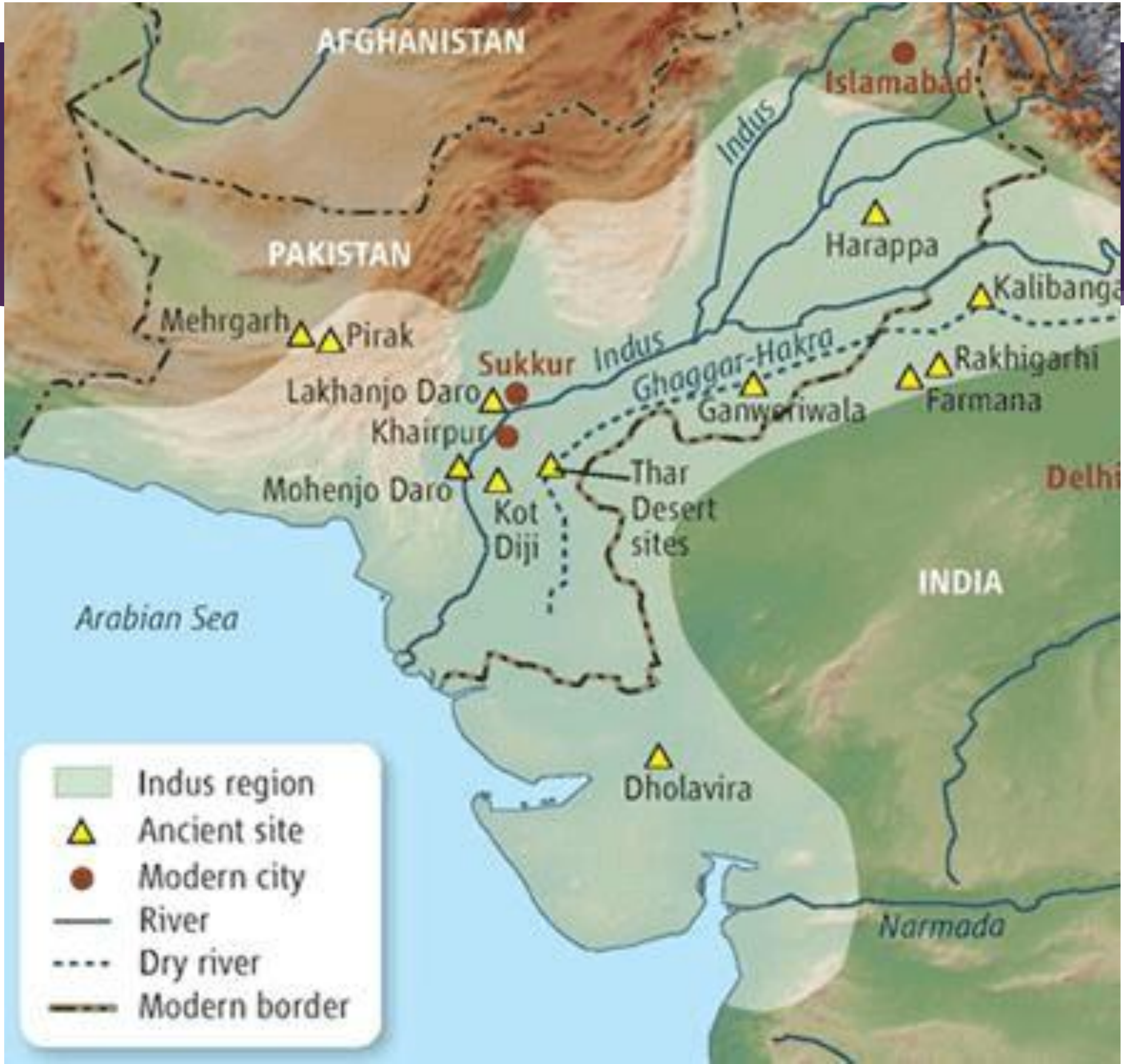
Gold Placer Deposits

- Oldest form of gold ore deposit
- Babylonians and Mesopotamians
- Egyptians
- Chinese
- Indus River Valley

Indus River Valley

- 4,000 to 2,000 BCE

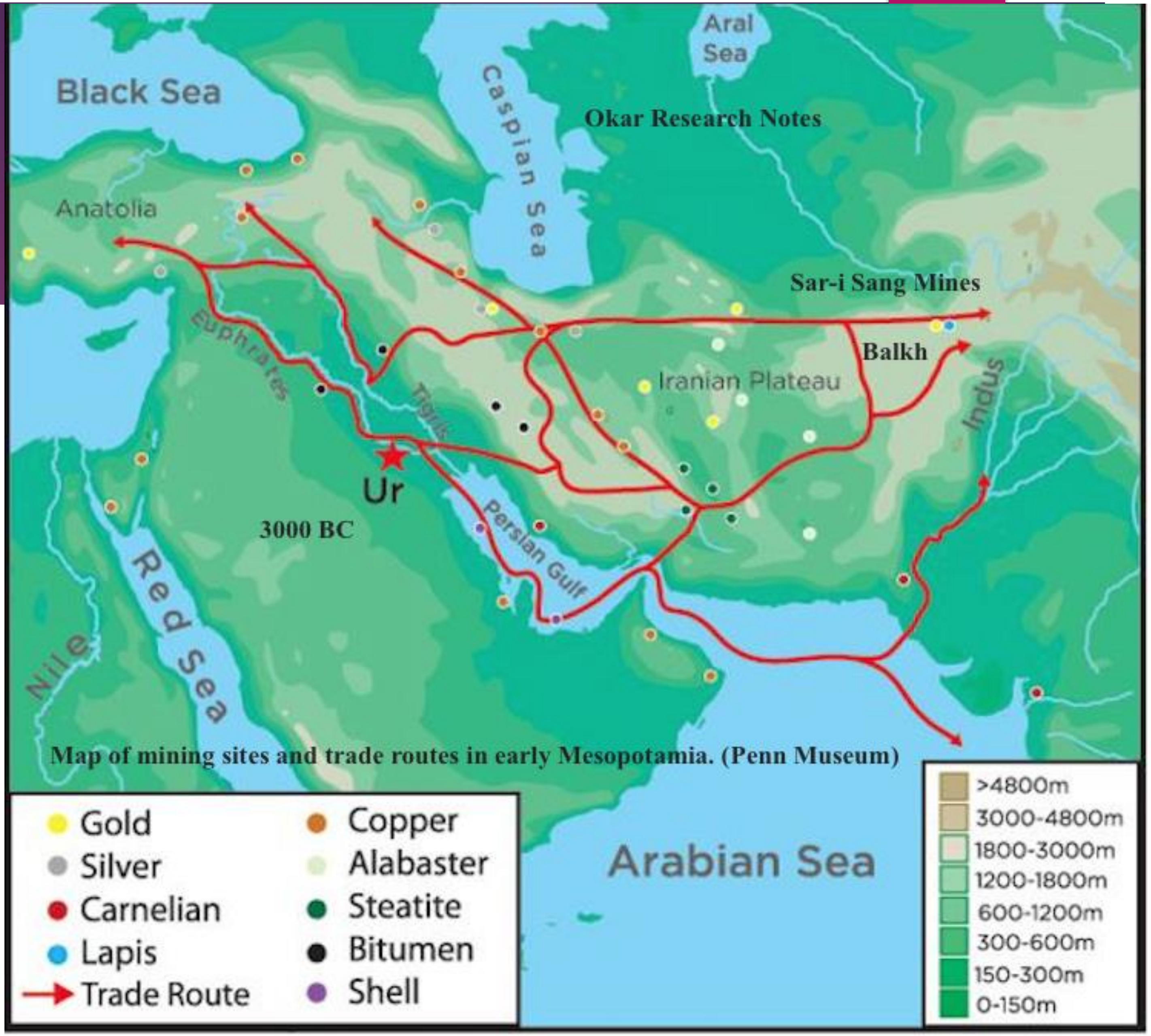


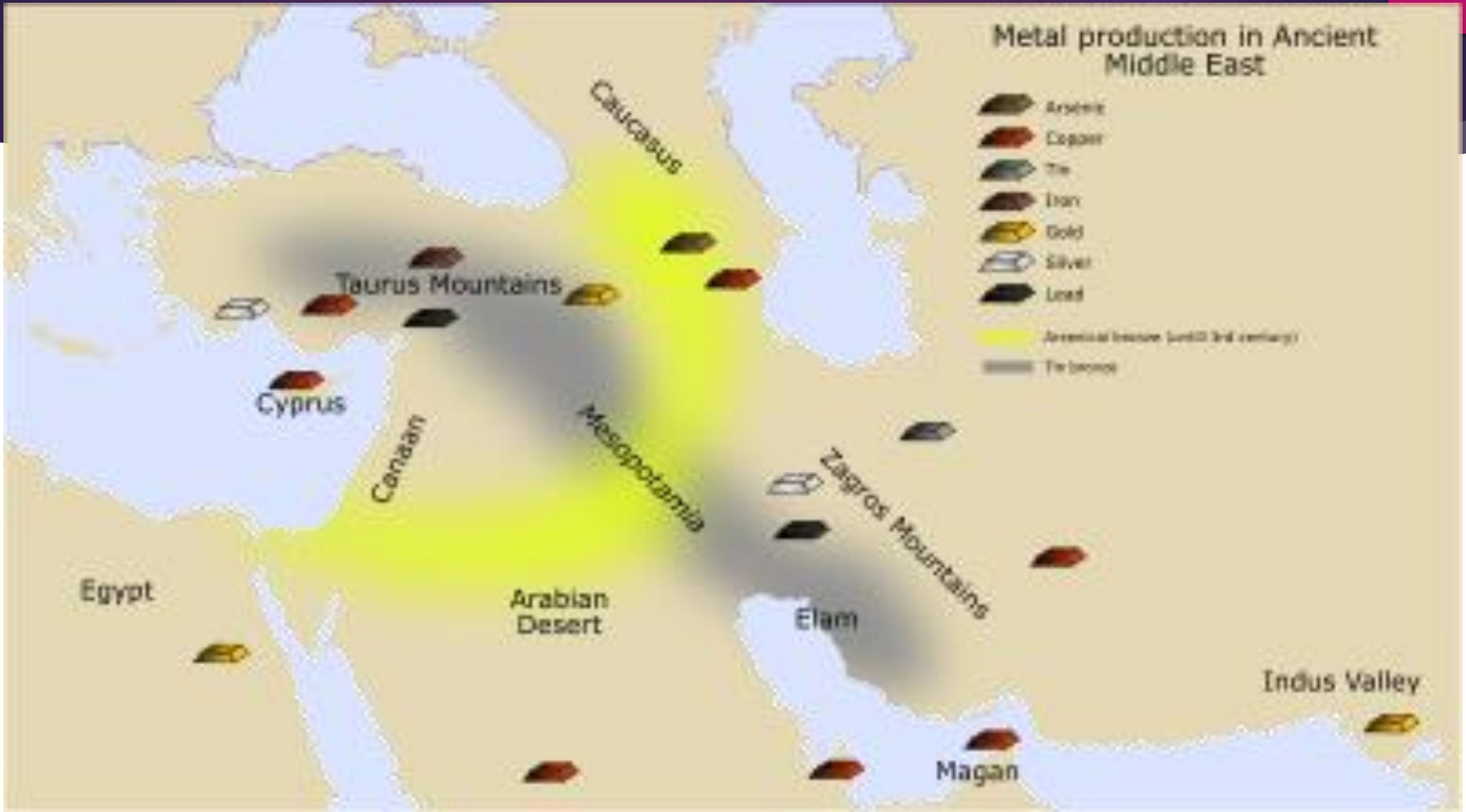

AFGHANISTAN
Islamabad
Indus
PAKISTAN
Harappa
Kalibanga
Mehrgarh
Pirak
Sukkur
Indus
Ghaggar-Hakra
Rakhigarhi
Lakhanjo Daro
Ganweriwala
Farmana
Khairpur
Thar Desert sites
Delhi
Mohenjo Daro
Kot Diji
INDIA
Arabian Sea
Dholavira
Narmada
Indus region
Ancient site
Modern city
River
Dry river
Modern border

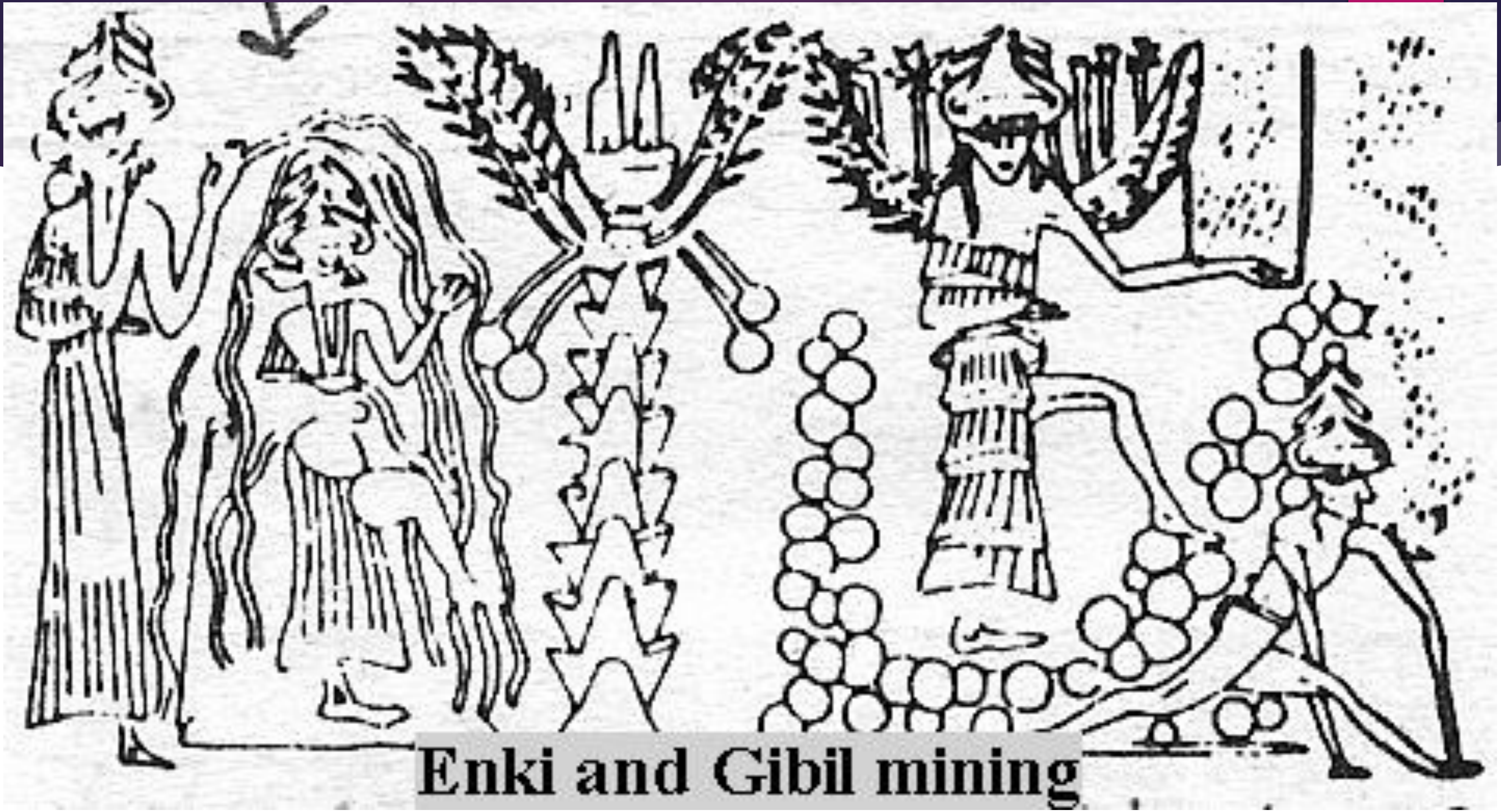
Indus River Valley

- well-planned, citadels, grid of streets
- clay brick houses, plumbing with sewer system
- bronze and copper tools, gold and silver jewels, clay pots, spun and woven cloth

Mesopotamia

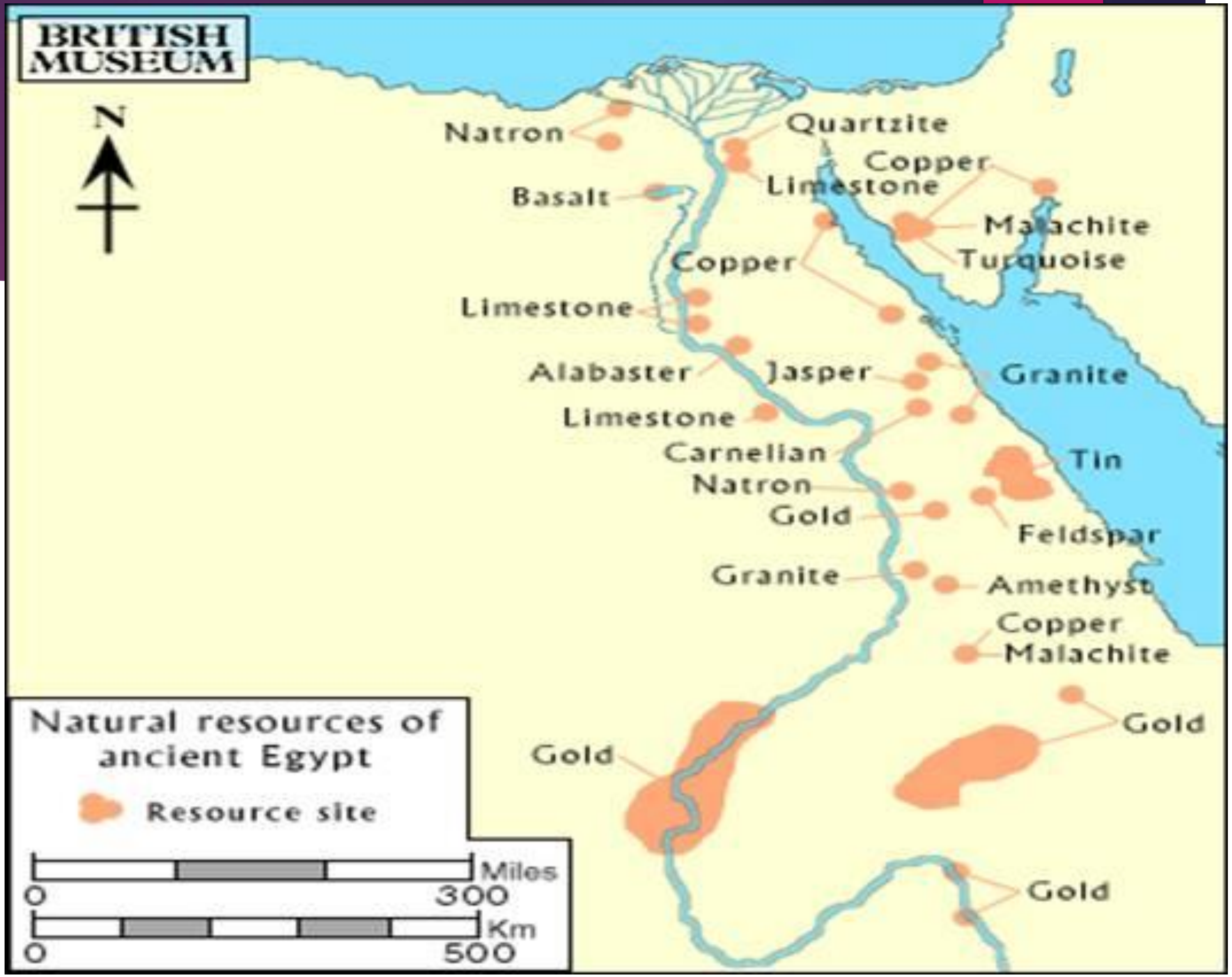



Metal production in Ancient Middle East
Arsenic
Copper
Tin
Iron
Gold
Silver
Lead
Caucasus
Taurus Mountains
Cyprus
Canaan
Mesopotamia
Zagros Mountains
Egypt
Arabian Desert
Elam
Indus Valley
Magan

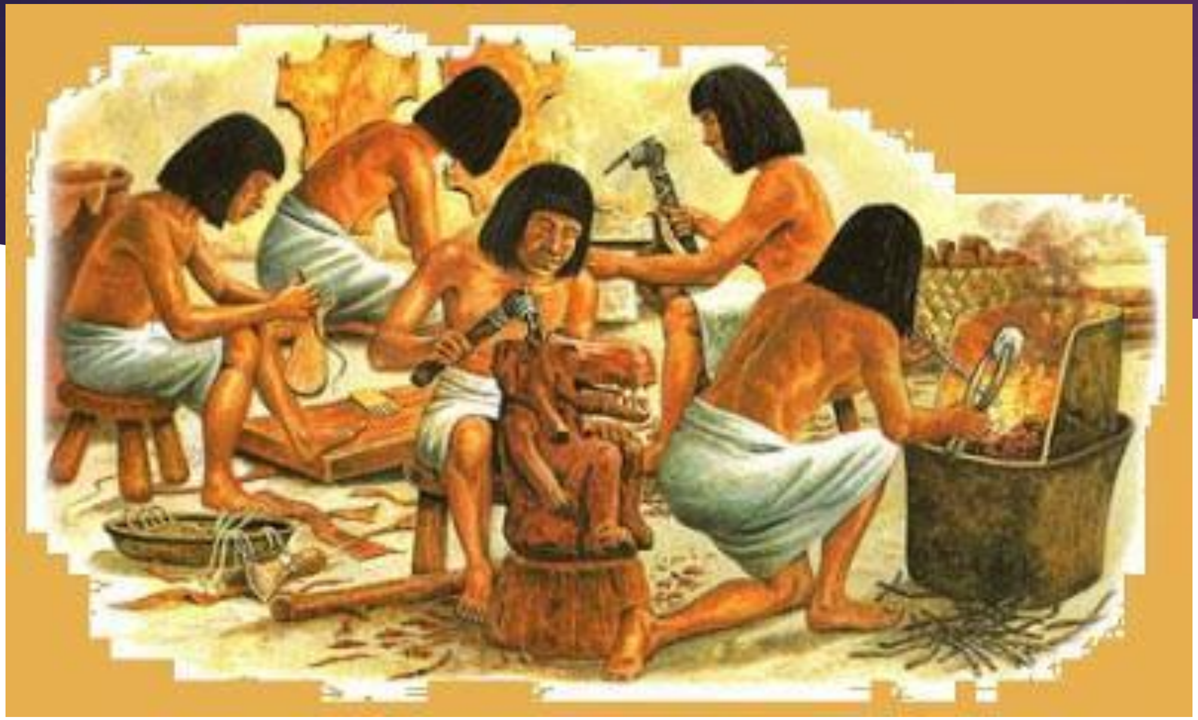


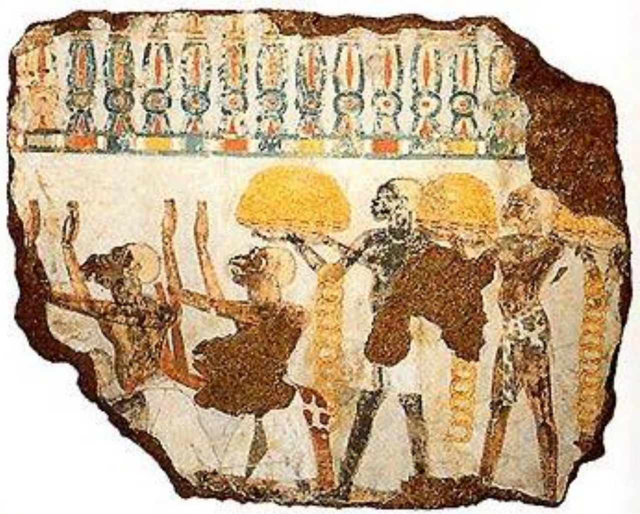
Enki and Gibil mining

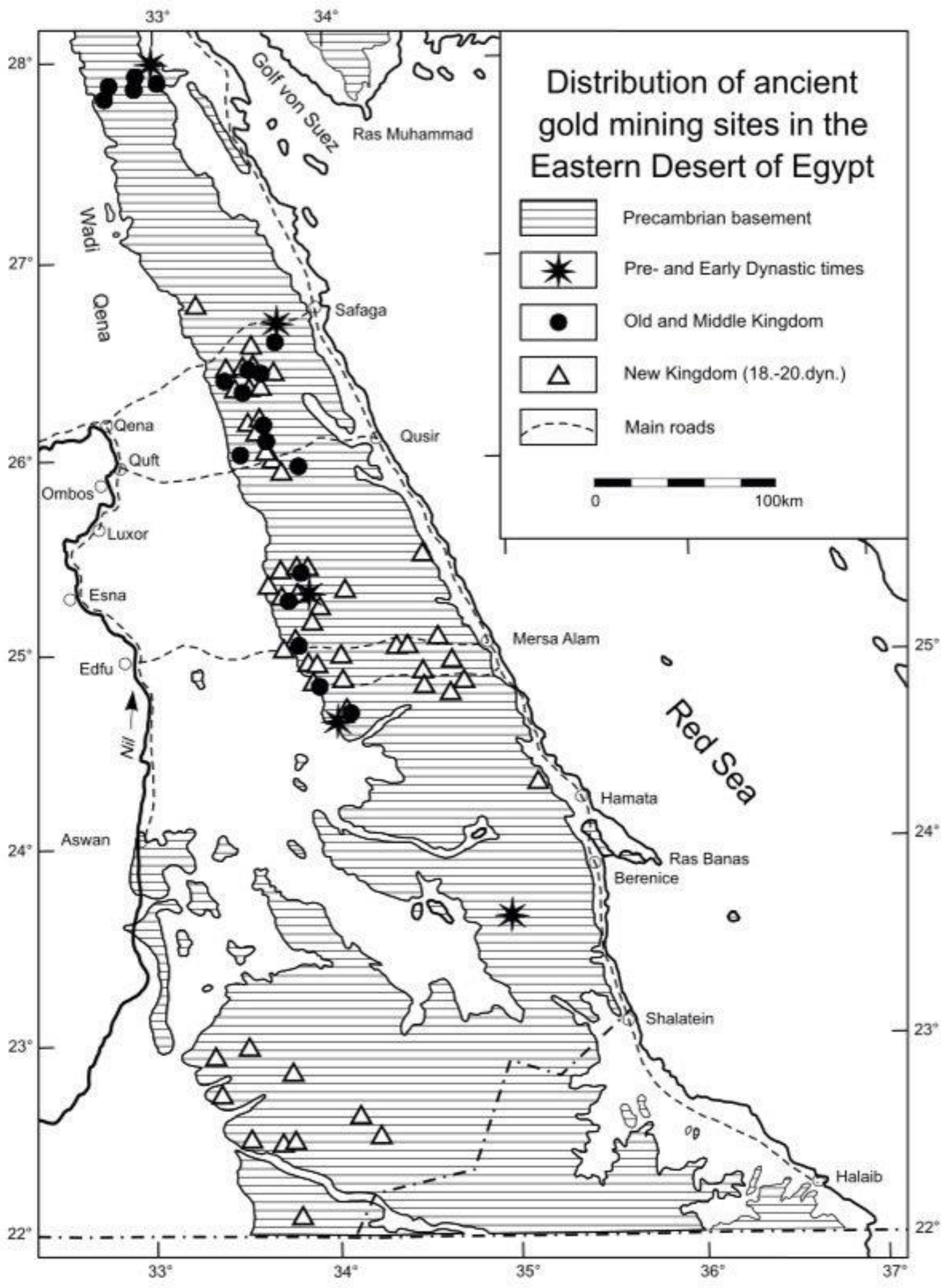
Egypt

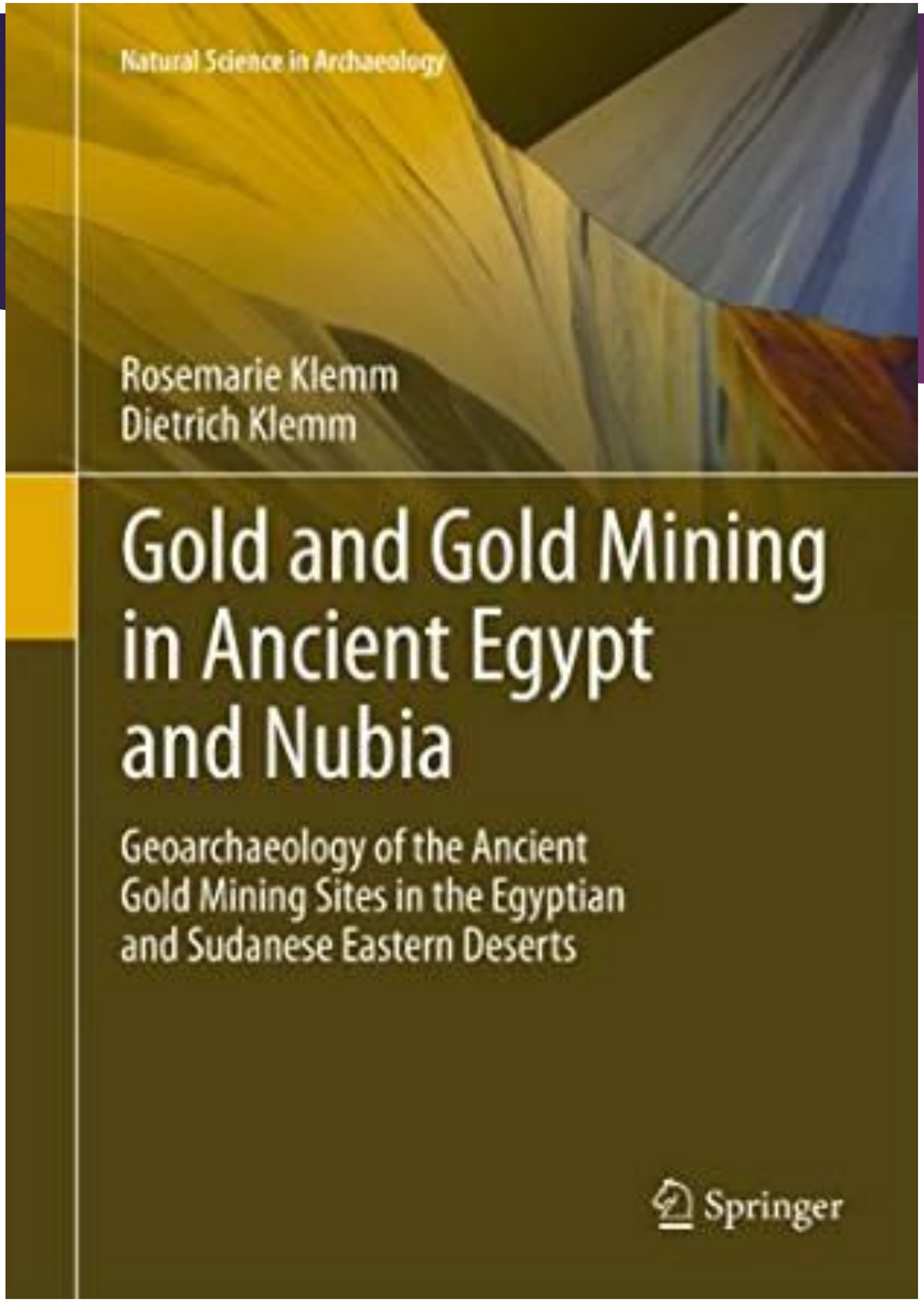


BRITISH MUSEUM
N
Natron
Quartzite
Copper
Limestone
Basalt
Malachite
Turquoise
Copper
Limestone
Alabaster
Jasper
Granite
Limestone
Carnelian
Tin
Natron
Gold
Feldspar
Granite
Amethyst
Copper
Malachite
Natural resources of ancient Egypt
Resource site
Gold
Gold
Miles
0
300
Km
0
500
Gold



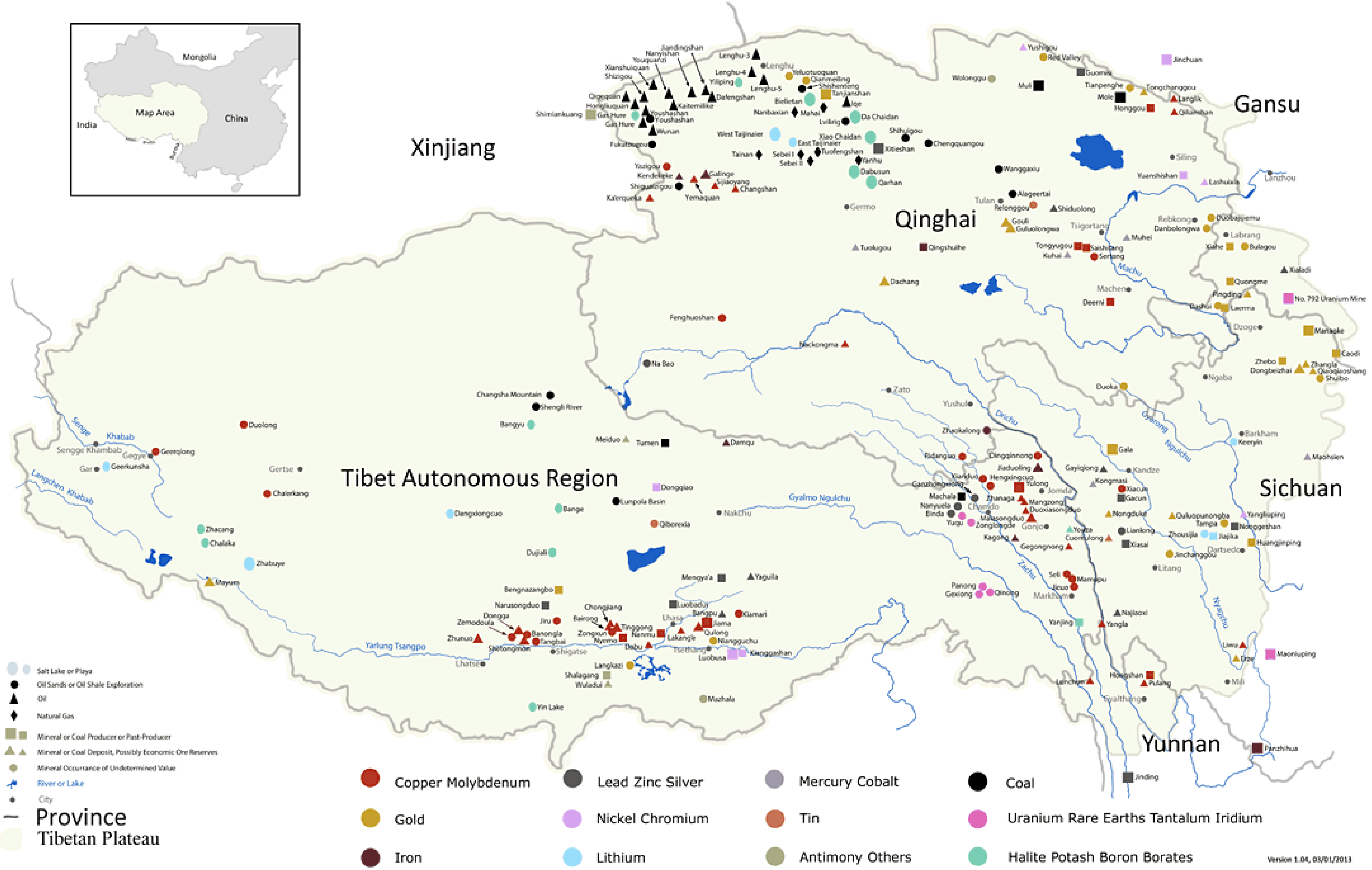


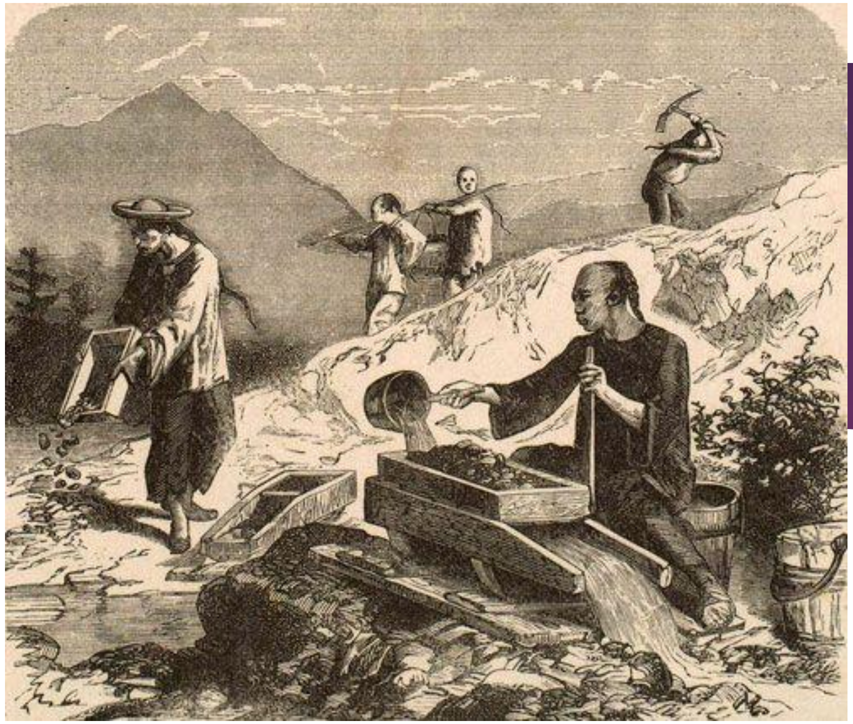

Distribution of ancient gold mining sites in the Eastern Desert of Egypt
Precambrian basement
Pre- and Early Dynastic times
Old and Middle Kingdom
New Kingdom (18.-20.dyn.)
Main roads
0
100km
Golf von Suez
Ras Muhammad
Wadi
Qena
Safaga
Qena
Quft
Qusir
Ombos
Luxor
Esna
Mersa Alam
Edfu
Nil
Red Sea
Hamata
Aswan
Ras Banas
Berenice
Shalatein
Halaib
33°
34°
35°
36°
37°
28°
27°
26°
25°
24°
23°
22°


Natural Science in Archaeology
Rosemarie Klemm
Dietrich Klemm
Gold and Gold Mining in Ancient Egypt and Nubia
Geoarchaeology of the Ancient Gold Mining Sites in the Egyptian and Sudanese Eastern Deserts
Springer

China

Petroleum and Mineral Deposits of the Tibetan Plateau






CHINESE ON THE ROAD TO THE PALMER.

weathering and Mass Wasting

Discuss with a friend:

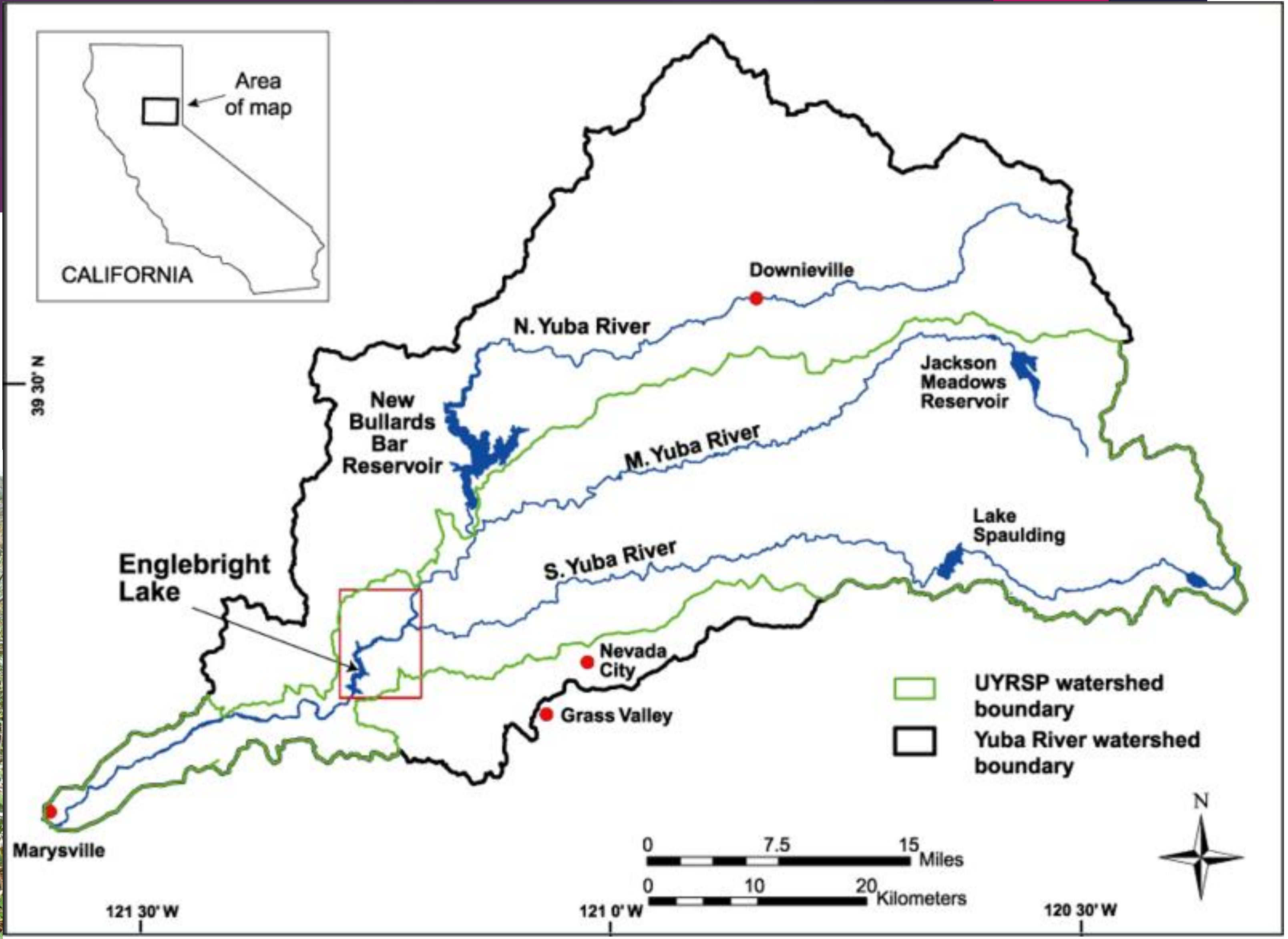
2. Could minerals have been mined by the Ancients without slaves?

3. What ancient civilizations practiced gold placer mining ?

I will get an A on my exams and quizzes

Grass Valley Gold Placers

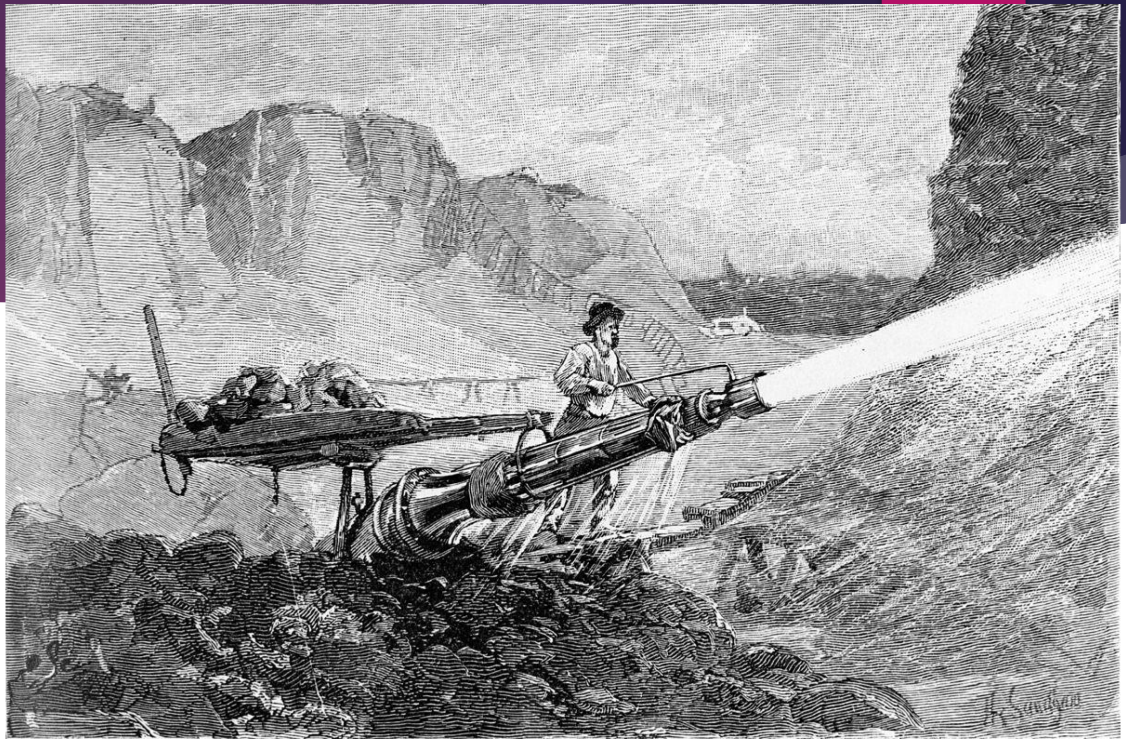
- Malakoff Diggins State Park
- VIDEO



Garton Road
To Relief
And North
Bloomfield
Relief Road
Kelsher
Day Use Area
Canyon
Creek
Artic Mine
Mtn. View Mine
Mayhert Road
Golden Quartz
Day Use Area
Maybertt Road
Fall
Creek
South Yuba
Trail
South Yuba
River
Washington
El. 2612
South Yuba River
Eagle Bird
Mine
Alpha
Diggings
Omega Diggins
Eagle Bird
Drop
Diamond
Creek
Washington Road
Alfa
Road
Omega
Road
Spring
Cabin &
Gold Bug
Mine
Washington
Overlook
El. 4373
Hwy 20
Omega
Cemetery
Omega
Drop
Last
Chance
Mine
Last Mtn.
El. 5747
To
Nevada
City
Omega
Road
Pioneer Trail
Alt. Trail
Diamond Creek
Or
Last Chance Road
N
E
W
S
Old Omega Road
Omega Rest
Stop
Omega Trail
Pioneer
Trail
Chalk Bluff
Road
Hwy 20 To Hwy 80
And Truckee

Malakoff Diggins

Hydraulic Mining




6-3-1919
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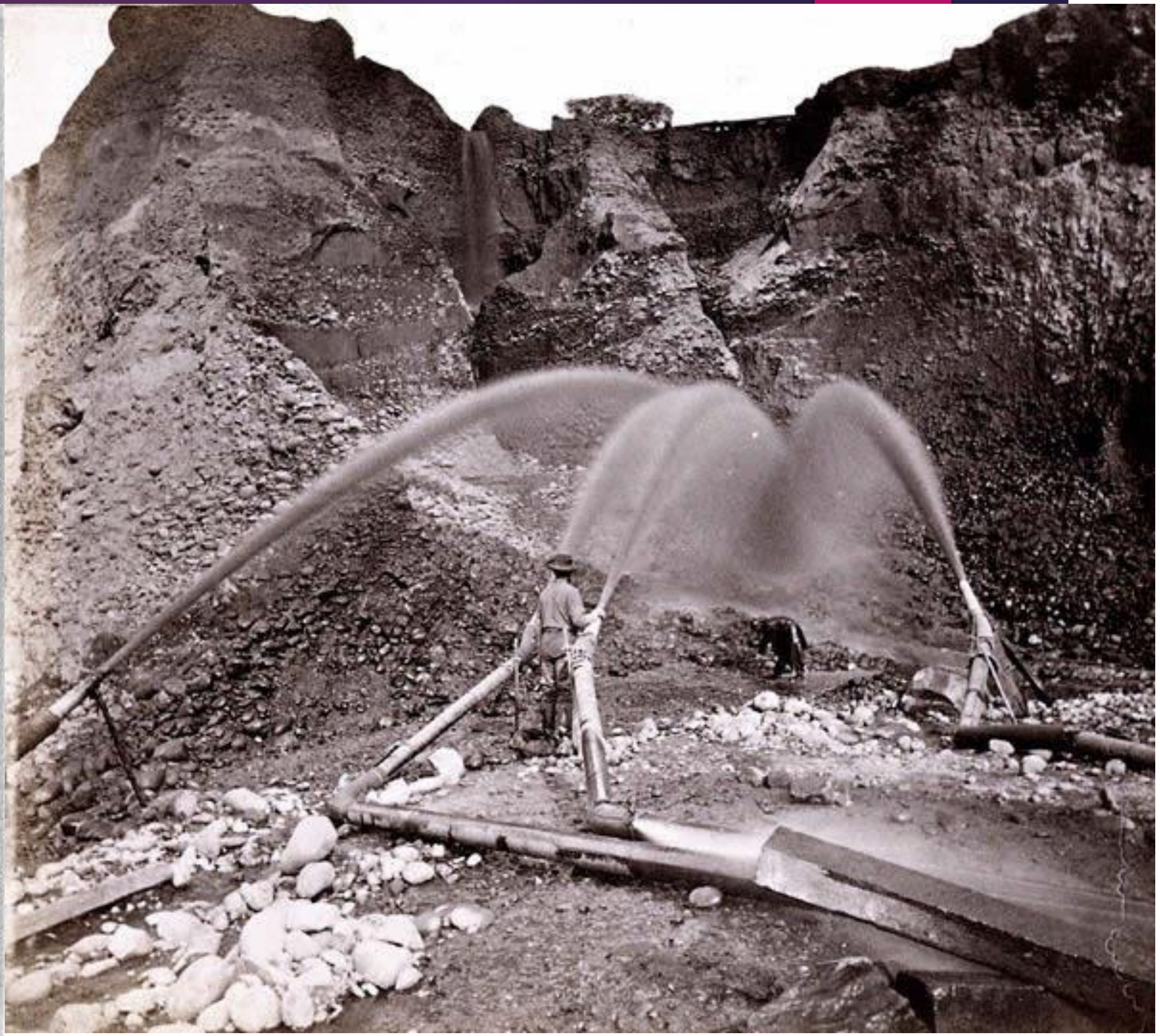
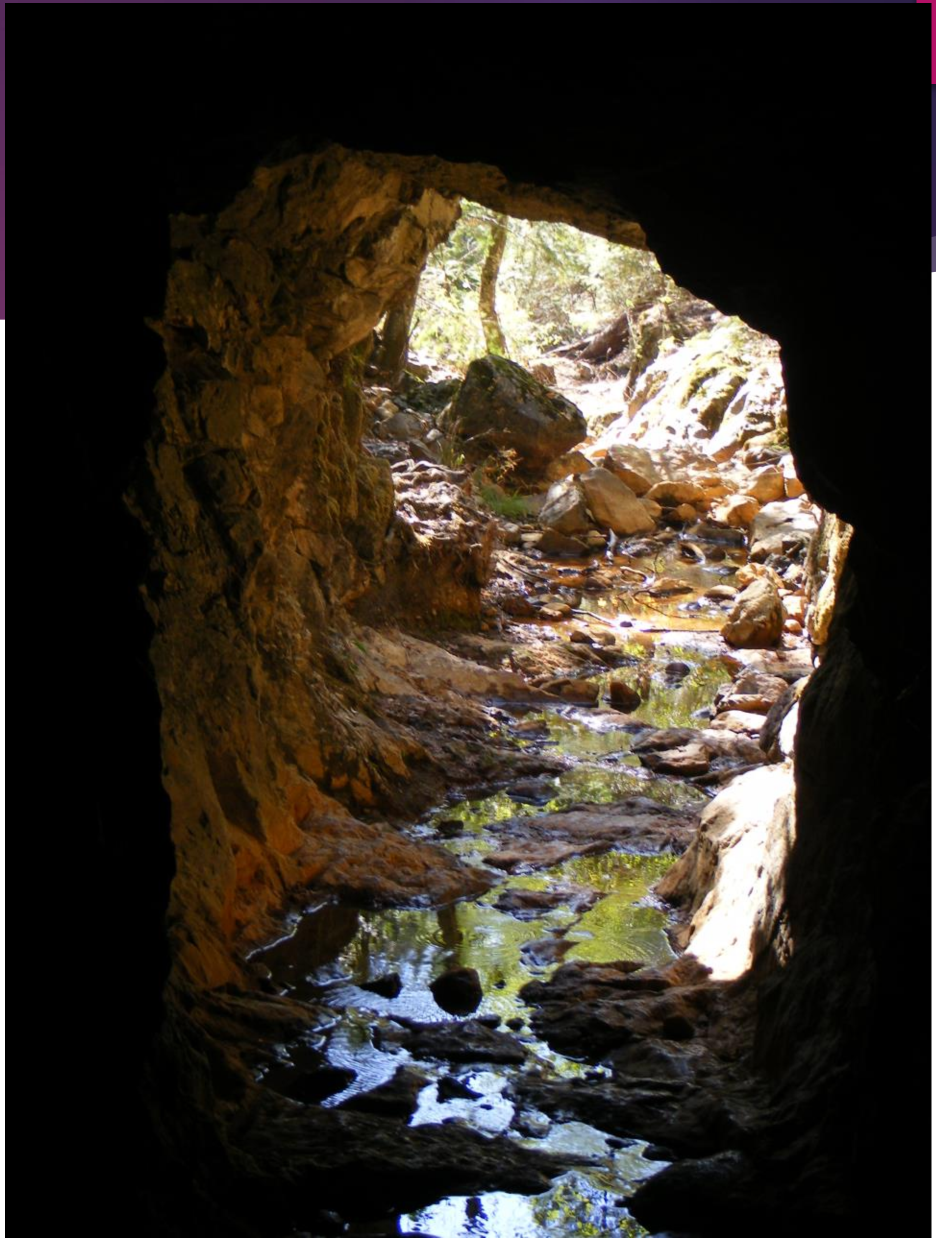
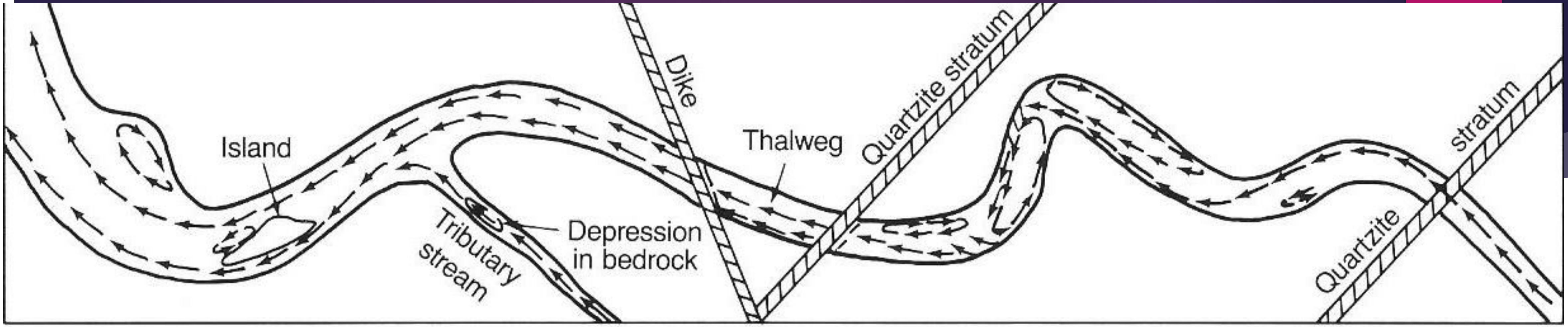


Drainage Tunnels

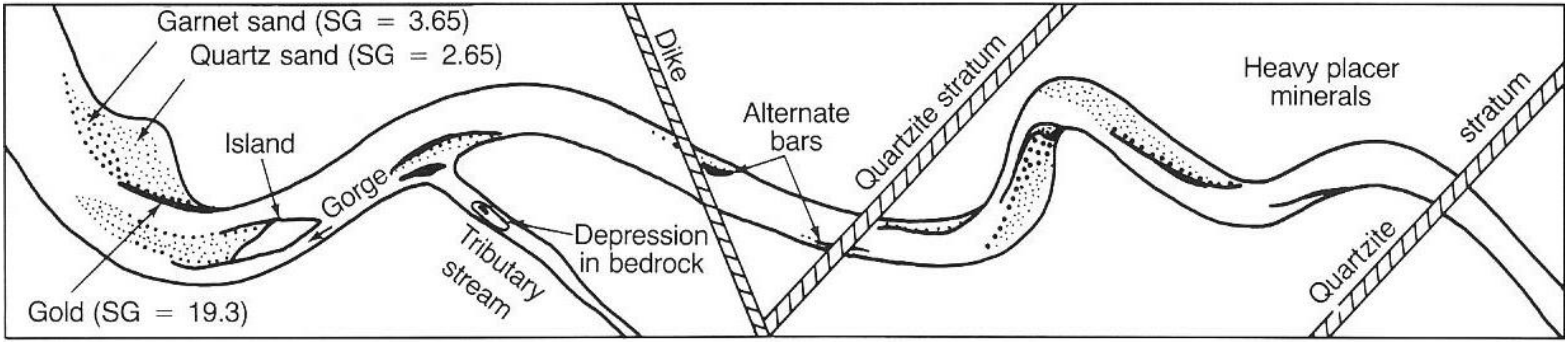


Sluice Box Recovery of Gold



Stream currents

Placer deposition at sites of reduction in water velocity (velocity "shadows"



Distribution of heavy minerals

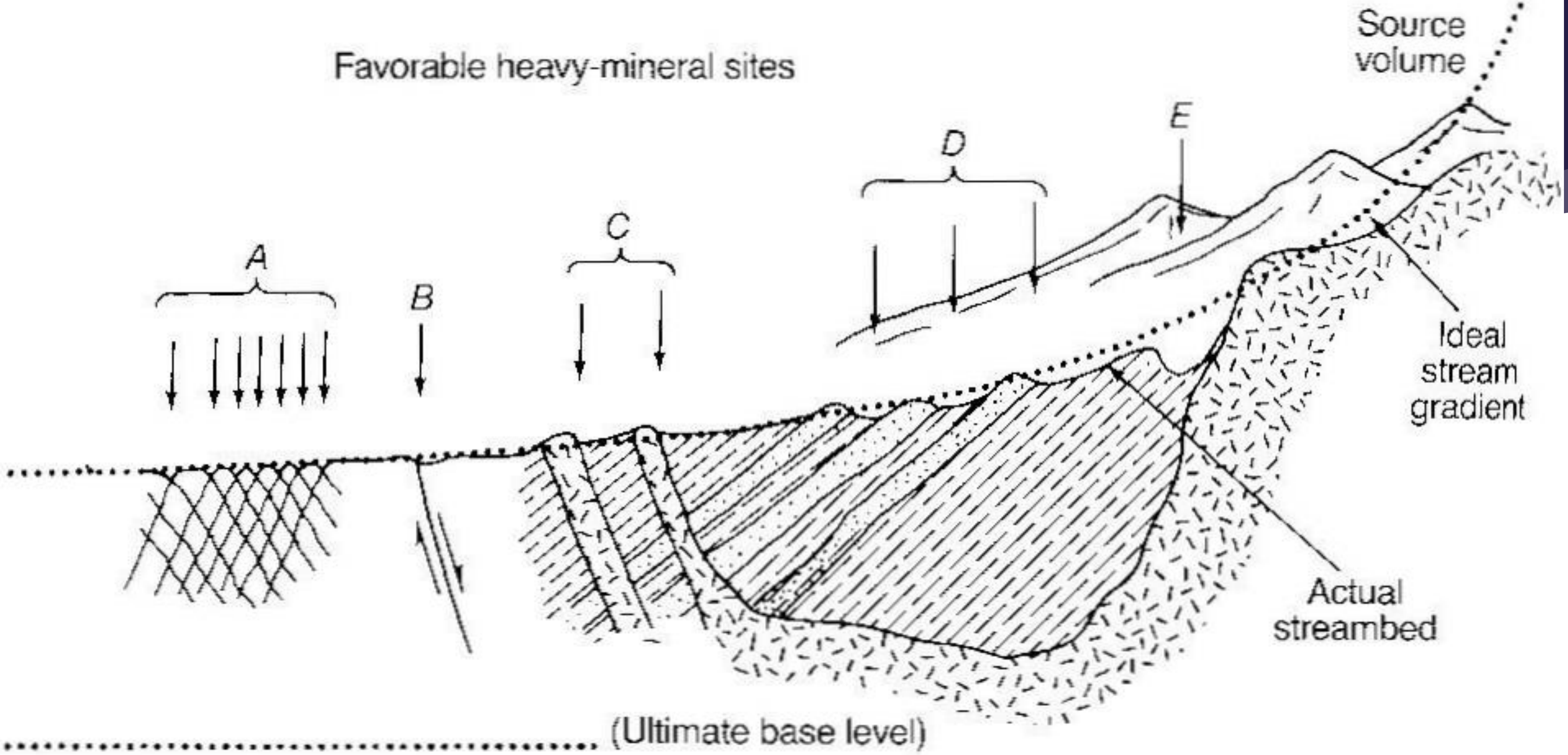


Figure 16-1. Favorable sites along a hypothetical stream profile for the accumulation of heavy minerals being carried downstream from a source volume include crevices formed by steep joints *A*, faults *B*, or outcrops of resistant dikes *C* or strata *D*, and plunge pools *E*, eddies, or potholes in rapids.

Stream Diversions

weathering and Mass Wasting

Discuss with a friend:

4. Where does gold accumulate in rivers?

I will get an A on my exams and quizzes

Aggregate Mines

- Sand and Gravel
- Critical ingredient for concrete



Ocean – Estuary Gravel Deposits: Dredges

Placer deposits: gold of Witwatersrand, South Africa

PreCambrian Placer Gold-Uranium

- Descriptive model of Quartz pebble conglomerate Au-U
- DESCRIPTION: Placer Au, U, and PGE in ancient Conglomerates
- Witwatersrand goldfields
  - "White Waters Ridge"
    - Derived from the white quartzite ridges which strike parallel to the edge of the basin
- Part of the Witwatersrand Basin- which is 350 km long and 200 km wide
- Possibly the deepest mines in the world (mining operations at 3600 m and core drilling up to 4600 m)

Deposit Location

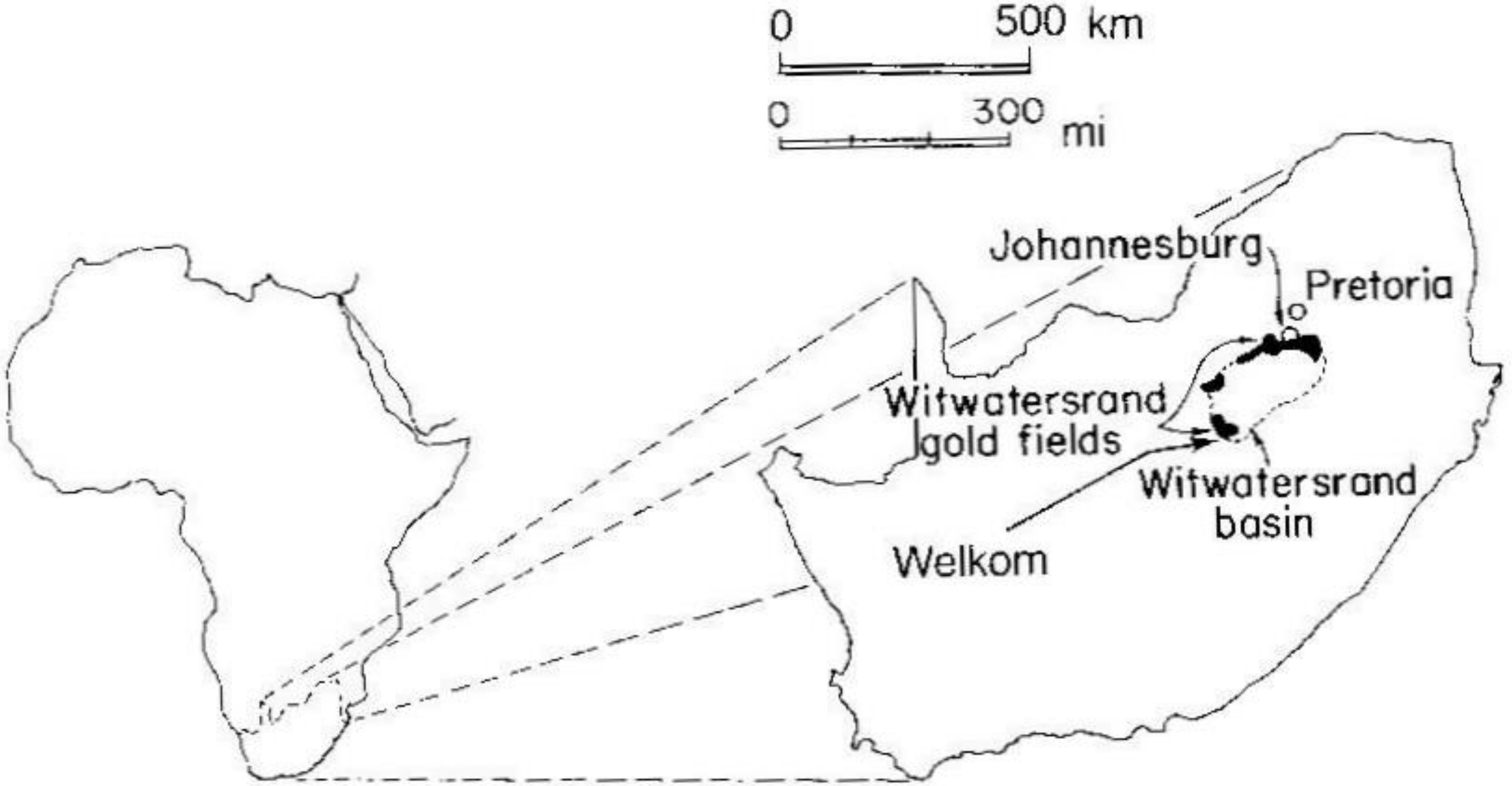
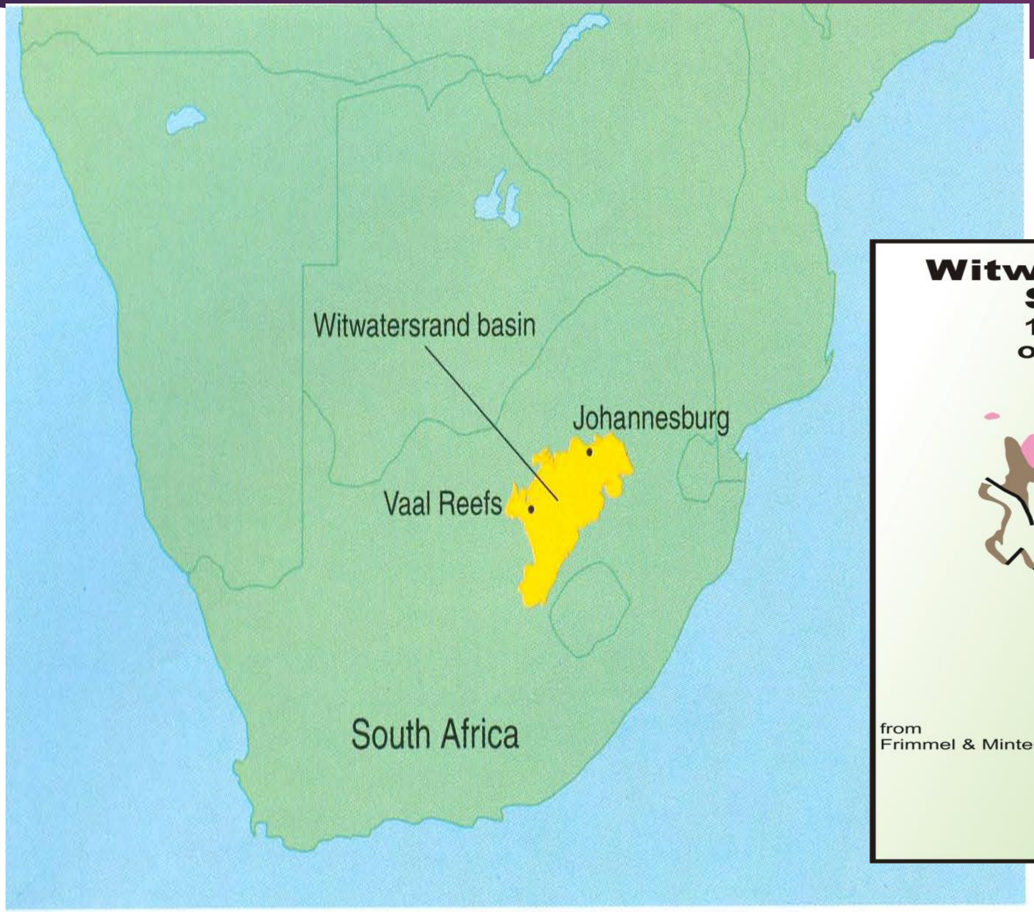
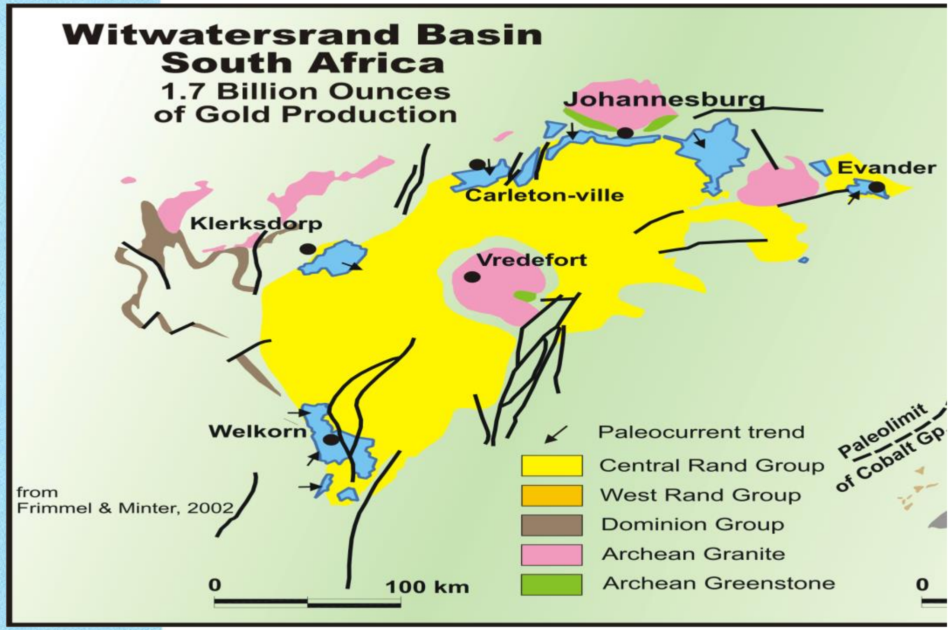


Figure 16-7. Map of the Republic of South Africa showing the location of the Witwatersrand deposits.

Deposit Location





USGS Ore Deposit Model #29a

GEOLOGICAL ENVIRONMENT

- **Rock Types**
  - Oligomictic mature conglomerate beds in thick sequence of less mature conglomerate and sandstone deposited on Archean granite-greenstone. Basal volcanic rocks locally. Thick sedimentary sequences underlying Superior type iron-formation.
- **Textures**
  - Well-rounded, well-packed pebbles of vein quartz, chert and pyrite. Bimodal clast-size distribution with well-sorted pebbles and well-sorted matrix. Matrix is quartz, mica, chlorite, pyrite, and fuchsite. Granite clasts are absent.
- **Age Range**
  - Major deposits are Archean to Early Proterozoic (3,100-2,200 m.y.), Tarkwa is 1,900 m.y.

Mining History

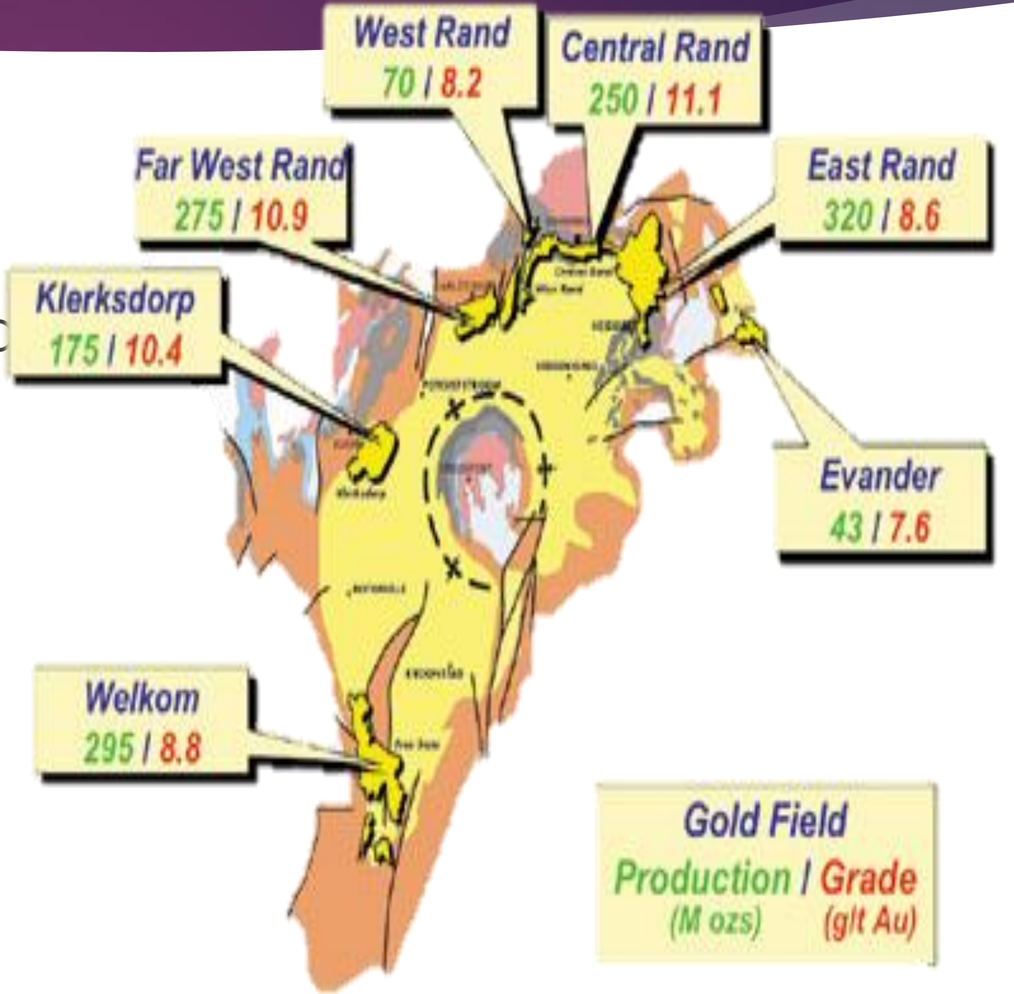
- Discovery
  - Gold discovered in Witwatersrand in 1886 by George Harrison on a Transvaal (South of African Republic) farm called Langlaagte-where the gold bearing reef outcropped briefly and then plunged below ground at an angle of 25 degrees or more.
  - Langlaagte became part of a bigger mining camp called Johannesburg
  - The first to gain control of the gold mining were those with capital-the diamond mine owners
    - Hermann Eckstein (1887) settled the Corner House, which became the Rand mines.
    - Cecil Rhondes and Charles Rudd with the Gold Fields of South Africa
    - Barnato brothers with Johannesburg Consolidated Investment Company
    - George and Leopold Albu with General Mining and Finance Corporations
    - Adolf Goerz started Union Corporation in 1893

Mining History

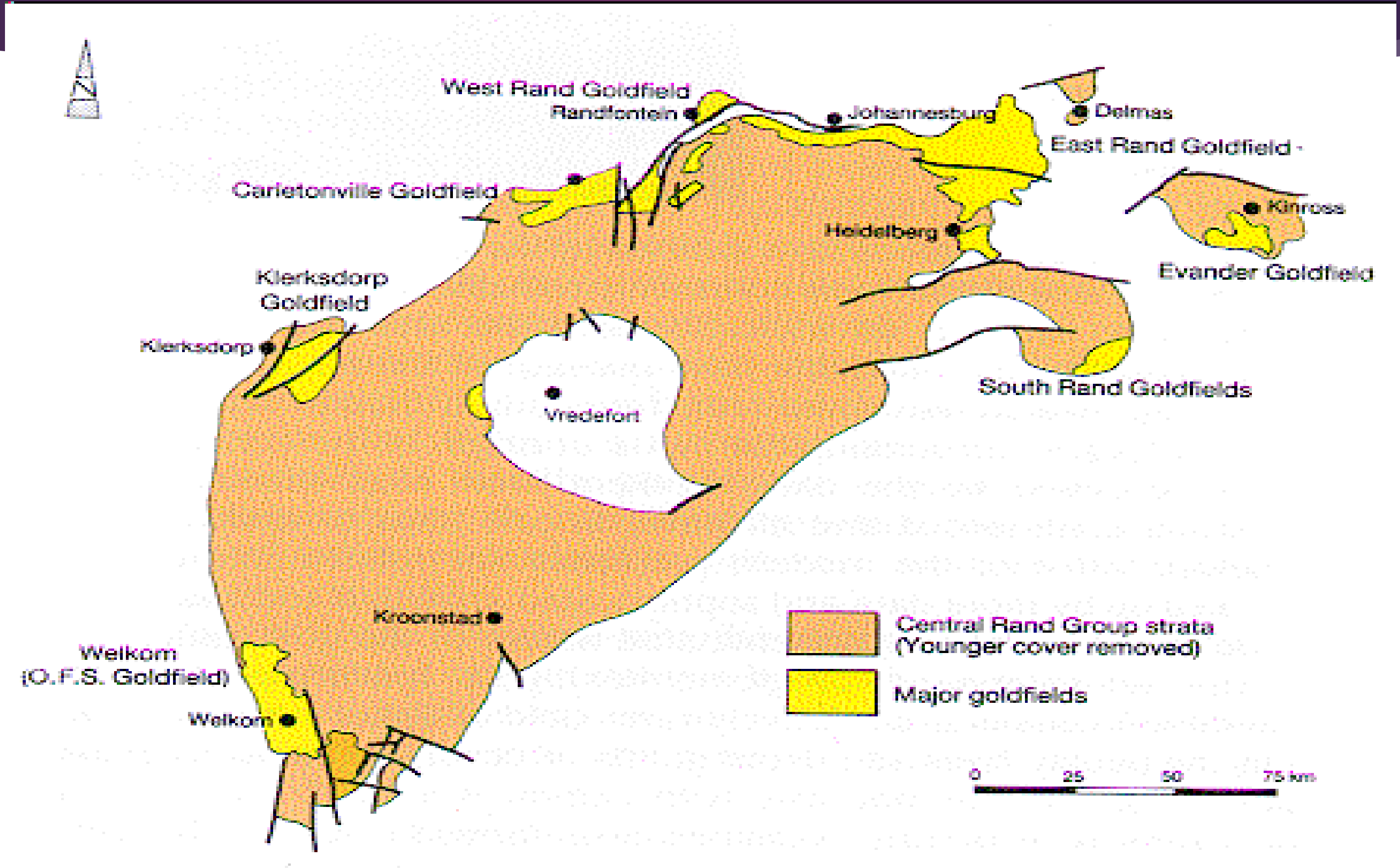
- Discovery
  - Other mining towns sprang up and form a curve on a map that is called the Witwatersrand where ever the reef outcropped at the surface
  - The extraction method previously used for gold did not work efficiently
    - They were only able to extract 70-65% of gold by crushing the rock to powder, which was then carried by water over copper plates coated with mercury, which amalgamated with gold.
  - This inefficiency started the decline of the gold boom.
  - Until Robert and William Forrest, and a chemist, John S. MacArthur came up with another solution for extracting gold.
    - 1887- they patented the MacArthur-Forrest process for extracting gold with cyanide. This process extracts 96 % of the gold from ore.

Mining History

- Production
  - 1948-97 % of gold output
  - 1979- 94% gold productic
  - 2002- 49,332 metric tons
  - w/ grade of 8 g/t
  - Production peaked in 1970 with over 1000 metric ton
  - 150,000 tons of Uranium

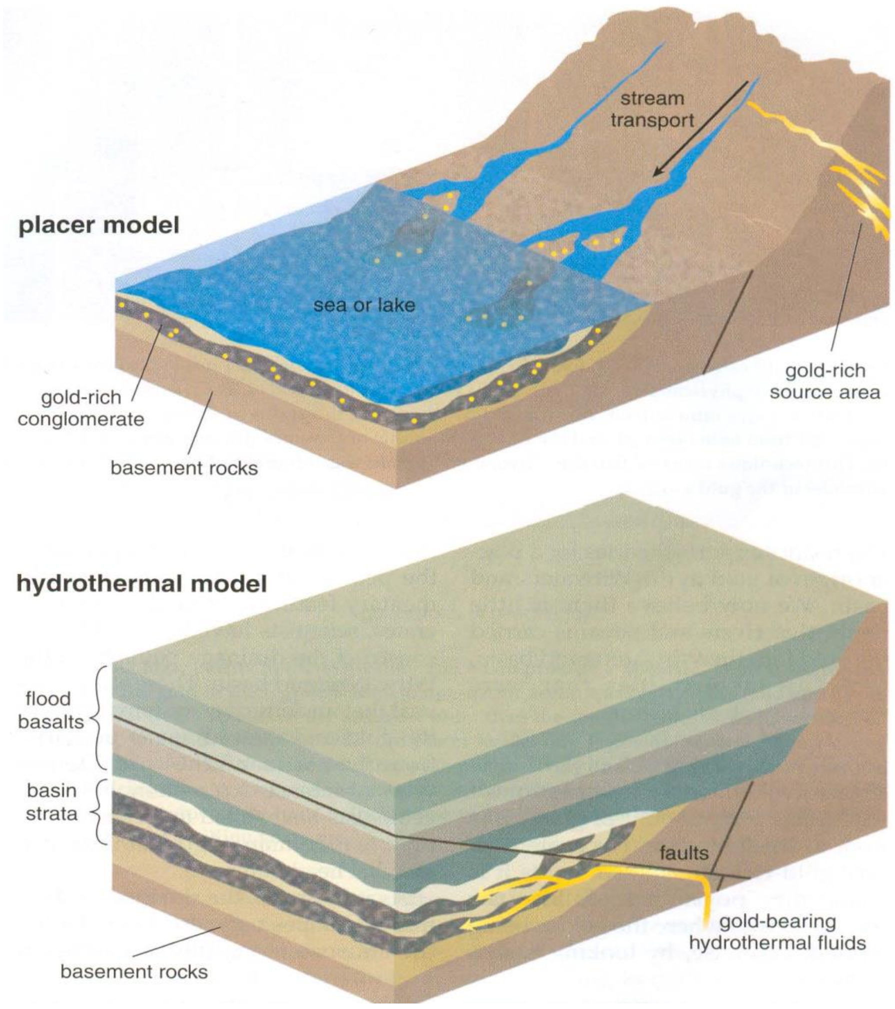


Mining history



Origin/transportation/deposition of the ore bearing fluids

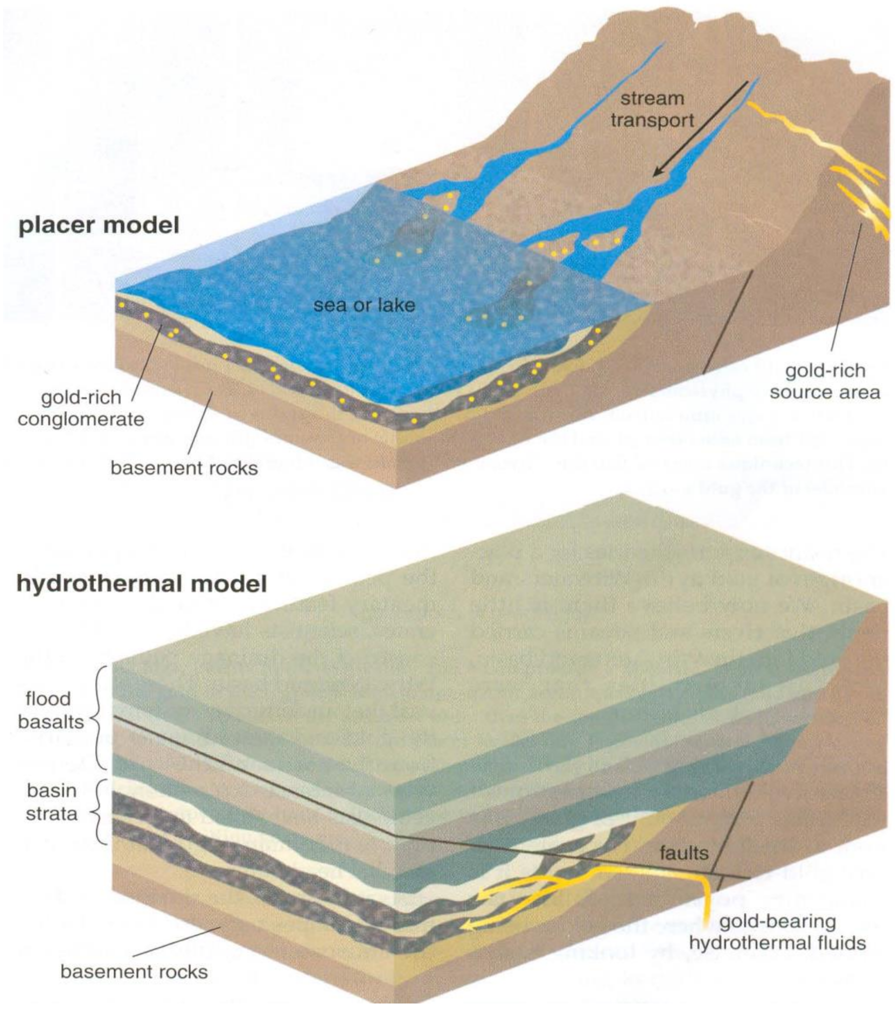
- The Witwatersrand Basin formed between 2.97 and 2.714 Ga and has a size of ~30,000 km^2
- There are gold deposits of varying ages.
- The origin of the ore has three models:
  - Paleoplacer
  - Synsedimentary
  - Hydrothermal
- The basin was filled with eroded material of pebbles and quartz arenite that came from the erosion of gneiss-granite-greenstone terrain via a system of braided rivers.



Origin: Placer vs Hydrothermal

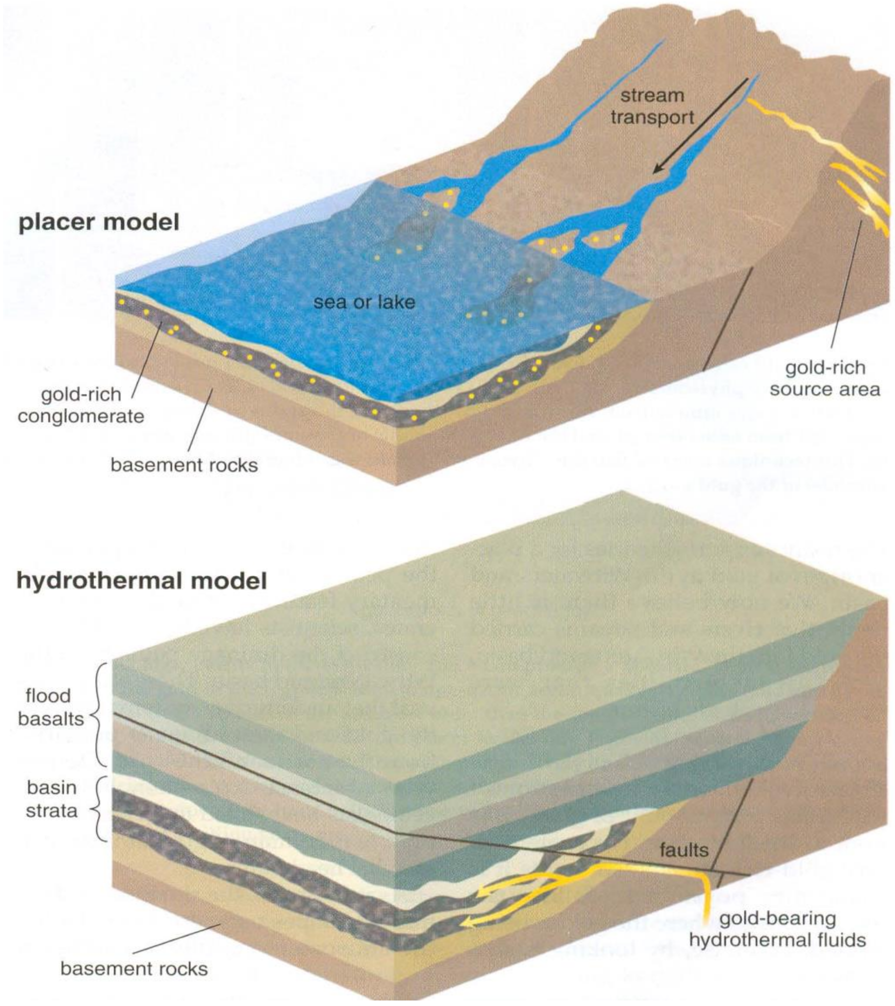
- The detrital gold that came out of the conglomerate shows sign of transport not exceeding 35 to 40 km.
- Gold and uraninite occurs with the sulfides in the conglomerate matrix.

- The eroded material was overlain by other material that continued to enter the basin, until they were overlaid by a large eruptions of flood basalts and more sediments.
- This layer provided heat and pressure necessary to change the unconsolidated material into sed. rocks.



Origin/transportation

- The placer model claims the rivers carried the small grains of gold and rounded pyrite into the basin.
  - Density of the minerals allowed them to fall out of suspension with the larger quartz pebbles in the gravel rich deltas and these deposits eventually became the conglomerates mined today.



Origin/transportation/deposition of the ore bearing fluids

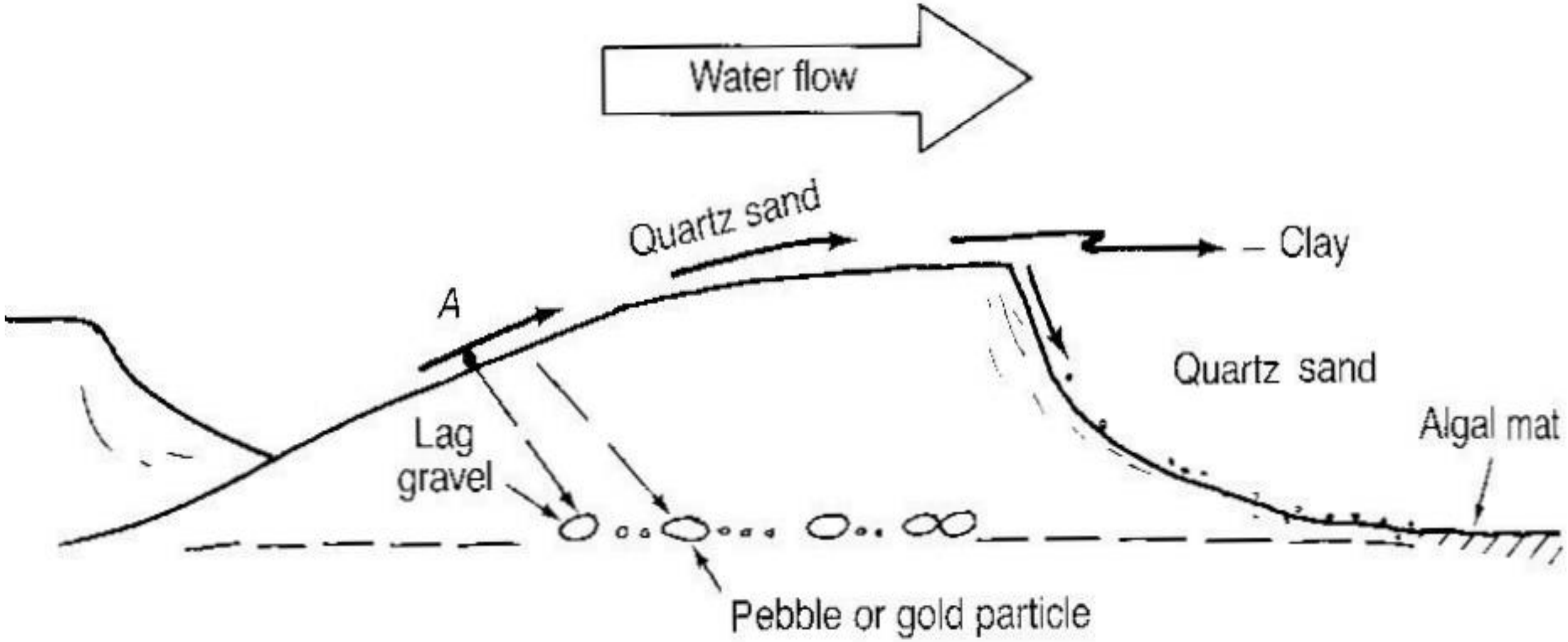
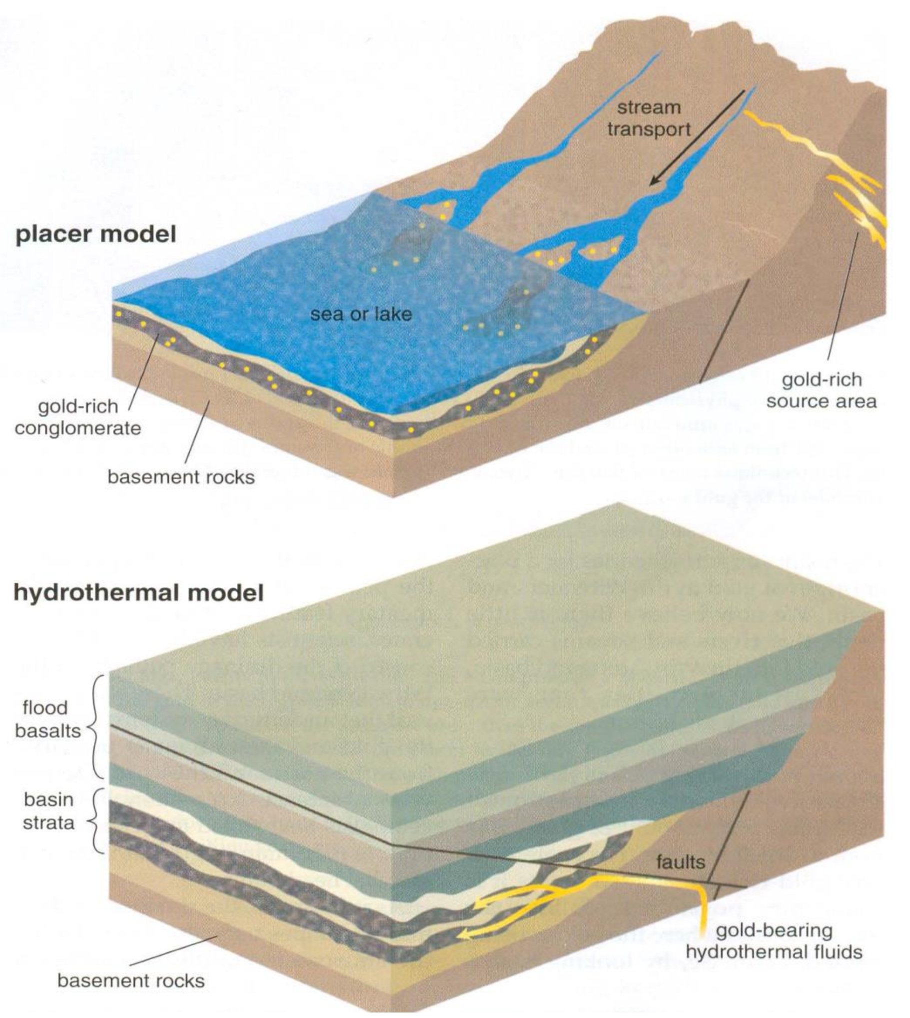


Figure 16-13. Ripple advancing downstream to right with the behavior of different particles indicated. Compare with Figures 16-14 and 16-15.

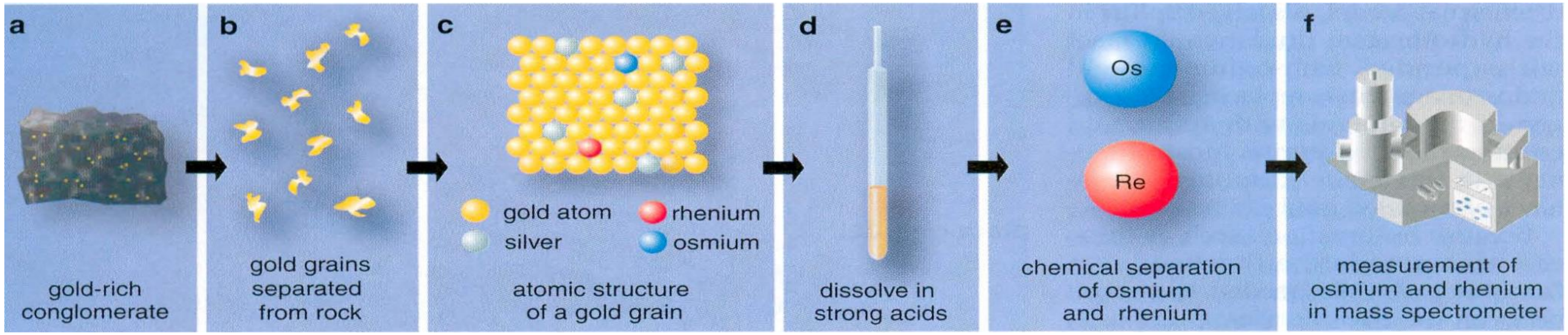
Origin/transportation/deposition of the ore bearing fluids

- The hydrothermal model states that the sediments that washed into the basin contained very little or no gold. Instead, gold-rich hot fluids emanating from deep within the Earth's crust, and traveling along faults and fractures, added gold to the basin long after the sediments consolidated into rock.
- The gold precipitated from these fluids along chemically favorable horizons within the basin, corresponding to the layers of conglomerate.



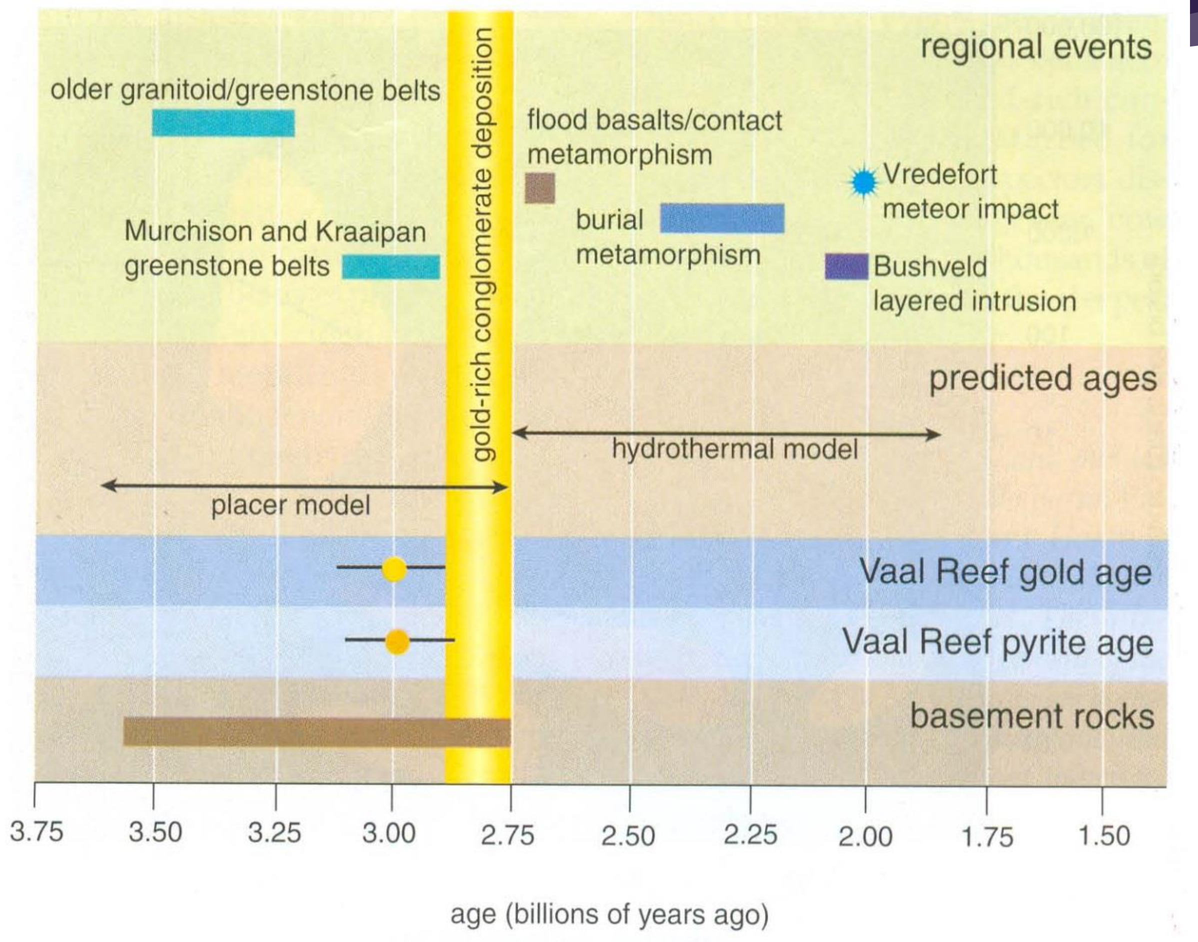
Isotope Studies

- Isotope of rhenium (187) is used to date gold
- This isotope decays over time into Osmium (187) at a known rate.
- Using this it was determined that the gold is 3.01 billion years old-older than the host conglomerate which are 2.76 to 2.8 billion years old.
- Thus the placer model is supported by data and the source of gold is to the north and west of the basin.

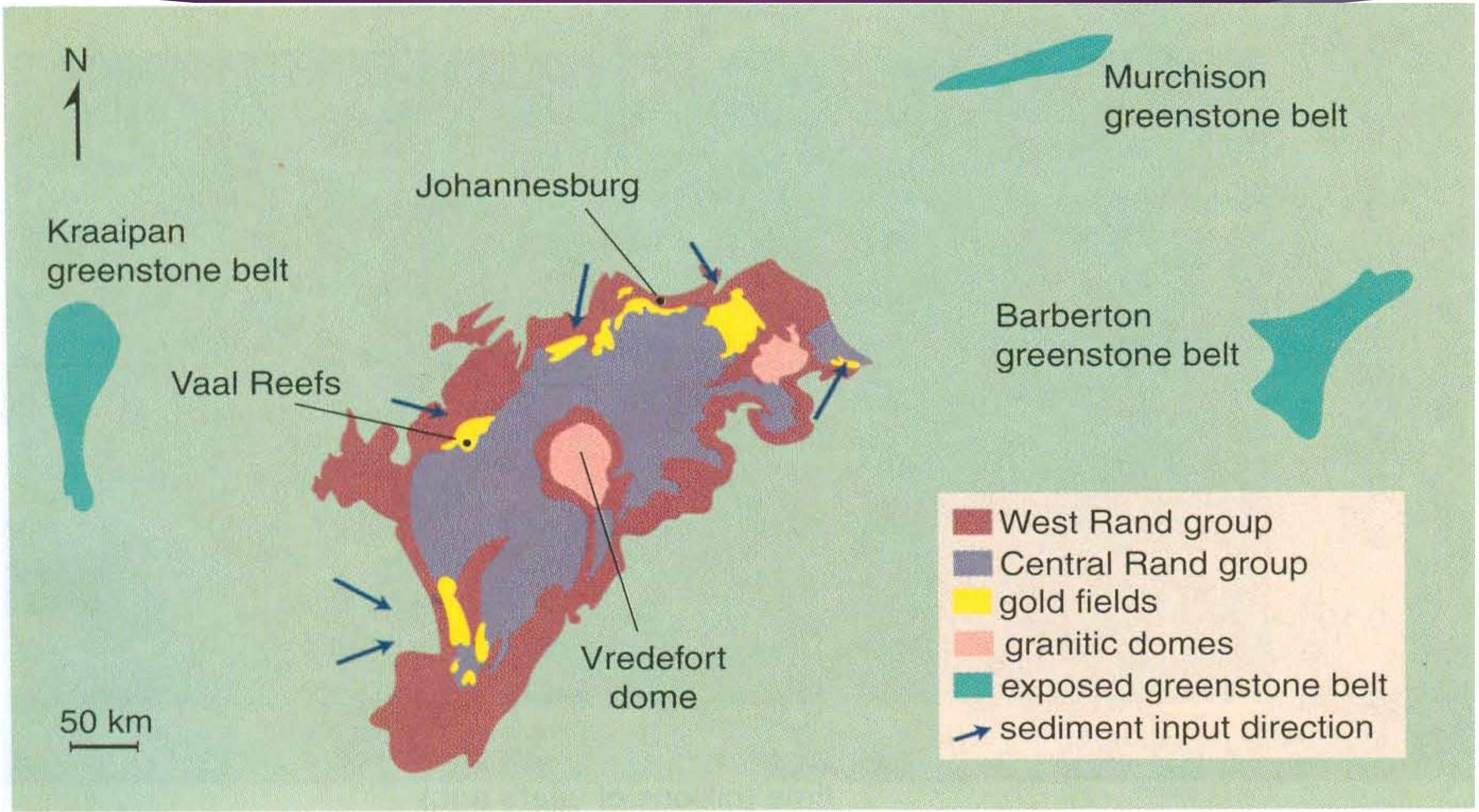


Origin/transportation/deposition of the ore bearing fluids

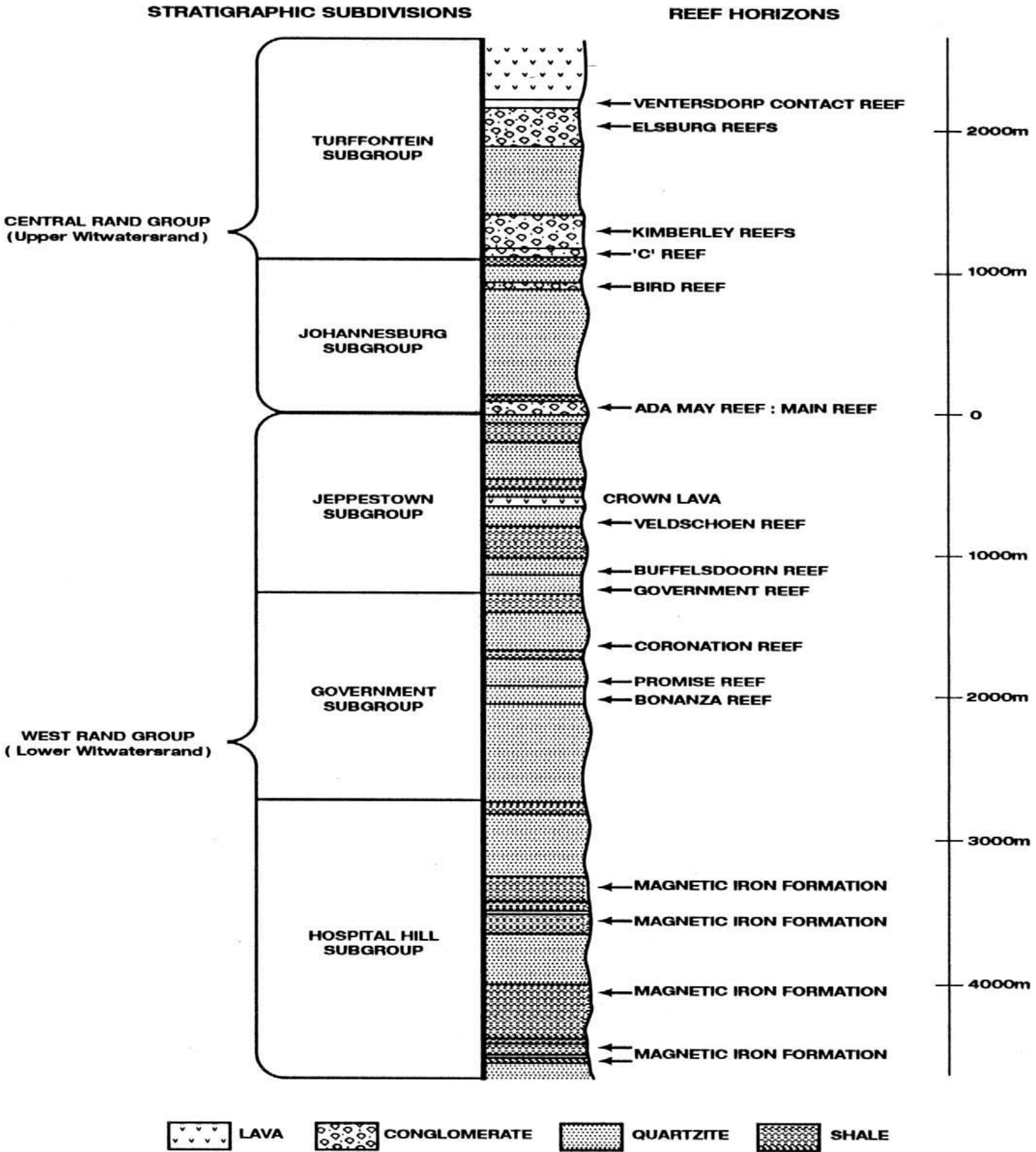
- The Osmium ratios, which are used to determine the source of the gold ore, determines that the gold came from the mantle that is three billion years old.
- May have originated from Komatiites, which are rich in magnesium and sulfur and are made from the upper mantle.



Origin/transportation/deposition of the ore bearing fluids

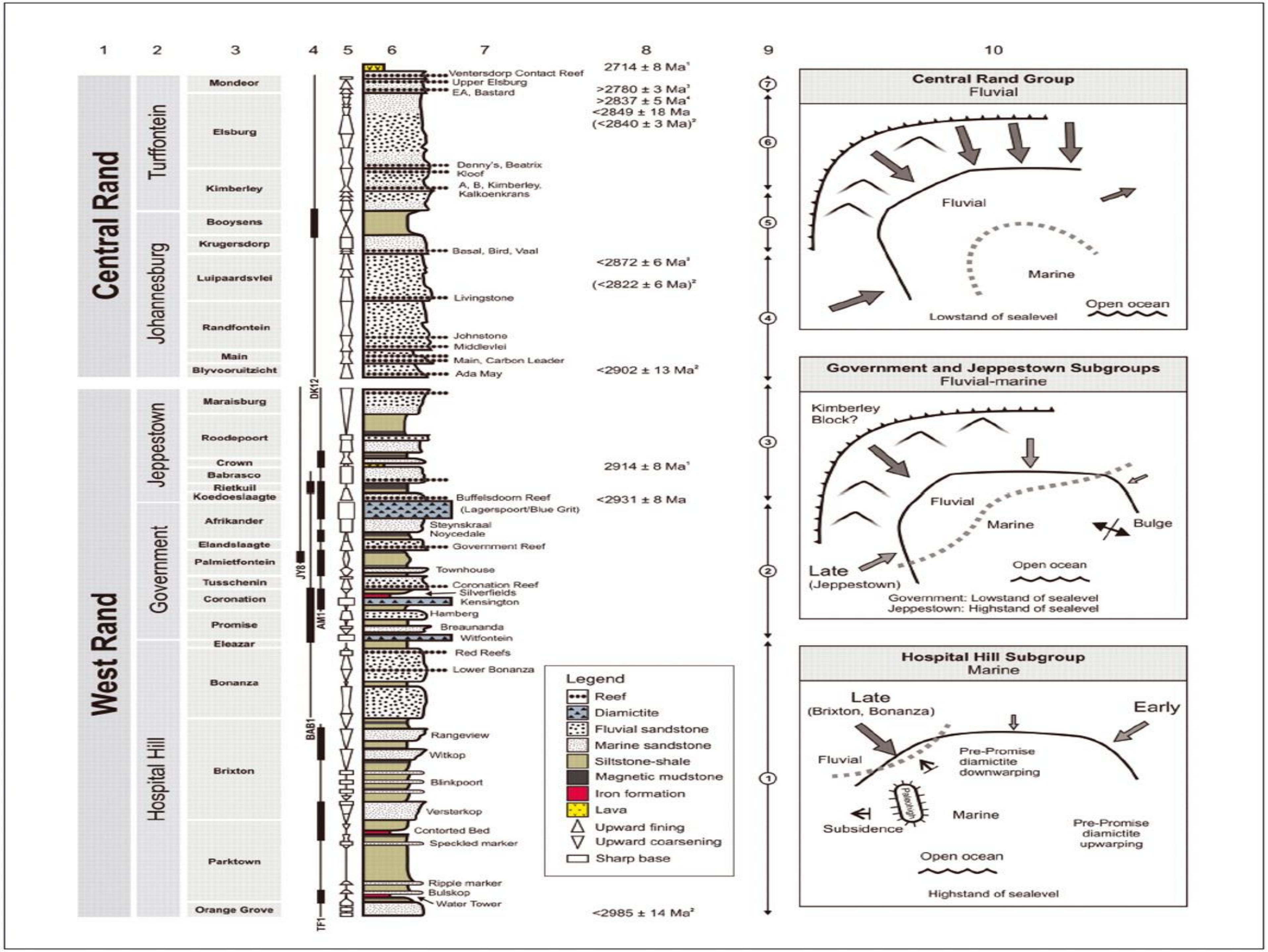


Deposition of ore



- Three depositional enviornments occur through the WRG & CRG.

1. Reefs in WRG that resemble the reefs in the Dominion Group and the Pongola Supergroup
2. Carbon reefs along the base of CRG, similar to the Bird Reef horizon.
3. The upper reefs of the CRG



1
2
3
4
5
6
7
8
9
10
Central Rand
Turffontein
Johannesburg
Mondeor
Elsburg
Kimberley
Booysens
Krugersdorp
Luipaardsvlei
Randfontein
Main
Blyvooruitzicht
West Rand
Jeppestown
Government
Hospital Hill
Maraisburg
Roodepoort
Crown
Babrasco
Rietkuil
Koedoeslaagte
Afrikander
Elandslaagte
Palmietfontein
Tusschenin
Coronation
Promise
Eleazar
Bonanza
Brixton
Parktown
Orange Grove
DK12
JY8
AM1
BAB1
TF1
Ventersdorp Contact Reef
Upper Elsburg
EA, Bastard
Denny's, Beatrix
Kloof
A, B, Kimberley,
Kalkoenkrans
Basal, Bird, Vaal
Livingstone
Johnstone
Middlevlei
Main, Carbon Leader
Ada May
Buffelsdoorn Reef
(Lagerspoort/Blue Grit)
Steynskraal
Noycedale
Government Reef
Townhouse
Coronation Reef
Silverfields
Kensington
Hamberg
Breaunanda
Witfontein
Red Reefs
Lower Bonanza
Rangeview
Witkop
Blinkpoort
Versterkop
Contorted Bed
Speckled marker
Ripple marker
Bulskop
Water Tower
2714 ± 8 Ma[1]
>2780 ± 3 Ma[3]
>2837 ± 5 Ma[4]
<2849 ± 18 Ma
(<2840 ± 3 Ma)[2]
<2872 ± 6 Ma[2]
(<2822 ± 6 Ma)[2]
<2902 ± 13 Ma[2]
2914 ± 8 Ma[1]
<2931 ± 8 Ma
<2985 ± 14 Ma[2]
Legend
Reef
Diamictite
Fluvial sandstone
Marine sandstone
Siltstone-shale
Magnetic mudstone
Iron formation
Lava
Upward fining
Upward coarsening
Sharp base
7
6
5
4
3
2
1
Central Rand Group
Fluvial
Fluvial
Marine
Lowstand of sealevel
Open ocean
Government and Jeppestown Subgroups
Fluvial-marine
Kimberley
Block?
Fluvial
Marine
Bulge
Late
(Jeppestown)
Open ocean
Government: Lowstand of sealevel
Jeppestown: Highstand of sealevel
Hospital Hill Subgroup
Marine
Late
(Brixton, Bonanza)
Early
Fluvial
Pre-Promise
diamictite
downwarping
Paleohigh
Subsidence
Marine
Pre-Promise
diamictite
upwarping
Open ocean
Highstand of sealevel

Regional Geology and Plate Tectonic Setting

- **Intercratonic basin**
- **Depositional Environment**
  - Very thick onlapping sedimentary deposits in elongate epicontinental basins or half-grabens. Middle and basal reaches of alluvial fans deposited on steeper side of basins. Reducing atmosphere believed to be necessary to preserve detrital pyrite and uraninite.
- **Tectonic Setting(s)**
  - Slow subsidence of Archean craton. Later moderate uplift and erosion to remove Phanerozoic strata and retain Early Proterozoic rocks.

Regional Geology and Plate Tectonic Setting

- Associated Deposit Types
- Recent gold placer deposits. Low-sulfide gold quartz veins and Homestake Au in basement rocks. Superior Fe in overlying sequences.
- World's principal source of gold and uranium

Regional Geology and Plate Tectonic Setting

- 4 Proterozoic Super-groups;
  - Transvaal
  - Ventersdorp
  - Witwatersrand
  - Dominion Reef Systems
- They rest unconformably on the Archaean basement complex of granites and high-grade metamorphics.
- Concentration of gold is confined to thin oligomictic quartz conglomerate beds which occur throughout the succession, particularly the Upper Witwatersrand and Lower Dominion Reef formations

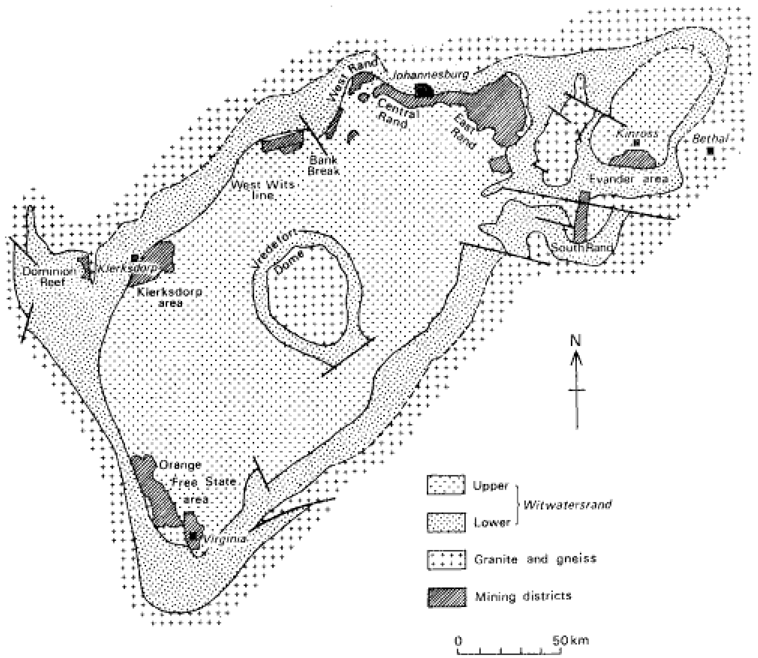


FIGURE 1. Simplified geological map of the Witwatersrand Basin beneath the Ventersdorp and younger cover (after R. Borchers 1961).

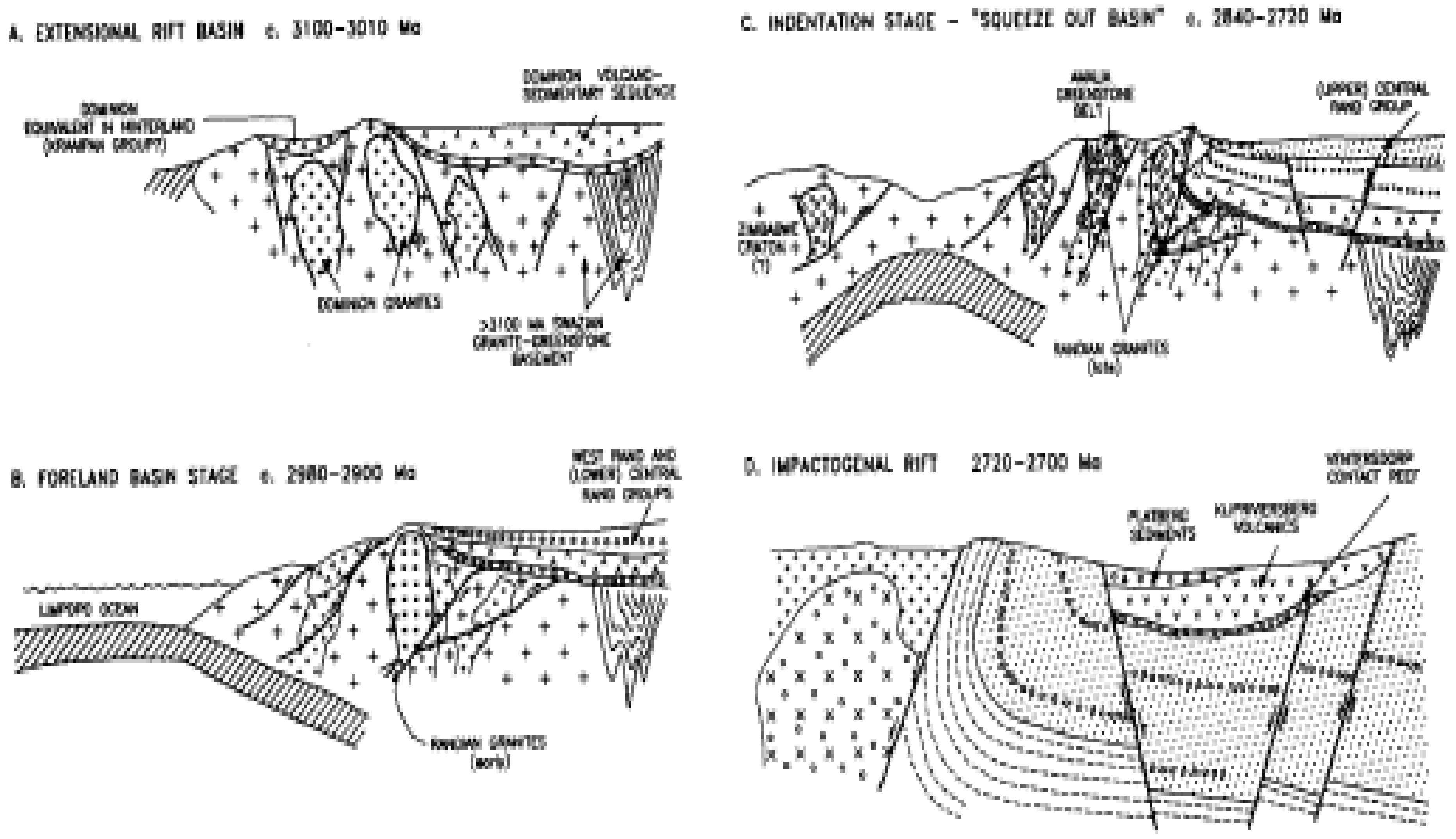
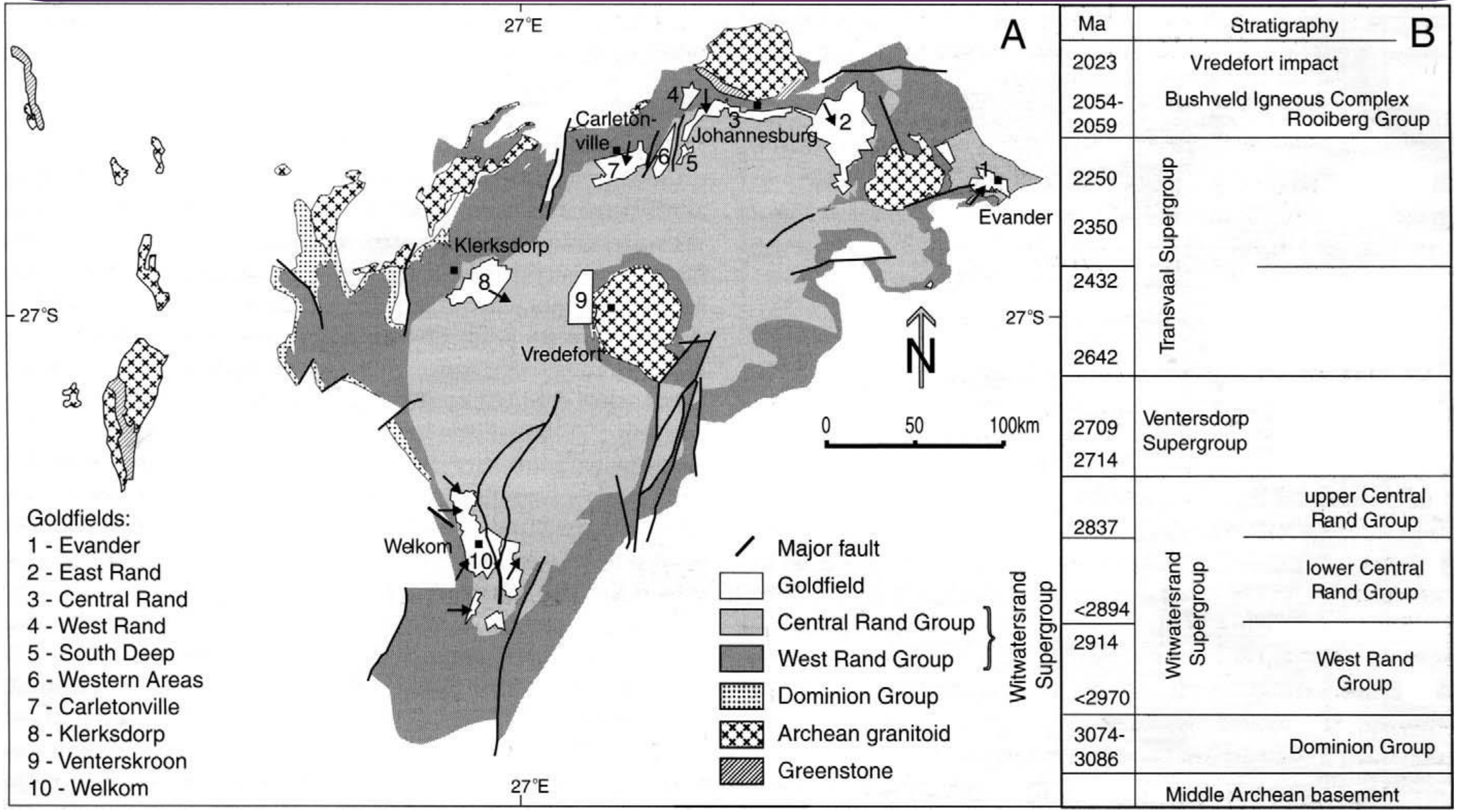
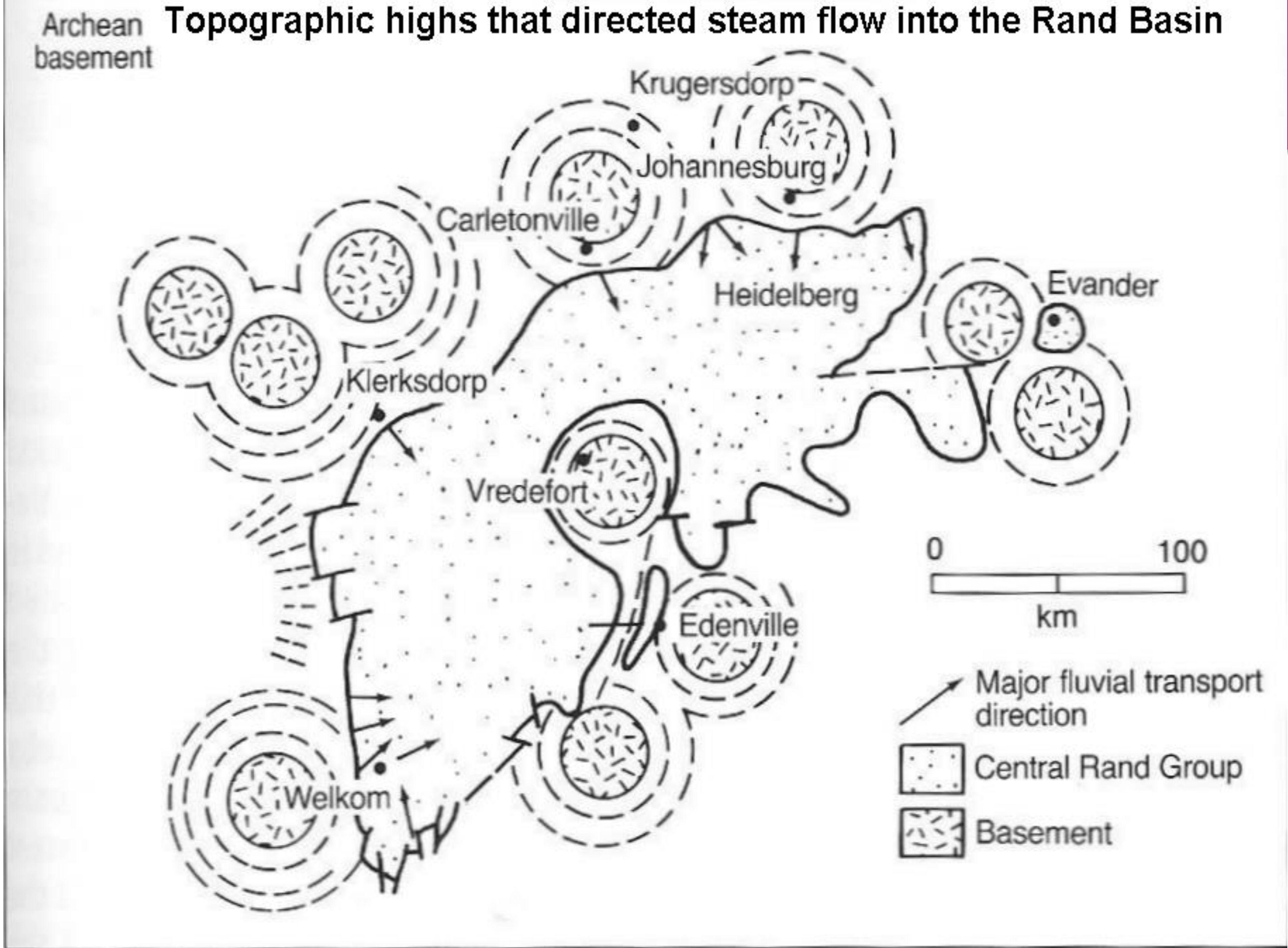


Fig. 6. Schematic representation illustrating the stages of tectonic evolution in the formation of the Witwatersrand Triad (after Robb et al., 1991). Sections do not have a specific geographic locality.

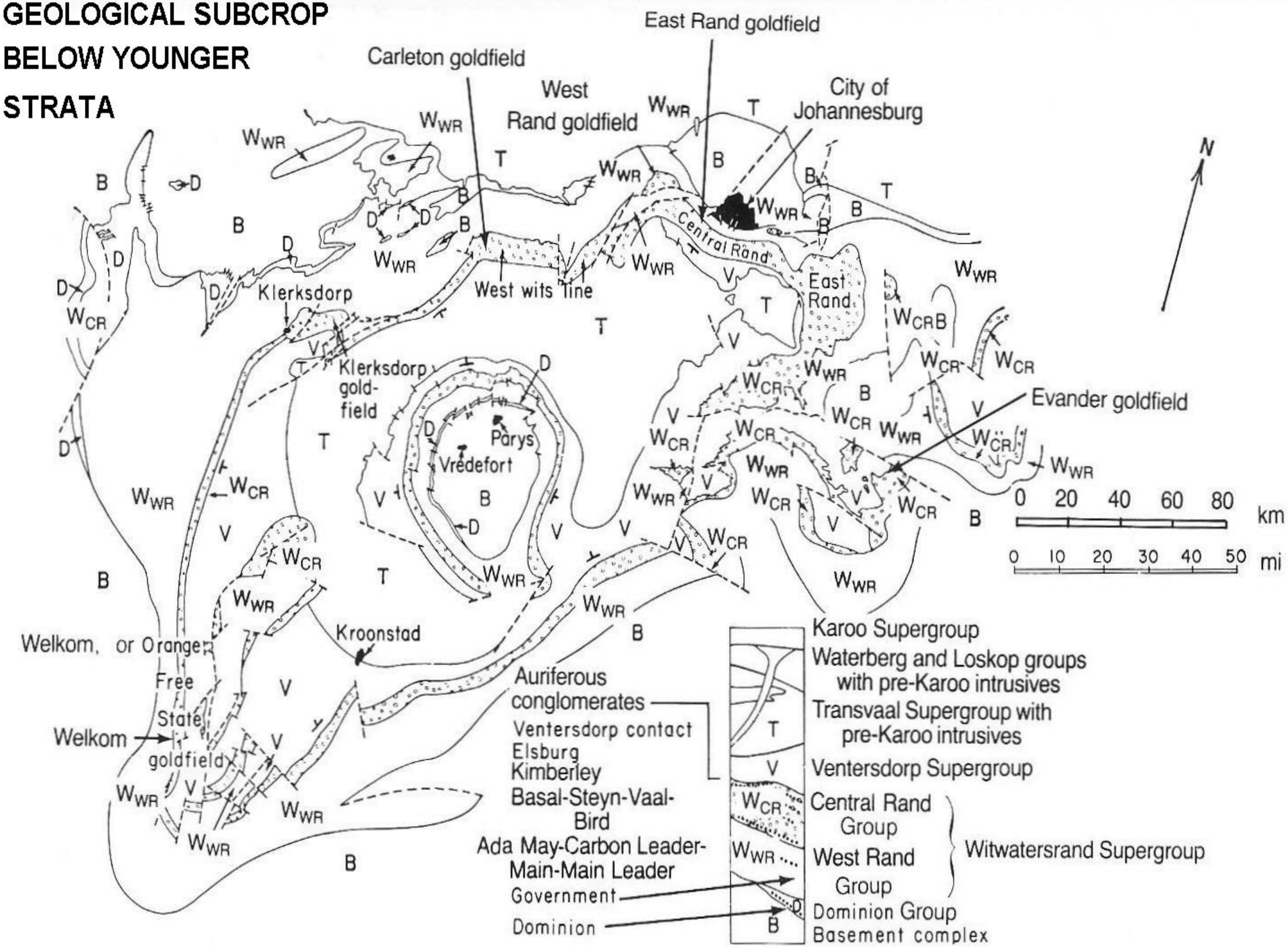
Regional Geology and Plate Tectonic Setting

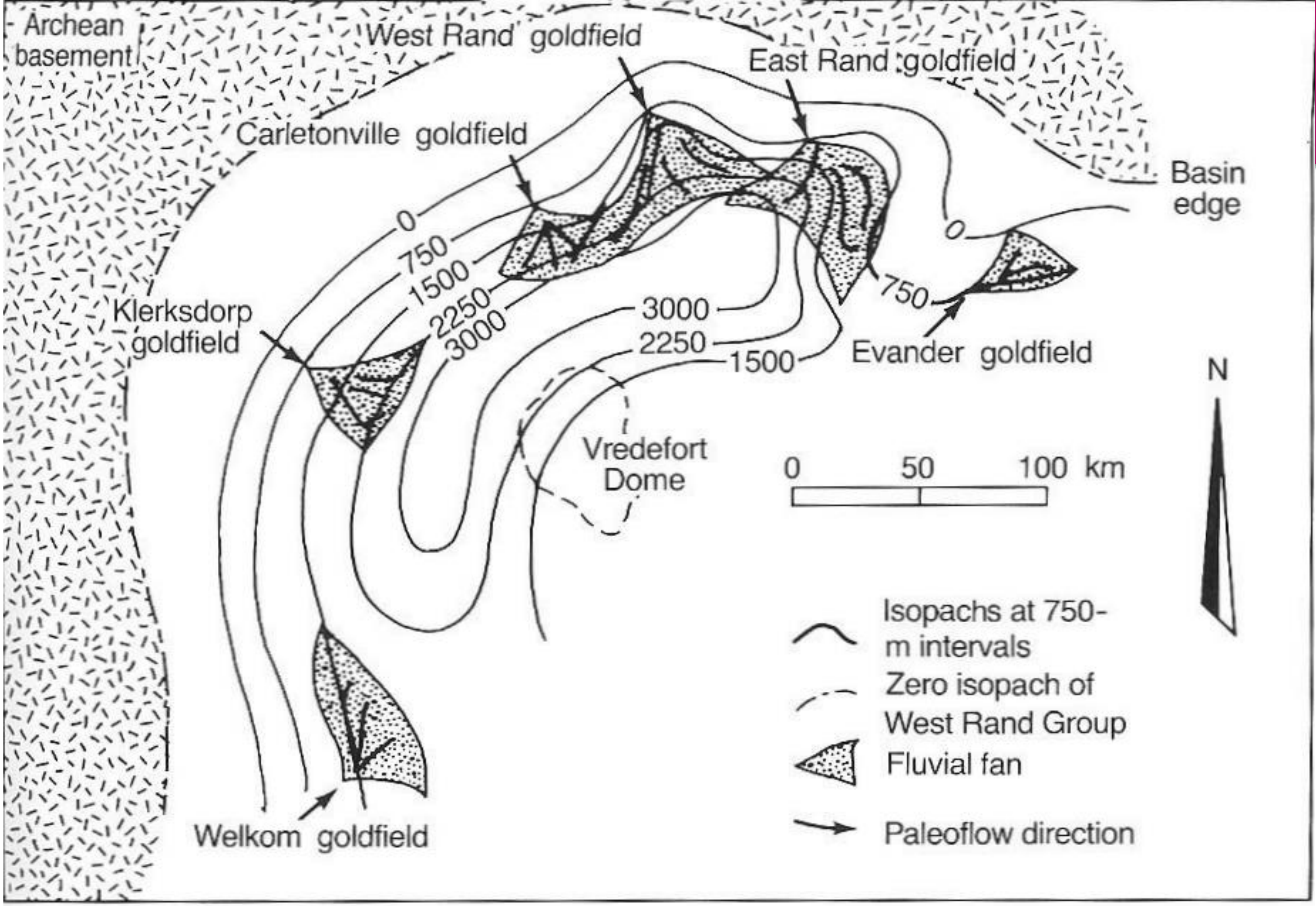


Topographic highs that directed steam flow into the Rand Basin



GEOLOGICAL SUBCROP BELOW YOUNGER STRATA

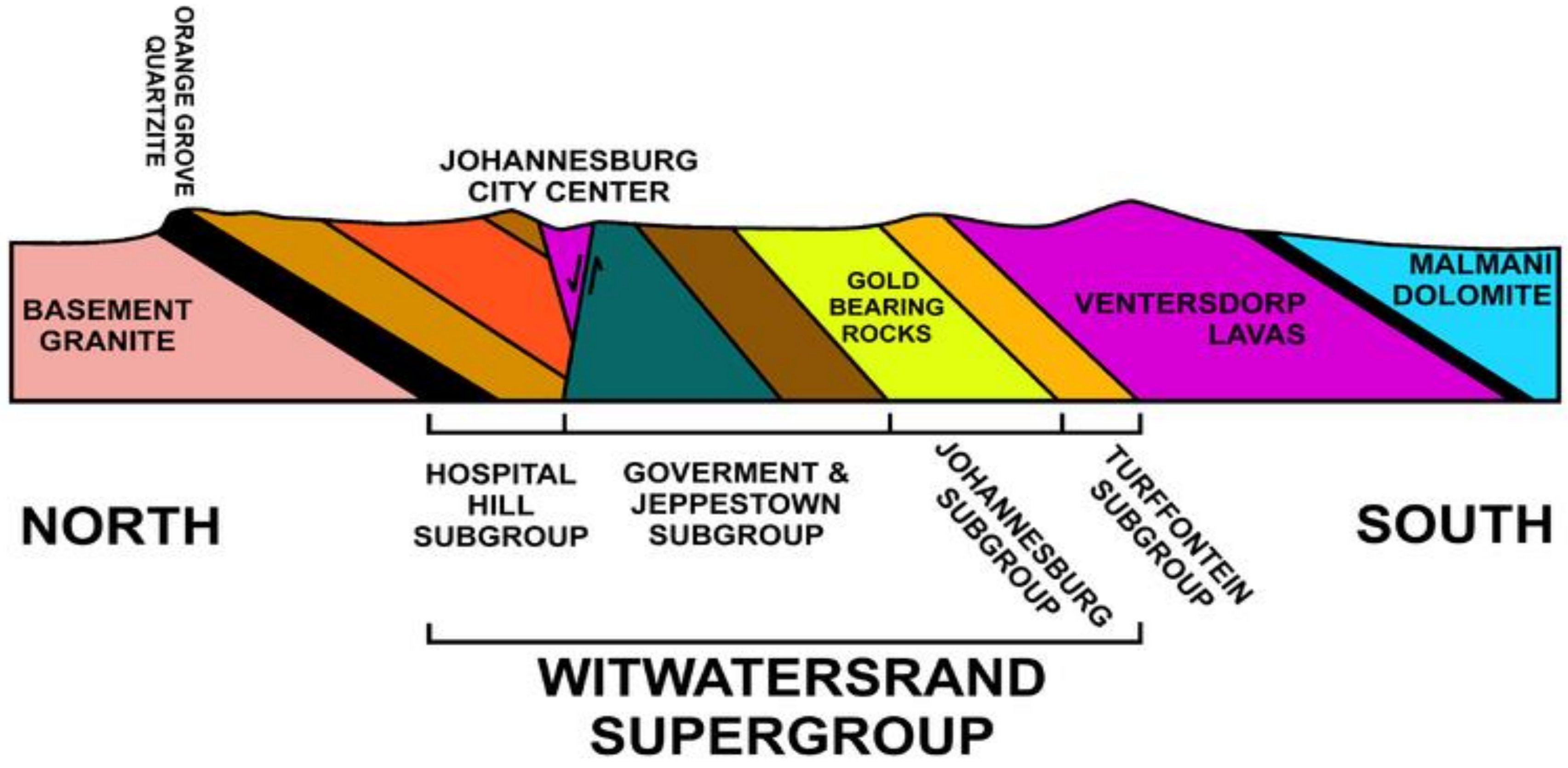




Gold-bearing fans and source areas for sediments of the Rand Basin

Regional Geology and Plate Tectonic Setting

- Structure



Mineralogy

- **Ore and Gangue Minerals**
  - **Mineralogy**
    - Quartz, gold, pyrite, uraninite, brannerite, zircon, chromite, monazite, leucoxene, osmium-iridium alloys, isoferro platinum and sperrylite. By-product Ag. Middle Proterozoic (Tarkwa) and Phanerozoic occurrences have only traces of pyrite and no uraninite.
  - **Texture/Structure**
    - Pyrite may occur as rounded grains, and concentrically layered concretions. Gold is in small angular grains, 0.005 to 0.1 mm in diameter.
  - **Weathering**
    - Residual gold in weathering zone.
  - **Geochemical Signature**
    - Au, U, PGE; anomalous radioactivity.

Economic minerals	Sulphides	Oxides	Silicates	Others
Gold	pyrrhotite	quartz	muscovite	calcite
Tellurium	leucopyrite		sericite	dolomite
	loellingite	cassiterite	pyrophyllite	
Silver	marcasite		chlorite	zenotime
Stromeyerite		chromite	chloritoid	monazite
Proustite	chalcopyrite		biotite	
Dyscrasite	chalcopyrrhotite	columbite		diamond
	cubanite		kaolinite	graphite
Platinum	chalcocite	corundum		
Platiniridium	neodigenite		epidote	
Osmiridium	covellite	magnetite		
Iridosmine	bornite	hematite	tourmaline	
Sperrylite	tennantite	goethite		
Braggite			garnet	
Cooperite	galena	rutile		
		leucoxene	zircon	
Uraninite	sphalerite	ilmeno-rutile		
Thucholite		ilmenite	sphene	
Brannerite	molybdenite	anatase		
Uranothorite	bismuthinite	brookite		
Pyrite				
	arsenopyrite			
	skutterudite			
	cobaltite			
	glaucodot			
	linnaeite			
	safflorite			
	gersdorffite			
	niccolite			
	millerite			
	pentlandite			
	bravoite			

Mineralogy

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Fluid Inclusions

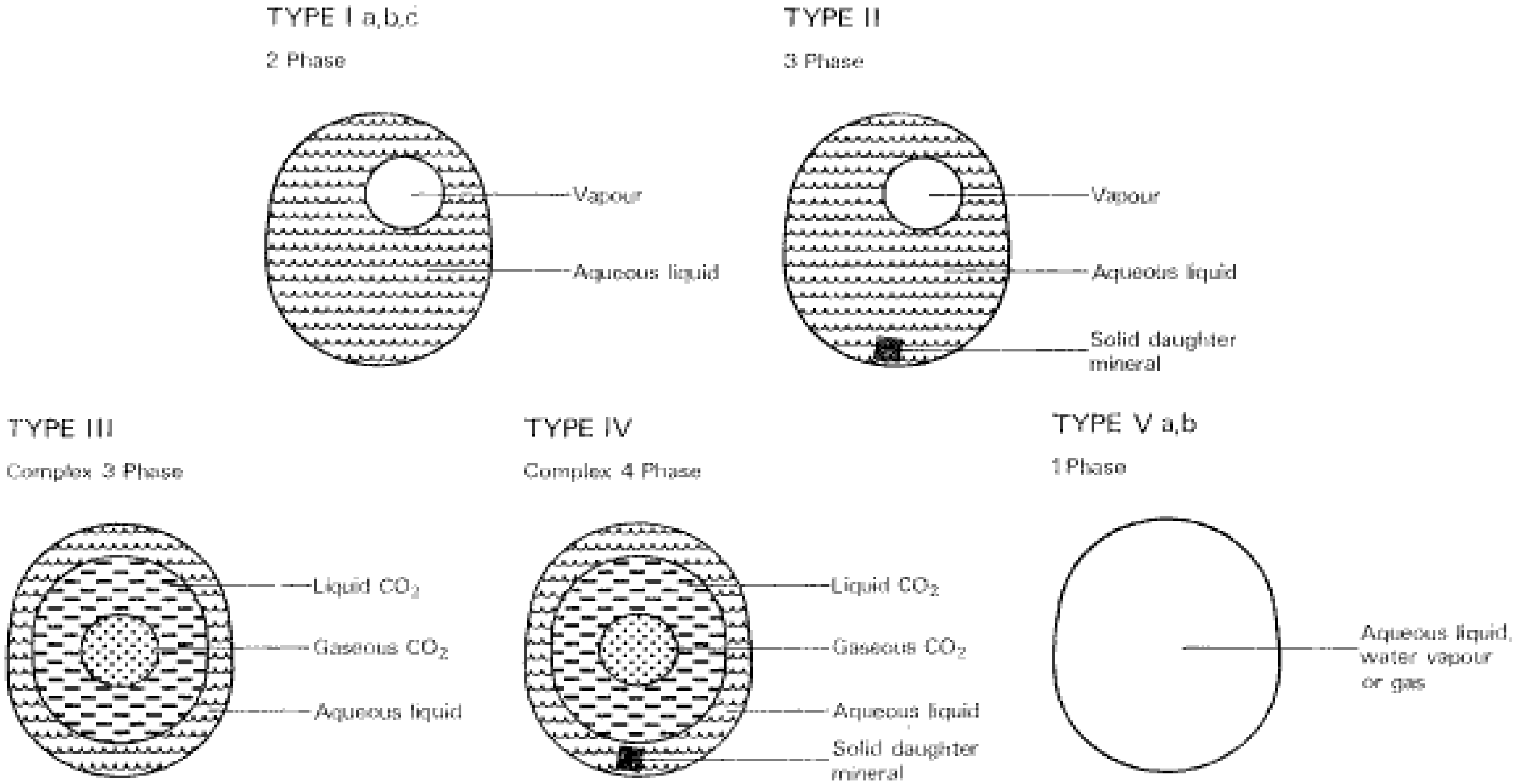
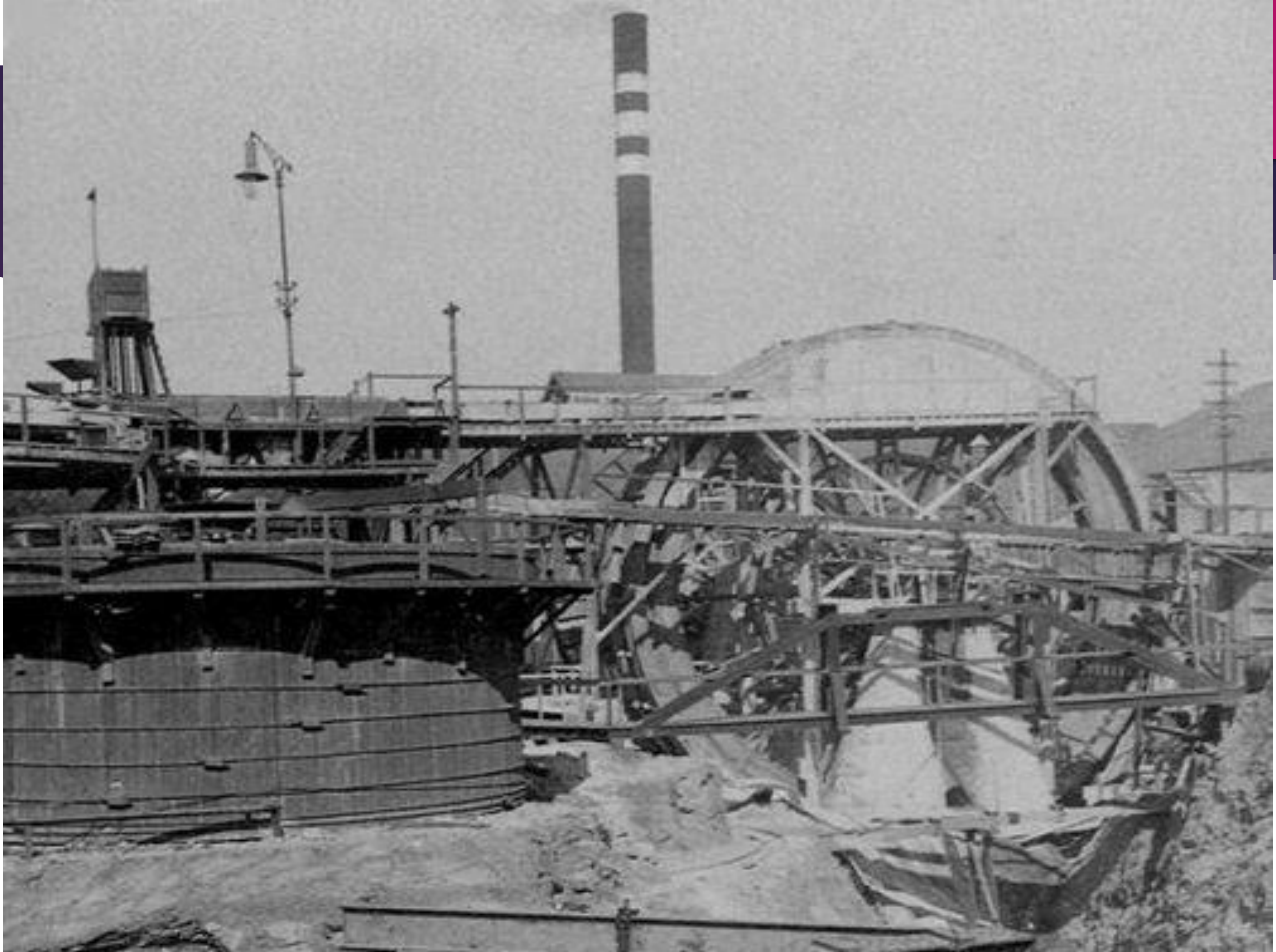


FIGURE 2. Diagrammatic representation of the principal types of fluid inclusion.

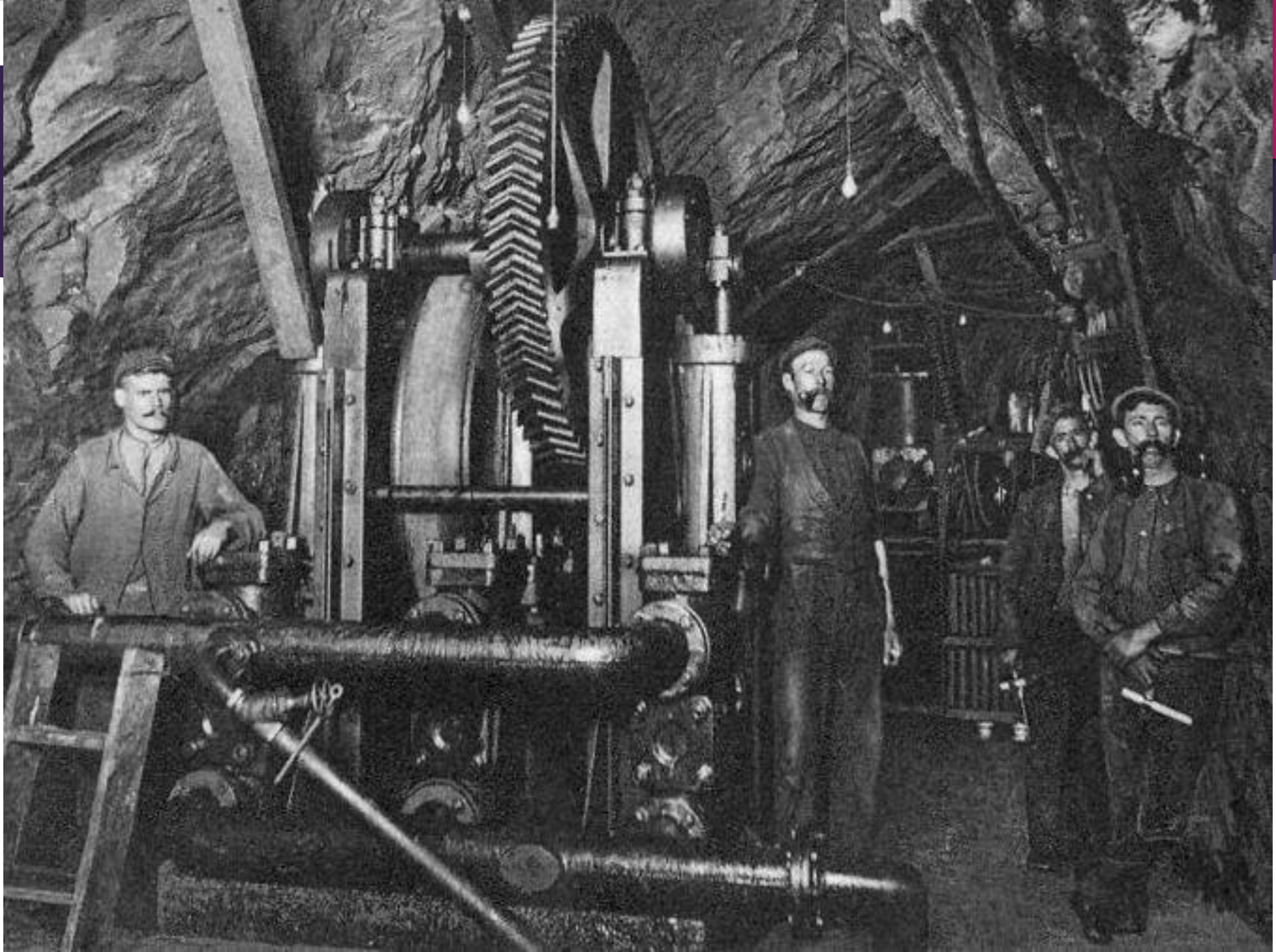

Crown Gold Mines, Johannesburg
S.A.R. 1.12


CROWN REEF




NEW PRIMROSE G.M.C
J.Barnett.
PHOTO


drive, Nourse Mine




Tripod Machine in a Stope, Rose Deep, G.M. Co.

Exploration Methods and Stratigies

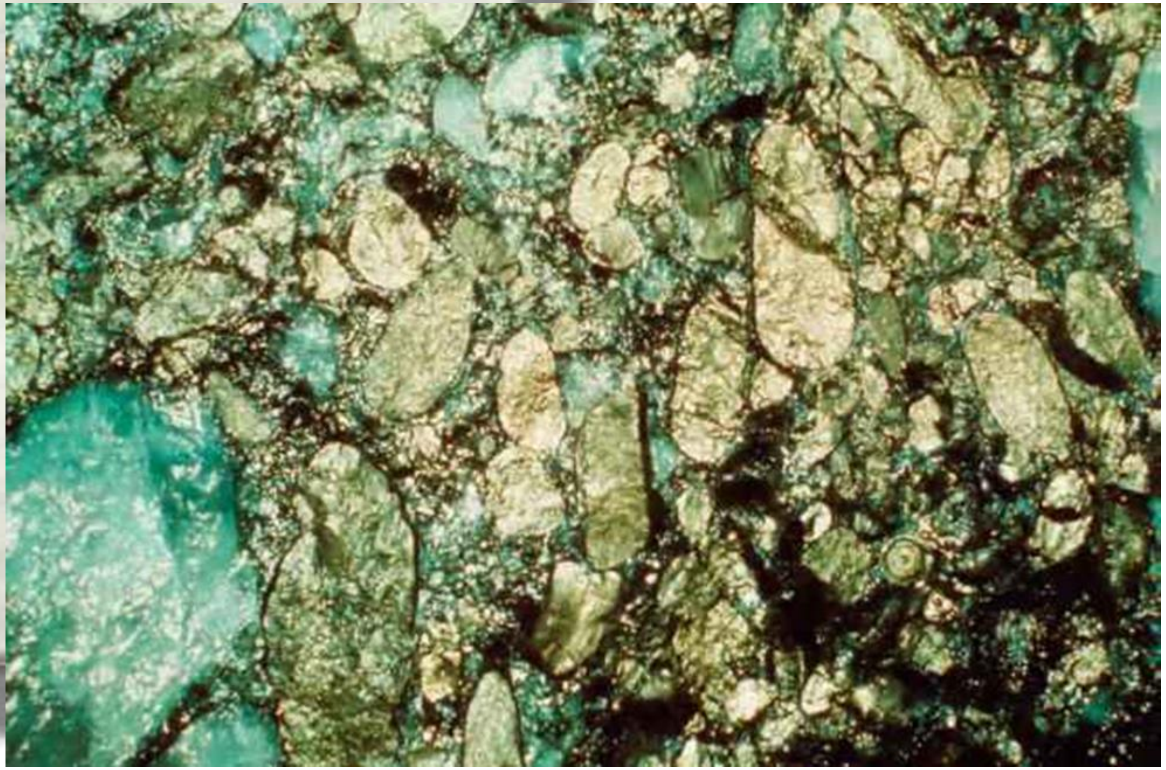
- Mapping
- Geochemical
- Gravity surveys for granite domes
- Magnetic surveys

weathering and Mass Wasting

Discuss with a friend:

7. How old are the Witwatersrand gold ores?

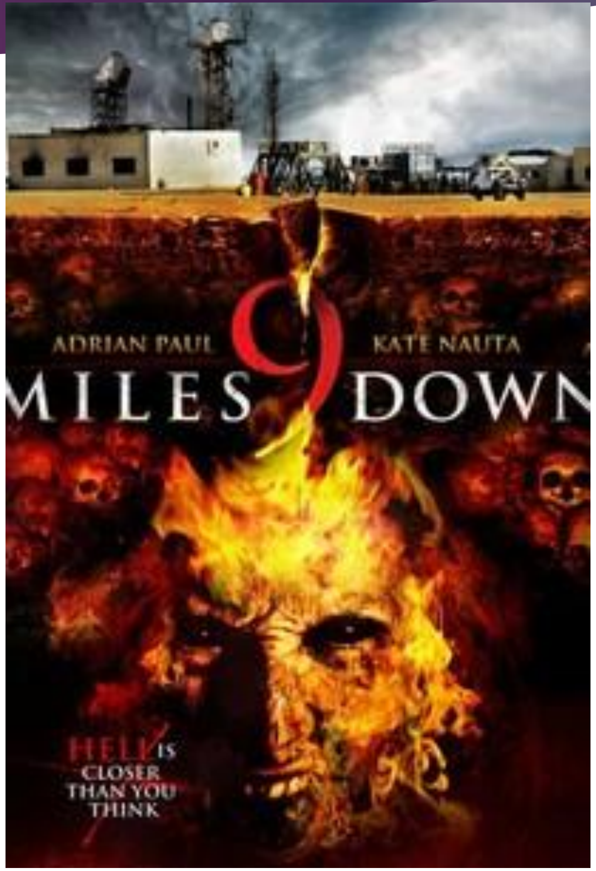
8. Why is the gold associated with uranium?



I will get an A on my exams and quizzes

Philosophical – Inspirational Moment

- Nine Miles Down (2009) "Myth and Science"
- https://youtu.be/E4HQvfAu8R8

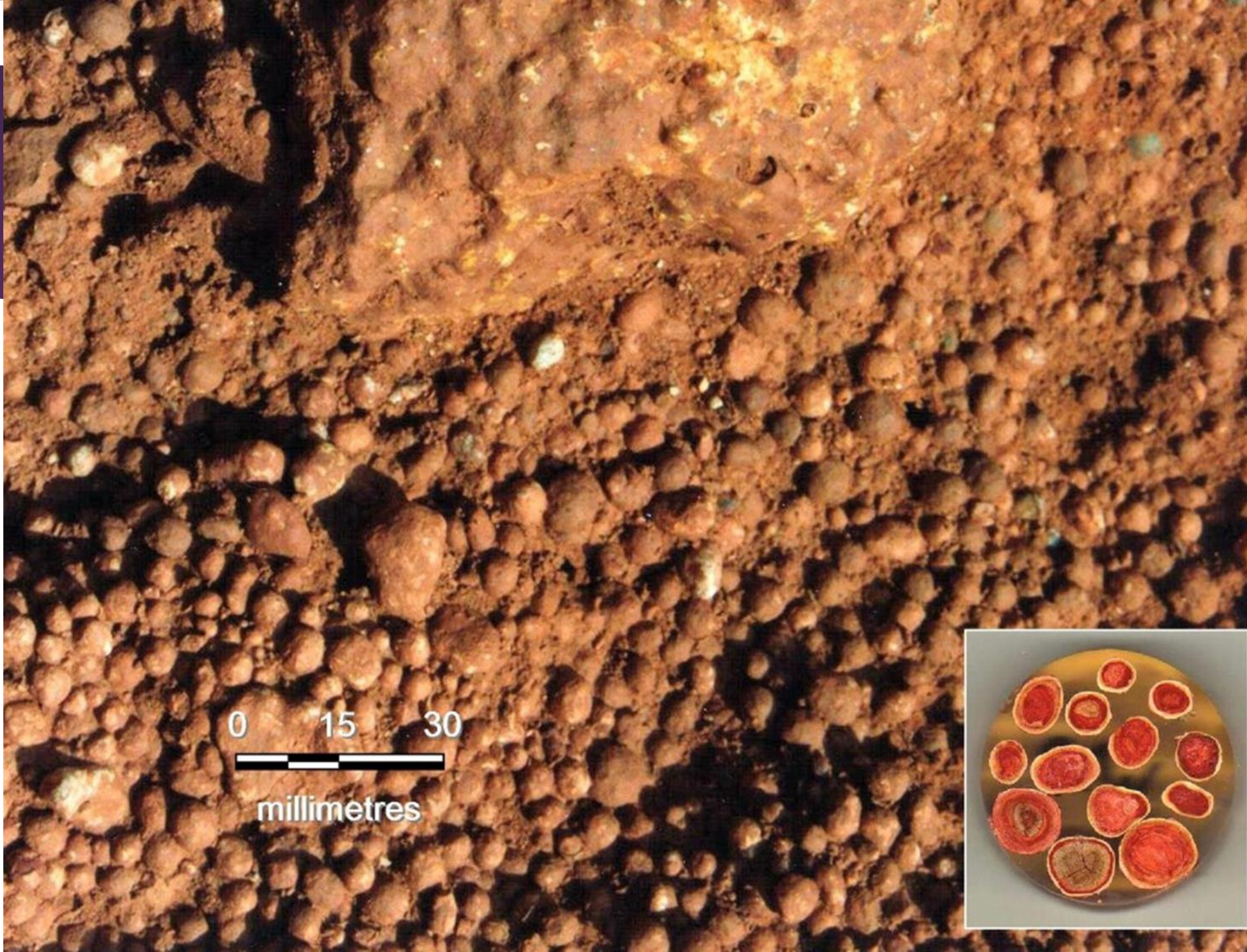


Sandstorm, Science, and Supernatural in Saudi Arabia

- Drill Site
- Where is the drive mechanism?
- Hallucinations
- Supernatural vs Science
- "We can not give up rational thought just because we can't explain it"
- WATCH IT!

Lateritic Bauxite Deposits

- From concentration of Alumina during weathering

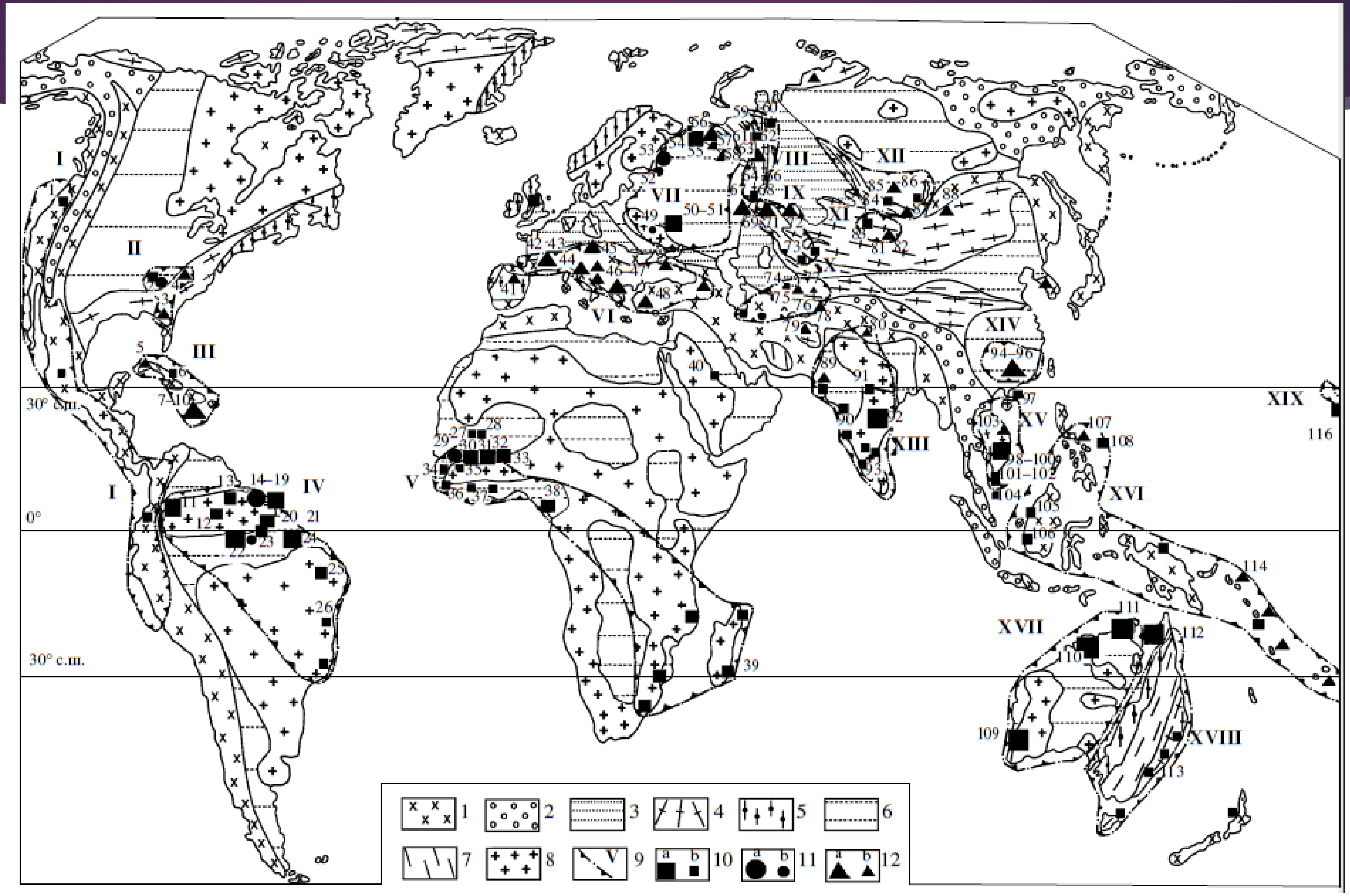


Lateritic Bauxite Deposits

- Lateritic Bauxite

- Laterite
  - Soil types rich in iron, formed in hot and wet tropical environments
- Bauxite
  - Aluminum ore
  - Not a mineral itself

Bauxite Provinces



10■ – Lateritic Bauxite

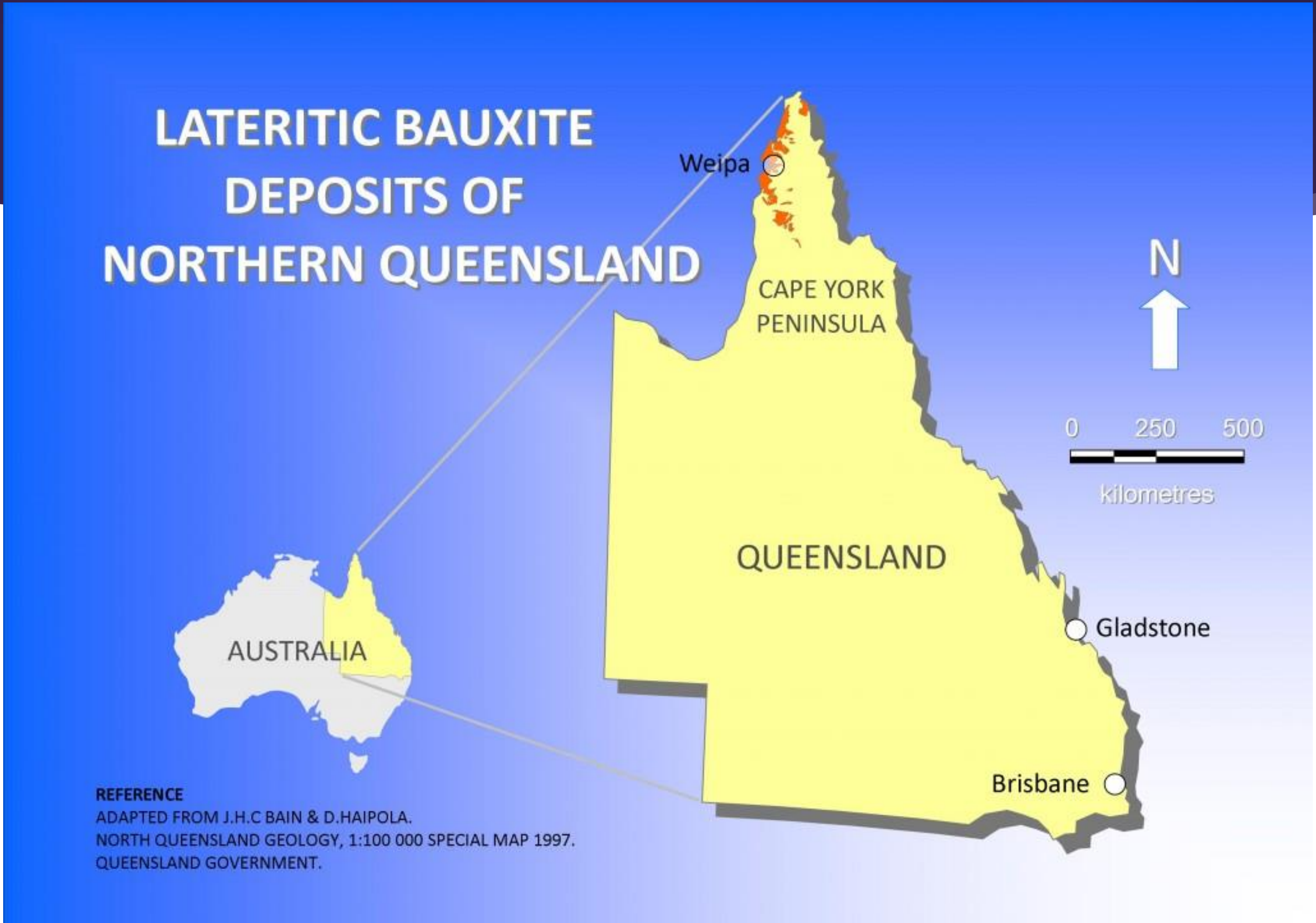
Weipa mine Australia

USGS Ore Deposit Model 38b

- **DESCRIPTION** Weathered residual material in subsoil formed on any rock containing aluminum.
- **GEOLOGICAL ENVIRONMENT**
- **Rock Types** Weathered rock formed on aluminous silicate rocks.
- **Age Range** Mainly Cenozoic, one Cretaceous deposit known.
- **Depositional Environment** Surficial weathering on well-drained plateaus in region with warm to hot and wet climates (tropical). Locally deposits in poorly drained areas low in Fe due to its removal by organic complexing.
- **Tectonic Setting(s)** Typically occurs on plateaus in tectonically stable areas.
- **Associated Deposit Types** Overlain by thin "A" horizon soil, underlain by saprolite (parent rock in intermediate stages of weathering).

USGS Ore Deposit Model 38b

- **DEPOSIT DESCRIPTION**
- **Mineralogy** Mainly gibbsite and mixture of gibbsite and boehmite; gangue minerals hematite, goethite, anatase, locally quartz
- **Texture/Structure** Pisolitic, massive, earthy, nodular.
- **Alteration** Aluminous rocks are altered by weathering to bauxite.
- **Ore Controls** Thoroughly weathered rock, commonly erosional boundaries of old plateau remnants.
- **Weathering** Intensive weathering required to form bauxite. Bauxite continues to form in present weathering environment in most deposits.
- **Geochemical Signature** Al, Ga.

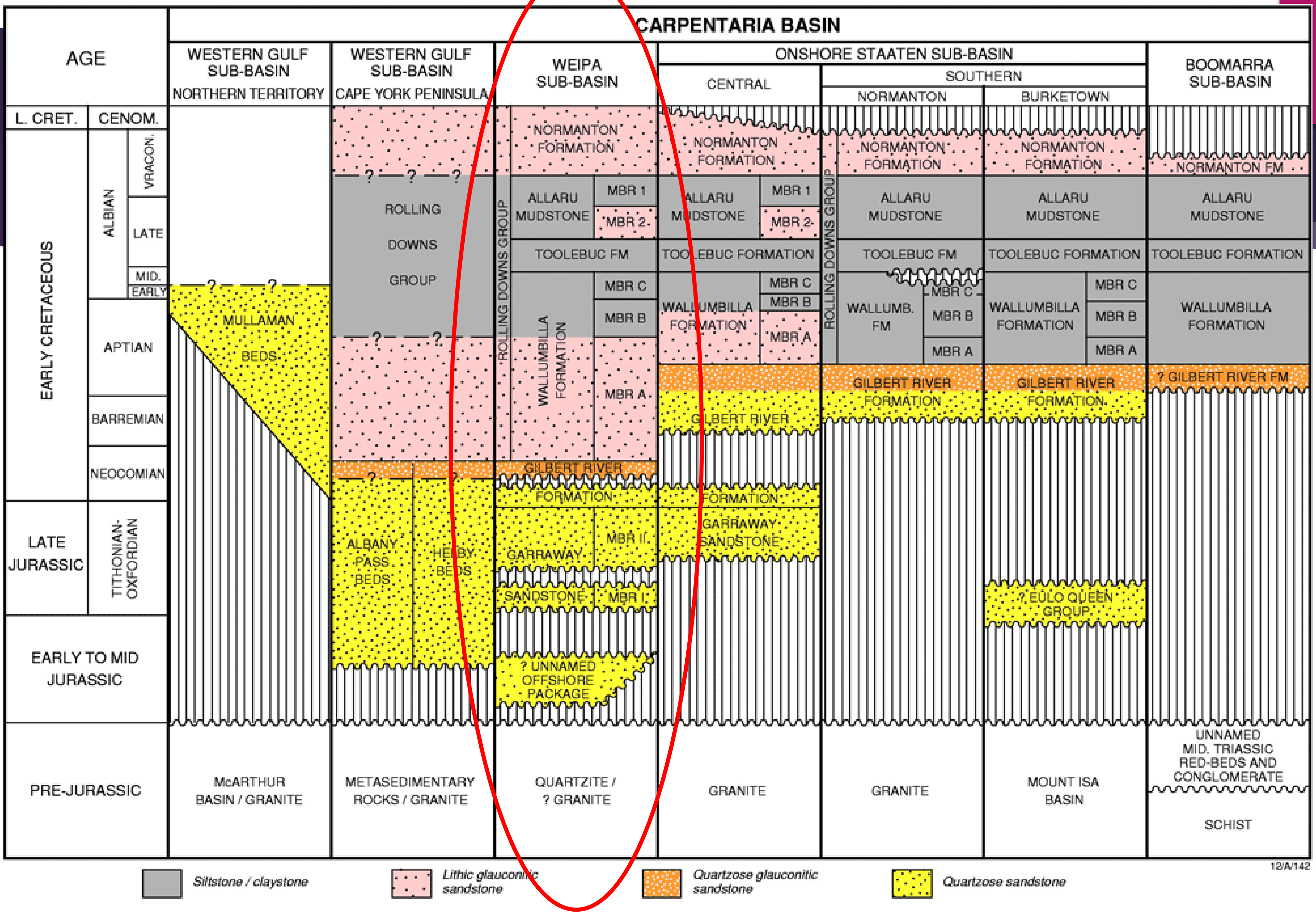

LATERITIC BAUXITE
DEPOSITS OF
NORTHERN QUEENSLAND
Weipa
CAPE YORK
PENINSULA
N
0 250 500
kilometres
QUEENSLAND
Gladstone
Brisbane
AUSTRALIA
REFERENCE
ADAPTED FROM J.H.C BAIN & D.HAIPOLA.
NORTH QUEENSLAND GEOLOGY, 1:100 000 SPECIAL MAP 1997.
QUEENSLAND GOVERNMENT.

Mining History: Cape York, Australia

- 1802 Matthew Flinders recognized the 'reddish cliffs' of the Cape York peninsula in Australia
- Not surveyed until the early 1900's
- 1955 Harry Evans was prospecting for oil and discovered the aluminum ore
- 1957 the Commonwealth Aluminum Corporation (COMALCO) was formed and granted an 84-year lease with the option for a 21-year extension
- 1964 first year of commercial production
- 2006 COMALCO was purchase by Rio Tinto
- 2008 reported annual production of 19.42 million tonnes

Regional Geology and Plate Tectonic Setting

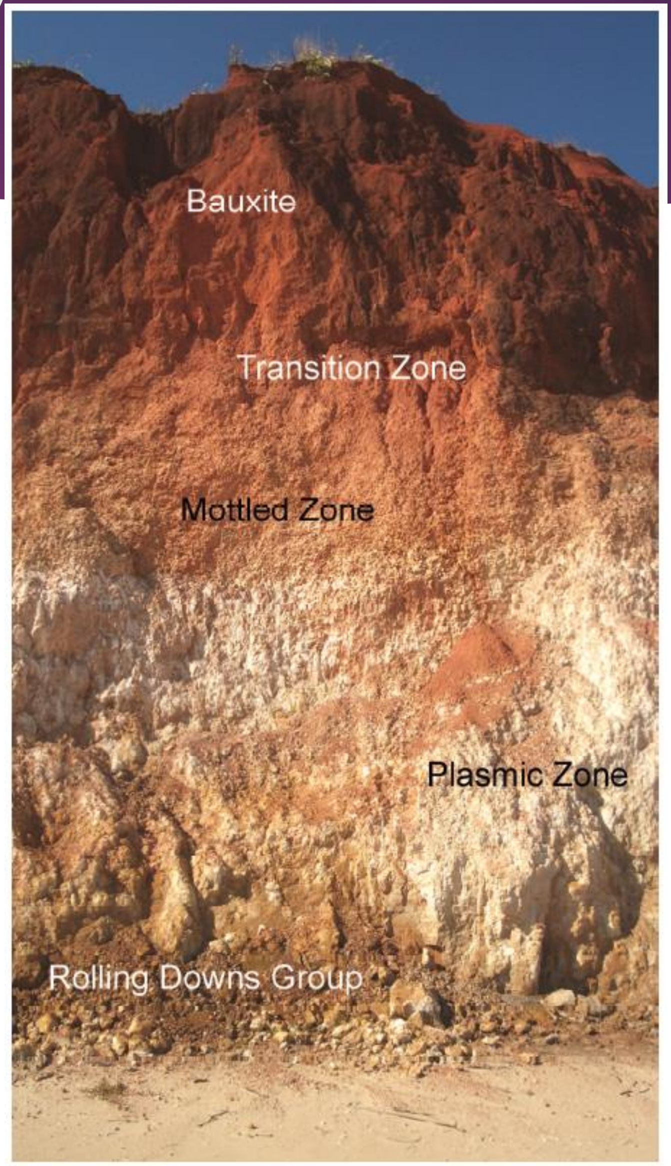
- Cretaceous silicate sediments
- Paleozoic bedrock
- Tectonically stable



CARPENTARIA BASIN
AGE
WESTERN GULF SUB-BASIN NORTHERN TERRITORY
WESTERN GULF SUB-BASIN CAPE YORK PENINSULA
WEIPA SUB-BASIN
ONSHORE STAATEN SUB-BASIN
CENTRAL
SOUTHERN
NORMANTON
BURKETOWN
BOOMARRA SUB-BASIN
L. CRET.
CENOM.
EARLY CRETACEOUS
ALBIAN
VRACON.
LATE
MID.
EARLY
APTIAN
BARREMIAN
NEOCOMIAN
LATE JURASSIC
TITHONIAN-OXFORDIAN
EARLY TO MID JURASSIC
PRE-JURASSIC
NORMANTON FORMATION
NORMANTON FM
ROLLING DOWNS GROUP
ROLLING DOWNS GROUP
ALLARU MUDSTONE
MBR 1
MBR 2
TOOLEBUC FM
TOOLEBUC FORMATION
WALLUMBILLA FORMATION
WALLUMB. FM
MBR C
MBR B
MBR A
MULLAMAN BEDS
GILBERT RIVER FORMATION
? GILBERT RIVER FM
GARRAWAY SANDSTONE
MBR II
MBR I
ALBANY PASS BEDS
HELBY BEDS
? UNNAMED OFFSHORE PACKAGE
? EULO QUEEN GROUP
McARTHUR BASIN / GRANITE
METASEDIMENTARY ROCKS / GRANITE
QUARTZITE / ? GRANITE
GRANITE
GRANITE
MOUNT ISA BASIN
UNNAMED MID. TRIASSIC RED-BEDS AND CONGLOMERATE
SCHIST
12/A/142
Siltstone / claystone
Lithic glauconitic sandstone
Quartzose glauconitic sandstone
Quartzose sandstone

Local Geology

Mottled zone – mainly kaolinite and hematite



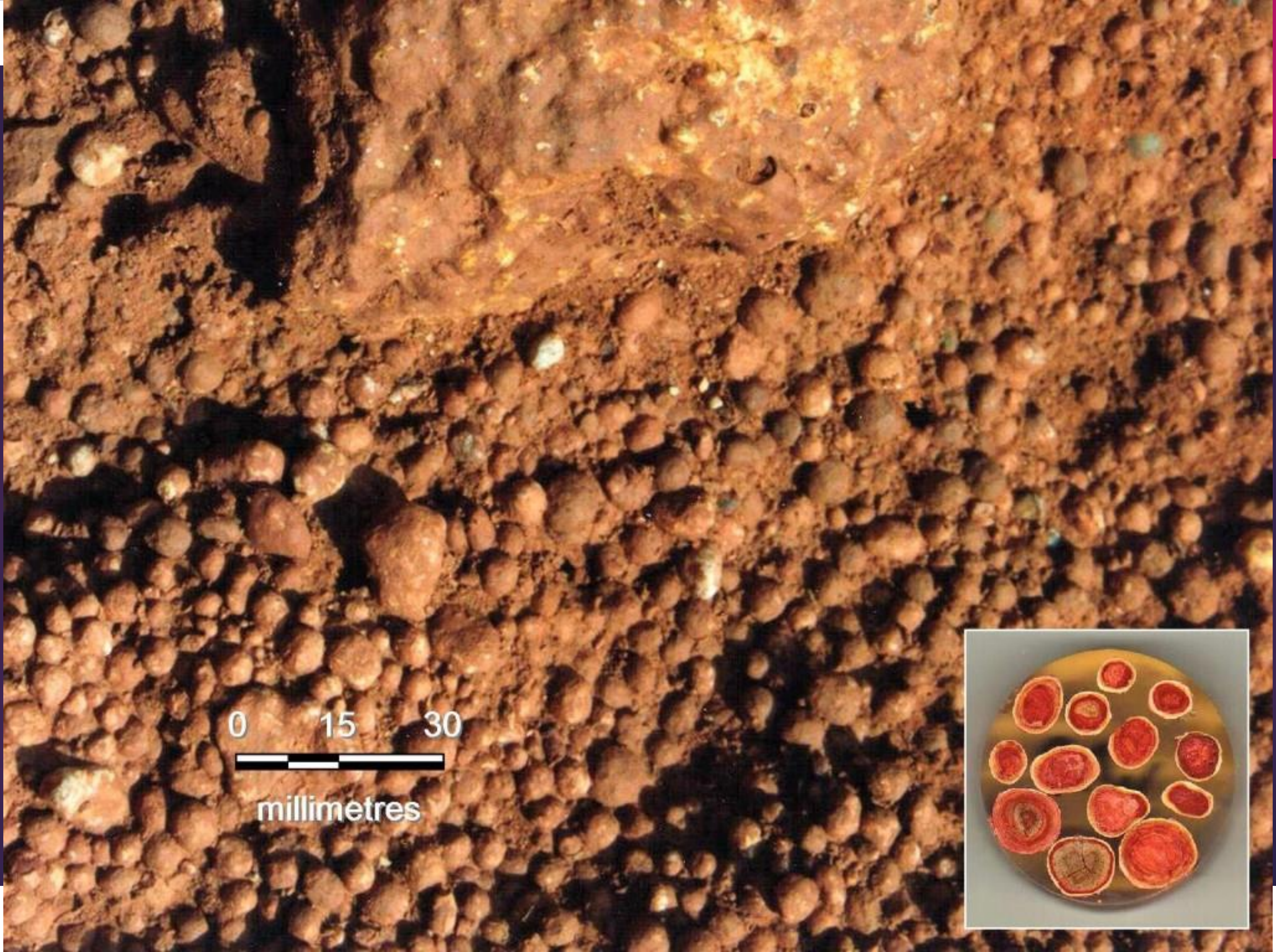
Plasmic zone – kaolinite and quartz

Mineralogy

- Ore minerals
  - Gibbsite, Boehtite, Diaspore
- Gangue Minerals
  - Goethite, Hematite, Kaolinite, Quartz

Mineralogy

- Water weathers glaucanitic sandstones depositing kaolinite in pore spaces
- Further weathering alters kaolinite to gibbsite and boehtite, and coats these cores with hematite creating pisolites
- Eventually all the source rock is altered leaving only the loosely compacted pisolith


0 15 30
millimetres

Alteration Assemblage and zoning

Isotope Studies

- K-Ar isotope dating
  - Cretaceous source rock
  - Tertiary weathering

Mining Methods

Mining Methods

Exploration targets in California

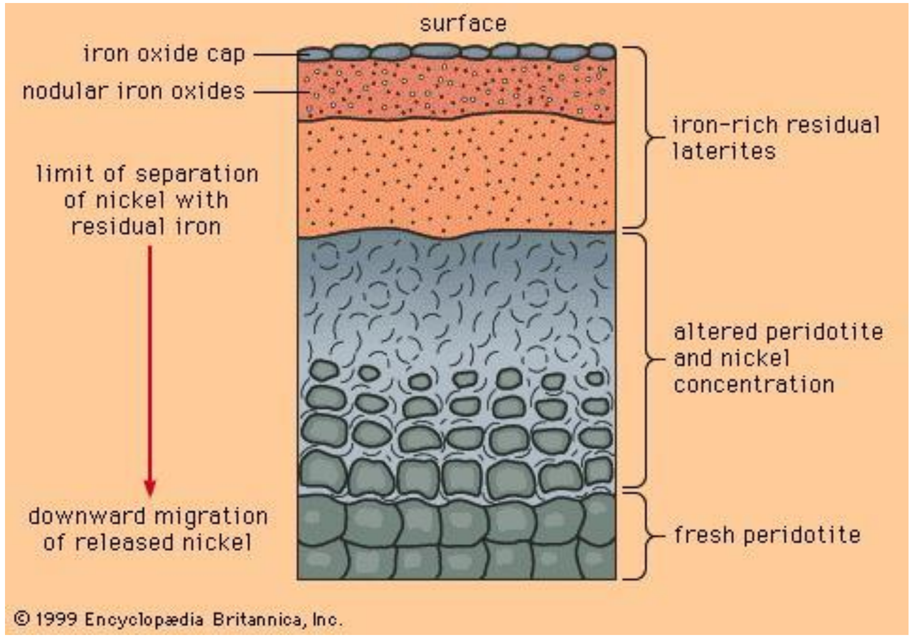
- Looking for:
  - Cretaceous sedimentary rocks in stable tectonic environment
  - Tropical climate

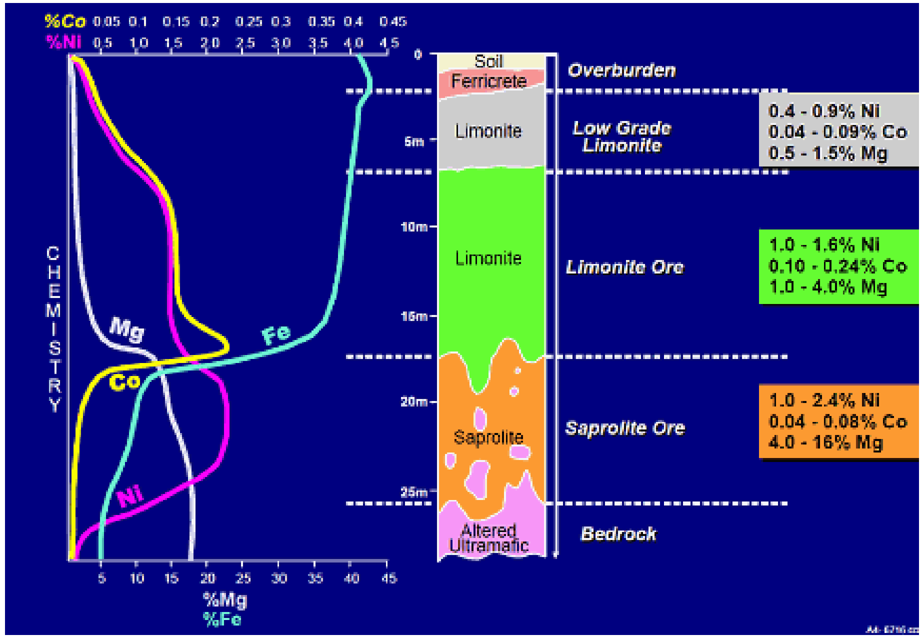
Weathered deposits Riddle Oregon nickel

GEOLOGY AND ECONOMIC GEOGRAPHY OF MINERAL DEPOSITS

Name of Deposit: Nickel laterites

- Ni laterites are formed from the pervasive chemical weathering of ultramafic rocks that are exposed at the surface mostly in tropical climates (hot, wet).
- Oxidation and weathering depletes the bedrock of MG and si, & concentrates fe and ni in the weathered zone
- laterization is a prolonged process of chemical weathering which produces a wide variety in thickness, grade and ore mineralogy of the resulting soils. The weathering process (leaching) helps concentrate less soluble ions, such as certain metallic minerals





Deposit Location: nickel mountain mine, riddle, or

- The nickel-silicate deposits are located on Nickel Mountain, in the Klamath mountains 4 miles west of Riddle in southwestern Oregon
- Its setting is unique in that it lies outside of the typical 20 degrees north and south of the equator that delineates most of the other Ni-Co laterite deposits.
- The average Ni grade was between 1.18 percent and 1.5 percent, with a total of 26.7 million tonnes (Mt) produced between 1954 and 1998, and an estimated total size of the deposit to be 63.8 Mt
- Though hydrous Mg-silicate is the dominant ore at Nickel Mountain, 20 percent of the reserve is held in oxides

Nickel Mountain Mine

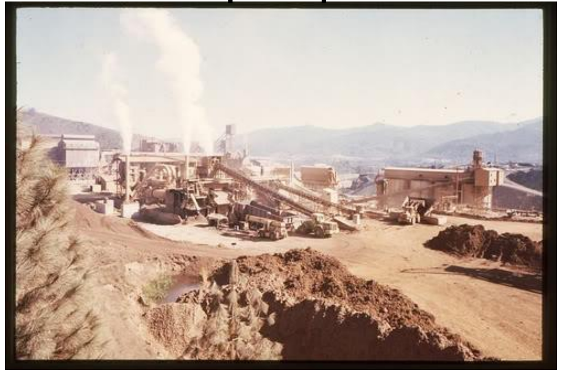
USGS Ore Deposit Model: 38a

- DESCRIPTION: Nickel-rich, in situ lateritic weathering products developed from dunites and peridotites. Ni-rich iron oxides are most common. Some deposits are predominantly Ni silicates.
- Rock Types: Ultramafic rocks, particularily peridotite, dunite, and serpentinized peridotite.
- Age Range: Precambrian to Tertiary source rocks, typically Cenozoic weathering.
- Depositional Environment: Relatively high rates of chemical weathering (warm-humid climates) and relatively low rates of physical erosion.
- Tectonic Setting(s): Convergent margins where ophiolites have been emplaced. Uplift is required to expose ultramafics to weathering.

Mining History

- 1865: Nickel ore was discovered at Nickel Mountain by sheep herders
- 1954: commercially mined- gov't needed ferro ni to construct fighter planes & to harden fe in steel (for the defense of our country)
- secretary of treasury was also chairman of hanna mining co when deal was struck. Gov't would build operation (subsidies) & hanna mining co would operate it for a fee. Co Would earn ownership for each lb produced
- 1966: congressional hearings, congress began to doubt the legality of the deal
- 1970: Hanna mining co owned the operation & Nickle sold on open market
- 1998: Mine & smelter closed due to low ore grade (higher grade ore in foreign mines), low Nickle prices

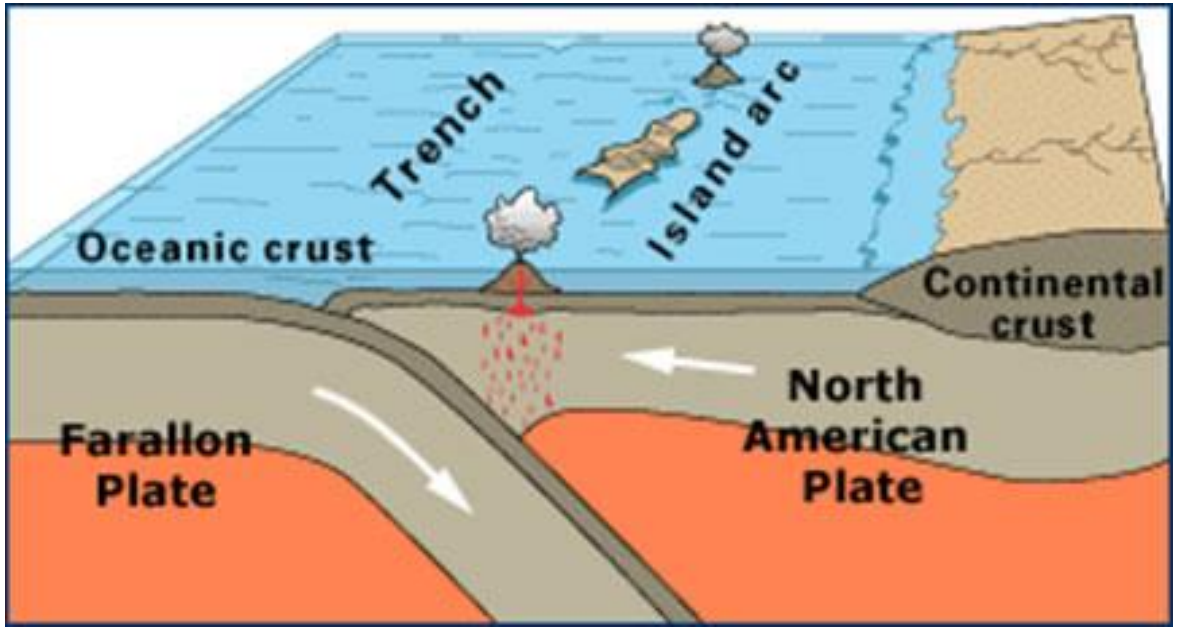
Hanna open pit mine



Hanna Smelter

Regional Geology and Plate Tectonic Setting

- The Nickel Mountain deposit developed from the Tertiary weathering of Jurassic peridotite, dunite, and serpentinite. The deposits are located in older accreted terranes and obducted ophiolites
- The rocks of the Klamath Mountains originated as A series of eight island terranes (island arcs) in the pacific ocean moved eastward on the ancient Farallon plate and collided with the North American plate 260-130 ma (Triassic, Jurassic).
- During the accretion, subduction of the plate metamorphosed the overlying rock and also produced magma which intruded the overlying rock as plutons. the metamorphism of basaltic oceanic rocks produced serpentinite (dunite), the obducted ophiolites resulted in peridotite rocks, and the intrusions produced intrusive rocks of gabbroic to granodiorite composition. These are common rocks within the Klamath terranes.
- Weathering during the tertiary of these Jurassic peridotite, dunite, and serpentinite rocks formed the nickel mountain deposit. The ni ore bodies are found over the peridotite rock



local geology: weathering of peridotite

- The saprolite formed by progressive chemical decomposition of peridotite and dunite through the selective removal of iron, magnesium, and silica and the residual concentration and enrichment of nickel. The relative losses and gains of these constituents took place without reduction in volume, and with the preservation of the original rock textures, joints, and fractures of the peridotite bedrock. The degree of saprolization is determined by the amount of parent rock preserved.
- The top of the laterite profile has been weathered away, leaving only the saprolite layer with a thin oxide-weathered cap that developed during more recent exposure
- A thin mantle of red and yellow soil overlies the saprolitic ore and probably originated by later weathering of the saprolite.

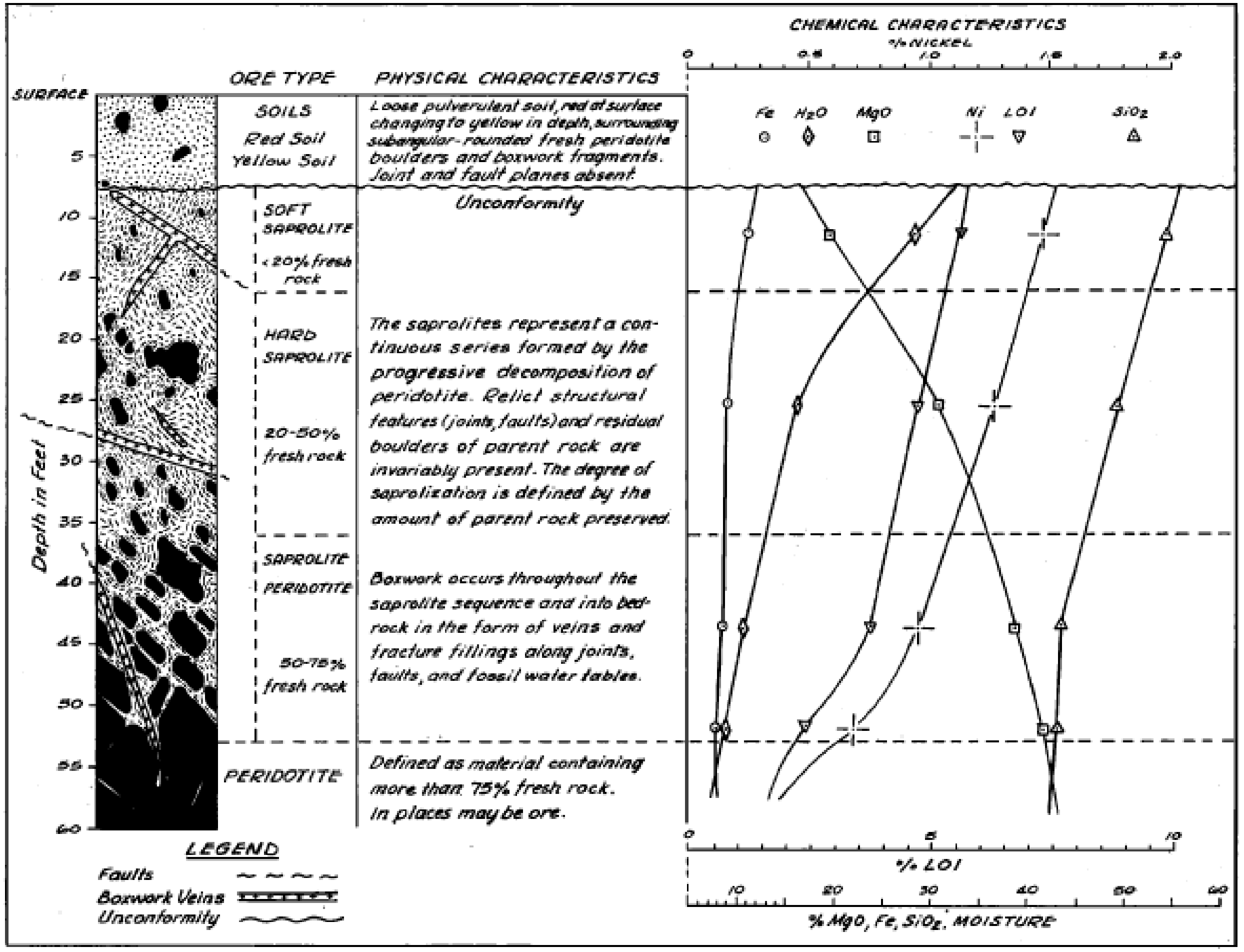


FIG. 1. Columnar Section, showing physical and chemical characteristics of ore types.

Local geology

- faults & joints controlled weathering and leaching of the bedrock (increases surface area & allows circulation of water) and allowed for deposition of nickel and Silica in the form of garnierite-bearing microcrystalline quartz veins called boxworks. The ore channels follow downward extension of the stronger cross faults.

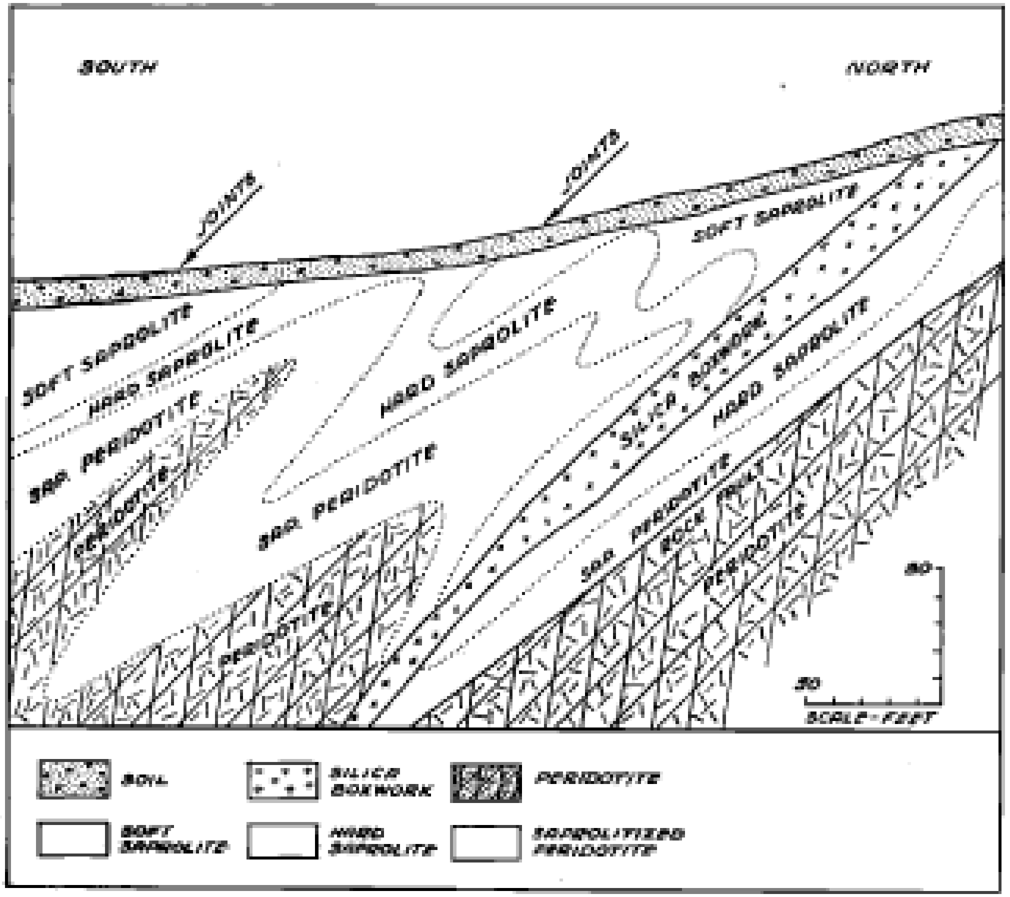


FIG. 3. Geological cross-section North-South, across Nickel Mountain Mine.

Local Geology

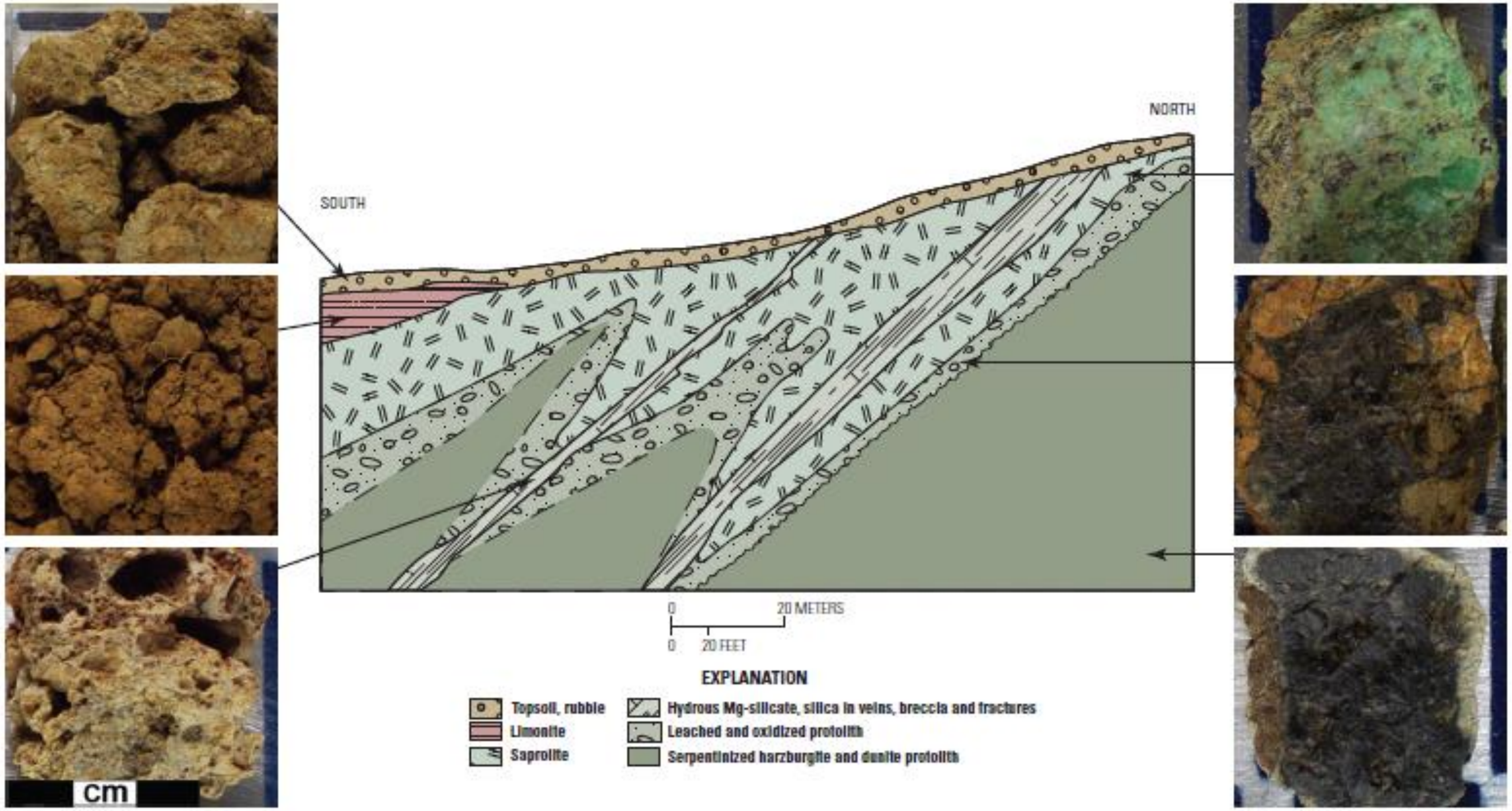


Figure 2. Cross section of an idealized laterite profile from Nickel Mountain, Riddle, Oregon, United States, with photographs of hand-specimen samples of (counterclockwise) topsoil, limonite, silica veins and breccia, serpentinized protolith, leached-oxidized protolith, and saprolite. Profile adapted from Data Metallogenica (2008) (*http://www.datametallogenica.com/*); photographs from Data Metallogenica by Peter Laznicka (1980). (Mg, magnesium)

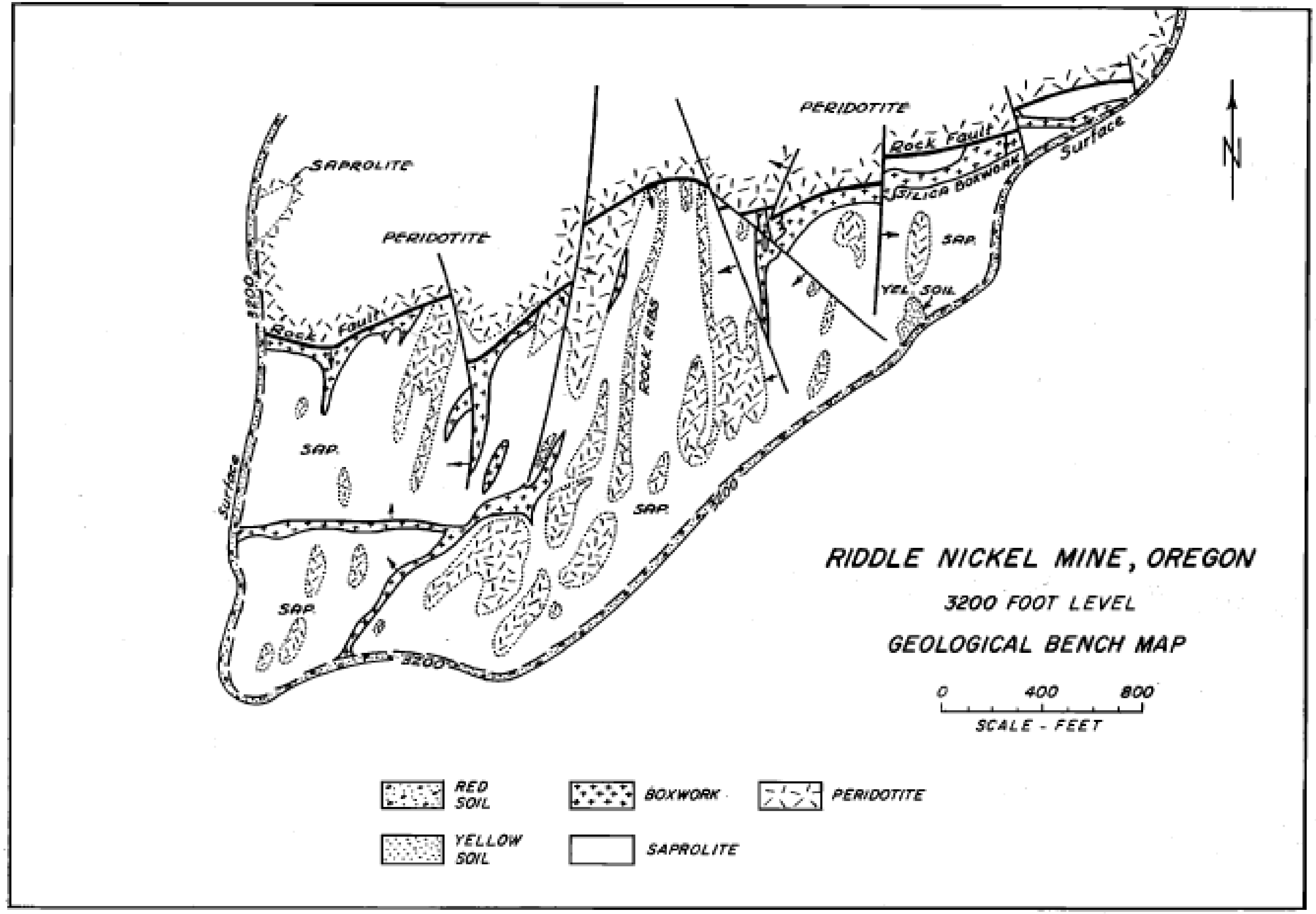
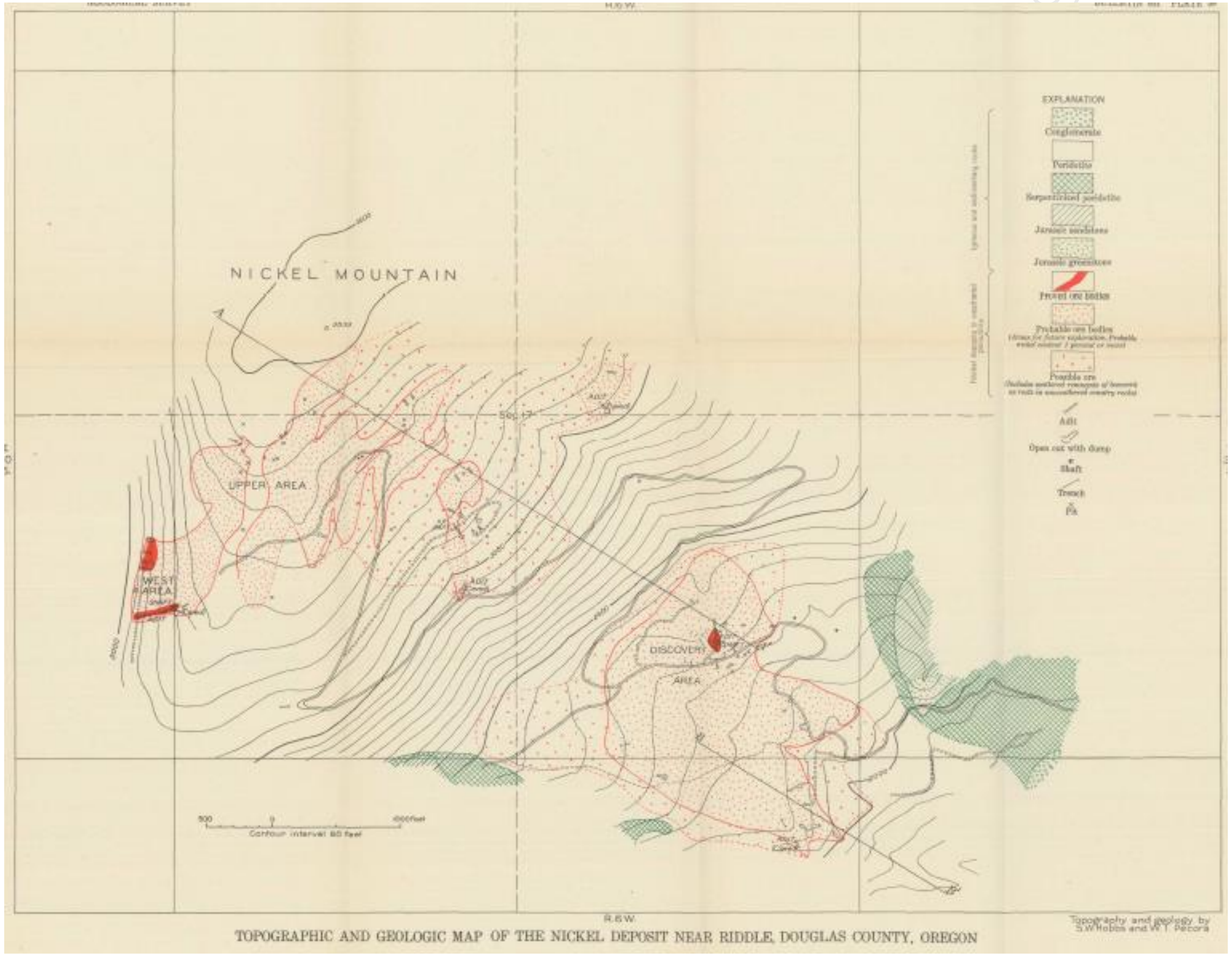


FIG. 2. Geological map, 3,200-foot level.

Mine Geology



- The laterite occurs in two areas : the largest area covers the top of the mountain; a smaller second deposit occurs on a bench on the southeastern slope of the mountain. Both deposits overlie peridotite and have a well-developed quartz-garnierite boxwork zone.
- These deposits are commonly from 5 to 30 feet thick, but the larger deposit has a maximum thickness of approximately 220 feet along a shear zone in the underlying peridotite, which has been more deeply weathered.
- The deposits have a superficial layer of reddish-brown soil at the top, 2-3 feet thick, which contains pellets of brown iron oxide and, locally, fragments of microcrystalline quartz.
- Below the surficial layer of red soil is a zone of yellowish-orange soil, which contains a ramifying network of residual quartz-garnierite veinlets, plus boxwork. This zone, which is commonly 5-10 feet thick, is the main nickel-bearing layer of the laterite.
- It grades downward into a thinner zone of altered peridotite that also contains abundant nickel but is thinner than the overlying yellowish-orange soil zone. The weathered peridotite in turn grades downward into fresh peridotite.
- The laterite at Nickel Mountain, like laterite elsewhere, has a highly irregular lower surface; pinnacles of unweathered peridotite project up into the lateritic soil, and the soil contains blocks and boulders of fresh to partly weathered peridotite. In places these peridotite inclusions are abundant; elsewhere they are sparse.

Mineralogy

- The principal minerals of the nickel deposit are garnierite (hydrous nickel-magnesium silicate), quartz, chalcedony, and chert (three varieties of silica), and limonite (hydrated iron oxide)-goethite. A small quantity of chromite ($FeCr_2O_4$) and manganese oxide present; Olivine, pyroxene

Garnierite from Nickel Mtn, Hanna Mine Plant, Oregon

Hanna nickel mine ore

Alteration Assemblage and zoning

- The general mineralogy of a Ni laterite profile can be separated by paragenetic sections:

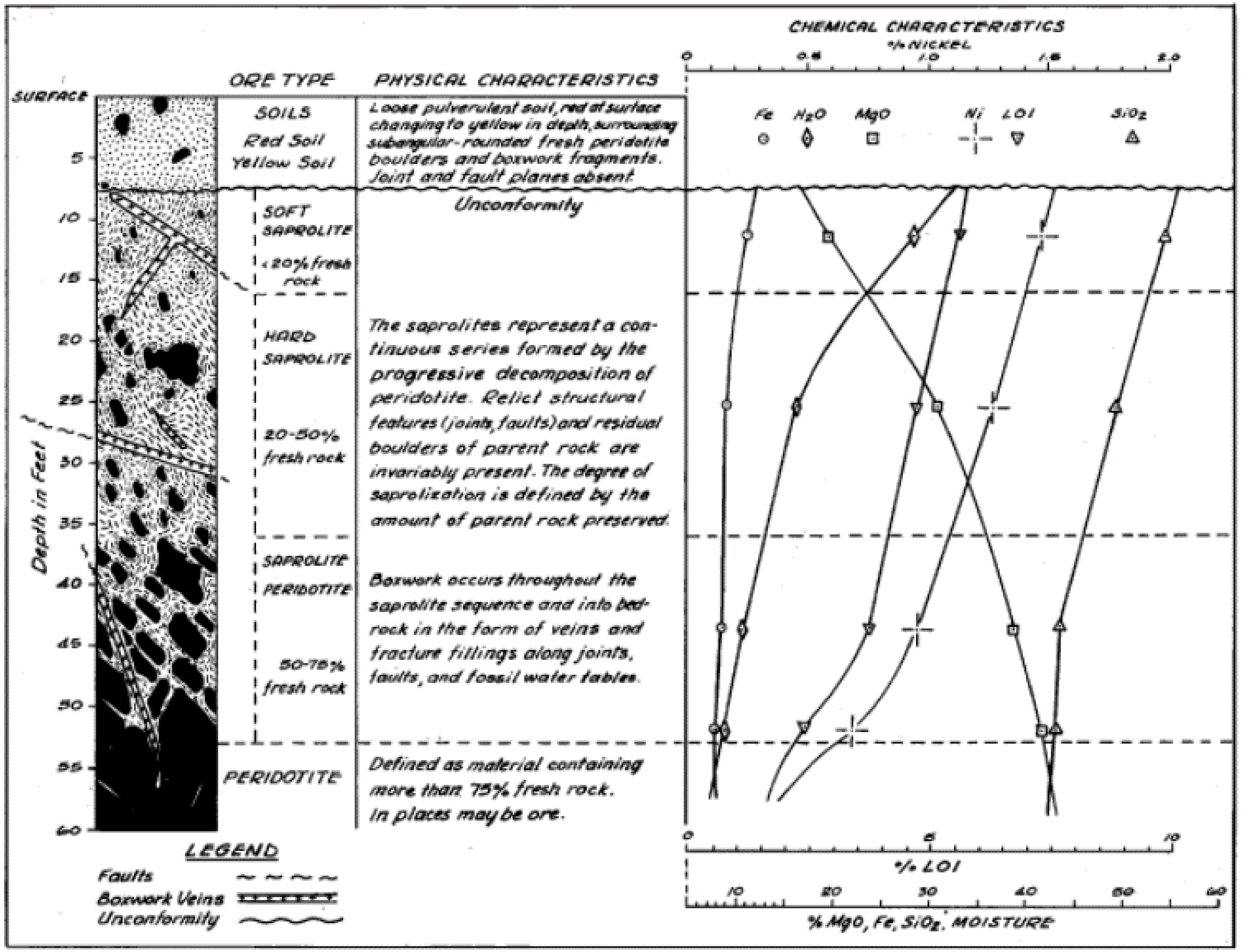


FIG. 1. Columnar Section, showing physical and chemical characteristics of ore types.

Origin

- Ni laterite deposits are formed from the chemical weathering of ultramafic rocks that removes the most soluble elements (Mg and Si) through the process of leaching and concentrates the least soluble elements (Fe, Ni, Co). (hydrolysis and oxidation of ni- and co- bearing minerals)
- fractures and faults increases the surface area exposed to the water driving the chemical weathering. The water responsible for this process is circulating rain water
- If the profile is well drained a hydrous Mg-silicate zone develops.
- garnierite formed concurrently with quartz, and therefore both were precipitated from the same solution. Nickel AND magnesium is carried as bicarbonate in rainwater with an excess of dissolved CO2.
- Nickeliferous hydrosilicates of magnesium forms by hydrolysis of the nickel bicarbonate with loss of excess carbonic acid, an increase of pH, and combination with the magnesium and silica which are also in the solution.
- Silica boxwork veins crystallized from solution
- The solubility of nickel in water is determined by the pH, the limiting value being 6 .6 to 6.8; at higher pH values it comes out of solution.

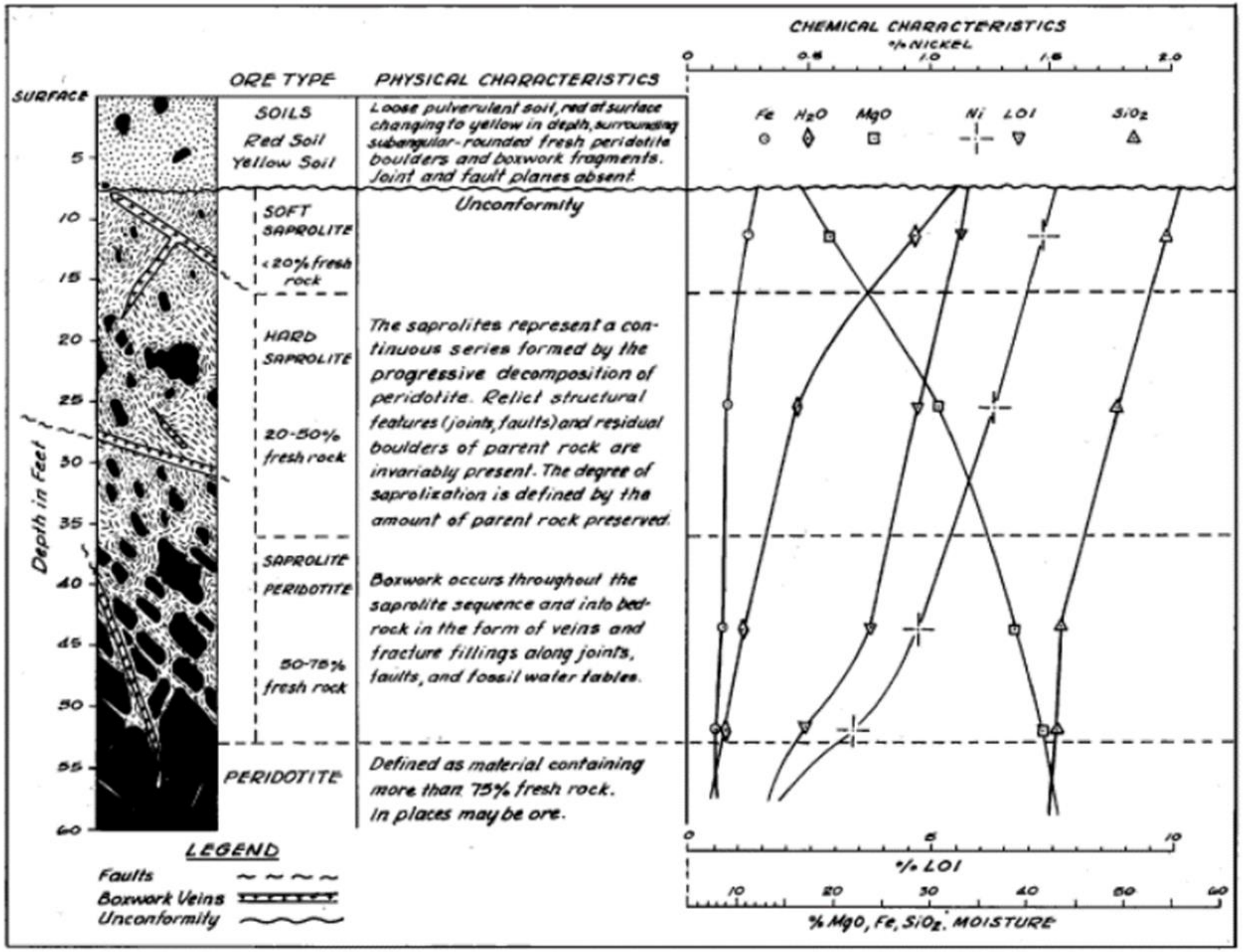


FIG. 1. Columnar Section, showing physical and chemical characteristics of ore types.

Mining Methods

- Open pit mine
- Smelting on site
  - Aerial tramway (tram cars suspended on cables running on a continuous loop), Small 75 ton trucks and shovels used - steepness of Nickel Mountain made hauling the nickel ore down to the smelter challenging. In the winter it would rain everyday & When temperatures dropped that would mean a great deal of snow on the mountain.

Nickel Mountain Mine

Glenbrook Nickel Smelter site

Exploration Methods and Strategies

- Field Mapping & drill hole logging (look for laterized zones)
- Geochemical-Enriched in Ni, Co, Cr
- Gravity survey- mafic igneous rocks tend to have high densities. During serpentinization, large amounts of water are absorbed into the rocks, thus increasing the volume of the rocks and decreasing the density. This density contrast can potentially be imaged in a high-resolution gravity survey
- Magnetic- ultramafic rocks tend to have higher magnetic susceptibilities & produce stronger magnetic anomaly highs
- Ground penetrating radar method (gpr)- been used in the advanced phases of exploration at multiple ni-co laterite deposits. GPR technique could define the saprolite horizon in a laterite profile. GPR technique provides a continuous image of the bedrock at depth, leading to a much higher resolution and a more complete projection of the orebody (i.e. its thickness).

Exploration targets in California

- NICKELIFEROUS laterites are known at several places in northwestern California in the Klamath mountains with a few isolated prospects in California occurring as far south as 150 miles from the state group of deposition near the state line.
- However, the nickel content in all these deposits is less than 1 percent (low grade, not economic to mine)

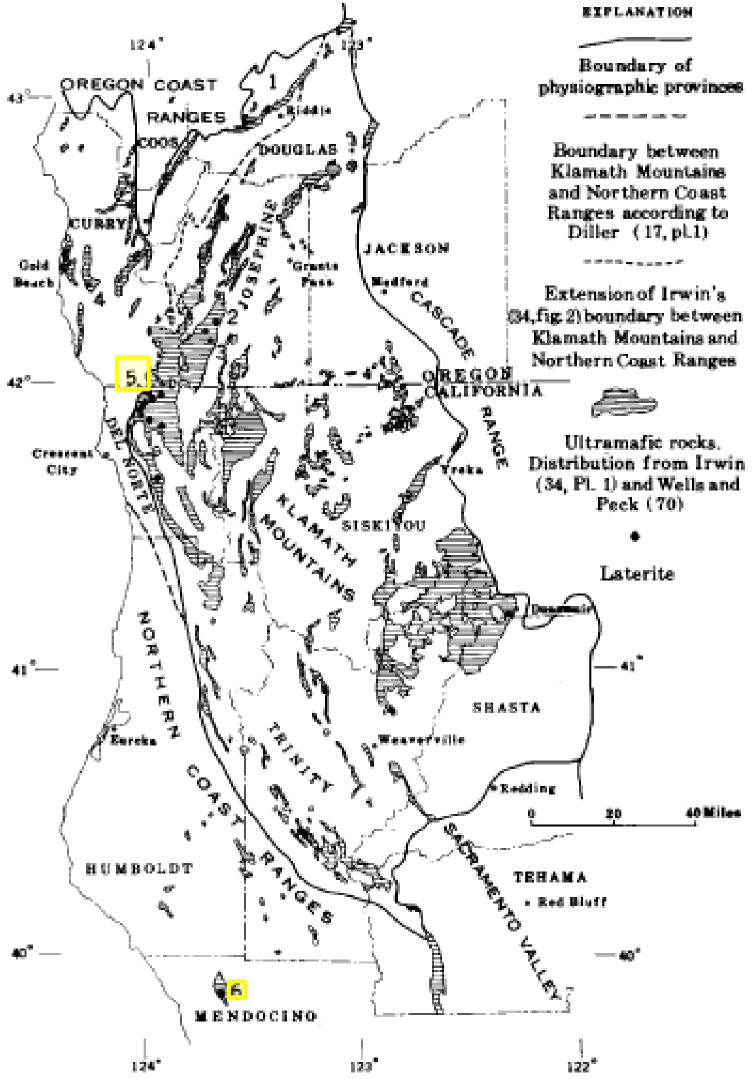


FIG. 1. Map of N.W. California and S.W. Oregon showing physiographic provinces, distribution of ultramafic rocks, and location of lateritic deposits: 1, Nickel Mountain; 2, Eight Dollar Mountain; 3, Woodcock Mountain; 4, Red Flats; 5, Pine Flat Mountain; 6, Little Red Mountain.

references

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- http://pubs.usgs.gov/bul/b1693/
- Chace, f.m., cumberlidge, j.t., Cameron, w.l., and va nort, s.d., 1969. Applied Geology at the Nickel Mountain Mine, Riddle, Oregon. Economic geology. Vol. 64, pp.1-16
- Hotz, p.e., 1964. NICKELIFEROUS LATERITES IN sOUTHWESTERN OREGON AND NORTHWESTERN CALIFORNIA. Economic geology. Vol. 59, pp. 355-396
- Marsh, Erin, Anderson, Eric, and Gray, Floyd, 2013, Nickel-cobalt laterites—A deposit model, chap. H of Mineral deposit models for resource assessment: U.S. Geological Survey Scientific Investigations Report 2010–5070–H, 38 p., http://pubs.usgs.gov/sir/2010/5070/h/.
- Pecora, w.t., hobbs, s.w., and murata, k.j. 1949. VARIATIONS IN GARNIERITE FROM THE NICKEL DEPOSIT NEAR RIDDLE, OREGON. Economic geology. Vol. 44, pp.13-23

weathering and Mass Wasting

Discuss with a friend:

12. Was the nickel originally part of the Oceanic crust or Continental Crust?

I will get an A on my exams and quizzes

Supergene Sulfide Enrichment of Arizona Cu

WILBERT NEUENKIRK

GEOLOGY AND ECONOMIC GEOGRAPHY OF MINERAL DEPOSITS

Sierrita Esperanza Mine

122 AIKEN AND WEST

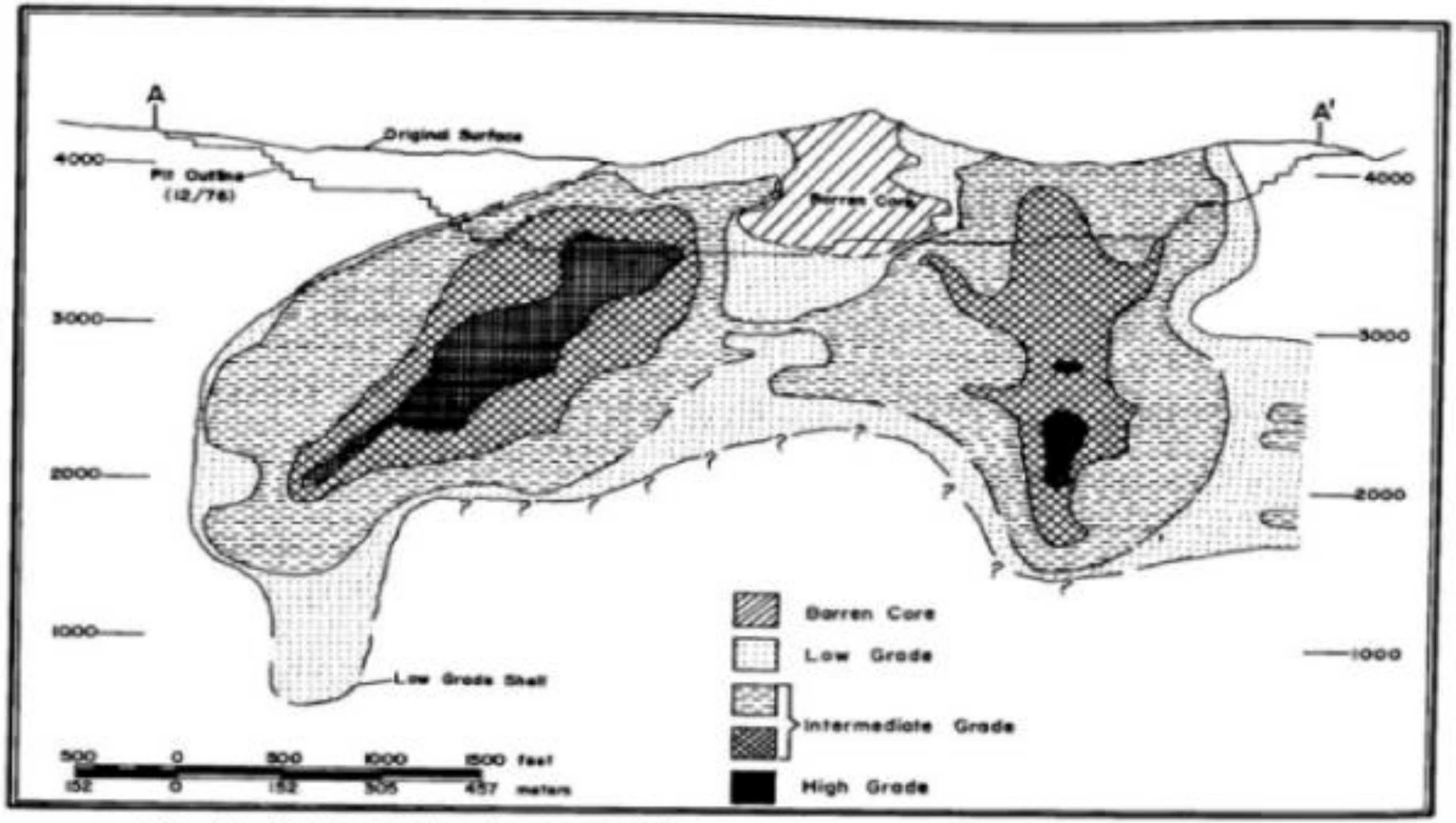


Fig. 3. Section A-A', showing distribution of economic mineralization at Sierrita

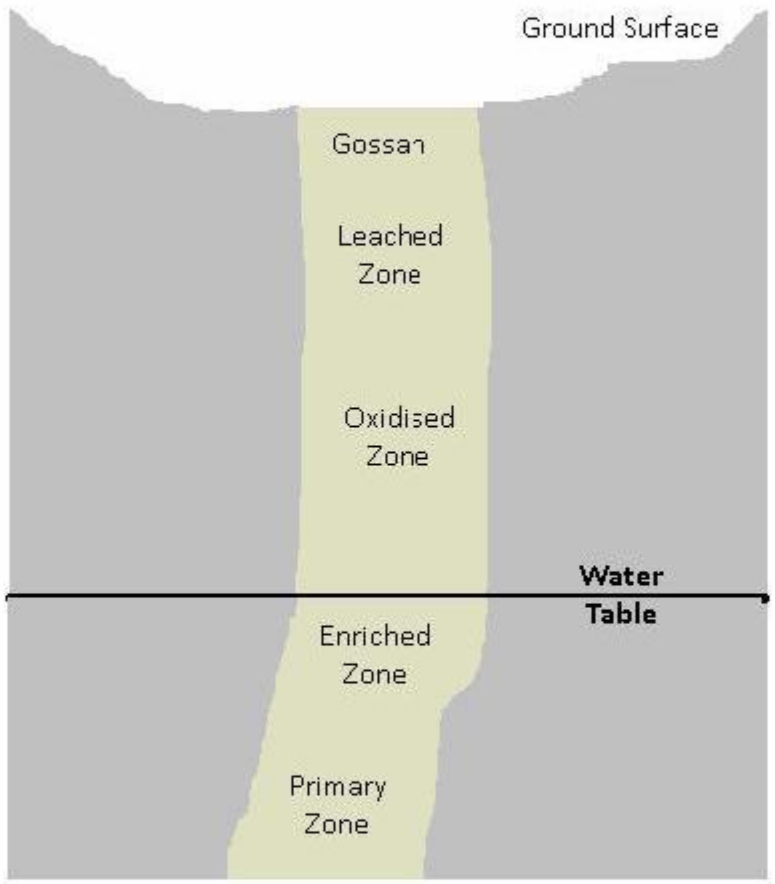
Dan Aiken and Richard West, 1978, Some Geologic Aspects of the Sierrita-Esperanza Copper-Molybdenum Deposit, Arizona Geological Society Digest Volume XI

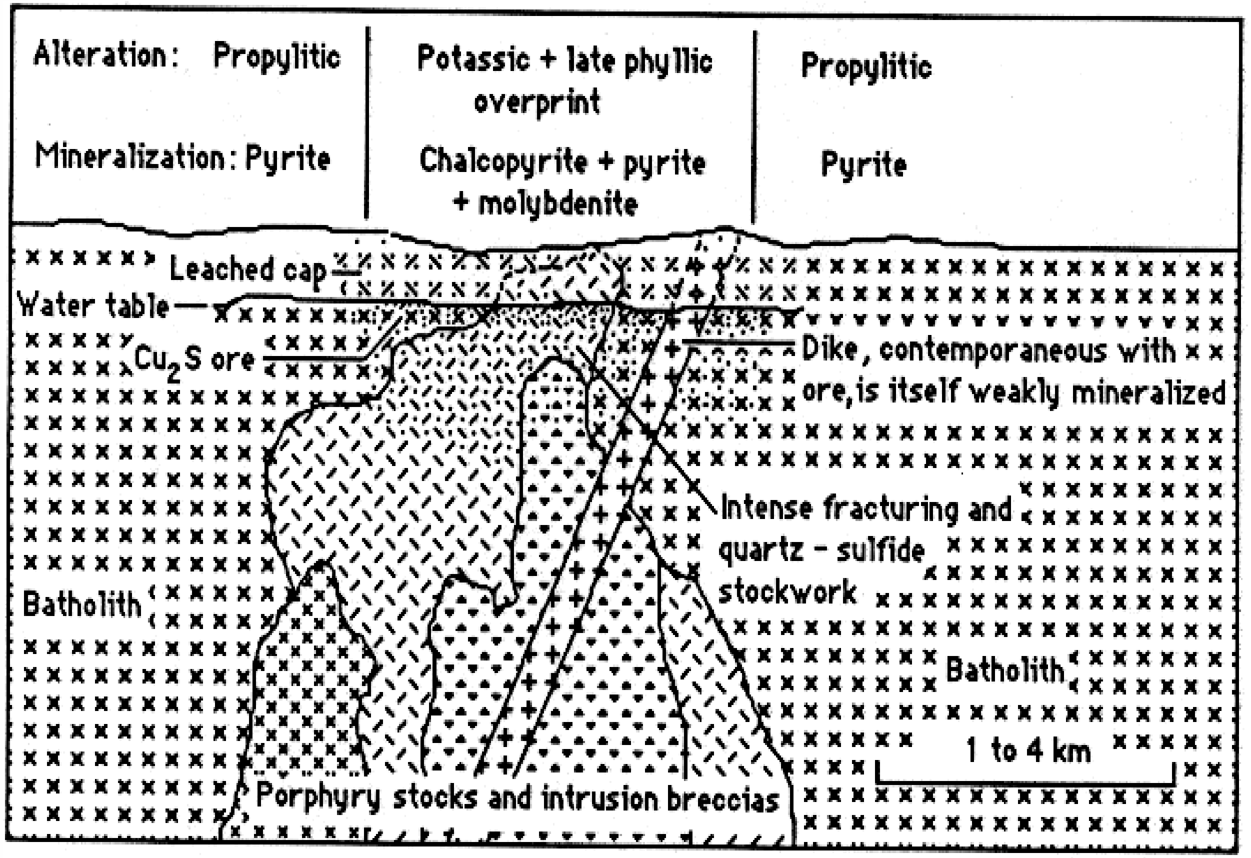
Sierrita Esperanza Mine

Deposit Location

USGS Ore Deposit Model

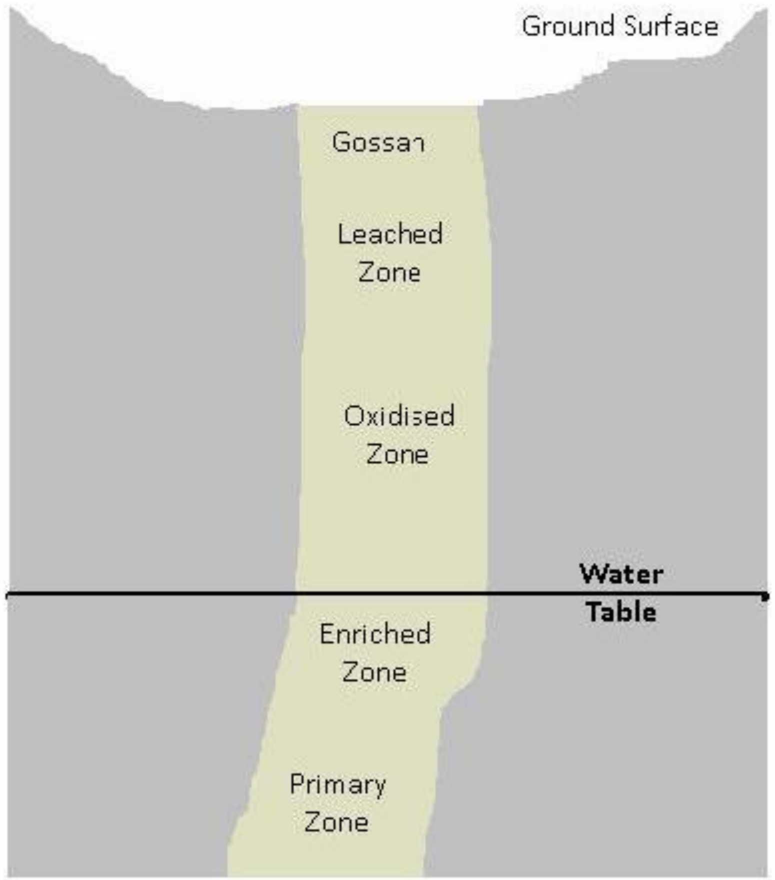
21a



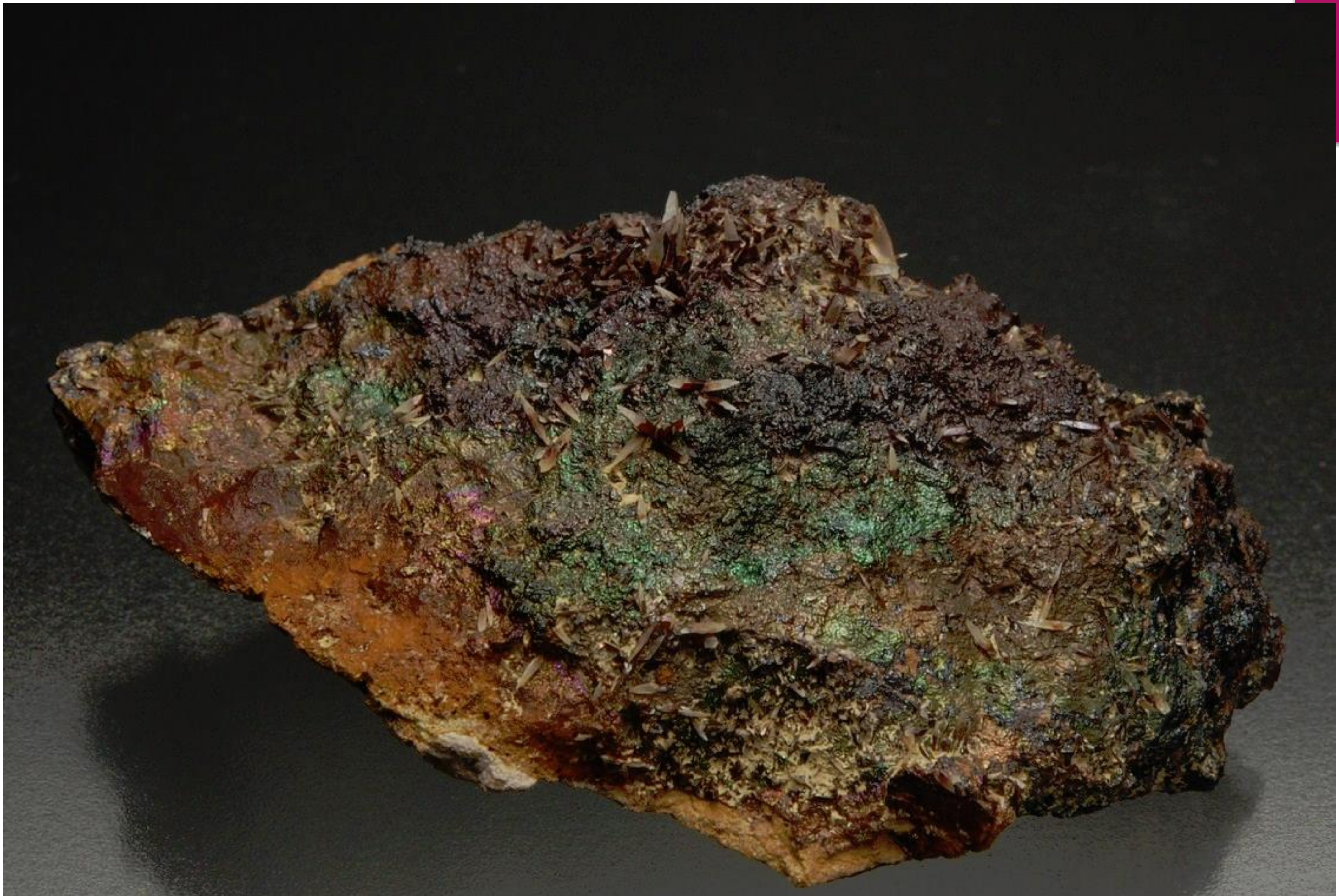



gossan
oxidized zone

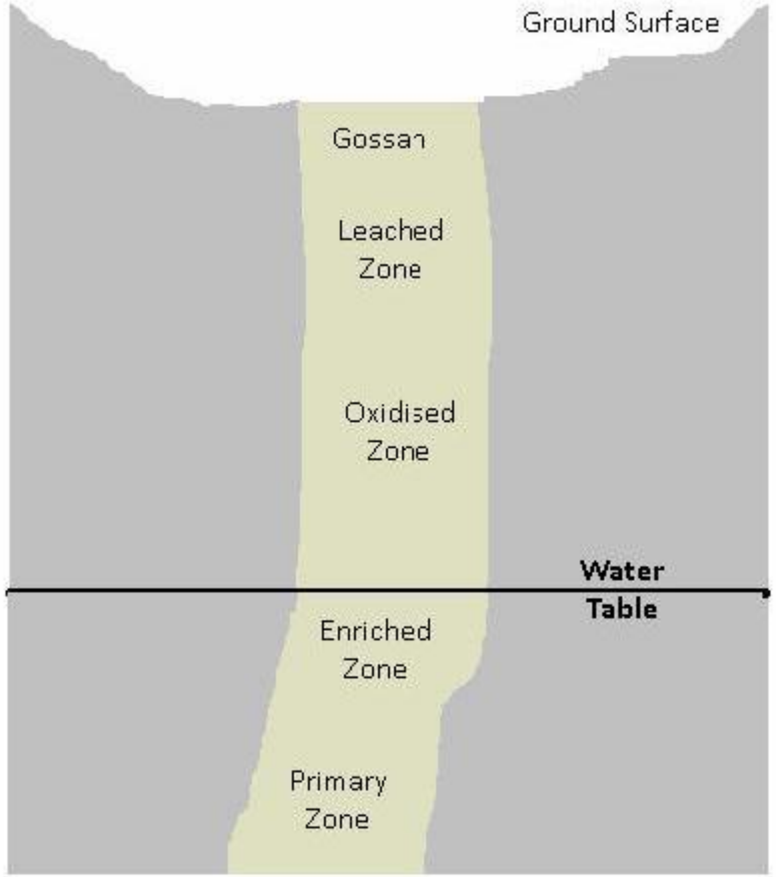
USGS Ore Deposit Model



Pyrite $FeS2$ is generally abundant, and near the surface it oxidises to insoluble compounds such as goethite $FeO(OH)$ and limonite, forming a porous covering to the oxidized zone known as gossan or iron hat. Prospectors take gossan as an indication that there might be reserves of ore underneath.
(wikipedia)

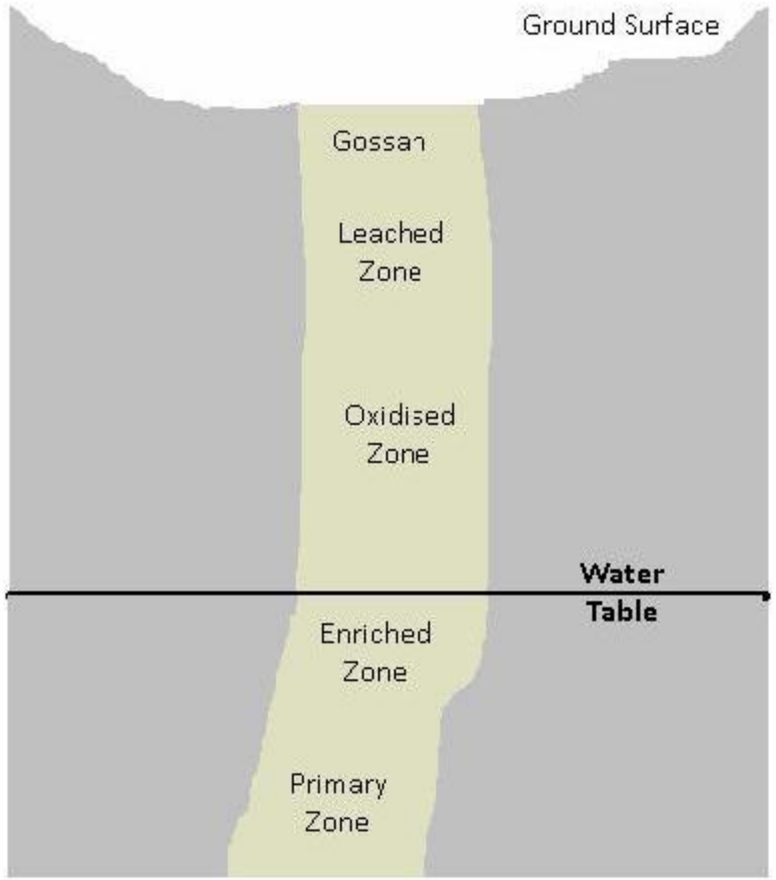


USGS Ore Deposit Model



The groundwater contains dissolved oxygen and carbon dioxide, and as it travels downwards it leaches out the minerals in the rocks to form sulfuric acid, and other solutions that continue moving downwards. (wikipedia)

USGS Ore Deposit Model



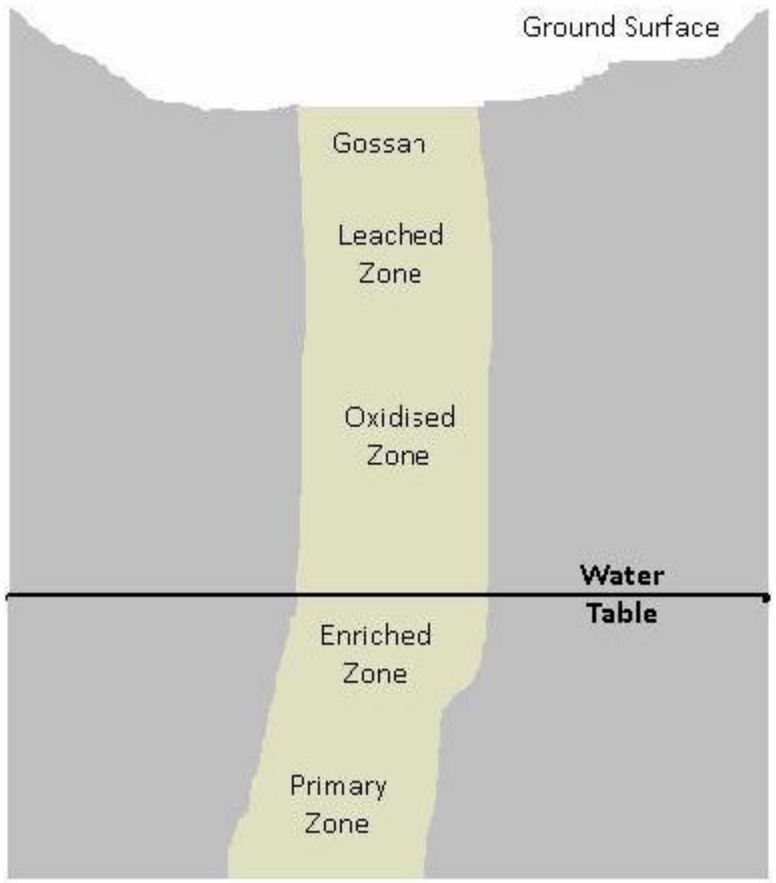
Above the water table the environment is oxidizing, and below it is reducing.[6] Solutions travelling downward from the leached zone react with other primary minerals in the oxidized zone to form secondary minerals[5]such as sulfates and carbonates, and limonite, which is a characteristic product in all oxidized zones.[3]
In the formation of secondary carbonates, primary sulfide minerals generally are first converted to sulfates, which in turn react with primary carbonates such
as calcite CaCO3, dolomite CaMg(CO3)2 or aragonite (also CaCO3, polymorphic with calcite) to produce secondary carbonates.[4] Soluble salts continue on down, but insoluble salts are left behind in the oxidized zone where they form. An example is
the lead mineral anglesite PbSO4. Copper may be precipitated
as malachite Cu2(CO3)(OH)2 or azurite Cu3(CO3)2(OH)2.[3] Malachite,
azurite, cuprite Cu2O, pyromorphite Pb5(PO4)3Cl
and smithsonite ZnCO3 are stable in oxidizing conditions[6]and they are characteristic of the oxidation zone. (wikipedia)

Cuprite Cu20

Malachite; $Cu_2CO_3(OH)_2$

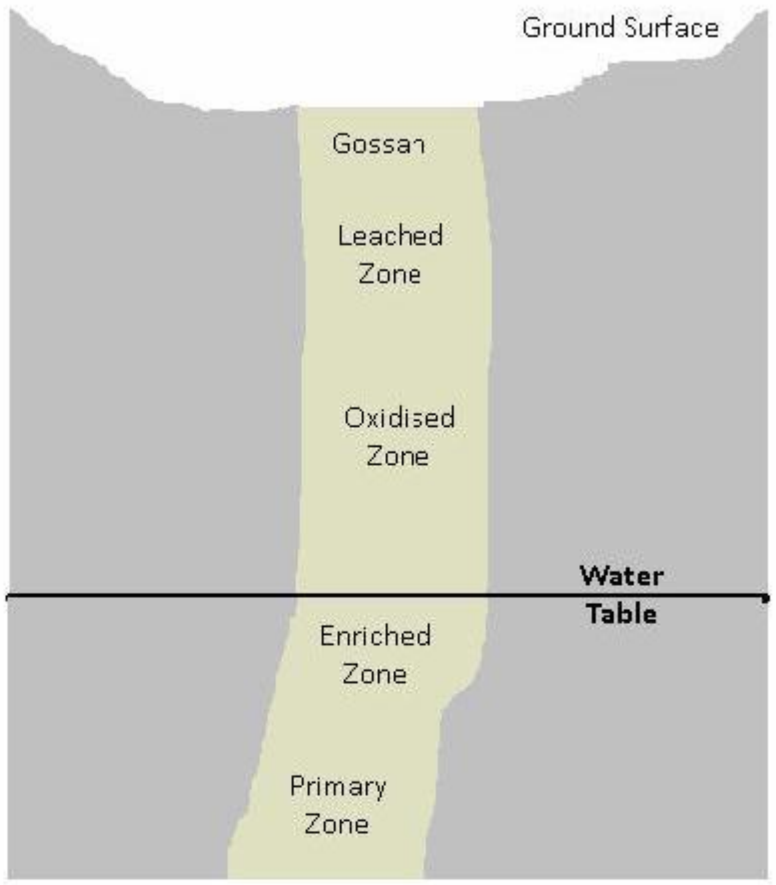
Azurite; $Cu_3(CO_3)_2(OH)$

USGS Ore Deposit Model



At the water table the environment changes from
an **oxidizing** environment to
a **reducing** one. (wikipedia)

USGS Ore Deposit Model

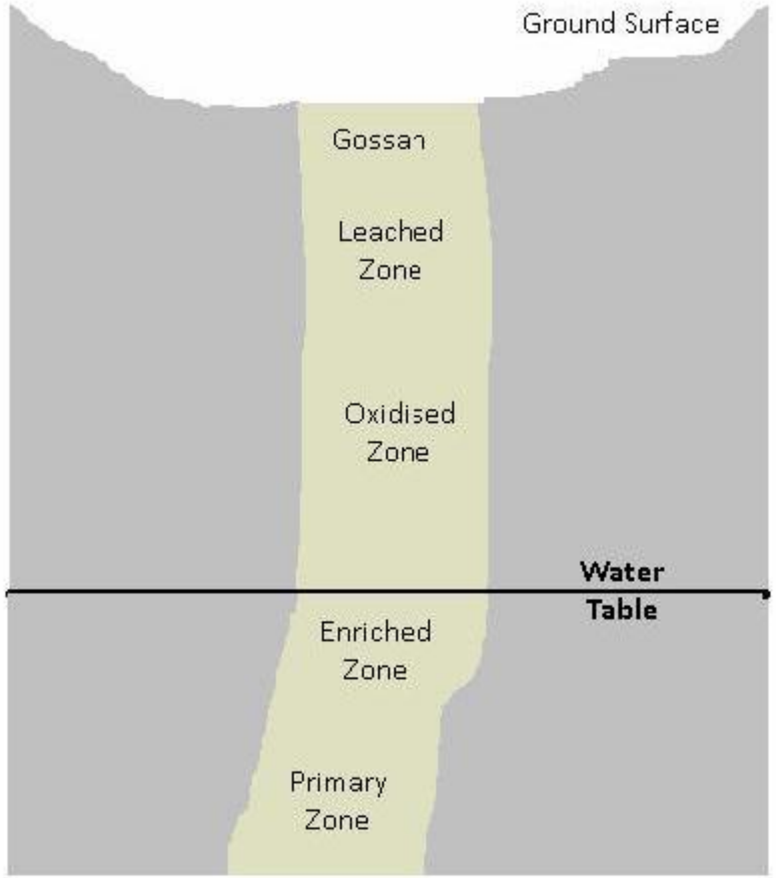


Copper ions that move down into this reducing environment form a zone of **supergene sulfide enrichment.**
Covellite CuS, chalcocite Cu2S
and native copper Cu are stable in these conditions and they are characteristic of the enriched zone. The net effect of these supergene processes is to move metal ions from the leached zone to the enriched zone, increasing the concentration there to levels higher than in the unmodified primary zone, possibly producing a deposit worth mining.
wikipedia)

Covalite, CuS, Cu+4Cu2+2(S2)2S2

Chalcocite, (Cu_2S)

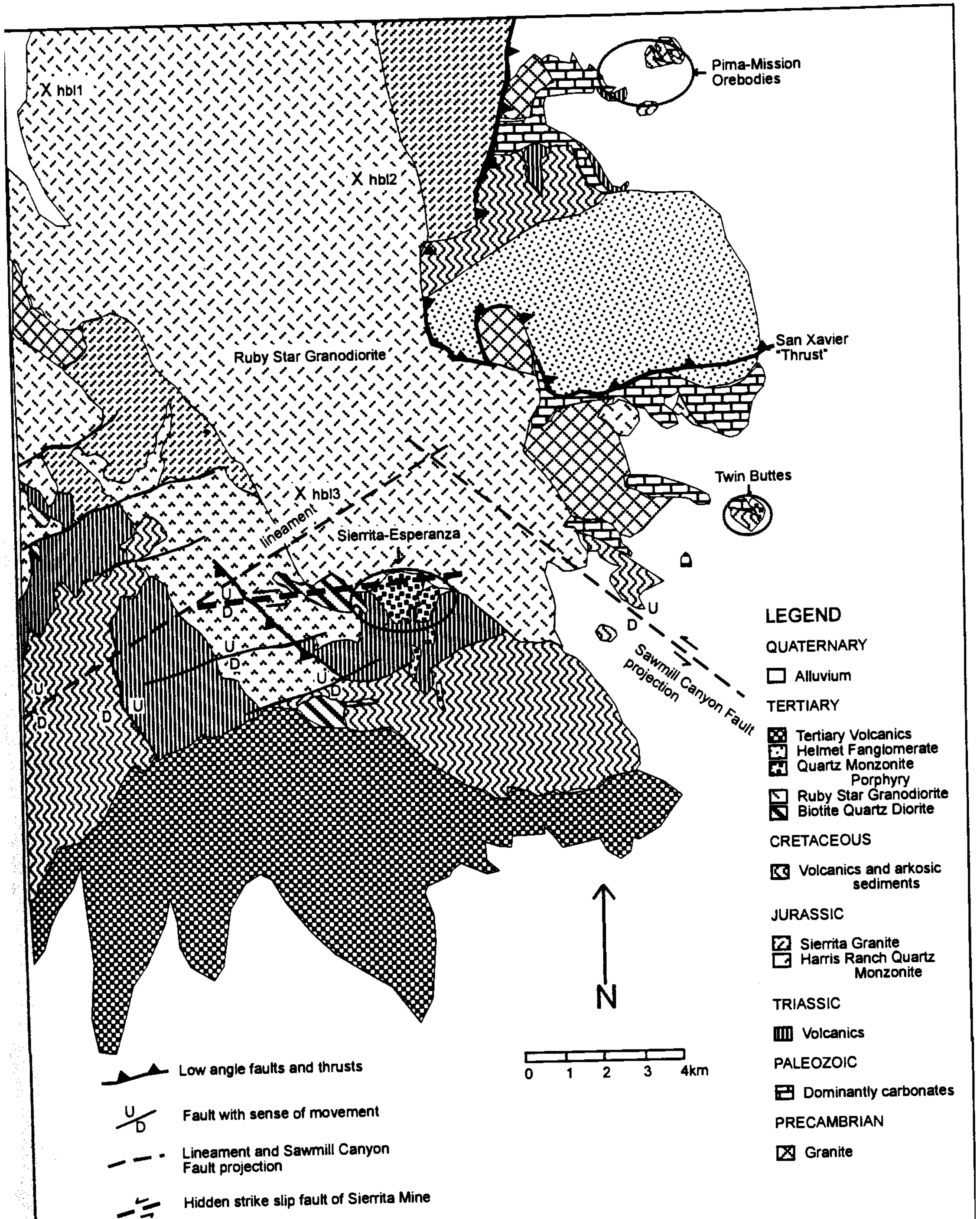
USGS Ore Deposit Model



The primary zone contains unaltered primary minerals wikipedia)

Local Geology

- Stratigraphy
- Structure



Mine Geology

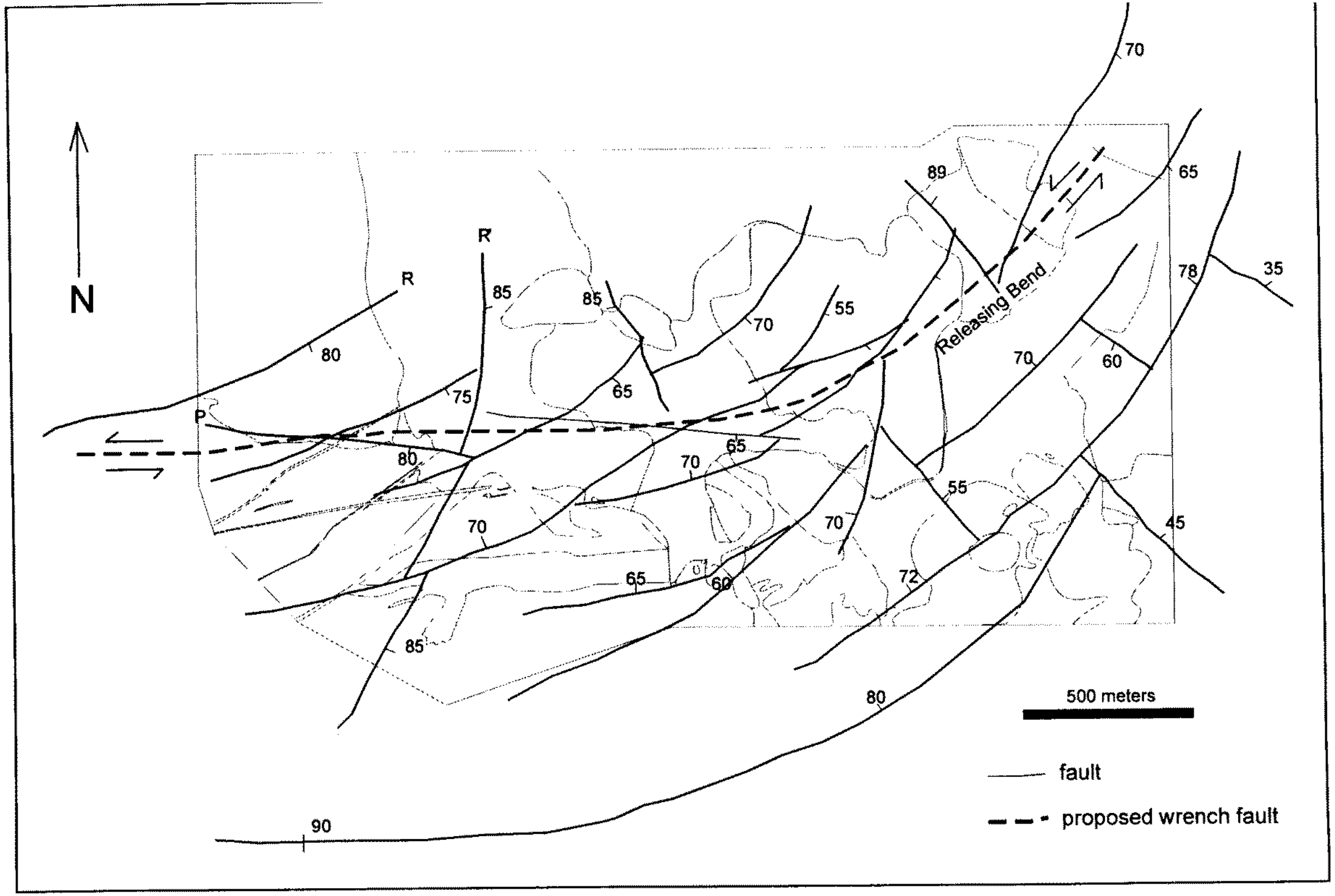


Figure 11. Diagramatic representation of dominant fault sets mapped in the Sierrita-Esperanza mine area. Proposed R, R', and P designations are included, based on a wrench fault at depth hypothesis. Dashed line represents the left-lateral wrench fault. All faults shown have potential strike-slip motion. Map of pit lithology is included to show how these structures relate to intrusions (see Plate 1 for unit identification).

Mine Geology

- Stratigraphy
- Structure
- Ore Bodies

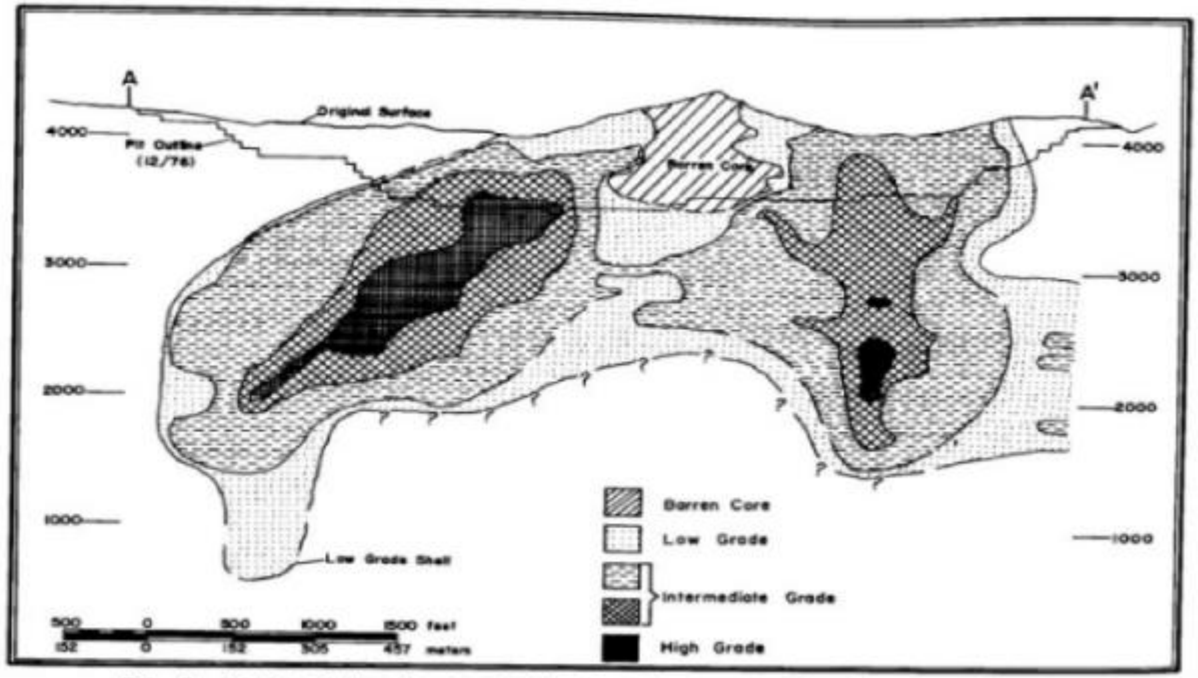
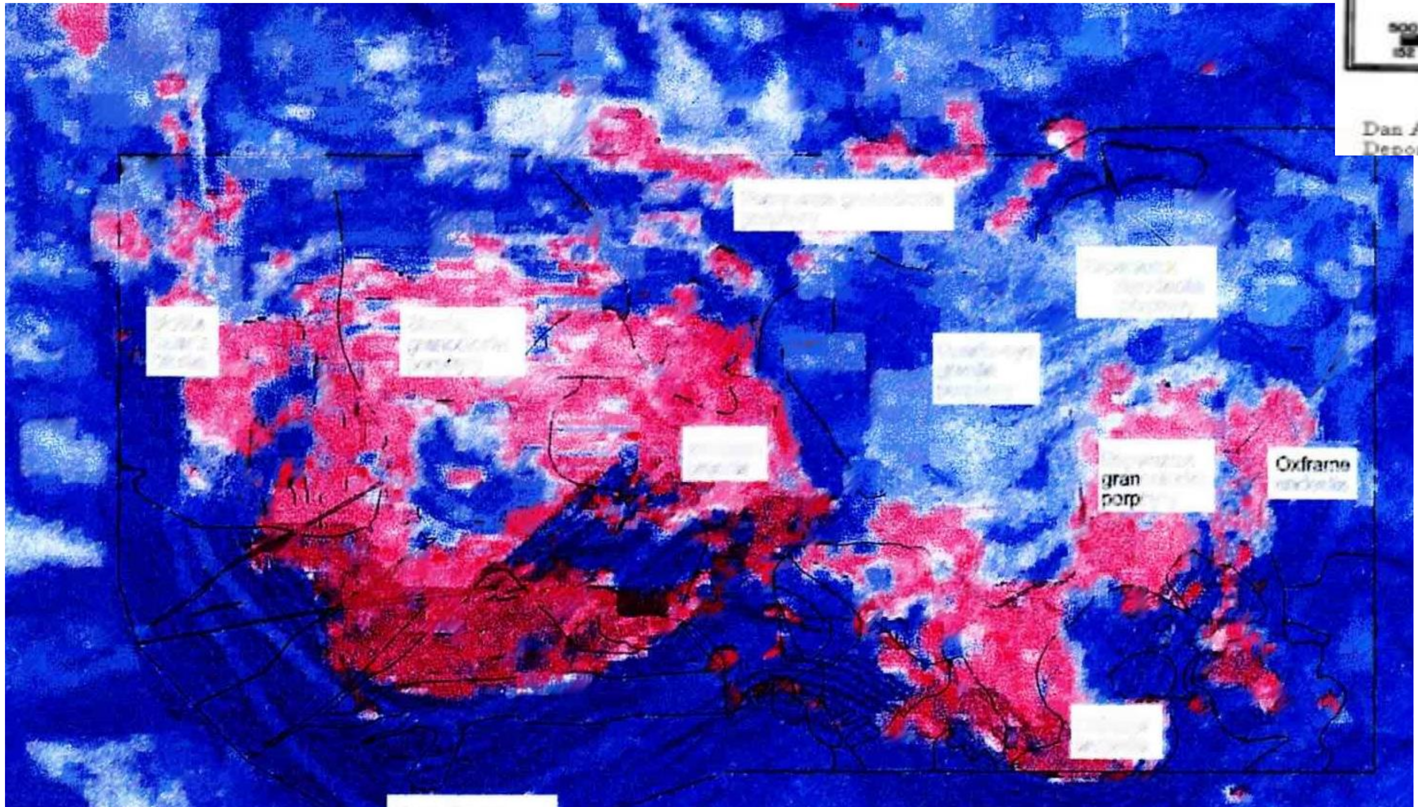


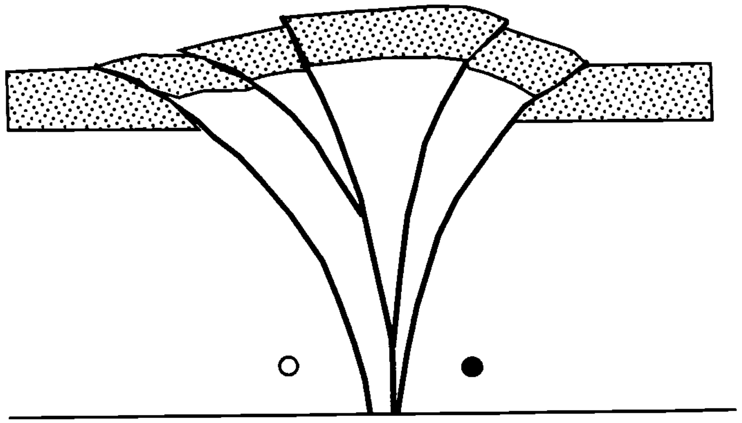
Fig. 3. Section A-A', showing distribution of economic mineralization at Sierrita

Dan Aiken and Richard West, 1978, Some Geologic Aspects of the Sierrita-Esperanza Copper-Molybdenum Deposit. Arizona Geological Society Digest Volume XI

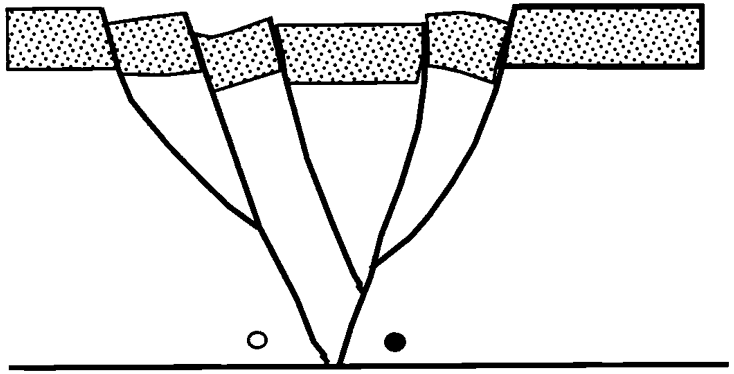


Mine Geology

- Stratigraphy
- Structure
- Ore Bodies



Positive Flower Structure (Palm)



Negative Flower Structure (Tulip)

Mineralogy

Ore is **Chalcocite** Cu_2S. (80% copper by weight)

It is all but mined out.

Isotope Studies

sample	Re (ppm)	187Os/190Os	(Os %1sigma)	187Re/185Re	(Re %1sigma)	% radiogenic Os	Age my (+/- .5% 2 sigma)
Oco	187	4.386	0.1	0.1186	0.004	99.93	63.5
3a	200	2.65	0.004	0.091	0.007	99.89	60.7
3b	258	5.6287	0.04	0.143	0.002	100.02	60
3bb	243	7.01748	0.006	0.143	0.001	99.95	60.8

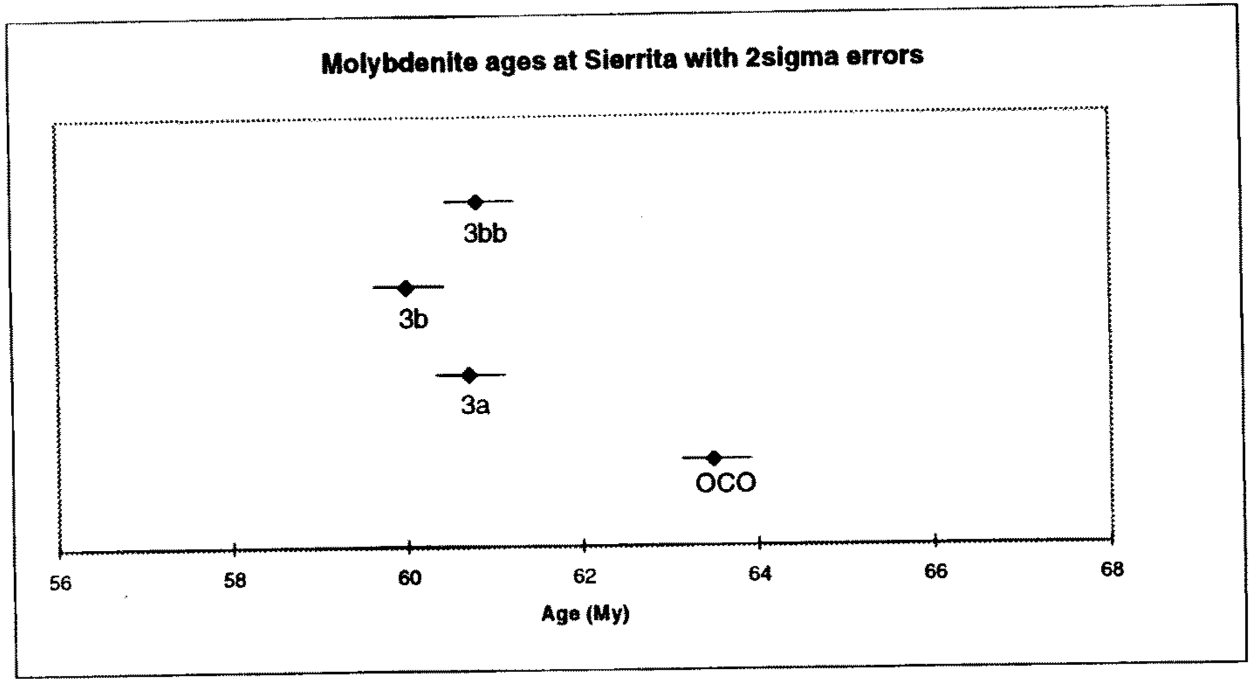


Figure 28. Summary of molybdenite samples. Those samples collected near to, and within the younger quartz-eye granite porphyry are younger, near 60ma, whereas the sample collected in Ocotillo pit, some 700m from the Sierrita granite porphyry, is older at 63.5 ma.

- https://www.youtube.com/watch?v=BucmR-kWwmo
- http://www.nytimes.com/video/business/1194830082116/arizona-s-copper-mining-towns.html

weathering and Mass Wasting

Discuss with a friend:

13. How did the copper mineralization become enriched at Sierra Espiranza?

I will get an A on my exams and quizzes