ME589/Geol571/GEOC 589-04D/GEOL 589-04/GEOL 589-04D Advanced Topics

Mineral Deposits in New Mexico

LARAMIDE PORPHYRY COPPER DEPOSITS

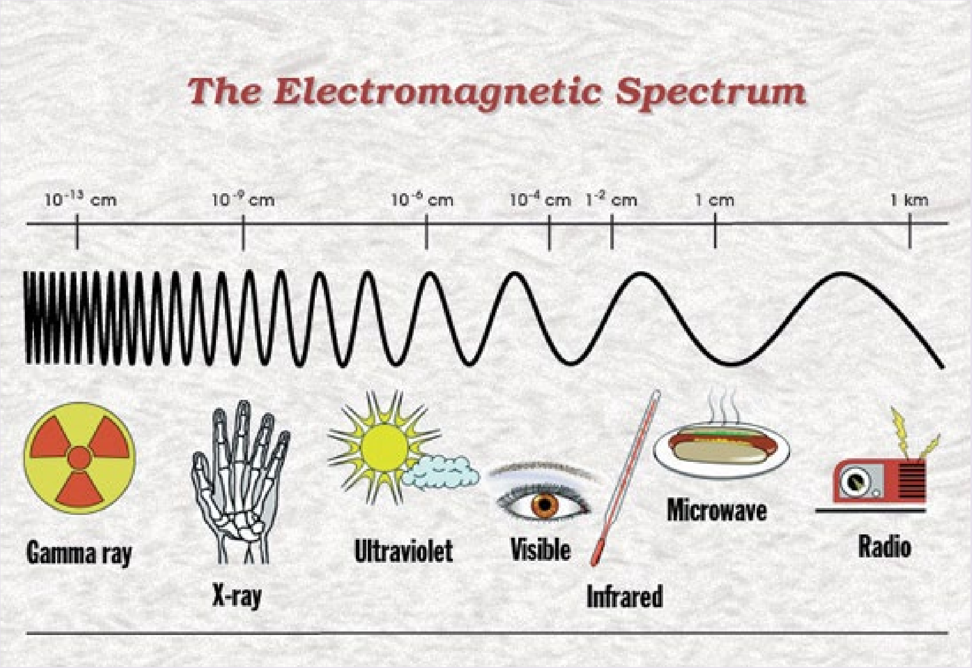
Virginia T. McLemore

Radiation Safety

Tyler Cantrell

What is radiation?

- Emission or transmission of energy through space or a medium
  - Movement of energy
- Radioactivity: spontaneous release of radiation from the nucleus of an unstable atom



Radiation safety basics

- Time
  - Less time near the source of radioactivity/radiation = less exposure
- Distance
  - More distance = less exposure
  - Inverse square law
  - 2x the distance from the source, decreases your dosage by 4
    - 3x = 9 times
- Shielding
  - Not handling material with bare hands

Appropriate Lab attire when handling radioactive materials

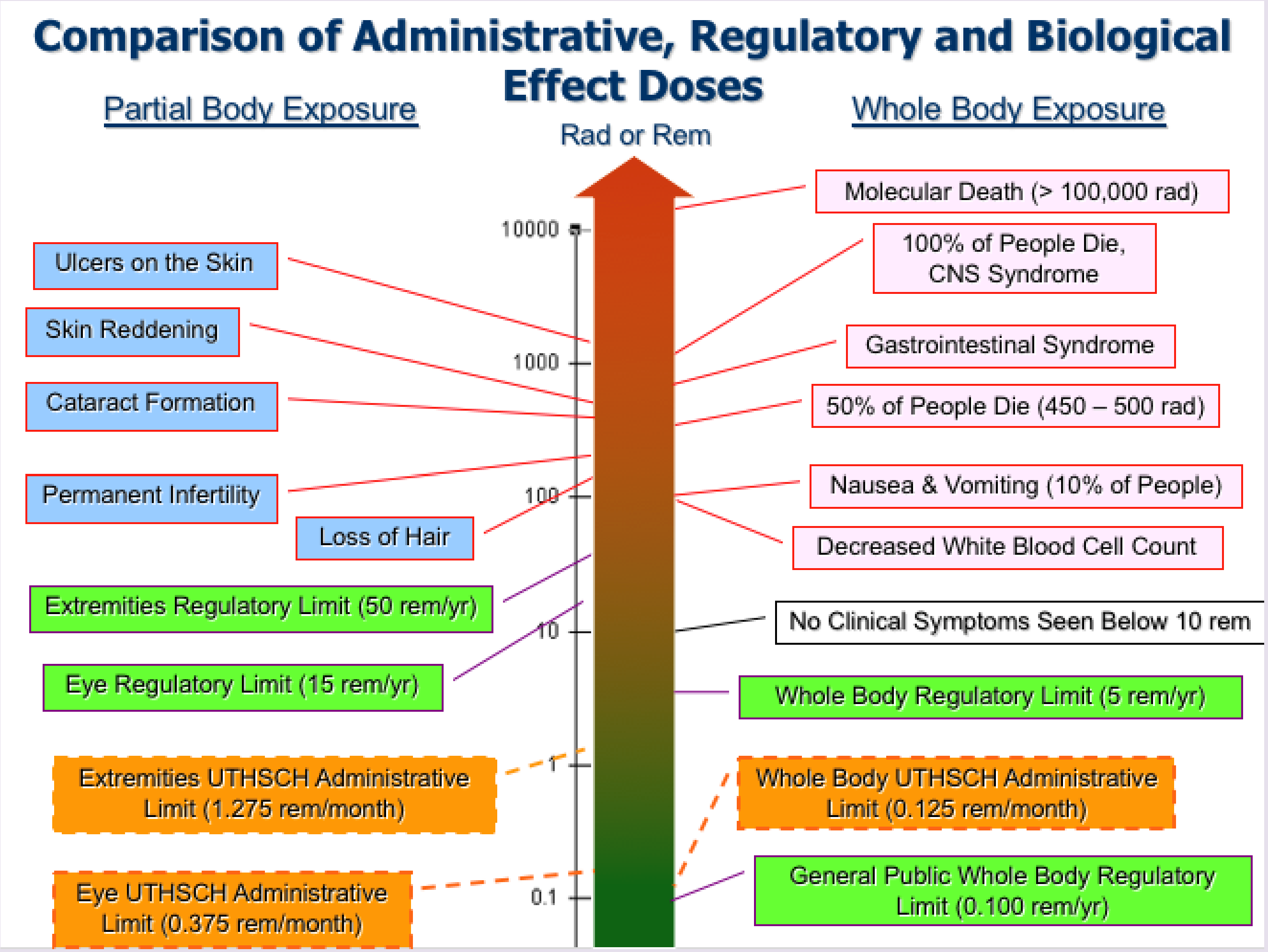
- Lab coat/long sleeves
- Safety glasses
- Gloves
- Safety glasses
- Radiation badge/monitor

Exposure limit per year

- Occupationally exposed limit = 5 rem / 5000 mrem
  - Average per year from natural and man-made sources (X-rays, etc.) = 360 mrem/year
  - OSHA
- Average person/work environment = 100 mrem/year or 2 mrem/hour
  - OSHA

Effects of radiation on the body

- Serious radiation exposure can cause large numbers of cells to die off
  - Isn’t seen for ~2+ months after exposure
- Long term exposure can cause a variety of health issues over many years



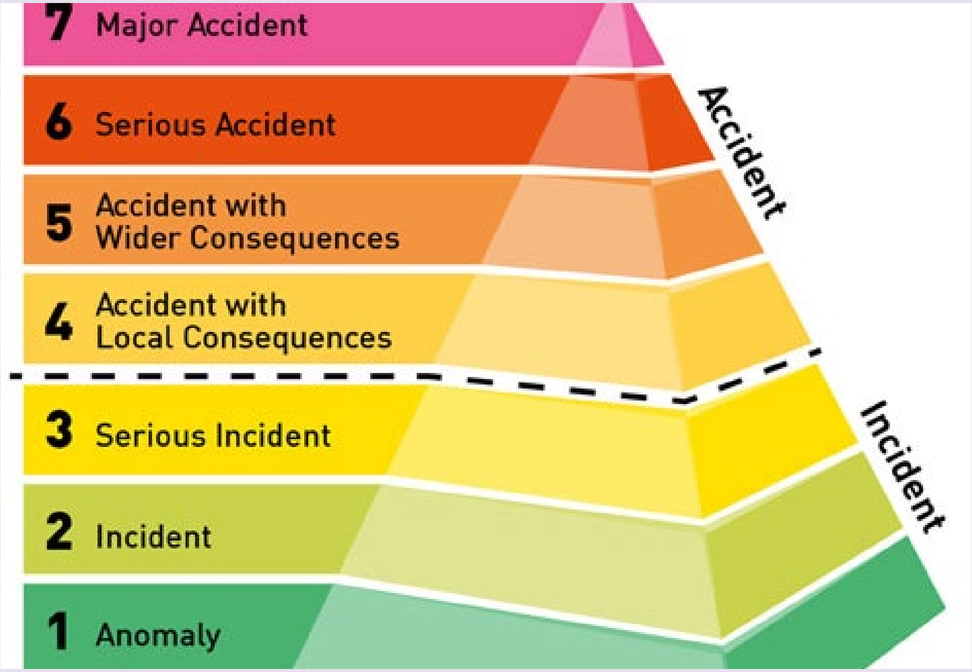
From The University of Texas Health Science Center at Houston

Medical Treatment

- Cleaning solutions applied to effected areas
  - Dish soap, other solutions specific for radiation
  - Don’t use anything rough that can push it into the skin or break material into smaller parts
- Internal exposure should be treated by a doctor right away to excrete radionuclides from inside of body

INES Level 2 - Incident

- March 11, 2002
- Truck going from Leeds to Sellafield, England contained defective shielding
- Minimal radiation exposure to human life
- Contained Cobalt – 60 and if container had tipped or had serious leak then could have exposed many to serious gamma rays.
- AEA Technology was eventually fined £250,000

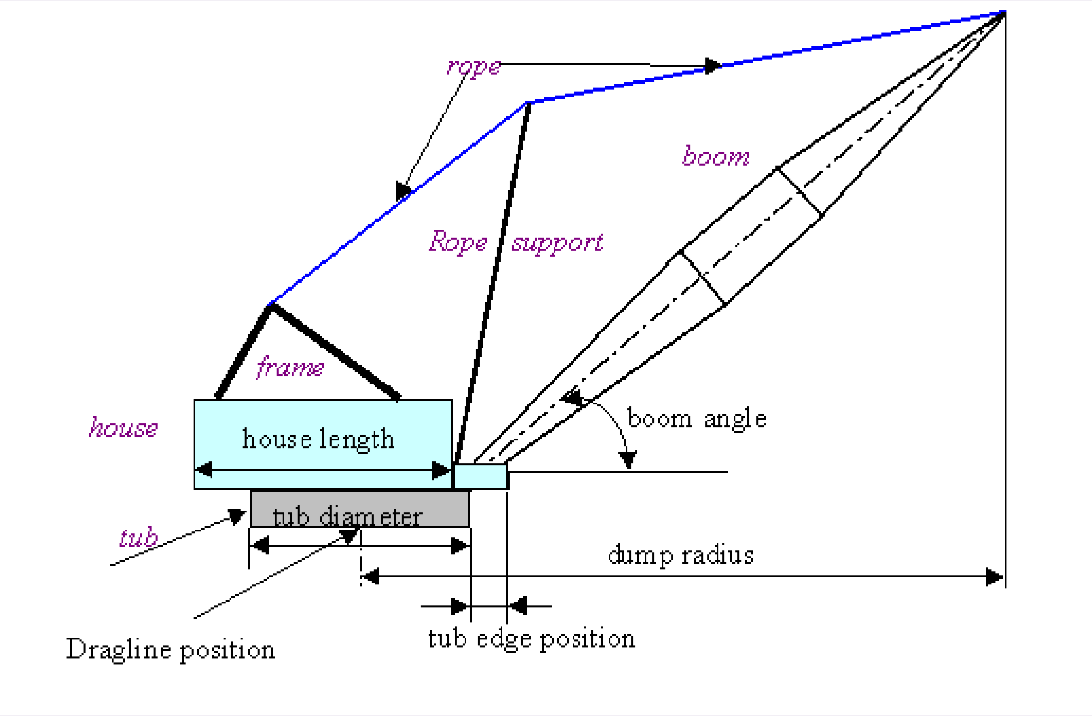


https://web.archive.org/web/20160113201140/http://www.hse.gov.uk/press/2006/e06017.htm

Dragline Safety

Brady Thompson

What is a Dragline?



- Extremely large excavator
- Uses a series of cables and pulleys to move a large bucket
- The bucket DRAGS along the ground to pick up waste material
- Once the waste material is in the bucket the dragline rotates and dumps the waste in the designated area

Importance of a Dragline

- A dragline is a cost-efficient way of moving large amounts of material without the need for haul trucks
- Runs on electricity, fuel is not needed
- Able to move (slower than a snail) to various areas of the mine by walking
- Moves material much faster than a typical shovel/excavator and haul trucks

Dragline Hazards

- The dragline bucket continues to swing due to momentum, even after the dragline has stopped rotating.
  - Will destroy anything in its path
- Limited field of vison
- Too much tension can cause the cables to snap and the bucket to fall
- Excessive noise pollution limiting operators hearing
- Falling material from the bucket
- Typically has a dozer operator to level areas for the dragline to move
- Bench failure

Outside Dragline Hazards

- Operator most likely cannot see you
- Power cables run across the mine and CANNOT be driven over in vehicles without protection
- Dragline is very large and may obscure other miners' field of view
- Produces large amounts of dust near dumps

How to Safely Operate a Dragline

- Be mindful of all other miners working in the area
- Don’t rush, operate slow and frequently check all blind spots.
- Ensure that you are working on a secure foundation
- Watch the tension on your cables
- Make sure your load is secure before rotating over to the dump
- Only dump in the specified area
- When maintenance is being conducted make sure the bucket is lowered to the ground and is not in use

How to Safely Work around a Dragline

- Call into the area the dragline is in, and get clearance from the operator before entering the area
- Park vehicles, and stay far away from the reach of the boom/bucket
- Watch for falling material
- Only drive over dragline power cords in designated areas where crossings have been established
- Be knowledgeable about all other equipment in the area, as you might not be able to see them, and they can't see you

Questions?

Works Cited

- http://3ddig.online/dragline_parameters.htm
- https://www.lnh.net/blog/new-innovation-draglines-eases-maintenance/
- https://www.mininggglobal.com/digital-mining/draglines-101-how-they-do-it
- https://im-mining.com/2020/06/25/flanders-achieves-australias-first-dragline-dc-ac-conversion-south-walker-creek/
- https://www.westrac.com.au/products/equipment/draglines/draglines/8750-18370146
- https://www.amsj.com.au/dragline-safety-incidents-bench-collapse-not-the-first/

LARAMIDE PORPHYRY COPPER DEPOSITS

ACKNOWLEDGEMENTS

- New Mexico Energy, Minerals and Natural Resource Department
- Company annual reports
- Personal visits to mines
- Historical production statistics from U.S. Bureau of Mines, U.S. Geological Survey, N.M. Energy, Minerals and Natural Resource Department (NM MMD), company annual reports
- Students at NM Tech

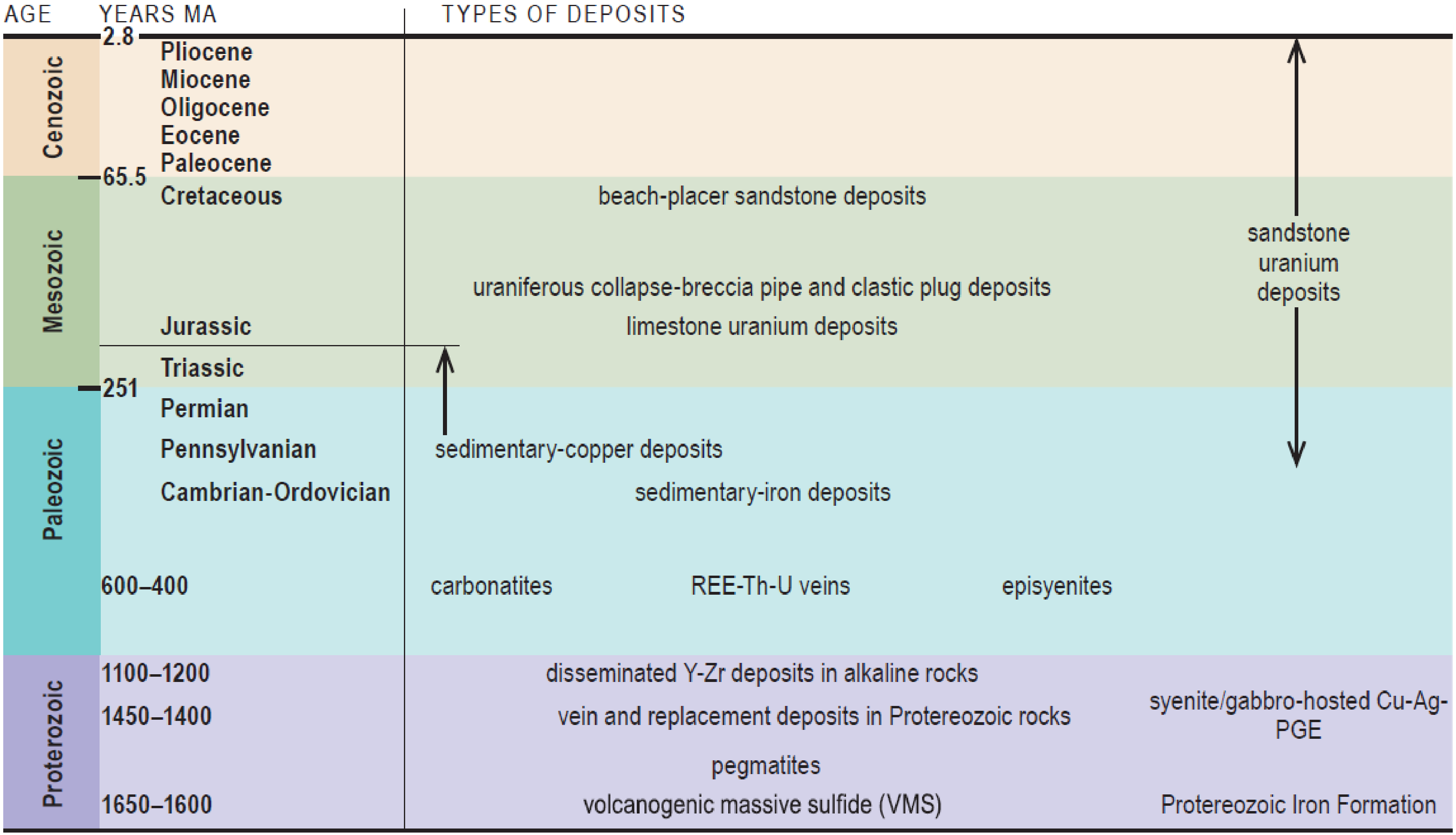


Figure 2. Distribution of Proterozoic-Mesozoic metallic mineral and uranium deposits in New Mexico through time. Arrows delineate the time period sedimentary-copper and sandstone uranium deposits span.

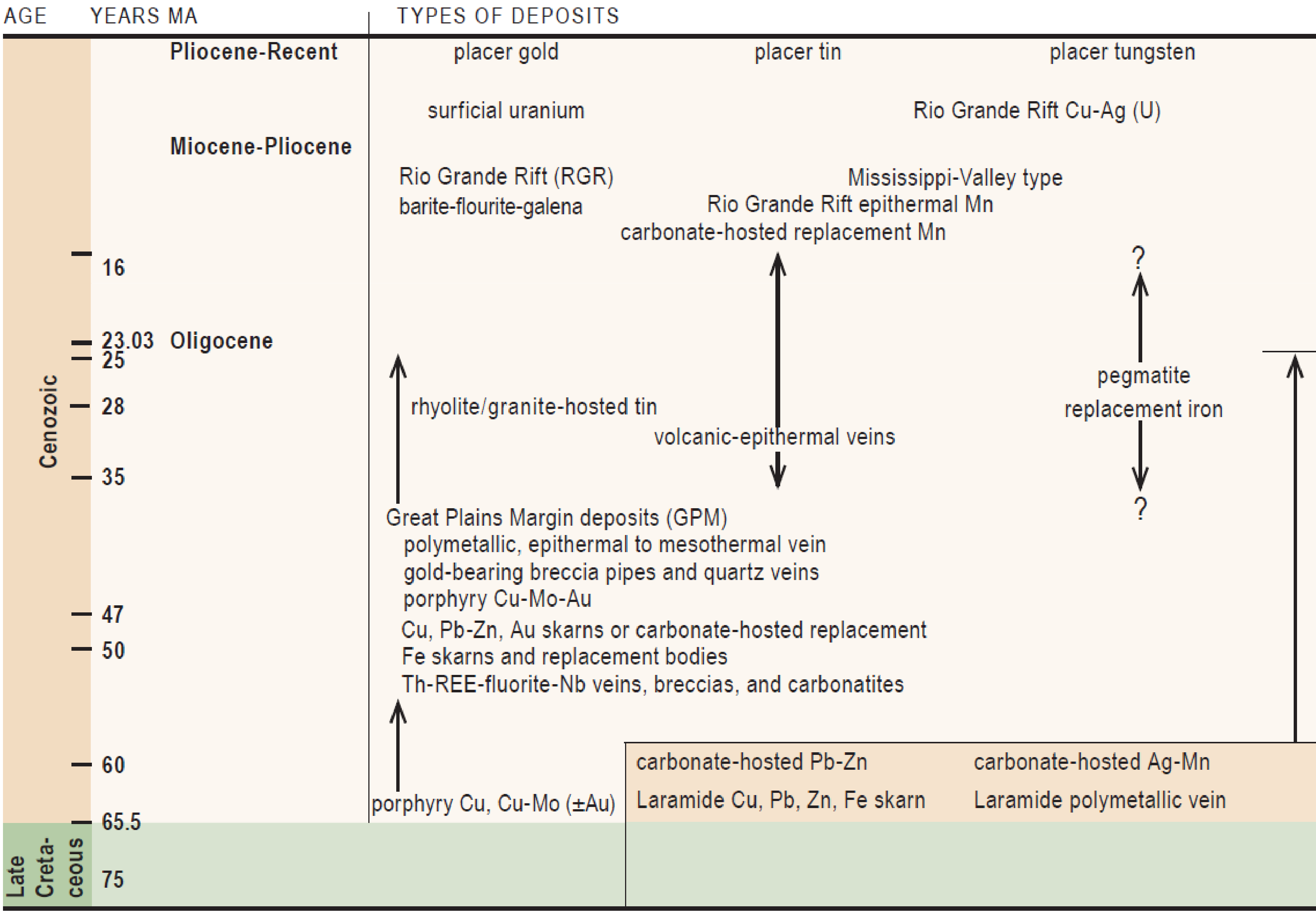


Figure 3. Distribution of Late Cretaceous to Cenozoic metallic mineral and uranium deposits in New Mexico through time.

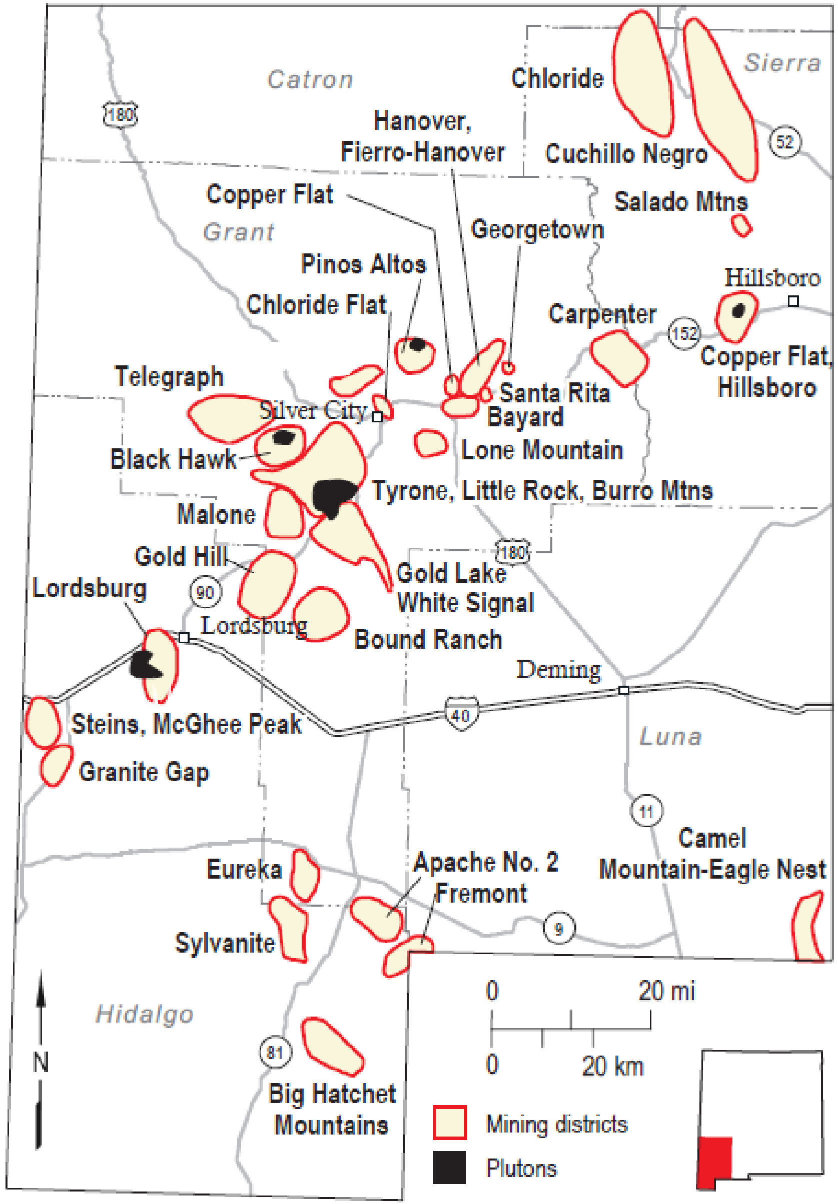
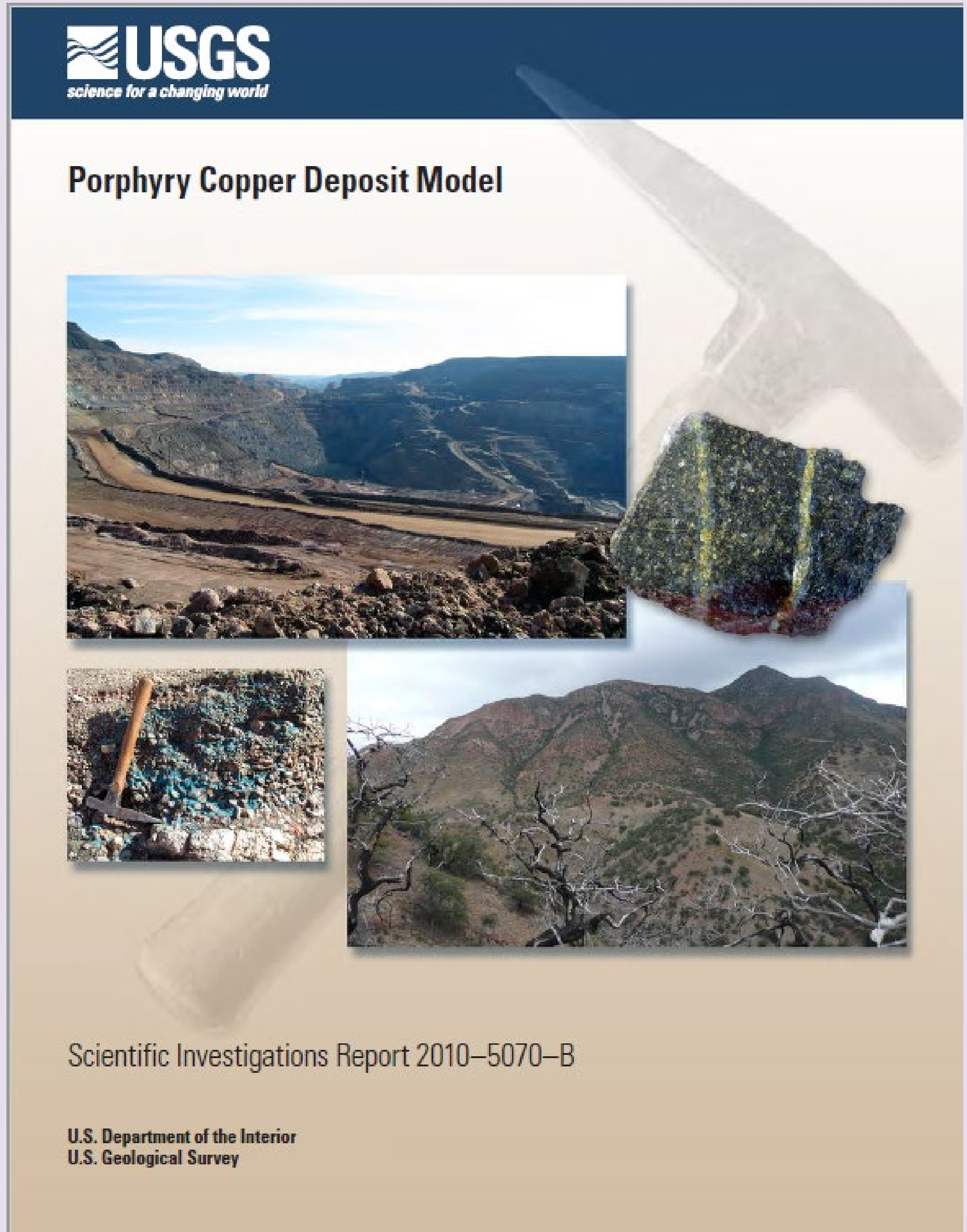


Figure 17. Districts with Laramide copper porphyry, polymetallic veins and skarn deposits (yellow) and plutons (black) in southwestern New Mexico (McLemore, 2008a).



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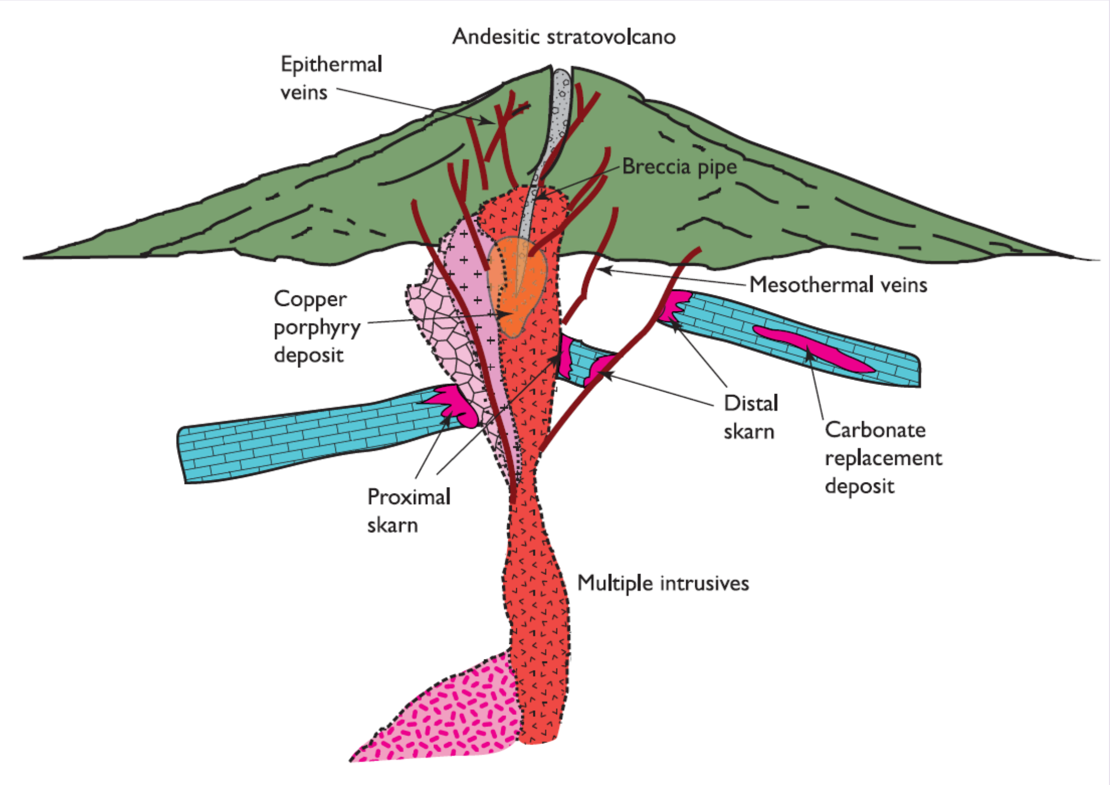
Copper porphyry (Mo, Au) deposits are large, low-grade (<0.8% Cu) deposits that contain disseminated and stockwork veinlets of copper and molybdenum sulfides associated with porphyritic intrusions



Secondary or supergene enrichment where leaching of materials occurs and precipitation at depth produces higher concentrations

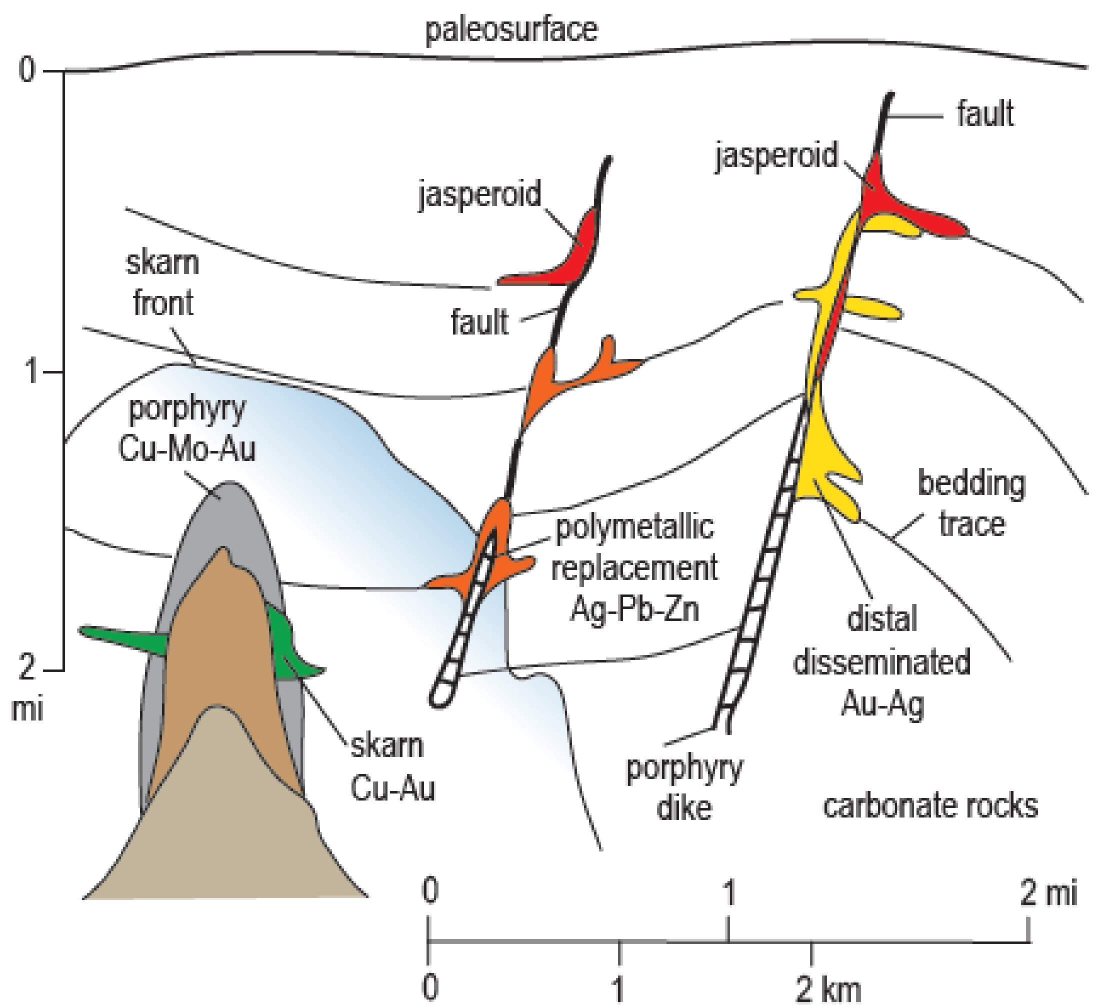


Figure 18. Simplified settings of porphyry copper and associated deposit types (modified from John, 2010). Distal disseminated Au-Ag deposits have not been found associated with porphyry copper deposits in New Mexico and are shown here as potential future exploration targets.

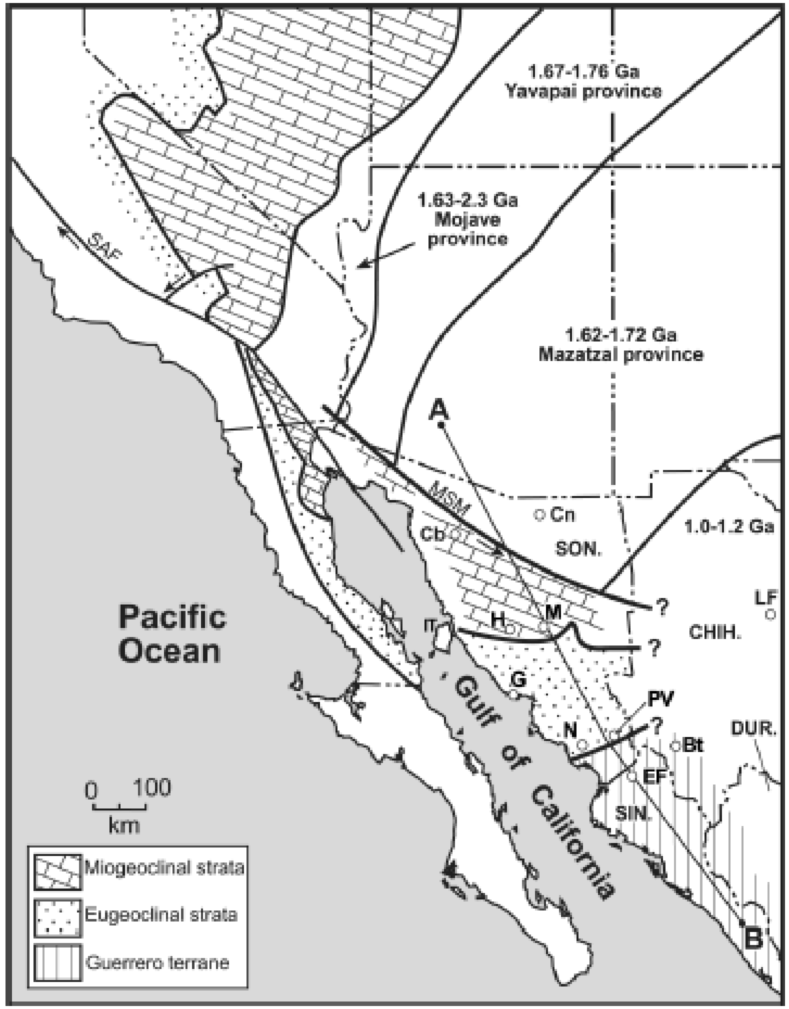
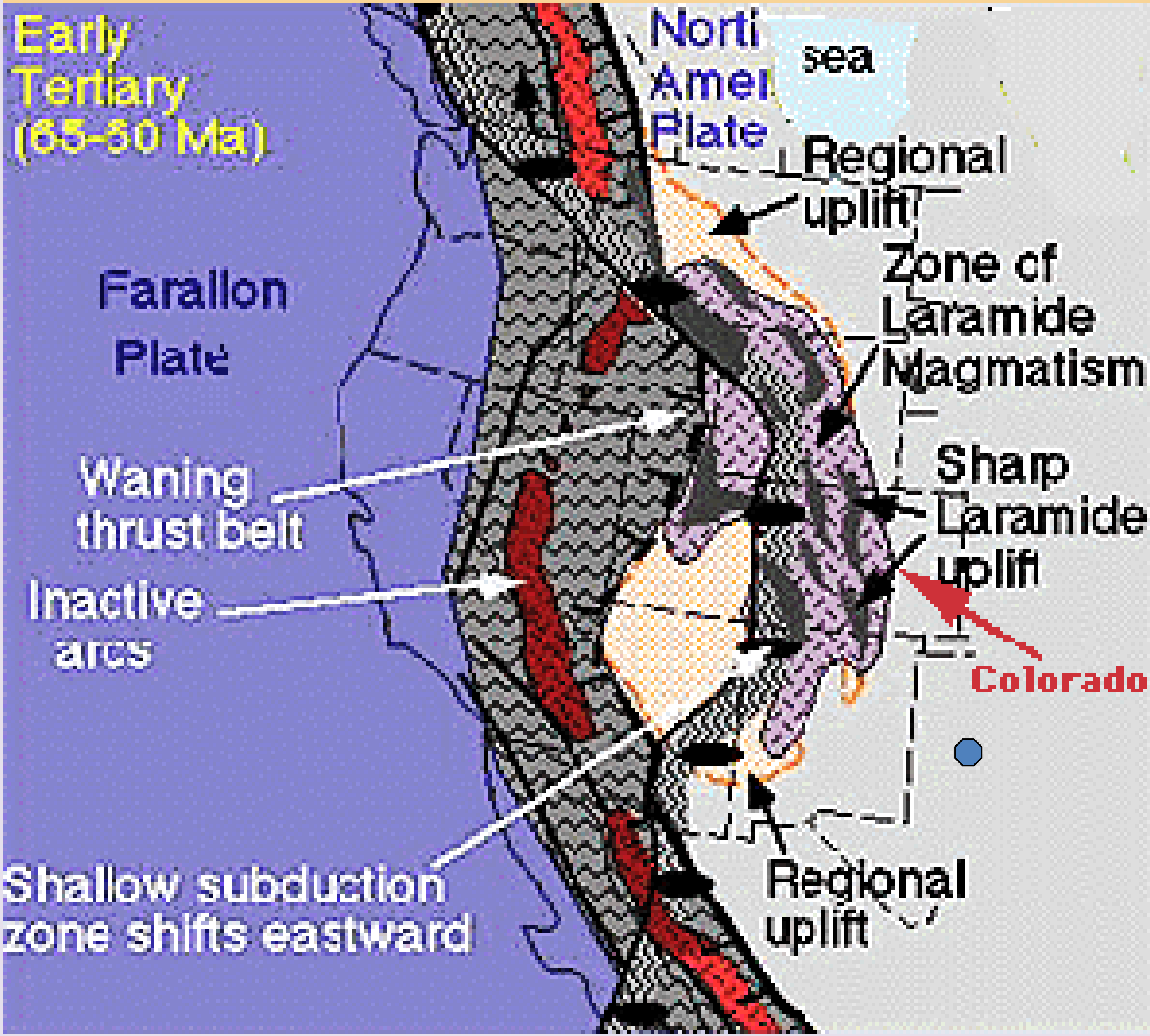


Figure 1. Generalized map of the pre-Laramide basement distribution in northwestern Mexico and the southwestern United States. MSM—Mojave-Sonora megashear, SAF—San Andreas fault, Cb—Caborca, Cn—Cananea, H—Hermosillo, M—Mazatán, G—Guaymas, N—Navojoa, EF—El Fuerte, Bt—Batopilas, PV—Piedras Verdes, IT—Isla Tiburón. The Paleozoic miogeoclinal-eugeoclinal boundary is modified from Stewart et al. (1990), and its extension into the Baja California peninsula is from Gastil et al. (1991). Proterozoic age domains adapted from Gehrels and Stewart (1997). Line A–B is for the cross section shown in Figure 2.

Valencia-Moreno et al., 2001



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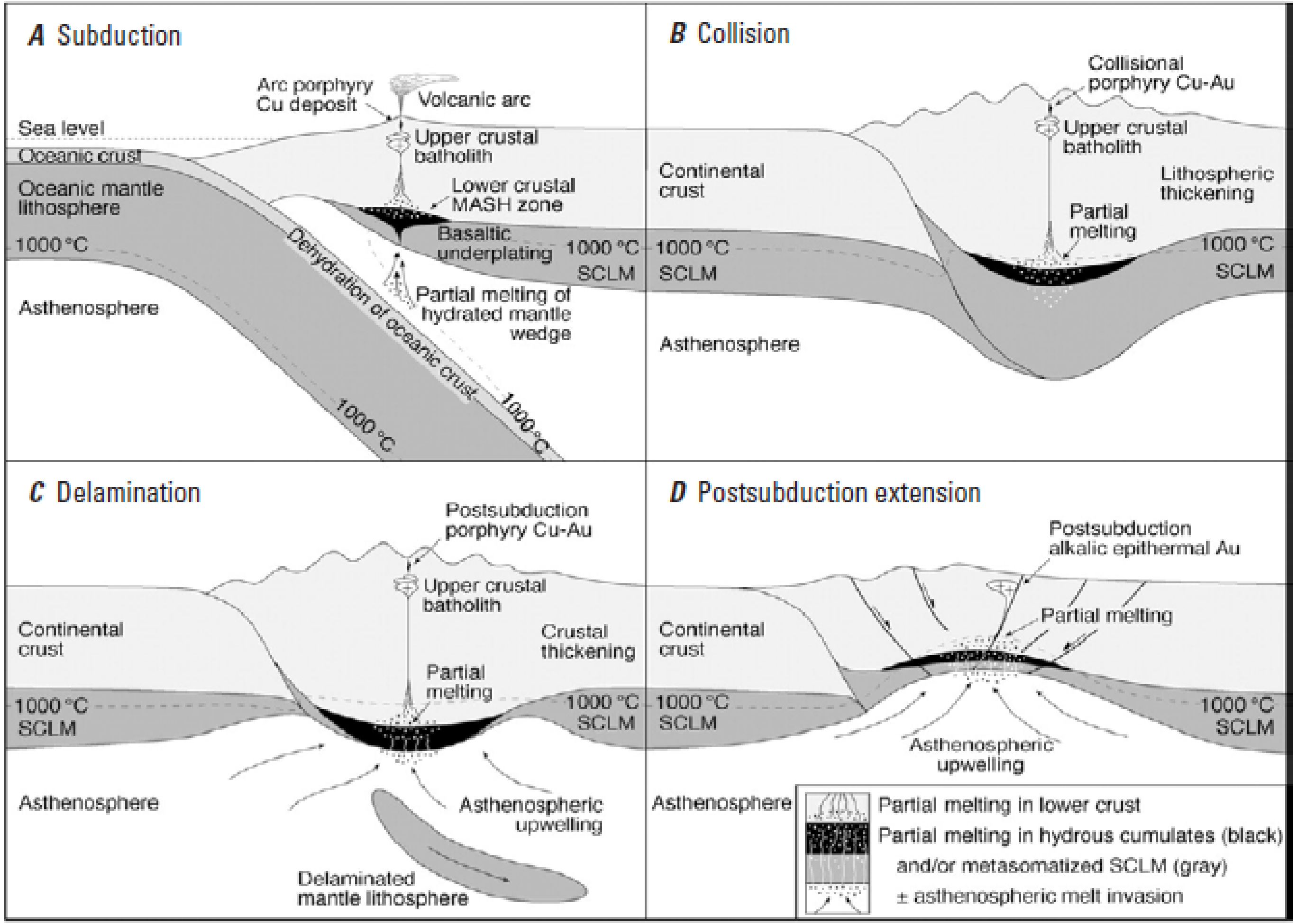

Figure D1. Plate tectonic setting of porphyry copper deposits. (*A*) Typical continental margin arc above subduction zone. Porphyry copper generation as a product of normal arc magmatism; continental arc is shown, but similar processes can occur in mature island arcs. MASH—melting, assimilation, storage, and homogenization. SCLM—subcontinental lithospheric mantle. (*B*–*D*) Remelting of subduction-metasomatized SCLM or lower crustal hydrous cumulate zones (black layer) leading to potential porphyry copper-gold and epithermal gold deposit formation. (*B*) Collisional lithospheric thickening. (*C*) Postcollisional lithospheric mantle delamination. (*D*) Postsubduction lithospheric extension. High strontium/yttrium and lanthanum/ytterbium magmas may be generated in all cases by residual or fractionating hornblende (±garnet, titanite) in the lower crust. Reproduced from Richards (2009, his Fig. 1).

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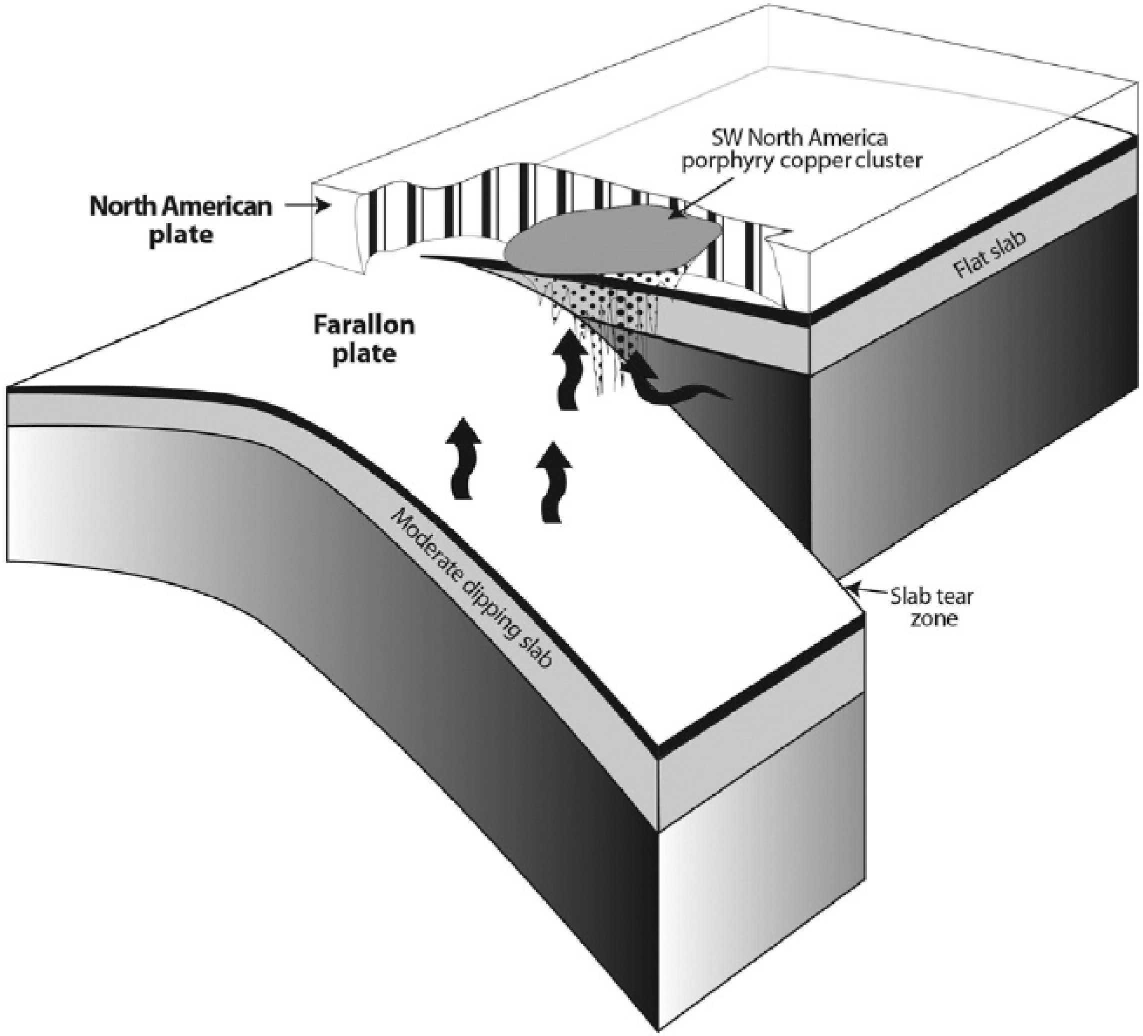

Fig. 6. Schematic tectonic model showing difference in slab dip between the segments below the region where the classic Laramide developed (flat slab) and the region of the great porphyry copper cluster of southwestern North America (moderate dipping slab). Both segments are separated by a tear zone, which feeds more asthenospheric mantle to the mantle wedge trapped above the southern slab segment. This mechanism may help to provide the abnormal metal budget required to form the large deposits of the Arizona-New Mexico-Sonora cluster. Away of the slab tear zone, normal calc-alkaline melting formed smaller deposits.

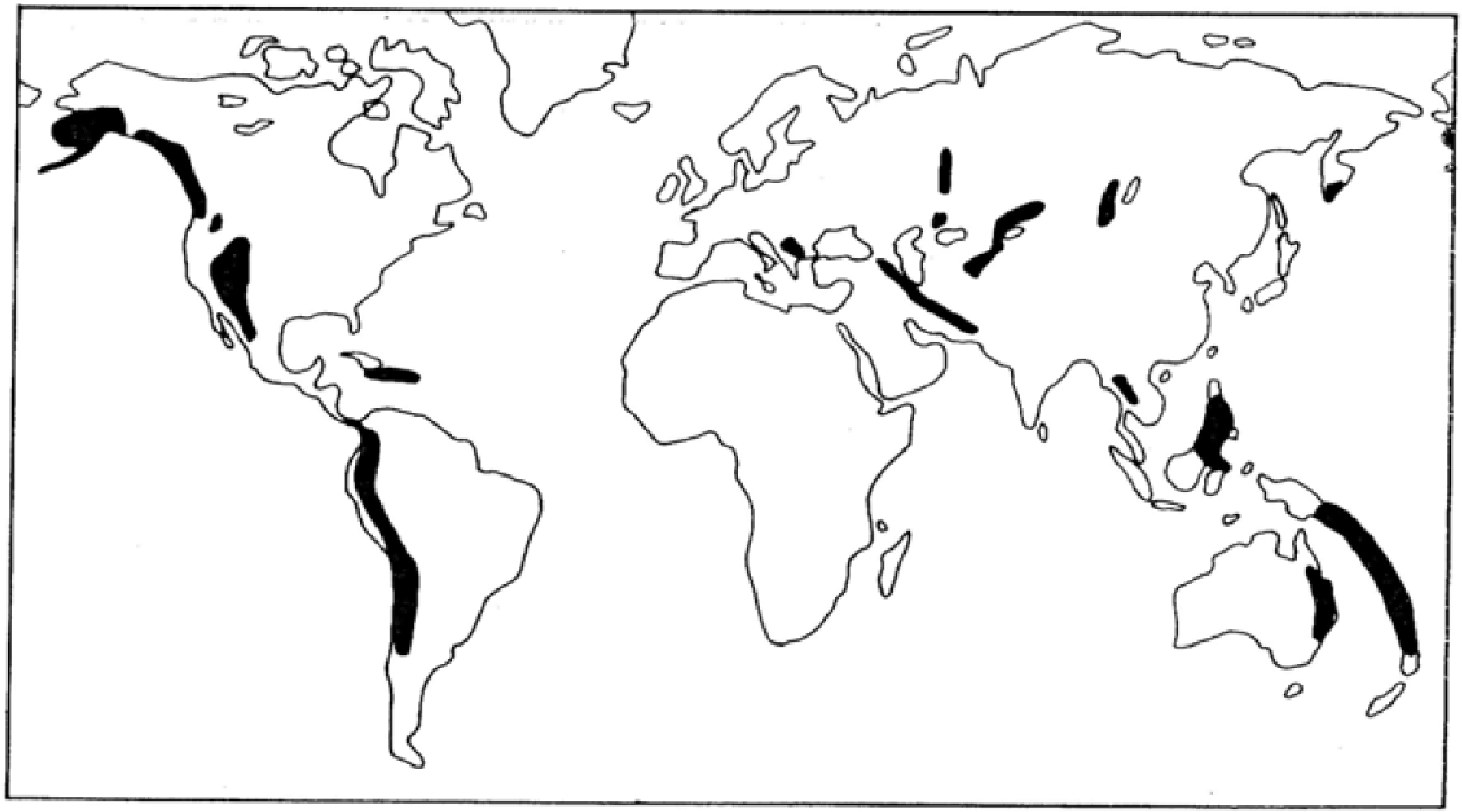

FIG. 1. Distribution of major porphyry copper provinces.

Hydrothermal alteration

- *Hypogene alteration* occurred during the formation of the ore body by upwelling, hydrothermal fluids.
- *Supergene alteration* is the natural weathering, before mining, of the ore body, at low temperatures near the Earth's surface.

The sources for the variety of mineral phases and chemical elements found in porphyry copper deposits

- Primary phases formed in the magma chamber and preserved in the rock (feldspar, quartz, pyroxene, amphibole, magnetite, apatite, etc.)
- Primary ore minerals formed during the main mineralization phase (chalcopyrite, pyrite) in the magma chamber
- Additional minerals formed when the ore deposit was hydrothermally altered (chalcocite, feldspar, pyrite, clay minerals, quartz, epidote, apatite, rutile, Fe- and Mn- oxides, etc.)
  - Addition of new elements by the hydrothermal fluids at different times
  - Redistribution of primary phases

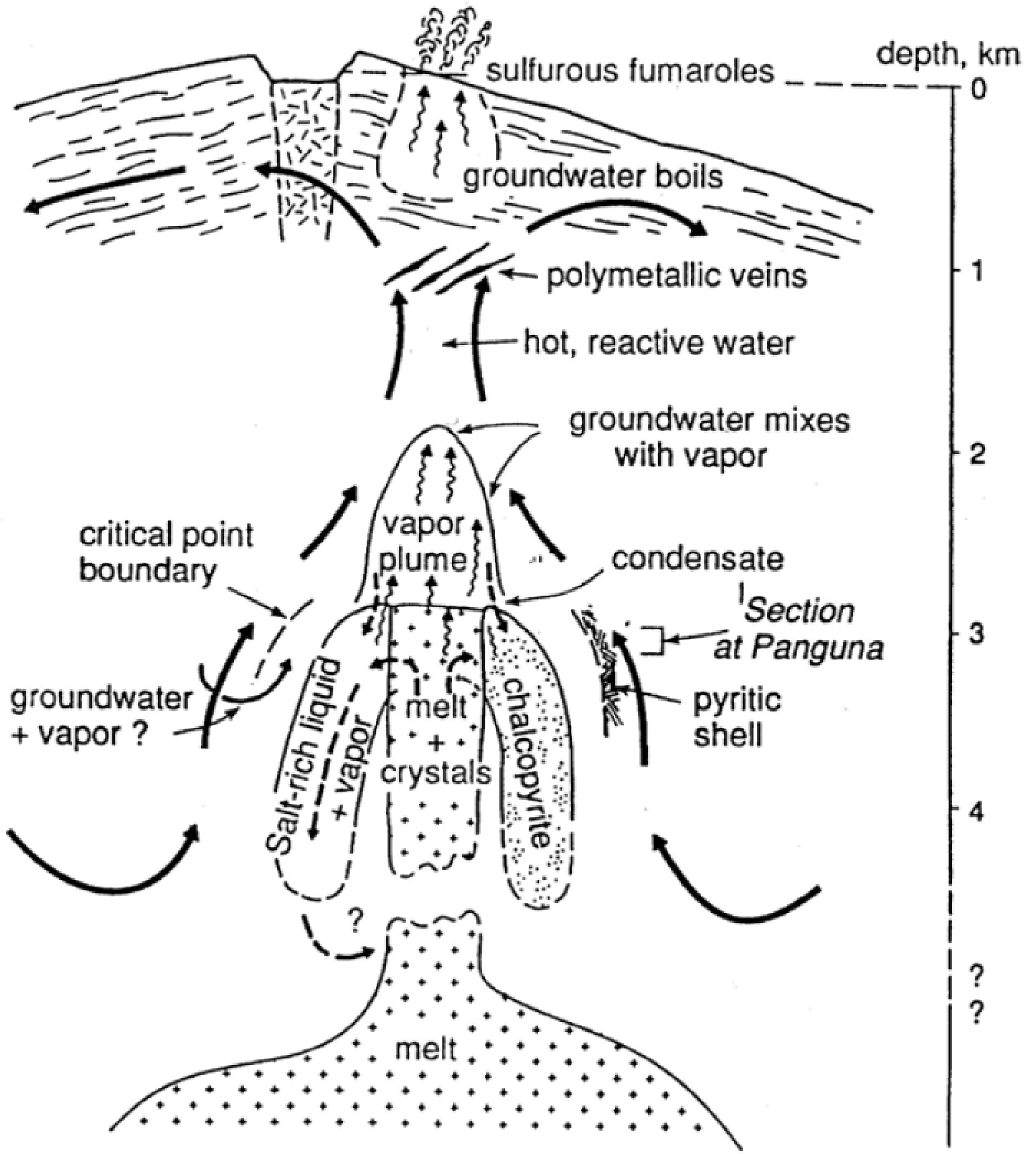

Fig. 1.6. Model of porphyry copper genesis developed by Eastoe based on his studies of the Panguna deposits in Papua New Guinea. On *right* side of the diagram at the level indicated for Panguna the mineralization is shown. On the *left* side of the diagram the fluids responsible for that mineralization (as indicated by fluid inclusion studies) are shown. Note presence of surrounding meteoric waters that will collapse inwards as soon as the flux of magmatic waters ceases (After Eastoe 1982)

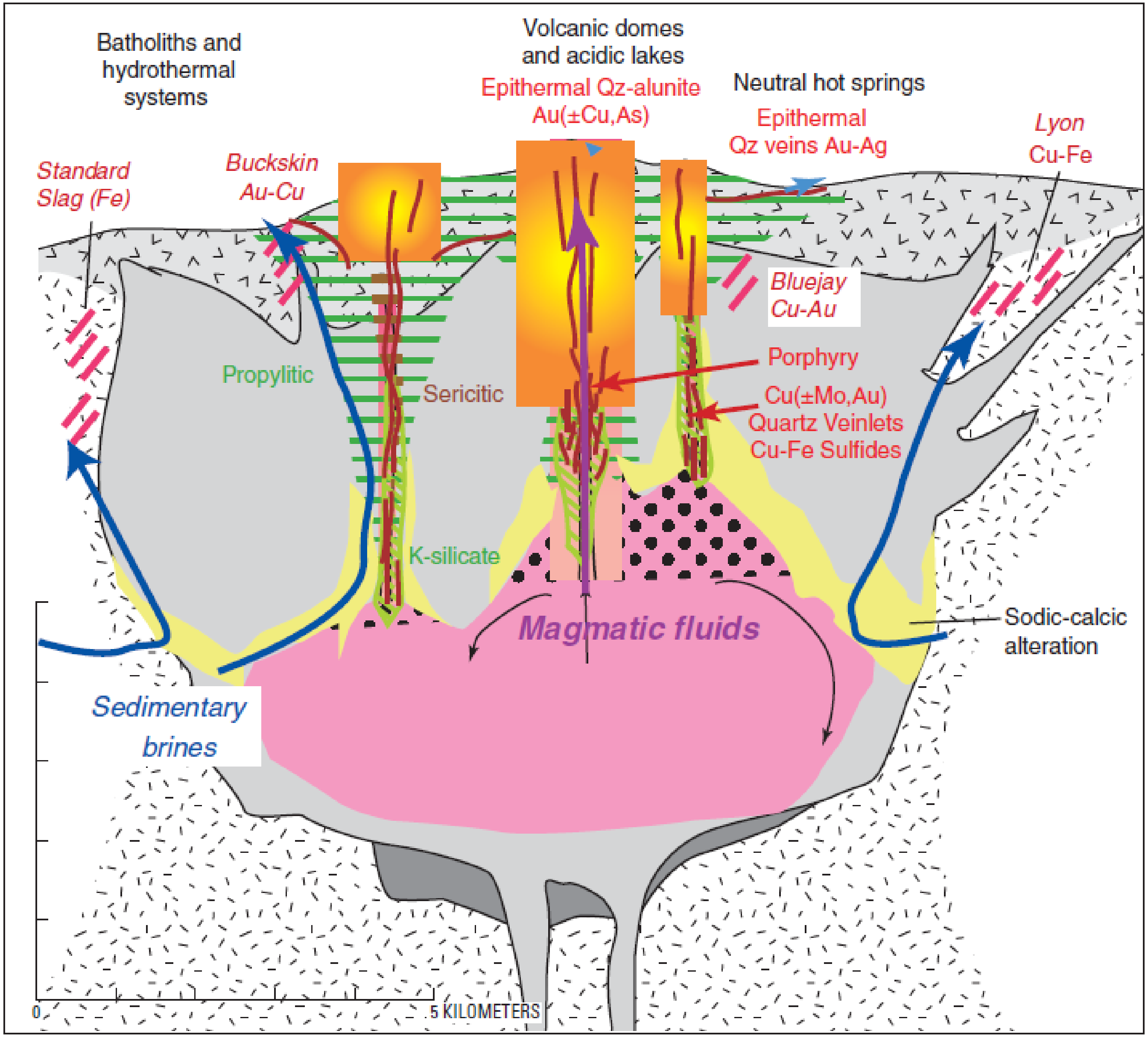

Figure E4. Relationship of hydrothermal systems and porphyry copper and related deposits to crystallizing granitic batholith based on exposed deposits and altered rocks in and near the Yerington district in western Nevada. Based on Dilles and Einaudi (1992), Dilles and Proffett (1995), and Dilles, Proffett, and others (2000).

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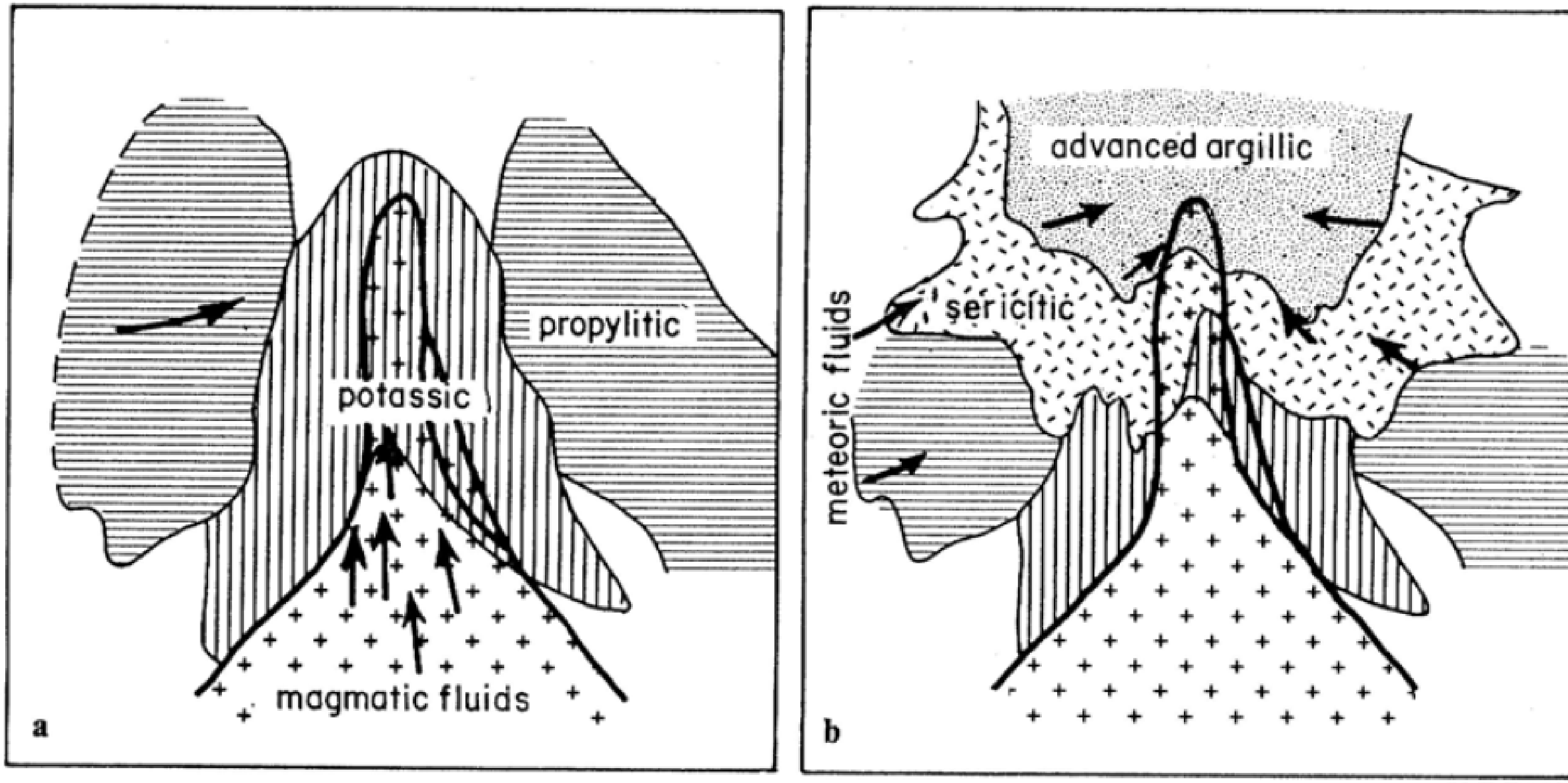

Fig. 1.5. Simplified cross-sectional illustration of the early and later stages of alteration and fluid movement deduced by Gustafson and Hunt (1975) from their study of the El Salvador porphyry copper deposit, Chile

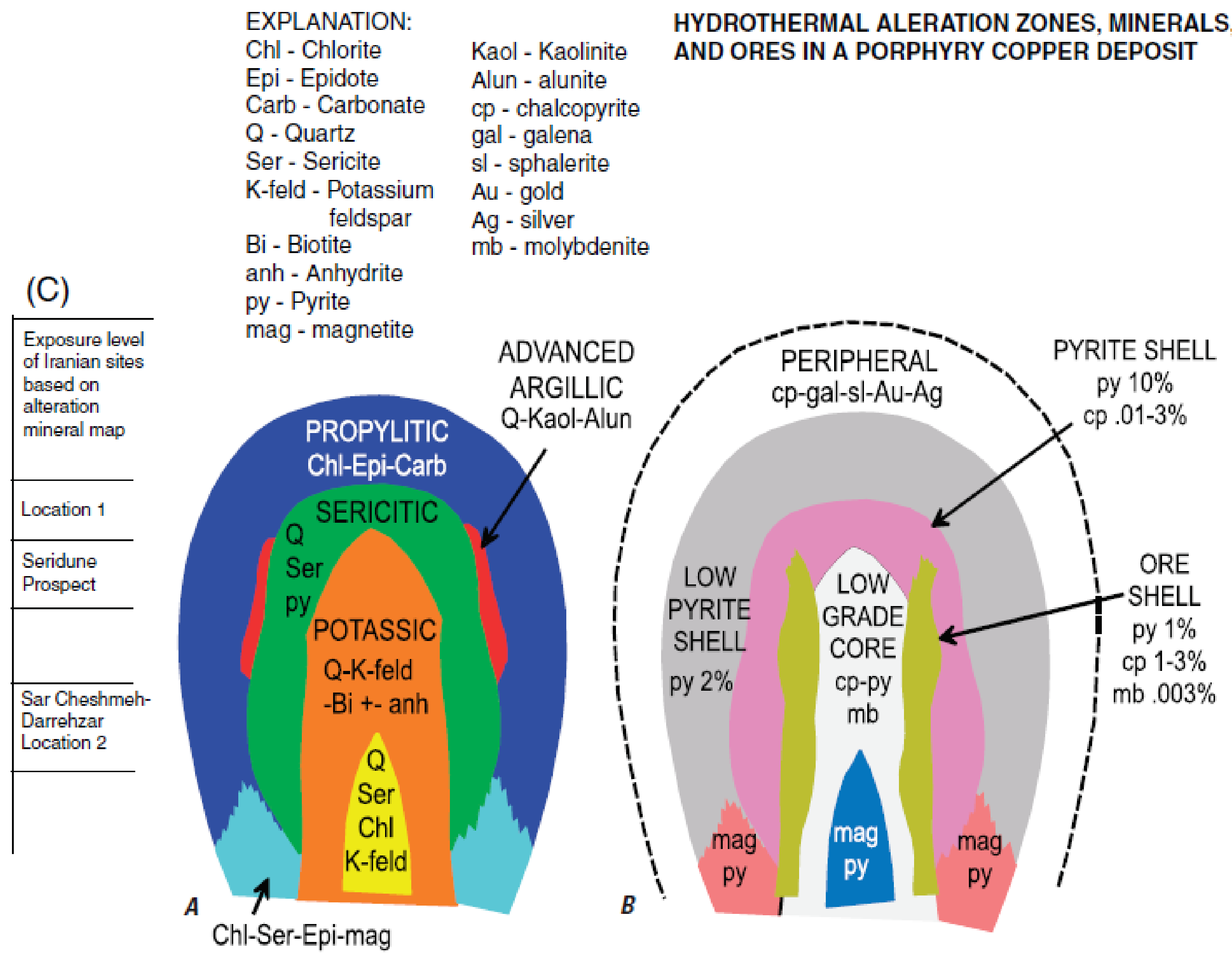

Figure F5. Illustrated deposit model of a porphyry copper deposit (modified from Lowell and Guilbert, 1970). (*A*) Schematic cross section of hydrothermal alteration minerals and types, which include propylitic, sericitic, advanced argillic, and potassic alteration. (*B*) Schematic cross section of ores associated with each alteration type. (*C*) Scale showing level of interpreted exposure for Iranian alteration sites based on ASTER mapped alteration units.

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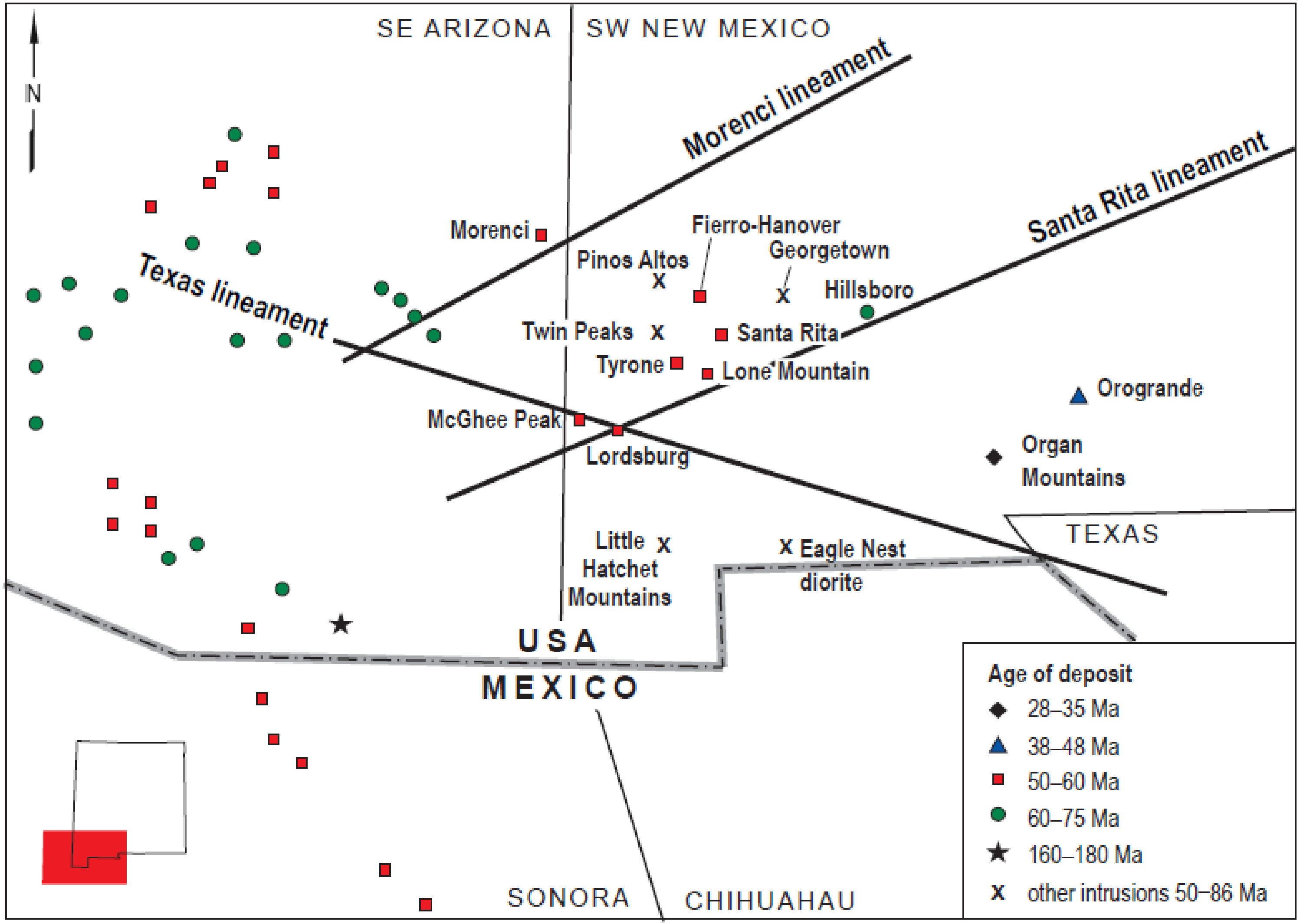

AZ-NM-TX-Mexico porphyry copper deposits are on the eastern edge of one of the world's great metal-bearing provinces

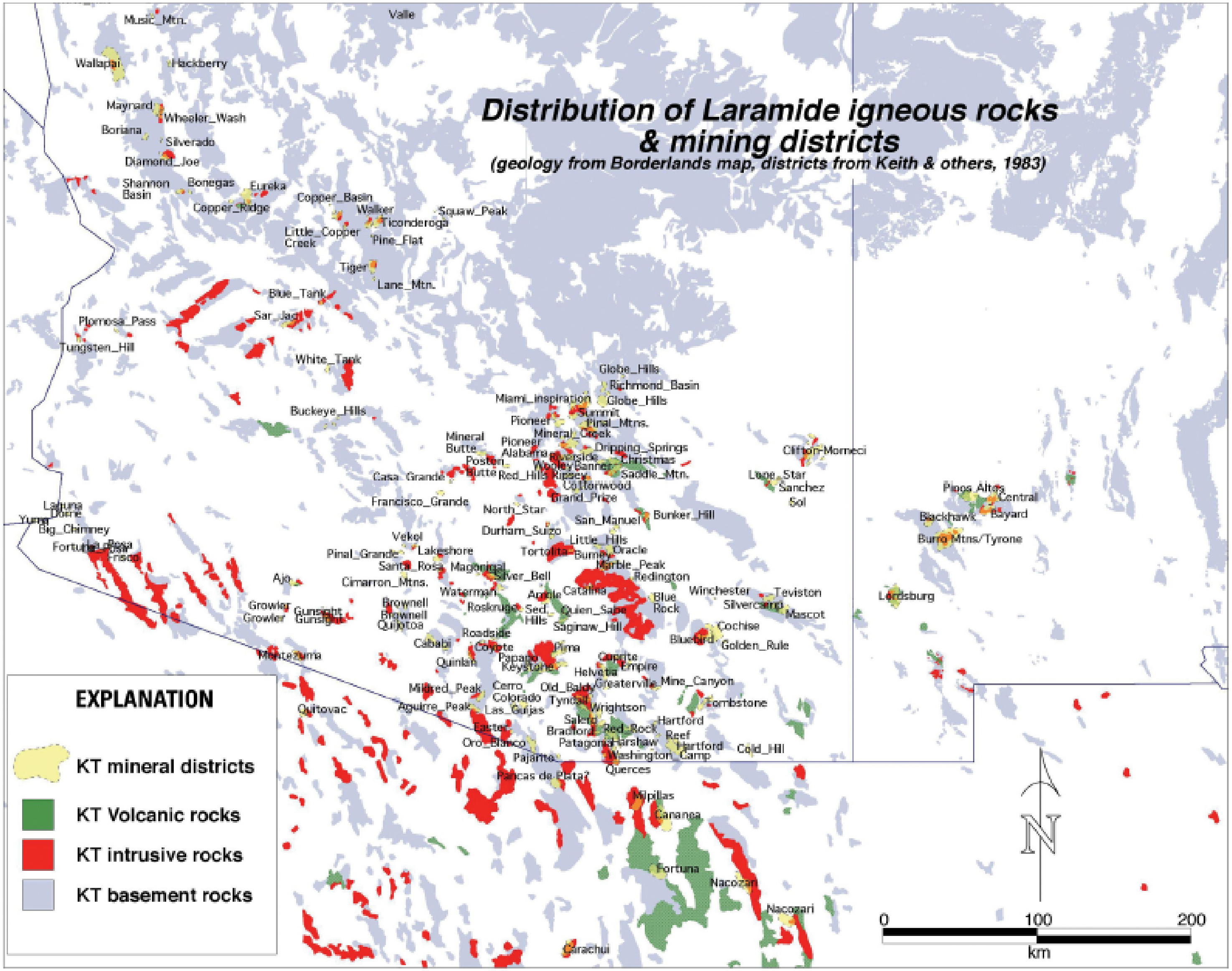

Figure 1–2. Arizona-New Mexico-Sonora, Mexico, region, showing distribution of Laramide (Cretaceous and Triassic [KT]) igneous rocks and related hydrothermal systems and older rocks in porphyry copper province. Note amount of cover and areal extent of hydrothermal systems. Generated from multiple digital sources, including the Mineral Resources Data System, mineral-district map of Arizona, and University of Arizona draft version of the Borderlands geologic map.

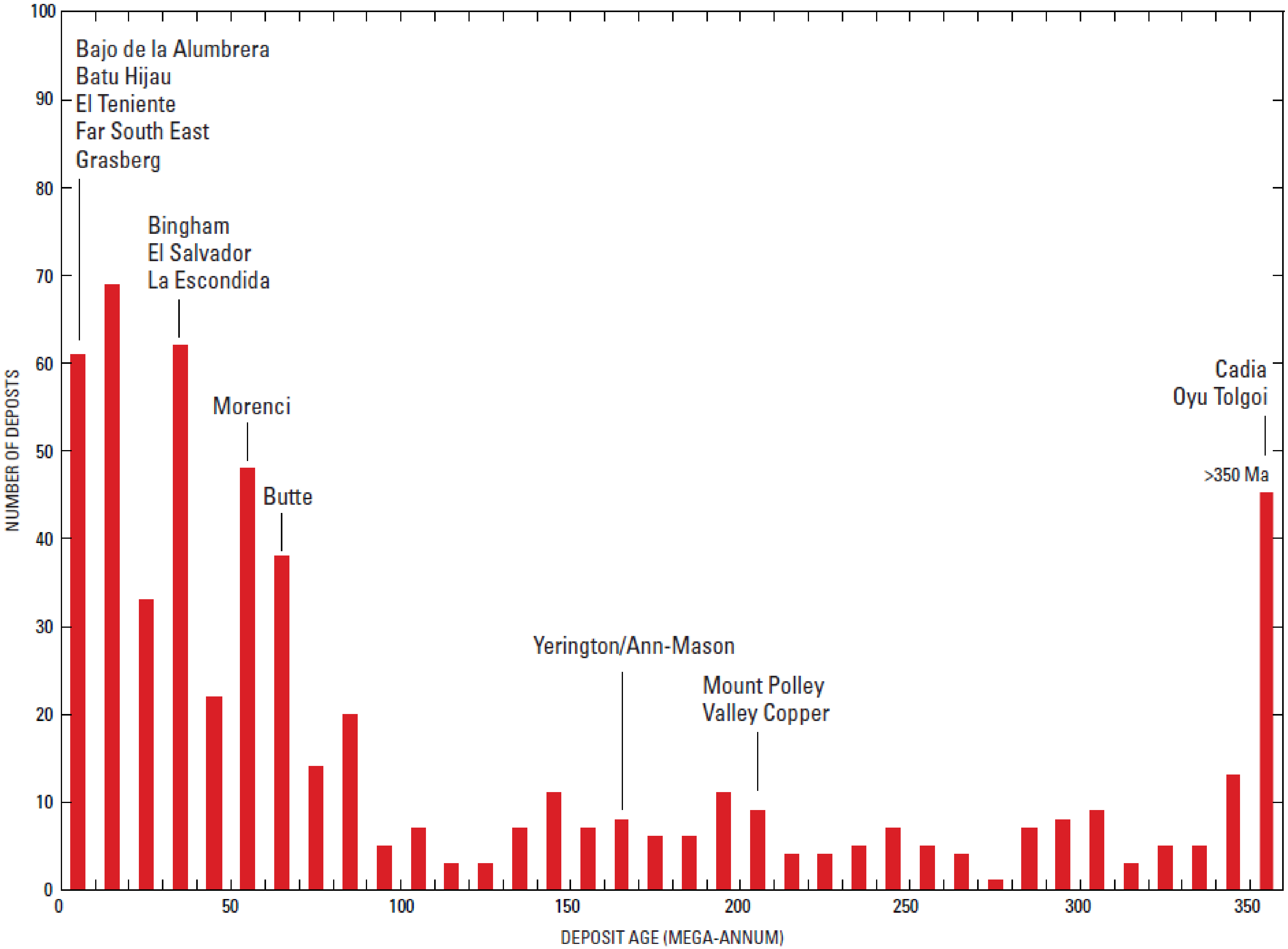

Figure D5. Ages of known porphyry copper deposits. Labeled deposits summarized in Appendix 2. Age data from Singer and others (2008).

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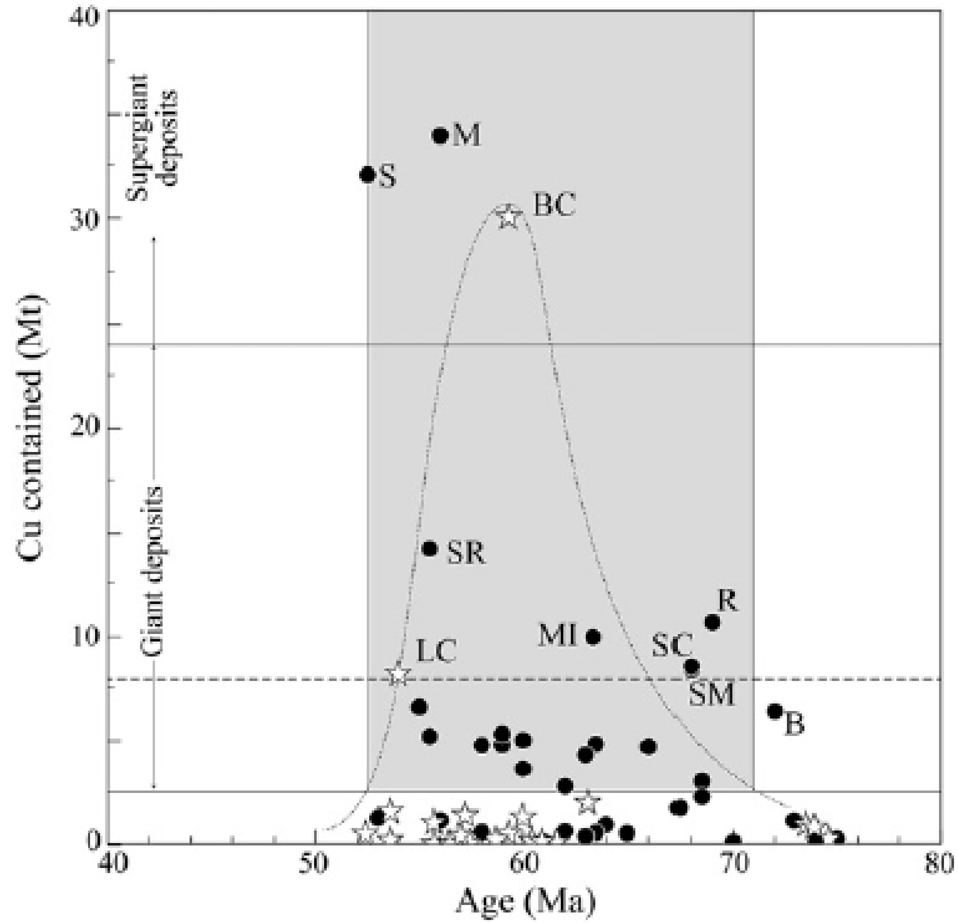


Fig. 4. Diagram of copper contained versus emplacement age form Laramide (80–40 Ma) porphyry copper deposits of Arizona, New Mexico and Mexico. Data from data in Table 1 and Singer et al. (2008). The dotted line encompasses the timing for the Mexican deposits. The shaded region holds the giant and supergiant copper deposits according to the classification of Laznicka (2006). Deposits above the dashed line separated a group of deposits with sizes larger than 8 Mt Cu, which concentrates most of the copper deposited in the porphyry copper belt. B: Bagdad; BC: Buenavista del Cobre; LC: La Caridad; M: Morenci; MI: Miami-Inspiration; R: Ray; S: Safford; SC: Santa Cruz; SM: San Manuel; SR: Santa Rita.

Valencia-Moreno et al., 2017

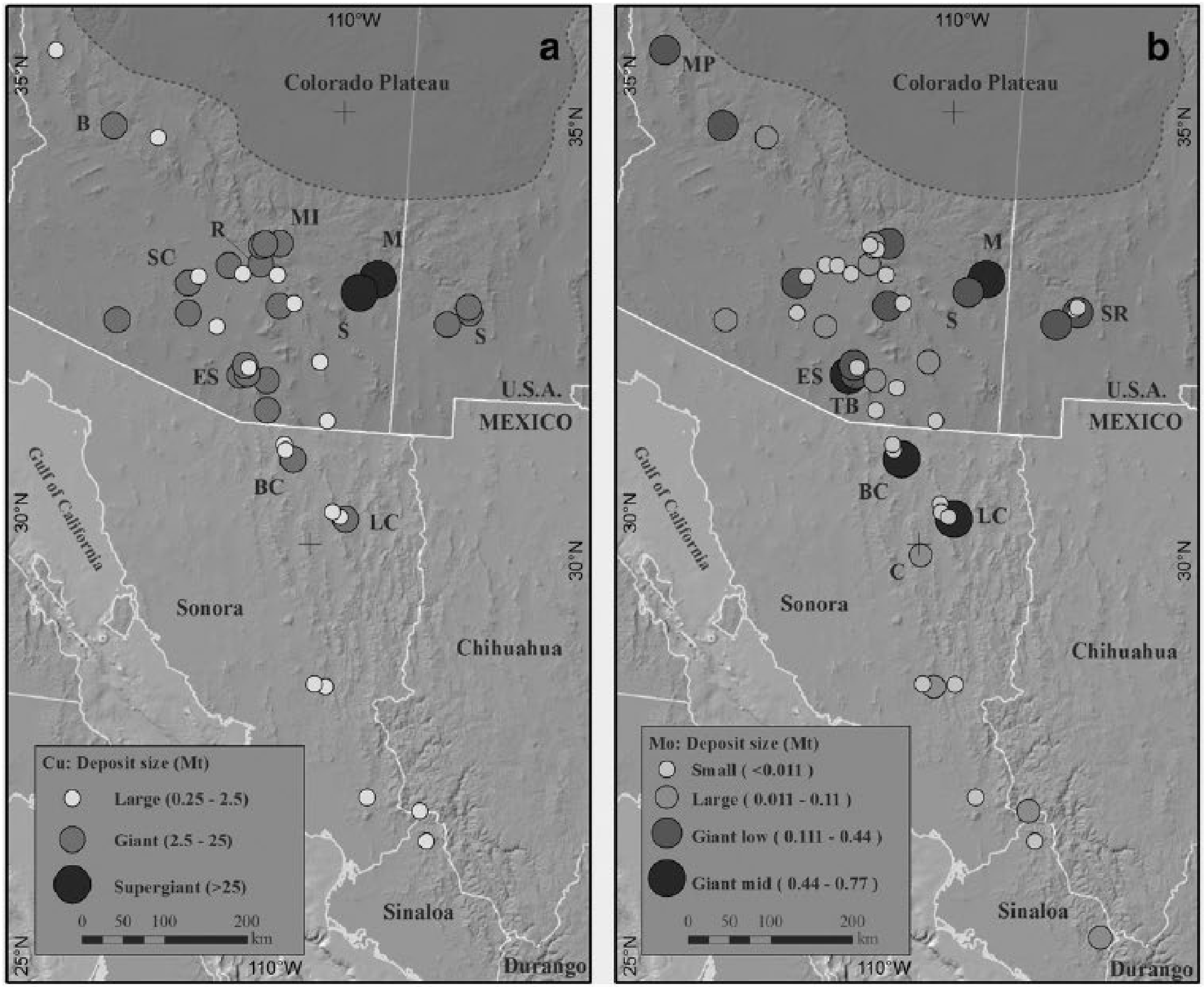
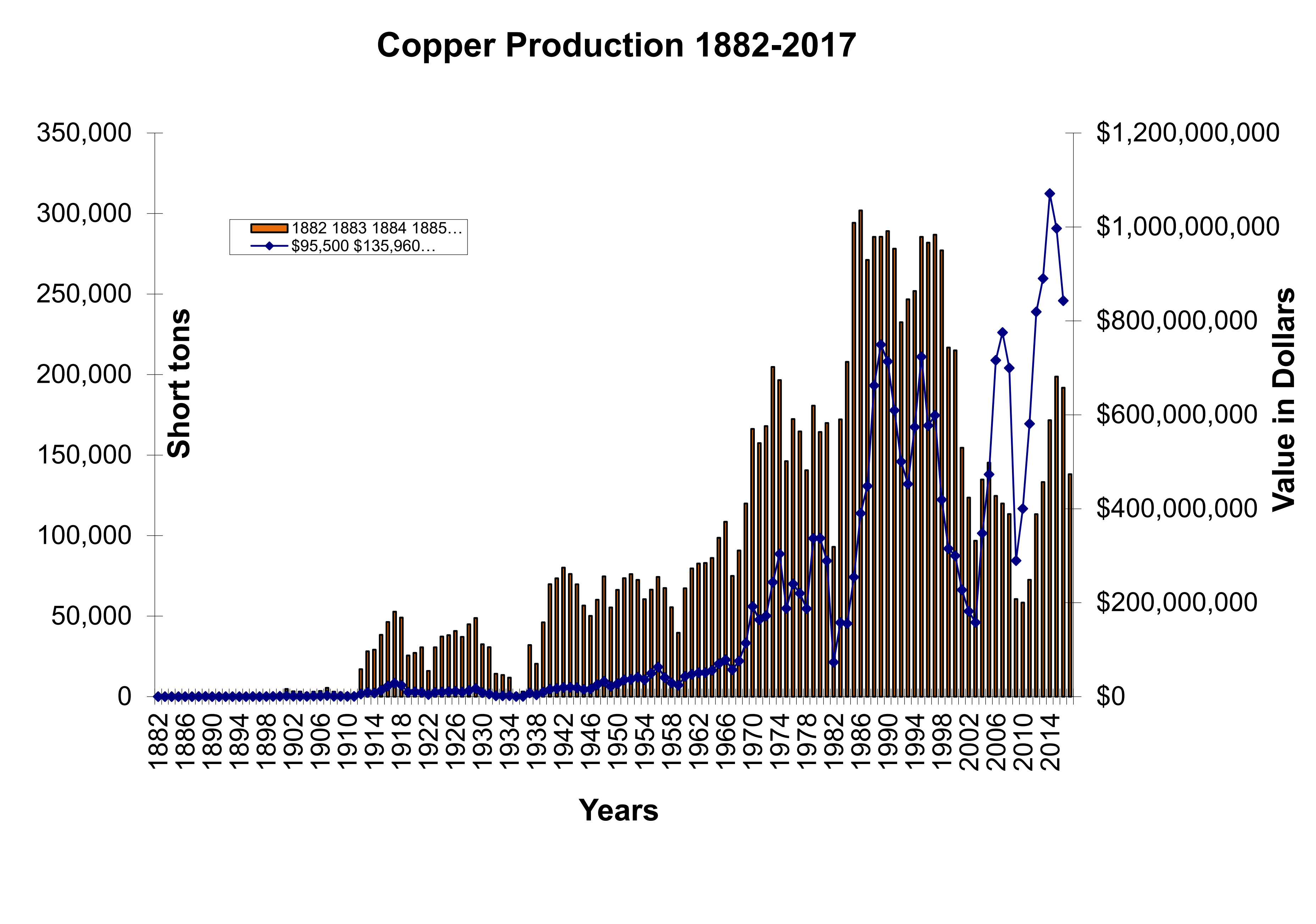


Fig. 3. Distribution of porphyry copper deposits in southwestern North America showing various categories according to their sizes, for copper (a) and molybdenum (b). In both figures, the region of the great cluster of Arizona, New Mexico and Sonora is clearly delineated by the size of the deposits. B: Bagdad; BC: Buenavista del Cobre; C: Crestón; ES: Esperanza-Sierrita; LC: La Caridad; M: Morenci; MI: Miami-Inspiration; R: Ray; S: Safford; SC: Santa Cruz; SM: San Manuel; SR: Santa Rita; TB: Twin Buttes. Categories adapted from Laznicka (2006).

Valencia-Moreno et al., 2017



12 million tons Cu worth over $23 billion 1882-2017 in NM

Table 3. Laramide porphyry copper deposits in southwestern New Mexico (McLemore, 2008a). References for age determinations are in McLemore (2008a).

Mine identifica-tion	Porphyry deposits	District	County	Latitude (decimal degrees)	Longitude (decimal degrees)	Year of dis-covery	Commodities	Estimated copper production (pounds)	Reported estimated reserves	Estimated metal endowment (production + reserves + resources)	References
NMGR0029	Chino**	Santa Rita	Grant	32.791667	108.06667	1909	Cu, Au, Ag, Mo	9,080,000,000	Estimated mill reserves (2016) of 135 million tons of 0.59% Cu, 0.04 g/t Au, 0.50 g/t Ag and 0.01% Mo and estimated leaching reserves of 91 million tons of 0.28% Cu*	11,398,000 tons Cu 197,900 tons Mo 1,047,600 oz Au 5,236,700 oz Ag	Leveille and Stegen (2012), Freeport-McMoRan Copper and Gold Inc. (2014)
NMGR0084	Tyrone	Burro Mountains	Grant	32.643889	108.36722	1903	Cu, Au, Ag, U, F	5,240,000,000	6 million tons leaching reserves of 0.50% Cu (2016)*	7,419,000 tons Cu 148,000 tons Mo 500,000 oz Au 5,360,000 million oz Ag	McDowell (1971), Hedlund (1985a), McLemore et al. (1996), Leveille and Stegen (2012), Freeport-McMoRan Copper and Gold Inc. (2014)
NMGR0033	Cobre	Fierro-Hanover	Grant	32.845	108.091667	1900s	Cu	Unknown	73 million tons leaching reserves of 0.30% Cu (2017)*	1,201,500 tons Cu	Leveille and Stegen (2012), Freeport-McMoRan Copper and Gold Inc. (2014)
NMGR0160	Little Rock	Burro Mountains	Grant	32.646698	108.40675	1970s	Cu, Au, Ag	Unknown	Unknown (included with Tyrone)		P.B. Hubbard (written report, 1983)
NMSI0610	Copper Flat**	Hillsboro	Sierra	32.806667	108.12222	1970s	Au, Ag, Pb, Zn, Cu, V	7 million	113 million short tons at 0.39% Cu, 0.009% Mo, 0.096 g/t Au, and 1.93 g/t Ag*	595,000 tons Cu 16,800 tons Mo 404,700 oz Au 10,647,700 oz Ag	Hedlund (1985b), McLemore et al. (1999b, 2000b); Geedipally et al. (2012), Leveille and Stegen (2012)
NMGR0478	Gold Lake	White Signal	Grant	32.55270	108.32957	1970s	Cu, Au, Ag, Bi, U, Mo	None	unknown/ exploration underway		McLemore (2008a)
NMGR0208	Hanover Mountain	Fierro-Hanover	Grant	32.833	108.083	1970s	Au, Ag, Cu, Zn, Pb, Fe, F, Mn, Bi	None	80 million tons 0.38% Cu (historic reserves)*		McLemore et al. (1996)
NMGR0409	Lone Mountain**	Lone Mountain	Grant	32.718056	108.17667	1970s	Cu, Au, Ag	None	unknown/ project on hold		P.B. Hubbard (written report, 1983)
NMHI0327	Steins	McGhee Peak	Hidalgo	32.186111	109.020833	1970s	Au, Ag, Pb,Cu, Zn	None	unknown/ project on hold		McLemore et al. (1996)

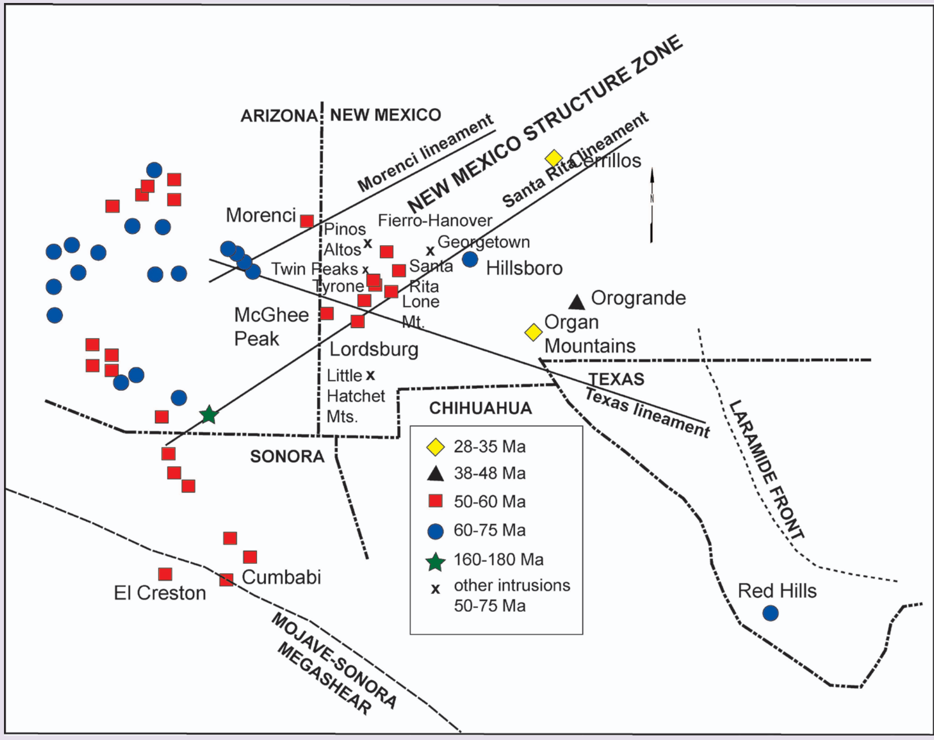
* Skarn or carbonate-hosted replacement deposits also present. Mine identification number is from the New Mexico Mines Database (McLemore et al., 2005a, b). Reserves for Copper Flat are 43-101 reserves (reserves, location and history; http://themacre-sourcesgroup.com/copper_flat_mine, accessed 1/29/16). ** Reported reserves are recoverable copper reserves as reported by the company (most are historic resources and not all are 43-101 compliant, see introduction).

Different authors divide the Laramide into different age groups

- McMillan (2004)—used all dates including K-Ar dates
  - 80-64 Ma
  - 64-48 Ma
  - 48-37 Ma
- Amato et al. (2017)—used U-Pb, precise Ar-Ar dates
  - 76-70 Ma
  - 61-57 Ma
  - 46-40 Ma
- This presentation
  - 75-60 Ma
  - 60-50 Ma
  - <45 Ma

Oldest porphyry copper deposits

- 75-60 Ma
- Exhibit alkaline to calc-alkaline geochemistry
- Include
  - Copper Flat (Hillsboro, 74 Ma),
  - Eureka (Oro in Little Hatchet Mns, 71.4 Ma)
  - Red Hills (Texas, 64.2–60.2 Ma)



Copper Flat, Themax Resources

Planned production per year for ~15 yrs

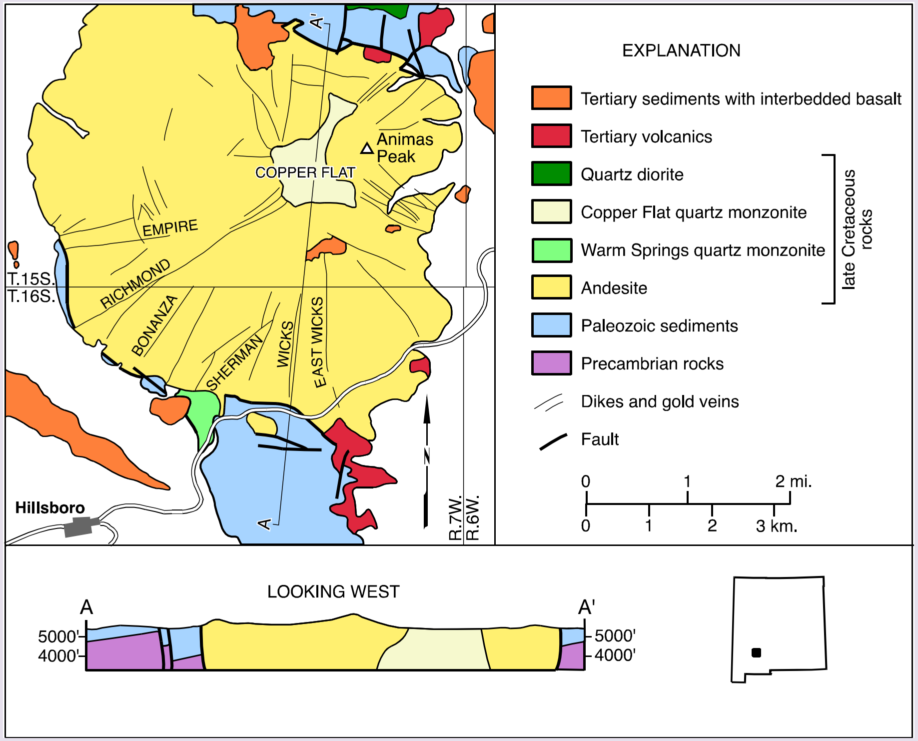
50.76 mill lbs Cu

1.01 mill lbs Mo

12,750 oz Au

455,390 oz Ag

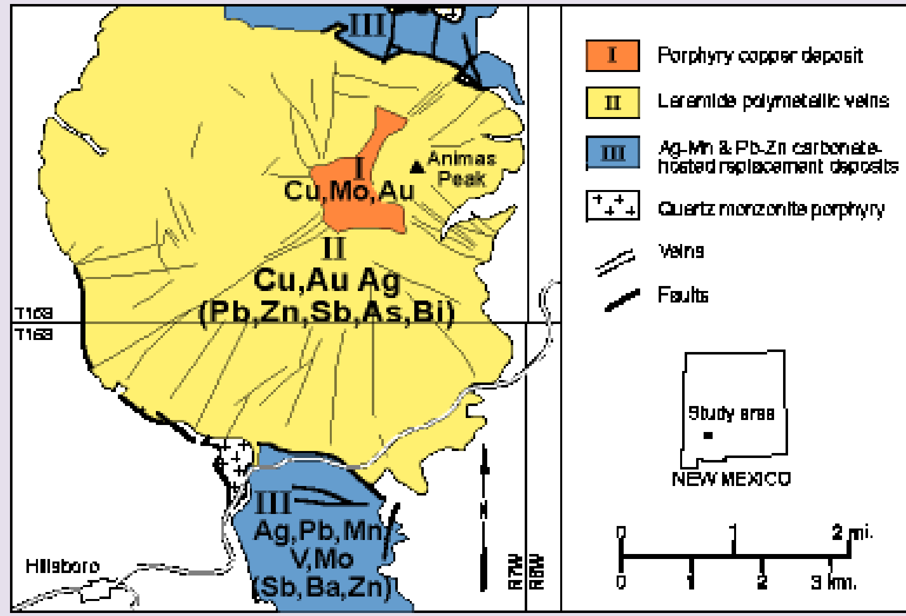
Start in 2020s?



Copper Flat, Themax Resources

DISTRICT ZONING

- The low sulfur (<7%) CFQM porphyry copper deposit forms the center of the district and is characterized by Cu, Mo, and minor Au (McLemore et al., 1999, 2000).
- Trending radially from the CFQM are Laramide polymetallic veins.
- Carbonate-hosted replacement deposits (Ag, Pb, Mn, V, Mo, Zn) are located in the distal southern and northern parts of the district.
- Placer gold deposits were formed by erosion of the porphyry copper and Laramide polymetallic veins and occur in the drainages and alluvial fans emanating from the CFQM and Laramide vein deposits.



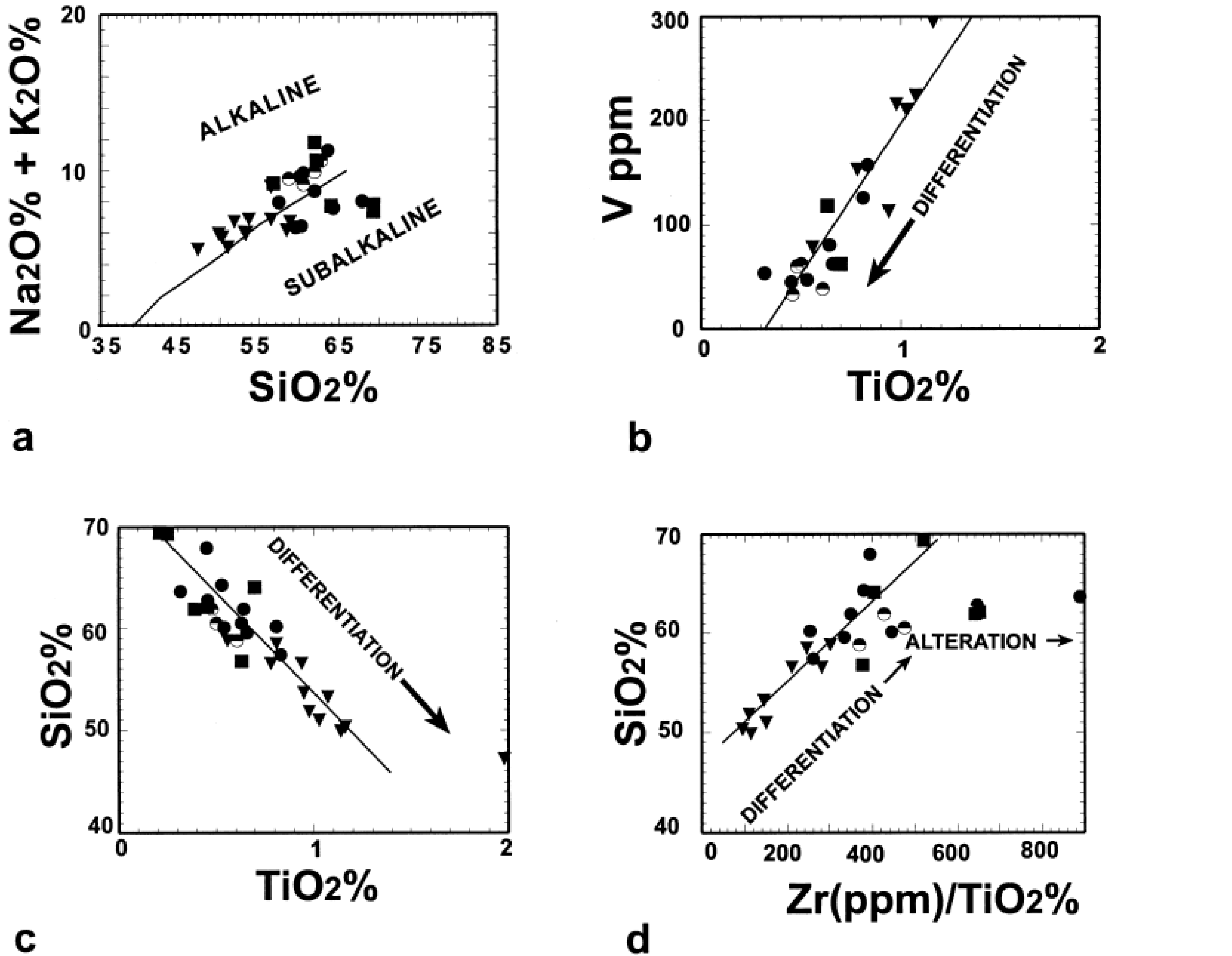


Fig. 5. (a–d) $Na_2O + K_2O/SiO_2$, V/TiO_2, SiO_2/TiO_2, and $SiO_2/Zr/TiO_2$ differentiation diagrams for the Hillsboro igneous rocks. Symbols are explained in Fig. 4.

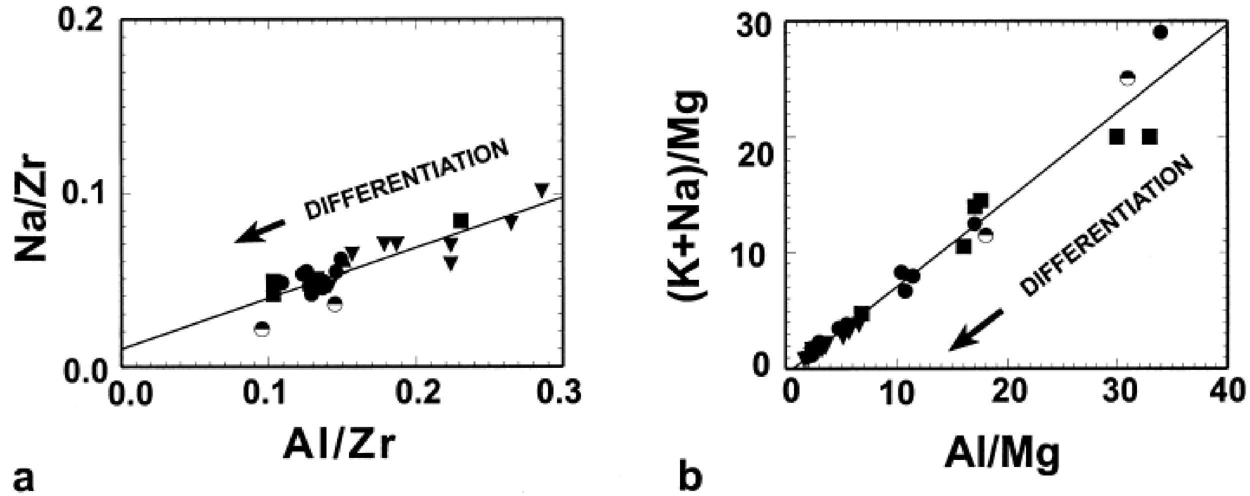


Fig. 6. (a,b) Pearce element plots of Na/Zr vs. Al/Zr and (K + Na)/Mg vs. Al/Mg, in molar concentrations. Symbols are explained in Fig. 4.

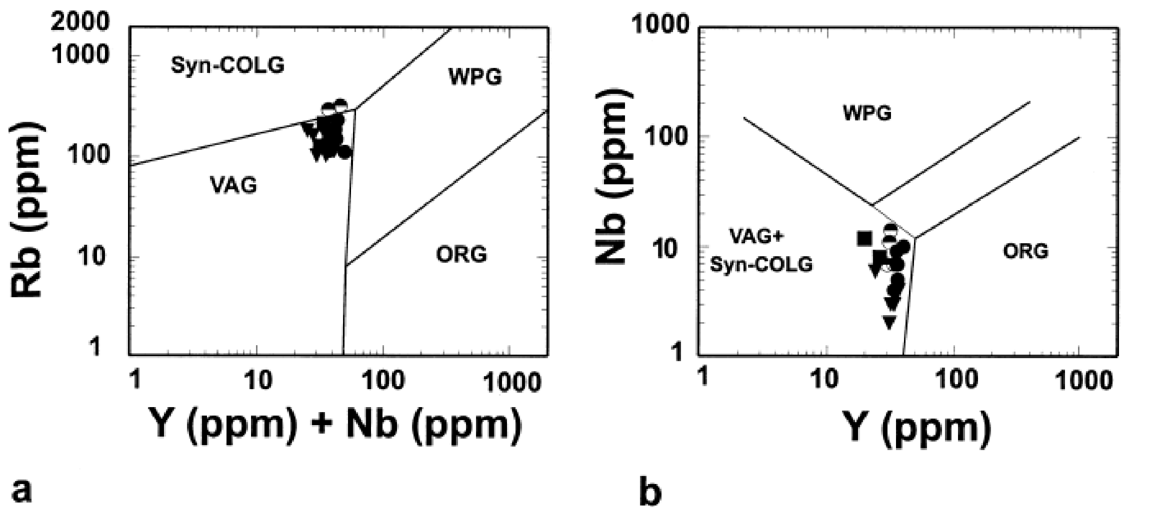
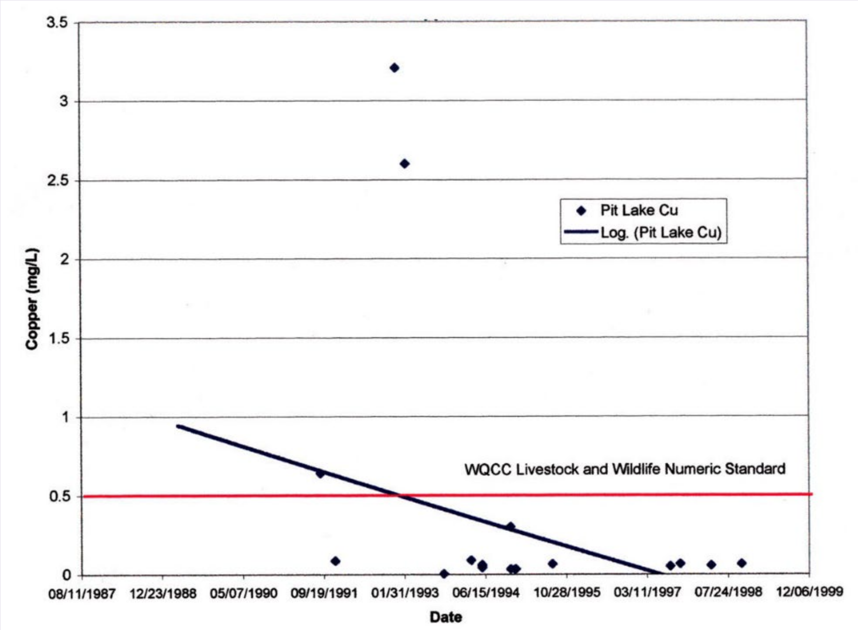


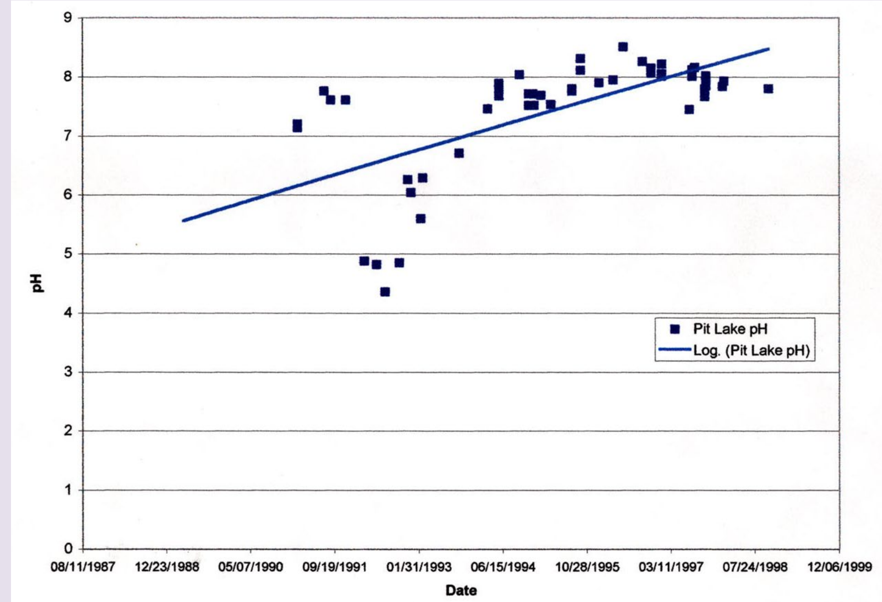
Fig. 7. (a,b) A scatter plot of Rb vs. Y + Nb and Nb vs. Y. Fields are from Pearce et al. (1984). *WPG* = within-plate granites; *ORG* = orogenic granites; *VAG* = volcanic arc granites; *Syn-COLG* = syn- collusion granites. Symbols are described in Fig. 4.

Table 14
Sequence of events in the Hillsboro mining district — deposition of the CFQM porphyry-copper and vein deposits and formation of jasperoids most likely overlapped in time

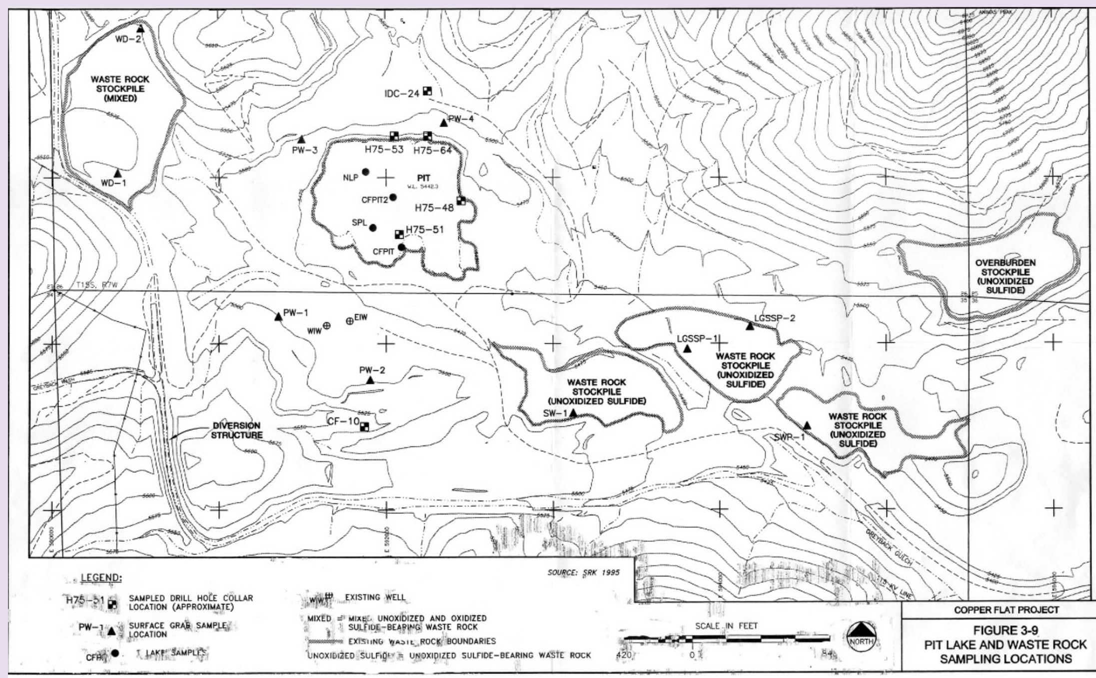
Geologic event	Age	Mineralization and alteration
Eruption of alkali basalt	4 Ma	None
Uplift of the Copper Flat volcanic/intrusive complex followed by erosion	22 Ma to present	Minor supergene enrichment of porphyry-copper deposit, placer gold deposits
Eruption of Sugarlump and Kneeling Nun Tuffs (Emory caldera)	35–34 Ma	None
Erosion? or burial?	75 Ma to 35 Ma	Minor supergene enrichment of porphyry-copper deposit?
Formation of jasperoids	75–35 Ma	Followed by deposition of carbonate-hosted replacement Ag–Mn and Pb–Zn deposits
Latite and quartz-latite dikes	75–70 Ma	Vein (Au, Ag, Cu) deposits, types 4, 5, and 6 alteration (Table 7)
Intrusion of quartz-monzonite porphyry and formation of breccia pipe deposit	75 Ma	Porphyry-copper deposits (Cu, Au, Ag, Mo), types 1, 2 and 3 alteration (Table 7), formation of skarn and marble in limestone
Eruption of andesitic volcano	75 Ma	None, possible early deuteric alteration



Copper Concentrations in the Mine Pit Lake, Copper Flat



pH in the Mine Pit Lake, Copper Flat

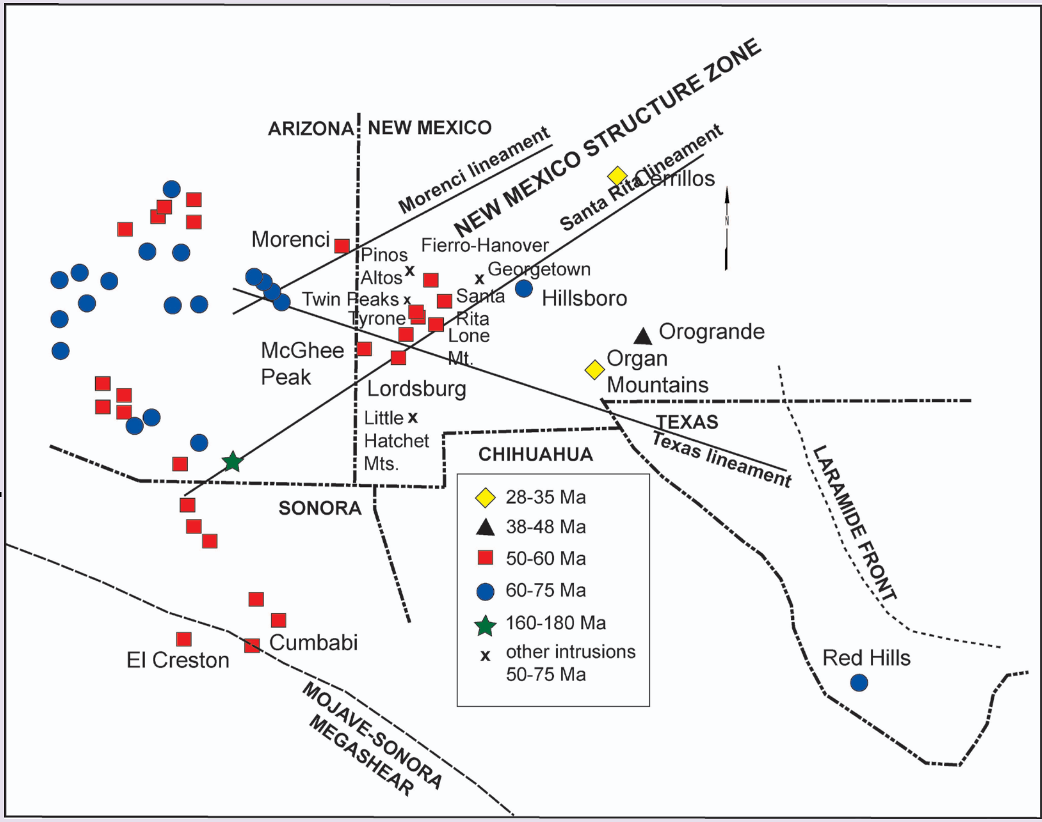


Pit Wall, Waste Rock, and Drill Core Locations, Copper Flat, New Mexico (from BLM, 1999, After SRK).

Raugust and McLemore, 2004

Intermediate age porphyry copper deposits

- 60-50 Ma
- exhibit calc-alkaline geochemistry
- include
  - Chino (58.6 Ma)
  - Tyrone—Little Rock (54.5 Ma
  - Cobre (Hanover Mountain, 57.55 Ma)
  - Lone Mountain (51.5–50.6 Ma)
  - Lordsburg (57.3–58.8 Ma)



Chino mine

HISTORY

- 1798 Col. Manuel Carrasco began mining
- 1881 stamp mill and minor production
- 1904 John M. Sully arrived and began exploration and development
- 1910 production from the open pit began
- 2003 In 2003, Phelps Dodge became the sole owner
- 2007 Chino Mines joined Freeport-McMoRan

PRODUCTION

- More than 5.9 million tons Cu, 500,000 oz Au, and 5.36 million oz Ag plus some molybdenum and iron ore from 1911 to 2006

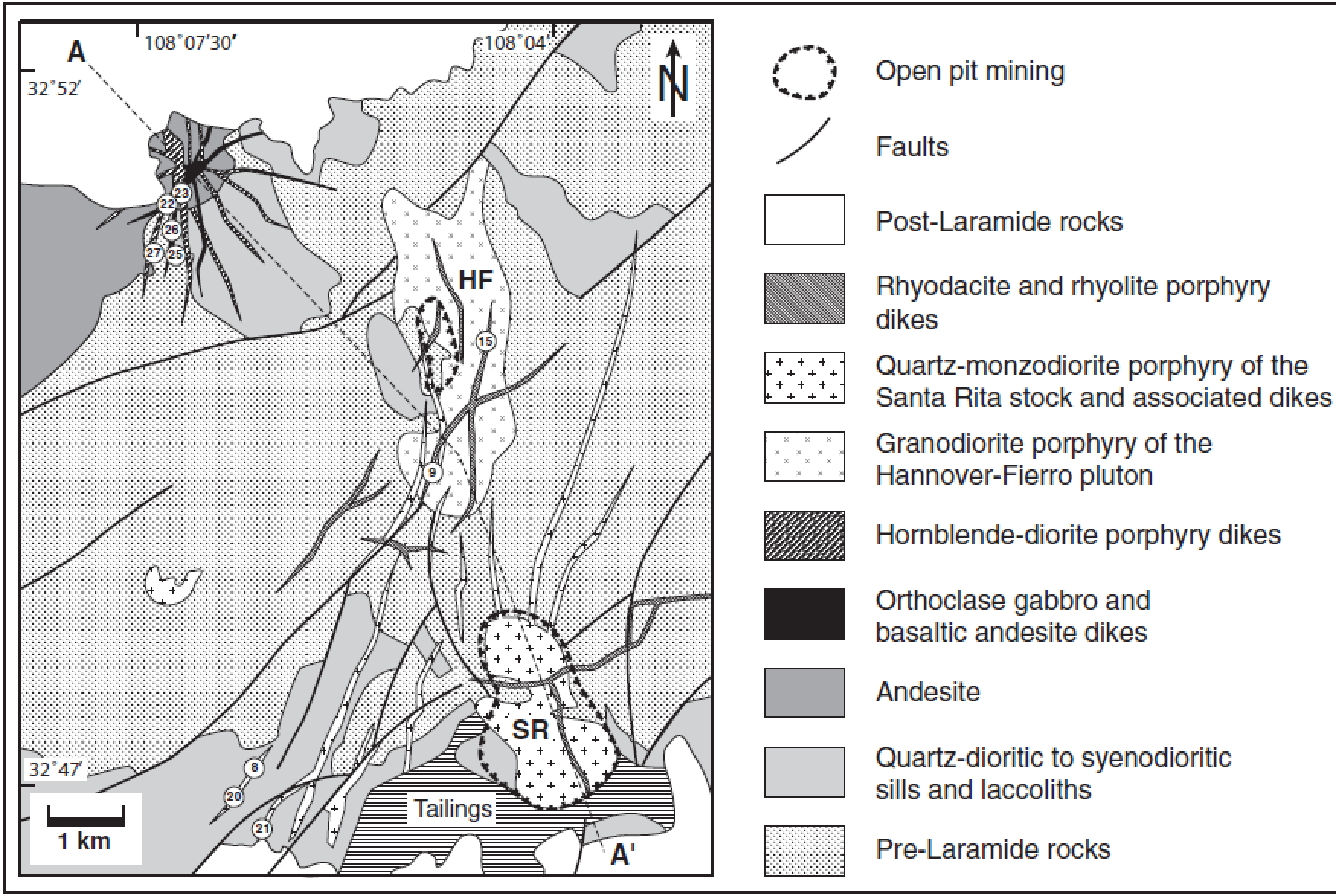


Fig. 2. Simplified geological map of the Santa Rita area, showing sample locations and major lithologies (after Hernon *et al.*, 1964). HF, Hannover–Fierro pluton; SR, Santa Rita Stock. Numbers in circles refer to the sample names used throughout the text (e.g. 22 corresponds to sample 'SR22'). Line A–A' marks the trace of the cross-section shown in Fig. 10.

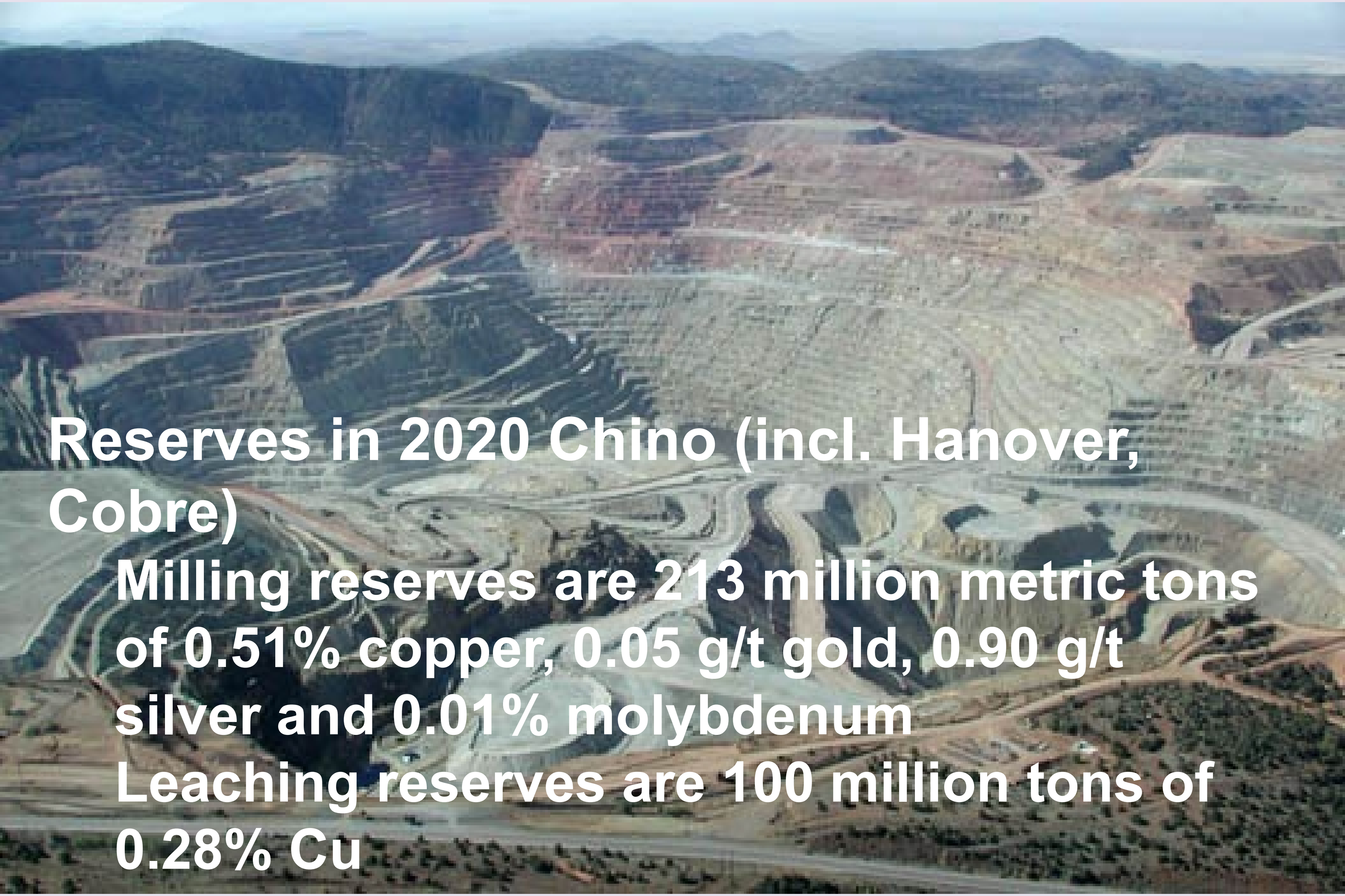
Audetat and Pettke, 2006

Chino mine

- 36,000 metric ton-per-day concentrator that produces copper concentrate
- 150 million pound-per-year SX/EW plant that produces copper cathode from solution generated by ROM leaching
- Chalcocite, chalcopyrite, molybenite
- April operations suspended due to COVID and restarted in Jan 2021

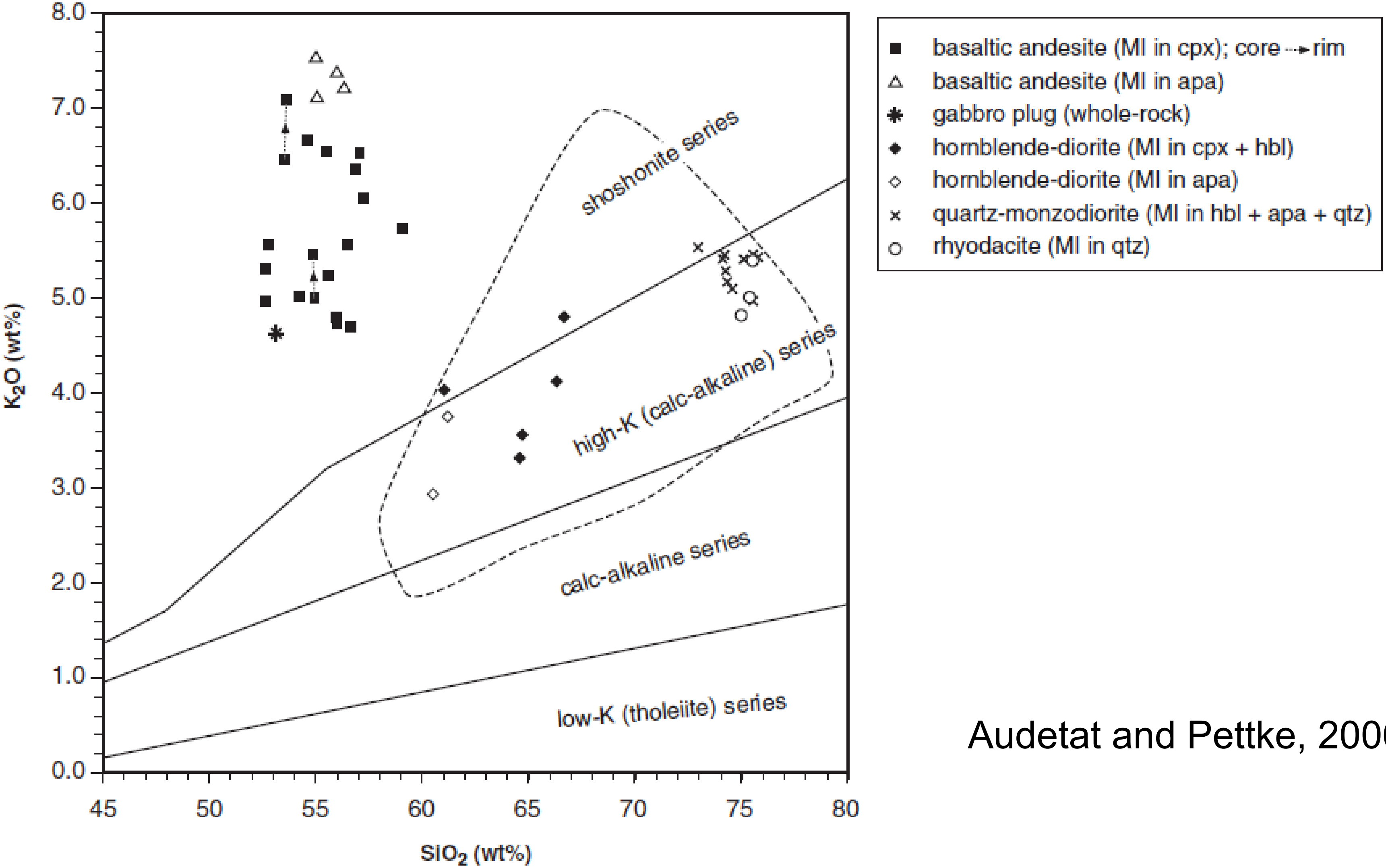
Chino mine

- Production
  - 92 million pounds Cu 2020
  - 175 million pounds Cu in 2019
  - 173 million pounds Cu in 2018



Reserves in 2020 Chino (incl. Hanover, Cobre)

- Milling reserves are 213 million metric tons of 0.51% copper, 0.05 g/t gold, 0.90 g/t silver and 0.01% molybdenum
- Leaching reserves are 100 million tons of 0.28% Cu



Audetat and Pettke, 2006

Fig. 4. Composition of whole-rocks and silicate melt inclusions from various rock types associated with the Santa Rita magmatic system. The array of whole-rock analyses published in Jones *et al.* (1967) is indicated by the dashed line, with the exception of the gabbro plug, which is shown separately. Remaining symbols represent melt inclusion (MI) compositions as reconstructed from LA-ICP-MS analyses. Core-to-rim trends of melt inclusions within single phenocrysts are indicated by dotted arrows. Boundary lines between series are from Rickwood (1989). (For abbreviations see Table 1.)

Audetat and Pettke, 2006

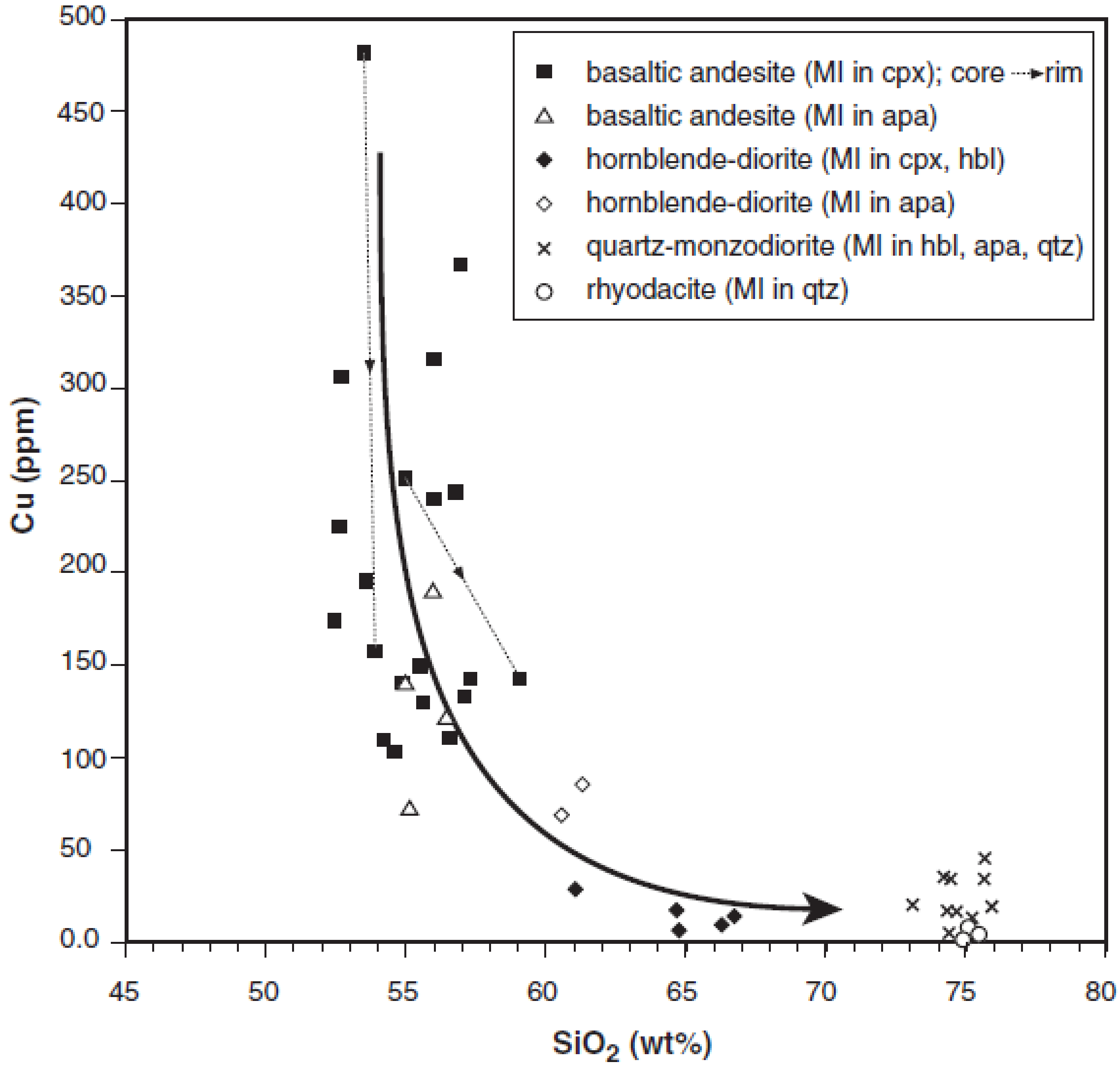


Fig. 11. Relationship between the Cu content and SiO_2 content of melt inclusions from Santa Rita. Noteworthy features are the general trend of decreasing Cu concentration with increasing SiO_2 concentration, and corresponding trends in individual augite phenocrysts (marked by dotted arrows).

Summary formation of Chino deposit

- Magmatic evolution is dominated by multiple injections of alkaline (shoshonitic), oxidized, high S mafic magma into cool, anhydrite-bearing magma of intermediate to felsic composition
- Initial exsolved phase is a low salinity aqueous fluid, later fluids were more saline
- Mafic magma supplies Cu, S, heat to keep the magma from solidifying
- Mixing of the magmas causes the precipitation of the sulfides

Audetat and Pettke, 2006

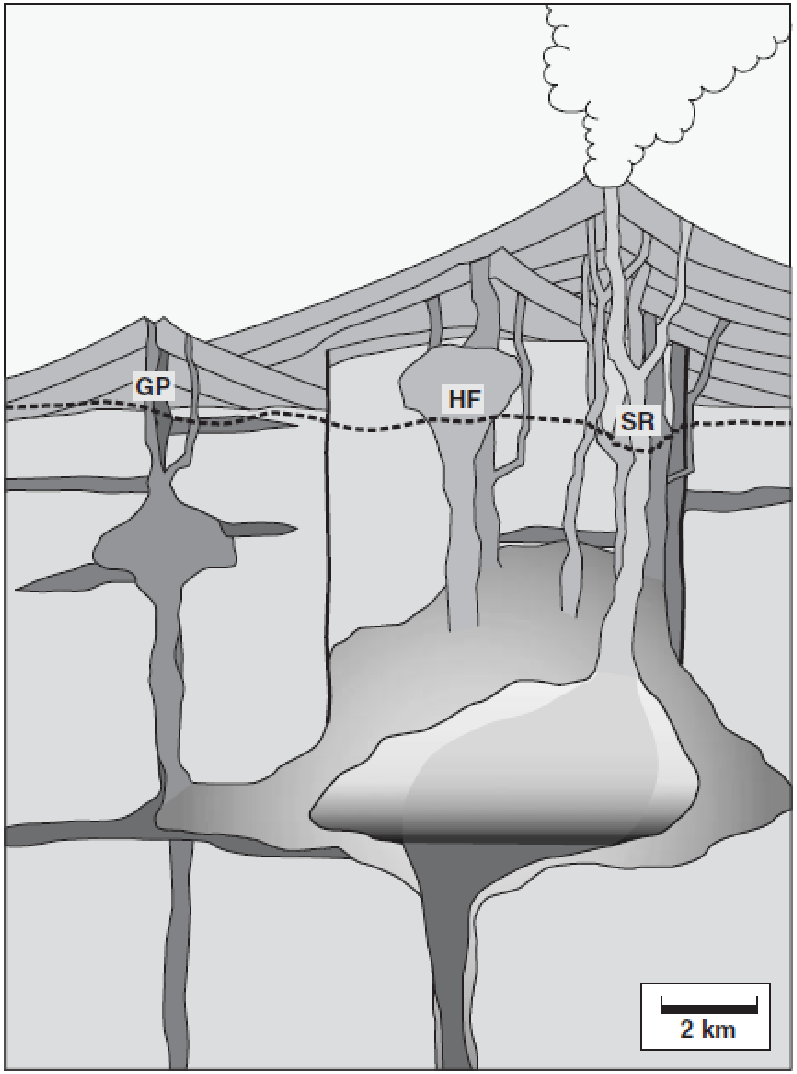


Fig. 10. Interpretative cross-section through the magmatic system at Santa Rita along line A–A′ marked in Fig. 2 (positions of magma chambers and eruption centers are hypothetical). The diagram shows a volcanic eruption triggered by intrusion of mafic magma (dark gray; on lower right) into an evolved, stratified magma chamber (light gray; above). The resulting hybrid andesite magma (medium gray) rises along a major conduit to the surface. GP, gabbro plug; HF, Hannover–Fierro pluton; SR, Santa Rita stock; dashed line marks present-day surface.

Tyrone mine

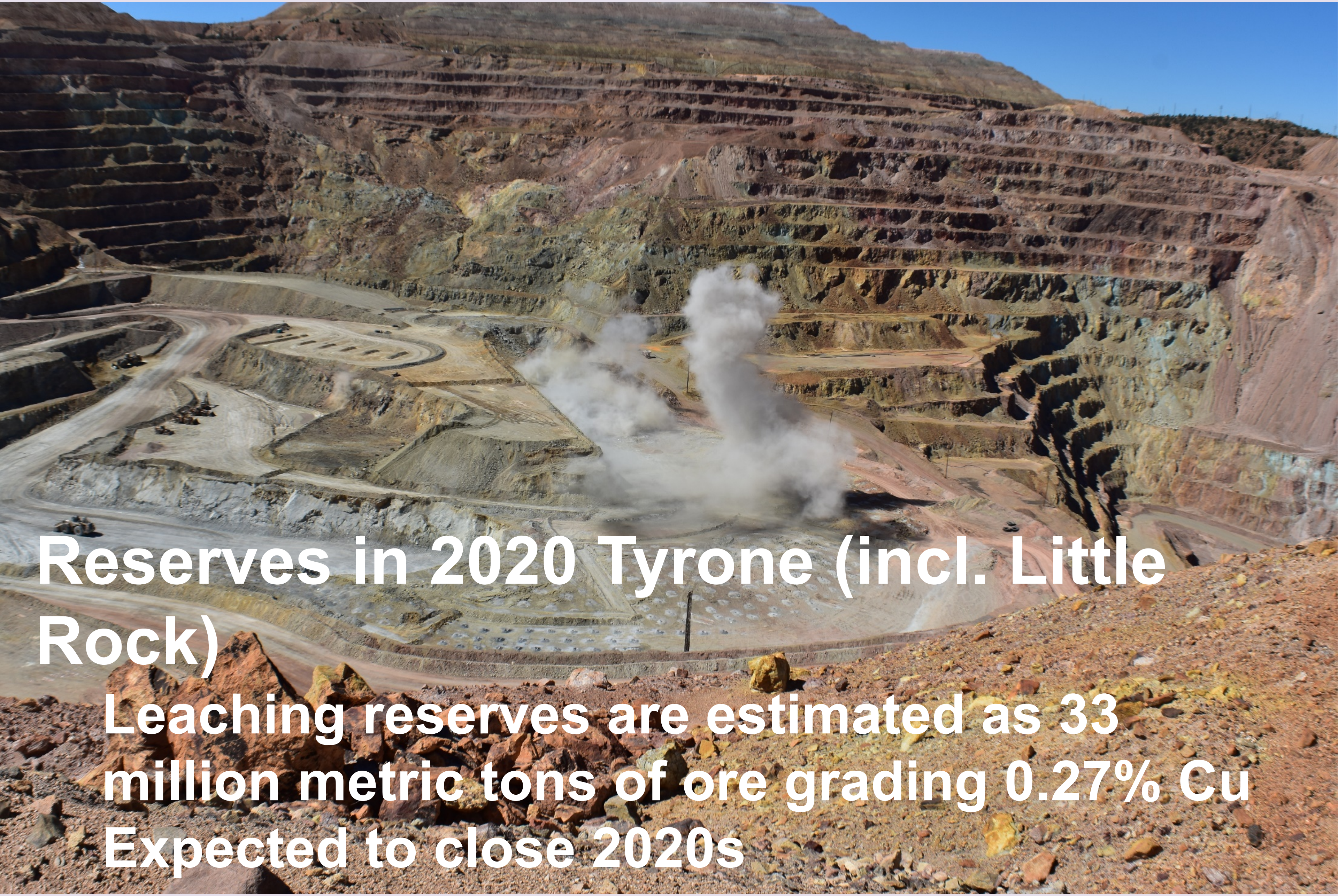
- Phelps Dodge purchase in 1909-1916
- 1941-1950 Dump and stope leaching
- 1949-1959 churn drilling program
- 1969 concentrator built
- 1984 SXEW plant constructed
- 1992 Concentrator closed
- Open pit since 1967

Tyrone mine

- Mine 40-60,000 short tons per day
- Average grade 0.27% Cu
- Two pits Little Rock and Valencia
- Produces 75-100 tons copper per day from leaching

Tyrone mine production

- Precip 1971-1997
  - 243 million pounds Cu
- Leaching 1984-present
  - 3.4 billion pounds Cu
- Current reserves
  - 100 million pounds at 0.42% Cu
- Total copper
  - 6.8 billion pounds Cu

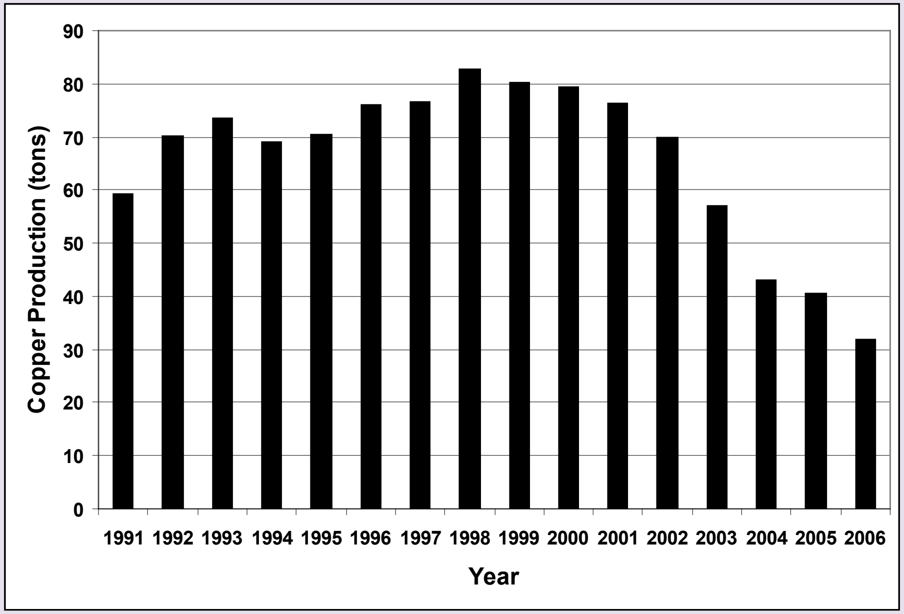


Reserves in 2020 Tyrone (incl. Little Rock)

- Leaching reserves are estimated as 33 million metric tons of ore grading 0.27% Cu
- Expected to close 2020s

TYRONE PRODUTION

- The mine has produced more than 5.3 billion tons Cu, 500,000 oz Au, and 5.36 million oz Ag plus some molybdenum and iron ore from 1911 to 2006



HISTORY

- 600 AD turquoise mining
- 1909 when Phelps Dodge Mining Co.
- 1916 mining
- 1967 open pit
- 1992 end of milling, heap leaching
- 2007 Tyrone joined Freeport-McMoRan

Tyrone

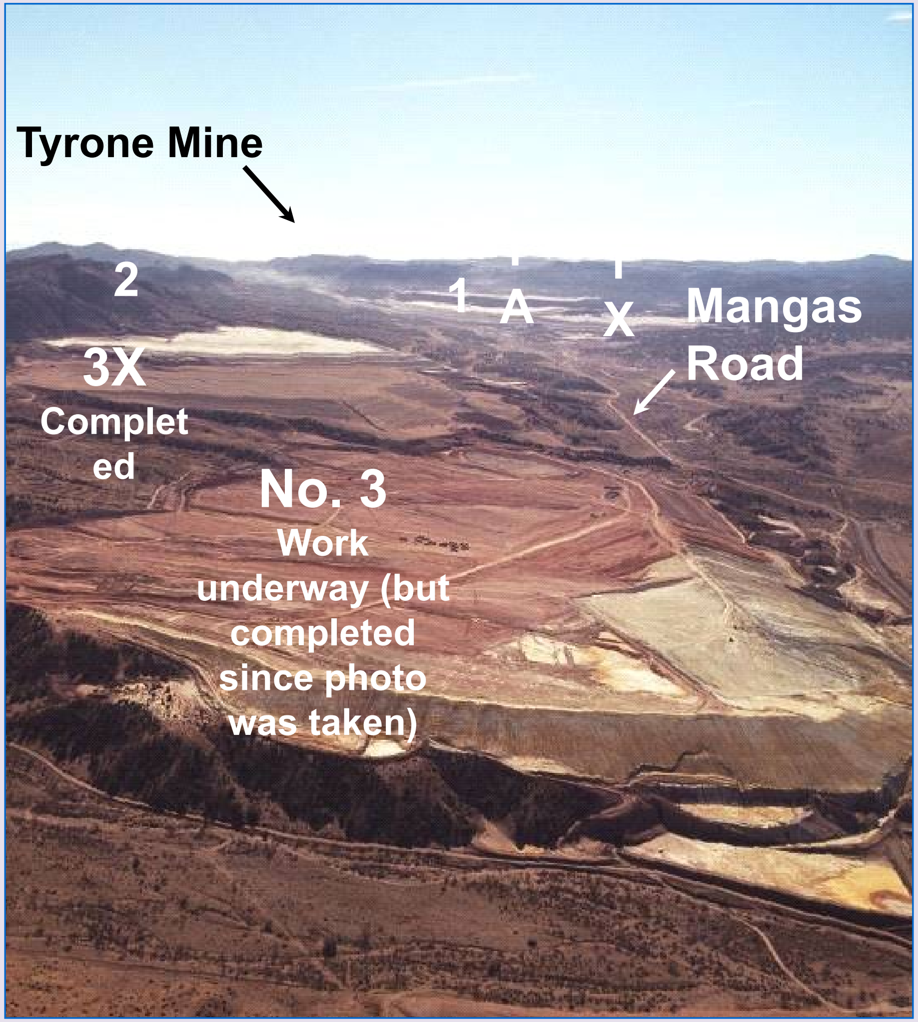
- SX/EW operation with a maximum capacity of approximately 100 million pounds of copper cathode per year
- Production
  - 45 million pounds Cu 2020
  - 48 million pounds Cu 2019
  - 55 million pounds Cu 2018

Ore types

Mineralogical Ore Types

POWERED BY COPPER

Oretype	Significant Minerals	Average Grade (% Cu)	Thickness (m)
Leached Capping	Hematite, goethite, jarosite	0.03 - 0.06	0 - 50
Green Cu Oxide	Chrysocolla, malachite, azurite	0.25 - 0.35	0 - 100
Black Cu Oxide	Cu-Mn Wad, neotocite, crednerite manganese oxides, iron oxides	0.15 - 0.25	0 - 75
Insoluble Oxide	Native Cu, cuprite, tenorite, iron oxides	0.15 - 0.25	Minor
Mixed oxide - sulfide	Chalcocite, pyrite, chalchanthite, Cu oxides	0.30 - 0.45	0 - 50
Chalcocite	Chalcocite, pyrite	0.82% ore 0.30 - 0.45 ROM	0 - 200
Mixed Sulfide	Chalcocite, covellite, chalcopyrite, pyrite	0.20 - 0.35	0 -100



TYRONE RECLAMATION

More than 34 million tons of overburden waste rock was removed from above the ore zones and placed in large stockpiles now being covered

Covering the rock piles will prevent O_2 from entering them and prevent acid production

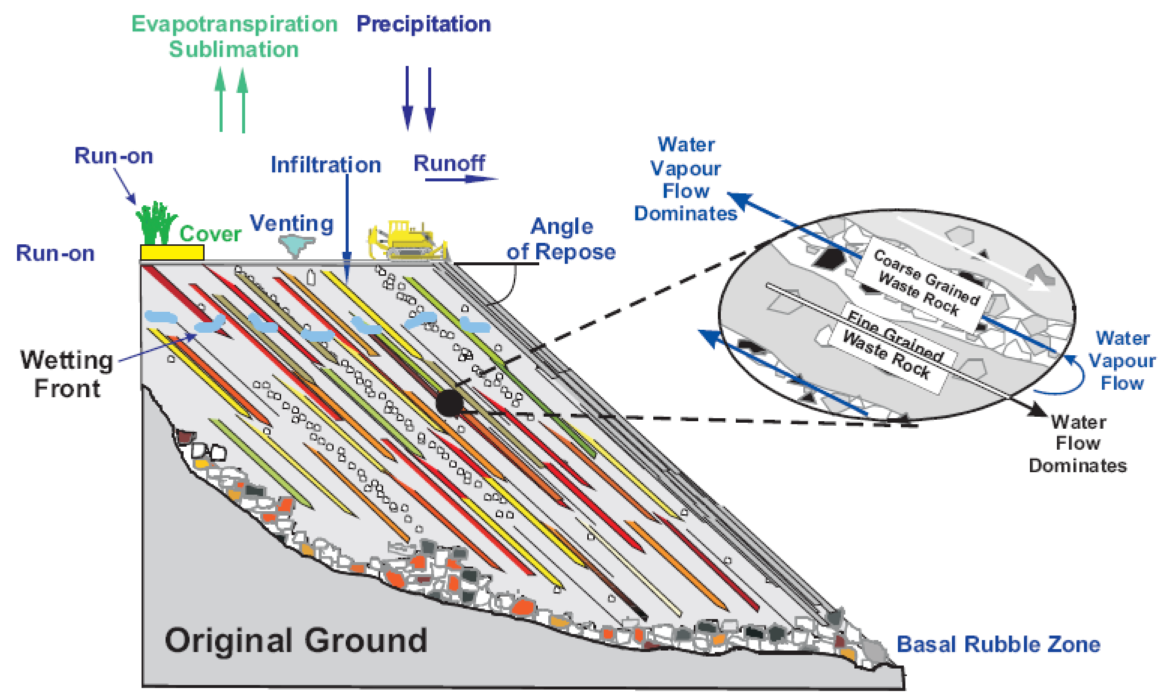


Figure 12: Conceptual model of water flow and vapour transport in a waste rock dump based on observations at Golden Sunlight Mine.

Herasymuik 1996

Lordsburg

Vein Type	g/t Au	g/t Ag	% Cu	% Pb	% Zn
Chalcopyrite Vein	3.9	84	2.4	---	---
Pyrite-gold Vein	3.0	54	0.6	0.3	0.3
Galena-Sphalerite Veins	1.0	215	1.2	2.6	< 0.5
Gangue-dominant Veins	—	---	---	---	---

Assays from old mine records (1903-1975), recent drill core data of Webster (1984), Phelps Dodge (1984), and Lordsburg Mining Co. (1990) and present production and exploration data (1990-1993). Values represent mean values.

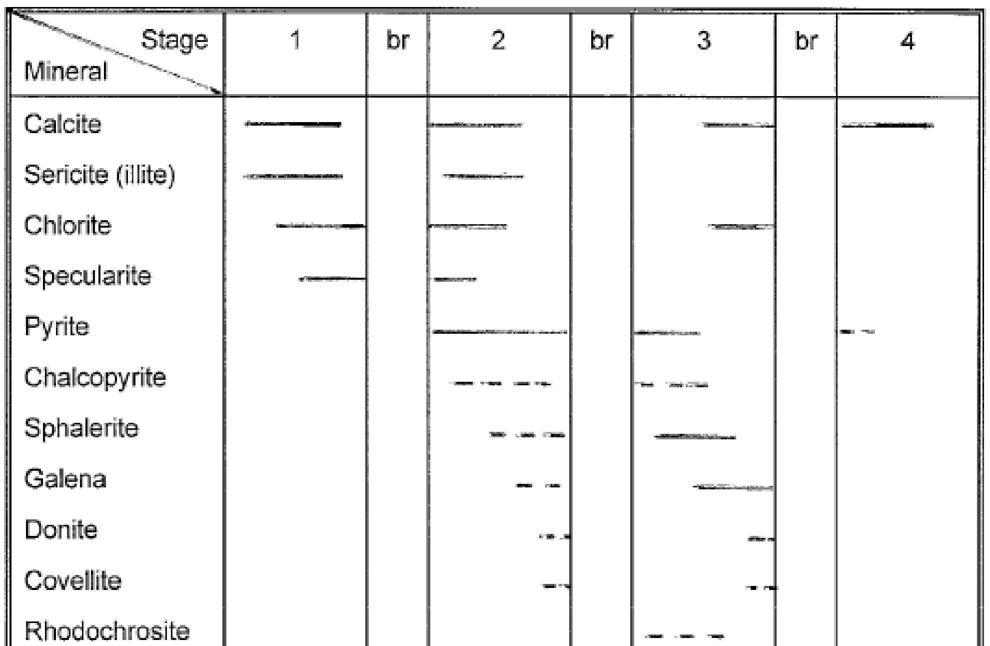


Fig. 8. Paragenetic sequence of hypogene minerals in the North Atwood Vein System. Solid lines represent major phases. Minor-trace phases are represented by dashed lines. br, brecciation event.

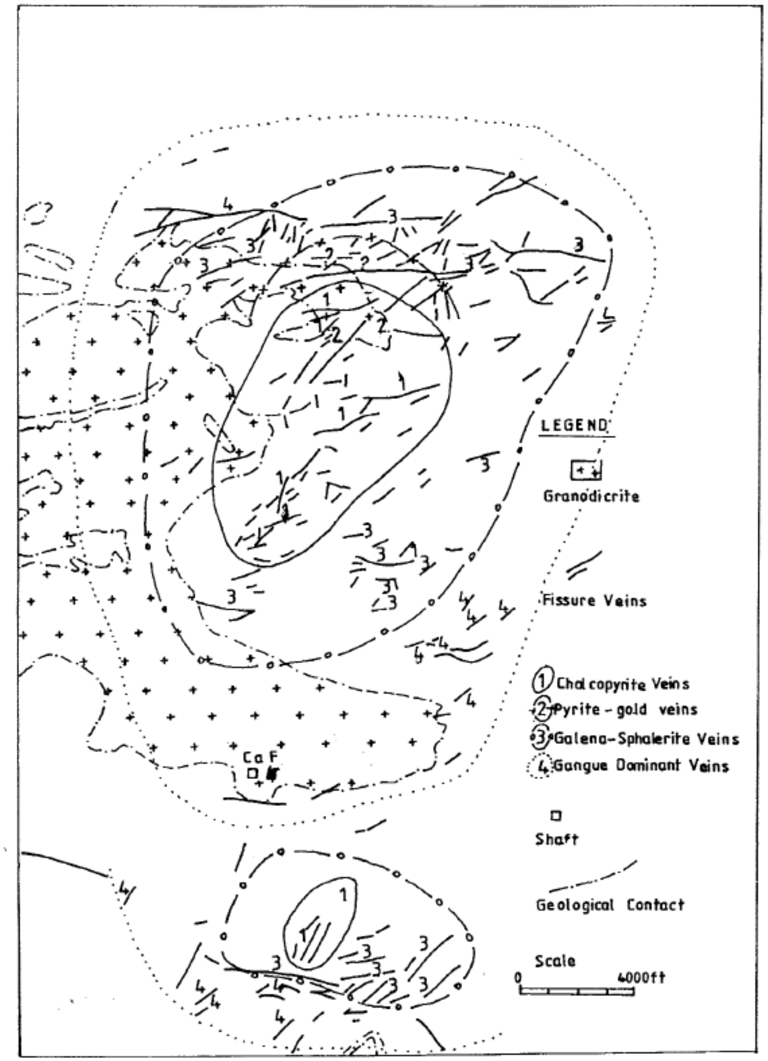
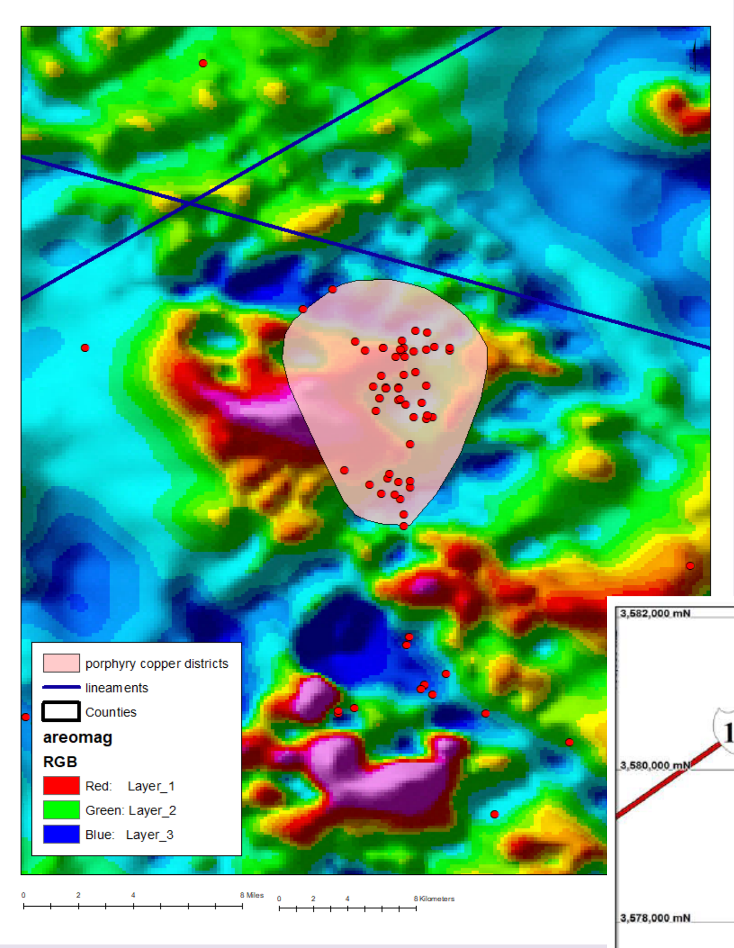


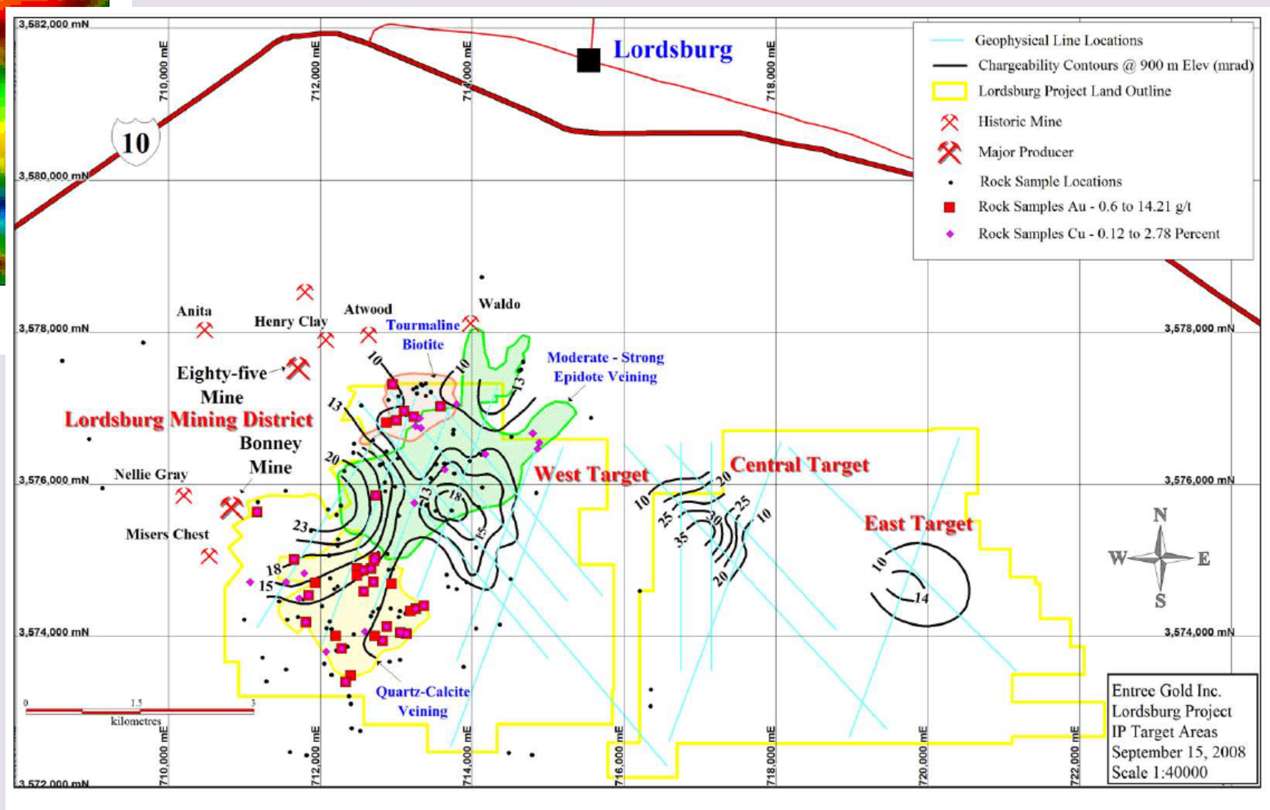
Fig. 4. Map of Lordsburg showing vein types. (See text for details.)

Agezo, 1995

Lordsburg

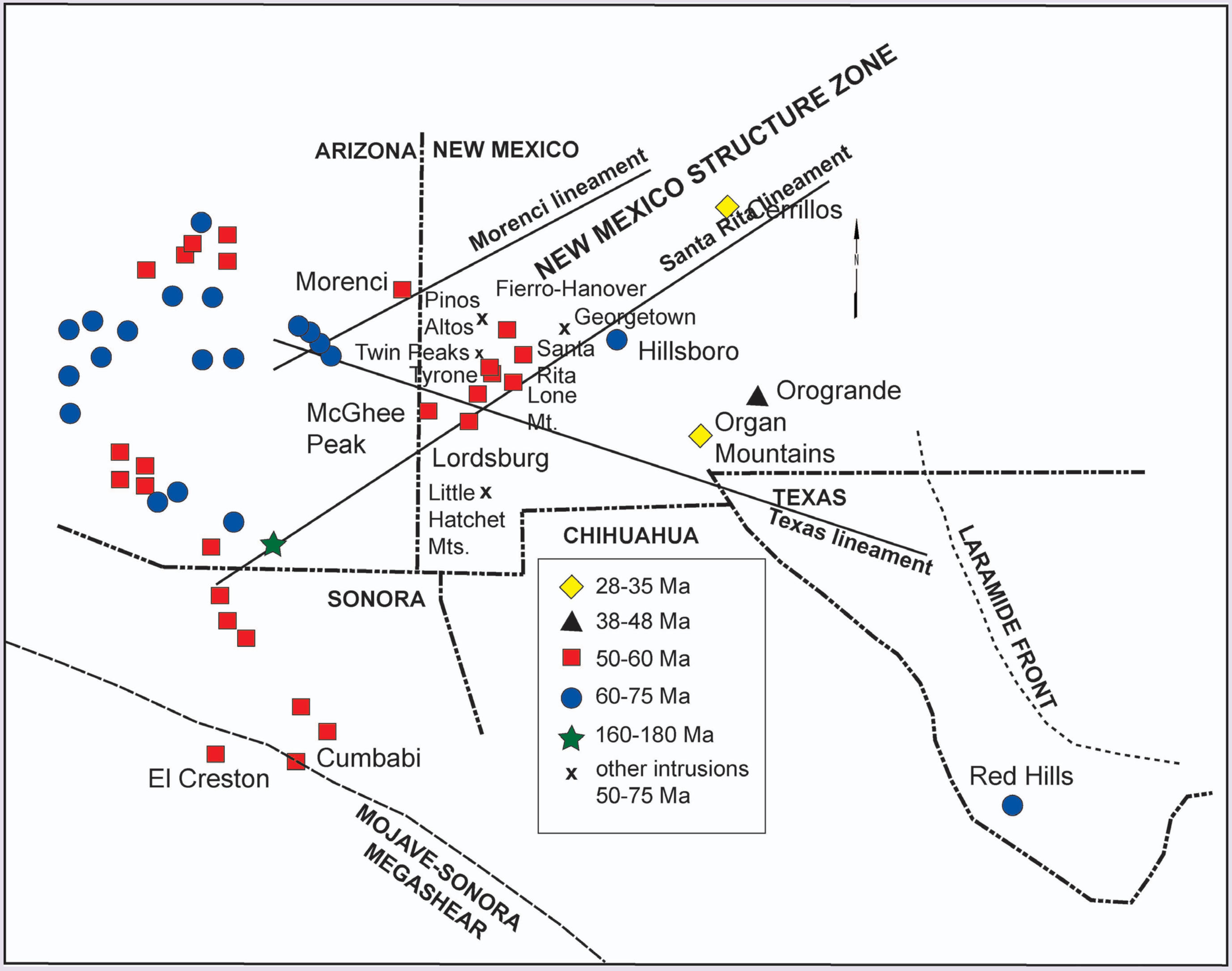
Lordsburg—mines associated with aeromagetic lows





Unknown age (suspected 60-50 Ma)

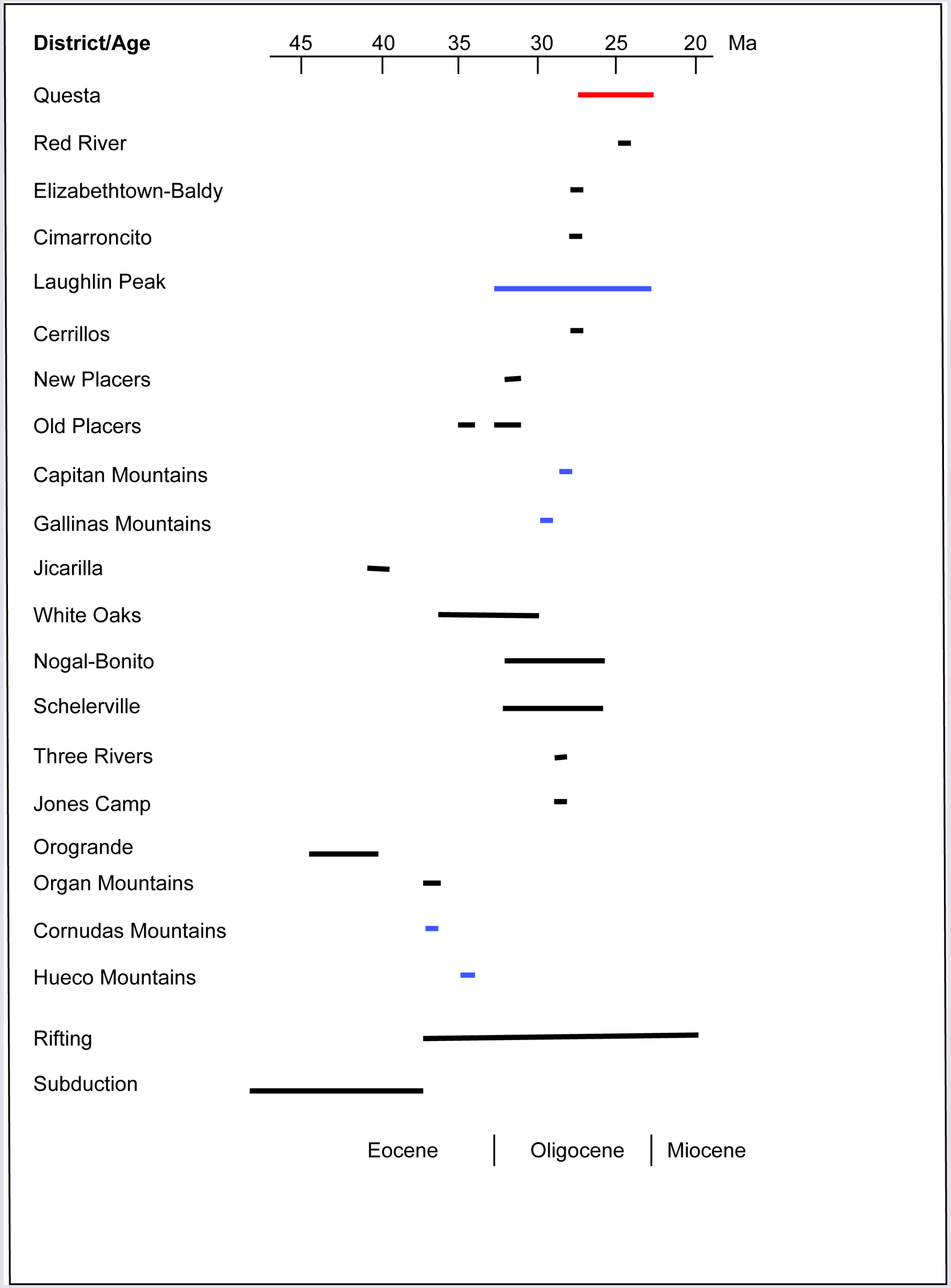
- Gold Lake (White Signal)
- Steins (McGhee Peak)
- Mimbres Mountains



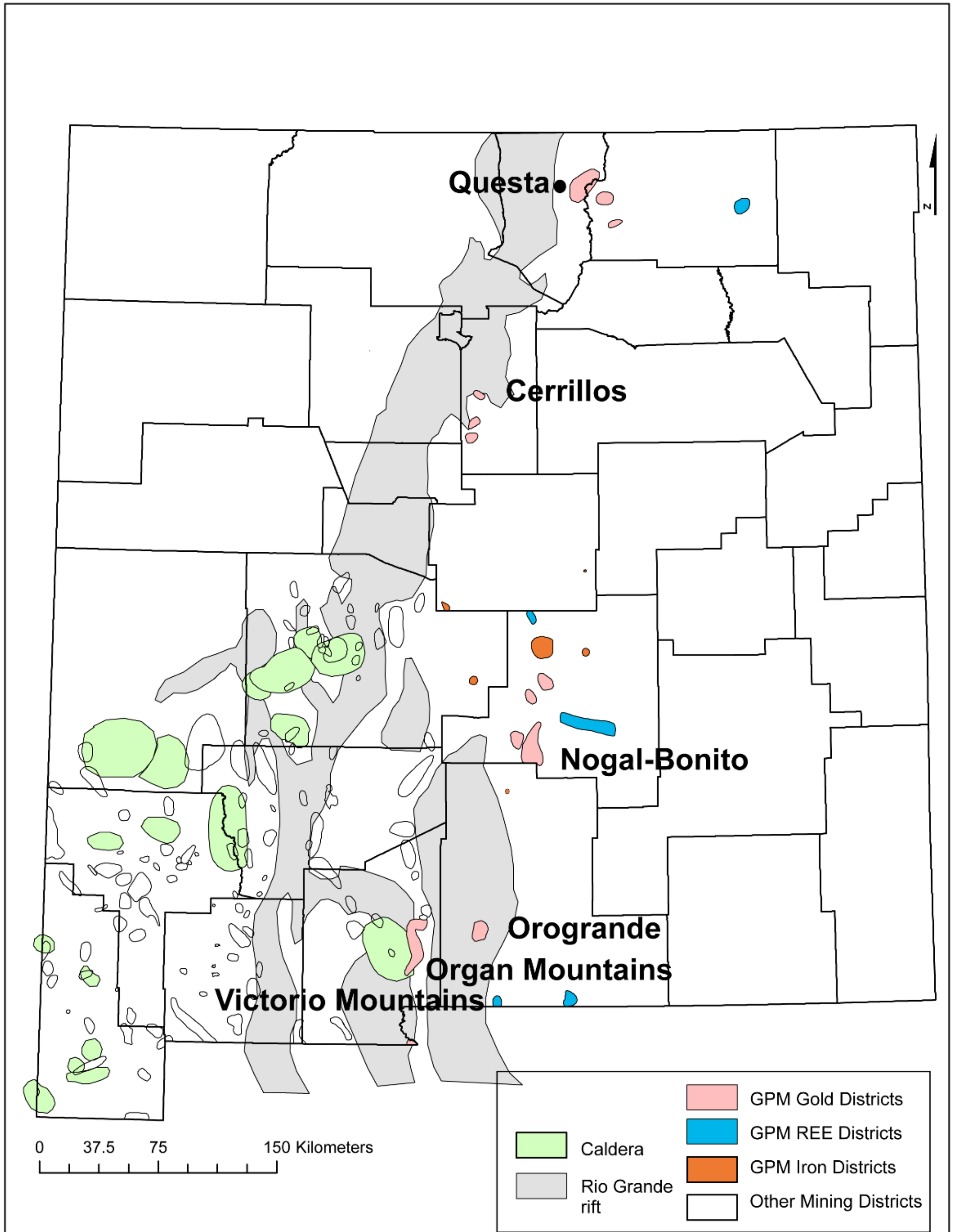
Youngest porphyry copper deposits

- <45 Ma
- Mostly eastern portion of New Mexico (Victorio Mountain in SW)
- Exhibit mostly alkaline geochemistry
- Includes
  - Organ (Cu-Mo; 26-36.45 Ma; Zimmerer and McIntosh, 2012)
  - Cerrillos (Cu-Au, 29.8 Ma; Sauer, 1994)
  - Orogrande (Cu-Au; 41.4-45.6 Ma; McLemore et al., 2014)
  - Victorio Mountain (Mo-W; 34.9 Ma, Donahue, 2002)

- By 46 Ma the style of magmatism changed
  - Eastern NM and western Texas—Texas-New Mexico alkaline belt
  - Western NM and Mexico—calderas
- Mineralized porphyry deposits are smaller, more alkalic, and relatively more enriched in Mo or Au (McLemore, 2018)



Red line represents predominantly porphyry molybdenum district



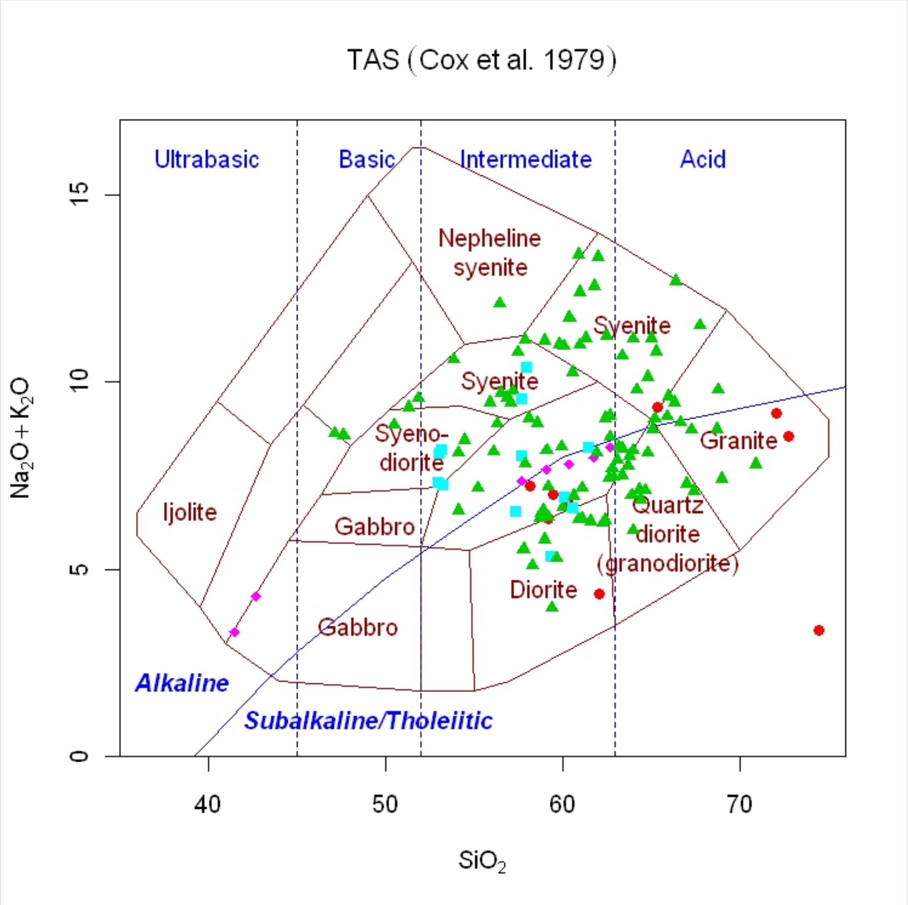
Younger porphyry deposits

<45 Ma

Cerrillos Hills

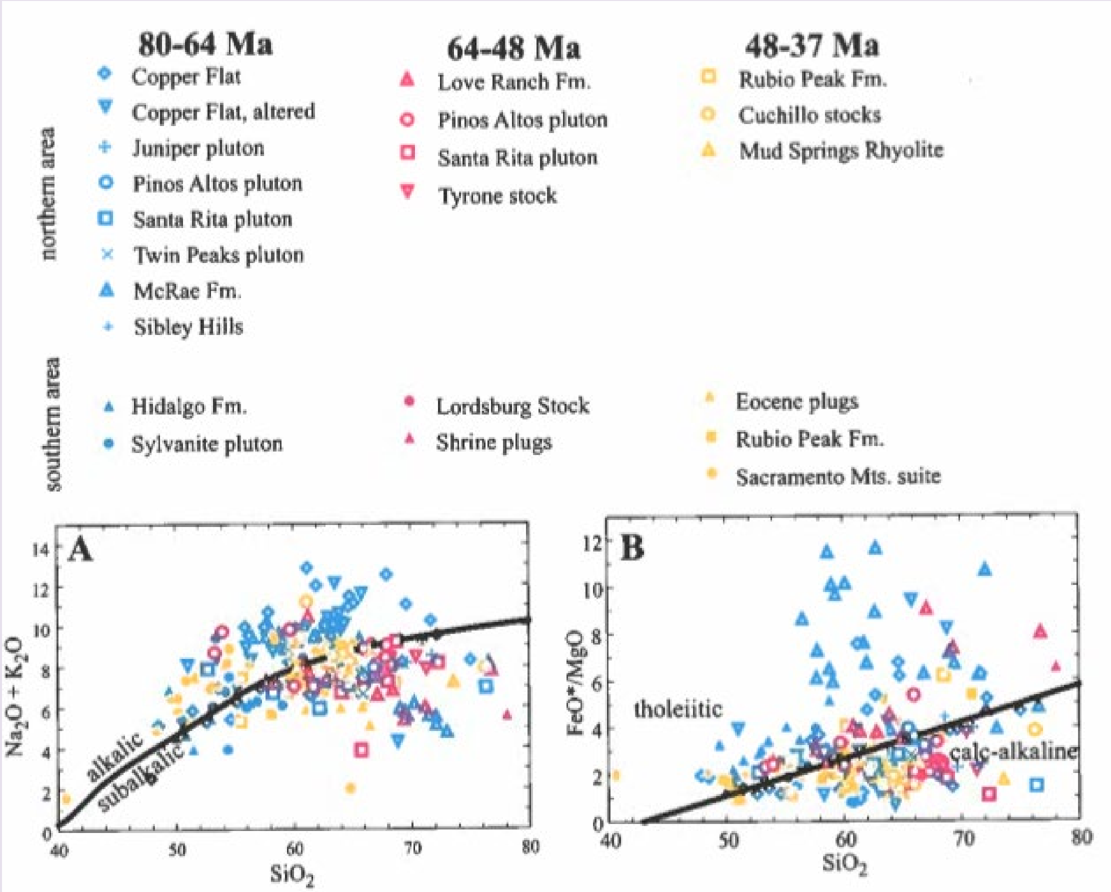
- Low grade (0.3% Cu), MoS2 poor, low sulfide system
- Potassic alteration
- No supergene enrichment
- Drilling indicates >2000 ppm Cu ring surrounds monzonite plug

Red=San Pedro
Green=Ortiz
Turquoise=Cerrillos

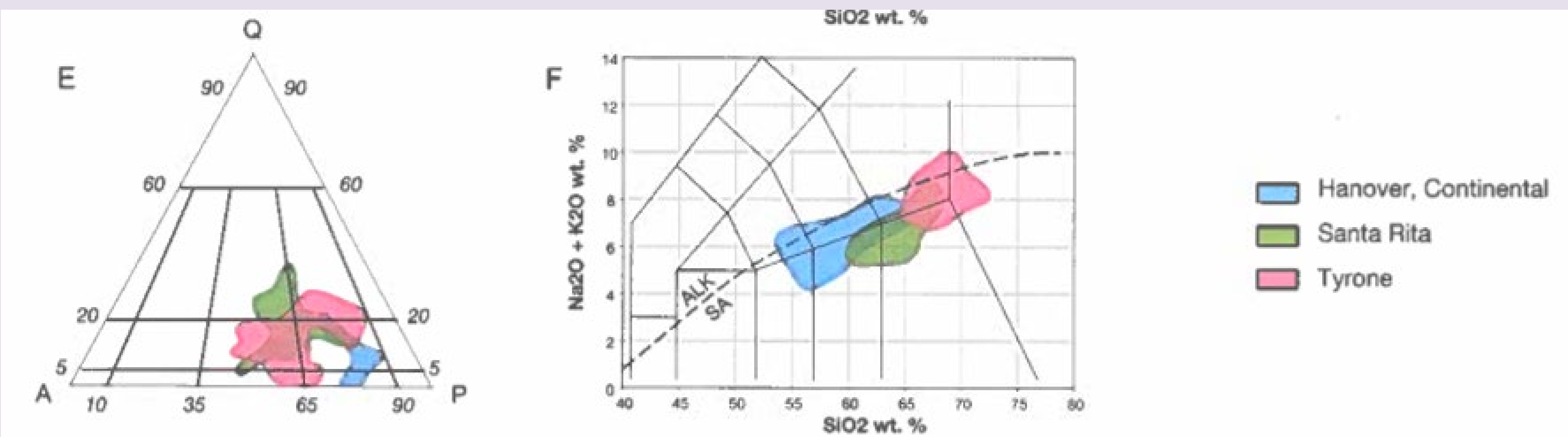


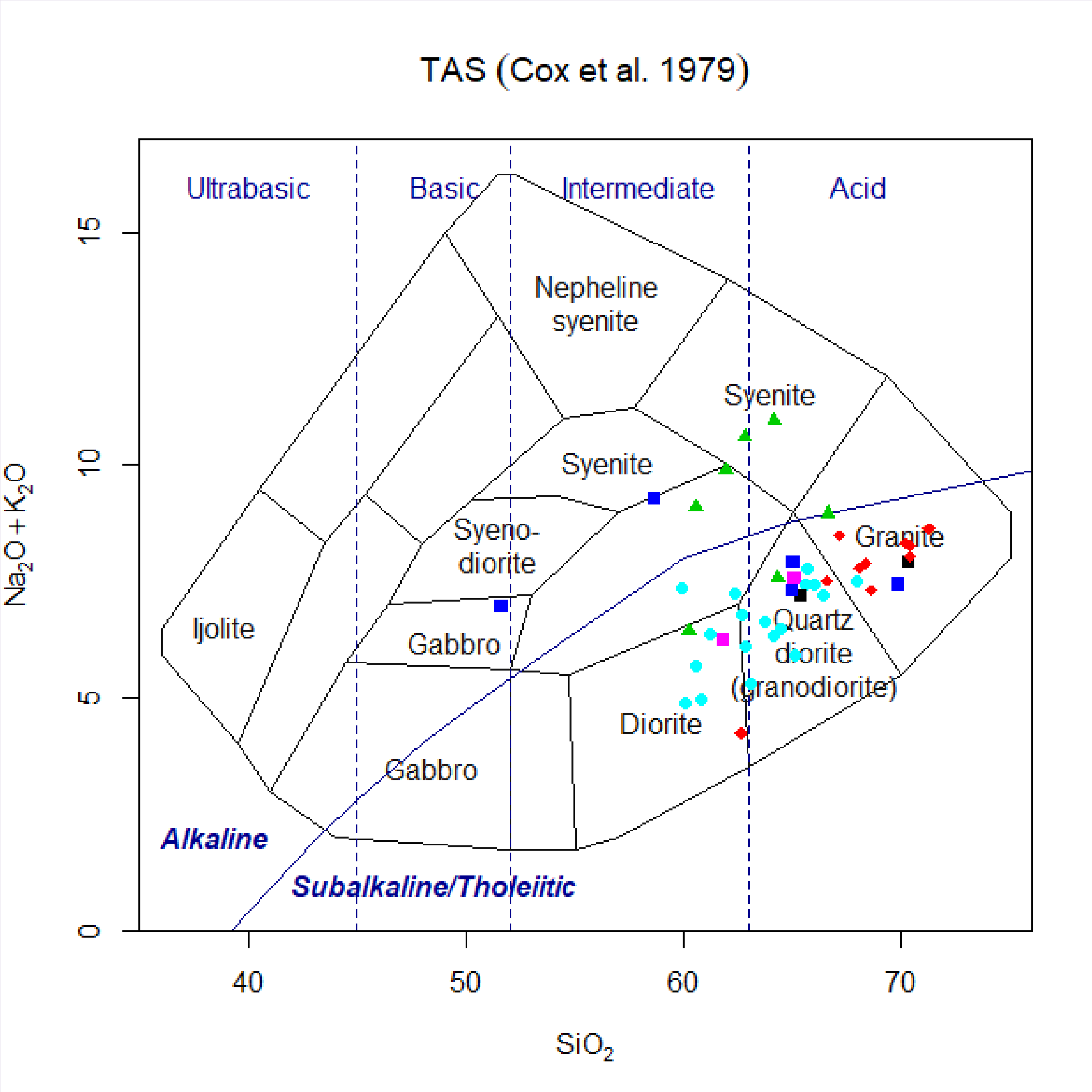
Geochemistry

- Grossly similar major and trace element chemistry of Laramide and younger intrusions suggests similar source regions
- Slight differences in geochemistry reflect changes due to fractional crystallization and variable water-rock interactions (McMillan, 2004)



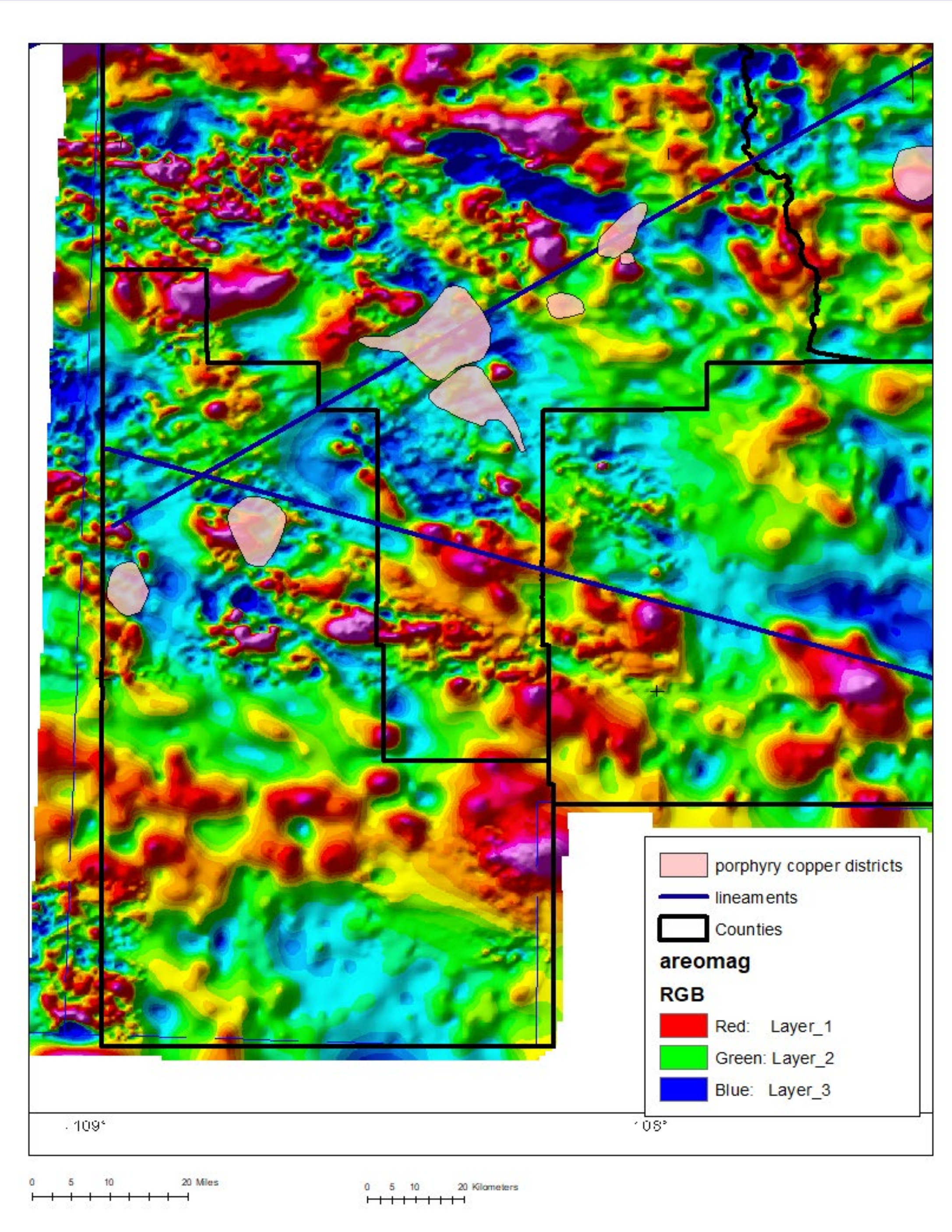
McMillan, 2004; Leveille and Stegen, 2012





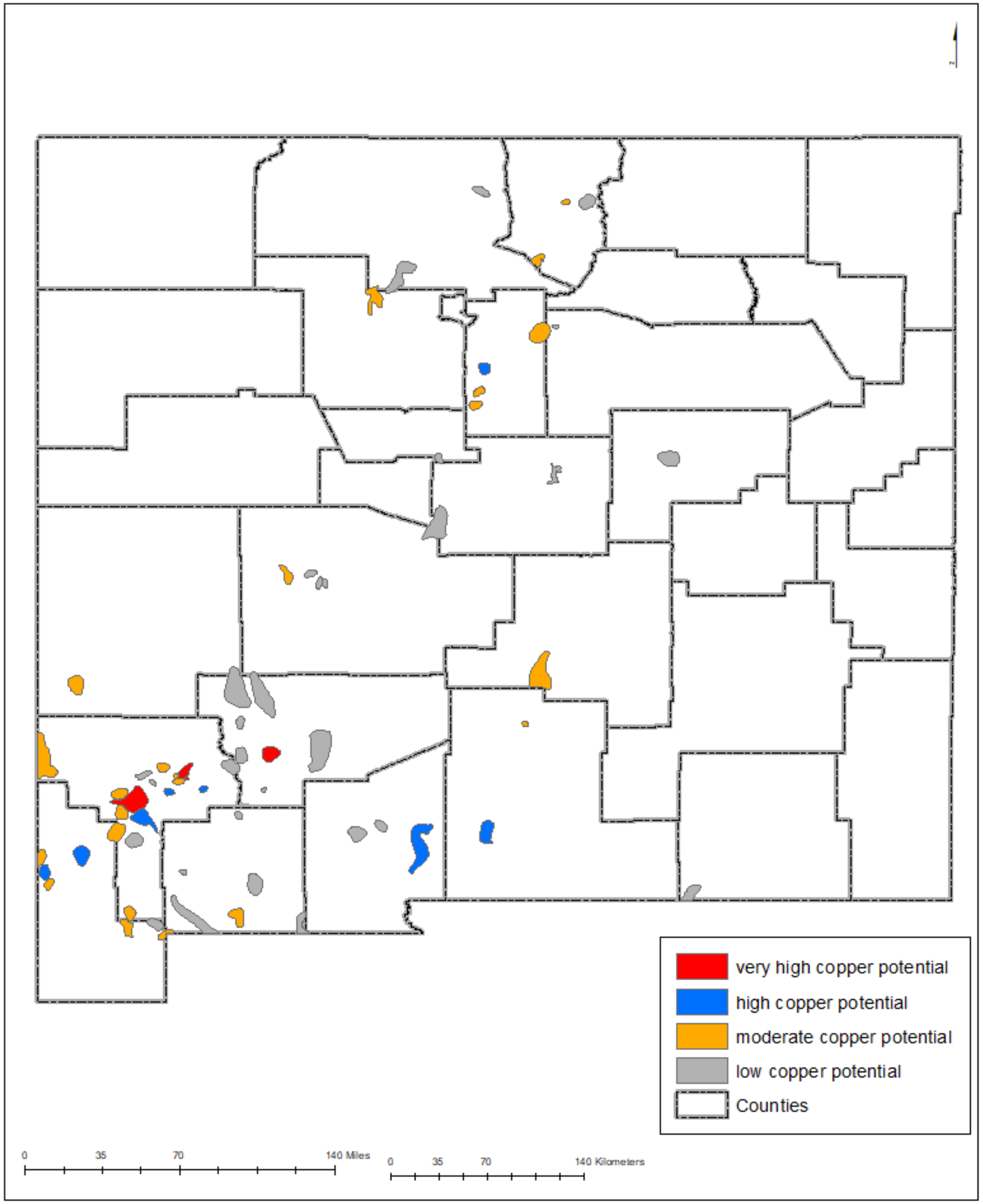
- Purple=Twin Peaks
- Turquoise=Chino
- Black=Fierro-Hanover and western Copper Flat
- Green=Hillsboro (eastern Copper Flat)
- Red=Tyrone
- Blue=Red Hills

Laramide (>45 Ma)



SW NM aeromag

Cu potential



SUMMARY

- Most of the larger productive porphyry copper deposits formed during 60-50 Ma period in SW NM
- Older porphyry copper deposits in NM and TX are 75-60 Ma, smaller then those in the 60-50 Ma
- Younger porphyry deposits (Cu-Au, Cu-Mo, Mo) in eastern NM and TX? are <45 Ma
- **Grades are decreasing in producing deposits and new deposits are required to maintain production**
- Only one deposit, Copper Flat is in permitting
- Several deposits in beginning exploration

SUMMARY

- Formation of a copper porphyry deposit is very complex and not as well understood as geologists would like
  - Magmatic processes
  - Hydrothermal processes
  - Supergene or weathering processes
- Stratigraphy and structure in this area is complex
  - Pre-porphyry rocks
  - Porphyry
  - Younger rocks
    - Kneeling Nun Rhyolite Tuff overlies the deposit

FUTURE STUDIES

- Continue to define the geochronology and chemistry of mineralized and other intrusions
- Stable and radiogenic studies to further identify sources
- Better geophysical studies to identify drill targets in the subsurface

ASSIGNMENT

- Safety moment
- 2 field trip reports and Midterms late
- Look for additional lectures on my web site https://geoinfo.nmt.edu/staff/mclemore/MineraldepositsofNewMexico.html
  - Status of Critical Minerals in New Mexico (AEMA)
  - Gold panning ***(think about why gold panning is an important tool in exploration)***
  - Sampling and monitoring
  - Sustainable development **(*to be added*)**
- Memoir 50D
  - Chapter 6 Transition stage