# PRECIOUS METAL DEPOSITS ASSOCIATED WITH VOLCANIC ENVIRONMENTS IN THE SOUTHWEST

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## ABSTRACT

A comparative study of over 60 precious metal vein deposits hosted by volcanics indicates that ubiquitous physico-chemical features relate to the genesis of, and exploration for, these deposits. Host rocks are largely Tertiary calc-alkaline extrusions with hypabyssal intrusions. Andesites are the more common host to ore shoots, however most districts have preore felsic tuffs, volcanogenic sediments, dikes, sills, and plugs. The deposits fill fractures often related to a caldera environment. The veins are vertically zoned from agate and clay near the paleosurface, passing with depth into barren calcite; then quartz and calcite; then quartz, calcite, adularia and precious metals; then in deeper levels to quartz, adularia and base metals. The interface between the upper precious metals and the lower base metals is a level of episodic boiling of the fluids. At this level, $CO_2$ and $H_2S$ are released to the vapor phase, pH rises in the remaining fluid, temperature drops slightly, and $f(O_2)$ increases. These results of boiling cause first the base metals, then the silver sulfide, and later the gold to deposit in a well-recognized temporal and vertical sequence. Episodic sealing of the fracture system, followed by episodic refracturing causes episodic boiling and mineral deposition at depths greater than hydrostatic conditions would allow, and yields the intra-mineralization brecciation and banded vein fillings so often observed in epithermal deposits. A low pH alteration assemblage, genetically related to the precious metal deposition, is nearly always present. This assemblage extends from the base of the precious metal ore horizon to the paleosurface, thus it serves as an excellent guide to non-outcropping ore shoots.

## INTRODUCTION

This paper will present data on epithermal deposits hosted by volcanics and will discuss the metal deposition mechanisms. A model will be presented of a "typical" deposit, describing vertical and horizontal patterns of wall rock alteration, mineralization, levels of ore deposition, and chemical and physical ore controls.

The study will limit itself to only those gold-silver vein deposits in an unmetamorphosed volcanic to subvolcanic environment. These deposits have been called "epithermal", "bonanza ores", "precious metal deposits of volcanic association", and by other names. These names are all slightly misleading in that most of the deposits were formed from solutions hotter than the 200°C limit set by Lindgren (1933) as the upper temperature of "epithermal", certainly only a few districts were "bonanzas", and it is not at all clear just what the association is between the veins and the host volcanics (especially as many ore shoots are in sedimentary rocks below a volcanic cover). As the word "epithermal" is so widely used and is now generally understood to refer more to a genetic-class rather than a temperature-class of deposits, the word "epithermal" will be retained in this report. With the limitation of discussing only deposits in a volcanic environment, some major precious metal districts (Coeuer D'Alene, Carlin, Leadville, Concepcion Del Oro, etc.) will not be discussed, although some of the ideas to be presented may apply equally to these.

## DATA BASE FOR THE MODEL

Table 1 gives physical and chemical characteristics of 60 epithermal districts. The compilation reveals several important common characteristics, features too often present to be relegated to mere coincidence:

A. The host is typically an Early to Late Tertiary calc-alkaline volcanic pile commonly containing andesite agglomerates, dikes, breccias and flows; rhyolite tuffs, dikes and small plugs; latite and rare dacite flows and breccias; lake bed and fluvial volcanogenic sandstones and shales. Although andesites are the more common host to ore (Silberman, 1976), most districts have some felsic units. Felsic intrusions are usually late in the volcanic event but are preore. Many field geologists feel a genetic tie exists between the mineralization and the felsic intrusions, with the intrusions acting as a heat source to drive cells of convecting water. Much more study is required to confirm this. Basalts are not known to host significant amounts of ore in any of the districts in Table 1.

B. Sediments or weakly metamorphosed sediments with typically Late Cretaceous to Early Tertiary intrusions often underlie the volcanics. These underlying rocks less commonly host ore shoots, but when ore does occur, it often contains more of a base metal assemblage than the precious metal deposits in overlying volcanics. Limestone replacement deposits adjacent to the deeper veins are not uncommon.

C. Only a few deposits are older than Tertiary: Rochester is believed to be Cretaceous and the Golden Plateau deposits are thought to be Paleozoic. On the other hand, many are younger than Tertiary. There is little geological reason why deposits cannot have formed throughout the Phanerozoic, however the older deposits are commonly either eroded away or metamorphosed to the point they no longer exhibit epithermal characteristics.

D. The deposits fill pre-existing fractures, not necessarily tension fractures, and where studied in detail, most deposits can be placed in a caldron or resurgent caldron setting. The fractures are

| DISTRICT | PRODUCTION |  | GRADE (2) |  |  |  | TONNAGE x10$^6$ | MAJOR HOSTS | ORE AGE | MINERALOGY OF VEIN (4) | ALTERATION ASSEMBLAGES |  |  |  |  |  | ORE SHOOT RATIO Hor:Vert |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Au Oz. (1) | Ag Oz. (1) | Au Oz/T | Ag Oz/T | Au:Ag | BASE METALS % (3) |  |  |  |  | PROPYLITIC | POTASSIC | ARGILLIC | PHYLLIC | ALUNITIC | SILICIC |  |
| OATMAN, MOHAVE CO., ARIZONA | 2.2 | 0.8 | 0.58 | 0.17 | 2.8:1 | 0 | 3.8 | MIOCENE LATITE, RHY. DIKES & TUFF | MIOCENE | Qt, Ad, Se, El, Ca, rare Py, Ch Fl | X | NO | NO | X<br>illite | X | X | 1:2 to 10:1 |
| PACHUCA, HIDALGO, MEXICO | 6.2 | 1500.0 | 0.06 | 15.0 | 1:200 | 3.5 | 100.0 | MIO.-PLIO. ANDESITE, DACITE, RHYOLITE DIKES | PLIO.? | Ad, Qt, Rb, Rc, Rs, Ca, Se, Ch, El, Ba, Sn, Gn, Sp, Cp, Ar | X | X | X | X | NO | X | 2:1 to 4:1 |
| COMSTOCK, STOREY CO., NEVADA | 8.3 | 200.0 | 0.43 | 9.9 | 1:23 to 1:40 | UNDER 1 | 19.3 | MIOCENE ANDESITE | 13.7 to 12.6 m. y. | Ad, Qt, Ca, Ar, Rb, Au, Py, Cp, Gn, Sp, Rc, Rs, Sn, Fl | X | NO | X | X | X | X | 1:2 to 2:1 |
| GUANAJUATO, GUANAJUATO, MEXICO | 3.55 | 815.0 | 0.05 | 11.0 | 1:200 | UPPER=0<br>DEEP=10 | APPROX. 70.0 | OLIGOCENE ANDES., RHY., LATITE; EOCENE RED BEDS; CRET. SHALES | 28.4 m. y. | Ad, Qt, Ca, Py, El, Ag, Ch, Se, Ar, Al, Na, Rb, Gn, Cp, Sp | X | X | X | X<br>illite | NO | X | 1:1 |
| TONOPAH, NYE CO., NEVADA | 1.86 | 174.0 | 0.23 | 20.7 | 1:80 to 1:110 | UNDER 2 | 8.80 | MIOCENE ANDES. FLOWS, RHYOLITE TUFFS | 19.1 m. y. | Ad, Qt, Ca, Se, Ar, Rb, Py, Cp, Gn, Sn, Na, As, Ba, Rc, Rs, Pl | X | X | X | X | NO | X | 1:1 to 1:3 |

| DISTRICT | EVIDENCE OF BOILING |  |  |  | SALINITY (7) | Th °C (8) | VERTICAL ZONATION | QT PSEUDOMORPHS AFTER CALCITE | VERTICAL ORE EXTENT m. | VEIN ATTITUDES | MAX. VEIN WIDTHS m. | COMMENTS | REFERENCES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | LOW pH CAP TO ORE | ORE SHOOTS WITH FLAT BOTTOMS (5) | VERY FINE-GRAINED QUARTZ | FLUID INCLUSION DATA (6) |  |  |  |  |  |  |  |  |  |
| OATMAN, MOHAVE CO., ARIZONA | X<br>illite | X | X | YES, CO$_2$ RELEASE? |  | 220 | NONE | X | 310 | N40-45W<br>70-80 N | AVE. 2<br>MAX. 20 | SOME MINERALIZED STRUCTURES DIP SOUTH<br>RARE ALUNITE IN ILLITIC CAPS<br>ORE HORIZON DOMED WITH HIGHER Ag:Au RATIO ON FRINGES OF DISTRICT | SCHRADER (1909)<br>RANSOME (1923)<br>CLIFTON & OTHERS (1980)<br>PERSONAL STUDY (1980) |
| PACHUCA, HIDALGO, MEXICO | X<br>phyllic | X | X<br>SOME | YES AT VEIN TOPS |  | 200 to 250 | BASE METALS INCREASE WITH DEPTH | X | 400 | N45-90W 40S-90<br>N00-20E 70W-90<br>N50E 60S-60N | AVE. 1.1<br>MAX. 45 | VEINS PINCH UPWARD TO CALCITE & QUARTZ STRINGERS AND ARE 50° COOLER THAN THAN IN ORE HORIZON, BASE METALS EARLY IN PARAGENESIS | DREIER (1976)<br>THORNBURG (1951)<br>FRIEDRICH & HAWKES (1966)<br>GEYNE & OTHERS (1963) |
| COMSTOCK, STOREY CO., NEVADA | X<br>clays | X | X |  |  | 250 to 300 | NONE | X | 610 | NNE 45E | AVE. 2.5 to 4.2 | Th FROM ONE SAMPLE DEEP IN VEIN SYSTEM<br>VEINS ASSOCIATED WITH CALDERA COMPLEX, ZEOLITIZATION OF WALLROCKS REPORTED | WHITEBREAD (1976)<br>BASTIN (1923)<br>ALBERS & KLEINHAMPL (1970)<br>BONHAM (1969)<br>PERSONAL STUDY (1980) |
| GUANAJUATO, GUANAJUATO, MEXICO | X<br>phyllic | X | SOME | YES | UNDER 1 | 230 | BASE METALS INCREASE WITH DEPTH | X | 650 | N-S to N45W<br>45-70W to 45-70E | 100 | BASE METALS ARE BELOW THE LEVEL OF BOILING WITH PRECIOUS METALS ABOVE, BASE METALS ARE PARAGENETICALLY EARLY | BUCHANAN (1980)<br>GROSS (1975)<br>ANTUNEZ (1964)<br>PERSONAL STUDY (1977-80) |
| TONOPAH, NYE CO., NEVADA | X<br>phyllic | X | X | YES | UNDER 1 | 240 and 265 | BASE METALS INCREASE WITH DEPTH | X | 185 | N70E, 70-90N | 12 | ORE HORIZON DOMED WITH HIGHER Ag:Au RATIO ON FRINGES; Th = 240 FOR PRECIOUS METAL STAGE AND 265 FOR BASE METALS | SPURR (1905)<br>TAYLOR (1973)<br>NOLAN (1935)<br>FAHLEY (ver. comm., 1981)<br>BURGESS (1909)<br>COUCH & CARPENTER (1943) |

TABLE 1: COMPARISON OF EPITHERMAL DISTRICTS
SEE LAST PAGE OF TABLE FOR ABBREVIATIONS AND NOTES

| DISTRICT | PRODUCTION | | GRADE (2) | | | | TONNAGE x$10^6$ | MAJOR HOSTS | ORE AGE | MINERALOGY OF VEIN (4) | ALTERATION ASSEMBLAGES | | | | | | ORE SHOOT RATIO Hor:Vert |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Au Oz. (1) | Ag Oz. (1) | Au Oz/T | Ag Oz/T | Au:Ag | BASE METALS % (3) | | | | | PROPYLITIC | POTASSIC | ARGILLIC | PHYLLIC | ALUNITIC | SILICIC | |
| GOLDFIELD, ESMERALDA CO., NEVADA | 4.2 | 1.65 | 0.79 | 0.3 | 3:1 | UNDER 1 | OVER 5.3 | MIOCENE DACITE AND ANDESITE | 21.0 m. y. | Qt, Se, Ka, Rb, Au, Py, Fa, Te, Ba, Go, Al, Tl | X | NO | X | X | X | X | |
| SILVER PEAK, ESMERALDA CO., NEVADA | 0.19 | 36.96 | 0.03 | 8.03 | 1:243 | 1-4 | 4.6 | MIO.-PLIO. LATITE, RHYOLITE, TRACHYTE, ANDESITE FLOWS | UNDER 6 m. y. | Ad, Qt, Ca, Rb, Ar, El, Ba, Py, Sp, Cp, Gn, Ag, Si | X | ? | X | X | NO? | X | 5:1<br>FOR 16:1 VEIN |
| CREEDE, MINERAL CO., COLORADO | 0.14 | 81.8 | 0.08 | 25.1 | 1:400 | 5 | 3.3 | OLIGOCENE ANDESITE AND RHYOLITE TUFF | OLIG. | Ad, Qt, Ca, Ba, Ch, Se, Ar, An, Fl, Si, Gn, Sp, Ag, Py, Rc, Te, Pa | X | X | X | X | NO | X | 4:1 |
| ROUND MOUNTAIN, NYE CO., NEVADA | 0.84 | 0.26 | 0.08 | 0.02 | 1:0.2 | 0.01 | 12.7 | MIOCENE LAKE BEDS, RHYOLITE TUFFS, IGNIMBRITE | 25.0 m. y. | Ad, Qt, Au, Fl, Py, As, Re, Ca, Al, Se | X | X<br>weak adularia | X<br>Kaolin | X<br>Sericite | X | X | |
| EUREKA DIST., SAN JUAN CO., COLORADO | APPROX. 0.15 | APPROX. 6.8 | 0.06 | 2.8 | 1:47 | 7.5 | APPROX. 2.5 | TERTIARY QUARTZ LATITE TUFF AND LAVAS | 13-16 m. y. | Ad, Qt, Au, Rb, Ag, Rc, Re, Te, Fl, Ag, Sp, Gn, Py, Tl | X | ? | X | X | NO | X | 1:1 to 1:3 |

| DISTRICT | EVIDENCE OF BOILING | | | | SALINITY (7) | Th °C (8) | VERTICAL ZONATION | QT PSEUDOMORPHS AFTER CALCITE | VERTICAL ORE EXTENT m. | VEIN ATTITUDES | MAX. VEIN WIDTHS m. | COMMENTS | REFERENCES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LOW pH CAP TO ORE | ORE SHOOTS WITH FLAT BOTTOMS (5) | VERY FINE-GRAINED QUARTZ | FLUID INCLUSION DATA (6) | | | | | | | | | |
| GOLDFIELD, ESMERALDA CO., NEVADA | X<br>alunite clays | X | X | Solutions Boiled During Low pH Alteration | | 200 to 300 | BASE METALS INCREASE WITH DEPTH | - | 305 | NS TO NW, HORIZ. TO VERT. | 55 | ALUNITE IS A GANGUE MINERAL, VEINS ASSOC. WITH CALDERA, BOILING IS NOTED TO OVER 330 M. DEPTH, GOLDFIELDITE & TELLURIDES IN ORES | ALBERS & KLEINHAMPL (1970)<br>TAYLOR (1973)<br>RANSOME (1909)<br>TOLMAN & AMBROSE (1934)<br>PERSONAL STUDY (1980)<br>ASHLEY (1981, verb. comm.) |
| SILVER PEAK, ESMERALDA CO., NEVADA | X<br>Phyllic | X | X | YES | | | BASE METALS INCREASE WITH DEPTH | X | 152 | NE, N & S DIP | 9 | DATA FOR VOLCANIC-HOSTED DEPOSITS ONLY, SILICIFICATION DECREASES WITH DEPTH, VEINS ASSOC. WITH CALDERA | ALBERS & KLEINHAMPL (1970)<br>SILBERMAN & MCKEE (1974)<br>ANONYMOUS (1980)<br>PERSONAL STUDY (1980) |
| CREEDE, MINERAL CO., COLORADO | X<br>illite | X | | YES NEAR VEIN TOPS | | 250 | BASE METALS INCREASE WITH DEPTH | | 310 | N-S TO N40W<br>40-80S AMETHY.<br>50-60N ALPHA-C. | | INCLUDES BULLDOG VEIN, HIGHEST GRADE AREAS ARE STRONGLY ARGILLIZED, TONNAGE GIVEN IS MINED AND PROBABLE, CHEVRON DEPOSIT NOT INCLUDED, VEINS ASSOC. WITH CALDERA | WETLAUFER & OTHERS (1965)<br>JACKSON (1974) |
| ROUND MOUNTAIN, NYE CO., NEVADA | X<br>alunite | X | | YES BELOW ALUNITE | | | | PRESENT, BUT RARE | 125 | N60W<br>WNW, HORIZ. | | INCLUDES SMOKEY VALLEY RESERVES, VEINS ASSOC. WITH CALDERA, BEST GRADES ASSOC. WITH ADULARIA | FERGUSON (1927)<br>PACKARD (1907)<br>COUCH & CARPENTER (1943)<br>BERGER (1980) |
| EUREKA DIST., SAN JUAN CO., COLORADO | X | X | | NO | 0.8 | 285 to 293 | BASE METALS INCREASE WITH DEPTH | | 610 | N50E and N60W | AVE. 1.0 | PRODUCTION IS APPROX., PRE-PRECIOUS METAL Th IS 285-290 °C WITH SALINITY OF 0.1-1.5%, ORE IN BENDS IN VEINS AND IN VEIN INTERSECTIONS | LANGSTON (1979)<br>CASADEVALL & OHMOTO (1977)<br>BURBANK & LUEDKE (1969) |

TABLE 1, CONTINUED

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| DISTRICT | PRODUCTION | | GRADE (2) | | | | TONNAGE x10$^6$ | MAJOR HOSTS | ORE AGE | MINERALOGY OF VEIN (4) | ALTERATION ASSEMBLAGES | | | | | | ORE SHOOT RATIO Hor:Vert |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Au Oz. (1) | Ag Oz. (1) | Au Oz/T | Ag Oz/T | Au:Ag | BASE METALS % (3) | | | | | PROPYLITIC | POTASSIC | ARGILLIC | PHYLLIC | ALUNITIC | SILICIC | |
| AURORA, MINERAL CO., NEVADA | 1.53 | 20.11 | 2.24 | 30.0 | 1:14 | UNDER 1 | 0.83 | MIOCENE QUARTZ LATITE, ANDES. FLOWS AND BRECCIAS | 10.0 to 12.5 m. y. | Ad, Qt, Au, Ar, Te, Ag, Py, Na, Cp, Ca | X | | X | X Sericite | | X | |
| GOLD CIRCLE (MIDAS), ELKO CO., NEVADA | 0.13 | 1.63 | 0.31 | 4.6 | 1:15 | UNDER 1 | 0.4 | MIOCENE RHYOLITE FLOWS (?) AND ANDES. FLOWS | 15.0 m. y. | Ad, Qt, Au, Ca, Ar, Cp, Rb, Ch, Te, Sp, Py, Ag, Sr, Pl | X | | X? | X | | X | 2:1 to 4:1 |
| CORNUCOPIA, ELKO CO., NEVADA | 0.134 | 0.762 | 0.43 | 24.6 | 1:68 | 0 | 0.031 | TERTIARY ANDES. PLUG, RHYOLITE | 15.0 m. y. | Qt, Ca, Cp, Ar, Rb, Py, Te, Ba, Bo, Sn, Gn, Sp | X | NO | X Close to ore | X Close to ore | | X | |
| BULLFROG, NYE CO., NEVADA | 0.12 | 0.874 | 0.34 | 3.0 | 1:8 to 1:16 | UNDER 0.1 | 0.29 | MIOCENE RHYOLITE BRECCIAS AND FLOWS | 9.0 m. y. | Ad, Qt, Ca, Cc, Ag, Ag, Py, Cy | | | X Assoc. w/ ore | | X | X | |
| JARBIDGE, ELKO CO., NEVADA | 0.22 | 1.28 | 0.49 | 1.4 | 1:3 | 0 | 0.89 | MIOCENE RHYOLITE ASH, FLOWS, BRECCIAS | 14.0 m. y. | Ad, Qt, Au, Rb, Ar, Cp, El, Ba, Py, Fl, Na, Se, Ca, Tl | X | X adularia | X | X | | X | |

| DISTRICT | EVIDENCE OF BOILING | | | | SALINITY (7) | Th °C (8) | VERTICAL ZONATION | QT PSEUDOMORPHS AFTER CALCITE | VERTICAL ORE EXTENT m. | VEIN ATTITUDES | MAX. VEIN WIDTHS m. | COMMENTS | REFERENCES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LOW pH CAP TO ORE | ORE SHOOTS WITH FLAT BOTTOMS (5) | VERY FINE-GRAINED QUARTZ | FLUID INCLUSION DATA (6) | | | | | | | | | |
| AURORA, MINERAL CO., NEVADA | YES, "CLAY" | | X | | | | | X | 1307 | N40-50E 45-60S<br>N60-80E | 24 | ASSOCIATED WITH CALDERA COMPLEX, Ag PRODUCTION IS APPROX.<br>SOME ORE SHOOTS WITH FLAT TOPS | ALBERS & KLEINHAMPL (1970)<br>ROSS (1961)<br>SILBERMAN & MCKEE (1974)<br>COUCH & CARPENTER (1943) |
| GOLD CIRCLE (MIDAS), ELKO CO., NEVADA | X Phyllic | X | SOME | | | | | X | 183 | N30-60W 65N-90 | 4.6 | SAID TO BE CHALKY NEAR ORE SHOOTS | ROBERTS & OTHERS (1971)<br>GRANGER & OTHERS (1957)<br>ROTT (1931)<br>SIRDEVAN (1913) |
| CORNUCOPIA, ELKO CO., NEVADA | X Sericite Kaolin | X | | | | | | | | N78E 83N | 0.6 | ORE LARGELY OXIDIZED, SOME ORE DISSEMINATED IN HOST ROCKS | GRANGER & OTHERS (1957)<br>ROBERTS & OTHERS (1971) |
| BULLFROG, NYE CO., NEVADA | X Clays | | X | | | | | X | OVER 124 | N60E 70W<br>N-S<br>N30E | 30 | GRADES ARE APPROXIMATED, ORES INSIDE ARGILLIC HALO, VEINS ASSOC. WITH CALDERA | ALBERS & KLEINHAMPL (1970)<br>TAYLOR (1973)<br>CORNWALL & KLEINHAMPL (1964)<br>RANSOME & OTHERS (1910) |
| JARBIDGE, ELKO CO., NEVADA | | X | X | | | | | X | 280 | "Northerly" w/ west dips, N to NW, 80E | 10 | MUCH ADULARIA IN VEINS, GRADES ARE APPROXIMATED | ROBERTS & OTHERS (1971)<br>GRANGER & OTHERS (1957)<br>SCHRADER (1923) |

TABLE 1, CONTINUED

| DISTRICT | PRODUCTION | | GRADE (2) | | | | TONNAGE $\times 10^6$ | MAJOR HOSTS | ORE AGE | MINERALOGY OF VEIN (4) | ALTERATION ASSEMBLAGES | | | | | | ORE SHOOT RATIO Hor:Vert |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Au Oz. (1) | Ag Oz. (1) | Au Oz/T | Ag Oz/T | Au:Ag | BASE METALS % (3) | | | | | PROPYLITIC | POTASSIC | ARGILLIC | PHYLLIC | ALUNITIC | SILICIC | |
| ROCHESTER, PERSHING CO., NEVADA | 0.078 | 8.88 | 0.086 | 9.74 | 1:113 | 0.02 | 0.911 | PERMO-TRIAS. RHYOLITE | 72.5 to 78.8 m. y. | Ad, Qt, Ca, Te, Se, Ar, Rb, El, Py, Sp, Cp, Po, As, Al, To | X | X | NO | X<br>Sericite | X<br>MINOR | X | 5:3 |
| MOGOLLON, CATRON CO., NEW MEXICO | 0.278 | 13.2 | 0.22 | 10.4 | 1:58 | UNDER 1% EXCEPT IN DEEP LEVELS | 1.39 | TERTIARY ANDESITE & RHY. TUFFS, FLOWS, BRECCIAS & DIKES | MIO.(?) | Ad, Qt, Ca, Ar, Py, Te, Fl, Gn, Sp, Cp, Bo | X | X<br>adularia | X | X | NO | X | 1:1 to 1:3 |
| BODIE, MONO CO., CALIFORNIA | 1.456 | 7.28 | | | 1:5 | VERY LOW | | MIOCENE ANDESITE AND DACITE, DACITE PLUGS | 8.6 to 7.1 | Ad, Qt, Ca, Ar, Rb, El, Sn, Py Sp | X | X | X? | | | X | |
| TUSCARORA, ELKO CO., NEVADA | 0.162 | 7.14 | 0.38 | 16.8 | 1:44 to 1:100 | 0.02 | 0.425 | EOCENE-OLIG. RHY. TUFF, ANDES. FLOW, ANDES. PLUG | 38.0 m. y. | Ad, Qt, Ca, Ar, Rb, Py, Sn, En, Bo, Gn, Sp, Cp, Cy, Au, Ag, As | X | X<br>adularia | X | X | | | |
| TAYOLTITA, DURANGO, MEXICO | 6.24 | 318.0 | 0.52 | 26.5 | 1:51 | 1 | OVER 12.0 | TERTIARY ANDESITE FLOW, EOCENE PLUG, RHYOLITE PORPHYRY | OLIGOCENE | Ad, Qt, Ca, Ch, Ar, Sp, Rb, El, Au, Ag, Py, Cp, Gn, Sr | X | X | | | | X | 2:1 to 4:1 |

| DISTRICT | EVIDENCE OF BOILING | | | | SALINITY (7) | Th °C (8) | VERTICAL ZONATION | QT PSEUDOMORPHS AFTER CALCITE | VERTICAL ORE EXTENT m. | VEIN ATTITUDES | MAX. VEIN WIDTHS m. | COMMENTS | REFERENCES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LOW pH CAP TO ORE | ORE SHOOTS WITH FLAT BOTTOMS (5) | VERY FINE-GRAINED QUARTZ | FLUID INCLUSION DATA (6) | | | | | | | | | |
| ROCHESTER, PERSHING CO., NEVADA | X<br>Phyllic | X | X | YES LOSS OF $CO_2$ | 6 | 270 to 310 | SILVER VALUES DECREASE WITH DEPTH | | 300 | N to N30E 30-70W | AVE. 3<br>MAX. 13 | ANDALUSITE-DUMORTIERITE ALTERATION REPORTED, BULK TONNAGE POTENTIAL NOT INCLUDED, SOLUTIONS HAD 15-20% $CO_2$, BOILING IS $CO_2$ RELEASE | VIKRE (1978)<br>KNOPH (1924) |
| MOGOLLON, CATRON CO., NEW MEXICO | NO? | X | | | | | BASE METALS INCREASE WITH DEPTH | X | 365 | N60W 75-89N<br>N10E 70S | 10 | QT VEINS PASS UPWARD TO CA VEINS | FERGUSON (1921)<br>KAMILLI & OHMOTO (1977)<br>PERSONAL STUDY (1977) |
| BODIE, MONO CO., CALIFORNIA | SAID TO BE BLEACHED NEAR ORE | X | X | | | 215 to 245 | Au, Ag VALUES DECREASE WITH DEPTH | | 400 | N60-70E<br>N10E | | ASSOCIATED WITH CALDERA COMPLEX | ALBERS & KLEINHAMPL (1970)<br>WHITE (1974)<br>SAWKINS (1980)<br>PERSONAL STUDY (1980) |
| TUSCARORA, ELKO CO., NEVADA | X<br>Sericite | | | | | | | yes | 110 | [illegible] | 1 | ADULARIA ASSOCIATED WITH HIGHEST Au VALUES, BULK POTENTIAL NOT INCLUDED, MUCH OF Au PRODUCTION IS FROM PLACERS | GRANGER & OTHERS (1957)<br>ROBERTS & OTHERS (1971) |
| TAYOLTITA, DURANGO, MEXICO | NO | X<br>WITH POST-ORE TILTING | X | YES | 3.3 to 8.4 | 265 | BASE METALS INCREASE WITH DEPTH | | 600 | N10W, 65-85E<br>N40-70E, 40-80W | 15 | WALLROCKS SAID TO BE ALBITIZED, FLUIDS BOILING ONLY IN AREAS OF HIGHER Au AND Ag VALUES AND AT VEIN TOPS VEINS ASSOC. W/ CALDERA | ALBINSON<br>BROCUM (1971)<br>SAWKINS, 1980, verbal com.<br>SMITH (1974)<br>SMITH & OTHERS (1979)<br>ORDONEZ (1973) |

TABLE 1, CONTINUED

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| DISTRICT | PRODUCTION |  | GRADE (2) |  |  |  | TONNAGE x10$^6$ | MAJOR HOSTS | ORE AGE | MINERALOGY OF VEIN (4) | ALTERATION ASSEMBLAGES |  |  |  |  |  | ORE SHOOT RATIO Hor:Vert |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Au Oz. (1) | Ag Oz. (1) | Au Oz/T | Ag Oz/T | Au:Ag | BASE METALS % (3) |  |  |  |  | PROPYLITIC | POTASSIC | ARGILLIC | PHYLLIC | ALUNITIC | SILICIC |  |
| REPUBLIC, FERRY CO., WASHINGTON | 0.86 | 5.45 | 0.345 | 2.18 | 1:6.3 | UNDER 1 | 2.5 | OLIGOCENE RHY. TUFF, ANDESITE TUFF AND QUARTZ LATITE PORPH. | OLIG. | Ad, Qt, Cp, Ca, Na, Au, Te, Ar, Ag, Sn, Py, Al, St, El, La | X | X | X | X |  | X | 1:2 |
| FRESNILLO, ZACATECAS, MEXICO | 0.32 | 20.5 |  |  | 1:646 | ABOUT 4 |  | CRETACEOUS SHALE & LIMESTONE CAPPED BY CONGL. & MISC. VOLCANICS | OLIG.? | Ad, Qt, Ca, Rb, Ar, El, Ag, Au, Py, Sp, Cp, Gn, Po, As, Pl | X |  |  |  |  |  | 1:1 to 3:1 |
| HAYDEN HILL, LASSEN CO., CALIFORNIA | 0.09 | ? | 1.0 | 1.5 | 1:1.5 | 0 | 0.13 | OLIG.-MIOCENE DACITIC VOLCANICLASTIC SHALES & CONGLOMERATE, AND AGGLOM. | MIOCENE | Ad, Qt, El, Au, Sn?, Pr | X | X<br>Adularia | MINOR, IN VEIN FOOTWALL | NO | NO | X |  |
| SEVEN TROUGHS, PERSHING CO., NEVADA | 0.16 | 0.996 | 1.2 | 6.5 | 1:5.4 | 0 | 0.152 | TERTIARY RHY. PLUGS, FLOWS & TUFFS. BASALT FLOWS | 14.0-13.7 m. y. | Ad, Qt, El, Rb, Ca, Py, Au, Ch, Ar | X | X | X<br>Kaolin | X |  | X | 1:1 to 5:8 |
| NATIONAL, HUMBOLDT CO., NEVADA | APPROX. 0.18 | APPROX. 0.18 | 2.8 | 2.8 | 1:1 | UNDER 1 | 0.115 | MIOCENE RHYOLITE DIKES, LATITE FLOWS | MIOCENE OR YOUNGER | Ad, Qt, Ca, Rb, El, Py, As, Cp, St, Gn, Sp, Se, Bo, Sn | X | X<br>Adularia |  | X<br>Sericite |  | X | 1:2 |

| DISTRICT | EVIDENCE OF BOILING |  |  |  | SALINITY (7) | Th °C (8) | VERTICAL ZONATION | QT PSEUDOMORPHS AFTER CALCITE | VERTICAL ORE EXTENT m. | VEIN ATTITUDES | MAX. VEIN WIDTHS m. | COMMENTS | REFERENCES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | LOW pH CAP TO ORE | ORE SHOOTS WITH FLAT BOTTOMS (5) | VERY FINE-GRAINED QUARTZ | FLUID INCLUSION DATA (6) |  |  |  |  |  |  |  |  |  |
| REPUBLIC, FERRY CO., WASHINGTON |  |  | X | SEE NOTES |  |  | Au DECREASES, CALCITE INCREASES WITH DEPTH | X | 260 | N30-60E SE DIP<br>N7E-N30W 45 to 80E DIP | 33 | MANY FLUID INCLUSIONS WITH 100% VAPOR, AVE. VEIN 1.0 m. WIDE, MAY HAVE STACKED ORE LEVELS, ORE SHOOTS AT BENDS CONCAVE TO FOOTWALL, SILICIF. DECREAS. W/ DEPTH | MUESSIG (1967)<br>FULL & GRANTHAM (1968)<br>BANCROFT (1914)<br>UMPLEBY (1910) |
| FRESNILLO, ZACATECAS, MEXICO |  |  |  | SEE NOTES |  |  | BASE METALS INCREASE WITH DEPTH |  | 1000 | E-W<br>N10-45W 45-90S | 1.4 | SOME STUDIES SHOW BOILING EVIDENCE, OTHERS DO NOT; ALTERATION NOT REPORTED, HAS MANTO REPLACEMENTS IN CRETACEOUS LIMESTONE | PERSONAL STUDY (1977)<br>DE CSERNA (1976)<br>LOWTHER (Verbal Comm., 1977-78)<br>ORDONEZ (1973) |
| HAYDEN HILL, LASSEN CO., CALIFORNIA | SEE NOTES | X | X |  |  |  | NONE | X | 120 | N68W 60-80N | MAX. 7<br>AVE. 0.3 | EXCLUDES BULK POTENTIAL OF 390,000 T OF 0.054 Au & 0.45 Ag,<br>DISTRICT APPEARS DEEPLY ERODED, HAS NO LOW pH CAP OR HALO | PERSONAL STUDY (1980-81) |
| SEVEN TROUGHS, PERSHING CO., NEVADA | X<br>Phyllic |  | SOME | NO |  | 240 to 318 | NONE | X | 245 | N00-20E | AVE. 0.9 | GRADES ARE APPROXIMATED, HAS INTRAVOLCANIC ALTERATION, ORE IN CONCAVE BENDS TO HANGING WALL & IN STEEP PARTS OF VEINS, MOST Th READINGS CENTERED ON 260° | BRUCE (Verbal. Comm., 1981)<br>PERSONAL STUDY (1980)<br>KECKLER (1980)<br>RANSOME (1909)<br>SILBERMAN & MCKEE (1974) |
| NATIONAL, HUMBOLDT CO., NEVADA |  |  | X |  |  |  |  | X | 245 | N15E-N25W, 50-80W | 1.5 | ORE IN CONCAVE BENDS TO HANGING WALL, TOP OF ORE IS 18 m. BELOW SURFACE, STIBNITE MOST ABUNDANT SULFIDE | LINDGREN (1915)<br>COUCH & CARPENTER (1943)<br>WINCHELL (1912)<br>ROBERTS & OTHERS (1971) |

TABLE 1, CONTINUED

| DISTRICT | PRODUCTION |  | GRADE (2) |  |  |  | TONNAGE x10$^6$ | MAJOR HOSTS | ORE AGE | MINERALOGY OF VEIN (4) | ALTERATION ASSEMBLAGES |  |  |  |  |  | ORE SHOOT RATIO Hor:Vert |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Au Oz. (1) | Ag Oz. (1) | Au Oz/T | Ag Oz/T | Au:Ag | BASE METALS % (3) |  |  |  |  | PROPYLITIC | POTASSIC | ARGILLIC | PHYLLIC | ALUNITIC | SILICIC |  |
| MONITOR, ALPINE CO., CALIFORNIA | 2.5 NOT MINED<br>0.009 MINED | 80.0 NOT MINED<br>0.25 MINED | 0.06 | 2.0 | 1:33 | NEARLY 0 | 40.0 NOT MINED | TERTIARY RHYOLITE PLUG AND BRECCIA | 5.0 m. y. |  | X | X adularia | X | X Sericite |  | X |  |
| GILBERT, ESMERALDA CO., NEVADA | 0.005 | Nil | 1.25 | Nil |  | 0 | 0.004 | MIOCENE RHY. ASH & PORPHYRY, ANDESITE | 8.0 m. y. | Ad, Qt, Ar, Rb, Au, Cy, Ca, Py, Cp | X |  | X | X | X | X |  |
| RAMSEY-TALAPOOSA, LYON CO., NEVADA | 0.07 | 6.6 | 0.89 | 83.5 | 1:95 | UNDER 1 | 0.09 | MIOCENE ANDESITE FLOWS & DIKES, RHY. | 10.0 m. y. | Ad, Qt, Py, Ca, Ar, Cp, Cy, Au | X |  | X Kaolin | X |  | X |  |
| CEDAR MTN., MINERAL CO., NEVADA | 0.034 | APPROX. 0.68 | 0.04 | 0.81 | 1:20 | 0 | 0.834 | TERTIARY ANDESITE, DACITE TUFF, QUARTZ LATITE |  | Qt, El, Py |  |  | X | X | X? | X |  |
| RAWHIDE, MINERAL CO., NEVADA | 0.051 | 0.697 | 0.72 | 9.9 | 1:14 | 0.2 | 0.071 | MIOCENE RHY., DACITE, ANDESITE | 11.0 to 16.0 m. y. | Ad, Qt, Ar, El, Rb, Cy |  | X | X | X |  | X |  |

| DISTRICT | EVIDENCE OF BOILING |  |  |  | SALINITY (7) | Th °C (8) | VERTICAL ZONATION | QT PSEUDOMORPHS AFTER CALCITE | VERTICAL ORE EXTENT m. | VEIN ATTITUDES | MAX. VEIN WIDTHS m. | COMMENTS | REFERENCES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | LOW pH CAP TO ORE | ORE SHOOTS WITH FLAT BOTTOMS (5) | VERY FINE-GRAINED QUARTZ | FLUID INCLUSION DATA (6) |  |  |  |  |  |  |  |  |  |
| MONITOR, ALPINE CO., CALIFORNIA | CLAY HALO |  | X |  |  |  |  | MINOR |  |  |  | BULK TONNAGE RESERVES OF ZACA MINE INCLUDED | SILBERMAN & MCKEE (1974)<br>PERSONAL STUDY (1980) |
| GILBERT, ESMERALDA CO., NEVADA | X |  | X |  |  |  |  | X | OVER 100 | N45W 60-90W<br>N-S 50W<br>N30E 80W | 1<br>12<br>1 | SAID TO BE "BLEACHED" NEAR ORES, MOST ORE IN ORDOVICIAN LIMESTONE BELOW VOLCANICS, SOME IN ANDESITES | SILBERMAN & MCKEE (1974)<br>ARCHBOLD & BLOMQUIST (1969<br>FERGUSON (1928) |
| RAMSEY-TALAPOOSA, LYON CO., NEVADA | X CLAY |  | SOME | YES |  | 221 |  | X | OVER 213 | E-W 55-65S | 8.5 | Au PRODUCTION IN PART FROM PLACERS, DATA INCLUDES GOOSEBERRY MINE, Th FROM GOOSEBERRY | SILBERMAN & MCKEE (1974)<br>COUCH & CARPENTER (1943)<br>WISSER & LINDSEY (1966)<br>PERSONAL STUDY |
| CEDAR MTN., MINERAL CO., NEVADA |  |  |  |  |  |  |  | X |  |  |  | Ag PRODUCTION APPROXIMATE | KNOPF (1922) |
| RAWHIDE, MINERAL CO., NEVADA | X Kaolin |  |  |  |  |  |  |  |  |  |  | HIGHEST GRADE ORES ASSOCIATED WITH KAOLIN | SILBERMAN & MCKEE (1974)<br>KOSCHMANN & BERGENDAHL (1968)<br>ROGERS (1911)<br>COUCH & CARPENTER (1943) |

TABLE 1, CONTINUED

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| DISTRICT | PRODUCTION | | GRADE (2) | | | | TONNAGE x10$^6$ | MAJOR HOSTS | ORE AGE | MINERALOGY OF VEIN (4) | ALTERATION ASSEMBLAGES | | | | | | ORE SHOOT RATIO Hor:Vert |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Au Oz. (1) | Ag Oz. (1) | Au Oz/T | Ag Oz/T | Au:Ag | BASE METALS % (3) | | | | | PROPYLITIC | POTASSIC | ARGILLIC | PHYLLIC | ALUNITIC | SILICIC | |
| BOHEMIA, LANE/DOUGLAS CO. OREGON | 0.031 | 0.035 | | | 1:6 | 9 | 0.08 | MIOCENE DACITE PORPHYRY; ANDESITE FLOW, BRECCIA & TUFF | | Ad, Qt, Ca, Au, Py, Gn, Cp, Sp, St, Ba, He | X | X | X<br>Kaolin | X | | X | 1:1 to 1:3 |
| SEARCHLIGHT, CLARK CO., NEVADA | 0.247 | 0.220 | 0.44 | 0.47 | 1:1 | 0.3 | 0.469 | TERTIARY QTZ. MONZON. STOCK, ANDESITE | | Ad, Qt, Ca, Au, Gn, Py, Ce, Wu, Sc, Cl | X | X<br>Adularia | X | X | | X | 3:7 |
| MOHAVE, KERN CO., CALIFORNIA | | | | | 1:2 to 1:12 | MINOR | | TERTIARY RHY. TUFF & FLOWS | PLIO.? | Ad, Qt, Ca, Ar, Au, Py, Bu, Cp, Sp, Gn, Ja | | | X | X | | X | |
| CALICO, S. BERNARDINO CO CALIFORNIA | 0.014 | 17.5 | | | 1 to 1200 | "MODERATE" | | OLIG.-MIOCENE LACUSTRINE TUFFACEOUS SED., VOLC. TUFF & BRECCIA | MIOCENE | Qt, Ba, Ca, Ag, Ar, Rb, Te, St, Si, Cy, Br, Py | X | | | | | X | |
| GREAT BARRIER ISLAND, NEW ZEALAND | 41.5 | 1250.0 | | | 1:4 to 1:30 | 3 | | EOCENE-MIO. ANDESITE TUFF & BRECCIA, DACITE, RHY. | PLIO. | Qt, Ar, Rb, El, Py, As, Ai, Cp, Gn, Sp, Ma, Ca, Ch, St, Rc, Ad, Se | X | X<br>Adularia | X | X | | X | |

| DISTRICT | EVIDENCE OF BOILING | | | | SALINITY (7) | Th °C (8) | VERTICAL ZONATION | QT PSEUDOMORPHS AFTER CALCITE | VERTICAL ORE EXTENT m. | VEIN ATTITUDES | MAX. VEIN WIDTHS m. | COMMENTS | REFERENCES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LOW pH CAP TO ORE | ORE SHOOTS WITH FLAT BOTTOMS (5) | VERY FINE-GRAINED QUARTZ | FLUID INCLUSION DATA (6) | | | | | | | | | |
| BOHEMIA, LANE/DOUGLAS CO. OREGON | X | | X | | | | BASE METALS INCREASE WITH DEPTH | | 100 | N45-90W 60-70S | AVE. 1 | CLAY DECREASES AND SERICITE INCREASES WITH DEPTH IN VEIN WALLS, WALLS SAID "BLEACHED" NEAR ORE | MACDONALD (1908)<br>TABER (1949) |
| SEARCHLIGHT, CLARK CO., NEVADA | | X | | | | | | X | 335 | N65W SW DIP | 15 | MUCH $PbMoO_4$ IN ORES, SOME FLAT VEINS | PERSONAL STUDY (1980)<br>PROCTOR & DORAIBABU (1977)<br>COUCH & CARPENTER (1943)<br>CALLAGHAN (1939) |
| MOHAVE, KERN CO., CALIFORNIA | | | X | | | | PYRITE INCREASES WITH DEPTH | X | 110 | NW, E & W DIP | 2 | | SCHROTER (1935) |
| CALICO, S. BERNARDINO C. CALIFORNIA | | | | | | | | | | NW | | DATA EXCLUDE 49.0 MILLION TONS OF 2.7 Ag OZ/TON AT WATERLOO & LANGTRY WITH MUCH BARITE GANGUE, THE COMPANY EXPECTS 65% Ag RECOVERY | PERSONAL STUDY (1962-80) |
| GREAT BARRIER ISLAND, NEW ZEALAND | Sericite Halo | | X | | | | BASE METALS INCREASE WITH DEPTH | X | 465 | N45-80W, DIPS 40-80S AND 80N | 10 | Ag PRODUCTION APPROXIMATE, ZEOLITIZATION OF WALLROCKS NOTED, Ag DECREASES WITH DEPTH, PHYLLIC POST-DATES POTASSIC ALTERATION AS AT GUANAJUATO | EMMONS (1937)<br>RAMSAY & KOBE (1974)<br>WEISSBERG & WODZICKI (1970) |

TABLE 1, CONTINUED

| DISTRICT | PRODUCTION | | GRADE (2) | | | | TONNAGE x10$^{6}$ | MAJOR HOSTS | ORE AGE | MINERALOGY OF VEIN (4) | ALTERATION ASSEMBLAGES | | | | | | ORE SHOOT RATIO Hor:Vert |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Au Oz. (1) | Ag Oz. (1) | Au Oz/T | Ag Oz/T | Au:Ag | BASE METALS % (3) | | | | | PROPYLITIC | POTASSIC | ARGILLIC | PHYLLIC | ALUNITIC | SILICIC | |
| GUADALUPE Y CALVO, CHIHUAHUA, MEXICO | APPROX 2.0 | APPROX. 28.0 | 1.18 | 16.6 | 1:40 | RARE | APPROX. 1.7 | TERTIARY ANDESITE FLOWS | OLIG.? | Qt, Ch, Ar, Ag, Au, Py, Gn, Cp, Sp | X | | X | | | X | |
| OCAMPO, CHIHUAHUA, MEXICO | 0.175 | 6.65 | 0.25 | 9.5 | 1:60 | 0.03 | 0.7 | EOCENE ANDESITE FLOWS & TUFF, RHYOLITE TUFF | 29.0 to 27.0 m. y. | Qt, Ca, Ar, Au, El, Te, Sn, Py, Sp, Cp, Gn | X | | X | X | | X | 1:1 |
| YOQUIVO, CHIHUAHUA, MEXICO | 0.052 | 5.4 | 0.35 | 36.0 | 1:74 | "MODER-ATE" | 0.150 | TERTIARY ANDESITE FLOWS & TUFF, LATITE FLOWS | | Ad, Qt, Au, El, Ag, Py, Sn, Gn, Ca, Sp, Cp, Ar, Sr | X | X | X | | | X | 2:1 |
| EL ORO, MEXICO, MEXICO | 0.86 | APPROX. 20.0 | ABOUT 0.4 | ABOUT 4.0 | 1:7 | 0 | OVER 5.0 | MIOCENE ANDESITE FLOW ATOP CRETACEOUS(?) SHALE AND SANDSTONE | | Qt, Ca, Ka, Ar, Rb, Au, Cp, Py | X | | X | | | X | 8:1 |
| GUANACEVI, DURANGO, MEXICO | APPROX. 1.0 | APPROX. 440.0 | 0.17 | 73.0 | 1:100 to 1:500 | 6-12 | 6.0 | TERTIARY ANDESITE FLOWS, REDBED CONGLOMERATE | POST 38.0 m. y. | Ad, Qt, Ca, Py, Ar, Rb, Hl, Te, Sn, Fl, Ba, Rs, Bo, Tn, Gn, Sp, Cp | X | | X | X | | X | 1:1 |

| DISTRICT | EVIDENCE OF BOILING | | | | SALINITY (7) | Th °C (8) | VERTICAL ZONATION | QT PSEUDOMORPHS AFTER CALCITE | VERTICAL ORE EXTENT m. | VEIN ATTITUDES | MAX. VEIN WIDTHS m. | COMMENTS | REFERENCES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LOW pH CAP TO ORE | ORE SHOOTS WITH FLAT BOTTOMS (5) | VERY FINE-GRAINED QUARTZ | FLUID INCLUSION DATA (6) | | | | | | | | | |
| GUADALUPE Y CALVO, CHIHUAHUA, MEXICO | | | X | | | | BASE METALS INCREASE WITH DEPTH | | 400 | NW, Dip W | 30 | Au VALUES DECREASE WITH DEPTH | BAILEY (1931)<br>TURNER (1978)<br>CLARK & OTHERS (1979) |
| OCAMPO, CHIHUAHUA, MEXICO | X argillic | | | | | | | | 400 | NW & NE, SW DIPS | 12 | BASE METALS EARLIER THAN PRECIOUS METALS, ORE IS POST-DACITE STOCK EMPLACEMENT | WISSER (1966)<br>KNOWLING (1977)<br>LINTON (1912)<br>CLARK & OTHERS (1979) |
| YOQUIVO, CHIHUAHUA, MEXICO | | | X Chalcedony | | | | | | 295 | N05-40E, 60-75E<br>N-S to N14E, 75-80E to 75-80W | 12 | CALCITE IS POST ORE. | WISSER (1966)<br>HALL (1926) |
| EL ORO, MEXICO, MEXICO | X bleached | X | X | | | | BASE METALS INCREASE WITH DEPTH | X | 215 | NNW, W Dip<br>N-S, E & W dip | AVE. 3<br>MAX. 38 | Au PRODUCTION APPROXIMATE, TONNAGE APPROXIMATE | EMMONS (1937)<br>LINDGREN (1933)<br>LOCKE (1913) |
| GUANACEVI, DURANGO, MEXICO | | X | X | | | | | | 400 | N10W, W dip | 40 | ADULARIA GANGUE ASSOCIATED WITH HIGHEST GOLD VALUES | DURNING (1978)<br>HALPERN (1939)<br>TERRONES (1922) |

TABLE 1, CONTINUED

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| DISTRICT | PRODUCTION |  | GRADE (2) |  |  |  | TONNAGE x10$^6$ | MAJOR HOSTS | ORE AGE | MINERALOGY OF VEIN (4) | ALTERATION ASSEMBLAGES |  |  |  |  |  | ORE SHOOT RATIO Hor:Vert |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Au Oz. (1) | Ag Oz. (1) | Au Oz/T | Ag Oz/T | Au:Ag | BASE METALS % (3) |  |  |  |  | PROPYLITIC | POTASSIC | ARGILLIC | PHYLLIC | ALUNITIC | SILICIC |  |
| SUMMITVILLE, RIO GRANDE CO., COLORADO | APPROX. 0.26 | APPROX. 0.50 |  |  | 1:2 | 5? |  | MIOCENE QUARTZ LATITE PLUG |  | Qt, Au, Py, Ba, Al, En, Gn, Sp, Cv, rare Cp | X |  | X | X<br>Illite | X | X | 2:1 |
| WONDER, CHURCHILL CO., NEVADA | 0.074 | 6.87 | 0.17 | 16.28 | 1:94 | 0 | 0.426 | OLIGOCENE-MIOCENE RHY., ANDESITE, LATITE, NEAR RHY. DOME | 22.0 m. y. | Ad, Qt, Fl, Ar, El, Cy, Br, Au |  |  | X<br>Kaolin | X? |  | X |  |
| BUCKHORN, EUREKA CO., NEVADA | 0.039 | 0.311 | 0.182 | 1.46 | 1:8 |  | 0.214 | MIOCENE ANDESITE | 15.0 m. y. | Ad, Qt |  |  | X<br>Kaolin |  |  |  |  |
| DIVIDE, ESMERALDA CO., NEVADA | 0.033 | 3.27 | 0.24 | 24.3 | 1:101 | VERY LOW | 0.135 | MIOCENE RHY. TUFF, RHY. BRECCIA, ANDESITE, RHY. PLUG | 15.0 to 16.5 m. y. | Ad, Qt, Se, Rb?, Ar, Gn, Au, Ag, Py, Cy, Mo, Ba, Cp, Pw | X | X<br>Adularia | X<br>Kaolin | X | X | X | 1:1 |
| KATHERINE, MOHAVE CO., ARIZONA | 0.175 | 0.424 | 0.25 | 0.75 | 1:3 | 0 | 0.69 | PRECAMBRIAN GRANITE, MIOCENE LATITE | MIOCENE | Ad, Qt, El, Ch, post-ore Fl, Py, Se, Ca | X |  | X | X | NO | X | 4:1 |

| DISTRICT | EVIDENCE OF BOILING |  |  |  | SALIN-ITY (7) | Th °C (8) | VERTICAL ZONATION | QT PSEUDO-MORPHS AFTER CALCITE | VERTICAL ORE EXTENT m. | VEIN ATTITUDES | MAX. VEIN WIDTHS m. | COMMENTS | REFERENCES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | LOW pH CAP TO ORE | ORE SHOOTS WITH FLAT BOTTOMS (5) | VERY FINE-GRAINED QUARTZ | FLUID INCLUSION DATA (6) |  |  |  |  |  |  |  |  |  |
| SUMMITVILLE, RIO GRANDE CO., COLORADO | X<br>Alunite | X | X |  |  |  |  |  | 305 | N30-55W |  | SOME ORE-BEARING PIPES IN DISTRICT, ORE HORIZON MAY BE DOMED | STEVEN & RATTE (1960) |
| WONDER, CHURCHILL CO., NEVADA |  |  |  |  |  |  | ZnS INCREASE WITH DEPTH |  | UNDER 215 | N60-70W 75N-90<br>N25W 72E | 6<br>12 | GRADES ARE APPROXIMATE | SILBERMAN & MCKEE (1974)<br>WILLDEN & SPEED (1974)<br>LEWIS (1966?)<br>BURGESS (1914) |
| BUCKHORN, EUREKA CO., NEVADA | X<br>Argillic |  |  |  |  |  |  |  | MUCH ERODED 37 | N5W 75E |  | BEST Au VALUES ASSOCIATED W/ ARGILLIC ALTERATION, GRADES ARE APPROXIMATED, "TALC" ALTERATION OF WALLS REPORTED | SILBERMAN & MCKEE (1974)<br>ROBERTS & OTHERS (1967)<br>COUCH & CARPENTER (1943) |
| DIVIDE, ESMERALDA CO., NEVADA | X<br>Argillic |  | X |  |  |  | Au VALUES DECREASE WITH DEPTH Ag VALUES INCREASE |  | 300 | N05-65E 55E<br>NW vert. dip | 6.6 | IN LOWER LEVELS Ag IS ASSOC. WITH KAOLINITE, IN UPPER LEVELS WITH SERICITE ORES LARGELY A REPLACEMENT OF RHYOLITE TUFF, OPALIZATION OF RHY. REPORTED | PERSONAL STUDY (1979-80)<br>KNOPF (1921)<br>CARPENTER (1919)<br>BONHAM & GARSIDE (1979)<br>WISSER (1966) |
| KATHERINE, MOHAVE CO., ARIZONA | X<br>Arg-illic(?) | X? | X |  |  |  | NONE | X | SEE NOTES | N70-80E 60N (KATH.)<br>N45E near 90 (TYRO) | 7.6 | DISTRICT MUCH ERODED, VERT. EXTENT AT TYRO IS 65 m., AT KATHERINE IS 170 m., DATA INCLUDES UN-MINED RESERVES AT PORTLAND MINE (157,000 TONS OF 0.18 | PERSONAL STUDY (1980)<br>GARDNER (1936)<br>JORALEMON (1925)<br>HENDERSON (1923) |

TABLE 1, CONTINUED

| DISTRICT | PRODUCTION | | GRADE (2) | | | | TONNAGE $x10^6$ | MAJOR HOSTS | ORE AGE | MINERALOGY OF VEIN (4) | ALTERATION ASSEMBLAGES | | | | | | ORE SHOOT RATIO Hor:Vert |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Au Oz. (1) | Ag Oz. (1) | Au Oz/T | Ag Oz/T | Au:Ag | BASE METALS % (3) | | | | | PROPYLITIC | POTASSIC | ARGILLIC | PHYLLIC | ALUNITIC | SILICIC | |
| PIZ PIZ, NICARAGUA | 0.1 | 0.2 | 0.25 | 0.50 | 1:2 | 2 | 0.4 | TERTIARY ANDESITE & DACITE, RHYOLITE PLUG | | Ad, Qt, Py, El, Rc, Sp, Cp, Gn, Bo, Sc | X | | | X | | X | 10:1 |
| COLQUI, (FINLANDIA) PERU | 0.388 | 10.24 | 0.97 | 25.6 | 1:26 | 17.4 | OVER 0.4 | TERTIARY ANDESITIC SANDSTONE, TUFF, & FLOWS | 10.3 m. y. | Qt, Si, Se, Ar, Rb, El, Py, Te, Gn, Sp, Ba, Ka | X | | X | X | | X | 7:4 |
| NAMIQUIPA, CHIHUAHUA, MEXICO | 0.000 | 26.13 | 0.00 | 29.03 | 1: 450000 | 8.5 | 0.9 | EOCENE-OLIG. LATITE, ANDESITE FLOWS & TUFF, AGGLOMERATE | OLIG.? | Qt, Ar, Au, Py, Fl, Ba, Gn, Sp, Cp | X | | | X | | X | 8:1 |
| TEMASCALTEPEC, MEXICO, MEXICO | 0.059 | 16.0 | 0.06 | 16.0 | 1:267 | "Low" | OVER 1.0 | TRIASSIC SHALE CAPPED BY TERTIARY ANDESITE & RHYOLITE BRECCIA | | Ad, Qt, Ca, Ch, Ar, Rb, El, Py, Gn, Sp, Cp | | X | X | | | | 3:1 |
| EL TIGRE, SONORA, MEXICO | 0.175 | 27.3 | 0.25 | 39.0 | 1:162 | 3 | OVER 0.7 | OLIGOCENE RHY. TUFF & FLOWS, LATITE BRECCIA | OLIG. (?) | Qt, Ca, Ar, Te, Au, Py, Cp, Sp, Gn, Sr | X | | X<br>Kaolin | | | X | 6:1 |

| DISTRICT | EVIDENCE OF BOILING | | | | SALINITY (7) | Th °C (8) | VERTICAL ZONATION | QT PSEUDOMORPHS AFTER CALCITE | VERTICAL ORE EXTENT m. | VEIN ATTITUDES | MAX. VEIN WIDTHS m. | COMMENTS | REFERENCES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LOW pH CAP TO ORE | ORE SHOOTS WITH FLAT BOTTOMS (5) | VERY FINE-GRAINED QUARTZ | FLUID INCLUSION DATA (6) | | | | | | | | | |
| PIZ PIZ, NICARAGUA | | | X | | | | | | | N45E 35-50NW | 23 | ORES SECONDARILY ENRICHED ESPECIALLY IN Ag | HAWXHURST (1921)<br>SPURR (1913) |
| COLQUI, (FINLANDIA) PERU | X<br>Phyllic | X | X | YES | 2-10 | 270 ±20 | | | 130 | N60-75E | 2.5 | BASE METALS ARE POST-Ag VEINS AVE. 1 METER WIDE | KAMILLI & OHMOTO (1977) |
| NAMIQUIPA, CHIHUAHUA, MEXICO | X | | X | | | | ZnS INCREASE WITH DEPTH | | 250 | N25 to 40E 70E<br>N05-20W | | Ag VALUES DECREASE WITH DEPTH, WALLROCKS AROUND ORE SHOOTS SAID "BLEACHED" | SHEFELBINE (1957)<br>DOUGLAS (1951) |
| TEMASCALTEPEC, MEXICO, MEXICO | | X | | | | | Zn & Pb INCREASE WITH DEPTH | | 250 | N40-90W 65N MANY DIPS APPROACH 90° | AVE. 10 | GALENA AND PYRITE INCREASE WITH DEPTH AND Ag VALUES DECREASE | CARDENAS & MARTINEZ (1947)<br>WILSON (1959) |
| EL TIGRE, SONORA, MEXICO | | | | | | | ZnS INCREASE WITH DEPTH | | 300 | N05E to N10W 60W Dip | AVE. 1 | ORE IN CYMOID LOOPS, SILICIFICATION INTENSE ABOVE ORE, PYRITIZATION INTENSE BELOW | MISHLER (1920)<br>WISSER (1966) |

TABLE 1, CONTINUED

| DISTRICT | PRODUCTION | | GRADE (2) | | | | TONNAGE x10$^6$ | MAJOR HOSTS | ORE AGE | MINERALOGY OF VEIN (4) | ALTERATION ASSEMBLAGES | | | | | | ORE SHOOT RATIO Hor:Vert |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Au Oz. (1) | Ag Oz. (1) | Au Oz/T | Ag Oz/T | Au:Ag | BASE METALS % (3) | | | | | PROPYLITIC | POTASSIC | ARGILLIC | PHYLLIC | ALUNITIC | SILICIC | |
| ZACUALPAN, MEXICO, MEXICO | Nil | 8.423 | Nil | 4.9 | | 1.4 | 1.72 | TRIASSIC ANDESITE AND SHALES | | Qt, Ca, Ar, Rb, Py, Te, Rc, Cp, Gn, Sp | X | | | X | | X | |
| STATELINE, TOOELE CO., UTAH | 0.0024 | 0.0084 | ABOUT 0.1 | ABOUT 0.4 | | VERY LOW | APPROX. 0.02 | TERTIARY LATITE FLOW, RHY. FLOW & TUFF | | Ad, Qt, Ca, El, Py, Fl, Mo, Tl | X | X | X | X Sericite | | X | |
| CINCO MINAS, JALISCO, MEXICO | 0.100 | 15.3 | 0.10 | 15.3 | 1:153 | | OVER 1.0 | TERTIARY RHY. TUFF, ANDESITE | | Qt, Ca, Ar, El, Au, Py, Gn, Sp, Cp | | | | | | | 1:2 |
| GOLDEN PLATEAU, AUSTRALIA | 0.484 | 0.363 | 0.44 | 0.33 | 1:0.8 | "minor" | 1.1 | PALEOZOIC DACITE, RHY., RHYODACITE, TRACHYTE | PALEOZ? | Ad, Qt, Ar, Au, El, Gn, Cp, Sp, As, Hs | X | | | | | X | 3:1 |
| SILVER CITY & DELAMAR, OWYHEE CO., IDAHO | 0.9 | 27.0 | | | 1:30 | UNDER 1% | | TERTIARY ANDESITE, RHYOLITE | 14.8-15.2 m. y. | Ad, Qt, Fl, Cp, Ca, Se, Gn, Ar, Rb, Ba, Py, Pl, El, Na, Ja, Mi | X | | X | X | | X | 5:3 |

| DISTRICT | EVIDENCE OF BOILING | | | | SALINITY (7) | Th °C (8) | VERTICAL ZONATION | QT PSEUDOMORPHS AFTER CALCITE | VERTICAL ORE EXTENT m. | VEIN ATTITUDES | MAX. VEIN WIDTHS m. | COMMENTS | REFERENCES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LOW pH CAP TO ORE | ORE SHOOTS WITH FLAT BOTTOMS (5) | VERY FINE-GRAINED QUARTZ | FLUID INCLUSION DATA (6) | | | | | | | | | |
| ZACUALPAN, MEXICO, MEXICO | | | X | | | | Ag/Pb, Ag/Zn, Zn/Pb DECREASE WITH DEPTH | | | N65W 80N DIP | 35 | | FRANCISCO (1979) |
| STATELINE, TOOELE CO., UTAH | | | X | | | | | X | 155 | E-W, N DIP<br>N-S, 50-70E | AVE. 1 | HIGHEST GOLD VALUES ARE ASSOCIATED W/ ADULARIA IN VEIN, INCLUDES GOLD SPRINGS & ESCALANTE DISTS. | EMMONS (1937)<br>BUTLER & OTHERS (1920) |
| CINCO MINAS, JALISCO, MEXICO | | | | | | | BASE METALS INCREASE WITH DEPTH | | 650 | N45-90W, S DIP | | CALCITE VEIN ON SURFACE CHANGES TO QUARTZ WITH DEPTH | OJEDA & MAPES (1963) |
| GOLDEN PLATEAU, AUSTRALIA | | X | | | | | | | OVER 215 | | | MAY HAVE VERTICALLY STACKED OREBODIES AS AT GUANAJUATO , UPPER IS 0-120 M. BELOW SURFACE, LOWER IS 120-215 M. | BROOKS (1970) |
| SILVER CITY & DELAMAR, OWYHEE CO., IDAHO | X Phyllic | X | | | | | | X | 460 | N25-62W 25-80S | 10 | VEINS AVERAGE 1.0 METER WIDE, PRODUCTION LISTED IS FOR 1863-1923.<br>ARGILLIC ALTERATION SAID ASSOCIATED WITH ORE | LINDGREN (1933)<br>PIPER & LANEY (1926)<br>PANSZE (1971) |

TABLE 1, CONTINUED

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| DISTRICT | PRODUCTION Au Oz. (1) | PRODUCTION Ag Oz. (1) | GRADE (2) Au Oz/T | GRADE (2) Ag Oz/T | GRADE (2) Au:Ag | GRADE (2) BASE METALS % (3) | TONNAGE $x10^6$ | MAJOR HOSTS | ORE AGE | MINERALOGY OF VEIN (4) | ALTERATION ASSEMBLAGES PROPYLITIC | ALTERATION ASSEMBLAGES POTASSIC | ALTERATION ASSEMBLAGES ARGILLIC | ALTERATION ASSEMBLAGES PHYLLIC | ALTERATION ASSEMBLAGES ALUNITIC | ALTERATION ASSEMBLAGES SILICIC | ORE SHOOT RATIO Hor:Vert |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SILVERBOW, NYE CO., NEVADA | | | | | 1:8 | | | TERTIARY RHY. FLOW | | Py, Qt, Rb, Au, Sn | | | X<br>Kaolin | X | | X | |
| TOVAR, DURANGO, MEXICO | | | 0.06 | 2.89 | 1:45 | 10 | | OLIGOCENE ANDESITE PORPHYRY, QUARTZ MONZ. PLUG | POST 31 m. y. | Qt, Ar, Rb, He, Py, Gn, Sp, Cp, Ba, Ma | X | | X | | | X | |
| PARRAL, CHIHUAHUA, MEXICO | 0.02 | 115.1 | 0.002 | 8.9 | 1:150 | 4 to 20 | OVER 13 | TERTIARY VOLCANICS CAPPING CRETACEOUS LIMESTONE & SHALE | POST 35 m. y. | Qt, Ar, Rb, El, Py, Fl, Ba, Gn, Sp, Te | X | | ? | | | X | 2:1 |
| LAKE CITY, HINSDALE CO., COLORADO | 0.071 | | 0.12 | | | OVER .5 | OVER 0.6 | TERTIARY QTZ. LATITE TUFF & BRECCIA, RHY., ANDESITE | 22.5 m. y. | Qt, Ca, Rb, Sp, Cp, Gn, Ba, Tl, Te, Rc, Se | X | | X<br>Kaolin<br>Dickite | X<br>Sericite | X<br>Higher elevation | X | |
| JULCANI, PERU | | | | | | | OVER 6 | TERTIARY DACITIC FLOW, RHY. PLUG, RHY. BRECCIA, RHY. TUFF | 10 m. y. | Qt, Si, Ta, Py, Tn, Sp, Cp, Sm | X | X | X | X | X | | |

| DISTRICT | EVIDENCE OF BOILING LOW pH CAP TO ORE | EVIDENCE OF BOILING ORE SHOOTS WITH FLAT BOTTOMS (5) | EVIDENCE OF BOILING VERY FINE-GRAINED QUARTZ | EVIDENCE OF BOILING FLUID INCLUSION DATA (6) | SALINITY (7) | Th °C (8) | VERTICAL ZONATION | QT PSEUDOMORPHS AFTER CALCITE | VERTICAL ORE EXTENT m. | VEIN ATTITUDES | MAX. VEIN WIDTHS m. | COMMENTS | REFERENCES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SILVERBOW, NYE CO., NEVADA | X<br>Kaolin | | MUCH AGATE | | | | | | | NW | 1.5 | | BALL (1906) |
| TOVAR, DURANGO, MEXICO | | | | | | | BASE METALS INCREASE WITH DEPTH | | | NW, 70-80E<br>NNE | 6<br>1 | | CLARK & OTHERS (1979)<br>DOW (1978) |
| PARRAL, CHIHUAHUA, MEXICO | | X | | | | | Pb + Cu INCREASE TO 20% WITH DEPTH | | 600 | N00-07W 53E<br>N06W 75W | 40 | Ag DECREASES FROM 600 TO 50 GRAMS WITH DEPTH, DATA INCLUDES UNMINED RESERVES | SCHMITT (1929)<br>PICKARD (1970) |
| LAKE CITY, HINSDALE CO., COLORADO | ? | | SOME | YES | 3 | 250 | Ag DECREASES BASE METALS INCREASE WITH DEPTH | | 460 | N45E 70E<br>N30E | 6 | VEINS AVE. 1.0 M. WIDE, FLUIDS BOILED DURING Au-Ag DUE TO PRESSURE RELEASES, NO BOILING IN BASE METAL STAGES, BASE METALS EARLY PARAGENETICALLY | SLACK & LIPMAN (1978)<br>SLACK (1980) |
| JULCANI, PERU | X<br>Phyllic | | | | | | | | | N45-60W 50-90N and 50-90S<br>N30-60E | | ORES IN ZONES OF ADULARIA ALTERATION OF WALLROCKS | PETERSEN & OTHERS (1977)<br>SCHERKENBACH & NOBLE (1978) |

TABLE 1, CONTINUED

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NOTES FOR TABLE 1

Footnotes:

1) In millions of troy ounces. Most production figures are from the literature; several are calculated from tonnage and grade figures assuming 100% recoveries.
2) In some cases, grade is recovered oz./ton; in others it is assay oz./ton. Most grade figures are from the literature; several are calculated from production and tonnage figures assuming 100% recoveries.
3) Combined Pb + Zn + Cu. In rare cases is as percentage of metal; in most is as percentage of sulfide.
4) Abbreviations are:

| | |
|---|---|
| Aa | Altaite |
| Ad | Adularia |
| Ag | Silver |
| Ai | Aguilarite |
| Al | Alunite |
| An | Ankerite |
| Ar | Argentite |
| As | Arsenopyrite |
| Au | Gold |
| Ba | Barite |
| Bo | Bornite |
| Br | Bromeyerite |
| Bu | Bournonite |
| Ca | Calcite |
| Cc | Chalcocite |
| Ce | Cerussite |
| Ch | Chlorite |
| Cl | "Clay" |
| Cp | Chalcopyrite |
| Cv | Covellite |
| Cy | Cerargyrite |
| Do | Dolomite |
| El | Electrum |
| En | Enargite |
| Fa | Famantite |
| Fl | Fluorite |
| Go | Goldfieldite |
| Gn | Galena |
| He | Hematite |
| Hs | Hessite |
| Ja | Jamesonite |
| Ka | Kaolin, Kaolinite |
| La | Laumontite |
| Ma | Marcasite |
| Mi | Miargyrite |
| Mo | Molybdenite |
| Na | Naumannite |
| Pa | Pyrargyrite |
| Pl | Polybasite |
| Po | Pyrrhotite |
| Pr | Pyrolusite |
| Pu | Proustite |
| Pw | Powellite |
| Py | Pyrite |
| Qt | Quartz |
| Rb | "Ruby Silvers" |
| Rc | Rhodochrosite |
| Re | Realgar |
| Rs | Rhodonite |
| Sc | Specularite |
| Se | Sericite |
| Si | Siderite |
| Sm | Semseyite |
| Sn | Stephanite |
| Sp | Sphalerite |
| Sr | Stromeyerite |
| St | Stibnite |
| Te | Tetrahedrite |
| Tl | "Tellurides" |
| Tn | Tenantite |
| To | Tourmaline |
| Wu | Wulfenite |

5) Shape of ore shoots is based on bottom of stopes, not on bottom of all mineralization.
6) For list of boiling criteria, see references listed for each district.
7) Expressed as equivalent weight percent NaCl.
8) Th = Temperature of homogenization of fluid inclusions with no pressure corrections.

General Notes:

X = Evidence present
NO = No evidence present
blank = Insufficient information
Alteration assemblages as listed do not imply they are related to the ore-forming event; however, deuteric propylitization and/or zeolitization have been ignored.

more complex nearer the paleosurface with numerous bends, cymoids, horsetails, and bifurcations, therefore, stockwork deposits are more likely to exist nearer the paleosurface and should pass to more structurally constricted veins with depth. Numerous intra-mineralization periods of brecciation are reported in most districts.

E. Ore shoots rarely fill the entire vein structure, rather they are isolated zones within the vein enclosed along strike and dip by subore to barren gangue. Normally, the ore-waste contact is formed by a rapid drop in grade, or by a thinning of the pay streak, or both. In almost all districts, very thin and very high grade veinlets may extend outward (into a wall or within the main vein along strike) from the stoped areas, but these veinlets often become subore grade when the necessary mining widths are considered. However, the ore shoots do relate to definite structural features within the veins, such as at dilatant zones in bends concave to the hanging wall (Seven Troughs, Oatman, Comstock), at areas of vein intersection (Hayden Hill, Comstock), and in areas of dip decrease resulting in crushing of the hanging wall (Las Torres at Guanajuato). As these structural features are localized, the ore shoots contained therein are localized within an otherwise subore structure.

F. The precious metal ore zones have a restricted vertical interval of up to 1000 meters, but the typical uneroded deposit averages close to 350 meters. Because of this restricted interval, most districts have a definite elevation which marks the bottoms of the precious metal ore shoots, as well as a definite elevation which marks the tops of ore shoots. These elevations may be evident only if the effects of post-ore faulting are subtracted out of the district geology (Tayoltita, Oatman). At Oatman, Pachuca and Tonopah, the precious metal interval is domed like an inverted saucer. No satisfactory explanation for this doming has yet been offered. If orebodies bottom at a particular elevation and top out at another higher elevation, we must look at the mineralogy of all three levels (above, within, and below precious metal ore shoots) in order to understand the orebody genesis.

G. Above this ore interval, precious metal values drop rapidly. Although the quartz vein filling extends well above the top of the ore zone, the quartz filling of the vein gradually diminishes in width (Guanajuato, Pachuca, Oatman, Gooseberry, Silver Peak), and the crystalline nature of the quartz changes to an agate or chalcedony far above the ore shoot. As quartz and agate diminish in volume toward the vein tops, calcite becomes relatively more common. Higher still in the vein system, calcite begins to diminish often to the point where an empty, paper-thin fracture is all that marks a productive and wide vein at depth (Bulldog Mountain, Guanajuato, Pachuca, Fresnillo, Oatman, San Francisco Del Oro, Kimberly).

H. Going the other way, that is, downward from the base of the precious metal ore shoots, vein fillings often differ from that of the productive horizon by two possible but different manners. These two types of changes appear to be mutually exclusive, thus are discussed separately:

a. The least common way a precious metal ore shoot may terminate with depth is illustrated by Oatman and by the upper ores at Guanajuato. In these districts, the precious metal content rapidly diminishes at the bottom of the ore shoot to anomalous but very subore grade. The quartz vein filling, as well as the strength (width, form, persistence) of the structure, continues downward. There is no appreciable change in vein mineralogy at the base except for a probable diminishing of gangue adularia, a possible increase in pyrite, as well as the near absence of calcite and precious metal minerals.

b. More commonly, the precious metal content gradually diminishes at the base of the precious metal ore interval until a level is reached where ore grade is not maintained. Concomittant with the decrease in precious metal values is an increase in galena, pyrite, sphalerite, and less commonly, chalcopyrite and/or pyrrhotite. Quartz persists downward without appreciable changes, but calcite is greatly reduced in volume, and sericite and adularia are slightly to greatly diminished.

I. Within the precious metal ore horizon, vein mineralogy is a rather simple assemblage of argentite, adularia, quartz, pyrite, electrum, calcite, and ruby silvers. Tetrahedrite, stephanite, polybasite, base metal sulfides, naumannite, fluorite, barite, sericite, chlorite may occur in most deposits in small to large amounts. Even less commonly found are stibnite, realgar, rhodochrosite, rhodonite, bornite, boulangerite and a host of other minerals. The veins show both a repetitively banded filling texture characteristic of open space fillings, as well as textures indicative of replacement of the walls and breccia fragments. Typically, where high precious metal values exist within a vein, the quartz gangue is very fine-grained and contains significant amounts of adularia (Guanajuato, Jarbidge, Oatman, Finlandia, Triunfo, Mogollon), and/or sericite intimately mixed with the precious metals.

J. Gold:silver ratios tend to be larger higher in the vein system, in those districts where ore shoots are not eroded. Oxidation and secondary enrichment of both gold and silver tend to obscure this primary precious metal vertical zonation in the many districts subjected to erosion of ore shoots.

K. The temperature of formation related to the precious metal ore interval is from around 200°C (the lower temperature postulated for Goldfield) to over 300°C, but averages around 240°C. Salinities are generally lower than 3 equivalent weight percent NaCl. Rapid or numerous temperature fluctuations are not noted in deposits studied in detail. The base metals appear to have been deposited at somewhat higher temperatures in all deposits studied in detail, from slightly more saline solutions, and are typically paragenetically earlier than the precious metals.

L. The repetitively banded vein fillings in the ore horizon deserves more description. Banded or crustified textures are so common in precious metal deposits hosted by volcanics that it has been considered a diagnostic feature of epithermal veins. The banded vein filling is little more than a series of layers, each one deposited atop the previous, of gangue and ore minerals. Often, but less often than generally assumed, the bands on each side of the centerline of the vein form mirror images of each other. This feature has led to the probably correct conclusion that each pair of bands deposited at the same time from the same solutions. However, little study has been directed toward answering two fundamental questions:

a. What trigger causes the deposition of certain minerals in one pair of bands but not in the next?

b. Why are many veins characterized by repetitively banded fillings; that is, having numerous bands of the same mineral assemblage separated by numerous bands of a different mineral assemblage? For example, a 4" slab of the Gold Road Vein from Oatman, Arizona, has 41 bands of quartz and chlorite separated by 40 bands of quartz and adularia. What physico-chemical parameter was repeated over and over again to give such repeated bands?

Answers given in the past to explain this feature appear unsatisfactory:

a. An explanation given is that wallrock and solution reactions cause changes in the solution chemistry, causing the bands to form. This is unlikely in that the wall rocks are already reacted with and the solutions are already buffered by the rocks. How could wall rock-solution reactions episodically buffer, then later episodically not buffer, the solutions?

b. A second answer given is that simple cooling of the solution forms the bands. Cooling could lead to bands of specific minerals, but cooling does not explain the repetition of bands of the same mineral. Assuming a mineral precipitates in a particular temperature interval, what causes that temperature interval to be entered and left again repeatedly throughout the vein-forming time span? Also, fluid inclusion studies of ores from Oatman, Pachuca, Tayoltita, Guanajuato, Creede, and others, indicate that rapid or numerous temperature reversals do not exist.

c. A final answer given is that changes in solution chemistry lead to the banding. What is meant by this is that influxes of volatile or dissolved species cause the bands. It is very difficult to imagine a hydrothermal system that can have repeated influxes of volatiles or dissolved species, with each influx so similar to the previous ones, as to cause the same mineral assemblage to deposit scores or hundreds of times within a narrow vein.

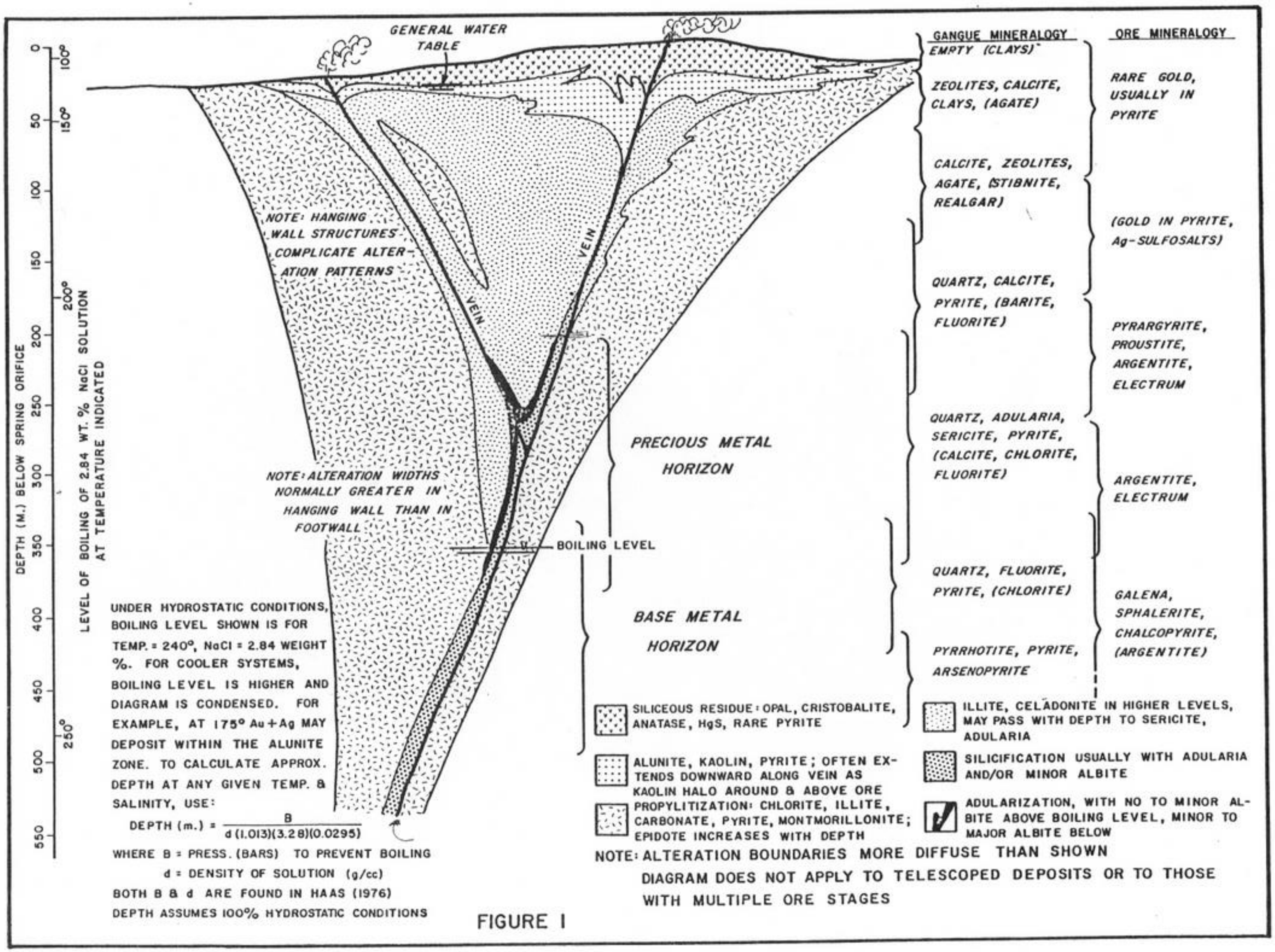
M. Evidence of boiling of the ore-forming solutions is common in those districts studied in detail. At Creede, Pachuca, and Tayoltita, vaporization evidence was found at the tops of the base metal ore shoots; at Guanajuato and Tonopah, the vaporization level was at the base of the precious metal ore horizon; and in others such as Lake City and Finlandia, the boiling occurred in discreet zones of high precious metal content within an otherwise base metal assemblage. These seemingly contradictory data may be seen to fit into a pattern if it is remembered that Creede, Pachuca, and Tayoltita are high in base metals, thus the boiling occurred near the top of the base metal horizon. This is the same position as the base of the precious metal horizon, thus boiling occurred at Creede, Pachuca, and Tayoltita at the same level as it did at Guanajuato and Tonopah. Deposits like Lake City and Finlandia are telescoped, but boiling is noted only in those zones of precious metal mineralization, not in the base metal zones.

N. Widespread propylitic alteration (an assemblage of chlorite, pyrite, carbonate, montmorillonite, and illite) is ubiquitous in the districts. Epidote is present in this assemblage at greater depths. The propylitic alteration commonly forms halos hundreds of meters wide around the veins, and usually is wider in the hanging wall than in the footwall. This alteration is often believed to be pre-ore. Silicified vein walls, and less commonly, adularized or albitized walls, often form a thick selvage around the veins at the ore horizon. This selvage may be tens of meters wide, but commonly is on the order of one meter or less. In many districts silicified or feldspathized vein walls have abundant enough precious metal values to constitute ore. The width of the selvage diminishes upward above the ore zones and often disappears completely a few score meters above the ore. Silicification has a much greater vertical extent than do adularization and albitization, often extending above the ore horizon for hundreds of meters, and very commonly extending well below the bottom of the precious metal horizon. Adularized wall rocks occasionally change with depth into adularized and albitized wall rocks. Neither the widespread propylitic alteration nor the more restricted silicification/adularization/albitization serve as very useful ore guides. The former is much too widespread to allow a target to be selected and the latter are usually so narrow as to be found at about the same time as the ore is found. What is needed for the explorationist is an alteration assemblage that is small enough to pinpoint individual targets, is genetically related to the process of ore formation, and extends well above the ore level so that non-outcropping ore shoots can be targeted. Fortunately, such an alteration assemblage exists, as what will be referred to as the low pH assemblage. This assemblage may contain any or all of the following minerals: Alunite, sericite, illite, kaolinite, montmorillonite, or any of the kaolin clay minerals. This alteration, commonly referred to as "bleaching" in the literature, forms a halo around and a cap above individual ore shoots. It is virtually absent below the precious metal horizon (Or, as at Guanajuato, it is absent below the lowest precious metal horizon) and forms a narrow but ever upward-widening halo in the hanging wall around the ore shoot, and expands or "blossoms" above the top of the ore shoot. In those districts studied in detail, the low pH alteration appears to be genetically related to the deposition of the precious metals, but unlike the ore itself, the low pH alteration zone extended to the paleosurface (See Figure 1). At the hot spring orifice on the paleosurface, siliceous sinter and opal are mixed with or forms a cap over alunite and kaolinite (Schoen and others, 1974). These layers often up to scores of meters thick, are believed to be caused by downward percolating sulfuric acid solutions formed by water mixed with oxidized $H_2S$. Beneath these layers are alteration assemblages of illite, adularia, and celadonite as wide halos around the fractures, formed primarily by the loss of $CO_2$ (near surface degassing) resulting in a rise in the $K^+/H^+$ ratio. This assemblage passes with depth and toward the fractures into more well-ordered white micas, often to a sericite structure. Often at the fracture wall, montmorillonite or kaolinite form an inner alteration halo, widest on the hanging wall of the fracture.

## THE MODEL

All of these common characteristics must somehow relate to the process of ore formation. The discussion to follow will offer a model which will unify all of these seemingly disconnected characteristics into a simple genetic model. Figure 1 should be consulted while reading this section.

It has long been suggested that epithermal de-



NOTE: HANGING WALL STRUCTURES COMPLICATE ALTERATION PATTERNS

NOTE: ALTERATION WIDTHS NORMALLY GREATER IN HANGING WALL THAN IN FOOTWALL

UNDER HYDROSTATIC CONDITIONS, BOILING LEVEL SHOWN IS FOR TEMP. = 240°, NaCl = 2.84 WEIGHT %. FOR COOLER SYSTEMS, BOILING LEVEL IS HIGHER AND DIAGRAM IS CONDENSED. FOR EXAMPLE, AT 175° Au + Ag MAY DEPOSIT WITHIN THE ALUNITE ZONE. TO CALCULATE APPROX. DEPTH AT ANY GIVEN TEMP. & SALINITY, USE:

$$\text{DEPTH (m.)} = \frac{B}{d\,(1.013)(3.28)(0.0295)}$$

WHERE B = PRESS. (BARS) TO PREVENT BOILING

d = DENSITY OF SOLUTION (g/cc)

BOTH B & d ARE FOUND IN HAAS (1976)

DEPTH ASSUMES 100% HYDROSTATIC CONDITIONS

| | |
|---|---|
| ▨ | SILICEOUS RESIDUE: OPAL, CRISTOBALITE, ANATASE, HgS, RARE PYRITE |
| ▨ | ALUNITE, KAOLIN, PYRITE; OFTEN EXTENDS DOWNWARD ALONG VEIN AS KAOLIN HALO AROUND & ABOVE ORE |
| ▨ | PROPYLITIZATION: CHLORITE, ILLITE, CARBONATE, PYRITE, MONTMORILLONITE; EPIDOTE INCREASES WITH DEPTH |
| ▨ | ILLITE, CELADONITE IN HIGHER LEVELS, MAY PASS WITH DEPTH TO SERICITE, ADULARIA |
| ▨ | SILICIFICATION USUALLY WITH ADULARIA AND/OR MINOR ALBITE |
| ■ | ADULARIZATION, WITH NO TO MINOR ALBITE ABOVE BOILING LEVEL, MINOR TO MAJOR ALBITE BELOW |

NOTE: ALTERATION BOUNDARIES MORE DIFFUSE THAN SHOWN

DIAGRAM DOES NOT APPLY TO TELESCOPED DEPOSITS OR TO THOSE WITH MULTIPLE ORE STAGES

FIGURE I

posits form in convecting water cells (White and others, 1971), where water of largely meteoric origin circulates deeply into a volcanic/sedimentary pile, becomes heated, and dissolves metals, alkalies, chlorides, and sulfur species. Eventually, the now heated but low salinity solution rises through a fracture system and deposits ore and gangue minerals as vein fillings.

Broadlands, New Zealand, is part of such a convection cell. Water at 280°C to 160°C (from depths of 1400 m. to 400 m., respectively), rises up a series of fractures, and gangue, precious metal, and base metal minerals are deposited at various elevations within the fractures. Data presented by Ewers and Keays (1977) indicates that the location of metal deposition is in part a function of the level of boiling of the rising fluids. Most base metals deposit at and below the boiling level, whereas precious metals deposit largely at and above that level. Thus, at the level of boiling, a mixed zone of precious and base metal mineralization occurs. The precious metal content decreases at and below the boiling level, and conversely, the base metal content decreases at and above that level.

It appears that boiling at a particular elevation in a vein system must mark that division between the now well-recognized upper precious metal ore horizon and the deeper base metal ore horizon. This elevation is the same as that district wide bottom of ore shoots mentioned previously, and as well, the boiling level marks the flat bottoms of individual precious metal ore shoots within a particular vein. Obviously, the level of boiling cannot remain constant in space or time: 1) Local irregularities in the paleotopography lead to local elevation differences of the boiling fluid; 2) No geothermal system has uniform isotherms (Ellis and Mahon, 1977) in a horizontal plane, thus warmer solutions in some areas will boil at greater depths than cooler solutions in other areas; 3) Similarly, no geothermal system has uniform isobars (Ellis and Mahon, 1977) in a horizontal plane, thus completely preventing boiling in some areas of the system; 4) Deep self-sealing of the fracture system and its later refracturing can allow boiling at depths much greater than allowed under hydrostatic conditions; and 5) Less commonly, episodic fluctuations in temperature and/or volatile content of the solutions can cause fluctuations in the boiling level. These factors, among others, can cause long vertical intervals of mixed base and precious metal mineralization.

Boiling affects profound change in the physical and chemical state of the fluids:

A. Significant amounts of $CO_2$ and usually lessor amounts of $H_2S$ are partitioned into the vapor phase, according to the simple reactions:

$$HCO_3^- + H^+ \longrightarrow CO_{2\,(vap.)} + H_2O$$
$$HS^- + H^+ \longrightarrow H_2S_{(vap.)}$$

This release of volatiles results in a pH rise in the remaining solutions. Data of Drummond and Ohmoto (1979) indicate that a 1 mole NaCl solution at 250°C containing 0.10 mole $CO_{2\,(aq.)}$ (similar to a typical epithermal fluid), will experience a one unit pH rise by the loss to the vapor phase of approximately 3% of the solution mass. By contrast, simple calculations indicate that at Guanajuato, approximately 24% mass loss to the vapor phase occured.

B. The salinity of the remaining solutions will rise, a result of simple concentration of salts by the loss of $H_2O$ steam.

C. Oxygen fugacity in the remaining liquid increases as the ratios of $CO_2:CH_4$ and $SO_2:H_2S$ increase. $CH_4$ and $H_2S$ have a greater rate of partitioning into the vapor phase than do $CO_2$ and $SO_2$, respectively (Drummond and Ohmoto, 1979).

D. The solution will cool, but much less so than is commonly believed. It is true that the heat of vaporization requires energy to convert water liquid to water steam, but the large thermal reservoir contained by the wall rocks will prevent any major temperature drop in the solutions. As the life of a geothermal system is measured in $10^4$ to $10^6$ years, the already heated rocks will act to buffer the solution temperature.

E. Major loss of $CO_2$ and lessor loss of $H_2S$ results in a rise in the activity of $S^=$ and $HS^-$, thus leading to formation of strong thio complexes with Au, As, Sb, and Hg (Weissberg, 1969). These complexes are stable to near the paleosurface, where the higher oxygen fugacity results in precipitation of the metals.

All of these consequences of boiling combine to promote mineral deposition. Drummond and Ohmoto's study (1979), cited earlier, indicates that most base metals in solution will precipitate after about 5% of the mass of the solution is lost to the vapor phase, but that about 20% of the solution must vaporize before the bulk of the silver will precipitate. As any packet of water will continue to rise as it is boiling, with the water bouyed up by bubbles, the silver will naturally tend to precipitate higher in the vein system than do the base metals. Gold, carried as a thio complex, will not precipitate until nearer the paleosurface in areas of high oxygen fugacity, where the thio complex is destroyed by oxidation to sulfate.

This single phenomena - boiling - explains the vertical zoning of precious metals passing into base metals with depth; as well as explains the early paragenetic position of the base metals so often observed in these deposits. Furthermore, as the pH of the solution rises to the alkaline side, the field of adularia stability is quickly entered, resulting in the association of high precious metal values and high adularia content in the vein. An exception may be those near surface, cool, systems like Goldfield, where the gold is deposited in an acid environment, where clays and/or alunite substitute for the adularia.

But, how can boiling explain the repetitive banding? At Guanajuato, Tayoltita, and Tonopah, studies of fluid inclusion morphology and distribution across individual veins or across individual gangue minerals suggest that the boiling was episodic. There were periods of intense boiling followed by periods of non-boiling or by periods of greatly reduced boiling. Buchanan (1980) has recently documented six major boiling episodes in a single 2.1 cm. wide veinlet at Guanajuato, with each boiling episode accompanied by acanthite and adularia deposition. These boiling episodes were not the result of temperature or chemical fluctuations, and Buchanan (1980) called upon episodic pressure release as the causative mechanism. Episodic drops in the total confining pressure will allow the solutions to boil episodically. This results in the episodic pH rises and precipitation of ore and gangue minerals. As minerals deposit, the thin, near surface veinlets become filled by calcite, zeolites, clays, alunite, and other minerals, effectively forming a sealed cap to the fracture system. Once sealed, the pressure increases (White and others, 1975), boiling at depth stops, and the pH of the solution drops to normal. Tectonism, or more likely hydrofracturing, can break the sealing cap to allow a second episode of boiling and mineralization, and later seal the system again. In this manner, a repetitively banded vein may result with no necessity to call upon a change in solution chemistry or temperature. Such near-surface self-sealing is well documented in modern geothermal systems (Facca and Tonani, 1967; Keith and others, 1978; Anderson and others, 1978).

The low pH alteration assemblage may also be explained using the boiling mechanism. Upon boiling, $CO_2$ and $H_2S$ were selectively partitioned into the vapor phase. As these vapors, along with steam, rise to cooler regions nearer the paleosurface, the vapors condense and heat the rocks slightly, or mix with cooler groundwaters, to form a solution of low pH. This solution then attacks rock-forming silicates to form the white micas and/or clay minerals. If the solution is of sufficiently low pH, alunite may form.

## IMPLICATIONS OF THE MODEL

Figure 1 illustrates the vertical and horizontal mineral zoning in a typical epithermal district, based upon the data of Table 1 and of the previous discussion. A major implication of the model presented is that epithermal vein deposits do not form under simple hydrostatic conditions. If sealed caps episodically develop a pressure on the system in excess of hydrostatic, then when the cap is fractured and the excess pressure is released, the solutions will boil at a depth greater than allowed under strictly hydrostatic conditions. This deep boiling is only momentary, and the boiling level will gradually rise until hydrostatic conditions prevail. Evidence that epithermal deposits do form at greater than hydrostatic depths is gathered from the data of Table 1, where numerous districts (Oatman, Pachuca, Guanajuato, Goldfield, and Bodie) have a greater vertical ore interval than should be allowed under hydrostatic conditions. As an example, the temperature of the solutions at Bodie would allow a low-salinity solution to begin boiling at a depth of about 330 meters, but the known ore interval is 400 meters. At the present time, there is no certain way to precisely calculate the depth in excess of hydrostatic.

Large concentrations of volatiles in the solutions will also allow boiling at depths greatly in excess of hydrostatic conditions, but few systems appear to contain appreciable volatiles (Rochester and Oatman may be notable exceptions).

## APPLICATION OF THE MODEL

If the model as presented is largely correct, then exploration for deposits unexposed by erosion will be greatly facilitated by mapping of alteration assemblages along otherwise unfilled and barren, or filled and barren structures. Also, the depth to a suspected ore shoot below the present surface may be estimated by noting type and degree of vein filling, by noting alteration grades and intensities, and by fluid inclusion temperature determinations.

As examples of the application of this model to exploration, Figures 2 through 5 are presented illustrating wall rock alteration patterns at Oatman, Arizona, and Guanajuato, Mexico. Also presented in each figure are longitudinal sections of the major veins with outcrops of the low pH alteration assemblage plotted on the profile, and known ore shoots at depth plotted in section. At Oatman, the low pH assemblage is illite and montmorillonite; at Guanajuato, it is kaolinite and halloysite adjacent to the fractures, passing outward into sericite, illite, and montmorillonite. Note that in both districts only a small percentage of ore shoots cropped out. Also note that the size of the low pH alteration assemblage is crudely proportional to that of the underlying ore shoot.

The data presented in Table 1 suggests that similar maps should be made for many districts in North America, and that many ore discoveries will likely result.

This author does not wish to imply that boiling is the only explanation for many of the features of epithermal deposits, but boiling does offer a genetic mechanism whereby most observable features may be connected. However, as an "orebody" by its very definition is an anomaly, it should not be unexpected that some deposits will vary drastically from this model of a typical system, nor should it be surprising that all deposits will vary in some degree from the model.

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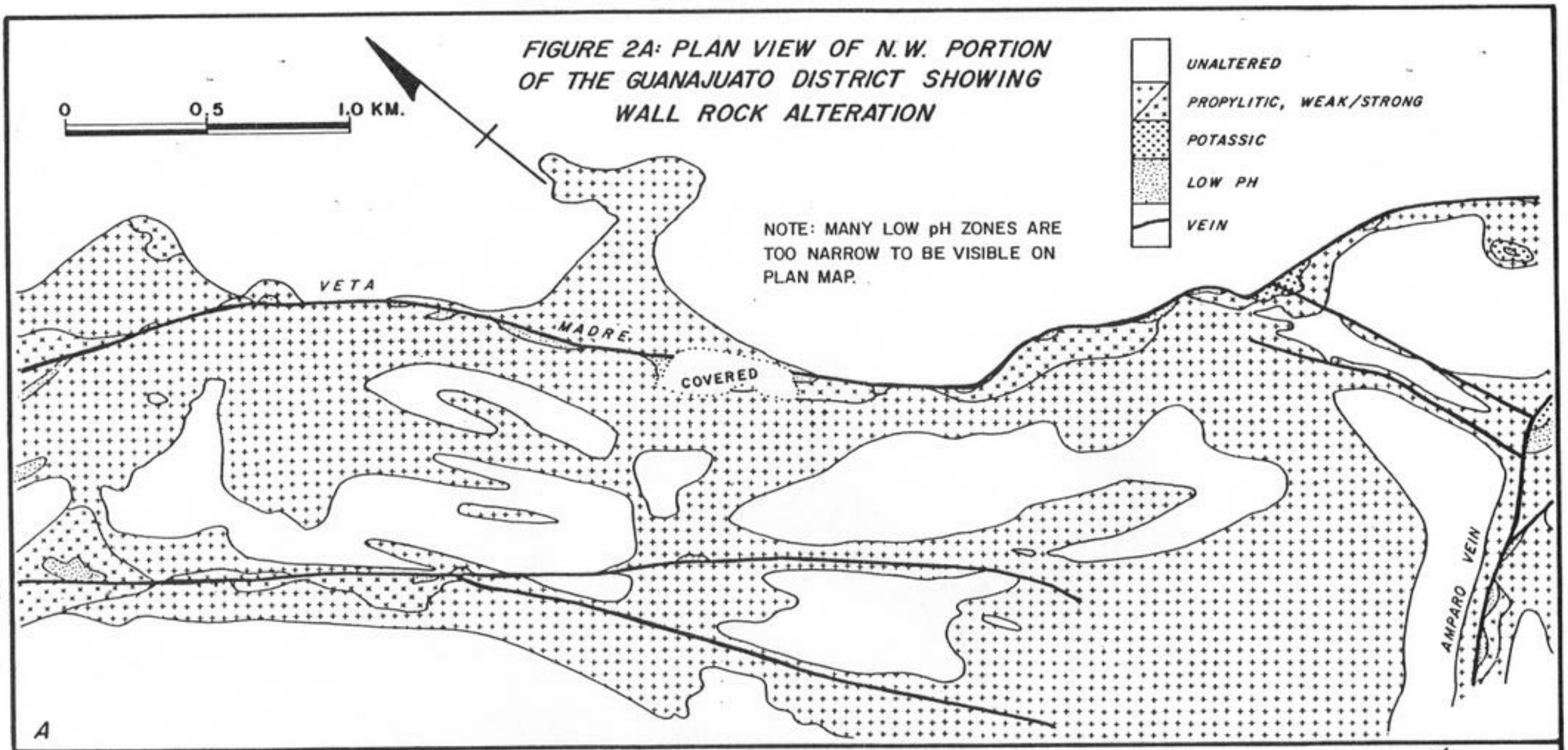


FIGURE 2A: PLAN VIEW OF N.W. PORTION OF THE GUANAJUATO DISTRICT SHOWING WALL ROCK ALTERATION

NOTE: MANY LOW pH ZONES ARE TOO NARROW TO BE VISIBLE ON PLAN MAP.

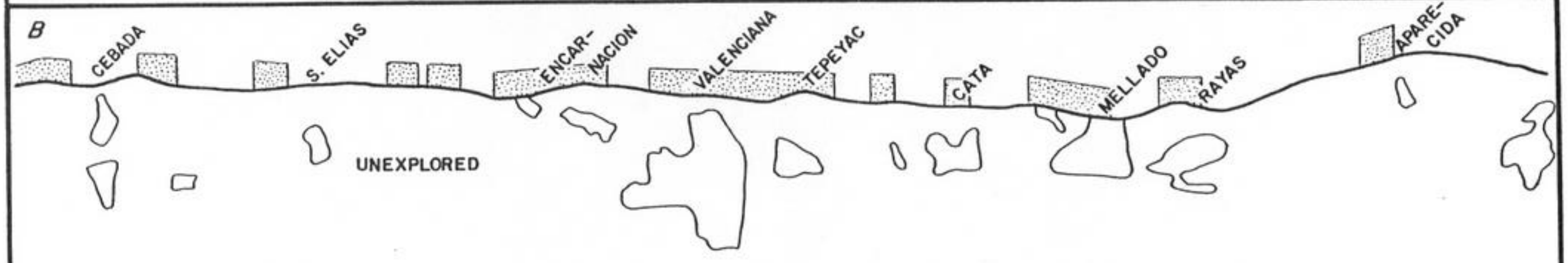
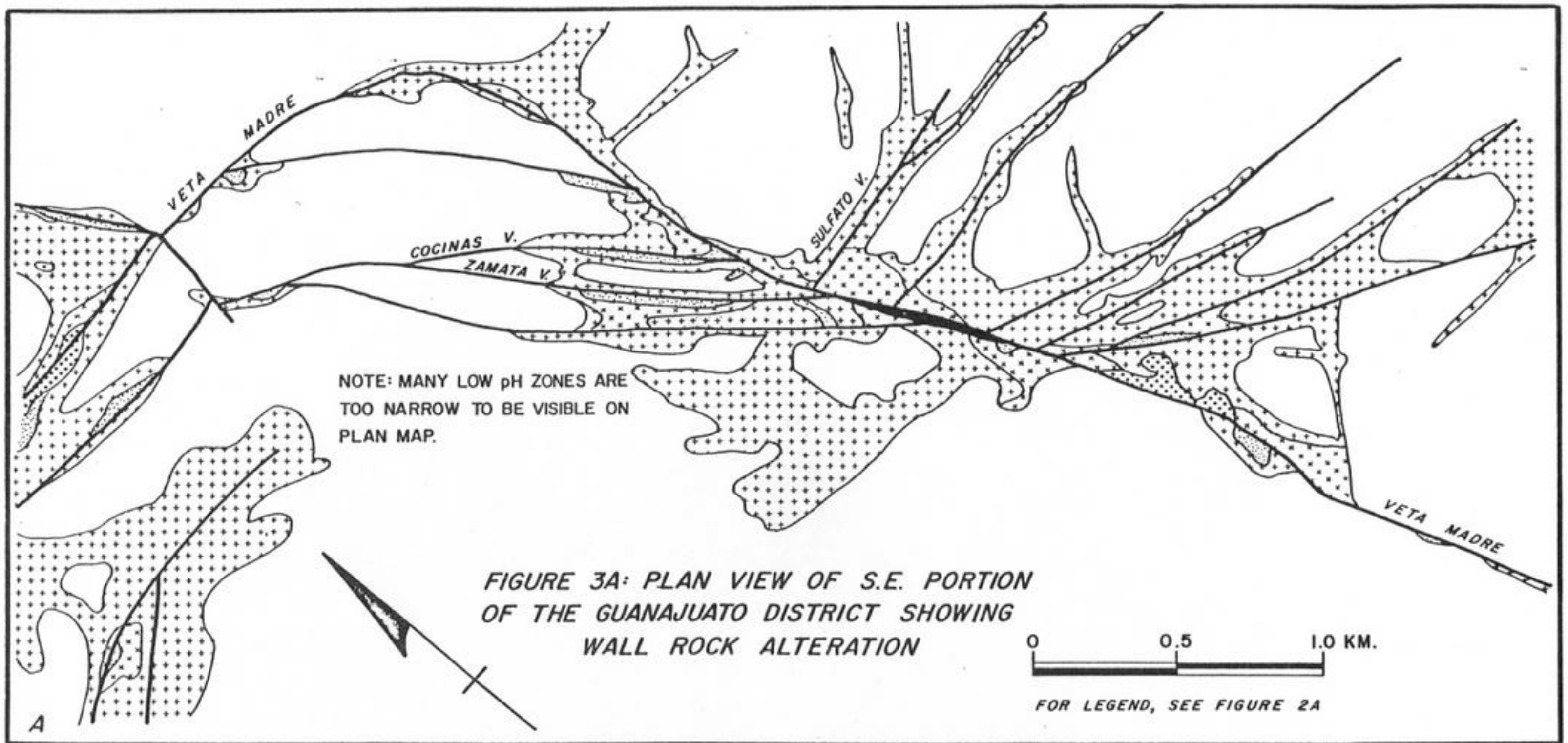


FIGURE 2B: LONGITUDINAL SECTION OF THE VETA MADRE SHOWING ORE SHOOTS AND LOW pH "CAPS"



NOTE: MANY LOW pH ZONES ARE TOO NARROW TO BE VISIBLE ON PLAN MAP.

FIGURE 3A: PLAN VIEW OF S.E. PORTION OF THE GUANAJUATO DISTRICT SHOWING WALL ROCK ALTERATION

FOR LEGEND, SEE FIGURE 2A

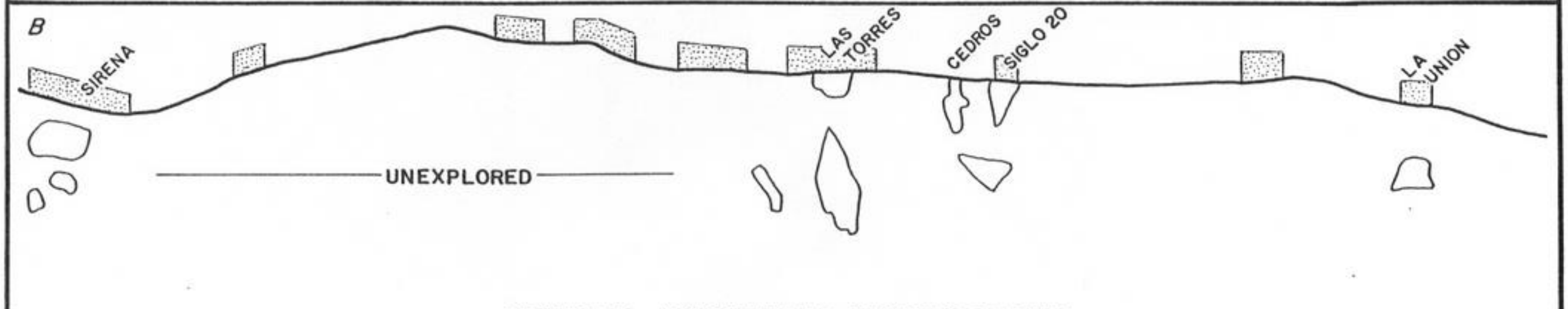


FIGURE 3B: LONGITUDINAL SECTION OF THE VETA MADRE SHOWING ORE SHOOTS AND LOW pH "CAPS"

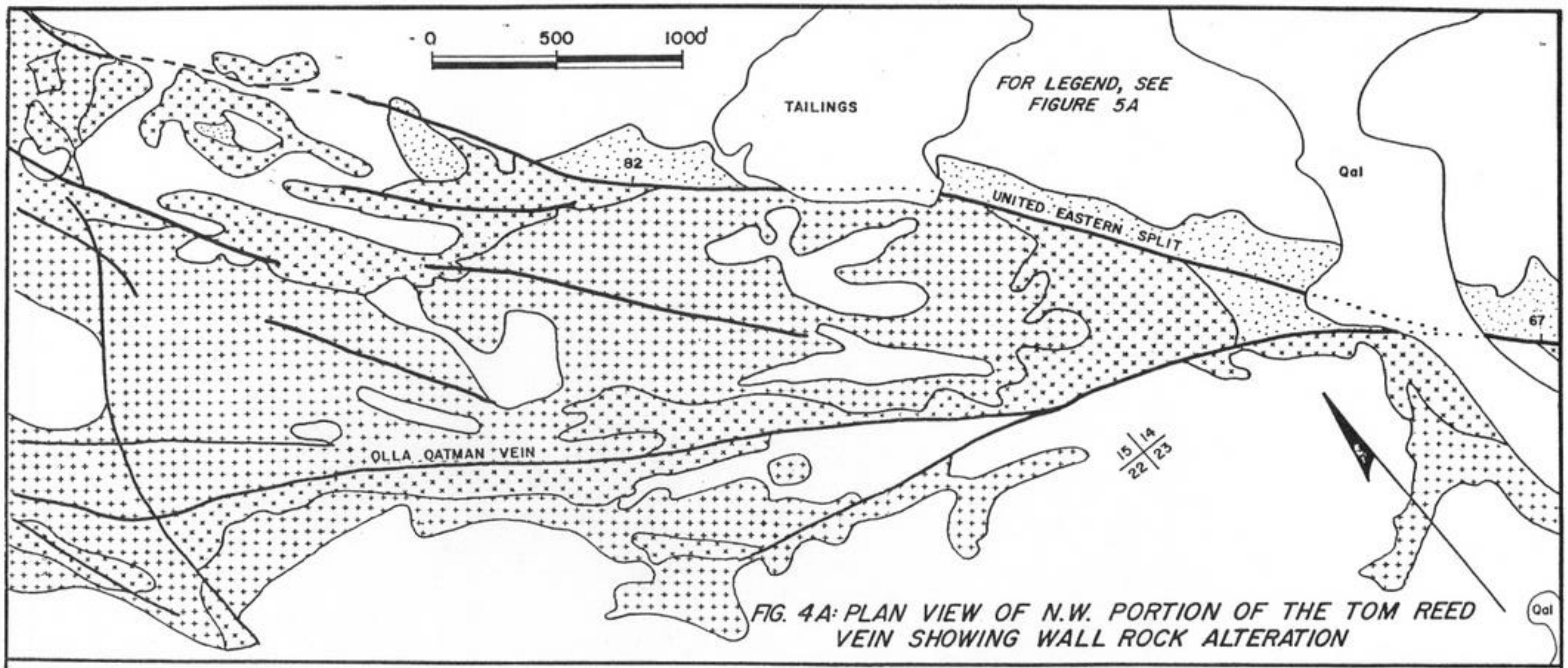


FIG. 4A: PLAN VIEW OF N.W. PORTION OF THE TOM REED VEIN SHOWING WALL ROCK ALTERATION

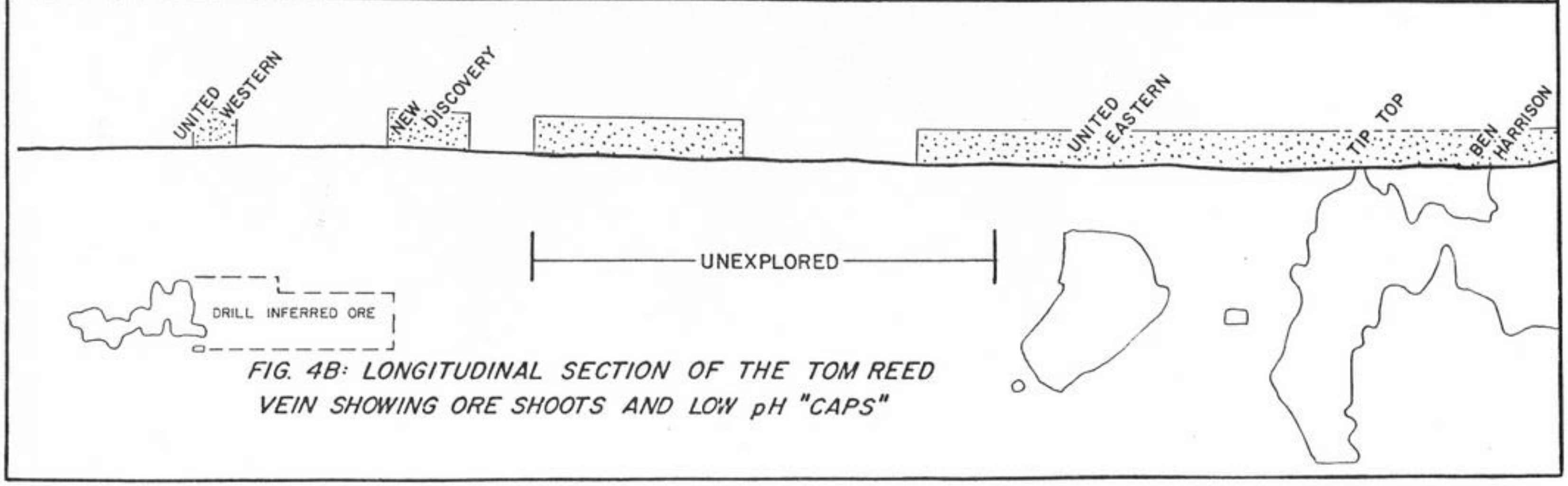


FIG. 4B: LONGITUDINAL SECTION OF THE TOM REED VEIN SHOWING ORE SHOOTS AND LOW pH "CAPS"

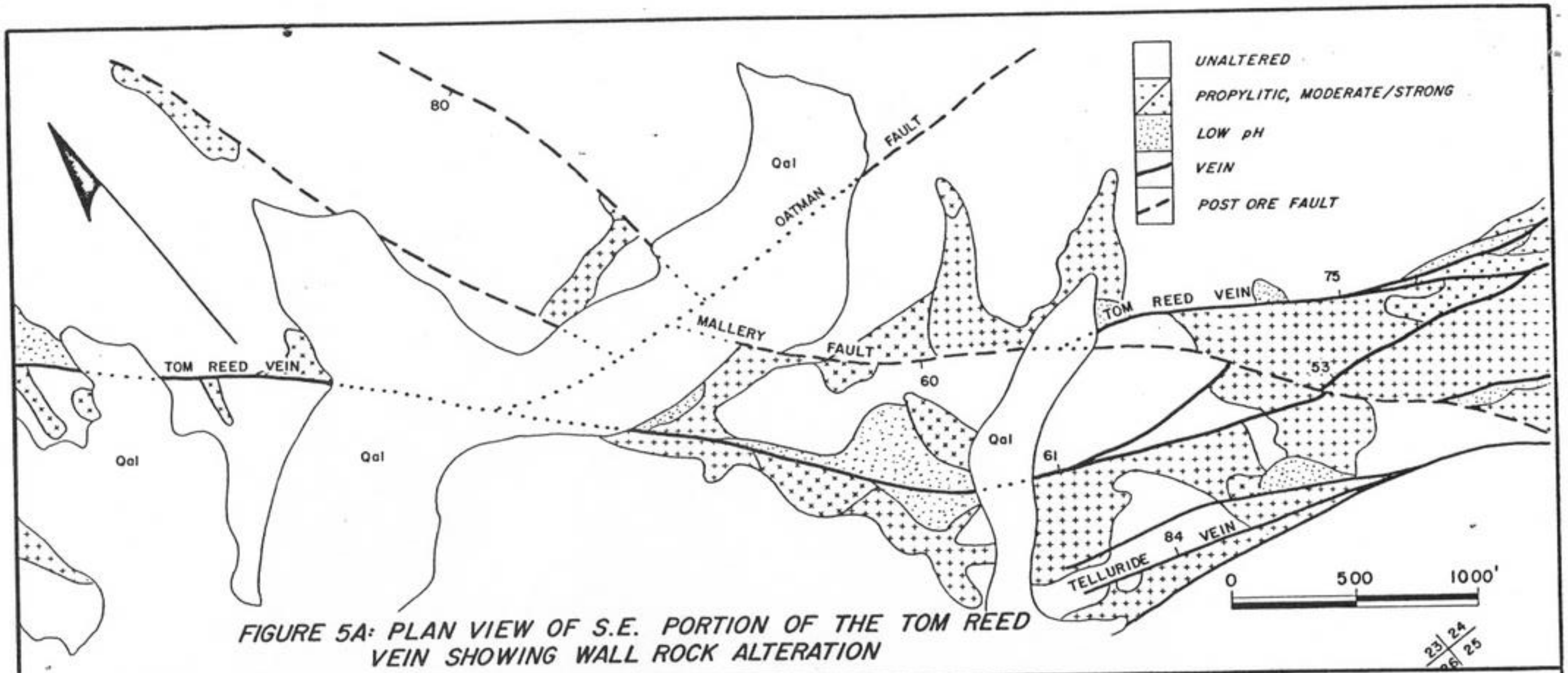


FIGURE 5A: PLAN VIEW OF S.E. PORTION OF THE TOM REED VEIN SHOWING WALL ROCK ALTERATION

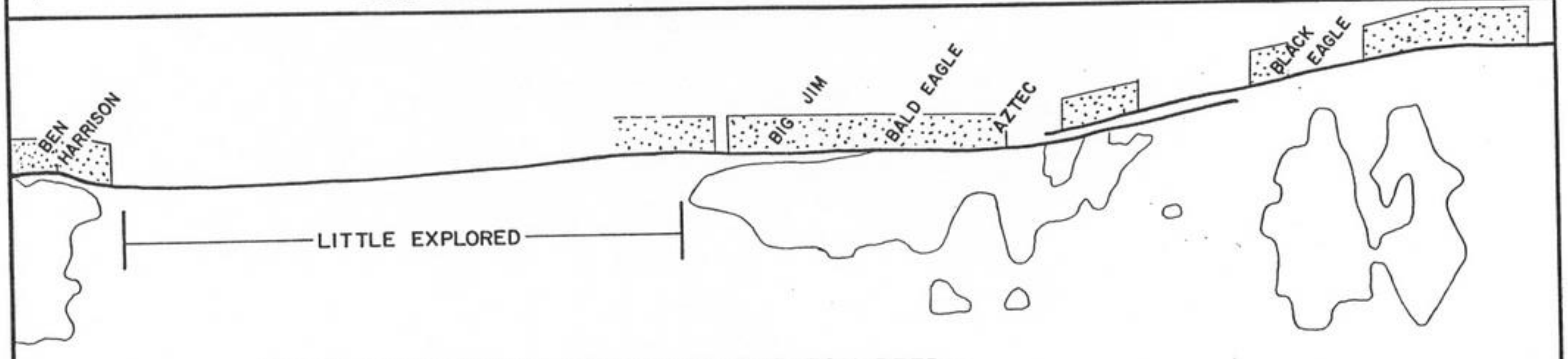


FIG. 5B: LONGITUDINAL SECTION OF THE TOM REED VEIN SHOWING ORE SHOOTS AND LOW pH "CAPS"

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