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A REVIEW OF THE SEDIMENT-HOSTED, DISSEMINATED PRECIOUS METAL DEPOSITS OF NEVADA : Geological Setting, Classification, Genesis and Exploration

by

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ABSTRACT

Carlin-type, fine-grained, "invisible" or Disseminated Replacement Type gold-silver deposits are all different names for a major new type of ore deposit that is currently being extensively developed in the Western United States. This type of deposit is now being found elsewhere. Thus a descriptive empirical model that emphasizes the geological and geochemical environment of formation is needed to assist the mining industry in the search for similar deposits.

These deposits are typically formed in carbonaceous, silty dolomites and limestones or calcareous siltstones and claystones. Gold-silver mineralization is disseminated in the host sedimentary rocks and is exceedingly fine-grained, usually less than one micron in size in unoxidized ore. Primary alteration types include decalcification, argillitization, silicification and pyritization. Silicification is commonly intense resulting in the formation of jasperoid bodies which may be the host to higher grade ore. Supergene alteration is dominated by oxidation resulting in the formation of numerous oxides and sulphates and the release of gold from its association with sulphides and organic carbon. Commonly associated trace elements are As, Ba, Hg, Sb, and Tl.

Available geological, geochemical, fluid inclusion and stable-isotope studies lead to the conclusion that a circulating hydrothermal system is the important factor necessary for gold-silver concentration and deposition. A direct genetic or only casual relation between ore deposition and discrete igneous formations remains unclear. However, it is considered that volcanism provided the source of heat necessary for the generation of a circulating hydrothermal system. High angle faults and fold structures facilitate transport and are of prime importance in directing ore fluids to favourable host lithologies. The host rocks, overwhelmingly carbonate - rich, include those whose original and/or altered compositions and resulting permeability provide favourable sites for the precipitation of disseminated gold.

The processes resulting in the formation of these deposits are not specialized. Any thick section of carbonate rocks has the potential to produce Disseminated Replacement Type deposits wherever underlying igneous activity has developed a hydrothermal system.

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1 INTRODUCTION

Gold! Treasured and esteemed by man since ancient times for its permanence and beauty, the desire for gold has markedly influenced our history and led to barter, invasion, conquest and exploration. It has been the forerunner of civilization in many lands and has provided real benefits to civilization to a far greater degree than most other commodities. It retains a unique status among all commodities as a long term store of value. providing a valuable standard against which wealth is measured and an imperishable medium for balancing international accounts. Still treasured mainly for its decorative or monetary value, gold has also emerged in the late twentieth century as an essential industrial metal. It is still eagerly sought throughout the world.

Gold deposits occur in a wide range of geological environments spanning the entire geological time scale. The Archaean (greater than 2 500 Ma) and Phanerozoic (less than 570 Ma) are the most favourable period for primary gold enrichment in the Earths crust, and broadly correspond to the main mobile phases of the earth's history.

The increased demand for gold and silver. high prices for these metals on world markets in the last decade, and the development of improved metallurgical techniques for the treatment of low-grade ores (in particular heap leaching) have stimulated a world-wide search for epithermal bulk-mineable precious metal deposits. It has also led to a fundamental redefinition of what constitutes an economic gold - silver deposit : In many areas deposits containing as little as 2 gm/tonne Au or 75 gm/tonne Ag can be profitably worked (Bonham, 1982). Phanerozoic magmatic arcs in particular are characterized by a wide spectrum of partly overlapping geological habitats which possess bulk-mineable low-grade deposits of gold. These have been considered and categorized by Sillitoe (1982) and Bonham (1982) to whom the interested reader is referred for additional information.

Another factor that has stimulated the search for bulk-mineable precious metal deposits, particularly gold, was the discovery, in 1961, of the Carlin gold deposit, Nevada. The Carlin ore is of the so-called microscopic type and visible gold is rare to absent, consequently outcropping ore zones do not form a placer train. This factor, together with the relatively ordinary appearance of the oxidized sedimentary host rocks prevented their discovery in earlier years. Although several deposits of this type had been exploited previously, the discovery of large relatively high-grade reserves at Carlin (10 million tonnes at 10.97 gm Au/tonne; Jackson, 1983) prompted increased precious metal exploration in the western United States. A number of these important precious metal deposits have been discovered, particularly in the State of Nevada. These hydrothermal deposits are typically developed in silty, carbonaceous dolomites and limestones or calcareous siltstones and claystones. Although they normally have high gold : silver ratios, silver does predominate in some deposits. Gold and silver mineralization occurs as a disseminated replacement within the host sedimentary rocks and is typically exceedingly fine grained, usually less than one micron in size in unoxidized ore. Silicification of calcareous host sedimentary rocks to form massive jasperoids is common within these deposits and in some cases they are the host of higher-grade ore. The host rock gangue consists normally of preserved dolomite, chert, kaolinite, illite and montmorillonite. Deposits of this type are commonly referred to as either Carlin-type, or as fine-grained or "invisible-gold" deposits. The designation preferred in this report is sediment-hosted, disseminated precious metal deposits, or, Disseminated Replacement Type deposits, to account for the diversity in geological, mineralogical and chemical characteristics of these ore bodies.

The aim of this dissertation is to provide a better understanding of the sediment-hosted, disseminated precious metal deposits as an aid to successful exploration for these elusive, yet lucrative ore bodies. Select type examples from Nevada will be reviewed and compared to provide the reader with an understanding of the similarities and differences that occur in these epithermal deposits at the regional-, district-, and deposit-scale. Together, the variations and similarities provide a basic geological framework from which it is possible to formulate a genetic model. Finally, this model will be used to consider exploration techniques applicable in the search for similar deposits elsewhere.

To assist the reader in following certain parts of this dissertation, reference should be made to the Precambrian-Phanerozoic geological time scale given in Appendix 1.

2 GOLD : DISTRIBUTION AND ASSOCIATIONS

2.1 General Geochemistry

Gold, Au : Atomic no. 79; atomic weight 196.967; specific gravity 19.32 (20°C), melting point 1063.0°C; valence 1 and 3

Gold is a member of the Group 1B of the Periodic Table which includes Cu, Ag and Au, the so-called "coinage metals". In its chemical reactions Au resembles Ag in some respects but its chemical character is markedly more noble. Gold is strongly siderophilic, and somewhat chalcophilic, whereas Ag (and Cu) is mainly chalcophilic (Levinson, 1974). Siderophile elements normally prefer the metallic bond characteristic and do not as readily form compounds with oxygen or sulphides, thus explaining why gold commonly occurs as native metal. On account of their identical atomic radii, Au and Ag (1.44Å) frequently occur as a continuous solid-solution mineral series.

The principal minerals of gold are given in Table 2.1. Of those listed the

Native elements, alloys and metallic compounds	
Gold	Au
Argentian gold (electrum)	(Au,Ag)
Cuprian gold (cuproauride)	(Au,Cu)
Palladian gold (porpezite)	(Au,Pd)
Rhodian gold (rhodite)	(Au,Rh)
Iridic gold	(Au,Ir)
Platinum gold	(Au,Pt)
Bismuthian gold	(Au,Bi)
Gold amalgam	Au_2Hg_3 (?)
Maldonite	Au_2Bi
Auricupride	$AuCu_3$
Palladium cuproauride	$(Cu,Pd)_3Au_2$
Sulphide	
Uytenbogaardtite	Ag_3AuS_2
Tellurides	
Calaverite	$AuTe_2$
Krennerite	$(Au,Ag)Te_2$
Montbrayite	$(Au, Sb)_2Te_3$
Petzite (antamokite)	Ag_3AuTe_2
Muthmannite	(Ag,Au)Te
Sylvanite	$(Au,Ag)Te_4$
Kostovite	$AuCuTe_4$
Nagyagite	$Pb_5Au(Te,Sb)_4S_{5-8}$
Antimonide	
Aurostibite	$AuSb_2$
Selenide	
Fischesserite	Ag_3AuSe_2
Tellurate	
Gold tellurate (?)	

TABLE 2.1 : Gold minerals (Boyle, 1979)

most common are native gold, the Au-Ag-Cu-Pd alloys and the tellurides. Sulphide minerals such as pyrite and arsenopyrite, and to a lesser exent chalcopyrite, stibnite, orpiment and realgar may be significant on account of contained gold in solid solution or as microscopic inclusions. Native gold crystallizes in a great variety of forms and variable purity. Purity is expressed in terms of fineness, which is commonly defined as the proportion of pure gold in the sample in parts per thousand. Thus, native gold which is 900 fine contains 90 per cent of the element gold. Alternatively gold fineness may be expressed as the ratio Au/ [(Au+Ag or total base metal content)] x 1000. In some deposits native gold is relatively pure, but more generally it contains Ag, Cu and Fe and traces to minor amounts of one or several of the following elements : Li, Na, K, Be, Mg, Ca, Sr, Ba, Zn, Cd, Hg, B, Al, Ga, In, Sc, Si, Ge, Sn, Pb, Ti, Zr, As, Sb, Bi, V, Se, Te, Cr, Mo, W, Mn, Co, Ni, Rh, Pd, Ir, Pt, U, Th and rare-earth (Boyle, 1979). Of these elements, gold has the most marked affinity for Te, Bi and Sb. The reason for this is a particularly stable electronic configuration.

In nature, gold consists of only one isotope, $^{197}Au_{79}$, whose half-life is estimated to be greater than 3 x $10^{1}6$ years. The isotope $^{130}Te_{52}$ is radioactive and decays by double beta mission to yield ^{130}Xe. These isotopic characteristics are frequently used in determing the age of gold and silver deposits.

Gold is usually found in one of three valence states : 0 (native), or in its oxidated states as +1 (aurous) and +3 (auric). These are designated Au, Au(1) and Au(111) respectively (Boyle, 1979). Gold in its native state is the most noble of metals. It is chemically unreactive and is not affected by water or most acids, nor attacked by oxygen or sulphur. The halogens (particularly F and Cl) react readily with gold. Gold dissolves readily in alkali cyanide solutions in the presence of air (O, H), sparingly in alkali sulphide solutions, readily in selenic acid, readily in solutions containing telluric and sulphuric or phosphoric acid, readily in sulphuric and hydrochloric acid solutions containing an oxidizing agent such as MnO_2 and Fe_2O_3, and sparingly in alkali thiosulphate solutions (Boyle, 1979). In summary, the complexes which are likely to be of most importance in the transport of gold in hydrothermal ore forming fluids will be those involving

Cl^-, sulphur donor ligands such as HS^-, S^{2-} and perhaps SO^{2-} in some high temperature environments, as well as thioarsenite (and less importantly thioantimonite) ligands such as AS_2 (or $As_2S_4{}^{2-}$) (Seward, 1982). In addition, complexes with NH_3 in ammonia-containing hydrothermal solutions must be considered. With increasing temperature, metal-ion hydrolysis proceeds to lower pH and mixed-ligand complexes involving OH^- may also be important. The solubility and transport of Au in hydrothermal solutions will be considered in more detail in Section 4 detailing the genesis of the sediment-hosted, disseminated precious-metal deposits.

Gold in hydrothermal solutions will precipitate as a result of changes in temperature, pressure, oxidation potential (Eh), pH, composition of fluid and also decreases in the activities of complexing ligands. Redox reactions suitable for precipitation of gold will also be considered in the subsequent section on genesis. However, it should be noted that gold precipitation reactions are facilitated when hydrothermal solutions enter reducing or slighly alkaline rocks such as those with high carbon, pyrite or carbonate content (Lewis, 1982). Also, gold complexed as a thio-complex may be precipitated by any process which causes a decrease in the activity of reduced sulphur, such as is accomplished by precipitation of sulphides (Seward, 1979, 1982). In hydrothermal deposits, Au is associated with Hg, Bi, Sb, As, Se, Te and Tl, as well as Ag and Cu.

Gold is widely distributed in the Earth's crust and its oceans, but only rarely does it occur in concentrations great enough to permit economic recovery. West (1976) estimated the Earth's crust to have an average gold content of 0,0035 ppm, or 3.5 ppb. Boyle (1979, 1982, 1984) calculated the abundance of gold in the Earths crust at about 0.005 ppm and the Au/Ag ratio at about 0.1. According to Boyle (1979), the average gold content of igneous-type rocks in parts per million is : ultramafic (0,004), gabbro-basalt (0,007), diorite-andesite (0,005), and granite-rhyolite (0,003). In both plutonic and volcanic rocks, gold content generally decreases from mafic to felsic types (Crocket, 1974). The average gold content of sedimentary rocks in parts per million is : sandstone and conglomerate (0,003), normal shale (0,004), and limestone (0,003). The normal crustal abundance of gold must therefore be concentrated by a factor of at least 1 000 before it can be considered as ore grade. For further discussion, and reference tables of Au content in a wide variety of rock types, the reader is referred to Boyle (1979), Crocket (1974) and Stephenson and Ehmann (1971).

2.2 Distribution of Gold in Time and Space

The source of the estimated 90 000 tonnes of gold that have been recovered since early civilization until 1974 is shown in Figure 2.1. Approximately one third of this production has been derived from the Witwatersrand palaeo-placer deposits (Woodall, 1979). It is of significance that the source of the Witwatersrand gold was probably Archaean-type crust. It is apparent that primary gold mineralization has accumulated unevenly through geologic time and a number of metallogenetic epochs, and related provinces, can be recognized. The greatest period of primary gold mineralization took place in Archaean time (Boyle, 1979; Woodall, 1979) (Figure 2.2). Primary gold enrichment was negligible during the Proterozoic (~ 2500 - 570 Ma). Gold deposits associated with volcanic activity and related intrusive events occur throughout the Palaeozoic (~ 570- 225 Ma) and show a distinct increase in the Mesozoic (~ 225 - 65 Ma) and Cenozoic (~ 65 - 0 Ma), the younger deposits often containing significant contents of silver.

The maxima of primary gold enrichment are the result of igneous and orogenic activity related to the more mobile phases of the Earth's crustal history. Archaean gold is associated with the intensely deformed metasediment-metavolcanic "greenstone belts", surrounded by extensive areas of massive and gneissic granitoid rocks. The distribution of primary gold deposits and occurrences of Precambrian age is shown in Figure 2.3, and should be compared with the distribution map of Archaean Provinces depicted in Figure 2.4. The increased stability and rigidity of the Proterozoic crust is reflected by the accumulation of great thicknesses of mature platform sediments within intra-continental rifts, aulacogens and basins, and the intrusion of major dyke swarms and layered complexes (Windley, 1977). The next major period of primary gold mineralization is related to the cycles of sedimentation, volcanism and orogeny associated with Phanerozoic "Wilson Cycle" plate tectonics (spreading ridges, subduction zones, magmatic arcs and rift zones). The distribution of primary gold deposits and occurrences of Palaeozoic, Mesozoic and Cenozoic age are shown in Figures 2.5, 2.6 and

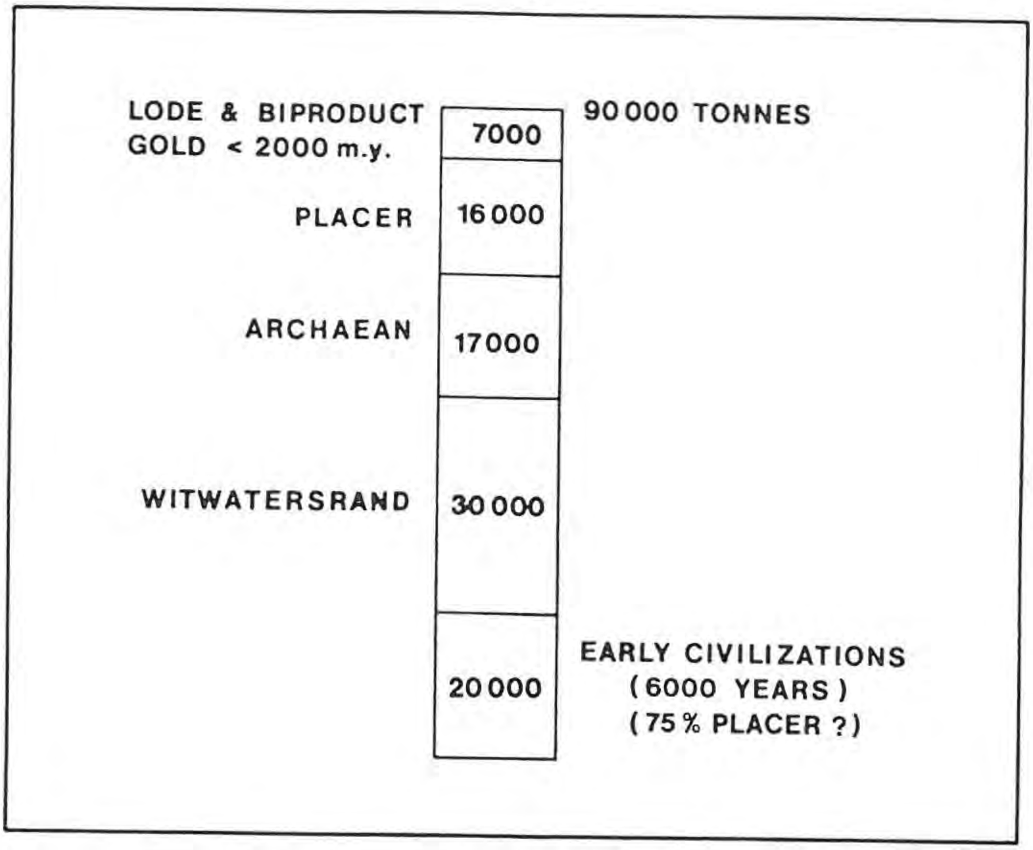


FIGURE 2.1 : Source of world gold (Woodall, 1979)

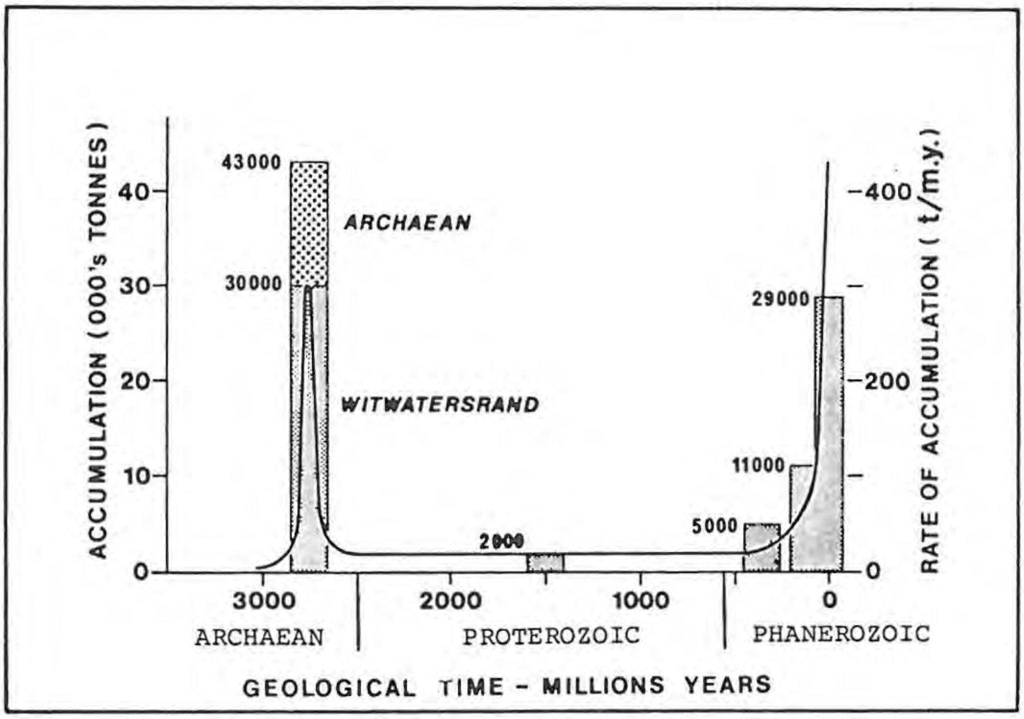


FIGURE 2.2 : Gold mineralization in geological time (Woodall, 1979)

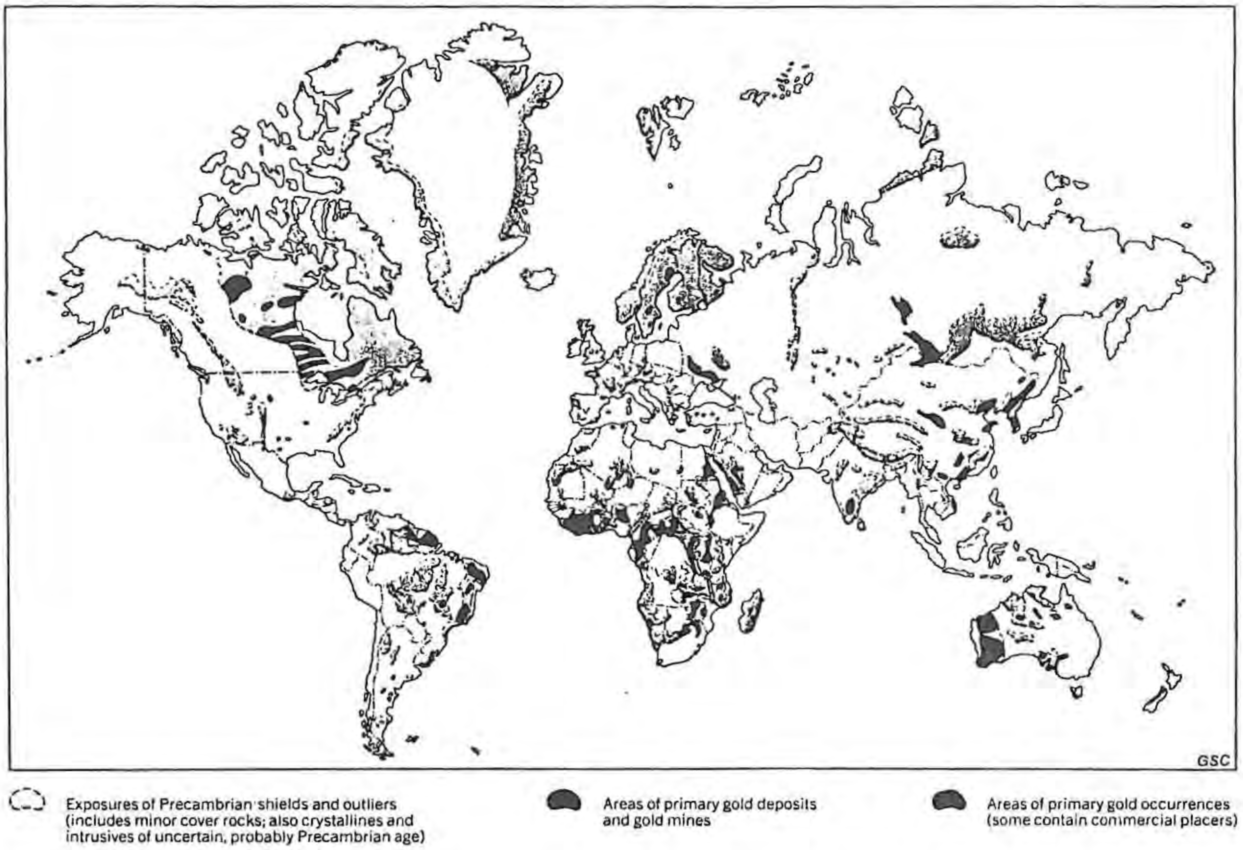


FIGURE 2.3 : World distribution of primary gold deposits, and occurrences, of Precambrian (> 570 Ma) age (Boyle, 1979)

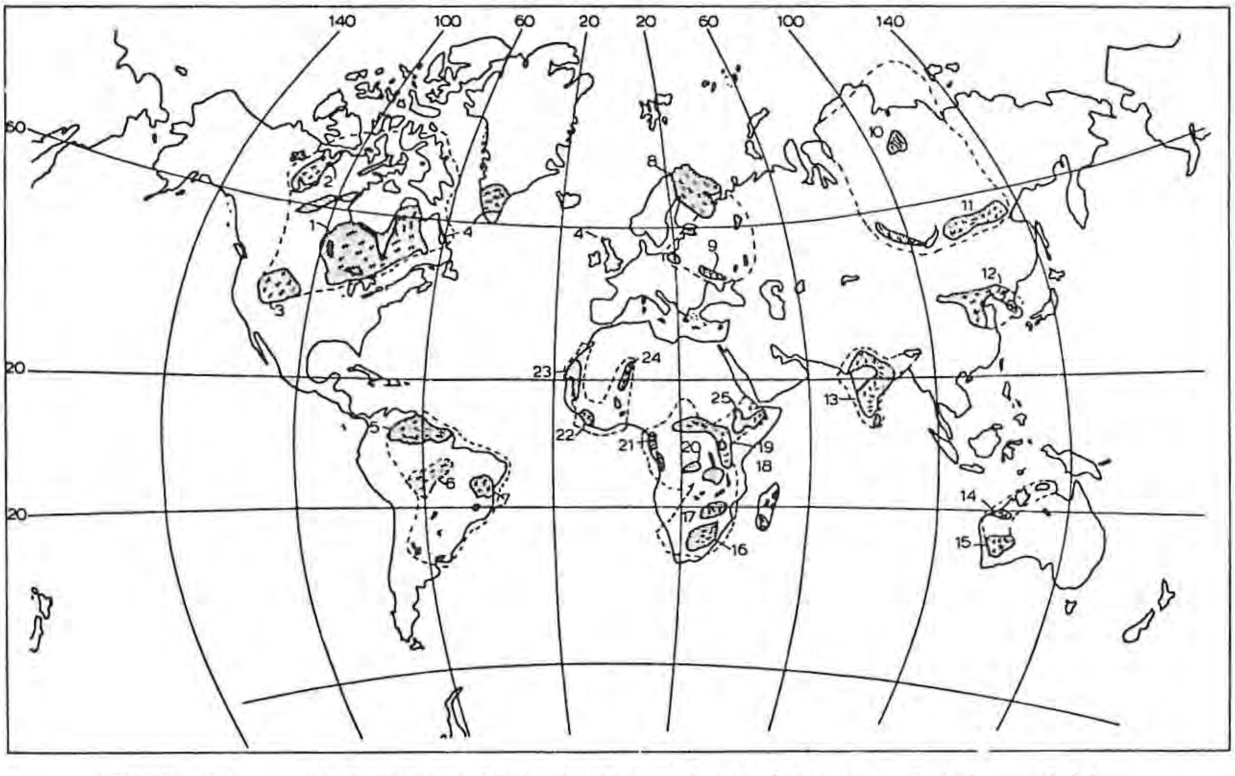


FIGURE 2.4 : Distribution of Archaean provinces (shown in gray). Bold dashed lines outline areas probably underlain by Archaean terranes. Structural trends are indicated where available. Key to major provinces : 1 = Superior (B), 2 = Slave (G), 3 = Wyoming (G), 4 = North Atlantic (H), (Nain, Godthaab, Lewisian), 5 = Guiana (H), 7 = Sao Francisco (B), 8 = Kola (B), 9 = Ukrainian (B), 10 = Anabar (H), 11 = Aidan (H), 12 = Chinese (H), 13 = Indian (B), 14 = Pilbara (G), 15 = Yilgarn (B), 16 = Kaapvaal (G), 17 = Rhodesian (G), 18 = Zambia (H), 19 = Central African (B), 20 = Kasai (H), 21 = Cameroons (H), 22 = Liberian (B), 23 = Maritanian (H), 24 = Ouzzalian (H), 25 = Ethiopian (H). Symbols : G = granite-greenstone terrane; H = high-grade terrane; B = both granite-greenstone and high-grade terranes (Condie, 1981).

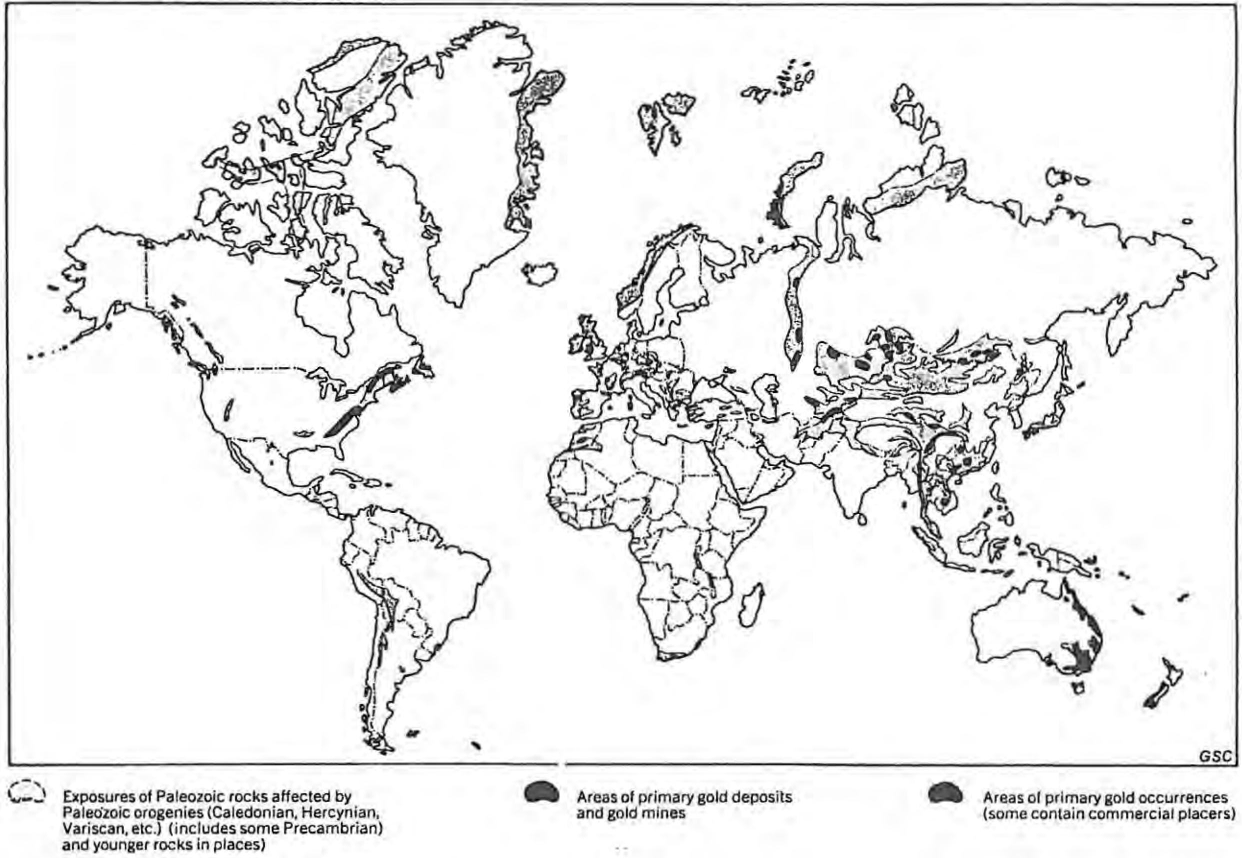


FIGURE 2.5 : World distribution of primary gold deposits, and occurrences, of Palaeozoic (225 - 570 Ma) age. (Boyle, 1979)

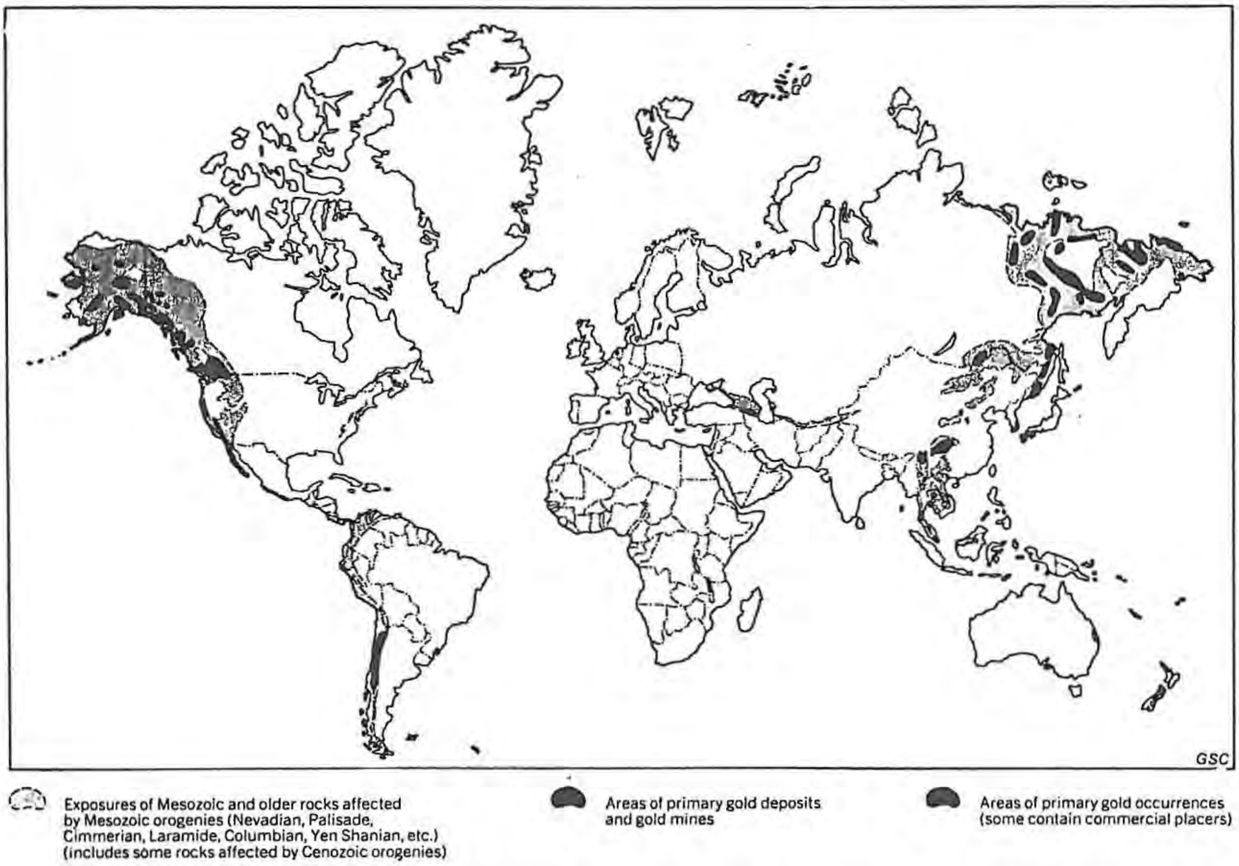


FIGURE 2.6 : World distribution of primary gold deposits, and occurrences, of Mesozoic (65 - 225 My) age (Boyle, 1979)

2.7 respectively. Their relationship to the major tectonic features of the world can be made by comparison with Figure 2.8.

2.3 Classification of Gold Deposits

Classifications attempt to arrange related subjects in logical order or sequence and thus help clarify a diverse assemblage (Jensen and Bateman, 1979). Numerous classifications of mineral deposits have been proposed, but to date no universally acceptable scheme has been formulated. Early classifications, formulated in the last century, were based on shape, form, attitude and other physical properties (Noble, 1955; Jensen and Bateman, 1979). Increasing emphasis on the "genetic" aspects of ore deposits culminated in the classification of Lindgren, first presented in 1907 (Lindgren, 1907) (Table 2.2). The chief basis of distinction between groups is the temperature and pressure (depth) of the formation of the deposits.

In general, most hydrothermal deposits (those formed by "hot ascending waters of uncertain origin" in Lindgren's classification) are formed in successive stages with later minerals replacing earlier ones. Earlier minerals of epithermal deposits may form at higher temperatures than the later minerals of mesothermal deposits. The mineral sequence of earlier to later minerals is generally also that of higher to lower temperature forms, and commonly minerals characteristic of the epithermal zone replace or are later than those characteristic of the mesothermal zone. It is clear, therefore, that depositional factors other than temperature and pressure play a part in the formation of mineral deposits. Thus structural control, the physical and chemical effects of wall rocks, the relative ratios of concentrations of different ions in solution, and chemical complexes all play a part in determining the position and mineralogical content of mineral deposits. A generalized summary of the chemical distribution of epi-meso-hypothermal zones is shown in Figure 2.9.

Graton (1933) proposed two important additions to Lindgren's classification of deposits formed by hot ascending waters, namely : the leptothermal group lying above the mesothermal and the telethermal group above the epithermal.

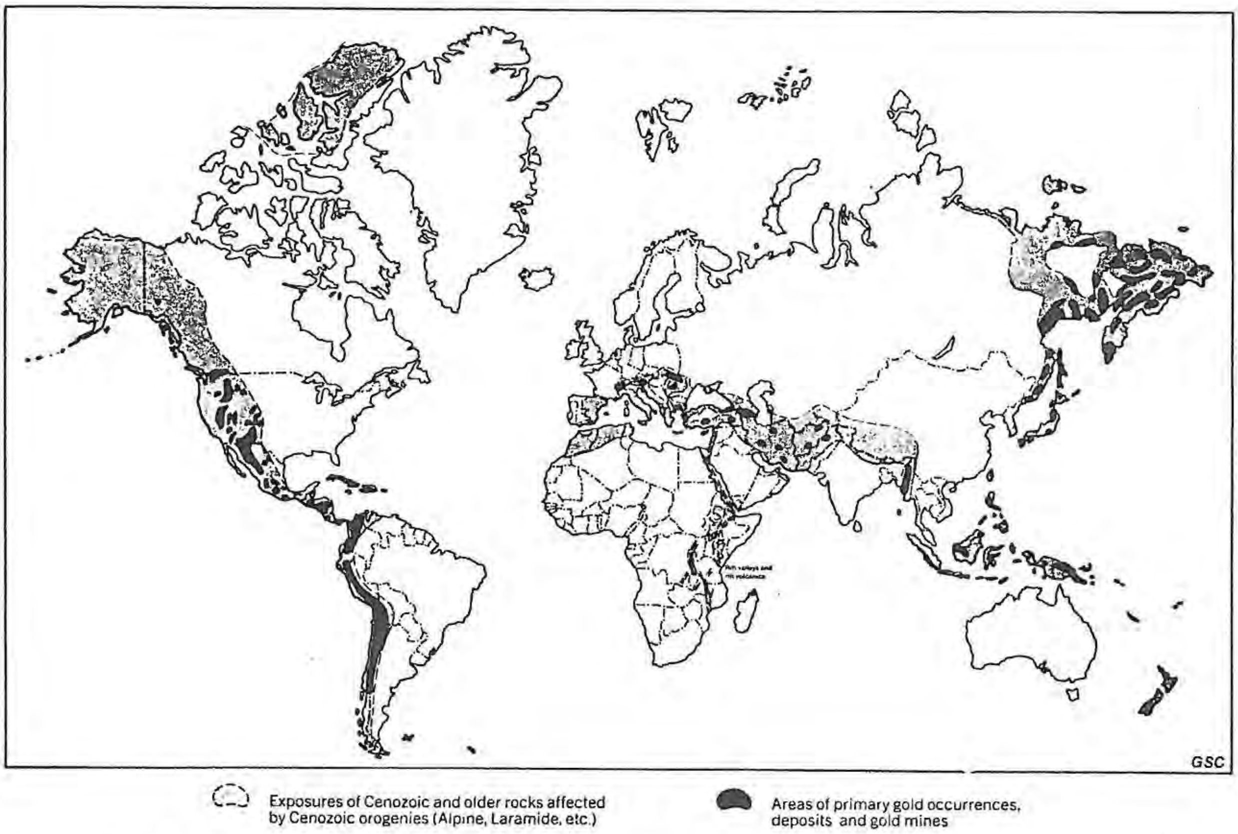


FIGURE 2.7 : World distribution of primary gold deposits, and occurrences, of Cenozoic age (may include some deposits older than Tertiary) (Boyle, 1979)

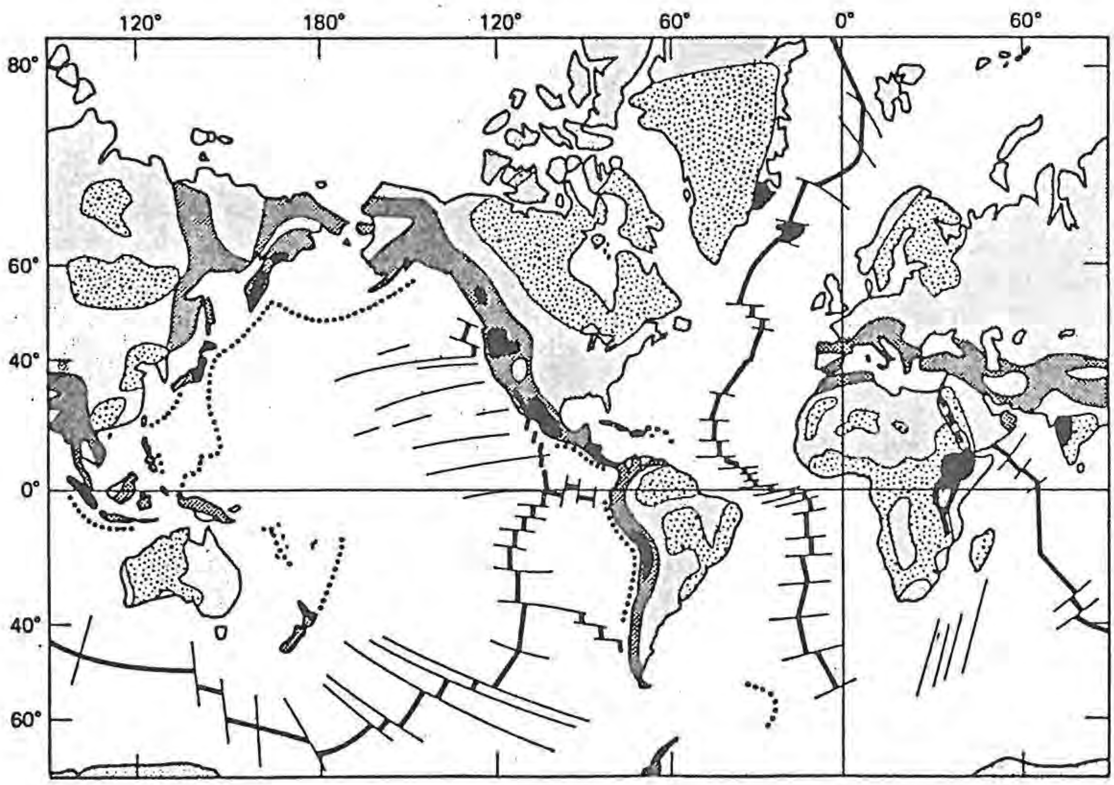


FIGURE 2.8 : The major tectonic features of the world : Heavy lines, active rift systems of oceanic ridges. Light lines, oceanic faults. Dotted lines, oceanic trenches. Light shading, continental platforms. Ornamented, continental shields. Dark grey, Tertiary folded mountain chains. Black, Cenozoic volcanic regions (Windley, 1977).

I Deposits produced by mechanical processes of concentration (Temperature and pressure moderate).	
II Deposits produced by chemical processes of concentration (Temperature and pressure vary between wide limits).	
A In bodies of surface waters.	
1 By interaction of solutions.	
a Inorganic reactions. b Organic reactions.	Temperature, 0° to 70° C ±. Pressure, moderate to strong.
B In bodies of rocks.	
1 By concentrations of substances contained in the geologic body itself.	
a Concentration by rock decay and residual weathering near surface.	Temperature, 0°–100° C ±. Pressure, moderate.
b Concentration by ground water of deeper circulation	Temperature, 0°–100° C ±. Pressure, moderate.
c Concentration by dynamic and regional metamorphism	Temperature up to 400° C ±. Pressure, high.
2 Concentration effected by introduction of substances foreign to the rock.	
a Origin independent of igneous activity.	
By circulating atmospheric waters at moderate or slight depth.	Temperature, to 100° C ±. Pressure, moderate.
b Origin dependent upon the eruption of igneous rocks.	
a By hot ascending waters of uncertain origin, but charged with igneous emanations.	
1 Deposition and concentration at slight depth. Epithermal deposits.	Temperature, 50°–200° C ±. Pressure, moderate.
2 Deposition and concentration at intermediate depths. Mesothermal deposits.	Temperature, 200°–300° C ±. Pressure, high.
3 Deposition and concentration at great depth or at high temperature and pressure. Hypothermal deposits.	Temperature, 300°–500° C ±. Pressure, very high.
b By direct igneous emanations.	
1 From intrusive bodies. Contact metamorphic or pyrometasomatic deposits.	Temperature, probably 500°–800° C ±. Pressure, very high.
2 From effusive bodies. Sublimates, fumaroles.	Temperature, 100°–600° C ±. Pressure, atmospheric to moderate.
c In magmas, by processes of differentiation.	
a Magmatic deposits proper.	Temperature, 700°–1500° C ±. Pressure, very high.
b Pegmatites.	Temperature, about 575° C ±. Pressure, very high.

TABLE 2.2 : The Lindgren "depth-zone" classification of mineral deposits (Noble, 1955).

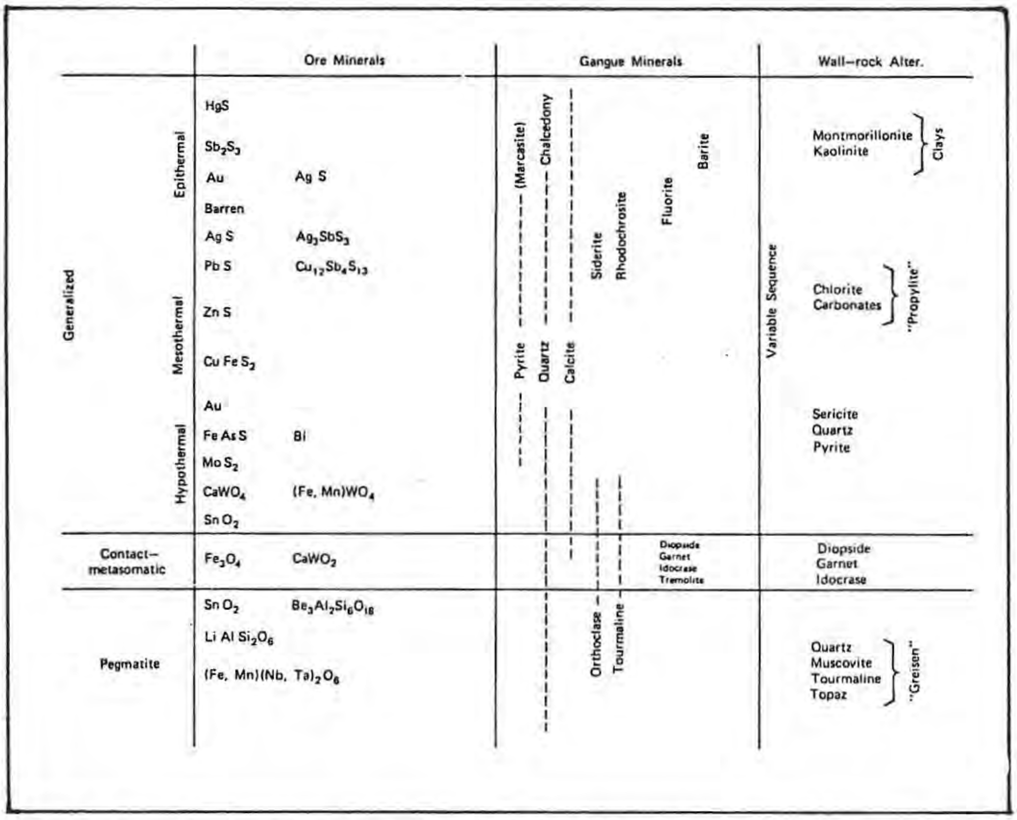


FIGURE 2.9 : Generalized chemical and mineralogical associations of the ore minerals, gangue minerals and wall rock alteration within the epi-meso-hypothermal zones (Jensen and Bateman, 1979).

1. Hydrothermal concentrations: gold is deposited from an aqueous solution of unspecified origin at elevated temperatures.

   A. Subvolcanic - Plutonic Type: concentrations directly associated with igneous activity in the subvolcanic - plutonic environment. e.g. Nickel Plate and French Mines - British Columbia; Gold Hill - Utah; Cable mine - Montana; Richardson mine - Ontario; Rosita mine - Nicaragua; Natas mine - S.W.A./ Namibia; porphyry Cu-Au.

   B. Epithermal Type: concentrations formed by near surface hydrothermal activity (dominantly of meteoric origin). e.g. Goldfield, Round Mountain, Rochester, Searchlight, Carlin, Cortez, - Nevada; Antamock, Acupan - Philippines; Vatukoula, Mt Kasi - Fiji; Yatani mine - Japan; Hauraki, Thames - New Zealand.

   C. Chemical Precipitate Type: concentrations formed by precipitation from fluids emanating from hydrothermal systems in a subaqueous environment. Archaean banded iron formation-hosted gold deposits are the only examples of this type. Economic concentrations are usually considered to be the result of metamorphic upgrading (1D). e.g. Vubachickwe and Giant Mine (original syngenetic ore grade deposits).

   D. Metamorphic Type: concentrations formed at depth by regional metamorphic dewatering. Includes metamorphically upgraded concentrations formed by other methods (i.e. multistage). e.g. Yellowknife - Northwest Territories; Mother Lode - California; Kalgoorlie - Australia; Homestake (upgraded type 1C) - South Dakota; Connemara (upgraded type 1C) - Zimbabwe.

2. Sedimentary concentrations: gold concentrated by sedimentary processes in recent and fossil eluvial and alluvial placers. e.g. Sierra Nevada Gold Belt - California; Teton Country - Wyoming; Witwatersrand - South Africa.

3. Residual concentrations: gold concentrated by weathering in place. e.g. Brazil, Madagascar, Tanzania, Australia, Appalachian states.

4. Organic concentrations: gold associated with carbon-rich material - (Adsorption - biochemical concentration?) e.g. carbon seams in Witwatersrand placers - South Africa; gold in coal, 0,01 - 1 ppm; gold in mangrove swamp, 1 ppm.

TABLE 2.3 : Classification of gold deposits (Rossiter, 1984)

The telethermal environment is therefore considered as the cooler and shallower ends of Lindgren's epithermal environment, representing the terminous of hydrothermal activity and is manifested normally as hot spring activity.

Classifications of gold deposits are equally numerous and varied. Deposits within the hydrothermal class are the most difficult to classify because of their extreme variability and intergradational relationships (Rossiter, 1984). A classification scheme proposed by Rossiter (op cit) is shown in Table 2.3. Lindgren's classification based on three pressure (depth) / temperature ranges (ie hypo-, meso- and epithermal) was not used because the Subvolcanic-Plutonic and Metamorphic Type deposits overlap in terms of pressure and temperature (hypo- to mesothermal), and it is geologically practical to only distinguish between two pressure/temperature groups (ie hypo-mesothermal and meso-epithermal). Mesothermal deposits in Lindgren's classification generally form the bottoms of epithermal deposits or the tops of hypothermal deposits. Four end members were chosen based on their environment and mode of formation. The Subvolcanic-Plutonic and Epithermal Types are depth related, the former being deposited below the latter. The Chemical Precipitate Type may be linked to Epithermal Type deposits in that they are considered to have formed by precipitation from fluids emanating from near surface hydrothermal systems, but in a subaqueous environment. Metamorphic Type deposits form as a result of the hydrothermal action of metamorphic fluids. They consist of primary deposits formed by concentration of gold from normal crustal sources, and upgraded concentrations from other metal occurrences.

Sedimentary concentrations of gold are found in fossil and recent eluvial and alluvial placers. Gold extracted from placer deposits, and in particular the Witwatersrand palaeo-placer deposits, constitutes the bulk of the world's gold production (Woodall, 1979).

Residual deposits are formed when grains of gold are released from their matrix and concentrated in situ during weathering. The gold occurs as angular particles illustrating the absence of transportation (Jensen and Bateman, 1979). Lateritic cover over mafic and ultramafic complexes (tholeiitic, ophiolitic, and komatiitic) in Brazilian greenstone belts occasionally contains native gold in the form of plates and rarely as nuggets (Rao et al., 1982).

Gold concentrations occur in association with organic material in the Witwatersrand placer deposits (Hallbauer, 1975). Gold is known to be present in coals at the 0,01 to 1 ppm level (Fyfe and Kerrich, 1982). In commercial ore recovery, carbon is commonly used to extract gold selectively from cyanide solutions (McDougal and Hancock, 1980). The importance and mechanisms of gold concentration by organic materials is generally poorly understood.

3 SEDIMENT-HOSTED, DISSEMINATED PRECIOUS METAL DEPOSITS OF NEVADA

Literally thousands of mineral occurrences of diverse type and metals are known in the western United States, one of the great mining regions of the world (Proffett, 1979; Guild, 1978). The area occupies the central section of the North American Cordillera which extends from Alaska to Central America (King, 1969), and is itself part of the circum-Pacific orogen (Spencer, 1974). The Cordillera ranges from 500 to 1 000 km in width along much of its extent but broadens to about 1600 km within the United States, where its eastern limit, the Rocky Mountain front, bulges eastwards opposite a similar western bulge of the continental margin (Figure 3.1). The geology of this area (Figure 3.2) is complex and will be only briefly considered in this section, with particular emphasis on features pertinent to the metallogenesis of the sediment-hosted, disseminated precious metal deposits of Nevada.

Gold and silver mineralization of this deposit type is disseminated usually in thin carbonaceous and calcareous host rocks and is typically very fine-grained, usually less than 1 micron in size in unoxidized ore (Radtke et al., 1980). Ore grade mineralization is frequently indistinguishable from barren rock. This, together with the markedly higher gold price since 1972, has led to an intensification in the search for and recognition of these large-tonnage, bulk-mineable low-grade gold deposits in various parts of the world. Although deposits of this type occur throughout the western United States, the largest concentration of deposits and also the best understood are in Nevada. Selected examples of some of these deposits will be

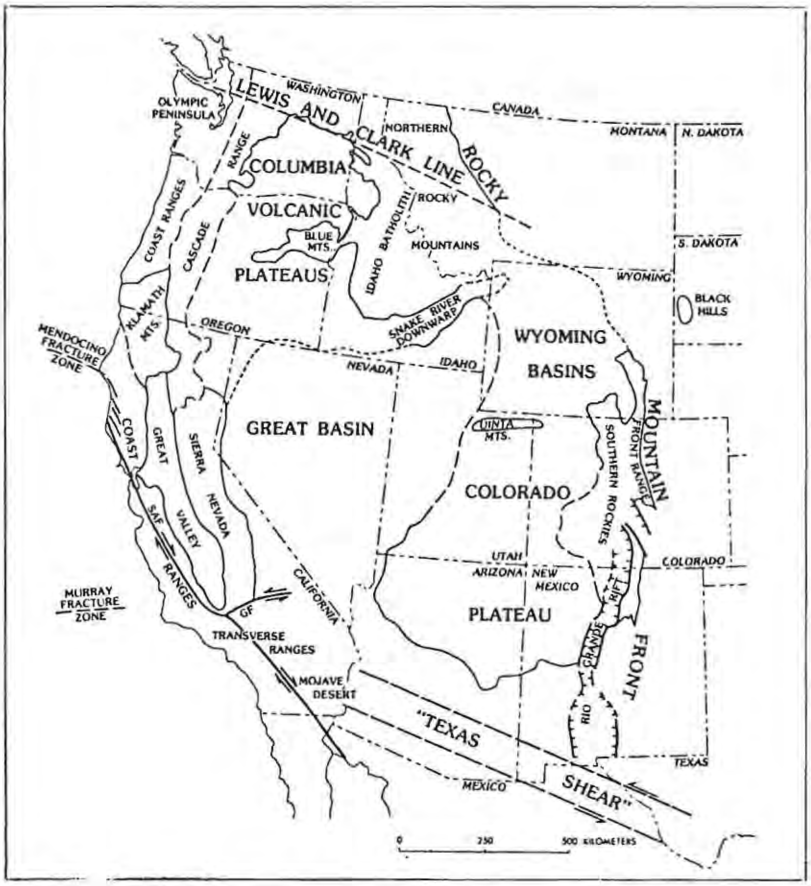


FIGURE 3.1 : Principal physiographic and some structural features of the western United States. SAF - San Andreas Fault. GF - Garlock Fault. (Guild, 1978)

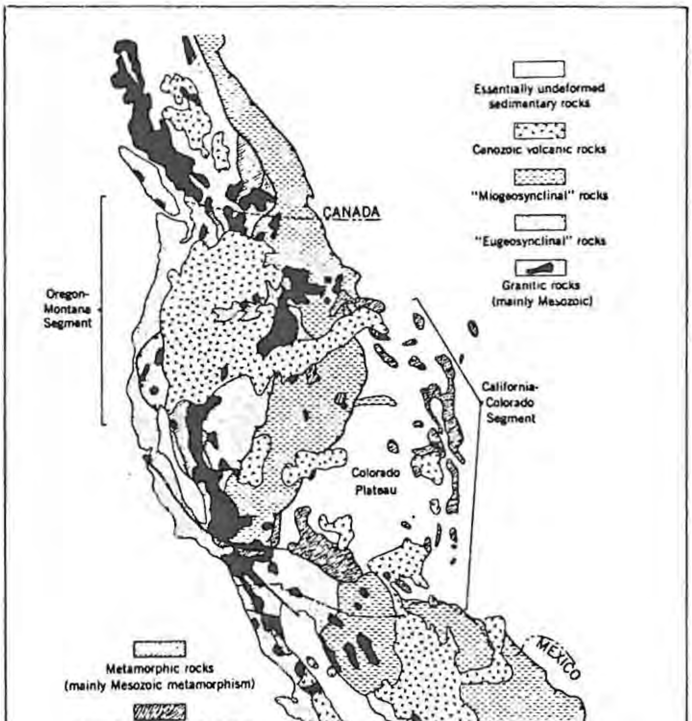


FIGURE 3.2 : Geological sketch map of western North America from Canada to central Mexico. The thrust fault between the eu- and miogeosynclinal facies rocks marks the late Devonian - early Mississippian Antler orogenic belt, whereas that between miogeosyncline and platform facies rock marks the eastern margin of the late Mesozoic to Sevier orogeny (Guild, 1978).

described to support a classification scheme, initially proposed by Bagby and Berger (in press), and to provide the reader with an understanding of the similarities and differences that occur in these deposits.

3.1 Geological Evolution of the Western United States

The ore deposits of the western United States are localized in a structural framework that formed in Precambrian time and which has continued to develop till the present day. Several major tectonic stages can be distinguished in a complex geological history, each of which is characterized by specific types and patterns of distribution of ore deposits (Proffett, 1979; Burchfiel, 1979; Guild, 1978; Silberman et al., 1976; Hewitt, 1968; Stewart et al., 1977; Roberts et al., 1971). Early-middle Precambrian crystalline basement rocks are discontinuously exposed only in the eastern and central part of the area affected by the Circum-Pacific orogeny (refer Figure 3.2). In general, these Precambrian rocks are separated from overlying terrigenous sediments of the Cordilleran geosyncline by an angular unconformity.

Palaeozoic evolution

Continental separation in late Precambrian time (~850 Ma) truncated older northeast- to east-trending basement structures and initiated the Cordilleran geosyncline (Stewart, 1972).

A westward thickening wedge of craton-derived terrigenous rocks developed comprising an eastern clastic-carbonate assemblage (miogeosyncline) and a western siliceous sediment - mafic volcanic assemblage (eugeosyncline) (Figure 3.3A). The hinge line between craton and geosyncline, known as the Wasatch Line (Burchfiel, 1979), remained nearly constant throughout the Palaeozoic. The boundary between the eu- and miogeosynclinal domains is somewhat uncertain because the former was thrust eastward along the so-called Roberts Mountain thrust, overriding the passive margin carbonate assemblage by at least 150 km, during the Antler Orogeny (late Devonian - early Mississippian) (Roberts et al., 1958) (Figure 3.3B). The Antler Orogeny is peculiar in that only the emplacement of the upper plate rocks, known also as the Roberts Mountain Allochthon, is left as a record of the

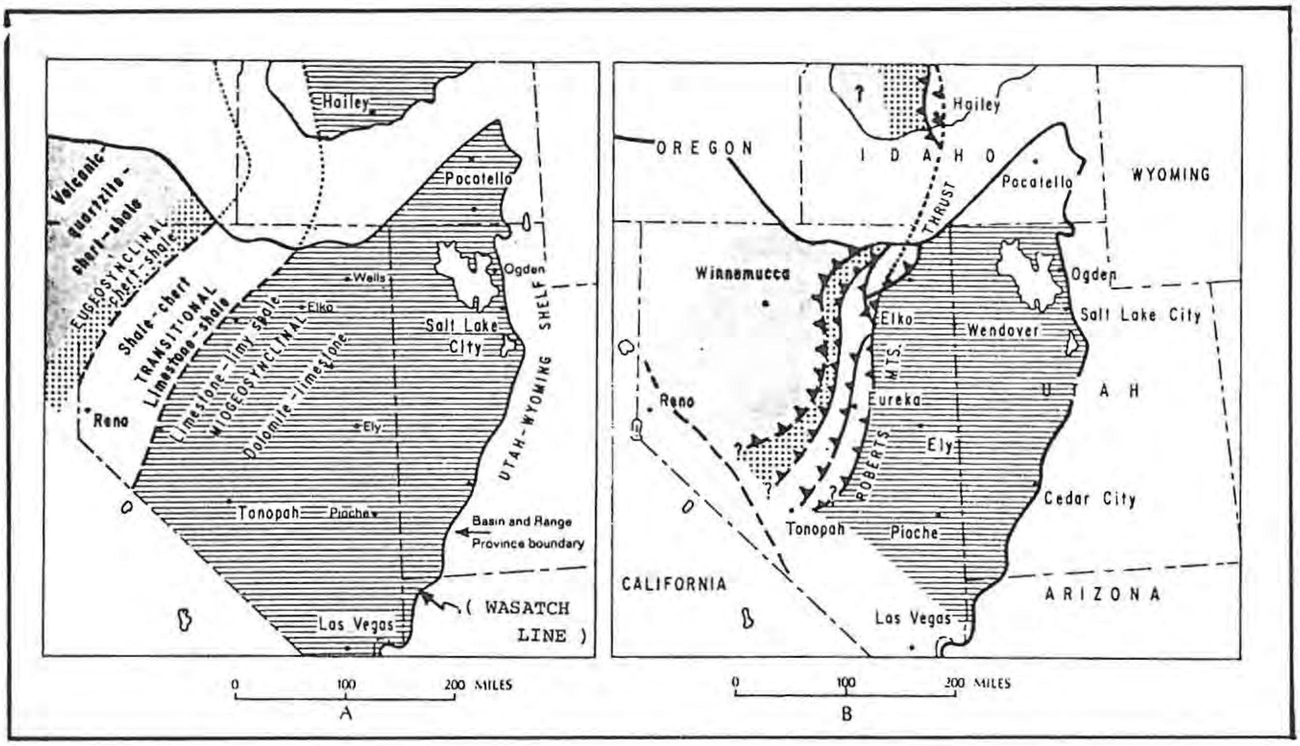


FIGURE 3.3 : (A) Map showing distribution of mio- and eugeosynclinal facies in the Cordilleran geosyncline developed from late-Precambrian through to Devonian time (+ 850 - 360 Ma). (B) Distribution of facies after late Devonian to early Mississippian thrusting related to the Antler orogeny. Area east of Wasatch Line was the North American Craton (Roberts et al, 1971)

orogeny. No magmatism or metamorphism can be related to the orogeny (Burchfiel, 1979). Fragments of ultramafic rocks are present at the base of the thrust, suggesting that the thrusted sequence was initially partly deposited on oceanic crust. It is quite possible that only a fragment of the original Antler Orogenic Belt, defined by the trace of the Roberts Mountain Thrust fault, is left in Nevada and Utah and that the remainder is either not exposed or was removed by subsequent tectonic and erosional events. Post-thrust uplift and doming together with high angle faulting and erosion has led to the upper plate being locally removed by erosion, so that carbonate assemblage rocks of the lower plate are exposed in "windows" (Figure 3.4). The principal mining districts occur within and around these windows.

The middle Palaeozoic Roberts Mountain Allochthon was the earliest terrane accreted to the western margin of the United States. It was followed in turn by the Golconda and Sonomia terranes emplaced during the late Palaeozoic, and early Mesozoic, respectively (Corey et al., 1980).

Mesozoic evolution

The onset of eastward underthrusting of oceanic lithosphere beneath the

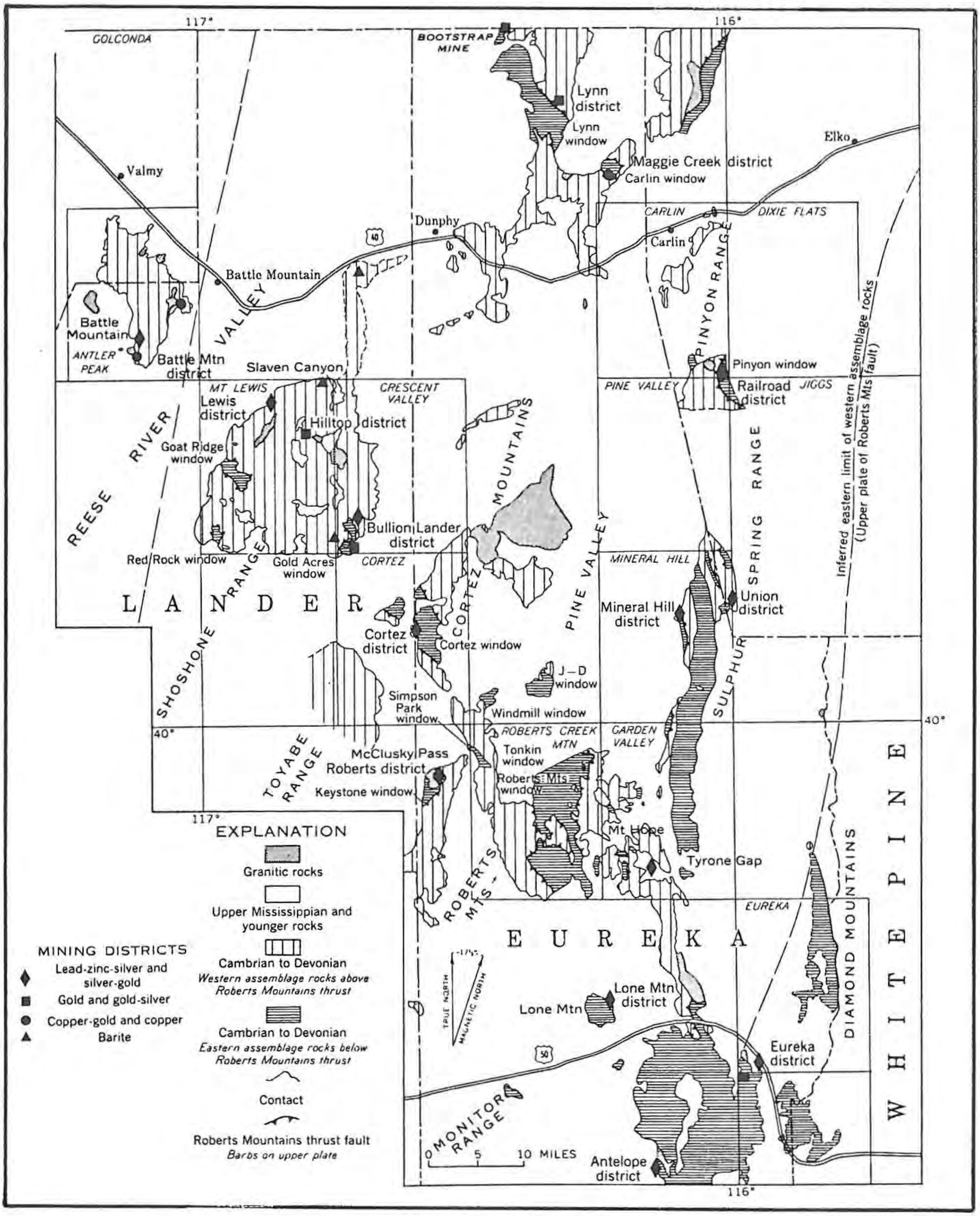


FIGURE 3.4 : Distribution of Roberts Mountain Thrust, allochthonous upper plate and autochthonous lower plate Palaeozoic rocks ("windows"), and principal mining districts in Eureka County, Nevada (Roberts et al, 1971)

continental crust of the North American Plate began and continued throughout most of Mesozoic time (Burchfiel, 1979; Guild, 1978). An S-shaped Andean-type volcano-plutonic arc was established from present day Alaska to Mexico and enormous volumes of calc-alkaline magma were episodically intruded to form great composite batholiths (Figure 3.5). Compositions range from gabbro to granite; most are granodiorite or quartz diorite (Guild, 1978). Most of the magmatism was concentrated in a zone some 200 km wide extending along the axis of the arc. Smaller, essentially synchronous bodies were intruded across a width of more than 600 km and may, at least in north-central Nevada, have been localized along northwest and northeast tectonic trends (Roberts et al., 1971). Tectonic trends are controlled by pre-existing basement structures. Limits of the magmatic arc changed spatially with time (Armstrong and Suppe, 1973). Distribution of Triassic (ie. ~225 - 180 Ma) magmatic rocks appear narrower, and it seems clear that the arc widened to its greatest width in the late Cretaceous (less than 100 Ma) (Figure 3.6). At the latitude of Nevada, the eastern limit of the arc migrated progressively eastward, whereas to the south in California the eastern limit of the arc fluctuated irregularly. East of the arc, back-arc east-directed thrust faulting characterizes Mesozoic deformation (Burchfiel, 1979). Several episodes of Mesozoic thrusting can be recognized, the most prominent having occurred during the late Jurassic-middle Cretaceous Sevier Orogeny. Thick plates of miogeosynclinal rocks were thrust eastwards over thin cratonal sedimentary sequences, thus telescoping the original geosynclinal hinge zone (Armstrong, 1968) (refer Figure 3.2).

Cenozoic evolution

Cenozoic evolution of the western United States is complex and rapid shifts in geologic activity can be discerned. Arc magmatism continued into Cenozoic time but in sharply reduced volume. In contrast to the general regularity of Mesozoic magmatism, that of Cenozoic type is difficult to characterize. Except in the far northwest, intrusions are small, lie mostly east of the Mesozoic arc, and have a tendency toward linear arrays at large angles to it. Basement control from pre-existing structures is again indicated.

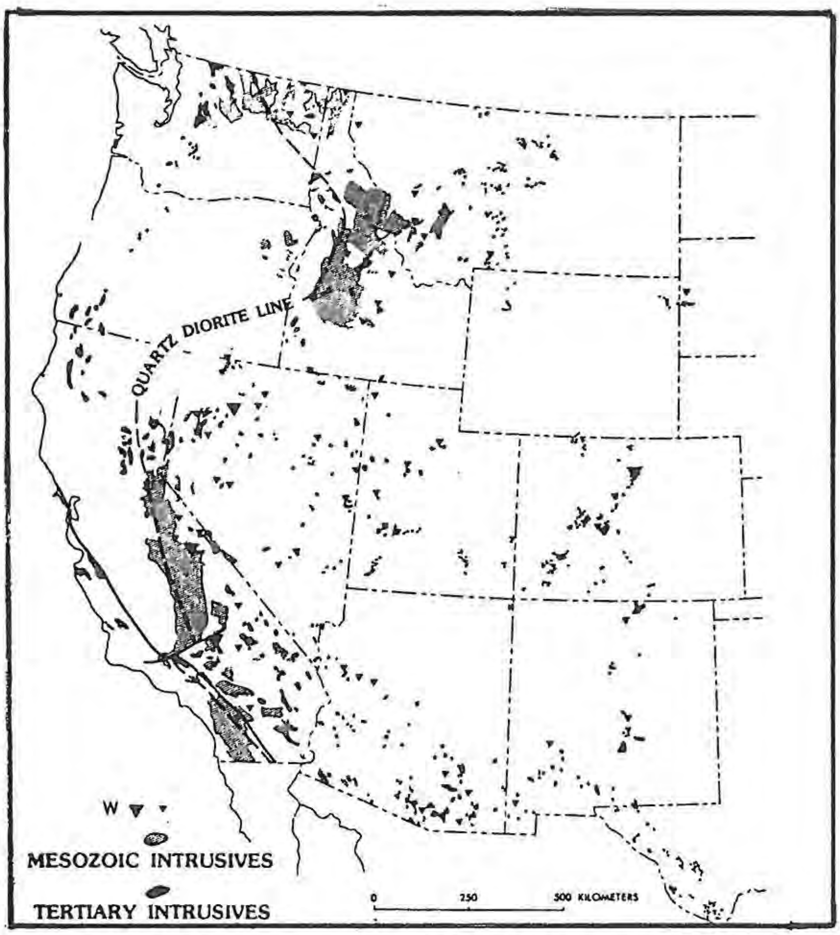


FIGURE 3.5 : Phanerozoic intrusive rocks of the western United States. An eastward increasing potash content of Mesozoic batholiths, indicated by the quartz diorite line, has been attributed to derivation of magmas from melting of oceanic lithosphere at increasing depths on a Benioff plane. Compare and contrast the essentially small, widespread distribution of Tertiary intrusives which have a tendency towards linear arrays at large angles to the more regular S-shaped Mesozoic magmatic arc of batholithic dimensions (Guild, 1978)

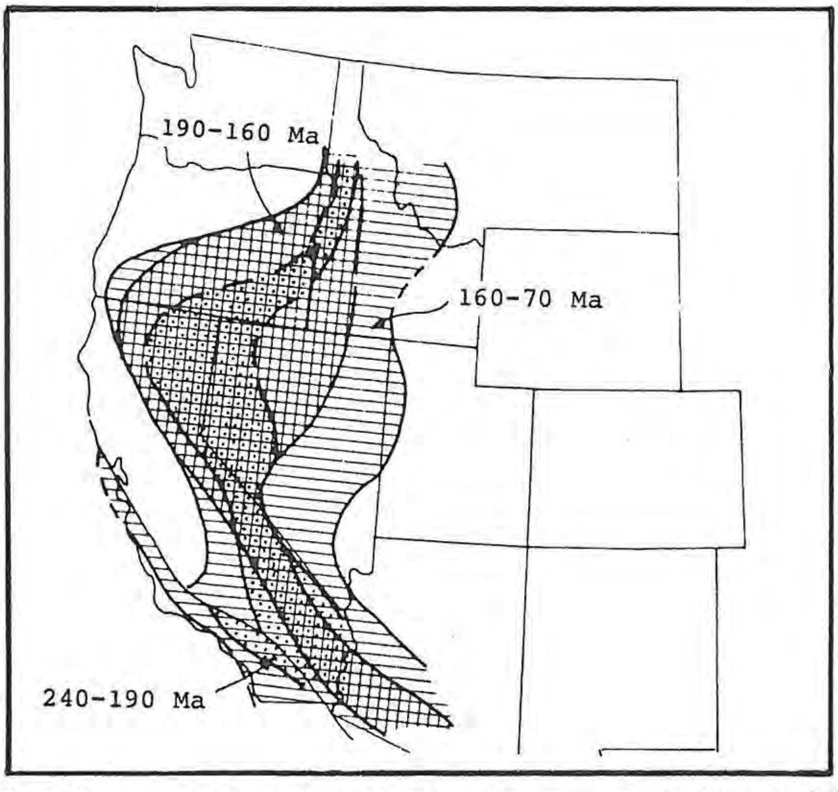


FIGURE 3.6 : Limits of Mesozoic magmatic arc activity for specific time intervals, 240 - 190 Ma., 190 - 160 Ma., and 160 - 70 Ma (Burchfiel, 1979)

At the close of Mesozoic time, during the Laramide orogeny of about 70 - 50 Ma, arc magmatic activity dropped in intensity and was largely localized in the north (Idaho, Montana and eastern Washington) and in southern Arizona and adjacent area (Figure 3.7A). Minor intrusions occurred in Nevada and for the first time, far to the east in Colorado (Guild, 1978; Burchfiel, 1979). From 40 - 20 Ma, arc magmatism progressed north and south from the south and north arc segments respectively, and it may have connected into one continuous arc during Miocene time (Stewart et al., 1977) (Figure 3.7B). These periods of arc magmatism are not associated with deformation and thrusting so characteristic of Mesozoic times. In fact, extensional faulting was initiated in the Rio Grande rift system at about 29 - 26 Ma. At about 20 Ma the magmatic arc narrowed significantly (Figure 3.8A), and extension, with associated horst and graben fragmentation, began throughout the Basin and Range province which was at that time in a back arc position (Figure 3.8B) (Snyer et al., 1976; Proffett, 1979; Stewart, 1971). Extension has continued to the present and is associated with bi-modal basalt rhyolite eruptions, distinct from the calc-alkaline plutonic-volcanic complexes which characterized the evolution of the western United States prior to 20 Ma. Thick sequences of basalt, such as the Columbia River Basalts, were extruded during a very short time.

The decrease in arc volcanism and extensional tectonics associated with the Basin and Range province has been related to the cessation of subduction, caused by the oblique intersection of the East Pacific Rise with the North American Plate at about 25 - 30 Ma (Guild, 1978; Burchfiel, 1979). At that time, motion became transform where the Pacific Plate was in contact with the North American Plate along the San Andreas Fault Zone. Transform motion has not been restricted to the San Andreas Fault Zone, but has extended at times several hundred kilometres into the North American Plate (refer Figure 3.8B). During Miocene to Recent time, northwest-trending right-slip faulting and oroclinal bending of older structures were active in California and western Nevada. Extension in the western part of the Basin and Range province came under the influence of the transform boundary, and extension is now northwest-southeast, whereas in the eastern part of the province it remains east-west.

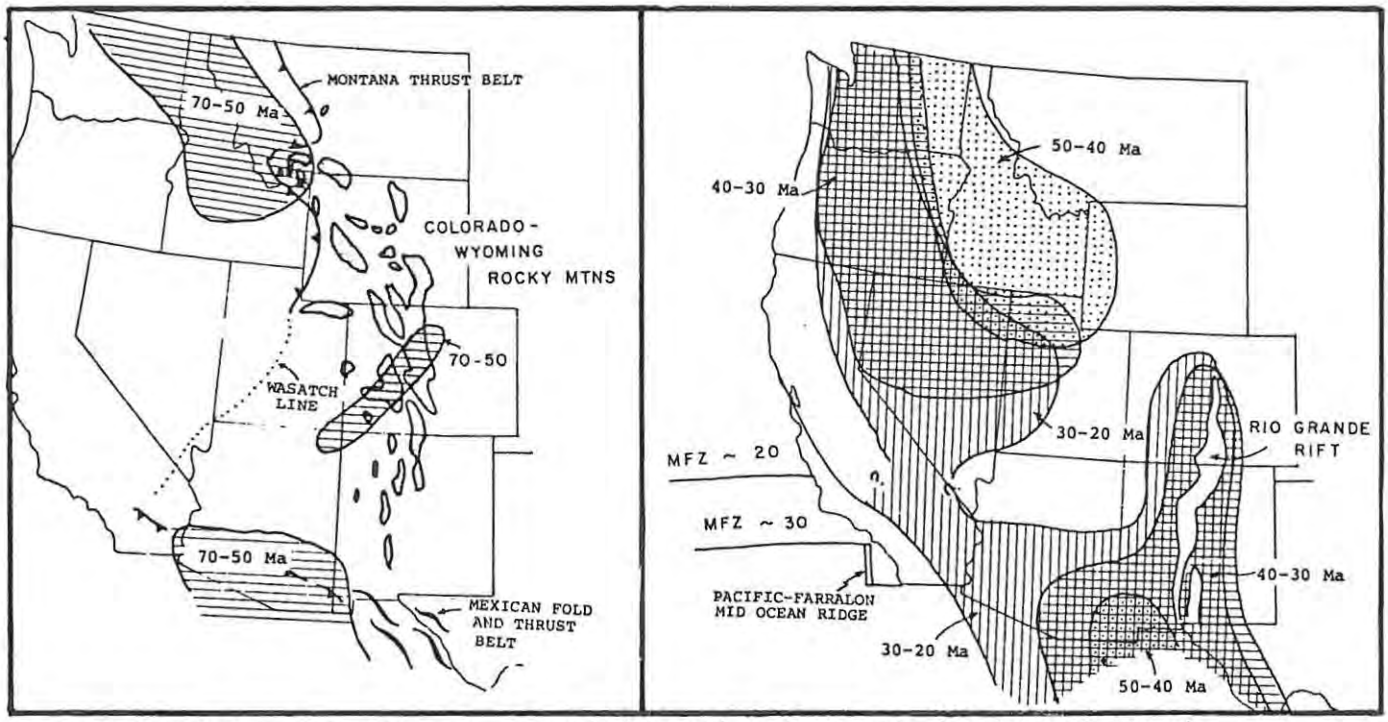
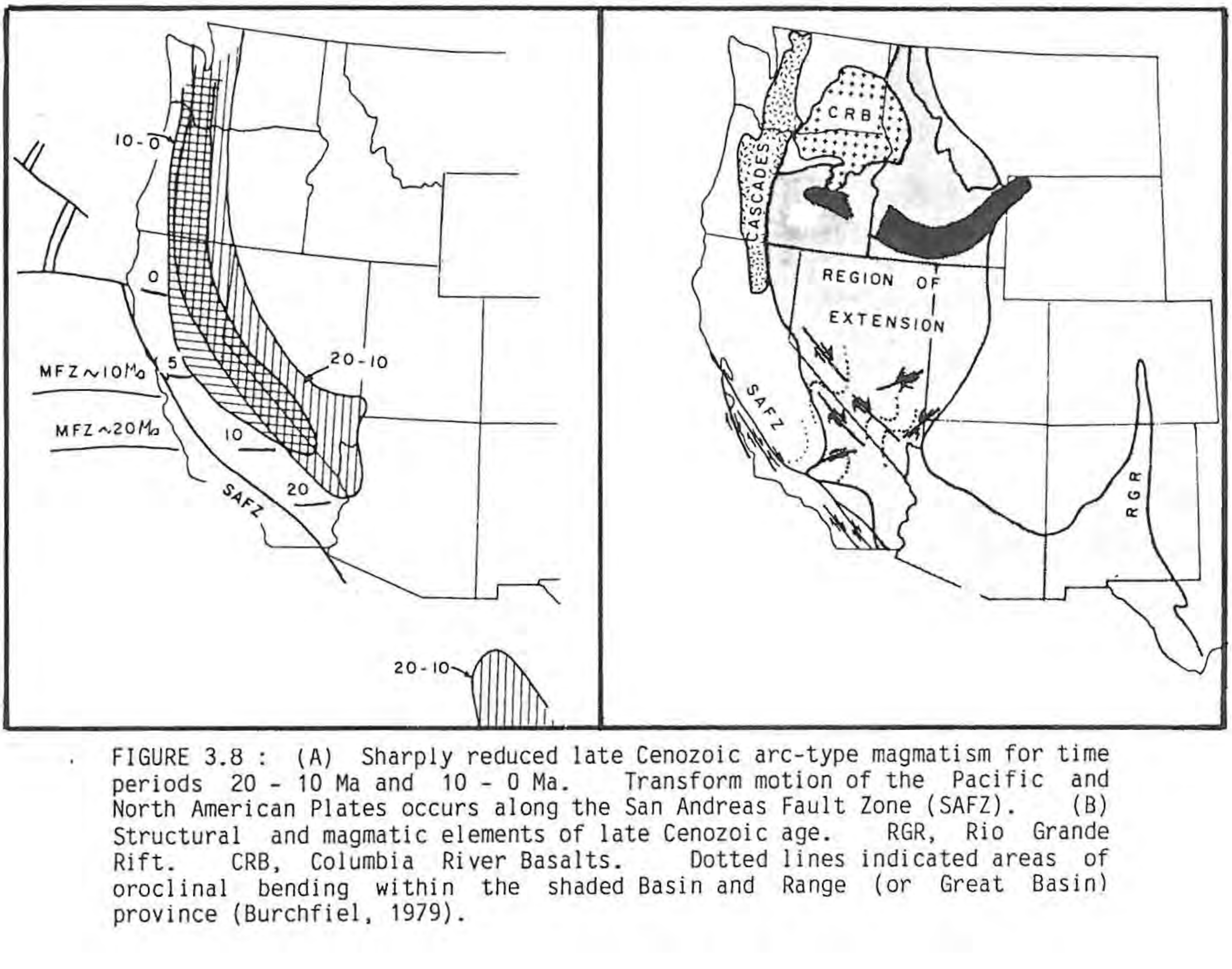


FIGURE 3.7 : (A) Major structural (shaded) and magmatic (horizontal lines) elements developed during the Laramide orogeny (70 - 50 Ma) of late Mesozoic - early Tertiary time. Note how magmatism is localized largely in a northern and southern magmatic arc segment. (B) Early Cenozoic arc-type magmatism for the time periods 50 - 40 Ma, 40 - 30 Ma and 30 - 20 Ma. The Pacific - Farallon mid-ocean ridge came into contact obliquely with the subduction zone about 30 - 25 Ma. Note onset of extensional faulting, initiated in the Rio Grande rift system at about 29 Ma. MFZ, Mendicino Fracture Zone (Burchfiel, 1979)



. FIGURE 3.8 : (A) Sharply reduced late Cenozoic arc-type magmatism for time periods 20 - 10 Ma and 10 - 0 Ma. Transform motion of the Pacific and North American Plates occurs along the San Andreas Fault Zone (SAFZ). (B) Structural and magmatic elements of late Cenozoic age. RGR, Rio Grande Rift. CRB, Columbia River Basalts. Dotted lines indicated areas of oroclinal bending within the shaded Basin and Range (or Great Basin) province (Burchfiel, 1979).

The Basin and Range extensional tectonics has split the surface into northerly trending horst and graben fault blocks, without regard to pre-existing structures. Block-faulted mountains, usually with gently tilted strata, form isolated ranges that rise above down-dropped blocks which are now buried beneath great thicknesses of alluvium. Vertical displacements in excess of 3 km are not uncommon (Hewitt, 1968). The bedrock floor of the intermontane valleys, in some cases, has been depressed beneath sea levle. The recent tectonic and igneous events of the Basin and Range province have resulted in the presence of active geothermal systems such as Steamboat Springs, Nevada, and Yellowstone Park, Wyoming (White, 1980; Ellis, 1979).

3.2 **Mineral Belts of Nevada**

It has long been recognized that the principal gold deposits in north-central Nevada occur in mineral belts that trend northwestward and northeastward (Roberts and Lehner, 1955; Roberts, 1960, 1966). Belts have been defined principally by major structural features, particularly the Roberts Mountain Thrust fault on which western assemblage rocks (cherts, shales and volcanics) rode eastward over correlative eastern assemblage rocks (autochthonous limestone, dolomite, quartzite) during the Antler orogeny.

The intrusive rocks in north-central Nevada follow at least two tectonic trends (Roberts et al., 1971) : (1) northeasterly, parallel to Cordilleran geosyncline trends. These intrusive rocks span a wide age range from middle-Jurassic to middle-Tertiary time. (2) Northwesterly, parallel to the deep seated fracture systems which probably control the mineral belts. These intrusive rocks, accompanied also by a large extrusive component, are mostly of late Tertiary age.

The locations of major known sediment-hosted, disseminated precious metal deposits in the western United States are given in Figure 3.9. The geological characteristics, and the ore body data, for these deposits are given in Tables 3.1 and 3.2 respectively. Most of these deposits occur along recognized mineral belts - the Carlin, Cortez and Getchell belts - whereas others are apparently isolated and have not yet been demonstrated to

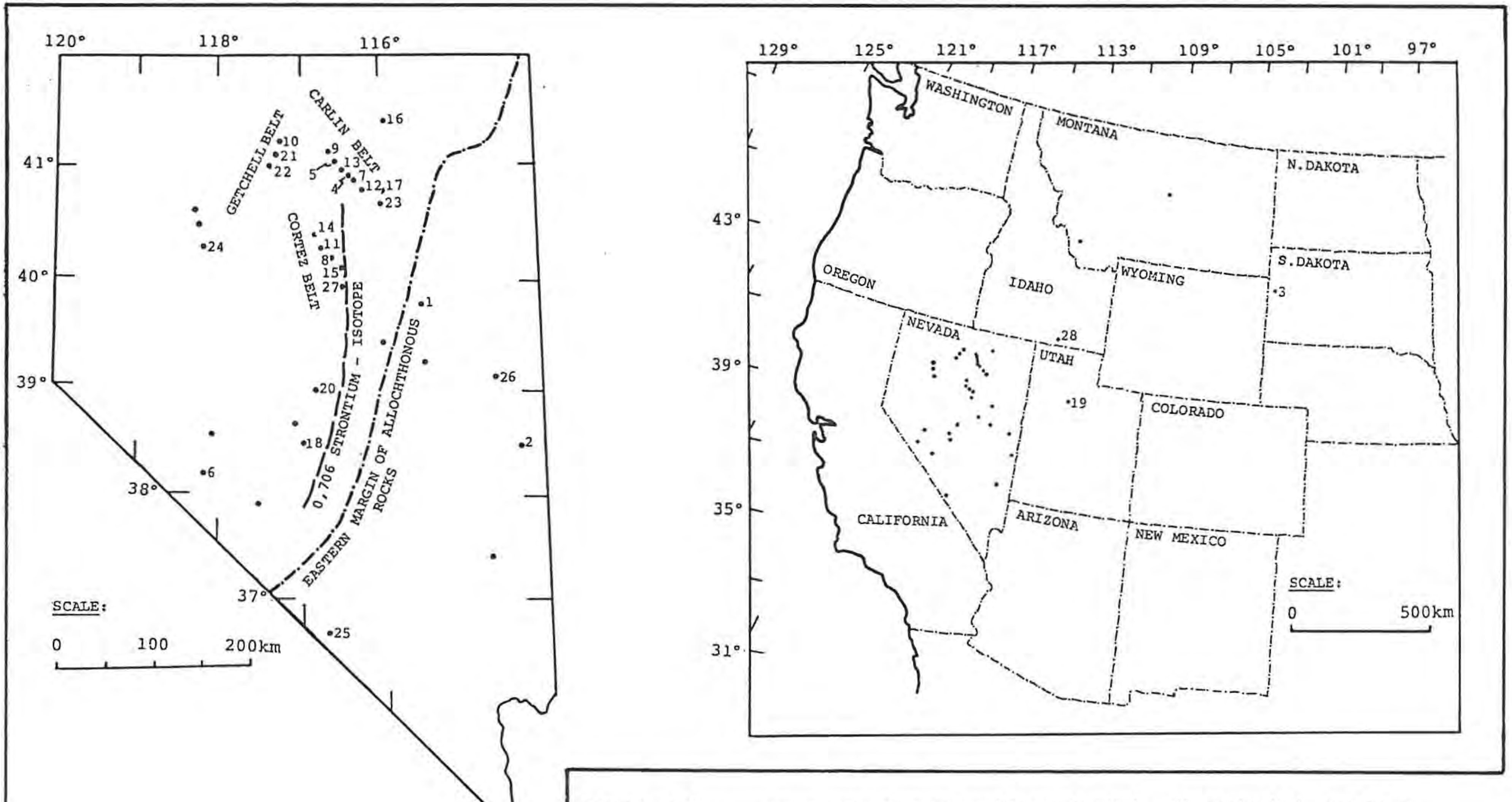


FIGURE 3.9 : Locations of major sediment-hosted, disseminated precious metal deposits in the western United States, with enlargement of the State of Nevada. Deposits 1 to 28 are keyed to those in Tables 3.1 and 3.2. The dashed line is the 0,7060 strontium-isotope isograd of Kistler (1983) and is generally accepted as representing the western extent of Precambrian continental crust. The dot-dash line represents the easternmost extent of allochthonous lower Palaeozoic siliceous assemblage rocks thrust eastwards over correlative autochthonous carbonate assemblage rocks during the Antler (late Devonian-early Mississippian) , Golconda (Permian) and Sonomia (Triassic) orogenies (redrawn and adapted from Bagby and Berger, in press).

DEPOSIT	FORMATION	AGE	LITHOLOGY	AGE	COMPOSITION AND OCCURRENCES	FAULTS	FOLDS	MINERALIZATION AGE	REFERENCES
1. Alligator Ridge. White Pine Co. Nevada	Pilot Shale	Devonian-Mississippian	Thin bedded. Calcareous, carbonaceous siltstones and clay stones.	Tertiary	Siliceous, pumiceous tuff and younger basaltic andesite lava flows.	N-NE, N-NW, and EW trending normal faults. The NE trending Vantage fault cuts Tertiary tuff. All faults post antiform.	N-NE striking asymmetrical antiform plunging to SW. Extensive fracturing and brecciation along crest. Age unknown.	No direct data of mineralization. Tertiary tuff may be be altered by gold system placing a lower age constraint.	Kiessig, 1984 Ainsworth and Brimhill, 1983 Bagby and Berger - in press
2. Atlanta. Lincoln Co. Nevada.	-	-	-	-	-	-	-	-	Bonham, 1983
3. Bold Mountain. Lawrence Co. South Dakota.	-	-	-	-	-	-	-	-	Morton, 1983
4. Blue Star Eureka Co. Nevada.	Vinini Formation.	Ordovician	Thin calcareous shale bands.	Cretaceous	Altered quartz diorite and diorite dykes	-	-	-	Bagby and Berger - in press Bonham, 1983
5. Bootstrap. Eureka and Elko Co. Nevada.	-	-	-	-	-	-	-	-	Bagby and Berger - in press
6. Candelaria. Mineral Co. Nevada.	-	-	-	-	-	-	-	-	Bonham, 1983
7. Carlin. Eureka Co. Nevada.	Roberts Mountains Formation	Silurian to Early Devonian.	Laminated, silty to sandy, carbonaceous, dolomitic limestone.	Cretaceous 130 Ma	Altered quartz diorite and diorite dikes.	Devonian-Mississippian thrust fault (Roberts Mountains thrust), high angle faults trending E, N, and NE and NW. Faults are pre-mineral with some post-mineral movement.	NW directed folds (antiforms and synforms). Major NW-trending antiform in the district. Age of folding is Mesozoic.	No direct date of mineralization. Post-mineral rhyolite lavas and domes dated at 14 Ma provide upper age constraint and altered Cretaceous dykes (130 Ma) provide lower age constraint.	Adkins and Rota, 1984 Hausen and Kerr, 1968 Radtke and Scheiner, 1970 Radtke et al., 1980 Jackson, 1983 Dickson et al., 1979 Bagby and Berger - in press
8. Cortez. Lander Co. Nevada.	Roberts Mountains Formation	Silurian to Early Devonian	Laminated, silty, argillaceous, carbonceous, pyrite-bearing limestone with dolomite.	Oligocene 33 - 35 Ma Jurassic 150 Ma	Altered dykes and sills of quarts latite. Mill Canyon granodiorite stock.	N, NW, and EW trending, high angle, normal faults. Roberts Mountains thrust surrounds district.	Drag folds associated with faults sympathetic to Roberts Mountains thrust. NW directed regional folds.	Altered and mineralized 33-35 Ma old quartz latite dykes place a lower age constraint.	Ryo et al., 1974 Wells et al., 1971 Wells et al., 1969 Wells and Mullens, 1973 Bonham, 1983 Bagby and Berger - in press
9. Dee. Elko Co. Nevada.	Devonian Limestone and Vinini Formation.	Devonian Ordovician	Massive, fossil-rich limestone.	Mesozoic (?) Tertiary (?)	Altered dykes in the Dee Mine. Intermediate composition.	N, NW, NE and EW trending high angle faults of Mesozoic (?) and Tertiary age. Roberts Mountains thrust (Dev.-Miss.).	NW directed folds of presumed Mesozoic age.	Unknown; altered dykes remain undated.	Wallace and Bergwall, 1984 Joralemon, 1951 Berger, 1975 Bonham, 1983 Bagby and Berger - in press.
10. Getchell. Humboldt Co. Nevada.	Preble Formation Comus Formation	Cambrian Ordovician	Phyllitic shale with interbedded limestone.	Cretaceous	Osgood Mountains pluton. Granodioritic with associated intermediate porphyritic dykes. All are altered and in part mineralized.	N. trending Getchell fault zone includes several strands. Inception of fault Late Cretaceous.	Fold axis plunges 45°NE. On southern limb sediments strike N and dip SE.	Sericite in mineralized granodiorite dated by K-Ar between 87-92 Ma. This is inferred age of gold mineralization.	Joralemon, 1951 Berger, 1975 Silberman et al., 1974 Berger and Taylor, 1980 Bonham, 1983 Bagby and Berger - in press.
11. Gold Acres. Lander Co. Nevada.	Roberts Mountains Formation. Valmy Formation. Wenban Formation.	Silurian to Early Devonian. Ordovician. Devonian	Carbonates, argillites, and siltstones. All mineralized rocks occur as fault blocks low in the upper plate of the Roberts Mountains thrust.	Cretaceous Tertiary (?)	Altered and mineralized dykes of intermediate composition. Quartz latite sills that are altered.	N, NE faults dip steeply west. Roberts Mountains thrust.	NW directed antiforms and synforms of presumed Mesozoic age.	Not directly dated. Altered Tertiary (?) sill places a lower age constraint.	Wrucke and Armbrustmacher 1975 Bonham, 1983 Bagby and Berger - in press.
12. Gold Quarry Eureka Co. Nevada.	-	-	-	-	-	-	-	-	Skillings, 1984
13. Gold Strike Eureka Co. Nevada.	-	-	-	-	-	-	-	-	Bonham, 1983
14. Hilltop. Lander Co. Nevada.	-	-	-	-	-	-	-	-	Bonham, 1983
15. Horse Canyon. Eureka Co. Nevada.	Vinini Formation Wenban Formation	Ordovician Devonian	Siltstones and chert. Silty carbonaceous limestone.	Tertiary	Altered dykes and sills of quartz latite.	N, NW, EW trending high angle normal faults of Tertiary age. Roberts Mountains thrust.	NW directed folds	Altered Tertiary (Oligocene) dykes place a lower age constraint on mineralization.	Coppinger and Cartwright, 1983 Bagby and Berger - in press.
16. Jerritt Canyon. Elko Co. Nevada.	Hanson Creek	Ordovician	Carbonaceous shaly limestones with chert, dolomite, and bioclastic limestone.	Mid-Tertiary(?)	Small dykes and plugs of diorite and a small rhyodacite flow 2.4km SW and 3km NE of mineralization, respectively.	Normal faults striking EW, NS and N. 20-30E. Roberts Mountains thrust fault. NS faults post-mineral and high angle.	Regional E-W trending folds.	Unknown	Hawkins, 1982 Stevens and Hawkins, 1984 Carraher, 1984 Bagby and Berger - in press
17. Maggie Creek. Eureka Co. Nevada.	Roberts Mountains Formation	Silurian to Early Devonian.	Laminated, silty dolomites and dolomitic limestones.	-	-	-	-	-	Anonymous, 1980 Bagby and Berger - in press.
18. Manhattan. Nye Co. Nevada.	-	-	-	-	-	-	-	-	Bonham, 1983
19. Mercur. Tooele Co. Utah.	Lower Great Blue	Mississippian	Massive, bedded limestone. Local bioclastic micrites and wackestones, with sparce siltstones.	Tertiary 31.6 Ma	Fine-grained, porphyritic rhyolite plug south of deposit, Believed to postdate gold mineralization. Also coarse-grained porphyritic plugs 1.6km north of deposit.	(1) Normal and strike slip faults associated with folding. (2) Normal faults due to Basin and Range extension, (3) Normal faults of minor displacement possibly associated with intrusions.	Northwest trending late Cretaceous to late Oligocene Ophir anticline and Pole Canyon syncline. Thrust faulting was associated with folding.	Unknown. Likely Tertiary as normal faults are mineralized. Porphyritic plugs are unmineralized.	Kornze et al., 1984 Anonymous, 1981 Larimer, 1983 Bagby and Berger - in press.

TABLE 3.1 : Geological characteristics of major known sediment-hosted, disseminated precious metal deposits in the western United States. Information from Bagby and Berger (in press) and indicated references.

DEPOSIT	FORMATION	AGE	LITHOLOGY	AGE	COMPOSITION AND OCCURRENCES	FAULTS	FOLDS	MINERALIZATION AGE	REFERENCES
20. Northumberland. Nye Co. Nevada.	Roberts Mountains Formation	Silurian	Laminated silty limestones, shales, and siltstones.	Jurassic Tertiary(?)	Altered tonalite and granodiorite dykes and pluton. Unaltered siliceous tuffs and altered rhyolitic dykes.	Thrust faults (Dev.-Miss.). NE, N, to NW trending high angle Tertiary and Late Cretaceous faults	Doming of Palaeozoic sediments near Mesozoic pluton and folding of sediments near thrust faults.	Altered dikes emplaced between 32 - 26 Ma which places lower age constraint provided alteration due to gold hydrothermal system.	McKee, 1974 Bonham, 1983 Motter and Chapman, 1984 Bagby and Berger - in press.
21. Pinson. Humbolt Co. Nevada.	Comus Formation	Cambrian Ordovician	Thin-bedded lime stone and shale	Cretaceous 90 Ma	Intermediate composition dykes and Osgood Mountain pluton.	NE trending high angle fault of Cretaceous (?) age.	NE plunging antiform	Not dated, but presumed to be same as Getchell (87-92 Ma).	Berger, 1980 Pinson staff, 1984 Antonink and Crombie, 1982 Crone et al., 1984 Bagby and Berger - in press.
22. Preble. Humbolt Co. Nevada.	Preble Formation	Cambrian	Phyllitic shale and interbedded limestone.	Cretaceous (?)	Altered dyke of intermediate composition.	N and NE to EW trending high angle faults. Cretaceous (?)	NE directed antiforms and synforms.	Not dated but presumed to be the same as Getchell (87-92 Ma).	Berger, 1980 Gone et al., 1984 Bagby and Berger - in press.
23. Rain. Elko Co. Nevada.	Webb Formation	Mississippian	Siltstone, shales and fine-grained sandstone.	Tertiary 35 Ma	Quartz monzonite stock 10km south of deposit.	W. and WNW trending high angle faults.	N - NW plunging antiforms.	Unknown.	Bonham, 1983 Bagby and Berger - in press.
24. Relief Canyon. Pershing Co. Nevada.	-	-	-	-	-	-	-	-	Bonham, 1983
25. Sterling.	Wood Canyon and Bonanza King Formations	Cambrian	Silty and sandy dolomite with minor carbonaceous matter.	Tertiary	Quartz latite dykes occur near the deposits.	Thrust fault contact between Wood Canyon and Bonanza King Formation.	-	Unknown	Bonham, 1983 Bagby and Berger - in press
26. Taylor. White Pine Co. Nevada.	Guilmette Formation	Devonian	Limestone and shaly limestone.	Tertiary 35 Ma	Rhyolitic dykes altered but not mineralized	N, NW, NE trending high Angle faults of Tertiary age.	Possible S plunging antiform.	The age constraints are provided by post-mineralization mid-Tertiary dikes, and early Tertiary, pre-mineralization faults.	Lovering and Heyl. 1974 Drewes 1962, 1967 Havenstrite, 1984 Bonham, 1983 Bagby and Berger - in press.
27. Tonkin Springs. Nevada.	Vinini Formation	Ordovician	Calcareous siltstones.	-	-	-	-	-	Bonham, 1983 Bagby and Berger - in press.
28. Tolman. Cassia Co. Idaho	-	Pennsylvanian	Sandy and calcareous siltstones, silty limestone, and claystone.	Tertiary	Altered intermediate to mafic dykes and remnants of rhyolitic ash-flow tuffs. Rhyolitic domes present 5km to the SW.	Low angle and high angle normal faults. No preferred direction.	Large and small scale folds trending N, and NE.	Unknown.	Brady, 1984 Bagby and Berger - in press.

TABLE 3.1 (cont.) : Geological characteristics of major known sediment-hosted, disseminated, precious metal deposits in the western United States. Information from Bagby and Berger (in press) and indicated references.

DEPOSIT	HYPOGENE	SUPERGENE	FORM	MINERALOGY	GOLD OR SILVER SITE.	VEINS	REFERENCE
1. Alligator Ridge (3.4/Unknown/5.4)	Decarbonization, decalcification, silicification, carbon remobilization, oxidation (?).	Oxidation.	Pod-like localized near high angle faults and extending into sediments.	Oxidized : metallic gold, specular haematite, jarosite, goethite, quartz, barite, calcite, gypsum, alunite and kaolinite. Unoxidized : stibnite, pyrite, orpiment, realgar, calcite.	Oxidized : metallic gold 85 % micron-size, 15 % coarse, visible.	Quartz veinlets cutting jasperoid. Alunite-quartz veinlets cutting jasperoid. Pyrobitumen veins.	Klessig, 1984 Ainsworth and Brimnall, 1983 Bagby and Berger - in press.
2. Atlanta (2.74 (2.74/54.86/1.0)	-	-	-	-	-	-	Bonham, 1983
3. Bald Mountain (6.82/12.75/6.9)	-	-	-	-	-	-	Morton, 1983
4. Blue Star (4.11/Unknown/1.6)	-	-	-	-	-	-	Bonham, 1983
5. Bootstrap (1.68/Present/1.3)	-	-	-	-	-	-	Bagby and Berger - in press
6. Candelaria (0.21/137.14/4.5)	-	-	-	-	-	-	Bonham 1983
7. Carlin (10.97/Unknown/10)	Decarbonization, silicification, calcification, carbon remobilization, acid leaching with oxidation (?).	Oxidation, calcite remobilization, clay formation.	Pods localized along high angle faults and extending into sediments.	Oxidized : metallic gold, goethite, illite, kaolinite, barite, anhydrite, alunite, dolomite, calcite, quartz, cinnabar, scorodite, stibiconite, avicannite, and various Pb-, Zn- and Cu- oxides. Unoxidized : quartz, calcite, dolomite, illite, pyrite, realgar, orpiment, stibnite, cinnabar, base metal sulphides, and rare Tl-As-Sb-S minerals.	Oxidized : metallic gold. Unoxidized : Gold with Hg, As, Sb, Tl, forms thin films on pyrite. Gold is locally associated with carbonaceous matter.	Quartz-calcite-orpiment, barite-galena, quartz-pyrobitume. Quartz-pyrite, and calcite veinlets. Calcite zoned away from deposits in general with quartz veins occurring within main ore deposit area.	Adkins and Rota, 1984 Hanson and Kerr, 1967 Radtke and Scheiner, 1970 Radtke et al., 1980 Jackson, 1983 Dickson et al., 1979 Bagby and Berger - in press
8. Cortez (9.57/Unknown/ 3.3)	Silicification, acid leaching and oxidation (?), decalcification, and dedolomitization.	Deep oxidation resulting in some redistribution of gold	Elongated zones paralleling faults and dykes and notably localized in breccia zones associated with folds.	Oxidized : quartz, clays, iron oxides, metallic gold, and calcite. Unoxidized: quartz, illite, dolomite, calcite, pyrite.	Oxidized : clusters of particles between silt grains, metallic gold grains in quartz veinlets, grains in limonite pseudomorphs after pyrite. Unoxidized : associated with As and pyrite.	Quartz-pyrite veinlets and post-mineralization calcite veinlets. Calcite veinlets zoned away from ore zone may have formed contemporaneously with decalcification within the ore zone.	Ryo et al., 1974 Wells et al., 1971 Wells et al., 1969 Wells and Mullens, 1973 Bonham, 1983 Bagby and Berger - in press
9. Dee (3.09/Present/3.63)	Silicification and argillitization	Oxidation	Zones localized along faults.	Oxidized : quartz, clays, minor calcite, metallic gold. Unoxidized : quartz pyrite, stibnite.	Oxidized : metallic gold. Unoxidized : unknown. May be with sulphides in quartz.	Quartz-stibnite and quartz-pyrite veins. Marked increase in gold content with silica veining and silicification.	Wallace and Bergwall, 1984 Joralemon, 1951 Berger , 1975 Bonham, 1983 Bagby and Berger - in press.
10. Getchell (6.65/Unknown/13.97)	Decarbonatization with silicification and argillitization Early calc-silicate skarn formation.	Minor oxidation.	Sheet-like zones localized along strands of Getchell fault and pods in fold hinges.	Oxidized : metallic gold(?) Unoxidized : pyrite, pyrrhotite, arsenopyrite, marcasite, stibnite, orpiment, realgar, cinnaber, magnetite, and metallic silver.	Oxidized : no published data. Unoxidized : metallic gold encapsulated by quartz. Gold also associated with pyrite, arsenopyrite, carbonaceous matter, and magnetite. Silver associated with sulphides.	Calcite veins in limestone and quartz veins in phyllitic shale. Stockwork quartz veins cutting igneous rocks are in turn cut by calcite-dolomite veins.	Joralemon, 1951 Berger, 1975 Silberman et al., 1974 Berger and Taylor, 1980 Bonham, 1983 Bagby and Berger - in press.
11. Gold Acres (2.23/Unknown/2.54)	Silicification, early contact metamorphism.	Deep oxidation.	Tabular dipping to SW parallel to thrust faults.	Oxidized : quartz, kaolinite, iron oxides, sericite, jarosite, gypsum, hexahydrite dolomite, calcite. Unoxidized : no published data available.	Oxidized : gold associated with iron oxide-clay fracture coatings.	Unreported.	Wrucke and Armbrustmacher, 1975 Bonham, 1983 Bagby and Berger - in press.
12. Gold Quarry (1.47/Unknown/166)	-	-	-	-	-	-	Skillings, 1984
13. Gold Strike ("Greater than 3110kg Au")	-	-	-	-	-	-	Bonham, 1983
14. Hilltop (2.71/Unknown/4.6)	-	-	-	-	-	-	Bonham, 1983
15. Horse Canyon (3.43/Unknown/4.5)	Decalcification, silicification, carbon mobilization.	Shallow oxidation.	Localized zones along NNE fractures and in permeable hosts near fractures.	Oxidized : Iron oxides, clay, quartz, metallic gold. Unoxidized : quartz, clay cinnabar, pyrite, and arsenopyrite.	Gold is recovered from silicified rock and carbonaceous rock. Actual site unknown.	Quartz and quartz-magnesite veins in silicified zones.	Coppinger and Cartwright, 1983 Bagby and Berger - in press.
16. Jerritt Canyon (8.33/Unknown/ 12.76)	Decalcification, silicification, remobilization of organic matter.	Oxidation and leaching.	Conformable to bedding as pods near faults.	Unoxidized : pyrite, realgar, orpiment, arsenopyrite, cinnabar, and organic matter. Stibnite, barite, and quartz occur near ore bodies.	Gold 1-4 microns. Mineral association unknown.	Quartz, stibnite, and barite veins occur in jasperoid near ore bodies. Calcite and arsenic minerals occur as veins in unoxidized ore.	Hawkins, 1982 Stevens and Hawkins, 1984 Bagby and Berger - in press Carraher, 1984
17. Maggie Creek (3.15/Unknown/ 4.35)	-	-	-	-	-	-	Anonymous, 1980 Bagby and Berger - in press.
18. Manhattan (1.23/Unknown/4.54)	-	-	-	-	-	-	Bonham, 1983
19. Mercur (3.5/Unknown/12.98)	Decalcification and silicification. Minor kaolinite and sericite addition.	Oxidation of sulphides to limonite. No effect on silicification or on clays.	Strongly conforms to bedding according to variation in fracture density, chemistry and proximity of faults.	Unoxidized : pyrite, realgar orpiment, cinnabar, barite fluorite. Organic carbon as both kerogen and hydrocarbon fractions. Oxidized : limonite, haematite, scorodite, gypsum.	Unoxidized : with pyrite/marcasite; in hydrocarbons, in kerogen, and metallic Au. Oxidized : with melanterite and rosenite.	Quartz crystals in vugs in jasperoid, calcite-realger veins and orpiment-pyrite-marcasite-organic matter veins. Barite-halloysite veins cut jasperoid.	Kornze et al., 1984 Anonymous, 1981 Larimer, 1983 Bagby and Berger - in press.

TABLE 3.2 : Geological characteristics and form of ore bodies in major known sediment-hosted, disseminated precious metal deposits in the western United States. Information from Bagby and Berger (in press) and indicated references.

DEPOSIT	HYPOGENE	SUPERGENE	FORM	MINERALOGY	GOLD OR SILVER SITE.	VEINS	REFERENCE
20. Northumberland (1.54/Unknown/15.42)	Early calc-silicate skarn formation, silicification, and intense argillitization.	Oxidation and clay formation.	Tabular zones along tonalite sill-sediment contact, diffuse in breccia zones, and stratiform bodies in sediments.	Oxidized : micron metallic gold, clay, iron oxides. Unoxidized : carbonaceous matter, silica, pyrite, freibergite, sphalerite, chalcopyrite and molybdenite.	Quartz-silver veins of early mineralization.	Quartz veinlets, cutting jasperoid. Calcite veins cut acid-leached rock and barite veins spatially associated with jasperoid.	McKee, 1974 Bonham, 1983 Motter and Chapman, 1984 Bagby and Berger - in press.
21. Pinson (4.11/Unknown/3.18)	Early calc silicate skarn formation, silicification, and minor argillitization.	Deep oxidation along fault zones.	"A" ore zone is massive jasperoid localized in fault. "B" ore zone partly in breccia zone of fold hinge.	Oxidized : silica, goethite, lepidocrocite, haematite, sparse remnant pyrite and marcasite, and metallic gold. Kaolinite and sericite present but minor. Unoxidized : none reported.	Micron metallic gold occurs with As-rich pyrite.	Quartz and calcite veins cut jasperoid.	Berger, 1980 Pinson staff, 1984 Antoniuk and Crombie, 1982 Crone et al., 1984 Bagby and Berger - in press.
22. Preble (3.09/Unknown/1.18)	Silicification, argillitization, dolomitization.	Oxidation to about 60m.	Ore body localized along shear zone.	Oxidized : iron oxides, minor pyrite and metallic gold. Unoxidized : pyrite, carbonaceous matter, and minor arsenopyrite, marcasite, chalcopyrite, and sphalerite.	Gold encapsulated in quartz and associated with pyrite Metallic, micron-size gold oxidized ore.	Quartz, dolomite, jasperoid breccia and calcite veins.	Berger, 1980 Crone et al., 1984 Bagby and Berger - in press.
23. Rain (2.85/Unknown/7.53)	Silicification, argillitization, baritization, leaching and oxidation (?)	Oxidation	Localized within a high angle fault zone and penetrates into wall rocks.	Oxidized : barite, silica, jarosite, alunite, iron-oxides, kaolinite, illite, metallic gold (?). Unoxidized : none reported.	Not reported.	Quartz-alunite, quartz, barite, and calcite veins.	Bonham, 1983 Bagby and Berger - in press.
24. Relief Canyon (1.37/Unknown/7.26)	-	-	-	-	-	-	Bonham, 1983
25. Sterling (7.8/Unknown/0.45)	-	-	-	-	-	-	Bonham, 1983 Bagby and Berger - in press.
26. Taylor (Present/93.3/9.07)	Silicification, late argillitization.	Significant oxidation resulting in silver enrichment blanket.	Tabular silicified bodies on top of Guilmette formation : localized by faults in breccia zone along fold hinge.	Oxidized : iron oxides, with remnant stibnite, sphalerite, tetrahedrite, chalcopyrite, galena, pyragyrite. Unoxidized : none reported.	Metallic silver.	Quartz and late stage calcite veinlets.	Lovering and Heyl, 1974 Drewes 1962, 1967 Havenstrite, 1984 Bonham, 1983 Bagby and Berger - in press.
27. Tonkin Springs (2.8/Unknown/greater than 2.27)	-	-	-	-	-	-	Bonham, 1983 Bagby and Berger - in press.
28. Tolman	Silicification followed by late calcification.	Oxidation	Concentrated below low angle normal fault.	Unoxidized : pyrite, tetrahedrite, cinnabar, barite, calcite, quartz, gold. Oxidized : limonite, gold, same gangue mineralogy as unoxidized ore.	Gold with organic matter and pyrite. Not associated with tetrahedrite.	Calcite veins with tetrahedrite. Barite veins with cinnabar. Silica micro-veinlets.	Brady, 1984 Bagby and Berger - in press.

TABLE 3.2 (cont.) : Geological characteristics and form of ore bodies in major known sediment-hosted, disseminated precious metal deposits in the western United States. Information from Bagby and Berger (in press) and indicated references.

occur with other deposits of this type. An important aspect of the regional geological setting of these deposits is their spatial relationship to Precambrian crystalline basement and accreted terranes. The 0.706 strontium-isotope isopleth in Figure 3.9 is generally accepted as representing the western extent of Precambrian continental crust in Nevada (Kistler, 1983: cited in Bagby and Berger - in press). The dot-dashed line representing the present day easternmost extent of allochthonous western assemblage siliceous rocks shows the approximate amount of overlap of continental crust by accreted terranes. Most of the deposits occur in this western area of accreted allochthonous terranes, but not necessarily within the allochthonous rocks themselves. The accreted terranes include the middle Palaeozoic Roberts Mountain, late Palaeozoic Golconda and early Mesozoic Sonomia terranes. Prominent exceptions to this are the Alligator Ridge, Sterling and Taylor deposits which occur east of any accreted terranes. Only parts of the Carlin belt overlie Precambrian crystalline basement. The geology of the Carlin, Cortez and Getchell belts and of the areas around isolated deposits will be considered in this section, to provide an understanding of the regional geological characteristics of sediment-hosted, disseminated precious metal deposits.

The Carlin belt

The Carlin belt, previously referred to as the Lynn-Railroad belt by Roberts (1960,1966) (refer Figure 3.4), includes the Rain, Gold Quarry, Maggie Creek, Carlin, Bullion Monarch, Blue Star, Gold Strike, Bootstrap and Dee sediment-hosted, disseminated precious metal deposits (Figure 3.10). The northwest striking belt cuts across the northerly trending regional geological fabric defined by the east-directed Roberts Mountain allochthonous terrane, which in turn overlies Precambrian crystalline basement. The western, or siliceous, assemblage rocks of the Roberts Mountain Allochthon are composed predominantly of interbedded cherts, shales and siltstones with only minor volcanics and carbonates. Although multiple thrust slices have been recognized locally, the contact between the western assemblage rocks and the eastern, or carbonate, assemblage rocks is sharp and well defined in the Carlin belt (Noble and Radtke, 1979). These latter, autochthonous rocks are predominantly silty limestones and dolomites with minor shales and siltstones. Rocks of both assemblages may serve as hosts

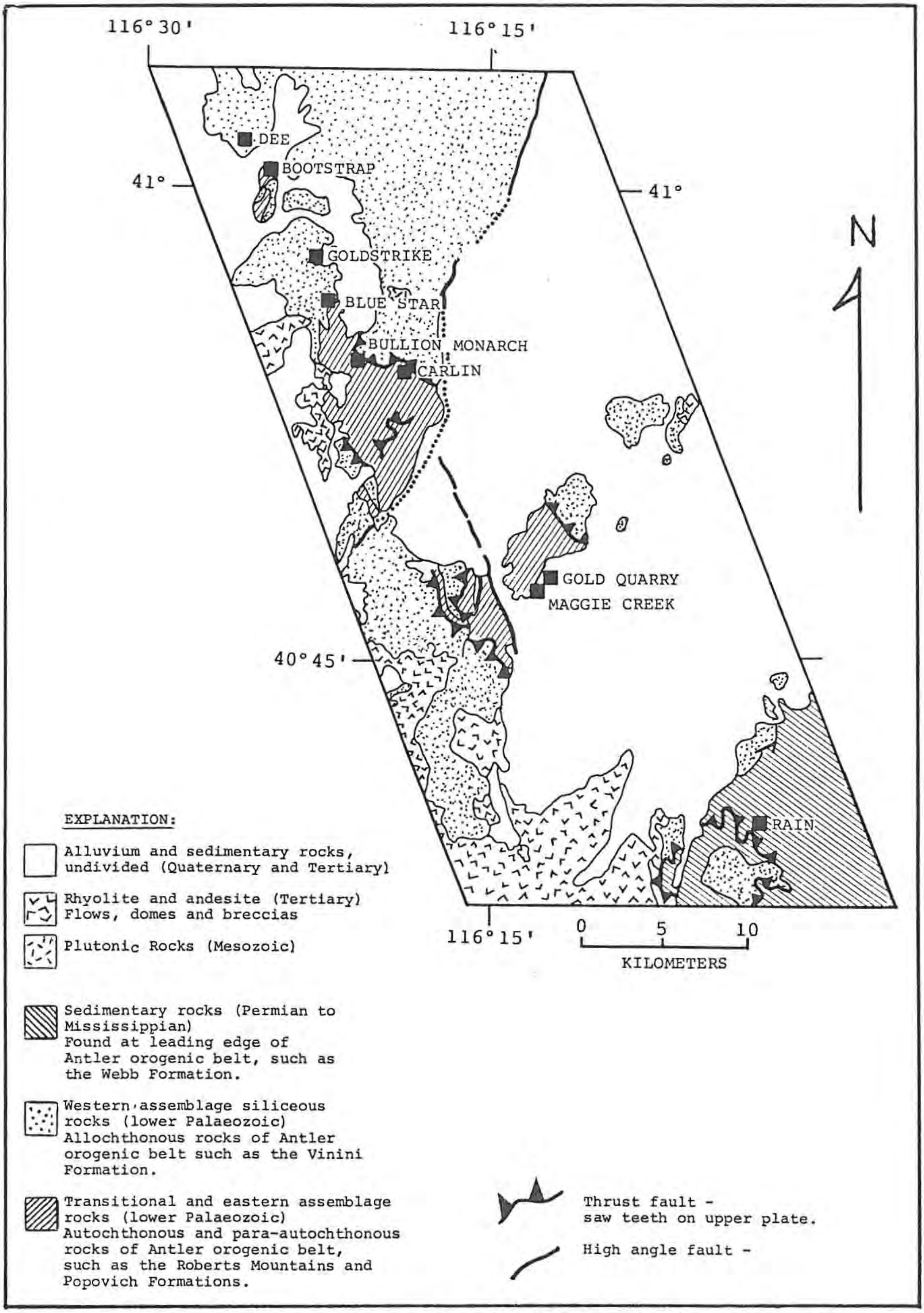


FIGURE 3.10 : Regional geology of the Carlin belt, Nevada. The major known sediment-hosted, disseminated precious metal deposits in this trend are Rain, Maggie Creek, Gold Quarry, Carlin, Bullion Monarch, Blue Star, Gold Strike, Bootstrap and Dee (Redrawn and adapted from Bagby and Berger - in press)

for mineralization, although the autochthonous carbonate assemblage rocks are the most important.

The major host formations of mineralization in this belt are :

- silty dolomites and dolomitic limestones of the middle Silurian - early Devonian age Roberts Mountains Formation (autochthonous), as at the Carlin, Bullion Monarch, Gold Quarry and Maggie Creek deposits;
- the thinly bedded silty dolomites and dolomitic limestones of the Devonian age Popovich Formation (autochthonous), as at the Carlin deposit;
- the massive fossiliferous limestone of an unnamed Devonian limestone unit (allochthonous), as at the Bootstrap and Dee deposits;
- thin calcareous shale bands of the bedded chert-siliceous shale - minor sandstone and quartzite assemblage of the Ordovician Vinini Formation (allochthonous), as at the Goldstrike, Blue Star and Carlin deposits;
- siltstones, shales and fine-grained sandstones of the Mississippian age Webb Formation, as at the Rain deposit.

A significant feature of the Rain deposit is that the clastic ore host lithologies are not calcareous rocks, as is the case with all the other Carlin belt deposits and in fact with almost all of the major sediment hosted, disseminated precious metal deposits of Nevada (refer Table 3.1). The Webb Formation post-dates the Antler orogeny and was formed from debris shed off of the leading edge of the Antler highlands into a foreland basin (Roberts et al., 1958).

The Carlin belt is not only identified by an alignment of windows in the Roberts Mountain Allochthon and by ore deposits, but also by igneous stocks and dykes of Cretaceous up to Tertiary age (Bagby and Berger - in press; Radtke et al., 1980). In addition, the belt is defined by a series of broad, aeromagnetic high anomalies related to stocklike Mesozoic age intrusive bodies (Roberts et al., 1971). Aeromagnetic high anomalies in the area of the Carlin deposit suggest the presence of extensive buried intrusions. This data all indicates a fundamental, underlying structural control for the existence of this belt. Hydrothermally altered and mineralized Mesozoic stocks occur in the Carlin to Dee part of the belt, indicating that the mineralization post-dates pluton emplacement and that hydrothermal fluids used the same regional structures that served as controls for Mesozoic pluton and dyke emplacement.

Other mineralization in the Carlin Belt includes copper mineralization associated with some of the Mesozoic intrusions (Bagby and Berger - in press). Tungsten skarn mineralization is reported from Gold Strike and barite occurs in cherts of the Vinini Formation north of the Dee deposit.

The Cortez belt

This belt, previously referred to as the Battle Mountain - Eureka belt by Roberts (1960, 1966), is defined by the alignment of the Gold Acres, Cortez, Horse Canyon and Tonkin Springs sediment - hosted disseminated precious metal deposits in north central Nevada (Figure 3.11). As with the Carlin belt, the Cortez belt contains a northwest alignment of mineral deposits, windows in the Roberts Mountain allochthon (refer Figure 3.4) and Mesozoic and Tertiary intrusive rocks.

Regional host rock for the mineralization in this belt includes :

- laminated silty carbonaceous limestone of the Roberts Mountains Formation (autochthonous), as at the Cortez and Gold Acres deposits ;
- silty carbonaceous limestones of the Devonian Wenban Limestone Formation (autochotonous), as at the Gold Acres and Horse Canyon deposits ;
- siltstones and cherts of the Ordovician Vinini Formation (allochthonous), as at the Horse Canyon and Tonkin Springs deposits;
- and within altered and mineralized Mesozoic and Tertiary igneous rocks.

These lithologies are little different from those in the Carlin belt. At Cortez, the disseminated mineralization is possibly contemporaneous with and genetically related to a 34 Ma altered and mineralized biotite-quartz-sanidine porphyry (Wells et al., 1969). Similarly altered, Oligocene dykes also occur at the Gold Acres and Horse Canyon deposits (Bagby and Berger - in press), suggesting that mineralization occured at least during the Oligocene or was even post-Oligocene.

Other mineralization in the Cortez window area includes silver in manto replacements and fissure veins in the Cambrian Hamburg dolomites at the old Cortez silver mine, and silver-lead-zinc-copper-gold veins in the Wenban Limestone Formation and a Jurassic quartz monzonite (Wells et al., 1969).

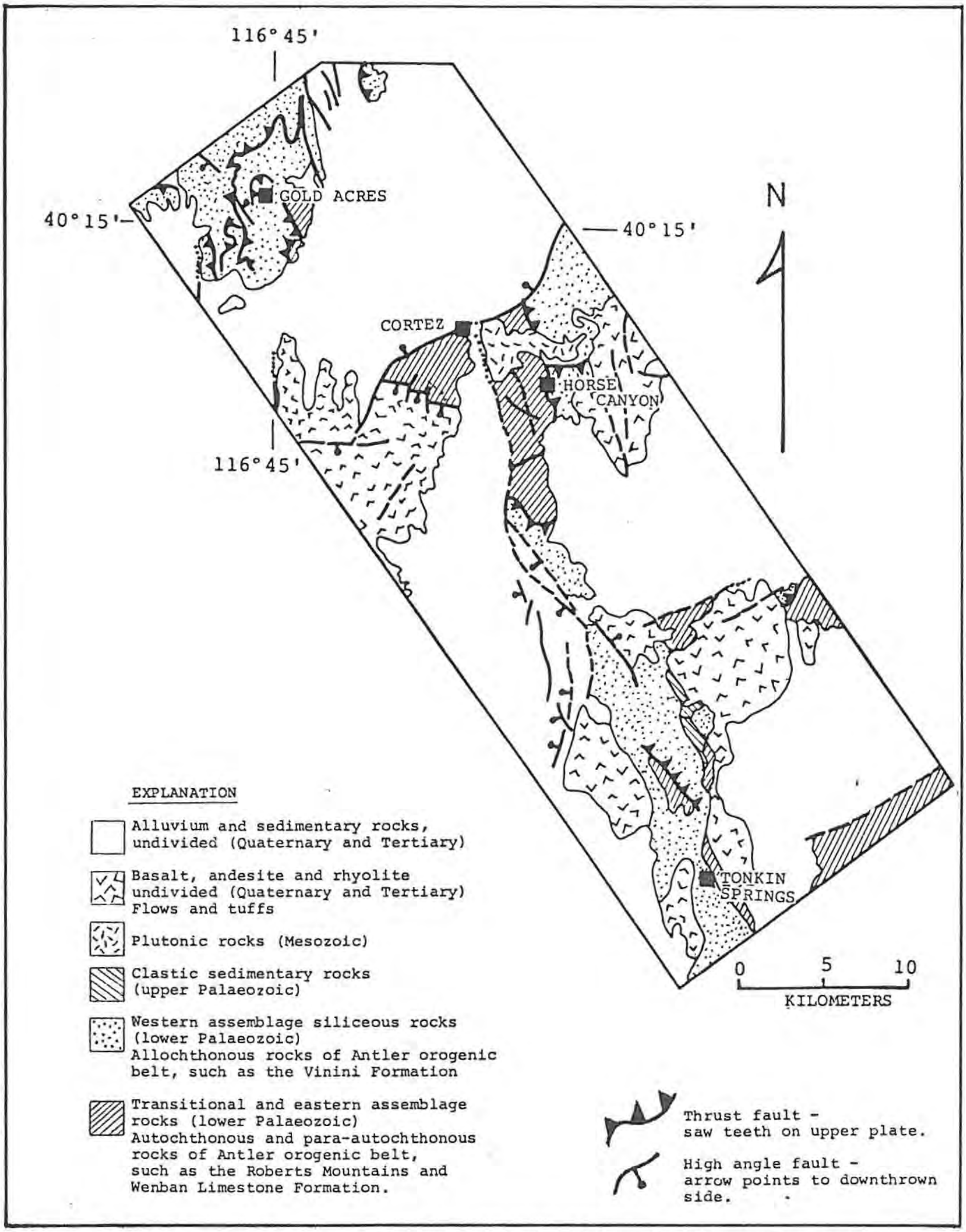


FIGURE 3.11 : Regional geology of the Cortez belt, Nevada. The major known sediment-hosted, disseminated precious metal deposits in this trend are Tonkin Springs, Horse Canyon, Cortez and Gold Acres. (Redrawn and adapted from Bagby and Berger - in press)

The Buckhorn epithermal vein gold deposit occurs along a fault zone within Pliocene andesitic basalt flows, to the east of the Gold Acres deposit. Bedded barite mineralization occurs within Ordovician sedimentary rocks.

The Getchell belt

The Getchell belt is localized along the fault bounded eastern margin of the typical Basin and Range-type Osgood Range Mountains, and is defined by the northeast alignment of the Preble, Pinson and Getchell sediment-hosted, disseminated precious metal deposits (Figure 3.12). At the Getchell deposit mineralization occurs as lenticular bodies lying along splays of a complex range - front system known as the Getchell fault (Joralemon, 1951; Berger and Taylor, 1980). The fault system cuts across all rocks of the district and is tentatively dated as late Tertiary. It is equivocal whether or not this fault system extends the complete distance of the belt. Midway along the belt, at Pinson, the fault system is smaller and consists of a single major fault zone. Continuation of this structure south to Preble is conjecture since the complete length is neither exposed nor has there been detailed geological mapping. There is however a major north-striking fault which controls mineralization at Preble, and may be the southern extension of the Getchell fault system (Crone et al., 1984).

Several stratigraphic formations occur along the belt and serve as host rocks for gold, tungsten and barite mineralization. Major host formations for disseminated gold mineralization are :

- variably calcareous and siliceous phyllitic shale and thin bedded limestones of the Cambrian age Preble Formation (autochthonous), as at the Getchell, Pinson and Preble deposits;
- thin bedded limestones and siltstones (frequently, but not necessarily calcareous) of the Ordovician age Comus Formation (autochthonous), as at the Pinson (Antoniuk and Crombie, 1982) and Getchell deposits ;
- and the Cretaceous age Osgood Mountain granodiorite.

The Osgood Mountain pluton intrudes both the Preble and Comus Formations, and marginal contact metasomatic tungsten-bearing skarns are developed in both formations.

Granodiorite and dacite dykes associated with the pluton are altered and

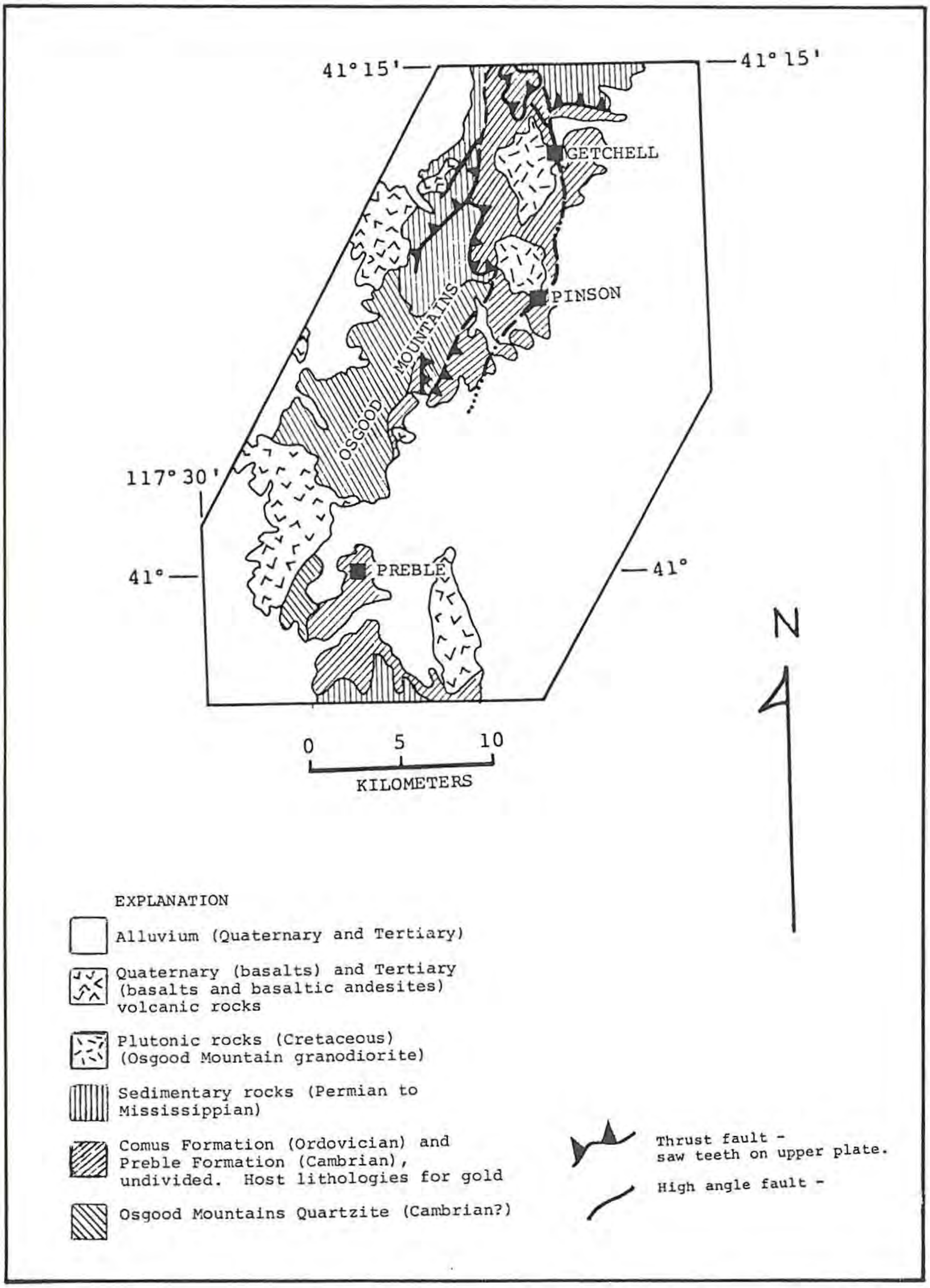


FIGURE 3.12 : Regional geology of the Getchell belt. The major known sediment-hosted, disseminated precious metal deposits in this trend are Preble, Pinson and Getchell . (Redrawn and adapted from Bagby and Berger - in press)

mineralized at the Getchell, Pinson, and possibly the Preble deposits (Crone et al., 1984; Antoniuk and Crombie, 1982).

Isolated deposits

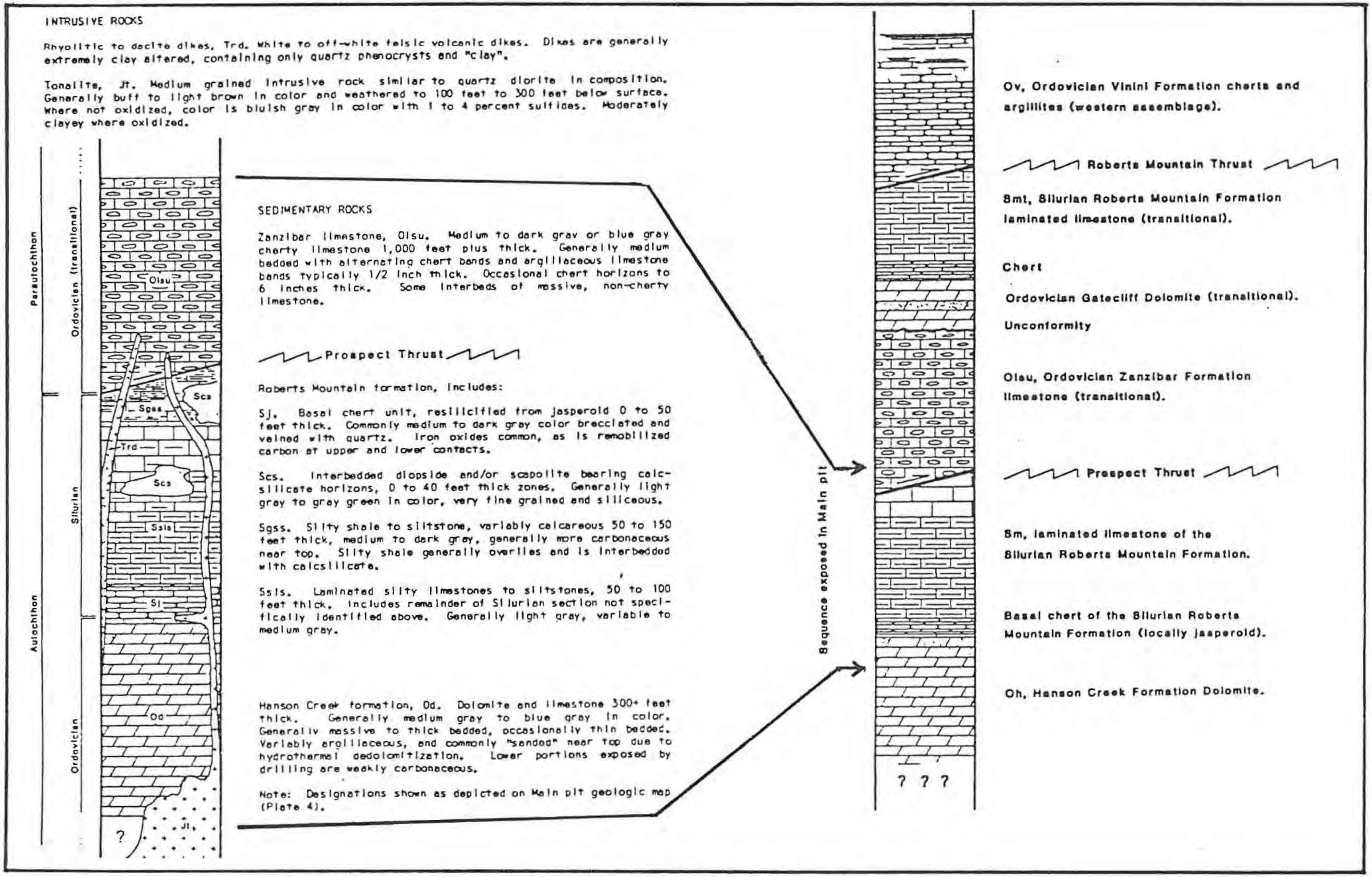
Several of the sediment hosted, disseminated precious metal deposits in Nevada occur isolated from other known deposits of this type. However, many of the isolated deposits do occur in recognized mineral belts that are defined by regional structures and by the alignment of several different types of mineral deposits. The isolated deposits discussed here are Taylor, Northumberland and Alligator Ridge.

The **Taylor silver deposit** is situated to the east of the accreted terrane occupying the western portion of Nevada (refer Figure 3.9) and is the only known sediment-hosted, disseminated precious metal deposit of the east-west orientated Hamilton-Ely belt of Roberts (1966). This belt is defined by an alignment of Tertiary intrusions, broad east-trending aeromagnetic highs and a variety of ore deposits (Stewart et al., 1977). The Taylor ore deposit consists of finely disseminated argentite and native silver in an intensely silicified limestone described as jasperoid (Havenstrite, 1984). The known commercial deposit is restricted to the upper portions of the late Devonian Guilmette Limestone and its transition (thin bedded limestone and siliceous shale) with the overlying early Mississippian Pilot Shale. Intrusive activity was confined to the mid Tertiary ($\sim$ 35 Ma) when a few rhyolite dykes, sills and irregular bodies intruded the sedimentary rocks. The silica and silver appear to be contemporaneous, and are slightly older than the mid Tertiary intrusive rhyolite (Havenstrite, 1984). Ore solutions were introduced along steep, north-trending Basin and Range-type normal faults and entered the upper portions of the Guilmette Formation by means of a crackle breccia zone developed on the crests and flanks of a mid Mesozoic asymmetrical anticline. This breccia became the host for the Taylor ore deposits. The Taylor deposit will be described in more detail in Section 3.3.3 as the type example for the jasperoidal silver-rich end member of the sediment hosted, disseminated precious metal deposits.

The geology of the Toquima Range mountains in the vicinity of the **Northumberland gold mine** (refer Figure 3.9) consists primarily of lower

Palaeozoic carbonate rocks in a repetitious series of imbricate thrust slices (Kay and Crawford, 1964). The eastern, or carbonate assemblage (autochthon), consists of Ordovician and Silurian limestones, laminated limestones and dolomites with minor chert horizons (Hanson Creek and Roberts Mountains Formation) (Figure 3.13). Thrust over these lower plate rocks along the Prospect Thrust fault are Ordovician and Silurian carbonates similar in composition to the eastern assemblage but with increased content of chert and proportionally thinner stratigraphic horizons; these are rocks of the transitional assemblage (refer Figure 3.3) and include the Zanzibar and Gatecliff Formations (para-autochthon). Thrust over the transitional rocks along the Roberts Mountain Thrust fault are the western assemblage cherts and argillites of the Ordovician Vinini Formation (Motter and Chapman, 1984). Locally the sediments have been intruded by a granodiorite stock dated at 154 ± 3 Ma. Bordering the granodiorite stock is a quartz porphyry tonalite which is believed to be a later intrusive occupying the same zone of structural weakness as the granodiorite. A number of Tertiary tonalite and rhyolite dykes (and lesser sills) occur in the mine area and frequently occupy north trending, high angle normal faults.

Two distinct periods of alteration and mineralization have been recognized at the Northumberland deposit (Motter and Chapman, 1984). The first period appears to be directly related to the emplacement of the Mesozoic age tonalite, and consists predominantly of silver bearing quartz veins both within the intrusive and the adjacent sediments. The second stage of alteration and mineralization coincides with the emplacement of the rhyolitic dykes. This episode is responsible for the main deposition of disseminated micron size gold particles. This occurs mostly within a typically brecciated (both hydrothermal and tectonic), silica flooded and veined jasperoid representing the hydrothermally altered basal chert of the Roberts Mountains Formation (Motter and Chapman, 1984). Although mineralized, the disseminated gold content of the silty limestones and siltstones of the Roberts Mountains Formation are generally below ore grade. The Northumberland mine therefore represents a jasperoidal gold-rich end member of the sediment hosted, disseminated precious metal deposits. The Preble and Pinson deposits, situated in the Getchell belt, will be described in Section 3.3.2 as type examples for this end member category.



INTRUSIVE ROCKS

Rhyolitic to dacite dikes, Trd. White to off-white felsic volcanic dikes. Dikes are generally extremely clay altered, containing only quartz phenocrysts and "clay".

Tonalite, Jt. Medium grained intrusive rock similar to quartz diorite in composition. Generally buff to light brown in color and weathered to 100 feet to 300 feet below surface. Where not oxidized, color is bluish gray in color with 1 to 4 percent sulfides. Moderately clayey where oxidized.

SEDIMENTARY ROCKS

Zanzibar limestone, Olsu. Medium to dark gray or blue gray cherty limestone 1,000 feet plus thick. Generally medium bedded with alternating chert bands and argillaceous limestone bands typically 1/2 inch thick. Occasional chert horizons to 6 inches thick. Some interbeds of massive, non-cherty limestone.

Prospect Thrust

Roberts Mountain formation, includes:

SJ. Basal chert unit, resilicified from jasperoid 0 to 50 feet thick. Commonly medium to dark gray color brecciated and veined with quartz. Iron oxides common, as is remobilized carbon at upper and lower contacts.

Scs. Interbedded diopside and/or scapolite bearing calc-silicate horizons, 0 to 40 feet thick zones. Generally light gray to gray green in color, very fine grained and siliceous.

Sgss. Silty shale to siltstone, variably calcareous 50 to 150 feet thick, medium to dark gray, generally more carbonaceous near top. Silty shale generally overlies and is interbedded with calcsilicate.

Ssls. Laminated silty limestones to siltstones, 50 to 100 feet thick. Includes remainder of Silurian section not specifically identified above. Generally light gray, variable to medium gray.

Hanson Creek formation, Od. Dolomite and limestone 300+ feet thick. Generally medium gray to blue gray in color. Generally massive to thick bedded, occasionally thin bedded. Variably argillaceous, and commonly "sanded" near top due to hydrothermal dedolomitization. Lower portions exposed by drilling are weakly carbonaceous.

Note: Designations shown as depicted on Main pit geologic map (Plate 4).

Ov, Ordovician Vinini Formation cherts and argillites (western assemblage).

Roberts Mountain Thrust

Smt, Silurian Roberts Mountain Formation laminated limestone (transitional).

Chert

Ordovician Gatecliff Dolomite (transitional).

Unconformity

Olsu, Ordovician Zanzibar Formation limestone (transitional).

Prospect Thrust

Sm, laminated limestone of the Silurian Roberts Mountain Formation.

Basal chert of the Silurian Roberts Mountain Formation (locally jasperoid).

Oh, Hanson Creek Formation Dolomite.

FIGURE 3.13 : Stratigraphic section of the Palaeozoic rocks exposed in the vicinity of the Northumberland gold mine, Nevada. The gold mineralization is mainly hosted by the basal chert of the Robert Mountain Formation, which has been hydrothermally altered to jasperoid (Adapted from Motter and Chapman, 1984)

The **Alligator Ridge gold deposit** is situated to the east of the accreted terranes occupying the western portion of Nevada (refer Figure 3.9), and is hosted primarily by lower, silicified portions of the thinly bedded calcareous, carbonaceous siltstones and claystones of the late Devonian - early Mississippian Pilot Shale Formation (Klessig, 1984) (Figure 3.14).

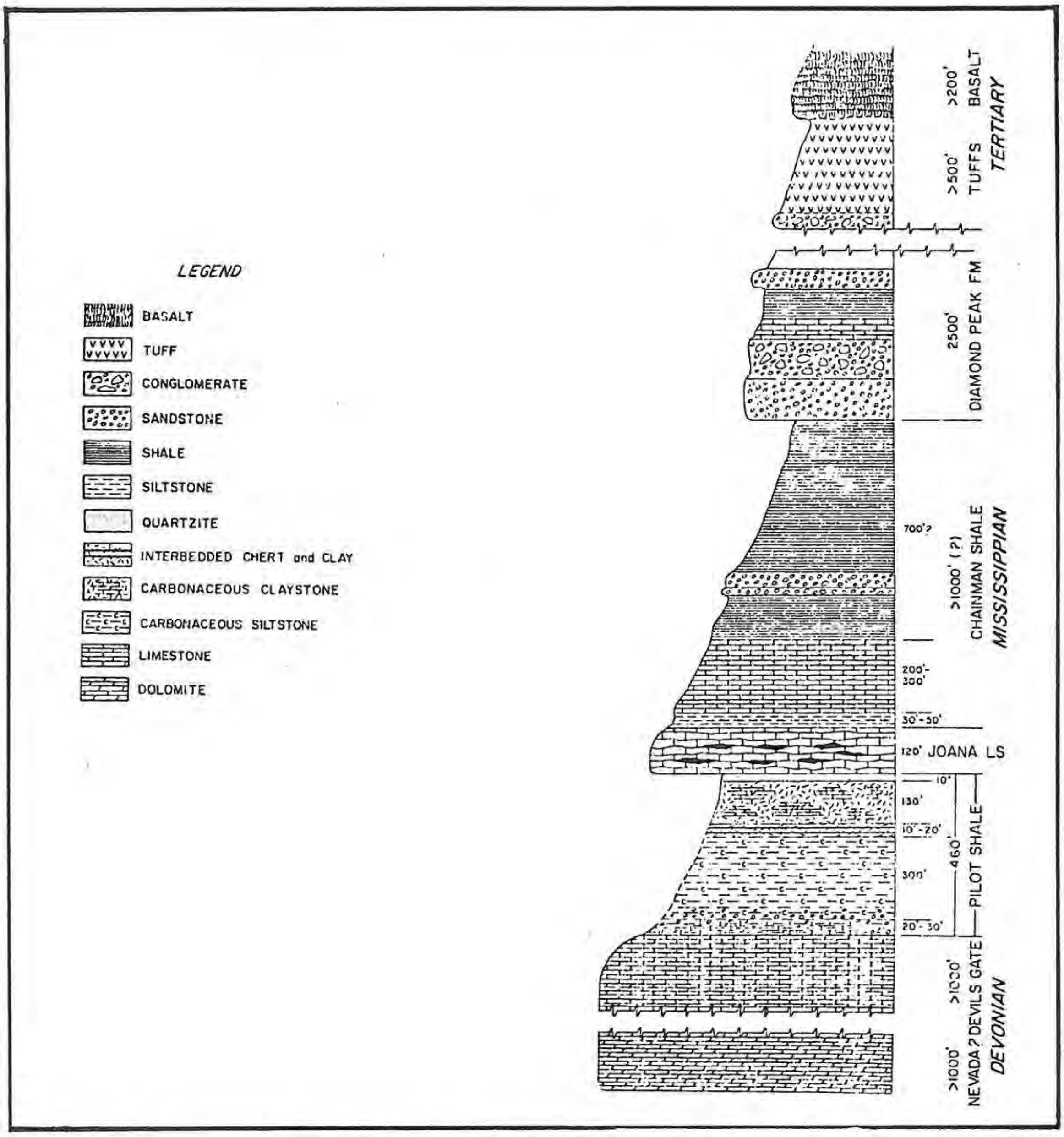


FIGURE 3.14 : Stratigraphic section of the Palaeozoic sediments, and Tertiary volcanics, exposed in the vicinity of the Alligator Ridge gold mine, Nevada. The disseminated gold mineralization is hosted mainly by the lower portions of the Pilot Shale Formation (Klessig, 1984)

The only known igneous rocks in the area are Tertiary age basaltic andesites and rhyolite tuffs. The rocks in the Alligator Ridge area have been folded into a series of low amplitude anticlines and synclines that strike north-south and plunge gently to the south. These folds have been truncated and deformed by later high angle faults that generally strike northwest, northeast and east-west. The predominant structural pattern in the area is that of the Basin and Range-type high angle normal faults and the Alligator Ridge mountain is itself a horst block between two Basin and Range Faults.

Three principal ore bodies, known as the Vantage One, Two and Three bodies, occur along a north - northeast strike with mineralization becoming progressively deeper from north to south (Figure 3.15). There is evidence that these ore bodies are aligned along the axis of an asymmetrical anticline which plunges gently to the southeast (Klessig, 1984). Along the crest of the anticline numerous extensional fractures and extensive brecciation may have provided conduits for one bearing solutions. Imprinted over the anticline are a series of northerly trending, and east-west trending normal faults along which multiple stages of movement are evident. Two of the north-northeast faults bound the greater area of mineralization on the east and west sides of the three ore bodies. The one fault which is apparently related to all the deposits is the north-northeast fault which transacts the eastern side of all three deposits. The footwall side of this fault is characterized by increasing intensity of alteration, such as decalcification, silicification and local remobilization of carbon (Klessig, 1984), suggesting that the structure has acted as one of the main fluid conduits. Irregular jasperoid bodies, formed where the rock is totally replaced by silica, commonly occur at the contact between the Devils Gate and Pilot Shale Formations adjacent to the normal faults, or within the normal fault zones. The regional significance of the north-northeast trending anticline is unclear other than its role in creating conduits for the ore bearing solutions at a local scale. No age dates are available for mineralization. Tertiary tuffs have been altered, probably by the mineralizing hydrothermal system, providing a lower age constraint.

3.3 Classification of Sediment-Hosted, Disseminated Precious Metal Deposits

Since its discovery in the early 1960's, the Carlin gold deposit has lent

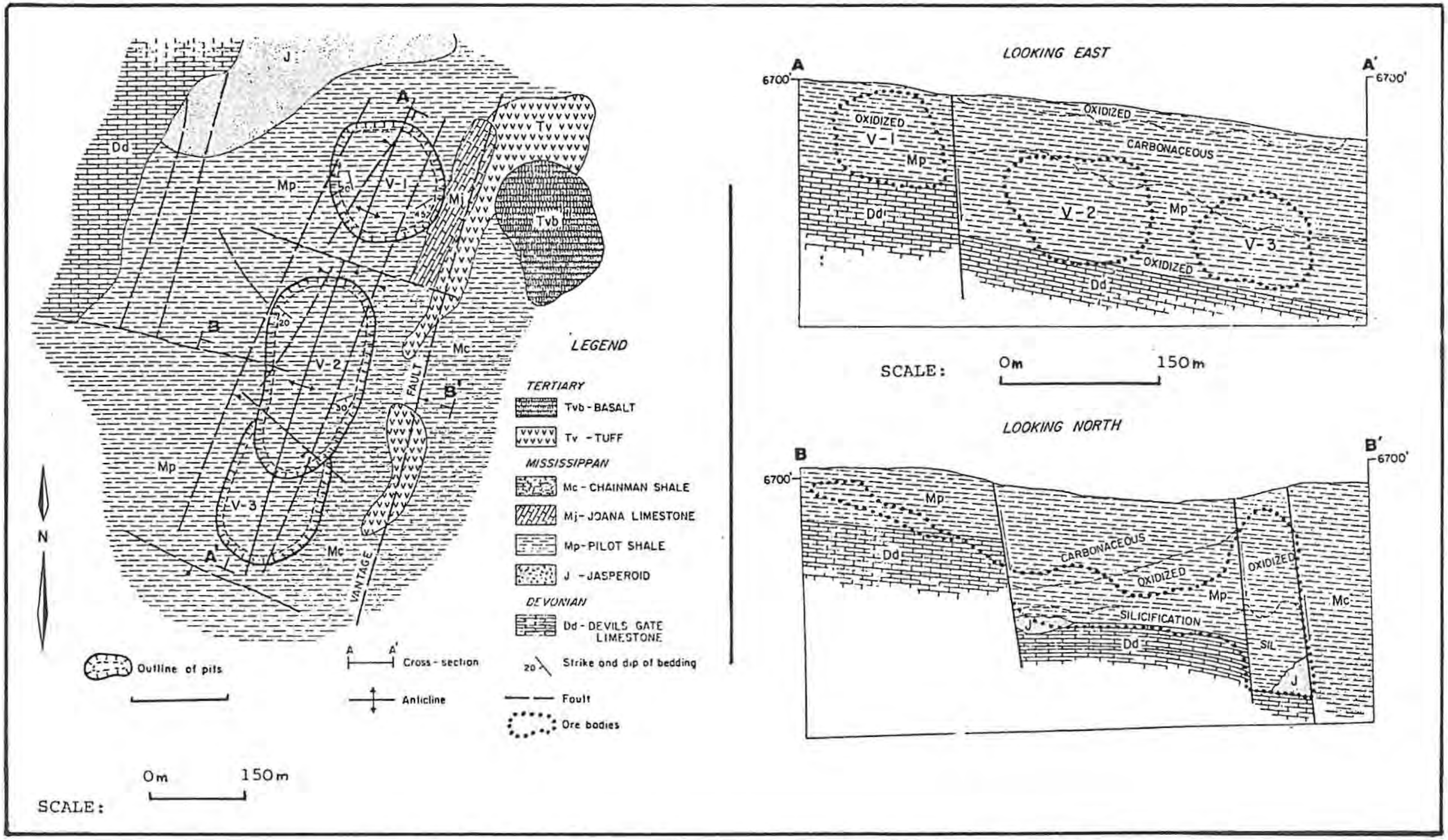


FIGURE 3.15 : Generalized geology map and crossections through the Alligator Ridge gold deposit, Nevada, comprising of the Vantage One (V-1), Vantage Two (V-2) and Vantage Three (V-3) ore bodies. Note that the oxidation in the near surface environment is due to supergene alteration, whereas the oxidation in the lower part of the Pilot Shale Formation is hypogene. Note also the development of jasperoid bodies, typically developed along the contact between a lower carbonate and upper shale unit (Klessig, 1984).

its name to a style of fine grained disseminated mineralization hosted usually by carbonate rocks. As more of these deposits were discovered and developed in the 1970's, it became apparent that Carlin was possibly an end member of the sediment-hosted, disseminated precious metal deposit type. Deposits in the western United States (refer Figure 3.9) display a wide variety of geological, mineralogical and geochemical characteristics (refer Tables 3.1 and 3.2). Thus, "Carlin-type deposit" is a misnomer for some sediment-hosted, disseminated deposits (Bagby and Berger - in press). For example, Carlin ore is hosted by silty dolomites whereas ores in other deposits are hosted in shales and siltstones (eg Rain, Horse Canyon). In addition, the gold ore at Carlin occurs in pod-like zones in favourable host lithologies adjacent to vertical faults and it is commonly difficult to visually distinguish ore from unaltered host-rock. On the other hand, the ore at some other deposits is more easily distinguished from unaltered rock because of direct association with either intense silicification in the form of jasperoids (eg Pinson, Northumberland) or with a noticeable increase in silica veining (eg Preble). Although "Carlin-type deposits" are frequently considered to have high gold to silver ratios, certain deposits included in this type have high silver values with gold as the major metal (eg Dee), others have high silver values and lack gold (eg Taylor), but retain similar associated trace elements (Sb, As, Hg, and in many deposits Tl) and alteration types (silicification, argillitization, decalcification, remobilization of carbonaceous matter).

On the basis of the above characteristics, Bagby and Berger (in press) have defined two deposit-type subsets : the Jasperoidal- and Carlin - type subsets of which there are gold-rich and silver-rich end members **Jasperoidal-type deposits** are those wherein the majority of the gold and/or silver is hosted in jasperoid or in quartz veins and related silicified wall rocks. On the other hand **Carlin-type deposits** are those wherein the gold and/or silver appears to be evenly distributed in the host rocks which do not always appear to be silicified. Ore zones in Carlin-type deposits are commonly pod-like and extend up to tens of metres away from faults. Ore zones in jasperoidal-type deposits are most commonly limited to narrow, shear zones and along the contact of carbonate rocks with overlying shale beds adjacent to high angle faults. There is a complete gradation between these two subset types, and a deposit classified as jasperoidal may have exploration potential for Carlin-type extensions and vice versa. The classification serves as a means for examining and understanding the differences that occur between and within the individual sediment-hosted, disseminated precious metal deposits. In addition, the separation is useful at the deposit scale for understanding genesis and is a useful concept in regional and district exploration programmes.

The term jasperoidal and jasperoids are used repeatedly in the text. Following on the definition of Lovering (1972), and Lovering and Heyl (1974), a jasperoid refers to an epigenetic rock body formed largely by fine-grained, chert-like siliceous replacements of a pre-existing rock. Chert, in contrast, means a siliceous rock body formed at the time of sedimentation. Most jasperoid bodies are controlled structurally by high angle normal faults and stratigraphically by the contact of carbonate rocks with overlying shale beds.

The geological and chemical characteristics of the Carlin, Preble/Pinson and Taylor ore bodies will be reviewed here as representatives of the end-member categories of the disseminated, sediment-hosted precious metal deposits. The Carlin deposit, considered in some detail, serves to illustrate the category that is characterized by fine-grained, disseminated gold ore that is sometimes difficult to visually separate from unaltered rock. Preble and Pinson illustrate the type that is characterized by gold ore associated with intense silicification (jasperoids) and quartz veining. These deposits are all gold-rich end-members. Taylor exemplifies the silver-rich end-member and is also characterized by intense silicification in the ore zone.

3.3.1 **Carlin-type subset : The Carlin gold deposit**

The Carlin gold mine is situated in the lower plate Lynn Window of northern Eureka County, Nevada, in the Tuscarora Mountain Range (refer Figures 3.4, 3.9 and 3.10). The Carlin Gold Mining Company, a 100% owned subsidiary of Newmont Mining Corporation, operates the Carlin, Maggie Creek and Blue Star open pits in the Carlin belt and has plans to develop the Gold Quarry and Rain deposits in the same belt. A brief history of the discovery of the Carlin deposit, and the evolution of the mining, milling and leaching operations is given by Jackson (1983). The following deposit characteristics are summarized mainly from Radtke et al., (1980). Adkins and Rota (1984), Dickson et al., (1979), Bagby and Berger (in press), Harris and Radtke (1976), Hausen (1983), Hausen and Kerr (1968), Radtke et al., (1972), Radtke and Dickson (1974), Radtke and Scheiner (1970), and Wells and Mullens (1973). A generalized geological map showing the structural and stratigraphic relationships of the northern part of the Lynn Window, and the Carlin gold deposit, is given in Figure 3.16 and Figure 3.17, respectively. A schematic north-south section through the Main Ore Zone and Popovich Hill is given in Figure 3.18.

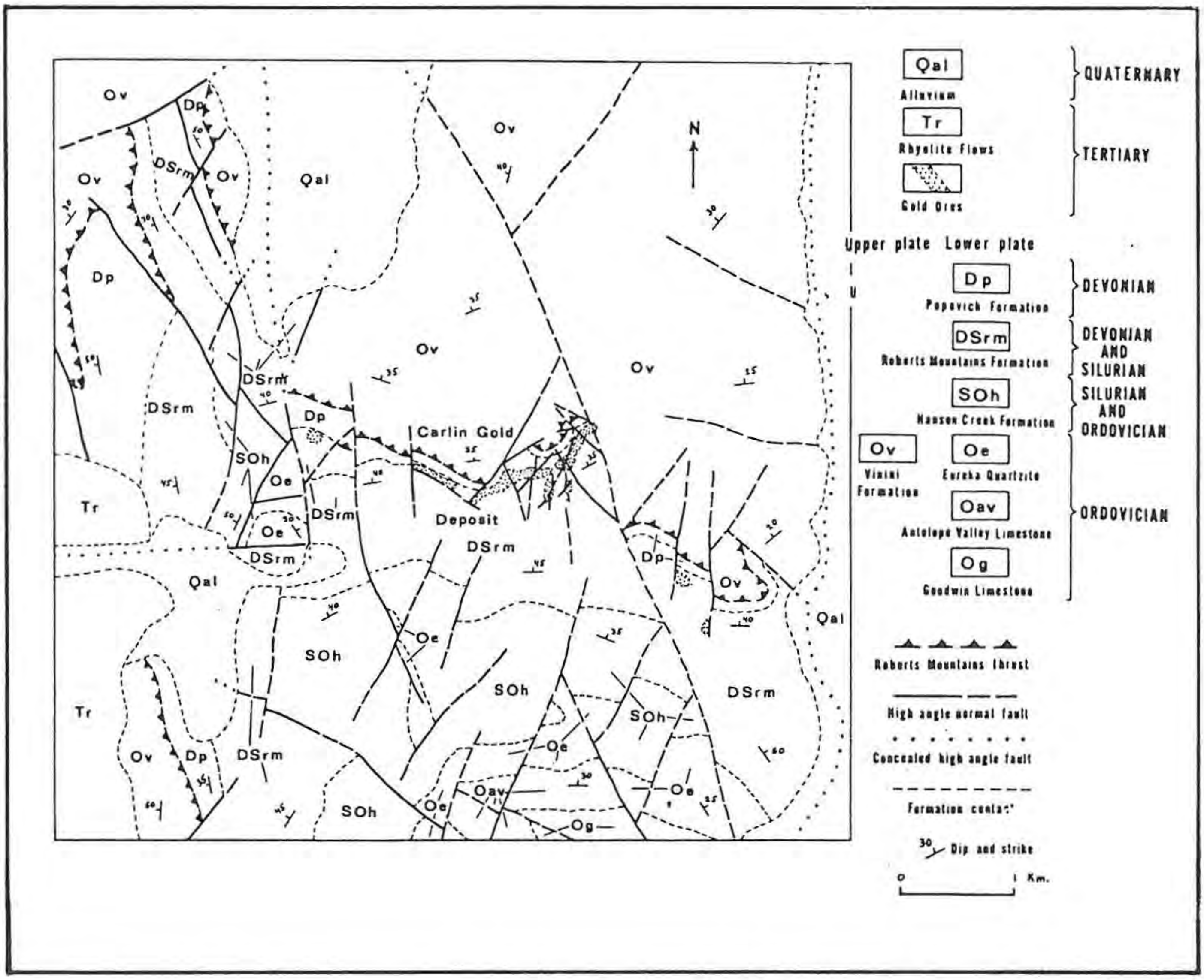


FIGURE 3.16 : Geological map of the area around the Carlin gold deposit in the northern part of the Lynn window, Nevada (Radtke et al, 1980)

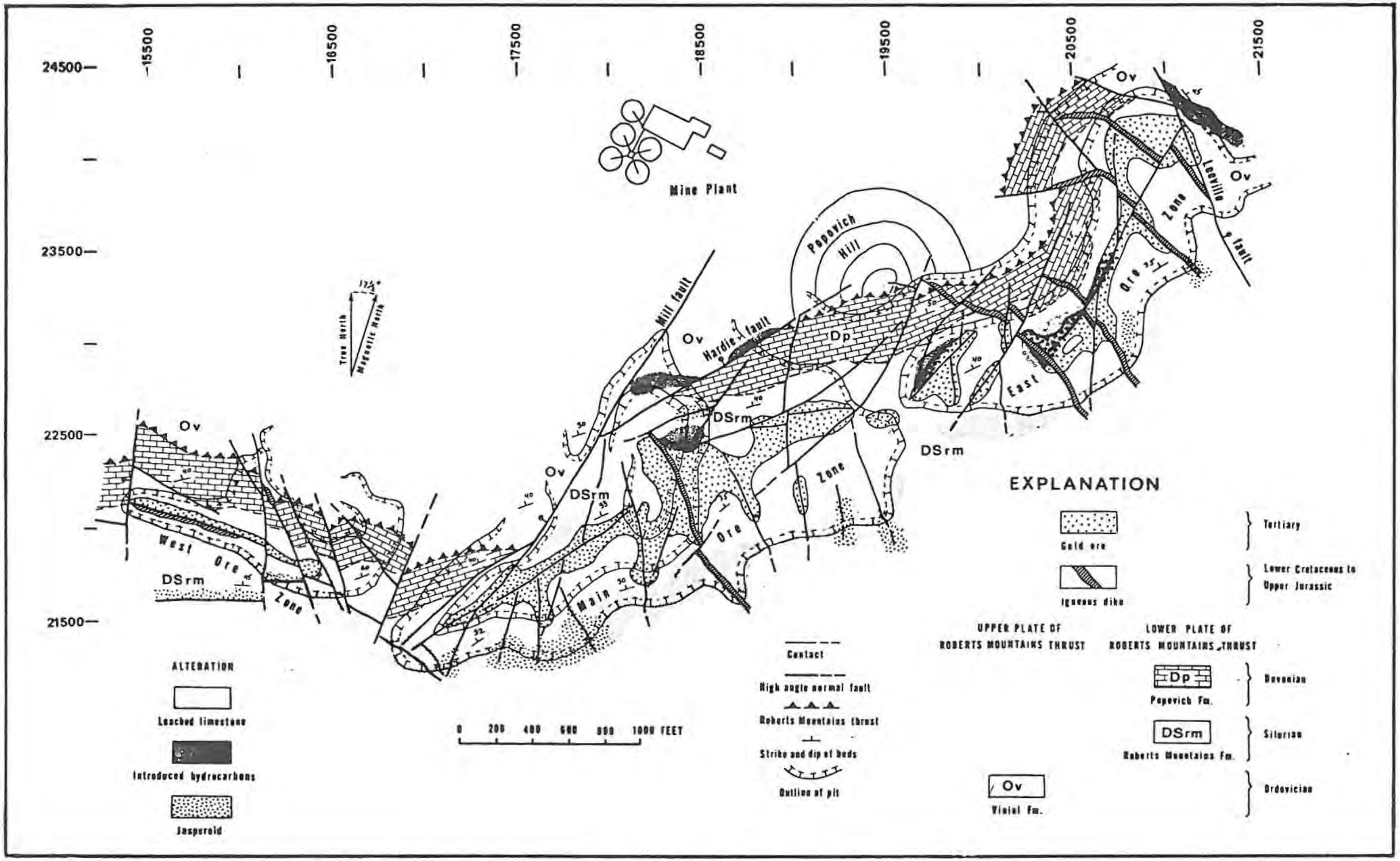
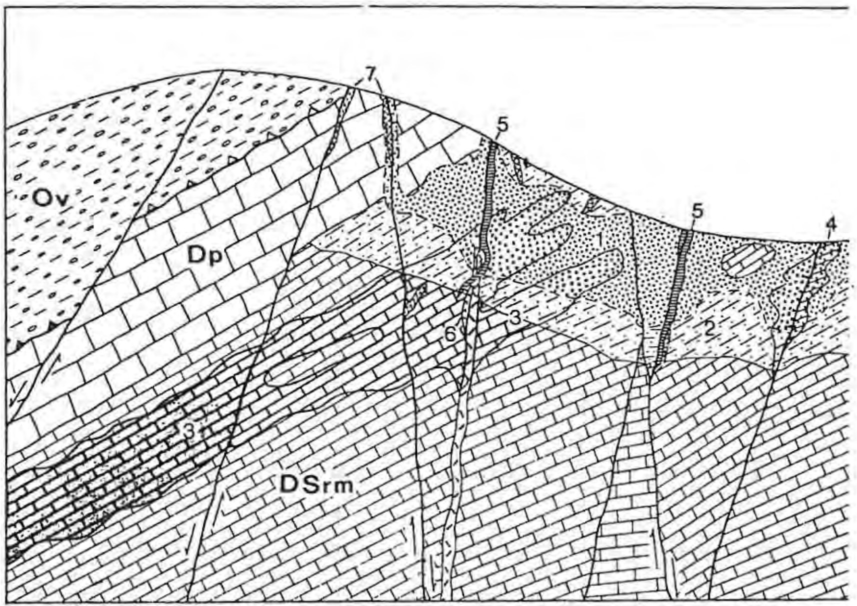


FIGURE 3.17 : Simplified geological map of the Carlin gold deposit, Eureka County, Nevada (Radtke et al, 1980)



1. The zone of oxidized acid-leached rocks, the bottom of which locally is parallel to the present topography but extends downward along fractures: this zone contains isolated scattered remnants of unaltered host rock and unoxidized mineralized rock.
2. Areas of oxidized but unleached rocks extending ± 20 m below the leached rocks and also present above the leached rocks; this zone of supergene oxidation actually extends from the surface through and below the leached zone.
3. Disseminated gold orebodies extending to unknown depths below the oxidized zone and upward into the zones of acid leaching and supergene oxidation.
4. Jasperoid bodies that extend as much as 30 m from faults developed through a vertical distance of about 130 m in the oxidized acid-leached zone; their thickness and lateral extent progressively decrease with depth to nearly zero at the bottom of the zone of acid leaching. The largest bodies tend to occur stratigraphically beneath orebodies, along their lower margins
5. Barite veins and veinlets are sporadically distributed throughout the deposit but are most abundant in the main and west ore zones. The barite veins range from paper-thin seams to about 1 m thick. They are most abundant and best developed in the leached zone, and they typically narrow abruptly or terminate at the bottom of the leached zone or in the underlying unleached oxidized zone. Only a few small stringers of barite have been observed to date in the upper 10 to 15 m of the unoxidized zone. Disseminated sphalerite, galena, realgar, orpiment, stibnite, and As-Sb-Tl-Hg-bearing sulfosalt minerals occur in minor amounts in many places in the lower parts of the barite veins.
6. Sparse but geochemically important quartz veinlets up to 1 cm thick occur at deep levels in unoxidized ore, in shallow parts of the oxidized zone, and in silicified carbonate rocks (jasperoid bodies) at the surface. In places quartz pods and seams occur in barite veins.
7. Thin calcite veinlets are sparsely distributed in the unoxidized ore. They are usually absent in the leached zone but are abundant in oxidized rocks immediately above and below the leached zone.

FIGURE 3.18 : Schematic north-south section through the Main Ore Zone and Popovich Hill at the Carlin gold deposit, showing important geologic features. Lithologic units include Vinini Formation (Ov), Popovich Formation (Dp), and Roberts Mountains Formation (DSrm) (modified from Radtke et al, 1980)

Host lithology

The Carlin ore bodies consist of tabular and irregular-shaped zones in the upper portions of the autochthonous Silurian age Roberts Mountains Formation. This Formation strikes northeast and dips northwest beneath the Roberts Mountain Thrust fault. In horizontal section the ore zones occur in several stratigraphic zones that define a northeast trend of about 2.8km and forms three recognizable mine units : The Main Ore Zone, the East Ore Zone and the West Ore Zone (refer Figure 3.17). The Main Ore Zone ranges in thickness from about a metre up to nearly 35 m, normally with gradational assay boundaries, and follows the inclination of the strata downward from the surface until intersected by northeast trending normal faults.

The upper portions of the unaltered Roberts Mountains Formation is composed of two types of interbedded carbonate rocks, similar in physical appearance yet significantly different in composition, texture, fabric and susceptibility to alteration and mineralization (Radtke et al., 1980).

The first type, Type 1, a favourable host for disseminated gold, is a strongly laminated argillaceous to arenaceous dolomite or limey mudstone. The rock contains 25 to 45 % dolomite rhombs ranging from 25 to 50 micron diameter, apparently of early diagenetic origin; 20 to 30 % angular quartz grains ranging from 50 to 100 microns in size; 15 to 20 % argillaceous material (mainly illite); and 5 to 20 % fine-grained calcite. Other constituents include 1 to 3 % chert, possibly of authigenic origin; 0,5 to 1 % diagenetic pyrite; 0.3 to 0.8 weight % organic carbon; and numerous minor accessory minerals including feldspar, zircon, hornblende, monazite, tourmaline, rutile, magnetite, haematite, chalcopyrite, galena, and sphalerite. The origin of these sulphides is not known, but they are not related to hydrothermal activity and may be diagenetic (Radtke et al., 1980). Illite and the carbonaceous material are commonly admixed and concentrated in fine current-induced laminations, 0.5 to 2mm thick. Replaced ore-bearing rocks have densities that vary from 1.95 to 2.40, while fresh limestone from near Maggie Creek has density values of approximately 2.65 (Hausen and Kerr, 1968).

The second type, Type 2, is not a favourable host rock, and within the deposit it is fresh or only weakly altered and/or mineralized. This facies is a poorly laminated thin-bedded arenaceous peloid wackestone. Peloids ranging in size from 50 to 300 microns make up 40 to 65 % of the rock; this facies also contains 10 to 20 % argillaceous material (principally illite), and a few percent dolomite. Except for a lower content of organic carbon (0.2 to 0.4 weight %), minor constituents are similar to those for the other facies. Small amounts of montmorillonite occur in near-surface samples of both types.

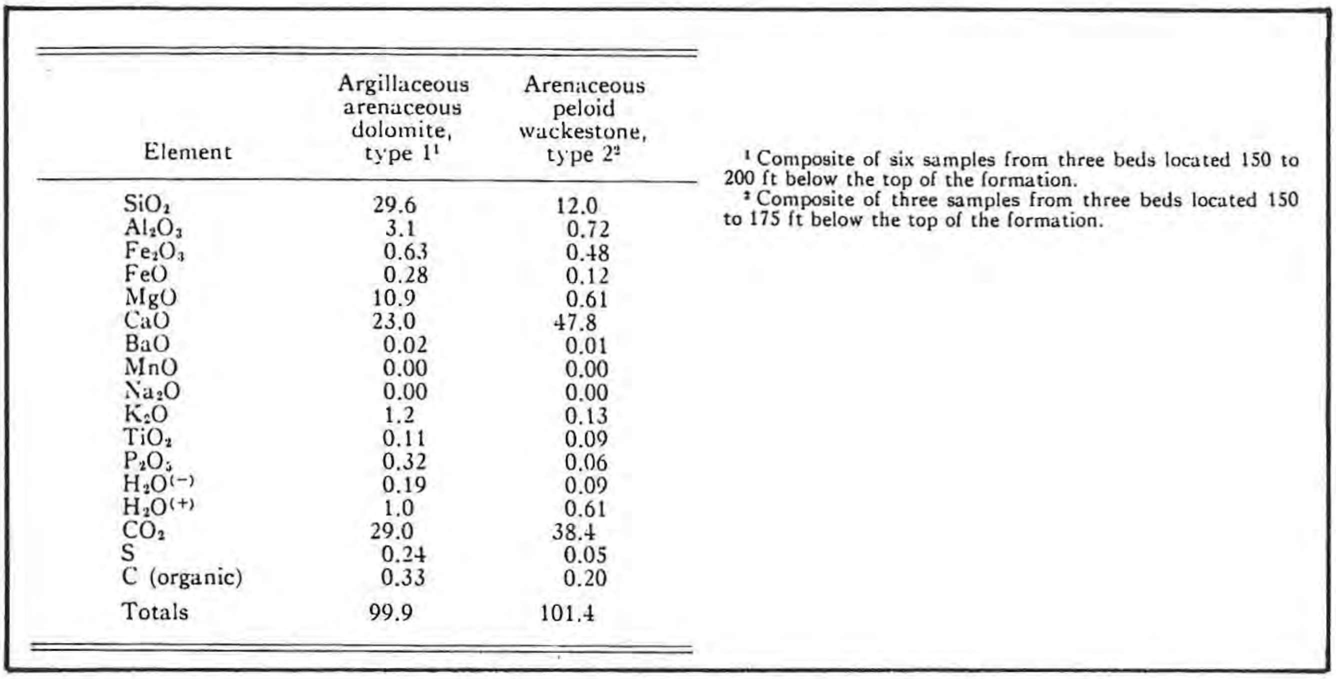
Chemical and spectrographic analyses of samples of both facies are given in Tables 3.3 and 3.4. Although no data on porosity and permeability of the rocks are currently available, it seems likely that the thin-bedded Type 1 rocks have higher porosity and permeability making them suitable for solution of interstitial calcite and for introduction of the hydrothermal ore components (Radtke et al., 1980). The average values for most of the minor elements in unaltered Type 1 facies are greater than average values for crustal limestones and less than average values for crustal shales as reported by Turekian and Wedepohl (1961).

Two aspects of the geological section that could have an important bearing on the genesis and geochemistry of the deposit should be noted : (1) all the Palaeozoic units in the area except the Eureka Quartzite contain diagnetic pyrite and organic material; and (2) the Eureka Quartzite is highly shattered, forms topographic highs, and dips northward toward and passes beneath the deposit. This unit is considered by Radtke et al. (1980) to have possibly served as an aquifer for the recharge of ground water and perhaps supplied waters to the mineralizing hydrothermal system.

Igneous rocks

Intrusive igneous rocks in the northern part of the Lynn district occur as two small stocks and numerous dykes of late Jurassic to early Cretaceous age. The Gold Strike stock, dated at 121 Ma (K-Ar age determination on biotite - Hausen and Kerr, 1968) and situated some 4 km north-northwest of the Carlin deposit, and the North Big Six stock located about 4 km north of the Carlin deposit, range from granodiorite to quartz diorite and diorite (Radtke et al., 1980). Many dykes in the Lynn district have a similar lithology and age and were emplaced in sets of northwest to northeast trending high-angle faults.

Igneous rocks in the Carlin pit occur solely as these Jurassic-Cretaceous fault filling dykes, and are either dacitic or quartz latitic in composition (Adkins and Rota, 1984). The general term quartz porphyry is used as a field description for these normally northwest-trending dykes

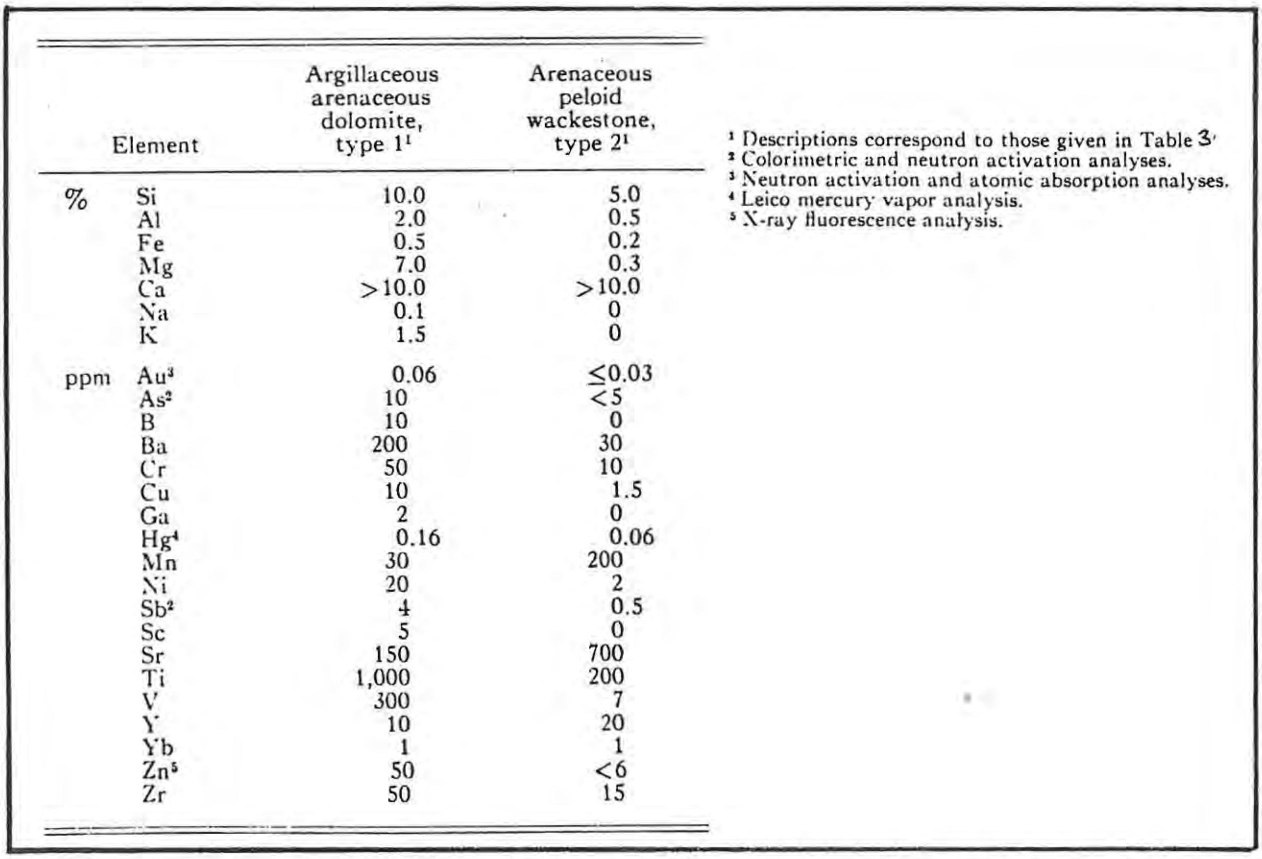


Element	Argillaceous arenaceous dolomite, type 1[1]	Arenaceous peloid wackestone, type 2[2]
SiO_2	29.6	12.0
Al_2O_3	3.1	0.72
Fe_2O_3	0.63	0.48
FeO	0.28	0.12
MgO	10.9	0.61
CaO	23.0	47.8
BaO	0.02	0.01
MnO	0.00	0.00
Na_2O	0.00	0.00
K_2O	1.2	0.13
TiO_2	0.11	0.09
P_2O_5	0.32	0.06
$H_2O^{(-)}$	0.19	0.09
$H_2O^{(+)}$	1.0	0.61
CO_2	29.0	38.4
S	0.24	0.05
C (organic)	0.33	0.20
Totals	99.9	101.4

[1] Composite of six samples from three beds located 150 to 200 ft below the top of the formation.

[2] Composite of three samples from three beds located 150 to 175 ft below the top of the formation.

TABLE 3.3 : Chemical analysis of samples of unaltered Roberts Mountains Formation, Lynn window, Eureka,Nevada (Radtke et al, 1980)



	Element	Argillaceous arenaceous dolomite, type 1[1]	Arenaceous peloid wackestone, type 2[1]
%	Si	10.0	5.0
	Al	2.0	0.5
	Fe	0.5	0.2
	Mg	7.0	0.3
	Ca	>10.0	>10.0
	Na	0.1	0
	K	1.5	0
ppm	Au[3]	0.06	≤0.03
	As[2]	10	<5
	B	10	0
	Ba	200	30
	Cr	50	10
	Cu	10	1.5
	Ga	2	0
	Hg[4]	0.16	0.06
	Mn	30	200
	Ni	20	2
	Sb[2]	4	0.5
	Sc	5	0
	Sr	150	700
	Ti	1,000	200
	V	300	7
	Y	10	20
	Yb	1	1
	Zn[5]	50	<6
	Zr	50	15

[1] Descriptions correspond to those given in Table 3

[2] Colorimetric and neutron activation analyses.

[3] Neutron activation and atomic absorption analyses.

[4] Leico mercury vapor analysis.

[5] X-ray fluorescence analysis.

TABLE 3.4 : Spectrographic analyses of samples of unaltered Roberts Mountains Formation, Lynn window, Nevada (Radtke et al, 1980)

(refer Figure 3.17). Most of the dykes have been affected by subsequent low temperature alteration to essentially quartz and secondary clays, and locally they have been mineralized, by gold-bearing hydrothermal solutions. Biotite from a dyke in the southwest corner of the Carlin Main pit yielded a date of 131± 4 Ma (Adkins and Rota, 1984).

Extrusive igneous rocks, consisting of flows of rhyolite and rhyodacite, are well exposed along the west flank of the Tuscarora Mountains (refer Figure 3.16). K-Ar age determinations on biotite give values of 14 Ma (Miocene), which falls within the youngest pulse of volcanic activity of 13 - 17 Ma in central Nevada (Silberman et al., 1976).

Structure

Two types of faulting of at least five ages have been recognized at Carlin. The low angle Roberts Mountain Thrust fault is the oldest prominent structure in the area. Numerous high angle normal faults of four ages disrupt the thrust fault : In order of decreasing age they trend easterly, northerly, northeasterly and northwesterly (Adkins and Rota, 1984). All faults are considered to pre-date the mineralization, but rejuvenation has occurred on the younger faults during Basin and Range development.

Both upper- and lower - plate rocks are folded by the regional Tuscarora anticline, which strikes roughly N20^{0} to 30^{0} W. The Carlin gold deposit is located near the crest of the anticline where the high-angle normal faults have broken the range into numerous blocks and produced intense shattering of the lower-plate carbonate rocks. Porous white silicification is most common along the northwest faults that cut the ore bodies and ore grade material of importance is located adjacent to such faults. It is clear that the high-angle normal faults served as channels for the mineralizing hydrothermal solutions, and resulted in a shattering of the upper 250 m of the Roberts Mountains Formation which was chemically favoured and suitably positioned for ore deposition. It should be noted however that these high angle fault zones are themselves only sparsely mineralized. The Roberts Mountain Thrust fault has had no influence on ore deposition.

Alteration

It is important to clearly distinguish, and discuss separately, the effects of hypogene and supergene alteration at the Carlin gold mine. Supergene alteration (oxidation) was so intense in some areas that it is difficult to interpret earlier hypogene alteration. Supergene alteration also has significant ramifications for enrichment of gold and ease of benefication.

The major **hypogene alteration** types that have affected all rocks in the Carlin ore zones are : 1) decalcification, 2) argillitization, 3) silicification, and 4) pyritization (Adkins and Rota, 1984). Perhaps the most striking alteration feature exposed in the Carlin pit are round to elliptical - shaped "bleached" white and light grey areas caused by extensive silicification of the Roberts Mountains Formation.

Decalcification of the Roberts Mountains and lower Popovich Formations represents the earliest stage of alteration in which carbonate minerals were removed selectively and redistributed. This initial penetration of the structurally fractured rocks was made by low temperature fluids, probably at less than 200^{o}C (Adkins and Rota, 1984), which dissolved calcite from the rock matrix, resulting in both an increase in porosity and permeability and a nett decrease in bulk density (ie ground preparation). Dolomite being less soluble commonly remained as rhomb-shaped crystals in a matrix of porous clays.

Argillitization accompanied the pre-gold decalcification stage resulting in the formation of illite from detrital feldspar grains, while montmorillonite and kaolin are less abundant. In most Carlin ore samples, clays constitute 20 to 60 % of the rock (Hausen and Kerr, 1968).

Silicification was a bulk replacement process at Carlin and, as at many deposits of this type in Nevada, is closely related to the introduction and concentration of the gold mineralization. Zones of sparse quartz microveinlets, vuggy and drusy quartz, and cherty silicification are prominent in close association with the tabular gold-bearing zones (Adkins and Rota, 1984). Also evident at the Carlin deposit are porous chimney-like ellipsoidal masses of fine recrystallized quartz (Figure 3.19A) (Hausen and Kerr, 1968). The bleached core zone is frequently cut by more or less

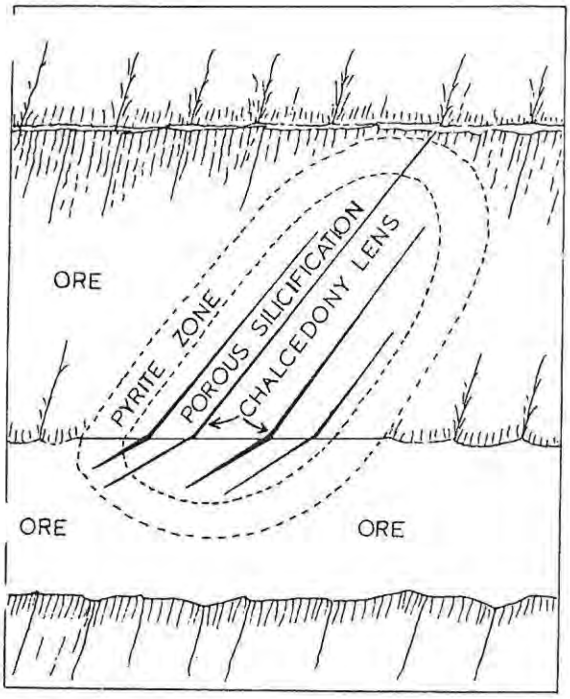


FIGURE 3.19A : Schematic diagram of a chimney-like form in the Main Ore Zone, Carlin gold deposit. An elliptical core of porous silicification is cut by more or less parallel chalcedonic lenses and surrounded by a pyrite-bearing zone. Ore grade material surrounds the chimney, but the chimney itself is non-ore bearing (Hausen and Kerr, 1968)

FIGURE 3.19B : Irregular, drusy dark grey chalcedonic seam from chimney structure at the Carlin gold deposit, Nevada (Hausen and Kerr, 1968)

parallel, porous and drusy to hard to massive dark-grey chalcedonic lenses or tongues. These follow stratification and may either pinch out in places or may swell to masses as much as 4 m thick (Figure 3.19B). Frequently encircling the "chimney" is a brownish pyrite-bearing zone about 1 - 2 m thick. Gold content within the core of porous silicification is relatively low, but increases beyond the perimeter of the brownish pyrite zone. It should be noted that zones of silicification, usually manifested by chalcedonic recrystallization and a darker colouration, are not necessarily enriched in gold and in many cases are relatively impoverished. Local silicification of permeable decalcified rocks accompanied the early stages of mineralization (ie pre-mainstage gold deposition) and would have diluted the amounts of mainstage gold in the ore body (Hausen and Kerr, 1968). The amounts of gold in bleached and silicified portions of the Carlin ore bodies therefore vary considerably.

Hypogene pyritization is common to all deposits of this type. Pyrite-rich (less than 2 volume %) rocks are locally auriferous, the pyrite containing visible gold in cavities and fractures. Growth rings suggest that at least two generations of pyritization have occurred in the ore bodies (Adkins and Rota, 1984). The earlier deposition of pyrite occurred before gold deposition began, the second generation accompanied mainstage gold deposition.

Post-gold mineralization hydrothermal activity is generally known as the acid leaching/oxidation stage, and has led to prominently visible alteration in parts of the upper portions of all three Ore Zones (Noble and Radtke, 1979; Radtke et al., 1980). This stage is characterized by strong acid leaching of shallow rocks and ores by H_20 produced from the oxidation OF H_2S. The vapour phase H_2S was driven off by the boiling, at 275^o - 300 ^oC, of ore forming fluids at the end of mainstage gold deposition. Most of the remaining calcite and large amounts of dolomite were removed from the Roberts Mountains Formation and from the lower parts of the overlying Popovich Formation. Organic carbon compounds and pyrite were oxidized and removed, and kaolonite and anhydrite formed. Calcite veins formed above and below the zone of acid leaching, sometimes cross-cutting the mineralization.

Following the close of hydrothermal activity the rocks and ores underwent

supergene alteration in the form of oxidation, by cool meteoric waters. Locally these waters penetrated 50+ metres below the bottom of the acid-leached zone (Adkins and Rota, 1984). Anhydrite was dissolved, remnant sulphides and organic materials in the rocks above and below the acid leached zone were oxidized and small amounts of calcite were removed (Noble and Radtke, 1979). The oxidation resulted in the removal of carbon in the altered Roberts Mountains Formation within the mine area appears to be a matter of permeability differences in the sediment due to two basic factors: 1) The character of original and seimentation was such that it produced sandy beds or horizons with less carbon and a higher overall permeability and porosity, 2) the wide variances in the intensity of structural fracturing produced certain areas of high permeability. Supergene oxidaiton is deepest along major faults and formation contacts. Both conditions permitted a deeper and more complete process of carbon removal and oxidation. The supergene oxidation profile for the most part parallels the present-day erosion surface.

Ore types

Most of the ore bodies known at the Carlin deposit occur in three areas, referred to as the West, Main and East Ore Zones (refer Figure 3.17). Although many of the general structural and stratigraphic features are similar in the various zones of gold mineralization, ore bodies within each Zone show differences in ore controls and in chemistry and mineralogy (Harris and Radtke, 1976; Radtke et al., 1980). The Ore Zones are localized near high angle faults. The ore is commonly difficult, if not impossible to visually separate from waste. Ore control is strictly dependent on gold assay. On the basis of mineralogy, chemical composition, and gold associations, the unoxidized ore may be classified into five types (Radtke et al., 1980). These are : 1) normal, 2) siliceous, 3) pyritic, 4) carbonaceous, and 5) arsenical. These types are not fixed and members, and may kinds of gradations occur. Chemical and spectrographic analyses of samples of various unoxidized ores, and both oxidized (ie supergene) and leached - oxidized ores are presented in Tables 3.5 and 3.6. The descriptions of different ore-types presented below are taken from Radtke et al., 1980.

Element	Normal[1]	Normal[2]	Siliceous[3]	Pyritic[4]	Carbonaceous[5]	Arsenical[6]	Oxidized[7]	Leached-oxidized[8]
SiO_2	32.6	39.6	95.7	51.9	33.4	42.1	50.9	73.9
Al_2O_3	5.2	6.7	1.6	4.2	3.3	6.0	5.5	12.0
Fe_2O_3	0.69	1.9	0.66	3.3	1.2	1.9	2.0	3.1
FeO	1.0	0.84	0.10	1.1	0.14	0.68	0.12	0.16
MgO	8.0	9.3	0.06	7.3	11.2	9.1	4.9	1.3
CaO	22.1	14.4	0	10.3	18.0	13.1	15.6	0.45
BaO	0.02	0.02	0.05	0.01	0.09	0.08	0.02	0.03
MnO	0.04	0.03	0.21	0.04	0.05	0.04	0.03	0
Na_2O	0.12	0	0	0	0.53	0.03	0.20	0.04
K_2O	1.5	1.7	0.26	1.0	1.1	1.06	1.3	3.5
TiO_2	0.26	0.36	0.03	0.26	0.18	0.30	0.23	0.63
P_2O_5	0.07	0.12	0.07	0.12	1.1	0.25	0.12	0.09
$H_2O^{(-)}$	0.17	0.42	0.10	0.41	0.23	0.39	0.24	1.1
$H_2O^{(+)}$	1.2	1.6	0.82	1.1	1.2	1.8	1.4	3.1
CO_2	26.0	21.6	0.02	15.9	25.6	19.1	16.9	0.04
S (total)	0.72	0.82	0.11	2.8	0.8	2.2	0.2	0.11
C (organic)	0.20	0.31	0.17	0.51	1.9	0.50	0.20	0.05
As	0.02	0.09	0.04	0.02	0.06	1.11	0.15	0.08
Totals	100.0	99.8	100.0	100.3	100.1	100.3	100.0	99.7

[1] Main orebody, 6,300 elevation; Au = 9 ppm.
[2] Main orebody, 6,280 elevation; Au = 18 ppm.
[3] East orebody, 6,320 elevation; Au = 23 ppm.
[4] Main orebody, 6,300 elevayion; Au = 6 ppm.
[5] East orebody, Rotary drill hole P8; Au = 5 ppm
[6] East orebody, 6,380 elevation; Au = 69 ppm.
[7] Main orebody, 6,330 elevation; Au = 10 ppm.
[8] Main orebody, 6,320 elevation; Au = 50 ppm.

TABLE 3.5 : Chemical analyses of samples of various types of unoxidized ores, and oxidized (ie supergene) and leached - oxidized ores, Carlin gold deposit, Nevada (Radtke et al, 1980)

Element	Normal[1]	Normal[1]	Siliceous[1]	Pyritic[1]	Carbonaceous[1]	Arsenical[1]	Oxidized[1]	Leached-oxidized[1]
Si (%)[2]	>10.0	>10.0	>10.0	>10.0	>10.0	>10.0	>10.0	>10.0
Al	5.0	7.0	0.5	2.0	3.0	5.0	5.0	5.0
Fe	2.0	2.0	0.5	3.0	1.5	2.0	2.0	2.0
Mg	5.0	10.0	0.15	5.0	10.0	7.0	5.0	0.5
Ca	7.0	>10.0	0.03	7.0	>10.0	10.0	10.0	0.2
Na	0.05	0.1	0.03	0.05	0.1	0.07	0.03	0.07
K	1.5	3.0	0	1.5	1.5	2.0	1.5	2.0
Ti	0.2	0.2	0.02	0.1	0.1	0.15	0.15	0.3
P	0	0	0	0	0	2.0	0	0
Mn (ppm)[3]	100	150	7	150	500	150	150	10
Ag	0	0	1	0	2	0	0	0.7
As[4]	154	800	385	180	480	11,000	1,450	790
Au[5]	9	18	23	6	5	69	10	50
B	150	70	7	20	100	30	70	70
Ba	200	200	500	100	500	500	150	300
Co	7	5	0	7	3	3	3	1.5
Cr	70	70	10	30	70	70	50	100
Cu	50	20	70	30	70	50	20	30
Ga	15	15	0	7	7	10	10	20
Hg[6]	25	40	55	25	20	200	35	100
La	50	0	0	50	0	50	70	50
Mo	15	7	5	15	50	10	5	5
Nb	0	7(?)	0	0	0	0	0	10
Ni	50	20	3	70	100	20	20	15
Pb	15	0	0	10	15	0	15	30
Sb[4,7]	<40	150	40	<40	60	115	129	360
Sc	10	15	0	7	7	10	15	15
Sr	150	0	10	100	200	150	100	100
Tl	70	200	0	0	0	150	50	0
V	200	0	70	100	700	70	50	200
W[7]	<20	<20	<20	<20	30	20	<20	<20
Y	20	30	0	15	70	20	30	30
Yb	2	1.5	0	1	3	1.5	3	3
Zn[4]	51	114	6	7	100	<5	163	65
Zr	100	150	20	100	70	150	200	300

[1] Descriptions correspond with those given in Table 3.
[2] Elements Si through P given in weight percent.
[3] Elements Mn through Zr given in parts per million.
[4] X-ray fluórescence analysis.
[5] Atomic absorption analysis.
[6] Leico mercury vapor analysis.
[7] Colorimetric analysis.

TABLE 3.6 : Spectrographic analyses of samples of various types of unoxidized ore, and oxidized (ie supergene) and leached - oxidized ores, Carlin gold deposit, Nevada (Radtke et al, 1980)

Normal ore, which accounts for over 60 % of the known oxidized ores, closely resembles the fresh host rock in physical appearance. In most samples, from 25 to 50 % of the original calcite was removed by the hydrothermal fluids; small amounts of pyrite were formed, and fine-grained quartz, together with Au, Hg, Tl, Sb and As were also introduced. The average abundances for these elements in this ore type are 8 ppm Au, 25 ppm Hg, 50 ppm Tl, 100 ppm Sb, and 400 ppm As. The organic carbon content of about 0.25 to 0.30 weight % is similar to or slighly higher than that of the fresh host rock. Most of the Au occurs with Hg, Sb, and As as coatings on surfaces and as fracture fillings in pyrite grains. Smaller amounts of Au are associated with organic carbon. A very minor amount of metallic gold occurs as small grains locked in quartz. Sulphide minerals other than pyrite are very sparse.

Siliceous ore contains large amounts of introduced silica and very small amounts of remnant dolomite and calcite. In physical appearance as well as mineralogy, this ore type grades from the normal type to jasperoid. The abundances of introduced hydrothermal elements, including Au, vary over wide ranges. Most of the Au occurs on surfaces of fine-grained pyrite locked in quartz, and small amounts of fine-grained metallic gold (less than 10 micron diameter) are dispersed in hydrothermal quartz grains. Stibnite, realgar, and pyrite are the only sulphide minerals recognized in this ore type. Siliceous ore accounts for only 5 % of the primary unoxidized ore in the deposit.

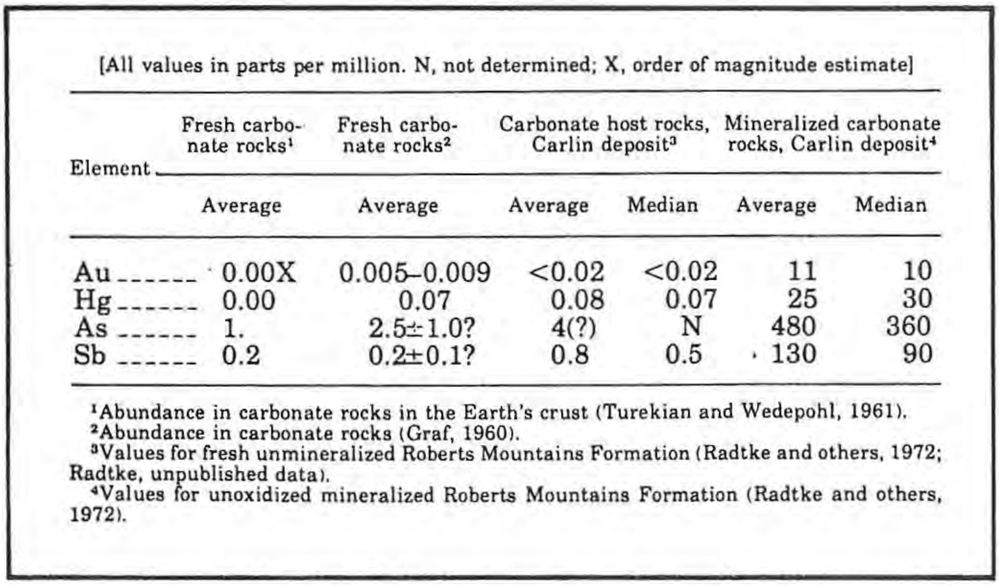
Pyritic ore makes up about 5 to 10 % of the known unoxidized ore, and contains from 3 to over 10 % introduced pyrite compared to the 0.5 - 3 % pyrite content of other unoxidized ore types. Compared to normal ore, pyritic ore has more hydrothermal silica and less calcite (refer Table 3.5) Pyrite occurs as euhedral to subhedral grains up to 200 microns long which are scattered through the rocks and concentrated in crosscutting veinlets, and as framboidal clusters of small microspheres, less than 10 microns diameter, associated with organic material and quartz. No framboidal pyrite has been found in the fresh unmineralized host rocks at Carlin. The occurrence of this form of pyrite only in mineralized rocks suggests that it is of hydrothermal origin (Radtke et al., 1980). Some framboidal pyrite has been coated by Au and other elements, indicating that the framboids formed somewhat earlier.

The contents of Au, Hg, Sb, and As vary widely in pyritic ore. Gold and Hg occur with carbonaceous material, and together with Sb and As, form coatings on both varieties of pyrite mentioned above (Radtke et al., 1972). The content of organic carbon varies from about 0.5 to 0.9 weight %, suggesting some introduction of hydrocarbons. Thin sections of these ores show an increase in hydrocarbons dispersed in the rock matrix,compared to other ore types described above (Radtke et al., 1980). Pyrite is the dominant sulphide mineral, although small sparse grains of realgar, stibnite, sphalerite, galena, molybdenite and chalcopyrite have been identified by microprobe studies.

The term **"carbonaceous ore"** has been used commonly as a general term in reference to all unoxidized ores at Carlin and other disseminated gold deposits in carbonate rocks. However, Radtke et al. (1980) restricts the term to those ores for which an introduction of hydrocarbons can be documented. Typically these contain from 1 to 5 weight % organic carbon. Carbonaceous ore is dark grey to black and contains small veinlets and seams of hydrocarbons in addition to the dispersed grains of amorphous carbon, hydrocarbons, and an organic or humic acid described by Radtke and Scheiner (1970). Carbonaceous ore makes up 15 to 20 % of the unoxidized ore at Carlin. Gold occurs both with carbonaceous material, and as Hg, Sb and As coatings on pyrite grains. In addition to pyrite, carbonaceous ore contains other sulphides such as realgar (As_2S_2), orpiment (As_2S_3), stibnite (Sb_2S_3), lorandite ($TlAsS_2$), cinnabar (HgS), sphalerite, galena and carlinite (Tl_2S).

Arsenical ore makes up 5 to 10 % of the known unoxidized ores. It contains large concentrations of As (0.5 to 10.0 weight %) most of which is in dispersed grains and veinlets of realgar and orpiment. The arsenic sulphides were deposited late in the paragenesis. Aside from As, the major chemical components and mineral phases in most of the arsenical ore correspond closely to those in the normal and carbonaceous ore types. Gold and Hg occur with carbonaceous material and as coatings on the surfaces of pyrite grains, dispersed through the carbonate rock and locked in realgar veinlets. Electron microprobe studies of Carlin ores show that small detectable amounts of gold occur in realgar (Radtke et al., 1980). Gold in some form, either in solid solution or as admixed metallic gold, has been reported in synthetic realgar and orpiment (Dickson et al., 1975). In addition to Au, arsenical ore generally contains unusually high concentrations of Hg, Sb, and Tl, and a wide variety of sulphide and sulphosalt minerals. Descriptions of arsenical ore in other Carlin-type deposits include those of Mercur, Utah (Gilluly, 1932); Manhattan, Nevada (Ferguson, 1924); and Getchell, Nevada (Joralemon, 1951).

The Au, Hg, As and Sb (sometimes with Tl) association at Carlin is common to a large number of disseminated precious metal deposits in the western United States (Akright et al., 1969; Joralemon, 1951; Radtke et al., 1974; Wells et al., 1969; Wrucke and Armbrustmacher, 1975; Harris and Radtke, 1976). The general levels of concentration of these elements at the Carlin deposit were established by Harris and Radtke (1976), who compared the abundance in mineralized rocks with that in normal carbonate rocks in general and the Carlin host rocks in particular (Table 3.7). Anomalous amounts of Ba, Cu, Mo, Pb and Zn are also reported in areas of disseminated gold mineralization (Akright et al., 1969; Radtke et al., 1972; and Wrucke and Armbrustmacher, 1975). Comparison of data for normal limestones and unmineralized host rocks with



[All values in parts per million. N, not determined; X, order of magnitude estimate]

Element	Fresh carbonate rocks[1]	Fresh carbonate rocks[2]	Carbonate host rocks, Carlin deposit[3]		Mineralized carbonate rocks, Carlin deposit[4]	
	Average	Average	Average	Median	Average	Median
Au	0.00X	0.005–0.009	<0.02	<0.02	11	10
Hg	0.00	0.07	0.08	0.07	25	30
As	1.	2.5±1.0?	4(?)	N	480	360
Sb	0.2	0.2±0.1?	0.8	0.5	130	90

[1] Abundance in carbonate rocks in the Earth's crust (Turekian and Wedepohl, 1961).

[2] Abundance in carbonate rocks (Graf, 1960).

[3] Values for fresh unmineralized Roberts Mountains Formation (Radtke and others, 1972; Radtke, unpublished data).

[4] Values for unoxidized mineralized Roberts Mountains Formation (Radtke and others, 1972).

Table 3.7 : Abundance of gold, mercury, arsenic and antimony in fresh limestones and unmineralized carbonate host rock, and unoxidized gold ores at the Carlin gold deposit, Nevada (Harris and Radtke, 1976).

mineralized rocks (Table 3.8) shows that except for Ba, these elements are concentrated from about 4 to 10 times in the ores. The content of Ba is only slightly increased in the mineralized unoxidized ores. These concentration factors are considerably less than the general range of 100 to 500 times for Au, Hg, As and Sb (refer Table 3.7).

[All values in parts per million]

Element	West ore body		Main ore body		East ore body	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Au	8.6	10	6.9	8.9	7.2	11
Ba	650	330	500	200	300	100
Cu	25	13	36	18	33	13
Mo	6.2	9.3	7.3	6.1	5.0	6.3
Pb	26	51	49	175	20	19
Zn	7	72	193	197	177	890

Table 3.8 : Abundance of gold, barium, copper molybdenum, lead and zinc in fresh limestones and unmineralized carbonate host rock, and unoxidized gold ores at the Carlin gold deposit (Harris and Radtke, 1976).

Post-hydrothermal supergene oxidized ore is composed of varying amounts of quartz, clay (illite, with lesser amounts of kaolinite, sericite and montmorillonite), and dolomite. Oxidized ore contains only about 0,03 - 0,35 % organic carbon and is bleached to a light green to tan colour. Limonite staining is common. Small particles of metallic gold, up to about 5 microns in diameter, are scattered through the rock and locked in fine-grained quartz, with lesser amounts associated with secondary iron-oxide minerals and clays.

Chemical changes during mineralization, acid leaching/oxidation, and supergene oxidation stages

The ore bodies at the Carlin deposit were formed where hydrothermal solutions moving along fault and breccia zones penetrated outward into thin-bedded (fissile) argillaceous carbonate rocks of the Roberts Mountains Formation. Reactions between the ore solution and the host rocks composed mainly of calcite, dolomite, illite and quartz, dissolved the calcite, deposited hydrothermal silica and pyrite and introduced gold and various other elements (Radtke and Scheiner, 1970; Radtke et al., 1972; Radtke et al., 1980). The major-element contents of the unaltered Roberts Mountains Formation and the changes in the rocks as a result of mineralization are shown in Figure 3.20. Only analyses of primary unoxidized ore can be used,

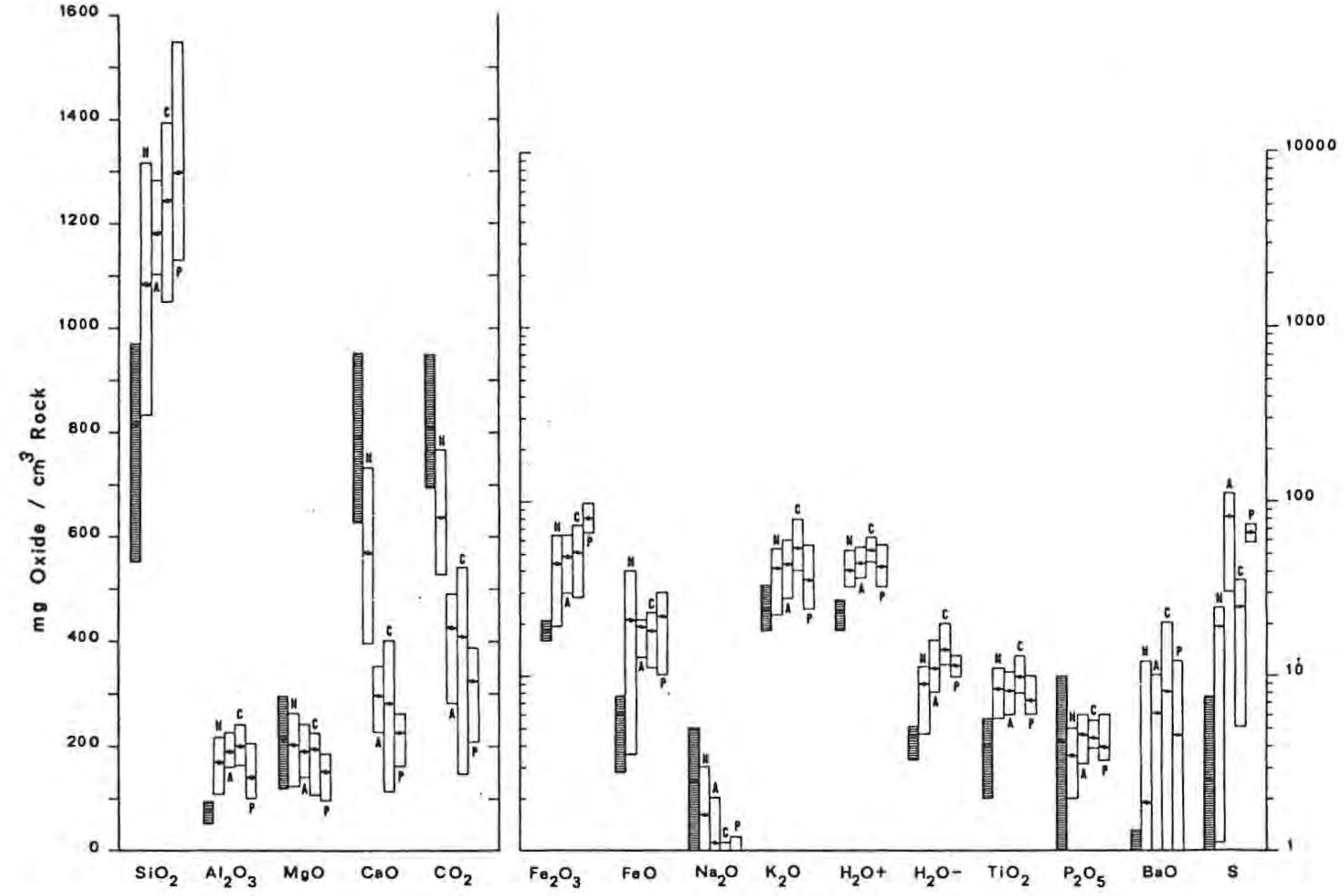


FIGURE 3.20 : Chemical changes in dolomitic carbonate rocks of the Roberts Mountains Formation during ore deposition. Vertical bars show ranges and median values (black diamond) of milligrams of the indicated oxide in a cubic centimeter of rock (these values are equal to the weight percent of the oxide times the bulk specific gravity times 10). Petrographic evidence shows that no significant change in volume occurred during alteration. Shaded columns show compositions of unaltered rock and open columns the compositions of various types of unoxidized ore; N = normal ore, A = arsenical ore, C = carbonaceous ore, and P = pyritic ore. Siliceous ore is not shown (Radtke et al, 1980)

as it is likely that highly variable supergene oxidation processes would produce complicated elemental distribution patterns different from those produced by the original hydrothermal conditions. The chemical changes in the dolomitic carbonate rocks hosting the Carlin ore deposit has been described by Radtke et al., (1980), from whom the following section is taken.

The most notable changes from the unaltered original rocks were the loss of CaO and CO_2 and the introduction of SiO_2. The components Al_2O_3, K_2O, and H_2O^+ increase, reflecting the formation of small amounts of kaolinite and sericite. H_2O^-, the loosely bound or absorbed water, follows closely the trend of Al_2O_3, K_2O and H_2O^+, revealing the tendency for the surfaces of fine-grained K-containing hydrous aluminous clays to absorb water. The increases of Fe_2O_3, FeO and S accord with the formation of pyrite. The increase in BaO content shows that some Ba was introduced, apparently as minor amounts of fine-grained barite dispersed throughout the rocks. The disseminated barite may have formed earlier than the barite in the veins. A small amount of TiO_2 was added. Electron microprobe analysis revealed a fine-grained mineral of composition TiO_2 dispersed throughout the matrix in various ore types (Radtke et al., 1980). The similar content of MgO in both fresh and mineralized rocks is in agreement with mineralogical data, which show that only small amounts of dolomite were dissolved by the hydrothermal fluids and that calcite was removed preferentially to dolomite. Only in areas where the hydrothermal alteration was very intense and siliceous-type ore formed has most of the dolomite as well as all of the calcite been removed. Data for the contents of organic carbon and As, both of which increase in the mineralized rocks, are omitted from Figure 3.20.

The visibly altered acid leached / oxidation zone, characterized by removal of carbonate from the rocks and the oxidation and removal of pyrite and organic matter, cuts across the dipping mineralized rocks in all three ore zones (refer Figure 3.18). The highly altered rocks in the acid-leached zone of the deposit are composed mainly of fine-grained quartz and illite, lesser amounts of kaolinite and sericite, minor montmorillonite, some remnant dolomite, small amounts of calcite (depending upon intensity of alteration and location), and scattered remnant iron oxides. Small amounts of remnant anhydrite that formed by reaction between the acid-leaching solution and calcite in the host rock also occur in the leached zone. Probably most of the anhydrite that formed in the upper rocks has been dissolved subsequently by ground water.

Important chemical changes produced in mineralized rock during this late stage hydrothermal acid leaching/oxidation stage are summarized by comparing data for normal unoxidized and acid-leached ores in columns 2 and 4 in Figure 3.21.

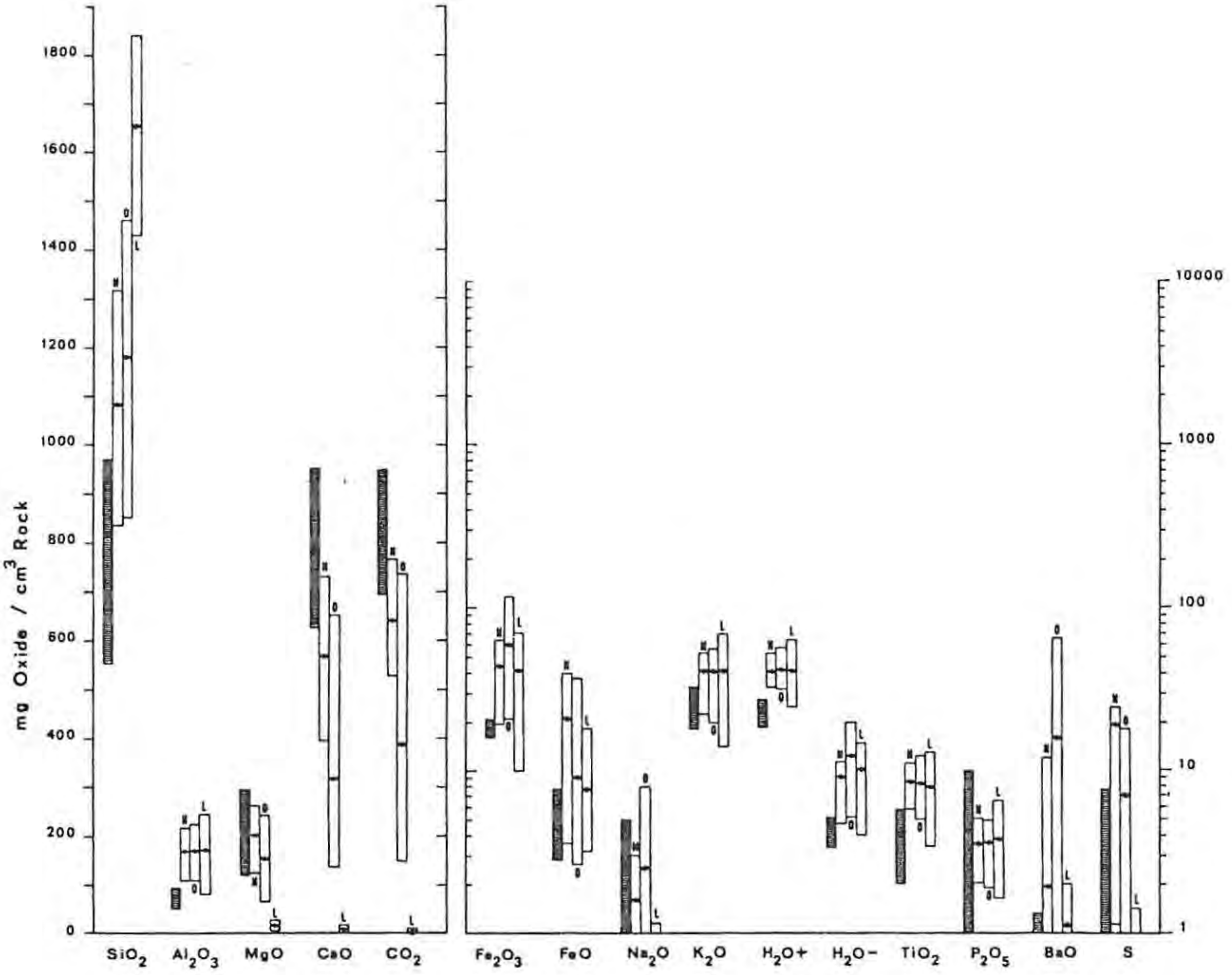


FIGURE 3.21 : Chemical changes in dolomitic carbonate rocks of the Roberts Mountains Formation during hydrothermal mineralization, acid-leaching and oxidation of the upper part of the deposit, and late oxidation. Vertical bars show ranges and median values (black diamond) of milligrams of the indicated oxide in a cubic centimeter of rock (these values are equal to the weight percent of the oxide times the bulk specific gravity times 10). Shaded columns show compositions of unaltered rocks and open columns the compositions of normal-type unoxidized ore (N), acid-leached oxidized ore (L), and unleached oxidized ore (O) (Radtke et al, 1980).

The very large losses of CaO, MgO and CO_2 reflect solution of nearly all calcite and much of the dolomite, and an increase in SiO_2 reflects introduction of quartz. The lack of change in K_2O, Al_2O_3, and H_2O^+ contents suggests that no additional potassic alteration occurred during leaching and oxidation in the upper part of the deposit. The decrease in Fe_2O_3 content indicates that iron as well as sulphur was removed during breakdown of pyrite. All changes are in agreement with petrographic evidence. Not shown in Figure 3.21 is the removal of organic carbon, an important feature of the acid leaching/oxidation stage.

Mineralized and unmineralized rocks to a depth of at least 20 - 50 m below the leached zone have undergone posthydrothermal supergene oxidation during which they were bleached to light green to tan; they can be distinguished from acid-leached rocks by the colour change and relatively unchanged mineral composition. In the oxidized but unleached ores and in the leached oxidized ores, small particles of metallic gold, up to about 5 microns in diameter, are scattered through the rock and locked in fine-grained quartz, with lesser amounts associated with secondary iron-oxide minerals and clays.

Comparison of columns 2 and 3 in Figure 3.21 reveals changes in the chemical composition of mineralized rocks caused by surface derived water (supergene) after the close of the hydrothermal activity. The data show that the chemical changes during late supergene oxidation were much less than those during the late hydrothermal leaching. Losses in CaO and CO_2 reflect the removal of small amounts of calcite; decreases in FeO and S correspond to the oxidation of pyrite and other sulphides. The higher values of SiO_2, suggesting some introduction of late quartz, are compatible with petrographic data showing microveinlets of quartz in some samples (Radtke et al., 1980).

Organic chemistry

The presence of organic carbon compounds in the unoxidized gold-bearing carbonate rocks at Carlin, and in fact in many of the disseminated precious metal deposits of Nevada, has long been recognized (Radtke and Scheiner, 1970; Hausen and Kerr, 1968; Joralemon, 1951). At Carlin, the organic compounds consist of veinlets, seams, and dispersed particles of amorphous carbon, hydrocarbon, and a substance resembling humic acid (Radtke and Scheiner, 1970). These occur in the primary unoxidized ores and are especially concentrated in the carbonaceous-type ore. Fresh Roberts Mountains host rock averages about 0.1% organic carbon and ranges up to about 0.25%. All ore types contain some organic carbon at levels in excess of that in the fresh host rock. Carbonaceous ores average about 2% organic carbon but range up to 5% locally. The organic carbon compounds occur in intimate associations with the ore suite of minerals in textural relationships that locally imply simultaneous deposition (Dickson et al., 1979).

The difficulty has been in defining the exact nature of the gold-carbon association and whether or not the carbonaceous material served as a transporting or precipitating agent for gold. It is now believed that most of the organic materials were introduced with the mainstage hydrothermal fluids (Radtke et al., 1980), and that the type and amount of carbonaceous material is unimportant in determining the amount of gold deposited. This will be considered in Section 3.3.4.

Vein types

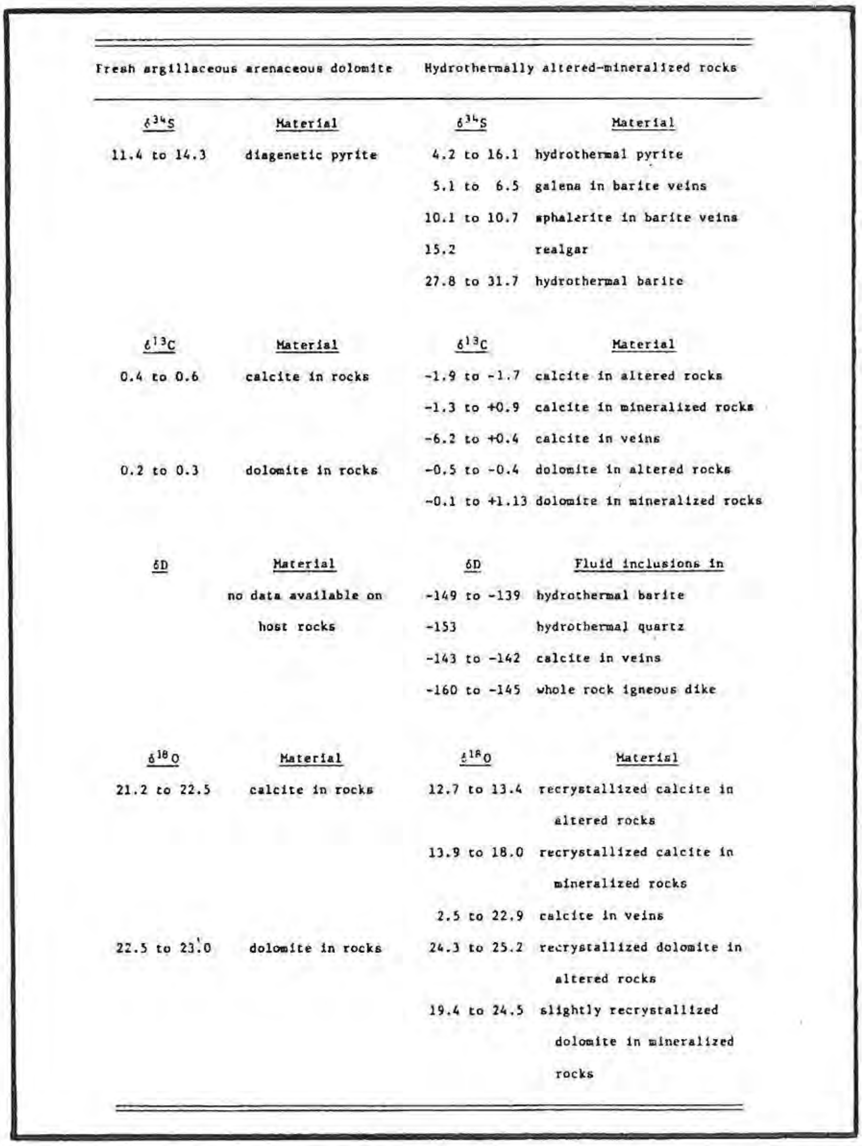
The Carlin deposit is known for its general paucity of veins. Although sparse, gold bearing quartz veinlets up to 1 cm thick do occur at deep levels in unoxidized ore, in shallow parts of the oxidized zone, and in jasperoid bodies at the surface (Radtke et al., 1980) (refer Figure 3.18). Thin calcite veinlets, possibly formed during gold deposition, are sparsely distributed in the unoxidized ore zone. Late-stage hydrothermal calcite veinlets formed during the acid leaching/oxidation stage, but are usually absent from the leached zone and well developed above and below this zone. Later, supergene related calcite veins are developed throughout the Carlin ore bodies. Barite veins, ranging from paper-thin seams to about 1 m thick, are best developed in the leached zone, and they typically narrow abruptly or terminate at the bottom of the acid-leached zone, or in the underlying unleached oxidized zone.

Fluid inclusions

The results of fluid inclusion studies at the Carlin deposit are reported by Nash (1972) and Radtke et al. (1980). Radtke et al. (op cit) report that temperatures and salinities of the fluids during main-stage mineralization were about 175^{o} - $200^{o}C$, and 3 ± 1 equivalent weight % NaCl, respectively. Temperatures of fluids during the acid leaching/oxidation stage, characterized by widespread boiling, were about 275^{o} - $300^{o}C$. The boiling of the fluids increased the salinities to values as high as 17.4 equivalent weight % NaCl. All fluids associated with the close of hydrothermal activity and post-hydrothermal supergene processes are of low temperature (less than 70^{o}C) and low salinities of between 0.0 to 1.1 equivalent weight % NaCl.

Stable isotopes

Stable isotope analyses of selected materials from the Carlin deposit, including fresh, altered and mineralized rocks, are reported by Dickson et al. (1979) and Radtke et al. (1980) and are summarized in Table 3.9. The isotopic data support a nonmagmatic source for the water, sulphur and carbon introduced into the deposit.



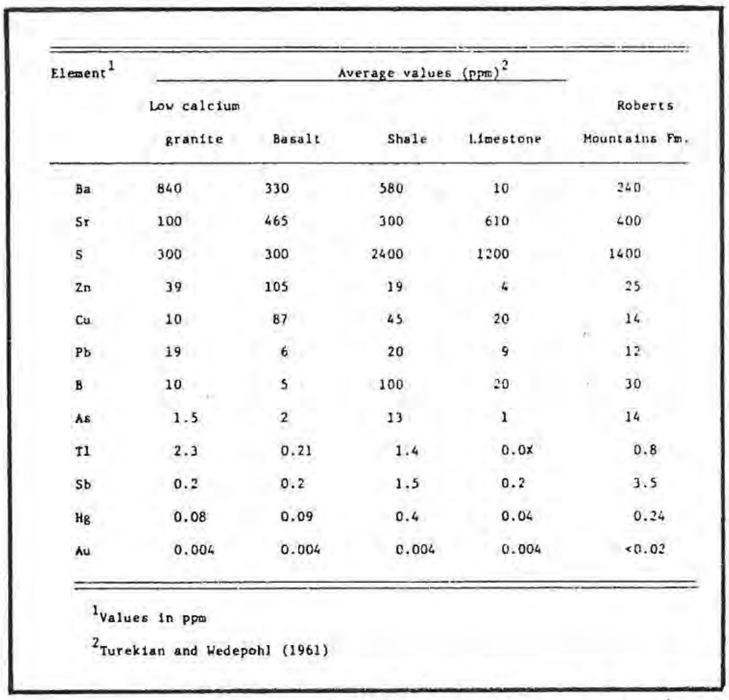
Fresh argillaceous arenaceous dolomite		Hydrothermally altered-mineralized rocks	
$\delta^{34}S$	Material	$\delta^{34}S$	Material
11.4 to 14.3	diagenetic pyrite	4.2 to 16.1	hydrothermal pyrite
		5.1 to 6.5	galena in barite veins
		10.1 to 10.7	sphalerite in barite veins
		15.2	realgar
		27.8 to 31.7	hydrothermal barite
$\delta^{13}C$	Material	$\delta^{13}C$	Material
0.4 to 0.6	calcite in rocks	-1.9 to -1.7	calcite in altered rocks
		-1.3 to +0.9	calcite in mineralized rocks
		-6.2 to +0.4	calcite in veins
0.2 to 0.3	dolomite in rocks	-0.5 to -0.4	dolomite in altered rocks
		-0.1 to +1.13	dolomite in mineralized rocks
δD	Material	δD	Fluid inclusions in
	no data available on host rocks	-149 to -139	hydrothermal barite
		-153	hydrothermal quartz
		-143 to -142	calcite in veins
		-160 to -145	whole rock igneous dike
$\delta^{18}O$	Material	$\delta^{18}O$	Material
21.2 to 22.5	calcite in rocks	12.7 to 13.4	recrystallized calcite in altered rocks
		13.9 to 18.0	recrystallized calcite in mineralized rocks
		2.5 to 22.9	calcite in veins
22.5 to 23.0	dolomite in rocks	24.3 to 25.2	recrystallized dolomite in altered rocks
		19.4 to 24.5	slightly recrystallized dolomite in mineralized rocks

Table 3.9 : Summary table of stable isotope data from the Carlin gold deposit, Nevada (Dickson et al, 1979)

The δD values of fluids in liquid inclusions and in altered rocks are so strongly negative, ranging from -139 to -160 per mil, that major amounts of meteoric water must have been present during the alteration process and formation of veins (Dickson et al., 1979) The timing of alteration and vein formation spanned the formation of the ore, hence the main stage mineralization fluids were very probably also of meteoric origin. Isotopic studies of the 35 Ma Cortez gold deposit (refer Figure 3.11) (Wells et al., 1971) led to the same conclusion (Rye et al., 1974). Studies of other epithermal gold deposits of the Basin and Range province have demonstrated the active role of meteoric water as an ore depositing fluid (O'Neil and Silberman, 1974).

At Carlin the $\delta^{34}S$ values of different introduced sulphides range from 4,2 to 15,2 per mil and average about 11,4 per mil, close to the average of 13,0 per mil for diagenetic pyrite in the Roberts Mountains Formation (Dickson et al., 1979). This would indicate that most of the sulphur in the Carlin deposit was derived by solution from sedimentary sulphide in this Formation. The $\delta^{13}C$ values of hydrothermal and recrystallized wall-rock calcite are close to those of calcite in unaltered carbonate host rocks and indicate that carbon in the ore fluids was also derived from the host rocks. The $\delta^{18}O$ data at both Carlin and Cortez are highly variable, suggesting either a complex wall-rock exchange history for the meteoric hydrothermal fluid or the mixing of meteoric waters from two different sources in the area of deposition.

In summary, the isotopic evidence indicates that the main stage hydrothermal fluids were highly exchanged meteoric waters which contained sedimentary sulphur and host rock carbon. It is of significance to note that all of the lower Palaeozoic carbonate units in the area contain diagenetic pyrite and organic material and probably all these carbonate rocks were potential source rocks for the ore and gangue components in the deposit (Dickson et al., 1979). Also significant is that the average abundance of As, Tl, Sb, Hg and Au in the Roberts Mountains Formation falls above the average values for crustal limestones, and crustal shales (except Hg and Tl), given by Turekian and Wedepohl (1961) (Table 3.10).



Element[1]	Average values (ppm)[2]				
	Low calcium granite	Basalt	Shale	Limestone	Roberts Mountains Fm.
Ba	840	330	580	10	240
Sr	100	465	300	610	400
S	300	300	2400	1200	1400
Zn	39	105	19	4	25
Cu	10	87	45	20	14
Pb	19	6	20	9	12
B	10	5	100	20	30
As	1.5	2	13	1	14
Tl	2.3	0.21	1.4	0.0x	0.8
Sb	0.2	0.2	1.5	0.2	3.5
Hg	0.08	0.09	0.4	0.04	0.24
Au	0.004	0.004	0.004	0.004	<0.02

[1] Values in ppm

[2] Turekian and Wedepohl (1961)

Table 3.10 : Average abundance of selected elements in crustal rocks, and argillaceous arenaceous dolomitic limestone facies of the Roberts Mountains Formation (Dickson et al, 1979)

Age of mineralization

The age of mineralization at Carlin has not yet been directly dated. An igneous dyke that is altered and mineralized within the deposit was dated at 131 ± 4 Ma (Bagby and Berger - in press). Rhyolitic lavas and domes west of the Carlin pit overlie jasperoid but are not altered and mineralized. McKee et al. (1971) have dated these lavas at 14.2 ± 0.3 Ma. Thus the age of the deposit could be as old as 130 Ma but no younger than 14 Ma.

Radtke et al. (1980) presented several lines of evidence in support of the Carlin deposit being formed during the late Tertiary as part of a volcanic episode. Fluid inclusion evidence suggests that the amount of overburden removed since mineralization has only been about 300 - 600 m. Furthermore, away from faults the surface of the lower boundaries of the acid-leached zones correspond closely to present topography. The northeast part of the East Ore Zone crosses the Leeville fault (refer Figure 3.17), a typical young Basin and Range fault with apparent Tertiary or younger displacement, showing that the mineralization postdates the movement of this structure. The highly negative δD values of mineral fluid inclusions imply that late Tertiary rather than early Tertiary meteoric water was involved, because as a first approximation such negative values reflect the colder climate known to have prevailed during the late Tertiary in the western United States.

Paragenesis - a summary

The fine-grained nature of the ores and the general lack of clearly defined crosscutting relationships between many important geologic features makes a definitive determination of the paragenetic sequence at Carlin difficult. The gross structural relations and proposed hydrothermal system for the deposit are depicted in Figure 3.22. Reference should also be made to Figure 3.18. The important geological and mineralogical features of a proposed four-stage paragenesis proposed by Radtke et al. (1980) is shown in Figure 3.23. The paragenetic summary presented below is taken from Radtke et al. (1980), Noble and Radtke (1979), and Dickson et al. (1979).

The δD and $\delta^{18}O$ data indicate that the hydrothermal fluids were entirely exchanged meteoric water. Recharge for the hydrothermal system was probably along topographic highs formed by the highly brecciated Eureka Quartzite and along steep faults, which also channelled hydrothermal fluids. The circulating hydrothermal system was set into movement by a buried thermal source, most probably late Tertiary volcanic activity. The $\delta^{34}S$ and $\delta^{13}C$ data show that the sulphur and carbon in the deposit is of sedimentary origin. All of the lower Palaeozoic carbonate units in the area contain diagenetic pyrite and organic material and probably all these carbonate rocks were potential source rocks for the ore and gangue component in the deposit. Variations in chemical and mineralogical compositions of the gold ore in different parts of the deposit could reflect different fluid reservoirs at different levels in the underlying sedimentary section.

The ore bodies formed near steep faults by replacement of carbonate minerals, principally calcite, in a favourable facies of thin bedded argillaceous arenaceous dolomitic rocks in the upper parts of the Roberts Mountains Formation. Unfavourable facies of pelloidal wackestone within

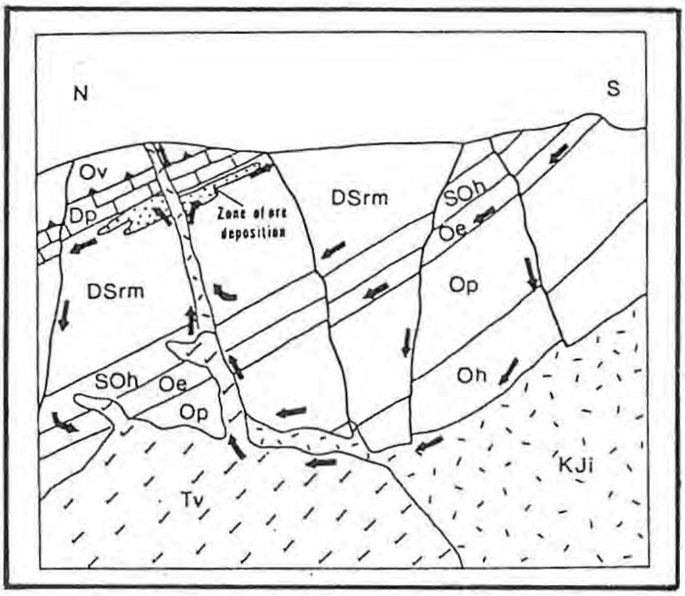


Figure 3.22 : Hydrothermal system and solution paths (large arrows) inferred for the formation of the Carlin gold deposit, Nevada. Key : Vinini Formation (Ov), Popovich Formation (Dp), Roberts Mountains Formation (DSrm), Hanson Creek Formation (SOh), Eureka Quartzite (Oe), Goodwin Limestone (Op), early Jurassic - late Cretaceous granodiorite (KJi) and Tertiary volcanics (Tv). Intrusive igneous rocks, and hydrothermal fluids, have been preferentially controlled by high angle normal faults (Radtke et al, 1980)

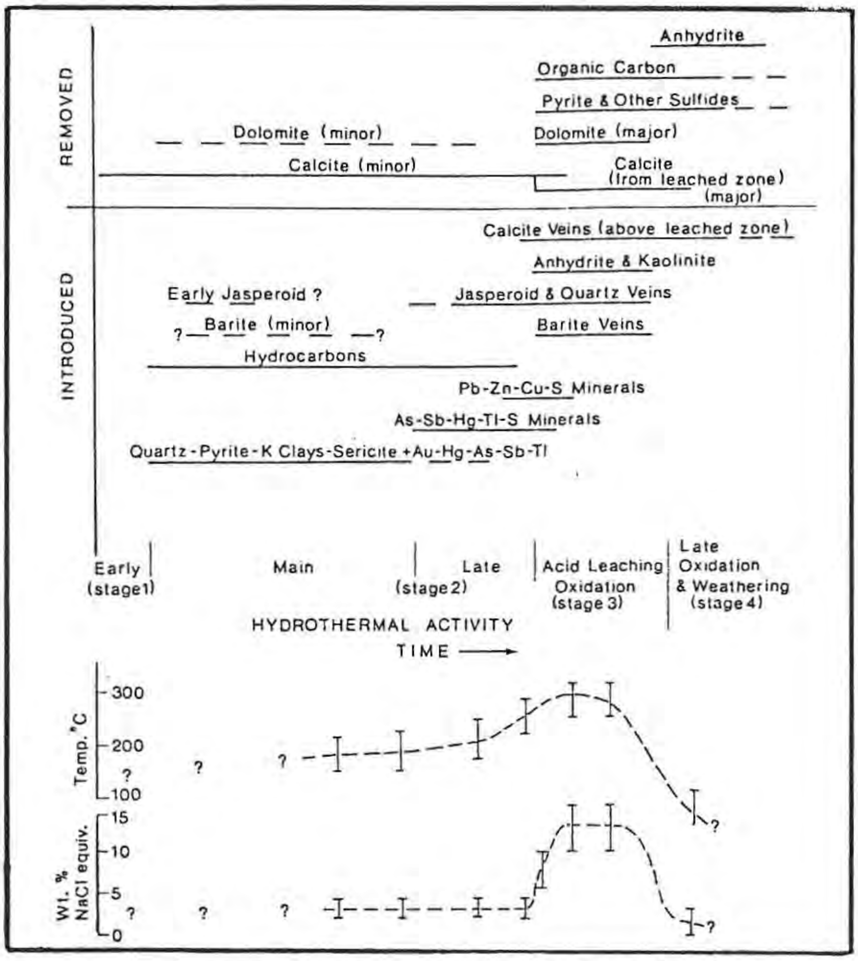


Figure 3.23 : Paragenesis of the Carlin gold deposit, Nevada. The acid-leaching and accompanying oxidation (stage 3) were superimposed on the late hydrothermal (stage 2) events in the upper part of the deposit. The extent to which main- and late-stage events including mineralization continued at depth during acid leaching in the upper levels is not known. Also shown are average temperature and salinity trends of hydrothermal fluids as indicated by fluid inclusion data. The curves are highly schematic (Radtke et al, 1980)

the same stratigraphic interval were not mineralized and only weakly altered.

Stage 1 - early hydrothermal: Initial penetration by low temperature fluids, probably less than $200^{\circ}C$, which dissolved out calcite from the rock matrix, resulting in increases in rock porosity and permeability.

Stage 2 - main and late hydrothermal: Main-stage fluids introduced Si, Al, K, Ba, Fe, S, and organic materials together with Au, As, Sb, Hg and Tl. Small amounts of pyrite, kaolinite and sericite formed, Au and Hg were precipitated on organic compounds, and, together with As and Sb were concentrated on rims of pyrite.

Late main-stage fluids introduced sulphide and sulphosalt minerals containing As, Sb, Hg, and Tl. Large amounts of hydrocarbons were introduced, initial formation of jasperoids and quartz veins occurred and sparse base metal sulphides of Pb, Zn and Cu were deposited. Temperatures and salinities of the fluids during main-stage mineralization were about 175° to $200^{\circ}C$, and 3 ± 1 equivalent weight % NaCl, respectively. The $\delta^{18}O$ of the meteoric water hydrothermal fluids varied depending on local conditions but averaged 3 ± 3 per mil.

Stage 3 - acid leaching/oxidation: The main stage of ore deposition was terminated by the onset of boiling of ore-forming fluids, and coincides with the formation of barite veins. Temperatures of ore fluids rose to as much as 275° - $300^{\circ}C$, and fluid salinities increased to values as high as 17.4 equivalent weight % NaCl. Loss of H_2S during boiling led to production of H_2SO_4 in the upper part of the deposit and to the subsequent intense acid leaching and oxidation of ores and surrounding rocks. Most of the remaining calcite, and large amounts of dolomite, were removed, barite veins formed, sulphides and organic carbon compounds were oxidized and removed, kaolinite and anhydrite formed, and remobilized Si was introduced. Some of the removed calcite may have been reprecipitated to form the abundant veinlets above the leached zone.

Stage 4 - supergene oxidation and weathering : Following the close of hydrothermal activity the rocks and ores underwent weak oxidation by cool meteoric supergene waters which locally penetrated 50+m below the bottom of the acid-leached zone. Anhydrite was dissolved, remnant sulphides and organic material in rocks above and below the acid leached zone were weakly oxidized and removed, and small amounts of calcite in the same rocks were removed.

3.3.2 **Jasperoidal - type subset : The Pinson and Preble gold deposits**

The Pinson and Preble gold deposits are on the east flank of the Osgood Range Mountains in Humboldt County, Nevada. They occur in the so-called Getchell belt (refer Figures 3.9 and 3.12), and serve to illustrate the end member category of gold rich deposits characterized by intense silicification and relatively common quartz veining in the ore zones. Mineralized rock can almost always be visually differentiated from unmineralized rock because of alteration and quartz veining.

Host lithology

The Osgood Range Mountains (refer Figure 3.12) are composed mainly of Palaeozoic sedimentary rocks that have been intruded by a Cretaceous granodiorite stock in the east - central parts. The Pinson deposit occurs in the sediments adjacent to the stock and within the contact metamorphic aureole. There is no evidence for the Preble deposit being adjacent to any outcropping, or suboutcropping, intrusives.

At Preble, the Cambrian age Preble Formation is the host rock for the gold deposit. This Formation consists mainly of calcareous and carbonaceous phyllitic shale with interbedded, finely laminated and massive limestones. The phyllitic shales host most of the ore (Bagby and Berger - in press). The Ordovician age Comus Formation overlies the Preble Formation in a thrust relationship.

At the Pinson gold deposit, the allochthonous Comus Formation consists mainly of intercalated thin beds of siltstone and limestone with two massive limestone beds up to 50 m thick. The lowest limestone unit is locally silicated to diopside and tremolite and contains the majority of the gold mineralization (Antoniuk and Crombie, 1982).

Igneous rocks

The Palaeozoic sediments in the vicinity of the Pinson mine have been intruded by the late Cretaceous age Osgood Mountain granodiorite stock. Numerous thin sills and dykes of Cretaceous age dacite porphyry occur throughout the Pinson area and are also present in the ore body.

At Preble a similar, altered, northerly trending granodiorite dyke cuts through the deposit (Crone et al., 1984). The dyke occupies a fault zone that has had recurrent movement subsequent to dyke emplacement. The genetic relationship of the dyke to the gold mineralization is unknown.

Structure

The structural geology of the Osgood Range mountains is very complex. Several thrust faults, possibly closely related in time, have been recognized. Typically high-angle Basin and Range type faulting has offset all of the rock units in the range. The dominant control of the Getchell belt deposits is the Getchell fault system, or structural trend, which has been traced for over 30 km along the eastern side of the Osgood Mountains.

In the Preble area, the host Preble Formation is folded and faulted (Bagby and Berger - in press). The deposit area is dominated by a broad northeast trending zone of shearing, brecciation and silicification dipping some 40^o to the southeast (Figure 3.24). This zone has controlled the emplacement of the altered felsic dyke and also channelled hypogene ore fluids from depth.

At the Pinson deposit, the northwest limb of a gently southwest plunging syncline has been truncated by a strong fault of the Getchell fault system. This normal fault, striking northeast and dipping $40 - 50^o$ to the southeast (Figure 3.25), has controlled the gold mineralization. For much of its distance in the mine area this fault structure occupies the contact between the Comus and Preble Formations, and is the locus of the so called Pinson A zone, while over the rest of the area it cuts through the Comus Formation and offsets the limestone and intercalated units (Antonuik and Crombie,

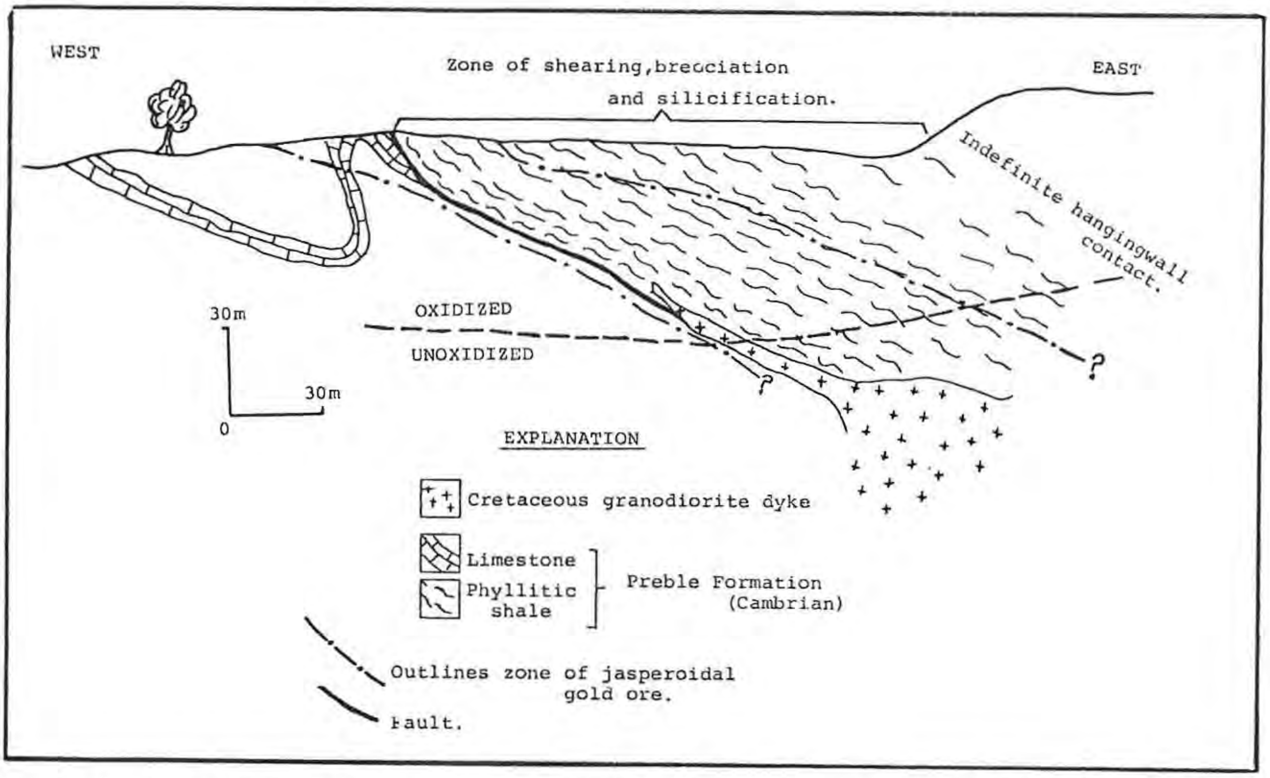


Figure 3.24 : Schematic cross section of the main ore zone at the Preble gold deposit, Nevada. The ore body is almost entirely restricted to a shear zone associated with an east-dipping normal fault (Redrawn from Bagby and Berger - in press)

1982). Where the structure occupies the contact zone it is a fairly uniform 10 - 20m wide sheared and brecciated zone with definite footwall and hangingwall contacts. Where it cuts the Comus Formation, a much thinner zone with less shearing and alteration is produced. To the southeast the fault structure steepens to nearly vertical and the Comus Formation is dropped down against the barren lower Preble Formation carbonaceous shale. The Pinson B zone is situated in this southeast area.

Alteration and mineralization

At the Preble gold deposit, the dominant alteration of the host Preble Formation phyllitic shales involves a major addition of silica. This is evident as a marked change in colour, characterized by bleaching of the original phyllite and the greenish sheen becomes buff (Bagby and Berger - in press). Jasperoid veins cut the Preble Formation limestone and silica replacement of limestone and phyllitic shales forms massive jasperoid bodies. Dolomitization of the limestones is also common near high angle faults. The finely disseminated gold ore at Preble is strongly correlated to silicification, either as intense replacement of limestone and phyllitic

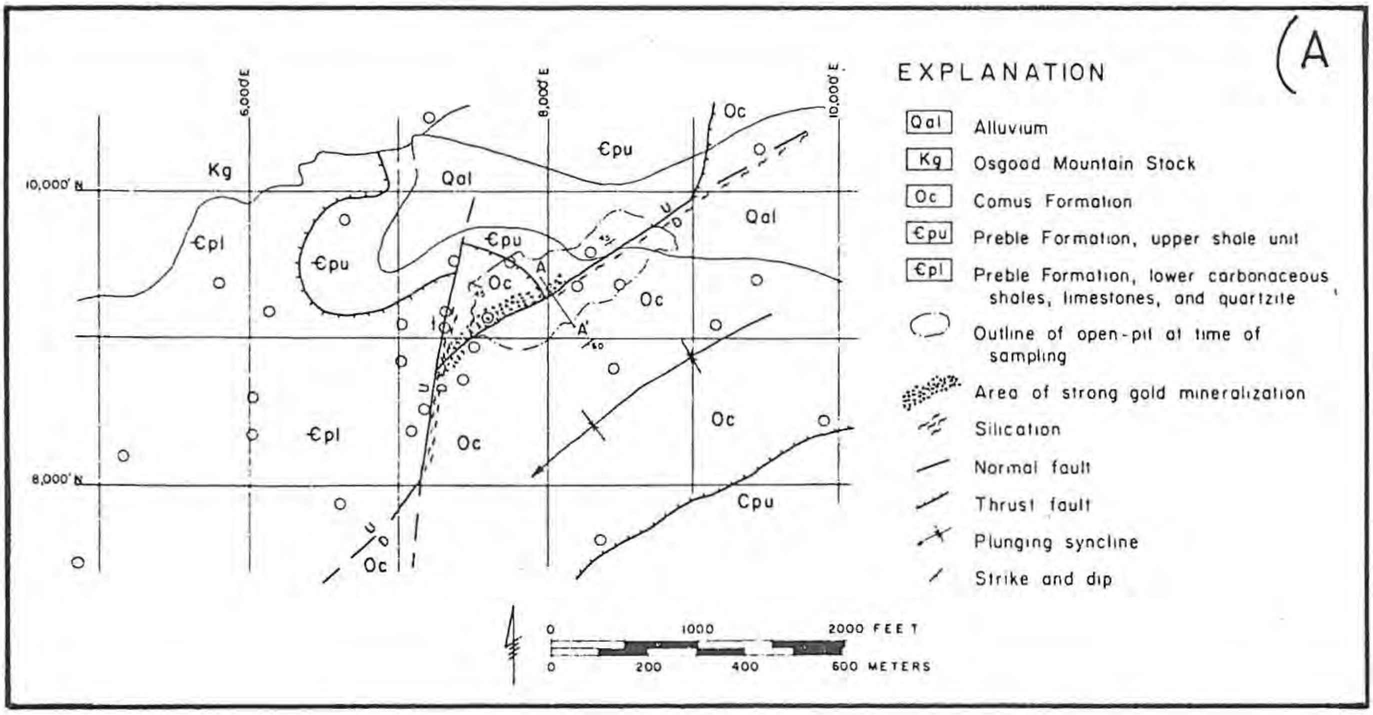
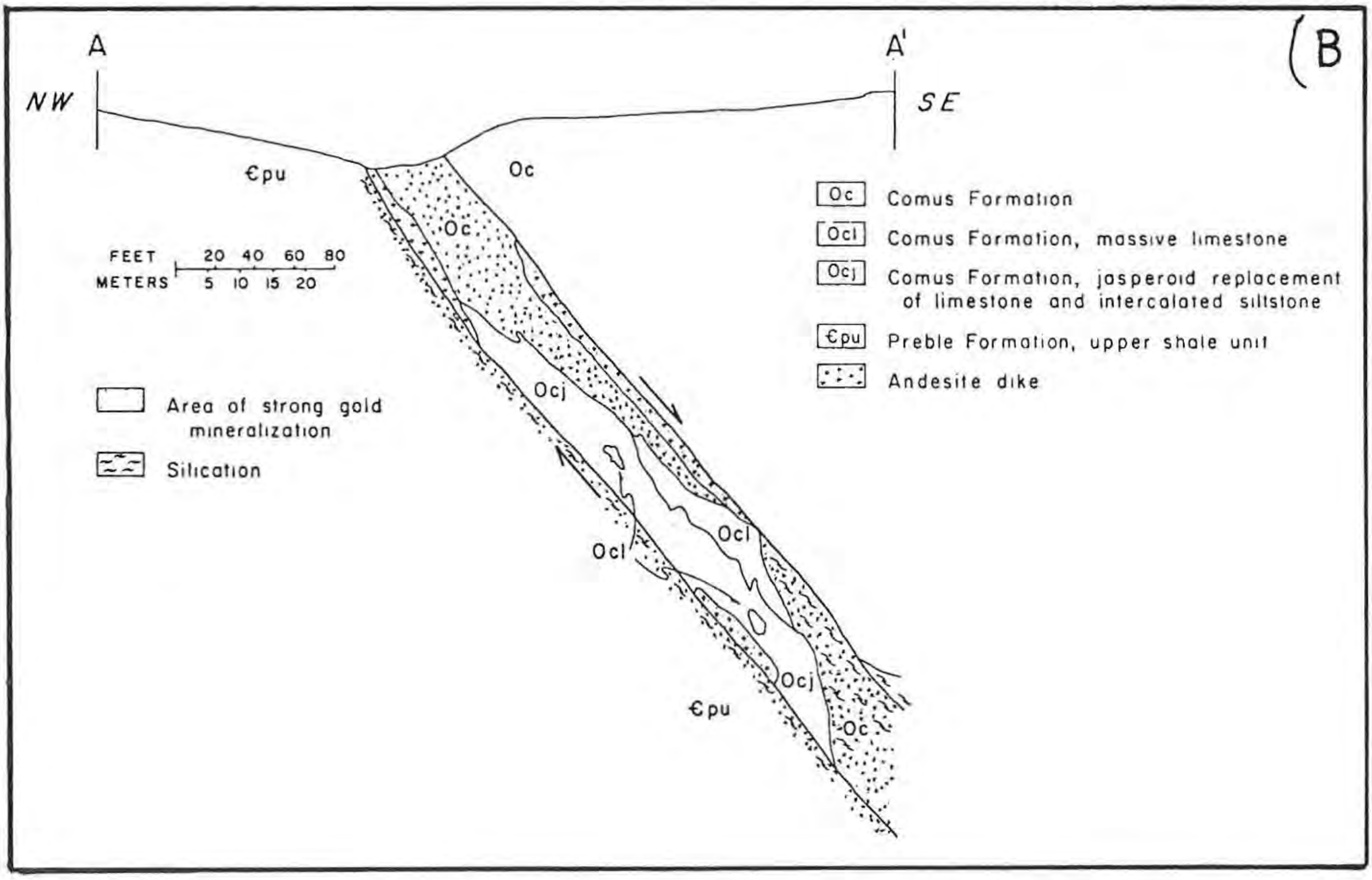


Figure 3.25 :(A) Generalized geological map of the Pinson gold deposit, Nevada. Note strong silicification along northerly trending normal fault zone of Getchell fault system. (B) Detailed geological cross section A - A through mineralized Pinson A zone, at the Pinson gold deposit (Crone et al, 1984)



shale or as quartz veining. The main ore body at Preble is localized within, or adjacent to, the northeast trending shear zone, particularly in the hanging wall host rocks (refer Figure 3.24). Supergene alteration has resulted in a prominent zone of oxidation in the upper parts of the deposit. Gold occurs with sulphides, and iron oxides after pyrite, in the unoxidized and oxidized zones respectively. The average size of the gold grains is about 2 microns. Pyrite, both cubic and framboidal varieties, is the most abundant sulphide with minor arsenopyrite, marcasite, chalcopyrite, and sphalerite (Bagby and Berger - in press).

At the Pinson deposit, the mineralization is of two types, the A and B types, both of which are related to intense silicification within a normal fault zone (refer Figure 3.25). There is an apparent relationship between the degree of silicification and gold content (Antoniuk and Crombie, 1982). The gold values in the Pinson B zone occur within the Comus Formation, tend to be lower grade (2.47 gm Au/tonne), have irregular ore boundaries. The mineralization is associated with silicification and fracturing of the massive limestone bed plus some intercalated limestones and siltstones. The A zone (5.79 gm Au/tonne) is characterized by more intense silicification where massive limestone beds of the Comus Formation are sometimes completely replaced to a dense jasperoid. Within this ore zone are areas of limestone and siltstone displaying varying degrees of silicification and alteration from the dense jasperoid to a totally leached limestone of which only the skeletal silica lattice remains. Mineralogy at Pinson is relatively simple, consisting of iron oxides of goethite and haematite with some remnant pyrite, marcasite and gold. The gold mineralization is extremely fine, mostly less than 5 microns, and occurs as a free phase associated mostly with quartz, and lesser pyrite.

In common with most of the sediment hosted, disseminated precious metal deposits of Nevada, there is a strong geochemical correlation of Au with anomalous Hg, As and Sb at Preble (Crone et al., 1984) and Pinson (Antoniuk and Crombie, 1982). Bagby and Berger (in press) report a further correlation of Tl, Ba and F with gold mineralization at Preble. At Preble, unoxidized ore occurs in black, carbonaceous phyllitic shale but there is no positive correlation between abundance of organic carbon and gold.

Vein types

The Preble and Pinson deposits are stockwork veinlet, jasperoidal deposits. At Preble in particular there are several generations of veining, some of which are definitely associated with the period of gold deposition (Bagby and Berger - in press). Vein types include metamorphic quartz, quartz-carbonate, and calcite veins, and later auriferous quartz, quartz-calcite, jasperoid, dolomite and calcite veins.

Age of mineralization

Mineralization at the Pinson and Preble deposits is believed to belong to the same episode as that at the Getchell mine. Silberman et al. (1974) dated the formation of the Getchell gold deposit at approximately 90 Ma (K-Ar on sericite). Support for a Cretaceous mineralizing event at Preble is also confirmed by Bagby and Berger (in press), who report that sericite from the altered felsic dyke yielded an Ar/Ar age of 100 Ma.

3.3.3 **Jasperoidal-type subset : The Taylor silver deposit**

The Taylor silver deposit is located on the west flank of the Schnell Creek Range mountains, near the eastern border of Nevada in the White Pine County (refer Figure 3.9). The ore occurs in intensely silicified rocks and is described here as the silver-rich jasperoidal end-member of the sediment-hosted, disseminated precious metal deposits. Details presented here are taken from Havenstrite (1984), Drewes (1962, 1967), Lovering and Heyl (1974), Graybeal (1982), and Bagby and Berger (in press).

Silver ore was discovered in the district, and has been produced intermittently since about 1868. The Schnell Creek Range consists of easterly-dipping Palaeozoic limestones, dolomite and shale, which have been intruded by dykes and sills of mid Tertiary rhyolite. Remnants of mid to late Tertiary intermediate flows and pyroclastic rocks occupy the western foothills of the range. Silver-bearing formations in the district consist of the Devonian Guilmette Limestone and its transition with the overlying Pilot Shale; and the Mississippian Joana Limestone (Figure 3.26). Known commercial deposits in the district are however restricted to the upper 35 m of the Guilmette Formation (Havenstrite, 1984).

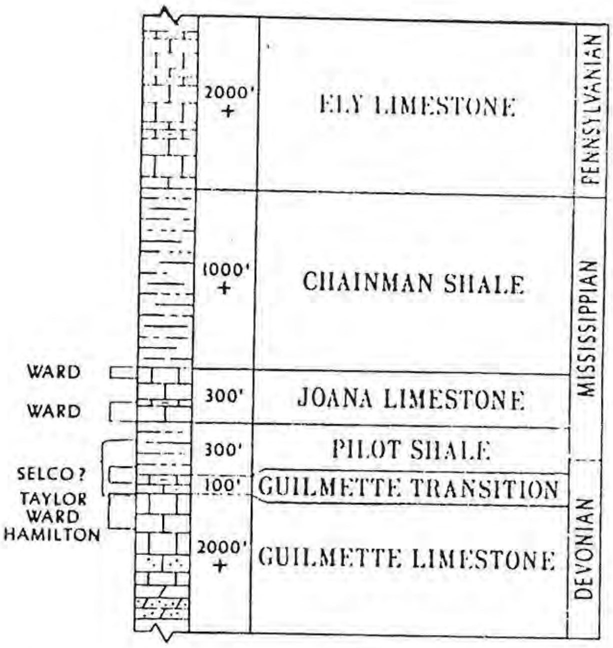


Figure 3.26 : Taylor silver mining district, eastern Nevada - Stratigraphic section (Havenstrite, 1984)

Host lithology

The Guilmette Limestone is the oldest Formation exposed in the central Taylor district. The upper portions of this Formation are the host for silver ores at the Taylor deposit and several other smaller occurrences in the district (eg Ward and Hamilton). This Formation consists of massive, fine-grained limestone in the upper 100m, grading downward into sandy limestone and sandy dolomite. The Guilmette is overlain by an approximately 35 m thick section of thin-bedded limestone and siliceous shale, which represents a Transition zone with the overlying Pilot Shale. The Pilot Shale consists of banded, siliceous shales. The transition beds above the Guilmette are the host for the gold deposits at Alligator Ridge. Havenstrite (1984) notes that rocks of the Guilmette-Pilot Shale section of the stratigraphy are under intensive exploration in eastern Nevada at present.

Igneous rocks

Many short, thick, northerly to northeasterly trending granophyric rhyolite porphyry dykes of Tertiary age, are exposed in a belt nearly 1 km wide and 2 km long (Lovering and Heyl, 1974; Drewes, 1962). The belt extends from just north of the Taylor deposit southward to about 1.5km beyond it. The feldspar in these dyke rocks is strongly argillitized but the rocks are not silicified or mineralized. Notably, the rhyolite bodies contain xenoliths of silver-bearing jasperoid, the predominant ore type at Taylor (Havenstrite, 1984). Havenstrite (op cit) infers that the rhyolite, dated at 35 Ma (method and mineral phase dated not reported), was emplaced only slightly later than the hypogene silver and silica.

Structure

The Schnell Creek Range is a north-trending, eastward tilted horst block typical of the Basin and Range province. The Range mountains have been cut by a complex network of north-, northeast-, and northwest-trending normal faults, which constitutes the so-called Taylor fault and its branches (Drewes, 1962; Lovering and Heyl, 1974). Beginning in the late Mesozoic, these faults have moved repeatedly up until the present. According to Havenstrite (1984) the rocks in the Schnell Creek Range have been subjected to three distinct periods of deformation :

1) Mid Mesozoic compressional phase which resulted in a north-trending assymetrical anticline in the Taylor district (Figure 3.27). The competent Guilmette Limestone fractured to crackle breccia on the crests and flanks of the anticline.

2) Regional uplift and intrusive phase extending from about 120 to 35 Ma. Numerous north to north-northwest trending, high angle, predominantly normal faults developed. A complementary east-northeast set also developed at this time. These northerly and easterly faults were the conduits for hydrothermal silver-bearing fluids which deposited the silver ore in the Guilmette crackle breccia.

3) Late Tertiary to recent Basin and Range-type faulting, frequently reactivating the second stage north-trending faults in the district.

Ore types

The ore deposits in the Taylor district consist of large tabular masses of argentian jasperoid which occur at the top of the Guilmette Limestone. The jasperoidal ore deposit is flat lying on the crest of the anticline, dips vertically on the west flank and gently to the east on the east flank (Havenstrite, 1984). The form of the ore bodies has been modified by later movement, of small magnitude, along the north and east - northeast trending

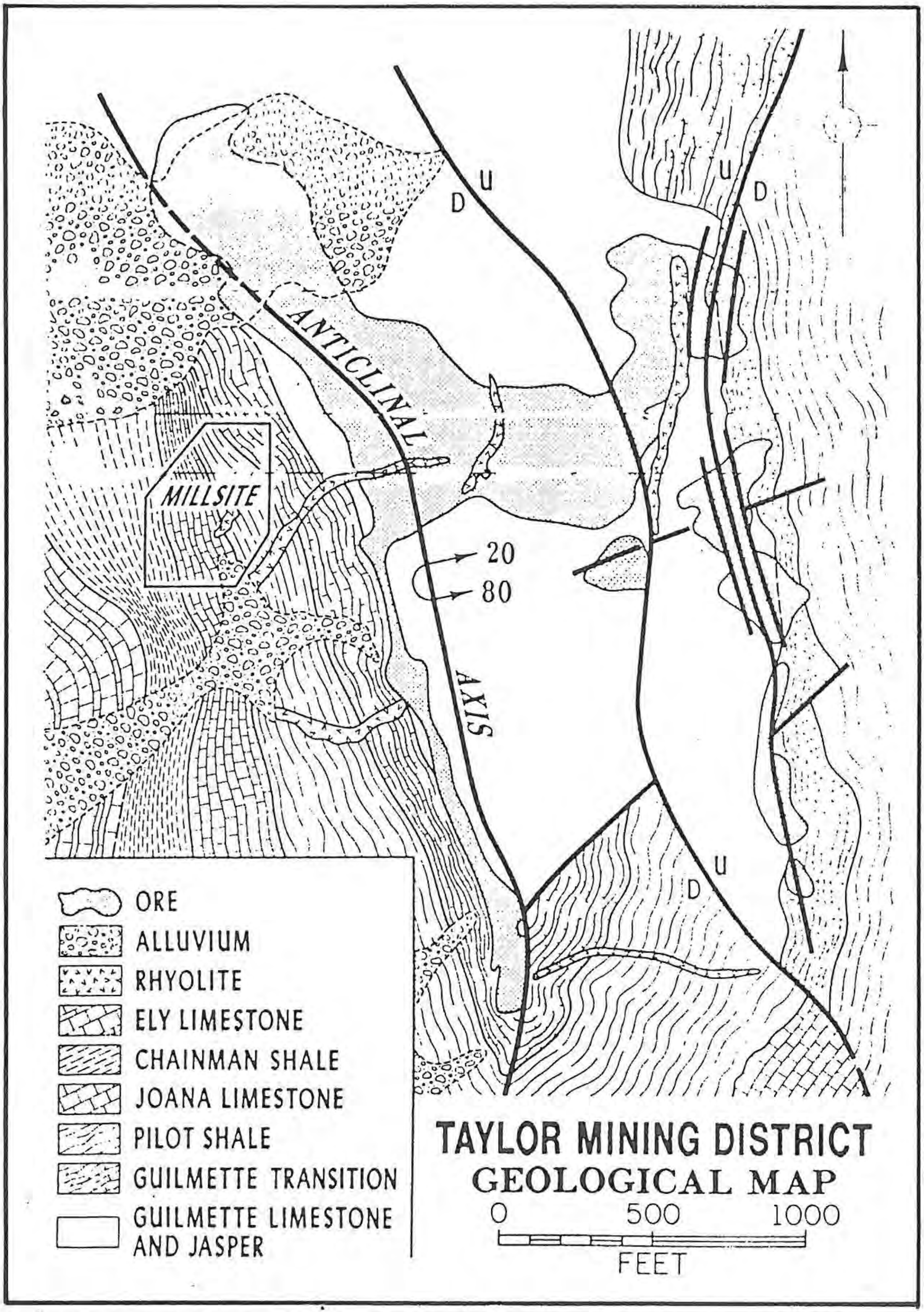


Figure 3.27 : Geological plan of the Taylor silver deposit, eastern Nevada (Havenstrite, 1984)

normal faults. Havenstrite (op cit) notes that the ore body averages about 15m in thickness based on a grade cutoff of about 65 grams Ag per tonne, occupies about 40 acres and contains about 6,3 million tonnes of ore averaging 103 grams Ag per tonne.

The ore-bearing jasperoids contain finely disseminated crystals of argentite and clots of native silver. Individual masses of jasperoid are strongly brecciated in most places and fragments of different types of jasperoid are commonly present in a single body. Much of the jasperoid within the main mineralized and productive part of the district is fine grained, vuggy, variegated and brecciated, and is very dark grey to medium grey (Lovering and Heyl, 1974). Jasperoid bodies outside of the central part of the district are commonly aphanitic, less vuggy than those in the central part, and are dominantly brown, pink, yellow or white. The grey to nearly black colour of the mineralized jasperoids largely results from abundant micro-inclusions of hydrocarbons, metallic and associated gangue minerals. Where unoxidized, these micro-inclusions consist of stibnite, sphalerite, tetrahedrite, native silver, chalcopyrite, pyrite, galena, ruby silver (pyrargyrite?), calcite, dolomite, sericite and hydrocarbon, with local accessory tourmaline, monazite, barite, fluorite and apatite (Lovering and Heyl, op cit). In addition to the disseminated minerals, the jasperoids also contain some veinlets and breccia zones cemented by non-metallic minerals. The veinlets generally consist of calcite, white quartz, barite and dolomite. In places these veinlets also contain manganese minerals and fluorite.

Alteration and oxidation

Silicification of the Guilmette Limestone, resulting in the formation of abundant bodies of mineralized and unmineralized jasperoids, is the only conspicuous rock alteration feature in the district. Argillitization is restricted to the feldspar minerals in the post-mainstage mineralization granophyric dykes. These jasperoid bodies range in size from small pods up to huge masses more than 300 m long and 150 m wide and are present throughout the district. Most of them are controlled structurally by the normal faults of the Taylor fault zone and stratigraphically by the contact of carbonate rocks with overlying shale beds (Lovering and Heyl, 1974).

Jasperoid contacts with unreplaced Guilmette Limestone are gradational, and frequently very poorly defined. Although not documented, an initial decalcification stage must have occurred prior to replacement of the host limestone by silica and ore minerals.

Havenstrite (1984) notes several lines of evidence suggesting that the present form of the Taylor deposit has been at least partially determined by supergene redistribution and enrichment of silver values. Firstly, the deposit is unique in its uniformity. The occurrence of either high grade zones or barren zones is rare and silver content "feathers" out both vertically and horizontally. Secondly a composite histogram of the 130 ore holes drilled into the deposit shows a distinct gradual increase in silver values from the surface downward to a maximum at a depth of about 20 m, followed by a gradual decline to a depth of about 55 m (Figure 3.28). At this point the jasperization of the limestone rapidly decreases as does the silver content. Thirdly, the jasperoid near the surface has a leached appearance, being lighter in colour and somewhat more "spongy" than the typical jasperoid developed below a depth of about 5 - 10 m. Fourthly, silver values are typically higher just above post-mainstage mineralization rhyolite dykes (dykes contain argentian jasperoid fragments), suggesting that the silver was remobilized.

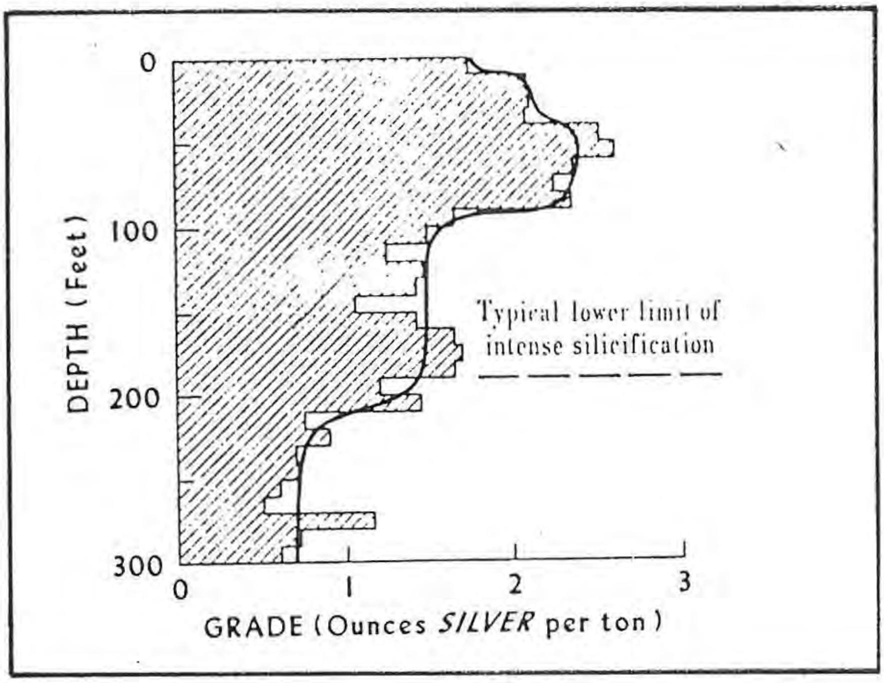


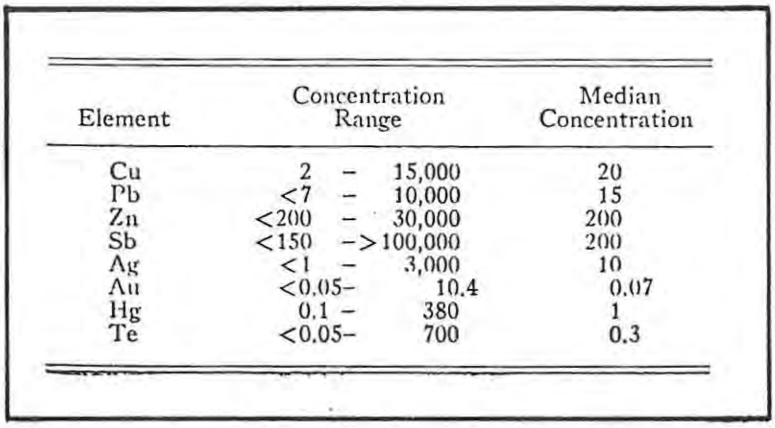
Figure 3.28 : Average grade versus depth plot of 130 ore holes drilled into the Taylor silver deposit, eastern Nevada (Havenstrite, 1984)

Geochemistry of jasperoids

Samples of mineralized jasperoid from the central part of the Taylor mining district, and of unmineralized jasperoid from outlying bodies were examined and reported on by Lovering and Heyl (1974). The most reliable indicators of proximity to mineralization centres are : a change in colour from dominantly brown to dominantly grey-black, a coarsening in texture of the matrix jasperoid, an increase in the number of vugs, and an increase in the ratio of Cu to Cr.

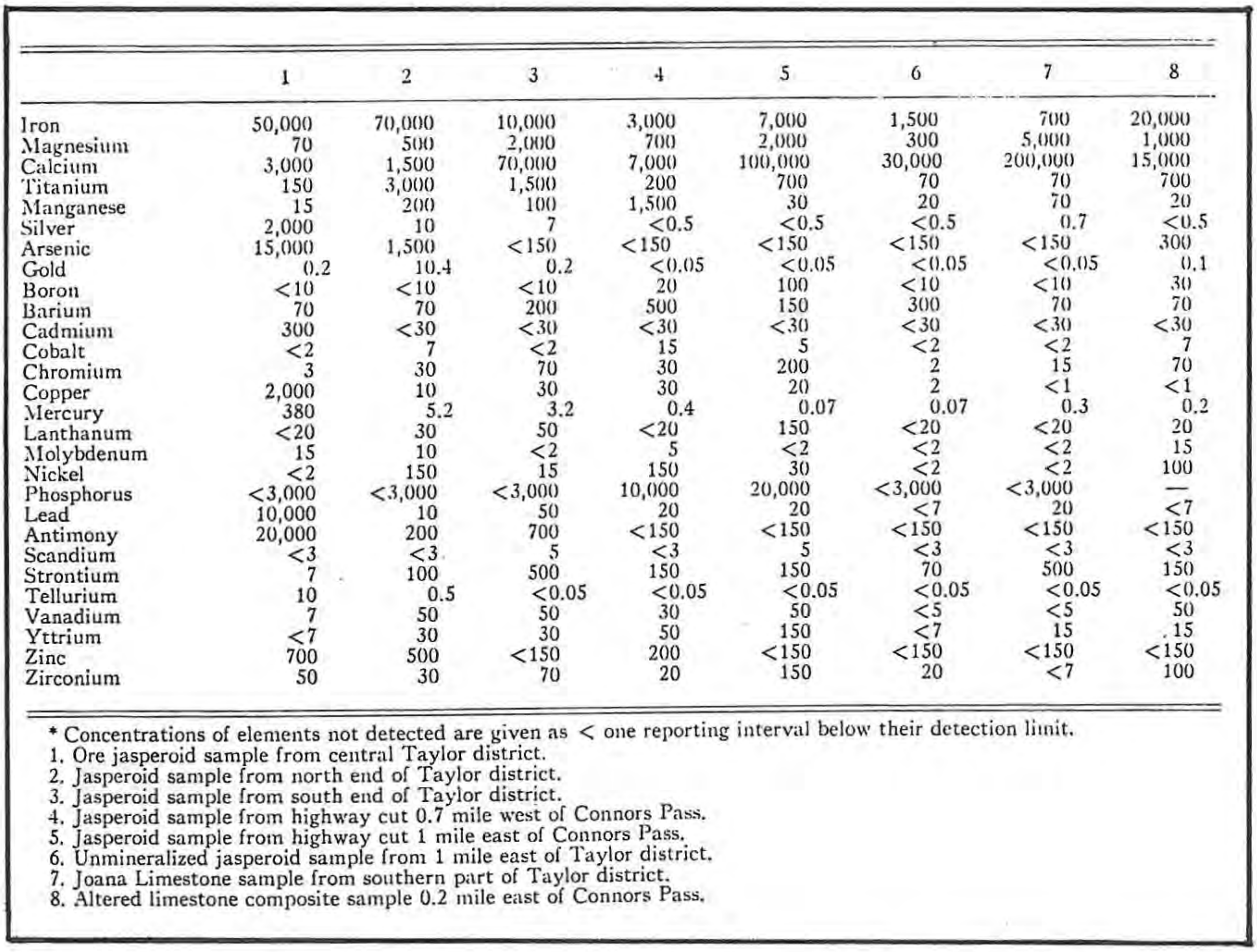
The normal (median) concentrations of minor elements in jasperoids from the Taylor district and vicinity have been estimated by Lovering (1972), and Lovering and Heyl (1974) (Table 3.11). Samples of jasperoid from the Taylor district contain anomalously high concentrations of Ag, Au, Cu, Hg, Pb, Sb and Zn relative to these estimated normal concentrations (Table 3.12). Plotting geochemical anomaly maps for jasperoid samples is complicated by large variations in minor element contents. In order to standardize treatment for all elements, Lovering and Heyl (op cit) computed enrichment factors which are contoured at values of 1 and 5 (Figure 3.29). The northward trending anomalies are controlled by the Taylor fault system. The marked similarity in the high anomaly areas covered by Ag, Cu and Te and the close correspondence between these high anomalies and the main central part of the Taylor district suggests that they are representative of the mainstage mineralizing event at Taylor. The ratio of total Cu to total Cr is considered to best show the main centre of mineralization in the Taylor district (refer Figure 3.29).

A single body of ore-bearing jasperoid in the main central part of the district was sampled by Lovering and Heyl (1974) at approximately 1 metre intervals. The approximately 7m sample traverse was taken from a fault on the west margin of the body, that was presumably the source of the silicifying and mineralizing solutions, to the outer contact with the unsilicified limestone host rock. In general, concentrations of ore metals and of minor elements do not show a systematic variation with distance away from the fault conduit (Figure 3.30). The only elements that show a relation to the fault are Ti, Al, Sr and possibly Ba, all of which decrease away from the fault, although not systematically. The ore elements Ag, Zn,



Element	Concentration Range	Median Concentration
Cu	2 – 15,000	20
Pb	<7 – 10,000	15
Zn	<200 – 30,000	200
Sb	<150 –>100,000	200
Ag	<1 – 3,000	10
Au	<0.05– 10.4	0.07
Hg	0.1 – 380	1
Te	<0.05– 700	0.3

Table 3.11 : Ranges and median concentrations of base and precious metals in 100 jasperoid samples from the Taylor district and vicinity, eastern Nevada (all values in parts per million) (Lovering and Heyl, 1974)



	1	2	3	4	5	6	7	8
Iron	50,000	70,000	10,000	3,000	7,000	1,500	700	20,000
Magnesium	70	500	2,000	700	2,000	300	5,000	1,000
Calcium	3,000	1,500	70,000	7,000	100,000	30,000	200,000	15,000
Titanium	150	3,000	1,500	200	700	70	70	700
Manganese	15	200	100	1,500	30	20	70	20
Silver	2,000	10	7	<0.5	<0.5	<0.5	0.7	<0.5
Arsenic	15,000	1,500	<150	<150	<150	<150	<150	300
Gold	0.2	10.4	0.2	<0.05	<0.05	<0.05	<0.05	0.1
Boron	<10	<10	<10	20	100	<10	<10	30
Barium	70	70	200	500	150	300	70	70
Cadmium	300	<30	<30	<30	<30	<30	<30	<30
Cobalt	<2	7	<2	15	5	<2	<2	7
Chromium	3	30	70	30	200	2	15	70
Copper	2,000	10	30	30	20	2	<1	<1
Mercury	380	5.2	3.2	0.4	0.07	0.07	0.3	0.2
Lanthanum	<20	30	50	<20	150	<20	<20	20
Molybdenum	15	10	<2	5	<2	<2	<2	15
Nickel	<2	150	15	150	30	<2	<2	100
Phosphorus	<3,000	<3,000	<3,000	10,000	20,000	<3,000	<3,000	—
Lead	10,000	10	50	20	20	<7	20	<7
Antimony	20,000	200	700	<150	<150	<150	<150	<150
Scandium	<3	<3	5	<3	5	<3	<3	<3
Strontium	7	100	500	150	150	70	500	150
Tellurium	10	0.5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Vanadium	7	50	50	30	50	<5	<5	50
Yttrium	<7	30	30	50	150	<7	15	15
Zinc	700	500	<150	200	<150	<150	<150	<150
Zirconium	50	30	70	20	150	20	<7	100

* Concentrations of elements not detected are given as < one reporting interval below their detection limit.

1. Ore jasperoid sample from central Taylor district.
2. Jasperoid sample from north end of Taylor district.
3. Jasperoid sample from south end of Taylor district.
4. Jasperoid sample from highway cut 0.7 mile west of Connors Pass.
5. Jasperoid sample from highway cut 1 mile east of Connors Pass.
6. Unmineralized jasperoid sample from 1 mile east of Taylor district.
7. Joana Limestone sample from southern part of Taylor district.
8. Altered limestone composite sample 0.2 mile east of Connors Pass.

Table 3.12 : Analysis of representative samples in and near the Taylor silver deposit, eastern Nevada (all values in parts per million) (Lovering and Heyl, 1974)

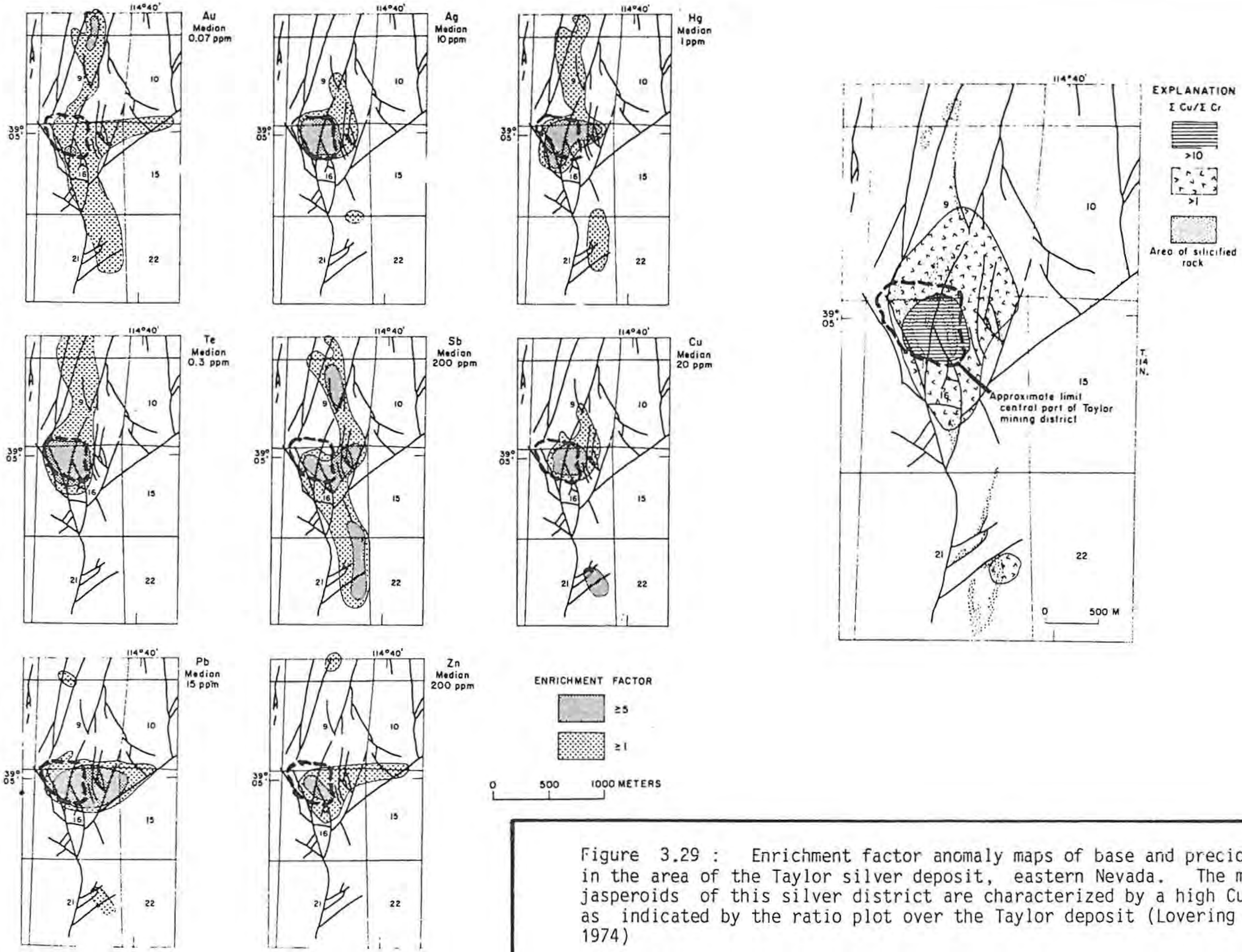


Figure 3.29 : Enrichment factor anomaly maps of base and precious metals in the area of the Taylor silver deposit, eastern Nevada. The mineralized jasperoids of this silver district are characterized by a high Cu:Cr ratio, as indicated by the ratio plot over the Taylor deposit (Lovering and Heyl, 1974)

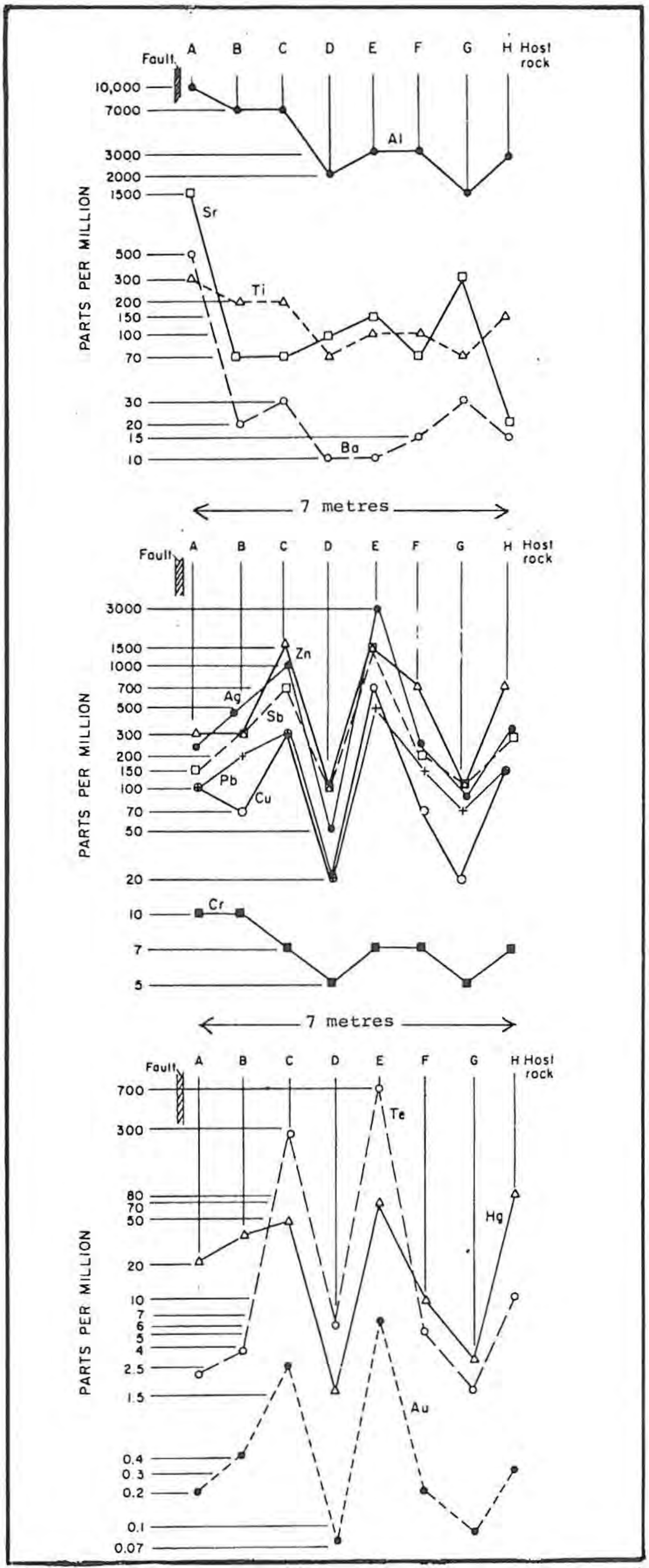


Figure 3.30 : Graph showing variations in ore metals and other selected minor elements from rock samples collected across a mineralized jasperoid body at the Taylor silver deposit, eastern Nevada. The ore-bearing jasperoid was sampled at approximately 1 m intervals from the fault conduit that is considered to be the source of the silicifying and mineralizing solutions, to the outer contact with unsilicified limestone host rock. (Lovering and Heyl, 1974)

Sb, Pb, Cu, Te, Hg and Au all follow a pattern of increase in concentration outward from the fault for the first 2 m, declining sharply at 3 m, then rising abruptly to a maximum at 4 m (approximately in the middle of the body), declining steadily outward from this point toward the limestone contact, and increasing again at this contact to a concentration similar to that adjacent to the fault conduit. The similarity in the distribution pattern of the ore elements suggests that they were introduced at the same time as the grey jasperoid by a single complicated mineralizing solution. Chromium is consistently low and shows little change in concentration across the jasperoid body. It is plotted only to corroborate the high Cu : Cr ratio that is characteristic of the mineralized jasperoids from this area. The variation in metal content across the jasperoid is explained by Lovering and Heyl (1974) as due to initial precipitation of a fairly impervious silica gel in certain zones of the host limestone. Slightly later, ore minerals were deposited in the more permeable zones of this proto-jasperoid, prior to the entire body being sealed by the continuation of silicification.

Vein types

Veins of quartz, calcite and barite occur in the Taylor district (Bagby and Berger - in press). Barite veins occur peripheral to the Taylor deposit, whereas both calcite and quartz veins crosscut the jasperoid bodies at the deposit. It is equivocal whether or not any of these veins are part of the same mineralizing event that deposited silver.

Paragenesis

Studies conducted at the Taylor deposit have shown that brecciation and initial silicification and brecciation of the host Guilmette Limestone preceded mainstage silicification and mineralization (Drewes, 1962; Lovering and Heyl, 1974; Havenstrite, 1984). The presence of a single major type of jasperoid containing disseminated particles of ore minerals (viz grey to black jasperoid), and the similarity in the distribution pattern of the ore elements, suggest that only one major phase of hydrothermal alteration occurred. During this phase both the silica and the primary ore minerals were introduced at this locality.

Drewes (1962, 1967) and Lovering and Heyl (1974) noted that the distribution of jasperoid bodies in the Taylor district coincides in part with the more restricted distribution of granophyric rhyolite porphyry dykes in a north-trending belt extending from about 1.5 km south of the Taylor silver deposit to about 0.5 km north of it. This coincidence was taken to indicate the presence of a buried intrusive source for the dykes, which was also the source of silica-rich magmatic fluids giving rise to the jasperoids. Noting that the dykes were unmineralized, it was concluded that siliceous solutions emanating from the buried magma chamber along faults and fractures first replaced some of the impure limestones. These silicified rocks were then fractured by continued faulting and were invaded by mineralizing solutions that led to jasperoid formation and deposition of the primary ore minerals. At a slightly later time, after the close of mineralization, the dykes were intruded.

Havenstrite (1984) envisaged a different mechanism, and much older age, for the formation for the Taylor silver deposit. Noting that the Schnell Creek Range is distinctive for its paucity of intrusive bodies or thermal effects related to such bodies, and that aeromagnetic surveys reveal no anomalous magnetism which might reflect a deeply buried intrusion, Havenstrite (op cit) proposed that heat generated during the mid-Mesozoic compressional orogeny resulted in connate water dissolving increasing amounts of silver from the Chainman Shale Formation. The Chainman Formation is preferred as it consists of black, euxinic shales which are frequently silver rich according to the work of Boyle (1970). These silver bearing hydrothermal solutions were then "squeezed up" along normal faults until they found their way into the crackle breccia zone at the top of the Guilmette Limestone. Continued migration was impeded by the capping shale of the Guilmette Transition zone, resulting in intense silicification to massive jasperoid and deposition of ore minerals. Rhyolite dykes and sills were subsequently intruded along the same channelways as the ore solution, and commonly contain argentian jasperoid fragments.

A more definitive account of the formation of the Taylor deposit remains to be established by further study, particularly stable isotope and fluid inclusion investigations. There is however a strong argument that the dykes and hydrothermal fluids used the same high angle normal fault structures as channelways. North of the Taylor deposit the Taylor fault zone cuts Tertiary tuffs and it is clear that most of the fault movement is Tertiary in age (Lovering and Heyl, 1974). It is entirely possible that, in common with other similar deposits in Nevada, the dykes are simply late intrusive stages of a much larger Tertiary age magmatic - hydrothermal system that had been depositing silver for considerable time prior to dyke emplacement. Continued tectonic movement along faults, and/or "tightening" of the assymetric anticline, led to brecciation of the jasperoid and recementing with quartz and calcite.

3.3.4 Summary of geological characteristics

The Carlin deposit of Nevada is the principal example of a group of deposits that displays considerable variation in its geological, mineralogical and geochemical characteristics (refer Table 3.1 and 3.2), yet has many similarities that allow definition of this type of deposit. This variation has been examined by contrasting gold and silver rich examples of two end-member subsets (the Carlin-type subset and the Jasperoidal-type subset) that represents of extreme cases the deposit type. A summary of the geological criteria used to define the end member subsets of sediment-hosted, disseminated precious metal deposits is given in Table 3.13. The combination of subjacent magmatism, high angle faulting and reactive carbonate host rocks appears to provide the critical environment in which such deposits can form.

The regional and district scale characteristics of the sediment-hosted, disseminated precious metal deposits show the least variation. Sedimentary rocks of any age that include thinly bedded silty or shaly carbonates or carbonaceous-calcareous siltstones and shales provide the ideal host environment. The primary structural controls of ore deposition in these deposits are high-angle faults, or fold structures, which transect favourable host rocks. These regional fluid pathways serve to concentrate and direct hydrothermal gold-silver bearing solutions generated and driven by a regional heat source, such as igneous intrusives, or perhaps even by tectonic deformation ("metamorphic waters") as suggested at the Taylor silver deposit by Havenstrite (1984). A number of deposits occur near the crest of regional antiforms. The regional lithology of formations through

Carlin-type	Jasperoidal-type
Host rocks are laminated, silty or shaly carbonaceous limestones and dolomites.Calcareous, carbonaceous shales and siltstones are also common hosts. Ages range from Cambrian through Pennsylvanian	Ditto
Igneous rocks are intermediate to silicic plugs, dykes, stocks and domes which commonly occur in a given deposit or within 5 km. Ages of igneous rocks are from early Cretaceous to late Tertiary.	Ditto
Structurally, high angle normal faults are present in all deposits. Faulting is pre- and post-mineralization. Thrust faults occur in many deposits, but have no genetic control on mineralization. Regional antiformal structures common, some deposits occur along fractured and brecciated crests eg Taylor, Alligator Ridge.	Ditto
Alteration relatively simple. Decalcification followed by silicification is most common. Pervasive argillitization common. Local remobilization and enrichment of carbonaceous matter in most deposits. Late calcite and barite veins. Most deposits are oxidized by supergene fluids, resulting in local removal of carbonaceous matter.	Ditto
The gold or silver ore is characteristically exceedingly fine grained, 1-5 microns diameter, and associated predominantly with sulphides (pyrite, arsenopyrite, sphalerite, chalcopyrite), and also organic material, hydrothermal quartz and clay. Ore bodies typically occur adjacent to high angle faults. 'Tectonic and hydrothermal brecciation common.	Ditto
Geochemically, these deposits are characterized by association of Au (or Ag) with As, Sb, Hg and commonly Tl. Anomalous also in organic carbon, W, Ba, S, Sr, Te, Se, Cd,F, (Zn), (Pb) and (Cu).	Ditto
Mineralized quartz veins are uncommon.	Mineralized quartz veins are common.
Main ore type is not intensely silicified.	Main ore type is intensely silicified jasperoid rock (chalcedonic quartz)
Pod-like ore bodies extent away from faults.	Ore bodies primarily restricted to fault zones, but may also occur along crests of antiforms, or along limestone-shale contacts
Jasperoids may be present, especially along limestone - shale contact, but are not the main ore type.	Ore body jasperoids may display several different silicification stages - brecciation common.
Gold rich variety most common.	Gold- and silver- rich varieties.

Table 3.13 : Geological characteristics of Carlin-type, and Jasperoidal - type subsets of the sediment-hosted, disseminated precious metal deposits of Nevada. Modified from Bagby and Berger - in press.

which hydrothermal solutions have circulated may be an important control on whether or not a deposit is gold or silver - rich. In this regard, the effect of underlying crystalline basement rocks, eu- and miogeosynclinal facies rocks, or extensive piles of mafic or felsic volcanic rocks is of significance. However, the importance of geochemical abundances is generally subordinate to the physical properties of the rock (porosity, permeability and fracturing) and the duration of the hydrothermal system leaching metals from the source bed. This will be considered in Section 4.2.

The importance, if any, of the widespread carbonaceous component of host carbonate rocks has not yet been determined. The presence of carbon capable of adsorbing gold complexes, and organic acids containing functional groups capable of forming gold organic compounds in the Carlin gold deposit, led Radtke and Scheiner (1970) to believe that organic carbon controlled gold deposition. Subsequent studies by Wells and Mullens (1973) showed no correlation of gold with carbonaceous material. Carbon content is thus not the dominant lithological deposition factor although it may be a contributor as are possibly the dolomite, silt and/or pyrite content in the host rock. The role of carbonates is important due to the replacement of the original calcite grains and cement by silica containing pyrite and micron- to submicron - sized gold particles. The removal of calcite is therefore of prime importance in creating permeability for hypogene silica-rich ore fluids.

Spatially associated with most of the sediment-hosted, disseminated precious metal deposits are igneous rocks ranging in composition from granodiorite to rhyolite and in form from stocks, to dykes, plugs and extrusive sheets. In Nevada, these igneous rocks range from Cretaceous to middle Tertiary, and are commonly altered and mineralized. In some deposits a close genetic association is suggested by the coincidence of igneous dykes and ore fluid conduits along the same high angle fault zones. At the Getchell gold deposit, (Joralemon, 1951; Silberman et al., 1974), a granodiorite stock, with associated scheelite-bearing skarns, abuts pod-like disseminated gold mineralization of the Carlin-type subset occurring along the high-angle Getchell fault (refer Figure 3.12). At the Gold Acres gold deposit quartz monzonite was intersected at a depth of about 150m during drilling beneath the heavily brecciated Roberts Mountain Thrust fault. Within the Roberts Mountain Thrust fault occur sericitized quartz porphyries, molybdenite- and sphalerite - bearing skarns and later Carlin-type subset disseminated gold mineralization (Wrucke and Armbrustmacher, 1975). At the Cortez gold deposit (Wells et al, 1969) and Northumberland gold deposit (Motter and Chapman, 1984) broadly sill-like intrusives of intermediate composition abut the gold ore (Figure 3.31).

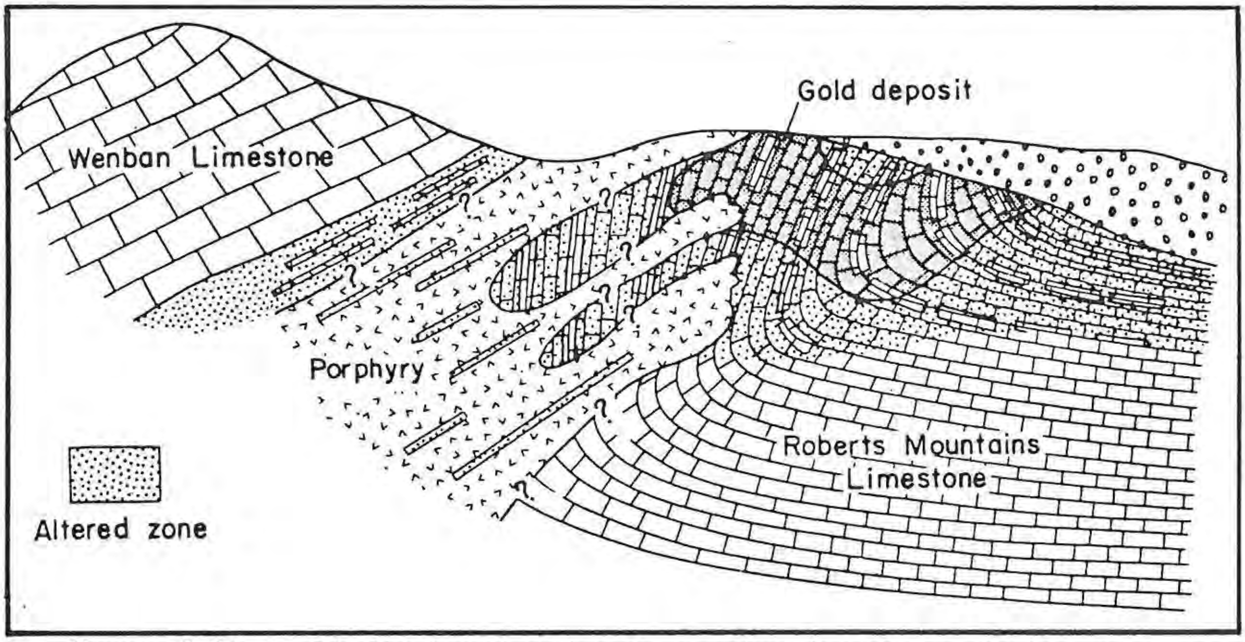


Figure 3.31 : Idealized west-east cross section through the Cortez gold deposit, Nevada, showing relation of gold mineralization and bleached alteration zone to intrusive biotite-quartz-sanidine porphyry intrusive. The gold deposit clearly cuts across the faulted, brecciated and folded bedding of the Roberts Mountains Limestone, along the intruded front of the thick sill-like mass of porphyry (Wells et al, 1969)

The orebodies of the Carlin-type subset are typically tabular or pod-like, extending away from steep faults which frequently contain pre-ore dykes. Orebodies are usually conformable or parallel to bedding. The ore bodies of the jasperoidal-type subset also occur as tabular bodies extending away from steep faults, but are also frequently restricted to the fault zone with only minor leakage into the surrounding wallrock (eg Pinson). Tectonic and hydrothermal breccia zones are common in the ore zones of both subsets and range from crackle breccias to pebble dykes to small breccia pipes. The mineralogy of both subsets always includes pyrite, generally less than 2 volume %. Other common, but variably present, ore minerals include cinnabar, stibnite, realgar, arsenopyrite, fluorite, barite, and various rare Tl- and As- sulphides and sulphosalts. Ore minerals are typically exceedingly fine grained, and gold particles in particular are usually in the order of 1 to 5 microns diameter. Base metal sulphides, including sphalerite, galena, chalcopyrite and molybdenite are uncommon and are locally late additions. Oxidized and unoxidized ores are present in both subsets, but in some of the smaller jasperoid-type deposits only the oxidized ore is mined.

Most of the gold in unoxidized ore occurs as submicroscopic native gold particles contained in pyrite, or, with Hg, Sb and As as coatings on surfaces and fracture fillings in pyrite grains (Radtke et al., 1980; Wells and Mullen, 1973). The association of gold with organic complexes, as indicated by Radtke and Scheiner (1970), is considered far less important than its association with sulphides, particularly pyrite. Gold is also concentrated in sparsely distributed arsenopyrite, and to a lesser degree, sphalerite and chalcopyrite. Quartz, carbonate, clay and carbonaceous material contain negligible amounts of Au and As. Silver ore occurs normally as micro-inclusions of argentite and tetrahedrite, and less commonly as the native metal, within hydrothermal quartz.

The distinctive geochemical association of Au with As, Sb, Hg and commonly Tl, is distinctive to nearly all deposits of this type. Other elements that are anomalous include W, Te, Se, Cd, F, Ba, Sn, Mo, Ag (sometimes to ore grade), Cu, Pb, Zn. Unoxidized ore in many of these deposits is furthermore characterized by the introduction of carbonaceous matter by the hydrothermal ore fluids. At the Carlin deposit, the carbonaceous ore type averages about 2% organic carbon (refer Table 3.5) but ranges up to 5% locally. The organic carbon compounds occur in intimate associations with the ore suite of minerals in textural relationships that locally imply simultaneous deposition (Dickson et al., 1979).

These deposits are characterized by relatively simple alteration processes, although intermittent and overlapping episodes complicate interpretation. Increasingly, further geological studies indicate that the processes of alteration and mineralization at all disseminated gold deposits are, at least, very similar to those documented at Carlin (Siems, 1985). Hypogene alteration invariably includes early decalcification followed by silicification. During early hydrothermal activity low temperature fluids, less than 200°C, leached much calcite and precipitated some quartz in the leached cavities. The importance of this initial decalcification stage in the formation of these deposits is stressed, as it allowed increased porosity and permeability for subsequent mineralizing fluids. The main hydrothermal stage (refer Figure 3.23) resulted in four main groups of mineral products (Siems, 1985). The potassic-argillic alteration (kaolinite-sericite-fine grained quartz) of the first group is pervasive and more extensive, laterally and vertically, than the gold mineralization. These typically very inconspicuous alteration minerals replace the groundmass of the carbonate rocks and occur as small veinlets along bedding planes and fractures. The second group includes deposition of pyrite, Au, Hg, As, Sb and Tl- minerals. Gold, Hg, As and Sb are normally deposited as coatings on surfaces and fracture fillings of pyrite. The third group, siliceous alteration, resulted in early and late periods of jasperoid formation. Carbonate rocks were flooded by large amounts of silica and limited, locally massive, jasperoid bodies formed in areas close to or within high-angle faults (refer Figure 3.18, 3.25). In the Jasperoidal-type subset these bodies constitute the dominant ore host (eg Northumberland, Alligator Ridge), where they occur normally as dense, fine-grained dark grey-black chalcedonic quartz. The fourth group includes an introduction of organic materials, with which realgar, orpiment, stibnite, lorandite and cinnabar are generally associated. The main stage of ore deposition was terminated by boiling of the ore fluids, mixing of H_2S vapour with oxygenated meteoric waters and intense acid leaching/oxidation in the upper part of the deposit. This led to nearly complete removal of remaining calcite and dolomite, oxidation and removal of pyrite and carbonaceous material and continued formation of kaolinite, sericite and some alunite (ie argillitization). Supergene oxidation is superimposed on the zone of hypogene alteration and complicates recognition of alteration minerals.

The age of the sediment hosted, disseminated precious metal deposits of Nevada is the subject of some controversy. Radtke and Dickson (1974) and Radtke et al. (1980) prefer a late Tertiary age for virtually all deposits of this type based upon a presumed very shallow depositional environment, control by Basin and Range faults and an inferred relationship to late

Tertiary volcanism as a heat source for the circulation of hydrothermal ore fluids. However, K-Ar ages of hydrothermal sericite from a number of these deposits indicate a wide age range from at least late Cretaceous to late Tertiary. The Getchell deposit has a K-Ar age of approximately 90 Ma (Silberman et al., 1974) and the Pinson and Preble deposits are also interpreted to be of late Cretaceous age (Bagby and Berger - in press). The Cortez deposit is related to altered intrusive dykes which have a K-Ar age of 35 Ma (Wells et al., 1971). The Gold Strike deposit has been dated at 78.4 Ma (Morton et al., 1977). At Carlin, post-mineralization rhyolite dykes dated at 14 Ma (Bagby and Berger - in press) provide an upper age constraint, and altered Cretaceous dykes (131 Ma - Radtke et al., 1980) provide a lower age constraint for mineralization. In summary, the available geologic and radiometric evidence suggests that although the majority of these deposits formed during Tertiary time, there is a wide variation in mineralization ages up to the early Cretaceous.

4 ORE GENESIS

Sediment-hosted, disseminated precious metal deposits are hydrothermal replacement bodies related to fossil geothermal systems. Several published models for the formation of these deposits have placed strong emphasis on a hot-spring environment (Radtke et al., 1980; Joralemon, 1951; Hausen and Kerr, 1968), the shallow, low temperature end of the epithermal spectrum (*viz* telethermal class of Graton (1933) - refer Section 2.3). Increasing evidence suggests that this proposed environment of deposition is misleading and that formation of these deposits may in fact be deeper than previously assumed. Before considering a genetic model the geological characteristics of the epithermal spectrum will be briefly discussed. The source of the fluids, ore and gangue components, and the factors which control the solution, transport and deposition of the metals in sediment-hosted disseminated precious metal deposits will also be considered.

4.1 Epithermal Precious Metal Deposits

Epithermal gold-silver deposits form at low to moderate temperatures in near surface hydrothermal systems (Lindgren, 1928; refer Table 2.2). Lindgren's upper temperature limit of 200^{o}C for these deposits is evidently too low according to recent fluid inclusion studies, which indicate that homogenization temperatures in epithermal gold deposits vary between 150^{0} to 300^{0}C (Lewis, 1982). The term "epithermal" is however still retained because it is widely used, and is now generally understood to refer to a genetic class rather than a temperature class of deposit. The general characteristics and conceptual models of epithermal precious metal deposits presented here, are taken from Berger and Eimon (1983) and Rossiter (1984).

4.1.1 General characteristics

Epithermal precious metal deposits are typically Cenozoic in age, and are characteristically found in continental regions showing evidence of igneous and tectonic activity (Table 4.1). Deposits occur as veins, stockworks and disseminations. Important epithermal districts are associated consistently with pre-existing faults and fractures such as Basin and Range-type normal faults, caldera ring fractures, caldera-related graben structures, complexly faulted or domed areas. Vein textures always include drusy cavities,

Temperature of formation:	~50° to~300°C
Depth of formation:	Surface to~1500 metres.
Mineralizing fluid:	Near neutral (pH 6-7), CO_2-bearing, weakly saline (0,5-5 wt% equivalent NaCl) solution dominantly or entirely of meteoric origin.
Nature of deposit:	Thin to large veins, stockworks, disseminations.
Common features:	Fine-grained chalcedonic quartz, quartz pseudomorphs after calcite, brecciation.
Ore elements:	Au, Ag, As, Sb, Hg, Te, Tl, Pb, Zn, Cu.
Gangue minerals:	Quartz, calcite, adularia, and lesser fluorite, barite, sericite, chlorite.
Ore textures:	Open-space filling, crustification, colloform banding, comb structure, brecciation.
Alteration:	Propylitization, silicification, adularization, albitization, argillization.
Host rock:	Any. Most commonly hosted by calc-alkaline volcanic sequences containing andesites, rhyolites, and dacites. Replacement deposits are found in carbonaceous carbonate rock.
Tectonic setting:	Continental regions showing evidence of tectonic/ igneous activity. Convergent plate boundaries are the most favourable settings.
Age:	Mostly Cenozoic.

Table 4.1 : General characteristics of epithermal precious metal deposits (Rossiter, 1984)

crustification, comb structures, colloform banding, and vein breccias. Most geochemical research utilizing light stable isotopes have shown that the hydrothermal fluids were predominantly, if not overwhelmingly, meteoric in origin (eg Bethke and Rye, 1979; O'Neil and Silberman, 1974; Dickson et al., 1979; Taylor, 1973). Fluid-inclusion studies indicate that most of the epithermal deposits were formed from dilute alkali-chloride solutions (approximately 0.5-5 weight % NaCl equivalent) over a temperature range of 150^{0} - 300^{0}C (eg Nash, 1972; Vikre, 1981).

Extensive studies of active geothermal systems or hot spring areas , especially in New Zealand and the western United States, have led to a better understanding of the fluid chemistry, wallrock alteration, and structural complexities of hydrothermal systems (eg Henley and Ellis, 1983; Weissberg et al., 1979) Similarities between epithermal ore deposits and these active hydrothermal systems have long been cited by White (1955, 1968, 1981) as evidence of a common genesis. Epithermal deposits are now considered to be the fossil equivalents of present day geothermal systems. Some of the salient features of present day hot spring systems are depicted schematically in Figure 4.1. The alteration at the top of the system consists characteristically of silicification underlain by a zone of mixed-layer illite-montmorillonite. This clay zone changes with depth into a sericite zone. An important attribute of both the Steamboat Springs, Nevada, and the Broadlands, New Zealand, hot spring systems is that primary quartz and orthoclase are unaltered throughout the drilled intervals. Kaolinite is important only where acid-leaching has occurred or is occurring, and is, therefore, superimposed on top of the other clay alteration patterns . Precious metals are abundant in the upper parts of the system and base metals generally are more abundant at deeper levels. Depending upon the structural framework, the isotherms in active systems are generally near-horizontal surfaces in the broader context of the whole system (Figure 4.2). The consequences of this in fossil epithermal systems are ore horizons at predictable elevations.

4.1.2 Conceptual models

Rossiter (1984) divided epithermal deposits into three groups - the Hot Spring, Open Vein and Disseminated Replacement Types - two of which are

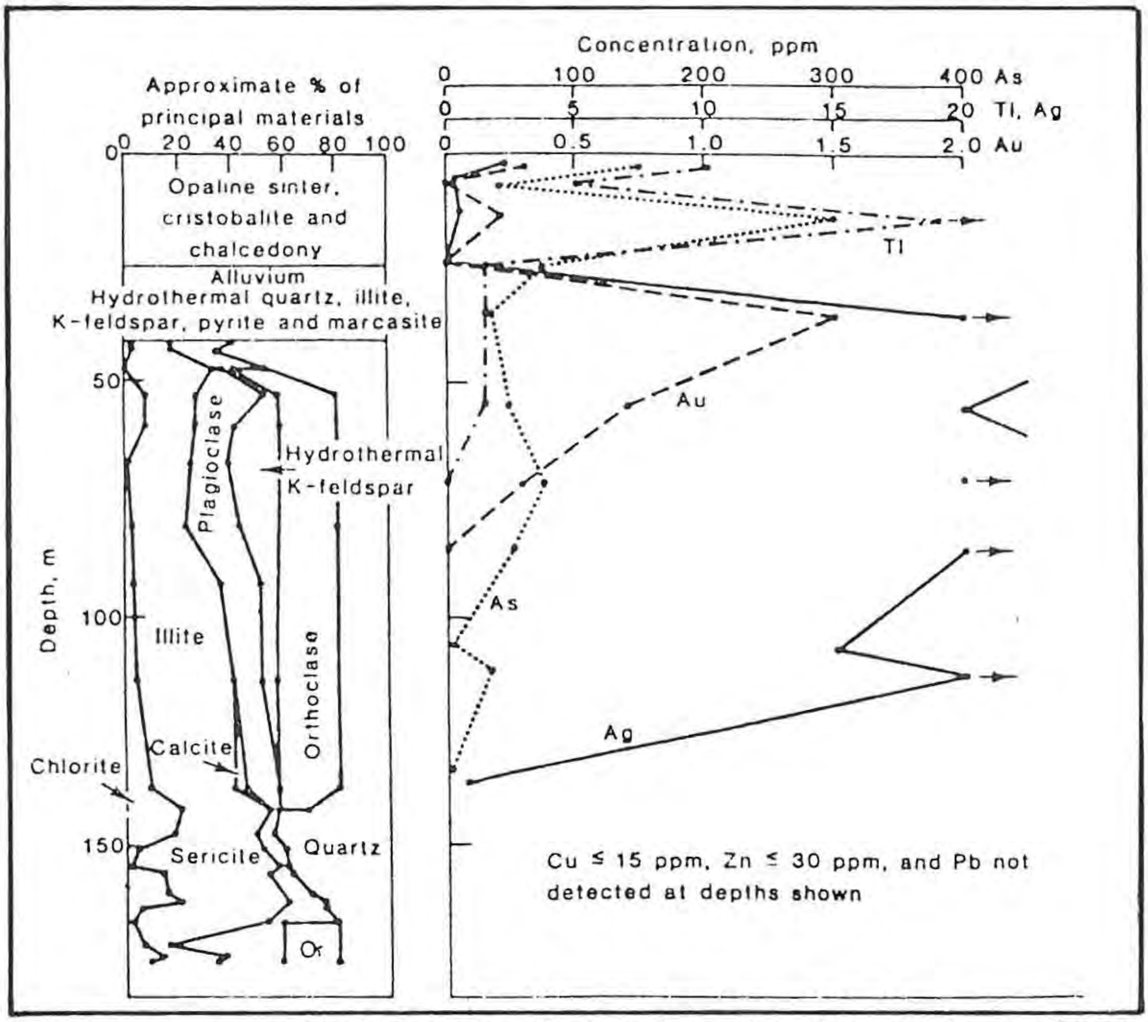


Figure 4.1 : Spatial relationships of alteration mineralogy and trace-element concentrations in drill hole GS-5, Steamboat Springs, Nevada. Water table is at or slightly above surface, and springs are still actively flowing. Data from Sigvaldson and White (1962). (Berger and Eimon, 1983).

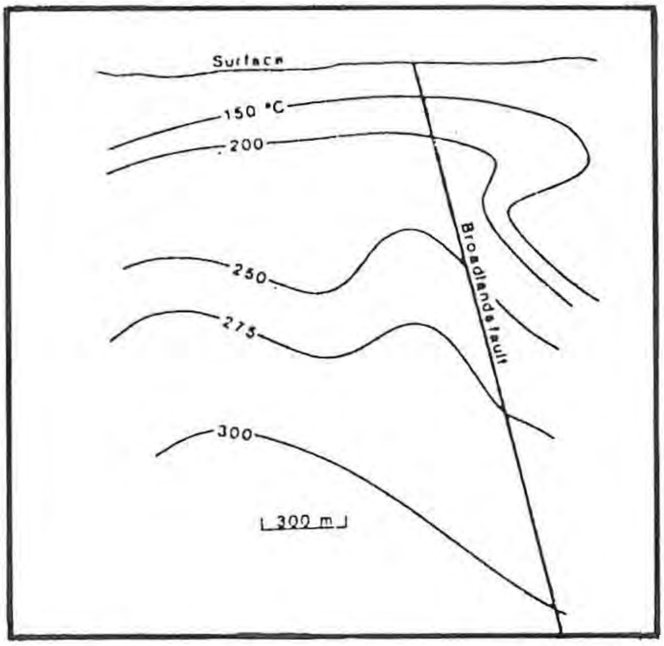


Figure 4.2 : Crossection of the Broadland thermal area, New Zealand, showing the generally flat upper surfaces of the isotherms (Berger and Eimon, 1983).

interrelated in terms of the depth of formation (Table 4.2). The Disseminated Replacement Type deposits were formed at varying depths beneath the palaeosurface by hydrothermal systems that did not necessarily vent to the surface as hot springs, geysers and fumaroles. The depositional environment of the three types is schematically shown in Figure 4.3, and general characteristics are given in Table 4.3.

4.2 Source of the Water, Ore and Gangue Components

Stable isotope analyses of selected minerals from Carlin (Dickson et al., 1979; Radtke et al., 1980) and Cortez (Ryo et al., 1974) are in accord with a nonmagmatic source for the water, sulphur and carbon (see Section 3.3.1).

In summary, the isotopic evidence indicates that the main stage hydrothermal fluids at Carlin and Cortez were highly exchanged meteoric waters which contained sedimentary sulphur and host rock carbon. It has been noted that all of the lower Palaeozoic carbonate units in the Cordilleran geosyncline contain diagenetic pyrite and organic material and probably all of these rocks were potential source beds for the ore and gangue components in the deposits.

The question arises as to which rocks are the most likely source beds. Rocks of the Roberts Mountains Formation contain high levels of minor elements, above the average values for crustal limestones given by Turekian and Wedepohl (1961) (refer Table 3.10), and are considered as source beds for the ore elements at Carlin (Dickson et al., 1979). It should however be stressed that whether a particular rock type could serve as a source depends on its physical properties (porosity, permeability, fracturing) and the duration of activity of the hydrothermal system, as much as on its composition. Geochemical abundance data for unaltered rocks are important and necessary to establish background levels for various rock types, but they provide no diagnostic clues or guides to areas favourable (or unfavourable) for gold-silver mineralization, nor do they help to identify source rocks (Tilling et al., 1973). In present-day hydrothermal systems, ore grade (ppm) concentrations of gold are being precipitated by transporting solutions that are extremely low in gold (0.05 ppb or less) and that flow through rocks also low in gold (1 ppb or less) (Seward, 1979;

1.	HOT SPRING TYPE:	formed at or near the surface. Characterized by: siliceous capping "sinter"; disseminated and stockwork mineralization; hydrothermal brecciation; large-tonnage, low-grade; element association Au, Ag, As, Sb, Hg, Tl; lack of base metals. e.g. Round Mountain, Nevada; Baley, U.S.S.R; Haile, Brewer and Sawer mines, Carolina; Pueblo Veijo, Dominican Republic.
2.	OPEN VEIN TYPE:	formed deeper in the system below the Hot Spring Type. Characterized by: substantial vein widths resulting in moderate tonnages of high-grade ore; higher total-sulphide concentrations, more complex mineralogies, and greater quantities of base metals than Hot Spring Type deposits. Vein textures include open-space filling, crustification, colloform banding, comb structures, and brecciation. e.g. Antamok and Acupan, Philippines; Vatukoula and Mount Kasi, Fiji; Yatani mine, Japan; Sunnyside mine, Colorado.
3.	DISSEMINATED REPLACEMENT TYPE:	associated with carbonaceous carbonate sediments and intrusive igneous bodies - also called "Carlin-type". Characterized by: tabular shape, exceedingly fine-grained ore and gangue minerals; element association Au, As, Sb, Hg, Tl; lack of base metals; paucity of quartz veining; large-tonnage, low-grade. e.g. Carlin, Blue Star, Bootstrap, Cortez, Gold Acres, Getchell, Pinson, Preble, Northumberland, Manhattan (White Caps), Jarritt Canyon - Nevada; Mercur - Utah; Black Hills - South Dakota.

Table 4.2 : Classification of epithermal precious metal deposits (Rossiter, 1984)

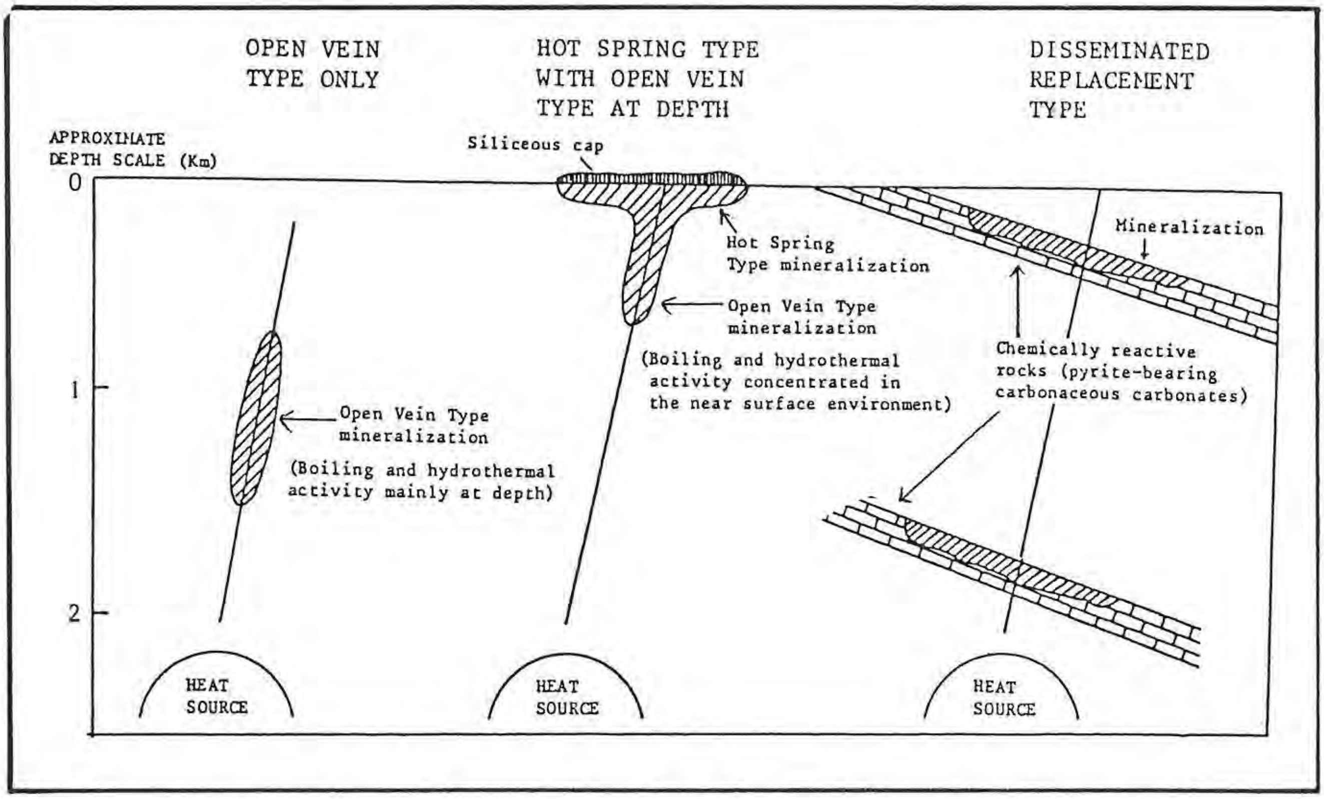


Figure 4.3 : Schematic representation of the depositional environments of epithermal precious metal deposits. Disseminated Replacement Type deposits span the interface between deep intrusive processes and near surface environments (Modified from Rossiter, 1984)

FEATURE	OPEN VEIN TYPE DEPOSITIONAL MODEL	HOT SPRING TYPE DEPOSITIONAL MODEL	DISSEMINATED REPLACEMENT TYPE DEPOSITIONAL MODEL
Depositional environment	Continental (i.e. on land), shallow hydrothermal systems. (Hydrothermal fluids may or may not vent at surface).	Continental (i.e. on land), shallow hydrothermal systems. (Hydrothermal fluids vent at surface).	Continental (i.e. on land), shallow hydrothermal systems.
Structural control on ore deposition	High-permeability structures (faults and fractures).	High-permeability structures (faults and fractures).	High-permeability structures (faults and fractures.
Nature of associated faults/fractures	Near vertical, substantial, relatively few.	Complex, small, numerous	Near vertical.
Host rock control on ore deposition	None. (mainly found in andesites, dacites, and rhyolites).	None.	Restricted to carbonaceous carbonate rock.
Timing of mineralization in relation to tectonic/igneous activity.	Towards end and/or immediately after tectonic/igneous activity.	Towards end and/or immediately after tectonic/igneous activity.	Towards end and/or immediately after tectonic/igneous activity.
Depth of formation	200m to 1500m.	Surface to 500m.	Surface to 500m.
Temperature of formation	150°C - 300°C (average 240°C).	100°C - 300°C.	100°C - 300°C (main ore stage 175°C - 200°C).
Mineralizing fluids	Dilute, near neutral (pH 6-7), CO_2,-H_2S-bearing, weakly saline (0,5 to 5 wt% NaCl) waters of meteoric origin.	Dilute, near neutral (pH 6-7) CO_2,-H_2S-bearing, weakly saline (0,5 to 5 wt% NaCl) waters of meteoric origin.	Dilute, near neutral (pH 6-7) CO_2,-H_2S-bearing, weakly saline (0,5 to 5 wt% NaCl) water of meteoric origin.
Source of introduced elements	Leached from underlying country rocks.	Leached from underlying country rocks.	Leached from underlying country rocks.
Metal transporting mechanism.	Dominantly thio complexes. Chloro complexes possibly transport base metals and silver at T>300°C.	Dominantly thio complexes.	Dominantly thio complexes.
Dominant ore depositional mechanisms	Boiling.	Boiling and mixing of ore-solutions with oxygenated near-surface waters.	Reaction with carbonaceous carbonate rocks and mixing of ore-solution with oxygenated near-surface waters.

Table 4.3 : Characteristics of Open Vein, Hot Spring, and Disseminated Replacement Type depositional models (Rossiter, 1984)

FEATURE	OPEN VEIN TYPE DEPOSITIONAL MODEL	HOT SPRING TYPE DEPOSITIONAL MODEL	DISSEMINATED REPLACEMENT TYPE DEPOSITIONAL MODEL
Nature of mineralization	Cross-cutting veins and minor breccias. Mineralization in ore shoots.	Stratiform, disseminated, stockwork, and minor veins in and just below a siliceous sinter capping.	Stratiform (tabular) disseminated replacement bodies.
Ore textures	Open-space filling, crustification, colloform banding, hydrothermal brecciation.	Hydrothermal brecciation and stockworks.	No visible difference between ore and fresh unmineralized host rock.
Dominant ore elements	Au, Ag, Te, Pb, Zn, Cu.	Au, Ag, As, Sb, Hg, Tl.	Au, As, Sb, Hg, Tl.
Gold occurs as:	Native gold, electrum, gold tellurides, and gold-bearing sulphides (mainly pyrite and arsenorpyrite).	Native gold and gold-bearing sulphides (mainly pyrite and arsenopyrite).	Gold-bearing sulphides (mainly pyrite and lesser arsenopyrite).
Relative total sulphide concentration	High	Low	Low
Dominant sulphides present	Pyrite, galena, sphalerite, chalcopyrite.	Pyrite ± arsenopyrite.	Pyrite ± arsenopyrite.
Element zonation	Top As, Sb, Hg ↑ Au, Ag, Te Pb, Zn, Cu.	Top As, Sb, Hg, Tl ↑ Au, Ag.	None apparent.
Vein minerals	Quartz, calcite, adularia, chlorite, ± fluorite, ± barite.	Quartz, calcite, adularia, ± fluroite, ± barite.	Calcite, barite, quartz.
Hydrothermal alteration	Propylitization, silicification, adularization, albitization, argillization.	Propylitization, silicification, adularization, argillization.	Silicification, argillization, decarbonatization, introduction of hydrocarbons.
Grade/tonnage relationships	High grade, moderate tonnage.	Low grade, large tonnage.	Low grade, large tonnage.
Dominant mining method	Selective underground methods.	Open cast methods.	Open cast methods

Table 4.3 (Cont) : Characteristics of Open Vein, Hot Spring, and Disseminated Replacement Type depositional models (Rossiter, 1984).

White, 1968; Weissberg, 1969). This is good evidence that a relatively high content of gold or silver in possible source rocks and/or mineralizing solutions need not necessarily be a requirement for precious metal mineralization. Also, the differences in gold content among common rock types are simply too small, relative to the more than thousandfold concentration needed to produce ore-grade material, for any particular rock to be considered as a more favourable source than another (Tilling et al., 1973). Thus the major factor in concentrating gold to economic levels is the duration, nature and efficiency of the hydrothermal mineralizing system, and not the presence or absence of a suitable source rock.

The contribution of magmatic waters to the hydrothermal solutions cannot be ignored. As much as 5 to 10 % magmatic water may remain undetected during isotope studies (Wetlaufer et al., 1979). The presence or absence of a magmatic component in the hydrothermal solutions, however, is not considered to be important for the genesis of epithermal ore deposits (Rossiter, 1984).

4.3 Transport and Deposition of Gold in Hydrothermal Systems

An understanding of the formation of hydrothermal gold deposits is linked to a knowledge of the chemistry of gold complex equilibria in high temperature-high pressure aqueous electrolyte solutions. At present, knowledge about the stability and stoichiometry of gold complexes in hydrothermal ore-forming fluids and, consequently, understanding of the conditions under which gold will precipitate in response to perturbations in temperature, pressure, oxidation potential (Eh), pH, and the activities of various complexing ligands, is very limited (Seward, 1982). The following discussion on the transport and deposition of gold in hydrothermal fluids is based on the reviews of Seward (1979, 1982) and Rossiter (1984).

4.3.1 Transport

Fluid-inclusion studies at Carlin indicate mainstage mineralization temperatures of 175^{o} to 200^{o}C and salinities of about 3 ± 1 equivalent weight % NaCl (Radtke et al., 1980). The only other reported fluid inclusion data for the sediment hosted, disseminated precious metal deposits of Nevada, is from Gold Acres, where Nash (1972) reported homogenization temperatures of between 160^0 to 185^{0}C (six samples) and fluid salinities of 5.4 to 7.3 equivalent weight % NaCl (four samples).

The bulk compositions of the relatively dilute hydrothermal waters at Broadlands, New Zealand, and the saline brines of the Salton Sea geothermal system, are given in Table 4.4. It may be seen that there are only a few components which will act as potential ligands in complexing and transporting gold. These are the halide ions (excepting F^-), ammonia $(NH_4)^+$, bisulphide (+ sulphide) and possibly species involving As, Sb and reduced S, such as thioarsenites and thioantimonites. Of the halide ions, Cl^-, Br^- and I^-, chloride is by far the most abundant and hence more important (Seward, 1982).

	Broadlands 2 T = 260°C	Salton Sea No. 11ID T = 320°C
pH	6.2	4.15
Li	7.95	16.0
Na	713.6	38369
K	152.2	13367
Rb	1.49	10.3
Cs	1.15	10.7
Ca	1.50	21970
Mg	0.05	1045
F	4.96	11.45
Cl	1184	118202
Br	4.35	91.6
I	0.54	13.6
NH_3 NH_4	1148	374
B	133	1206
CO_2 HCO. CO_3	5278	570
SiO_2	547.1	711.7
HSO_4 SO_4	5.43	3.71
H_2S HS	136	15.9
As	5.7	12

Table 4.4 : Composition of deep waters (in parts per million) from two active geothermal systems which have deposited ore-grade precipitates (Seward, 1982)

Studies of both active geothermal systems and epithermal gold deposits indicate that thio-complexes of gold, in which Au(1) is complexed by a sulphur-donor ligand such as HS^-, are probably the dominant mechanism of gold transport (Seward, 1979). This is not surprising as sulphur-donor ligands form extremely stable complexes with Au(1). Simple thio-complexes such as $Au(HS)^-_2$ (found predominantly in near neutral pH solutions) and its protonated equivalent, $HAu(HS)_2$ (found usually in more alkaline solutions), are probably the most important complexes responsible for gold transport. Chloride complexing of gold (as $AuCl^-_2$) will only be predominant in fluids containing high Cl^- and anomalously low S concentrations, or in fluids of elevated Eh (Seward, 1982). Chloride complexing is however important for Ag transport in hydrothermal solutions.

4.3.2 Deposition

Assuming that gold in hydrothermal systems is dominantly transported as simple thio-complexes, then changes in temperature (caused either by decreases attendant on the ascending fluid or interaction with cooler surface waters), pH, Eh, or decrease in the activity of reduced S, could cause the precipitation of gold (Seward, 1979, 1982). With respect to $Au(HS)^-_2$, Seward (1973) has shown that a decrease in pressure will in fact lead to an increase in gold solubility above 250°C. A decrease in the activity of reduced S may be accomplished by boiling, precipitation of sulphide minerals, dilution and oxidation (eg sulphide to sulphate). In addition, a decrease in pH accompanying oxidation of H_2S would also cause precipitation of gold. The deposition of gold as a result of the precipitation of sulphide minerals is of prime importance in the Disseminated Replacement Type deposits.

Cole and Drummond (1984) used chemical modelling experiments to determine the transport and depositional mechanisms for Au and Ag in boiling hydrothermal solutions, complexed by both hydrosulphide (HS^-) and chloride (Cl^-) ligands. Their results are of particular importance in explaining the Au- and Ag-rich end members of the Disseminated Replacement Type deposits. The following important trends were observed :

a) Regardless of Cl^- concentration and pH, Ag/Au ratios less than 10 are associated with 150° to 200°C fluids; Ag/Au ratios greater than 10 are dominated by 250° to 300°C fluids.

b) Ag/Au ratios decrease with increasing total H_2S.

c) Ag/Au ratios decrease with increasing pH, but overall, pH is subordinate in its effect.

d) For Ag/Au ratios less than 10, $Au(HS)_2^-$ is the dominant complex; but for Ag/Au greater than 10, $AuCl_2$ predominates.

In summary, the bimodal nature of Au in solution (either as a HS^- or Cl^- complex) results in two distinctly different Ag/Au populations in solutions over the range of expected natural conditions.

Gold solubility is highly influenced by redox reactions (Lewis, 1982). During deposition, the redox change is always one of reduction ($Au(1) \longrightarrow Au$). Rossiter (1984) notes that redox environments suitable for gold depositon may be caused by the following processes :

a) boiling, which results in major changes in the physical and chemical state of the hydrothermal fluids;

b) the migration of the hydrothermal fluids into chemically reactive host rocks such as those containing pyrite, carbon and carbonate;

c) mixing of the ore-bearing hydrothermal fluid with near surface waters having a relatively high oxygen fugacity.

All three processes may operate within a single epithermal system to varying degrees. Boiling and interaction of hydrothermal fluids with near-surface waters are important for the formation of Hot Spring and Open Vein Type deposits. Chemically reactive host rocks and interaction of hydrothermal fluids with near-surface waters are important for the formation of Disseminated Replacement Type deposits.

4.4 Genetic Model

Formulation of a genetic model for sediment-hosted, disseminated precious metal deposits is complicated by a considerable variation in their geological, mineralogical and geochemical characteristics (refer Tables 3.1 and 3.2). Also, the literature is dominated by the results of research work undertaken at the "classic" deposit of this kind, namely the Carlin gold deposit of Eureka County, Nevada. Ongoing research at similar deposits in Nevada suggests that the environment of deposition for such deposits may in fact be deeper than previously assumed, extending depths of formation to deep epithermal and mesothermal zones (Bagby and Berger - in press).

The mesothermal zone was interpreted by Ridge (1968) to represent depths of one to three kilometres. The environment of formation will be considered prior to discussion of the genetic aspects of these deposits. The discussion on genetic aspects is based largely on the review by Rossiter (1984).

4.4.1 Environment of formation

Deposits of this type have been classified as epithermal to telethermal (near-surface) deposits since the first descriptions of Getchell (Joralemon, 1951) and Carlin (Hausen and Kerr, 1968). Joralemon (op cit) cited the telescoped nature (meaning the close association of gold, realgar, stibnite, and cinnabar over a short vertical distance - viz steep thermal gradient) of the mineralization, large vugs and an intensely shattered ore zone as evidence for epithermal to telethermal deposition at Getchell. Hausen and Kerr (op cit) also classified the Carlin deposit as a low-temperature, epithermal to telethermal class of deposit. Although the common epithermal vein features of crustification, banding and comb structures ("vuggy") are lacking at Carlin, the silicified zones strongly resemble hot-spring type siliceous sinters. The typical silicification and argillic alteration, and Hg-Sb-As-Ag trace element association at Carlin is also cited as being analogous to the active Steamboat Springs geothermal area, Nevada (Schoen and White, 1965).

The Disseminated Replacement Type deposits have thus been considered epithermal to possibly telethermal without any rigorous pressure and temperature studies (Bagby and Berger - in press). Of the deposits studied in some detail, the Carlin deposit is the only one for which a shallow (200 - 400 m) depth of formation has been proposed (Radtke, 1981; cited by Bonham, 1982). The Gold Acres deposit is considered to have formed approximately 1500m below the surface and to be genetically related to a Cretaceous age granitic pluton present about 150m below the gold ore body. The disseminated gold ore (with associated As-B-Hg-W) is believed to have been deposited in the waning stages of the hydrothermal activity accompanying emplacement of the Cretaceous pluton, which also deposited molybdenite, base metals and scheelite in contact metasomatic tactites within the mine area (Wrucke and Armbrustmacher, 1975). A similar geological setting, involving disseminated gold mineralization distally associated with scheelite-molybdenite-base metal tactites within a conspicuous metamorphic aureole, is reported at the Getchell gold mine (Silberman et al., 1974; Bonham, 1982). Similar geological environments can be inferred for the Northumberland, Blue Star, Gold Strike, Bootstrap, Pinson and Preble deposits (Bonham, 1982).

Current research, alluded to but not reported by Bonham (1982) and Bagby and Berger (in press), indicates therefore that the Disseminated Replacement Type deposits may also have formed at depths of 1000 m or more below the palaeosurface. They can be related to a near-surface hot springs model only in the context that these hydrothermal deposits form in geothermal systems that usually, but not always, vent to the surface as hot springs and fumaroles. Unfortunately there are no reported fluid inclusion or stable isotope data suggesting whether the mineralizing fluids at these deeper level deposits were of magmatic parentage. It is clear however that the Disseminated Replacement Type deposits span the interface between deep intrusive processes and near-surface environments, and may be considered as distal contact metasomatic deposits.

4.4.2 Plate tectonic setting

Epithermal ore deposits are formed in continental environments (Rossiter, 1984). This is supported by fluid inclusion and stable isotope studies which indicate that the mineralizing hydrothermal fluids are dominantly or entirely of meteoric origin. Continental regions having favourable high heat flows are dominantly associated with convergent plate boundaries and include Andean-type magmatic arcs, island arcs, back-arc extensional cratonic basins, and Himalayan-type orogenic belts. Continental rifts, aulacogens, hot spots, and transform faults may also have high heat flows. These continental tectonic environments with a favourably high heat flow are schematically illustrated in Figure 4.4.

4.4.3 Fault and fracture control

Faults and fractures are commonly associated with igneous activity. Concentric and radial fracture patterns generally surround volcanic centres (Koide and Bhattacharji, 1975). Caldera subsidence results in substantial graben structures. These structures in conjunction with Basin and Range -

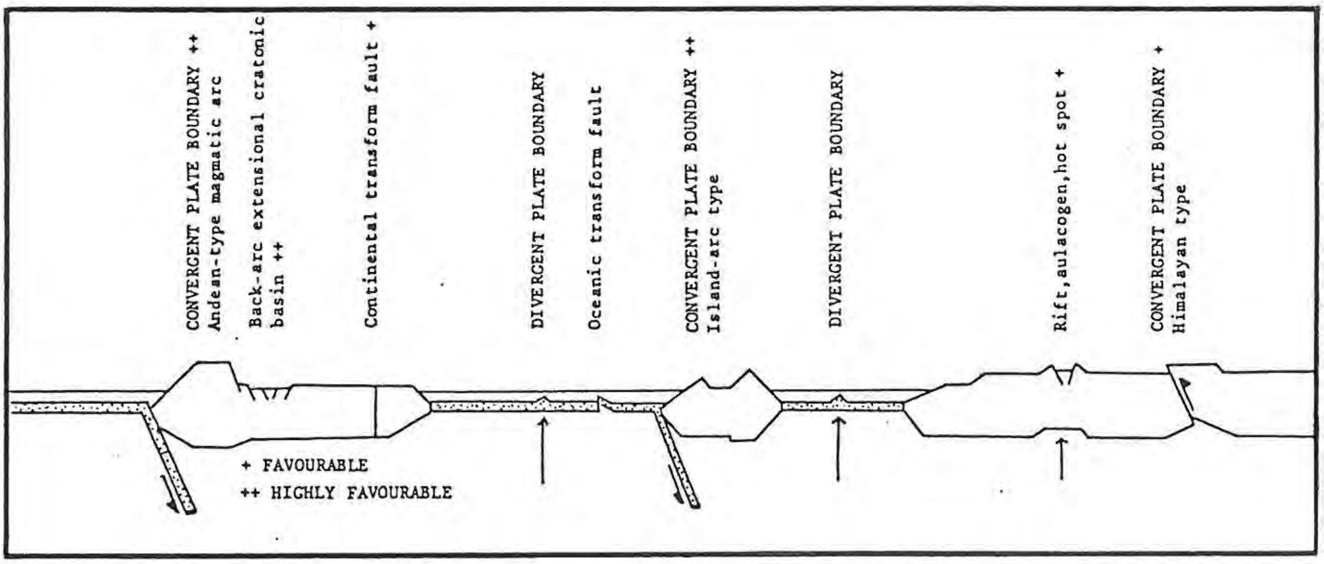


Figure 4.4 : Schematic illustration of continental tectonic environments with a high heat source (Rossiter, 1984)

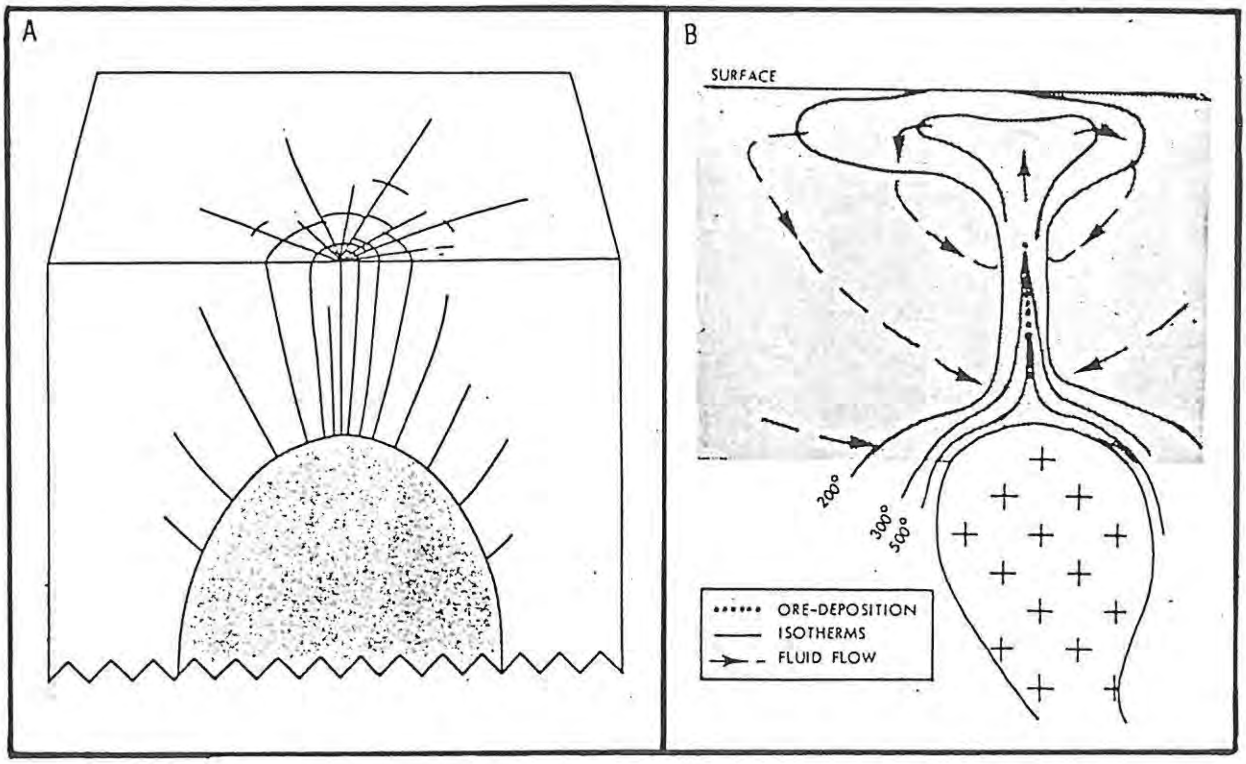


Figure 4.5 : (A) Possible fracture pattern above a rising pluton (Koide and Bhattacharji, 1975). (B) Idealized diagram of hydrothermal convective system generated above an intrusive pluton (Fyfe and Henley, 1973).

type fault zones (extensional environment) are the sites of active geothermal activity and mineralization (Rossiter, 1984). The presence of both a heat source and fractures results in the generation of hydrothermal systems (Figure 4.5 A and B). Substantial hydrothermal cells, necessary for ore genesis, are generally developed late in the igneous cycle and persist well after the conclusion of volcanic activity. As such, alteration and mineralization is younger, but roughly comparable in age to that of the epizonal intrusions. The onset of hydrothermal activity initiates the process of ore formation.

4.4.4 **Hydrothermal circulation**

The hydrothermal fluids are derived dominantly or entirely from local meteoric or connate waters. Waters more distant from the heat source move down faults, fractures, and other permeable structures by convective flow. During their downward passage these waters become heated and interact with the country rocks. These deep waters are near neutral (pH 6 to 7), reduced, CO_2-bearing, and weakly saline (0,5 - 5 weight % NaCl).

Various elements and compounds are leached from the rocks and become concentrated in the fluids. Potassium, Na, Cl^-, HCO_3, B, Si, F^-, S, As, Te, Se, gases (CO_2, H_2S), and minor metals, are commonly enriched in the solution at high temperatures (possibly up to 350°C). The contribution of various components from a magmatic source at depth cannot be ignored but is considered unimportant in this model. Minor metals enriched in the solution include Au, Ag, Sb, Hg, Tl, Bi, Pb, Zn and Cu. Tungsten concentrations may also be high locally.

Metals are dominantly complexed with sulphur donor ligands such as HS^- (ie thio-complexes) in the solution. Minor chloro- and hydroxochloro complexes may transport metals (particularly base metals and possibly silver) at relatively high temperatures (ie more than 300°C). Chloride complexing may be important to account for the infrequent occurrences of disseminated silver deposits (eg Taylor) but the data base in support of this is incomplete. Once the waters are sufficiently heated, they move up faults and fractures away from the heat source towards cooler near surface environments.

The form of the hydrothermal cell is governed by the intensity of the heat source and the nature of the fluid pathways. In general fluid movement above a heat source is vertical following high angle faults and fractures. Shallow dipping faults and permeable strata may influence the direction of fluid flow. Also important in the development of the Disseminated Replacement Type bodies are antiformal structures and more impermeable "capping" strata overlying favourable carbonate host rocks. The hydrothermal cell may or may not vent at surface. This is probably related to the position of the water table, the intensity of the heat source, and the degree of faulting and fracturing. Physical and chemical changes in the fluids as they move up the thermal plume result in the alteration of the country rocks and the deposition of minerals including the ore.

4.4.5 **Alteration and deposition**

The sediment-hosted, disseminated precious metal deposits are the integrated result of igneous (or possibly even tectonic) heat, injected into sedimentary rock-fluid systems, dispersed by convective movements of fluids, which dissolved ore and gangue components at high temperatures and deposited them at lower temperatures in chemically favourable carbonaceous carbonate rocks. Ore fluids ascended from depth along steep faults and migrated into permeable thin-bedded carbonate rocks where they dissolved carbonate minerals (principally calcite) and deposited quartz and pyrite, and fine-grained Au and/or Ag. During mainstage and late hydrothermal alteration and deposition the fluids introduced varying amounts of K, Si, Ba, Fe, S, W, Pb, Zn, Cu and organic materials, plus Au, Ag, As, Sb, Hg and Tl. Argillic alteration, mostly as K-clays, is widespread and extends laterally and horizontally far beyond the zone of gold mineralization. Sulphides and sulphosalts containing Au, As, Sb, Hg and Tl are characteristic of many of these deposits. Widespread silicification, often resulting in irregular jasperoid bodies, is also a characteristic feature of the Disseminated Replacement Type deposits. Many of these deposits occur within prominent high angle fault planes.

The main stage of ore deposition is commonly terminated by the formation of barite veins, and the onset of boiling. The loss of H_2O, CO_2 and H_2S led to production of H_2SO_4 acid solutions and to subsequent intense acid-leaching and oxidation (argillic alteration) of the ores and surrounding rocks. Large amounts of calcite, dolomite, sulphides and organic compounds are removed, kaolinite and anhydrite formed, and silica was added.

The Au/Ag ratio of the deposits is mainly dependent on chemical and physical characteristics of the ore fluid. Specifically, chloride complexing and higher temperatures of deposition appear to account best for the infrequent sediment-hosted, disseminated silver deposits, such as Taylor, but the data base in support of this is incomplete (Cole and Drummond, 1984).

5 EXPLORATION

Precious metal exploration is currently dominating the world-wide mineral exploration scene. The exeedingly fine-grained nature of gold and silver mineralization and the relatively ordinary appearance of Disseminated Replacement Type ore deposits, has largely prevented their discovery in earlier years. Excellent potential must still exist for further discoveries of this deposit type as the processes that formed them are not specialized. Any thick section of carbonate rocks has the potential to produce gold deposits wherever underlying igneous activity has developed a hydrothermal system.

Exploration for epithermal gold-silver deposits is orientated towards geological and geochemical prospecting techniques. The recognition criteria and prospecting techniques applicable to these deposits will be considered in the following section.

5.1 Geological Prospecting

The differences and similarities in geological characteristics between deposits of this type are summarized in Tables 3.1 and 3.2, and provide a wealth of recognition criteria. The essential regional characteristics that may be used to identify favourable areas for exploration are host lithology, structure and heat flow. Exploration parameters for Disseminated Replacement Type deposits are as follows :

1) The ore deposits typically occur in thinly bedded (fissile), silty to

sandy, carbonaceous, carbonate units and have a stratabound configuration. Some deposits, particularly those of the jasperoid-type subset, are restricted to fault zones with little penetration into surrounding host rocks (eg Preble and Pinson).

2) A common feature of all epithermal precious metal deposits is their association with fault zones and centres of magmatism in tectonically active regions. Magmatism tends to be felsic but may be bimodal, either calc-alkaline or alkaline in composition. Intrusive igneous rocks occur as plugs, dykes, sills or stocks. The composition of these igneous rocks does not have a bearing on whether the mineralizing system will contain gold or silver.

3) There is a definite combination of favourable lithology and structural preparation in all Disseminated Replacement Type deposits. Fluid access is via fracture conduits and prime exploration locales occur at the intersection of high angle faults with favourable lithostratigraphic units. Regional antiforms may direct and concentrate ore fluids in hinge zones. Hinge zones are also of exploration significance because of suitable permeability barriers which may exist (especially between carbonate - shale units), and the fracturing/brecciation that commonly occurs during fold deformation. Tectonic and hydrothermal breccias are commonly present in and ajacent to the ore zones.

4) No specific age of mineralization exists. In Nevada, Disseminated Replacement Type deposits range in age from Mesozoic to at least late Tertiary and there seems to be no good geological reason why deposits older than Mesozoic should not occur.

5) The hydrothermal systems which generate epithermal gold-silver deposits develop characteristic patterns of alteration, which are closely associated with major fault zones or fold hinge zones. In the Disseminated Replacement Type deposits, intense silicification results in the formation of jasperoid bodies. These bodies are typically developed best within fault zones and along carbonate/shale contacts, and are erratically mineralized. Jasperoid bodies may themselves constitute the ore zones (eg Taylor, Pinson, Preble), or they may occur as relatively unmineralized

bodies above and below the ore zones. Evidence of multiple episodes of brecciation and re-silicification in the jasperoid bodies is a positive sign. Carbonate removal, pervasive argillitization, and introduction of pyrite and carbon are also characteristic of Disseminated Replacement Type deposits. "Bleached" and iron stained rocks are important guides to the exploration geologist.

6) Vein types and their cross-cutting relationships help define a target area. Most of the Nevada deposits have late calcite veining cross-cutting oxidized rocks. Jasperoidal breccia and jasperoid veins generally occur near ore, even when they themselves may not carry high gold values.

7) Peripheral zones to high level porphyry systems are important exploration target areas.

One of the most cost effective approaches to defining exploration targets of this type lies in the careful interpretation of air photographs and the systematic ground truth evaluation and adjustment of such interpretation (Mason, 1985). This approach is especially useful for identifying structurally complex zones where faulting has allowed access and/or prepared the ground for mineralizing hydrothermal fluids, and for mapping outcropping zones of hydrothermal alteration. The resistant jasperoid bodies would be expected to show up on air photos and are an important prospecting guide. Geological target zones can then be explored by further detailed geological appraisal and geochemical assessment. Alteration and vein types, and their relationships to structures and different potential host lithologies must be mapped and reasonably understood prior to geochemical sampling. All this assumes that the exploration geologists involved have a good working knowledge of structure and hydrothermal alteration.

An important aspect of the Disseminated Replacement Type deposits is that the grade distribution and dimensions of any deposit will be intimately related to the degree of structural preparation involved. This is because structure is the key factor in opening the depositional site to mineralizing fluids. Thus the determination of ore reserves, and subsequent mine development and grade control, will depend on understanding the structural controls of the mineralizing system.

5.2 Geochemical Prospecting

Geochemistry plays an important role in the discovery and development of Disseminated Replacement Type precious metal deposits. Typically, Au predominates over Ag and is associated with Hg, As, Sb, and to a lesser extent with Tl, Ba, F, W and Mo. Careful follow up of all reported mercury and antimony occurrences is obviously an important part of any exploration programme for this type of deposit. Extremely high values for all these elements are not necessary to define a favourable area, instead, it may be more significant that the suite of indicator elements is present. Most known disseminated gold deposits in the Basin and Range province are exposed at the surface and considerable potential for concealed deposits exists. The need for exploration techniques that are suited to the detection of concealed mineralization is of prime importance and will be emphasized in this section.

The most serious problem in utilizing geochemical surveys in the search for auriferous deposits concerns adequate sampling and accurate gold analysis. Few problems are encountered with silver analyses. This section will consider the application of different sampling techniques, and sample media, to geochemical exploration for Disseminated Replacement Type deposits. The choice of sample media in a specific area would be governed largely by the local geochemical environment (nature and thickness of cover, climate, geomorphology, dominance of mechanical or chemical transport), and determined either by a pilot orientation survey at a similar deposit in a similar environment to that of the region to be explored, or, by selecting media that have given good results in other areas.

5 2 1 Lithogeochemical (rock) methods

In regions of extensive bare-rock exposure, rock samples collected from outcrops provide a logical medium for geochemical exploration. The category of outcrop samples embrace many different kinds of altered rock, vein fillings, and fracture coatings.

Altered rocks

The trace element content of a relatively small number of samples of unaltered and altered rock (argillitization, silicification, pyritization, hydrocarbons) may be used as an effective indicator of host rocks with ore potential or as an aid to eliminate barren areas in regional exploration. Closer to a potential Disseminated Replacement Type deposit, geochemical anomalies in altered and mineralized rock outcrops commonly exhibit zonal patterns related to the target ore zone (refer Figure 3.29). Geochemical assessment is facilitated by the large range of indicator elements, as is shown in Table 5.1 which summarizes the trace element characteristics of some Disseminated Replacement Type deposits in the Basin and Range province.

Vein filling and fracture coatings

Vein fillings and fracture coatings generally represent two different types of sample media. Most veins contain primary metal concentrations of hydrothermal origin (though they may be highly modified by oxidation near the surface) whereas many fracture coatings are formed by movement of meteoric water (Lovering and McCarthy, 1978).

A comparison of Fe oxide-rich fracture coatings and conventional rock chip samples at the Pinson and Preble disseminated gold deposits is reported by Crone et al, 1984. Iron oxide-rich coatings were selected as the sampling medium largely because of their demonstrated capacity to "scavenge" trace metals from solution, either by coprecipitation or adsorption (Levinson, 1974; Murray, 1975; Chao and Theobald, 1975; Hem, 1977). Also, previous studies have shown that Fe and/or Mn oxide coatings on stream boulders can effectively reflect upstream base metal mineralization (Carpenter et al., 1975, 1978) and that Fe oxides in fracture coatings contain anomalous base metal contents that reflect mineralization in the Silver City mining region of New Mexico (Watts et al., 1981).

Approximately 5 - 10 g of Fe oxide fracture coatings, and a normal rock sample free of obvious fractures or veining, were collected at each site and analysed for Au, Ag, Hg, Sb, As, Cu, Zn, Fe and Mn by a variety of

NAME AND LOCATION OF AREA	ORE ELEMENTS AND TYPE OF DEPOSIT	SAMPLE MATERIAL	TRACER ELEMENTS	COMMENTS
Bell mine, Jerrit Canyon, Nevada (Carraher, 1984)	Au; disseminated	Altered rock	Au, As, Sb Hg, Tl	As values have "bullseye" correlation with Au mineralization. Hg anomalies also occur along structures.
Cortez-Buckhorn area, Lander and Eureka Counties, Nevada (Wells and Elliott, 1971)	Ag, Au : vein and replacement	outcrop samples of fresh and altered rock	Ag, As, Au, Cu, Hg, Mo, Sb, Te, Zn	Large region As, Hg, and Sb correlate best with Ag and Au along mineralized fractures.
Detroit mining district, Juab and Millard Counties, Utah (Lovering and McCarthy, 1978)	Cu, Au, Ag : vein and replacement	jasperoid	As, Au, Bi, Cu, Hg, Mo, Pb, Sn	Large zoned anomaly ; significance not yet established.
Getchell mine, Humboldt County, Nevada (Joralemon, 1951)	Au : disseminated	Altered rock	Au, Ag, Hg, Sb, As, Tl, F	Anomalies reflect structure more than mineralization.
Gold Acres mine, Lander County, Nevada (Armbrustmacher and Wrucke, 1978)	Au : disseminated	altered rock	Hg, As, B, W, Ag	Elements listed are those associated with Au.
Mercur district, Tooele County Utah (Lenzi, 1973)	Ag, Au : vein and replacement	fresh and mineralized rock	Ag, Au, Cu	Anomaly zoned with Au in center, Ag outward along fractures, Cu farthest out.
Northumberland deposit, Nye County, Nevada (Motter and Chapman, 1984)	Au, Ag : vein and replacement	altered rock (jasperoid)	Au, Ag, Sb, Hg, Ba	Highest metal anomalies coincide with main mineralized area
Saddle prospect, Lander County, Nevada (Wargo and Powers, 1978)	Au : disseminated	soil	Au, As, Hg	
Taylor district, White Pine County, Nevada (Lovering and Heyl, 1974)	Ag-Sb, Cu, Pb : vein and replacement	altered rock (jasperoid)	Ag, Au, Cu, Hg, Pb, Sb, Zn	Highest metal anomalies coincide with main mineralized area.

Table 5.1 : Summary of some characteristics of lithogeochemical exploration case histories in the Basin and Range province, western U.S.A.

techniques (Crone et al., 1984). The histograms and estimated threshold values for Au, As, Sb and Hg in fracture coatings and rock chips at the Pinson and Preble deposits are shown in Figure 5.1. Geochemical anomalies determined from fracture coatings are typically more intense than those determined from rock samples. Using as a relative index of enrichment the ratio arithmetic mean (fracture coatings) / arithmetic mean (roch chips), the order of increasing enrichment in fracture coatings at the Pinson mine is Hg(3.42) < Au(3.61) < As(5.13) < Sb(14.37). At the Preble deposit, the order of increasing enrichment is Hg(1.85) < Au(3.13) < Sb(9.18) < As(9.72).

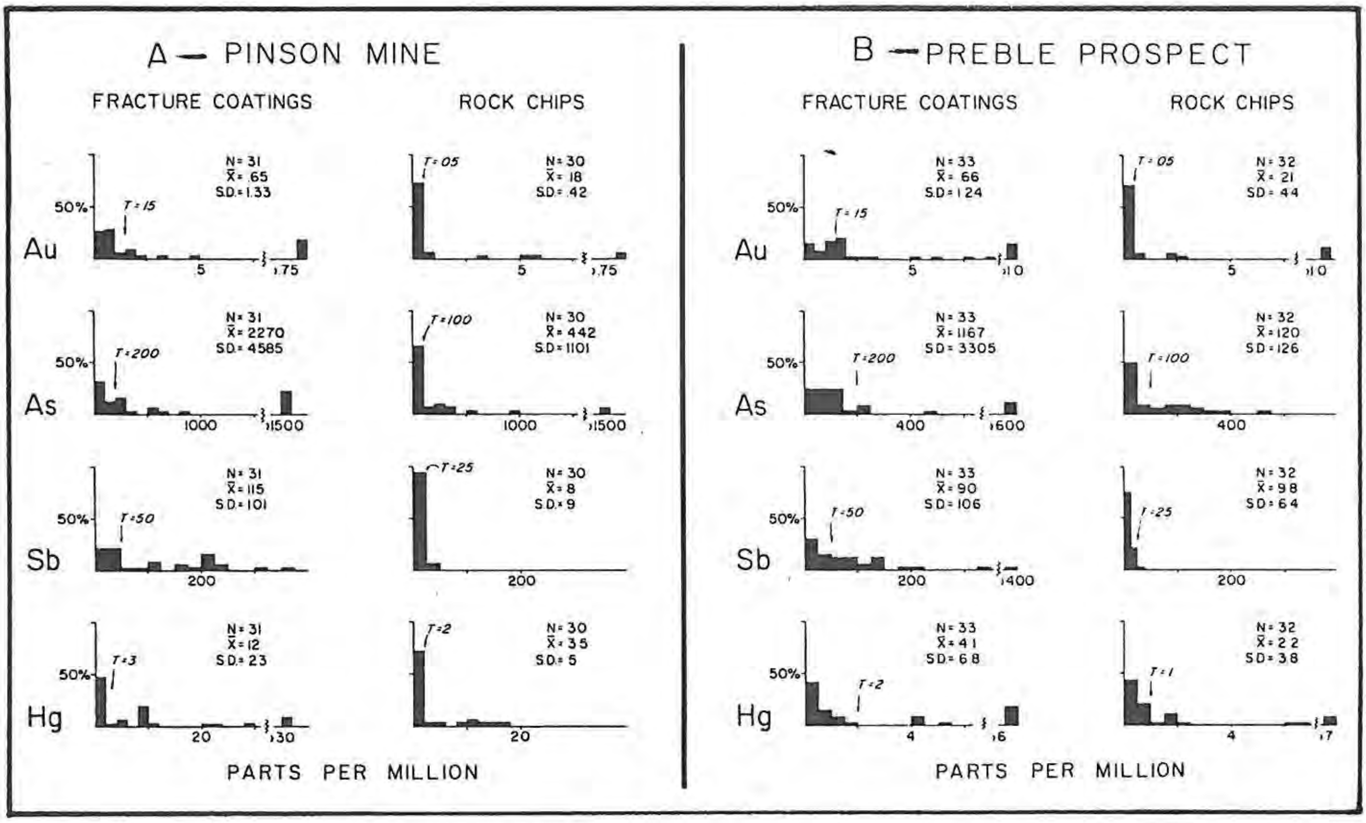


Figure 5.1 : Histograms for Au, As, Sb, and Hg in fracture coatings and rock chips at the Pinson mine (A) and Preble prospect (B). Key: Estimated threshold values (T) are indicated by arrows, arithmetic mean (x), number of samples (N) and standard deviation (S.D.) (Crone et al, 1984).

A comparison of the geometric means shows the same progression (Crone et al., 1984). For both deposits, As and Sb show maximum enrichment in fracture coatings. Au and Hg are also enriched in the coatings, but to a lesser degree. The size of anomalies indicated by fracture coatings are also somewhat larger than those indicated by the normal rock samples. (Figure 5.2). For both sampling media, a general order of increasing anomaly size is Au < Sb < Hg < As. The increased anomaly size, and enhanced

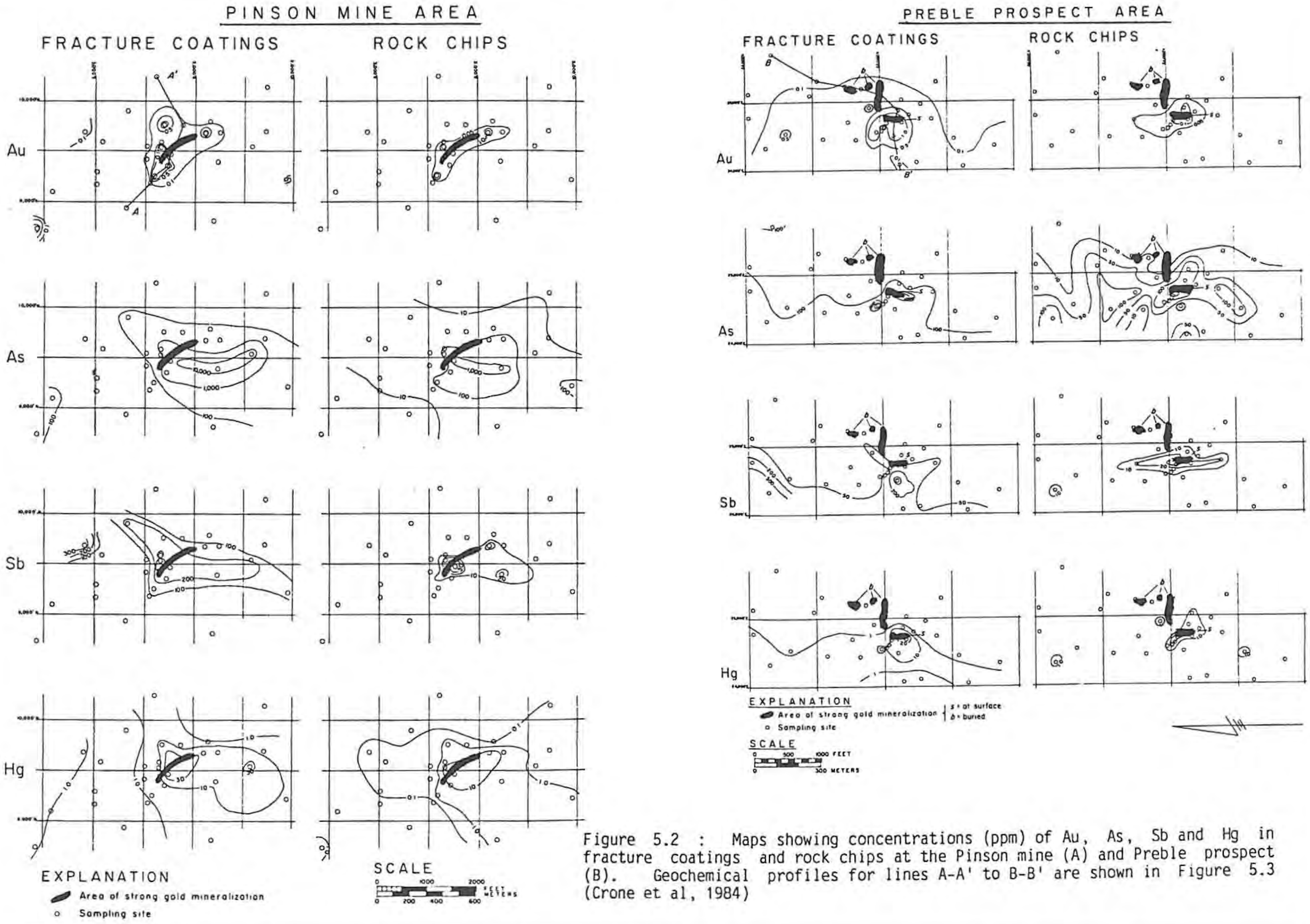


Figure 5.2 : Maps showing concentrations (ppm) of Au, As, Sb and Hg in fracture coatings and rock chips at the Pinson mine (A) and Preble prospect (B). Geochemical profiles for lines A-A' to B-B' are shown in Figure 5.3 (Crone et al, 1984)

values, for the fracture coating sample media is also apparent in the geochemical profiles taken across mineralized zones at the two deposits (Figure 5.3).

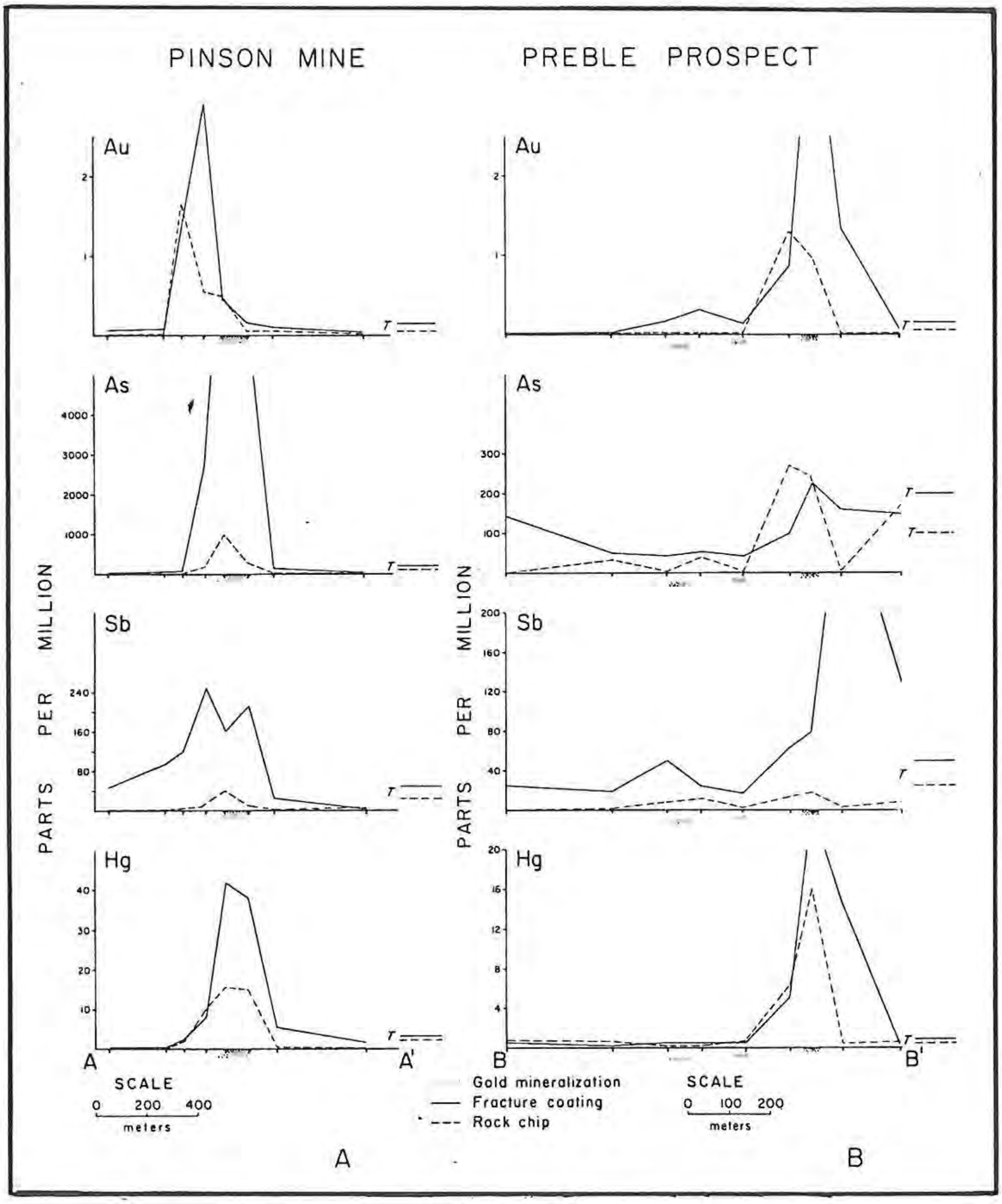


Figure 5.3 : Profiles for Au, As, Sb and Hg across the Pinson orebody (A) and Preble prospect (B). Location of profiles in Figure 5.2 (Crone et al, 1984)

5.2.2 Pedo (soil)- and hydrogeochemical methods

Soil and stream-sediment surveys remain the most commonly used and effective geochemical exploration methods for outcropping Disseminated

Replacement Type deposits. Standard fine-fraction stream sediment samples are especially useful during regional reconnaissance exploration of a large area and for detecting anomalies related to ore deposits exposed in small drainage basins. During this reconnaissance exploration stage attention should be directed towards identification of cobbles and pebbles of hydrothermally silicified and otherwise altered rock, which would be expected to persist in stream beds many kilometres downstream from deposits. Coatings of iron and manganese oxides deposited on ordinary stream bed pebbles may also contain anomalous metal contents, and can indicate the presence of mineralization in the upstream drainage basin (Lovering and Mc Carthy, 1978; Carpenter and Hayes, 1978).

Soil sampling is not well suited to rapid reconnaissance exploration of large areas and its use is best restricted to detailed exploration in small areas of known or suspected mineralization. In particular, the soil sample medium can yield anomalies that closely delineate ore targets in areas of low or moderate relief where bedrock is concealed beneath residual soil. It must also be borne in mind that strong soil anomalies for the volatile element Hg may be more closely related to faults and fractures than to subjacent ore deposits. This phenomenon is reported from the Getchell Mine, Nevada by Brooks and Berger (1978).

5.2.3 Atmogeochemical methods

Sampling of the atmosphere and soil for volatile gases or vapours emanating from ore deposits is a relatively new technique. According to Boyle (1979) gold forms no common inorganic volatile compounds. However some of the common associated minerals yield volatile gases, such as Hg vapour, SO_2, H_2S, CO_2, O_2, noble gases and organometallic compounds (Levinson, 1974; Joyce 1976; Mawson, 1984; Taylor et al., 1982). A major problem in using gases as a sampling medium is that their escape is highly dependant on atmospheric conditions and soil geochemistry. A falling barometer favours the emanation of gases and vapours from the soil, whereas rising pressure drives them back beneath the surface. Surface temperature also has an appreciable effect, vapours escape more readily on a hot day than on a cold one. Heavy rain may "wash" the air and surface soil clean of volatile gases. The composition of soils, especially the contents of organic materials, Fe-Mn oxide and hydroxides, clays and moisture also cause difficulties in the interpretation and reproducibility of the gas signal.

Although only very limited technical success can be ascribed to atmogeochemical exploration techniques, the method has considerable potential for the future. Its major attraction lies in the high mobility of gases which makes it possible to prospect deeply for blind ore deposits, some of which may not even have entered the weathering zone. Mercury gas in particular can be used as a pathfinder element for Disseminated Replacement Type deposits. A comparison study at the Getchell mine, Nevada, illustrated that Hg-vapour analyses better delineated the controlling Getchell fault system than conventional soil-Hg analyses, but was subject to high variability (Brooks and Berger, 1978). The recent introduction of a "mercury cup" has potential to obviate the extreme variability and bad reproducibility of conventional Hg-vapour analyses. This consists of a precious metal detector mounted in a plastic cup that is buried in the ground and allowed to collect mercury by amalgamation for a period of time varying between 15 and 45 days (Dunkhase, 1984). The device is later collected and analyzed for its mercury content. No details are available on cost, practical use, accuracy or successful case histories but the technique holds much promise.

5.2.4 Biogeochemical methods

Many attempts have been made to utilize the chemistry of plant samples in prospecting. The technique involves analysing the ash of selected parts of certain plants. It is not to be confused with geobotanical prospecting which relies on the recognigion of indicator plant species or plant growth abnormalities which can be correlated with anomalous soil chemistry overlying mineralization.

Brooks (1979, 1982, 1983) and Brooks et al (1981) has shown that plants are not effective accumulators of Au, though some varieties of the horsetail Equisetum are significant accumulators of the pathfinder As. Twigs of shrub alder collected in the vicinity of several mineralized zones in the northern forests of Saskatchewan, Canada, commonly contain in excess of 50 ppb Au in the ash of the outermost 50cm of twig growth (Dunn, 1984).

Background value are about 10 ppb Au. Huang (1984) reported slightly elevated Au values in sagebrush cover overlying the Borealis disseminated gold deposit, Nevada.

The use of vegetation in geochemical exploration has not been readily accepted as it is considerably more complex and time consuming than using soil geochemistry, with little added benefit in terms of reliability, anomaly contrast and cost.

6 CONCLUSION

In the Basin and Range province of the western United States, large, low- to medium-grade disseminated gold-silver deposits constitute a major resource. These deposits normally exhibit high Au/Ag ratios (greater than 20:1) although Ag may predominate in some cases eg Taylor silver district. Deposits commonly range in grade from 1.5 - 11gm Au/tonne and vary in size from 1.0 - 15 million tonnes.

Published reserve data for 29 sediment-hosted, disseminated precious metal deposits in the western United States indicate a median gold grade of 2.5 gm Au/tonne and a median tonnage of 5.1 million tonnes (Bagby and Berger - in press). The largest deposits in terms of gold grade are Carlin (10 million tonnes at 10.97 gm Au/tonne) and Jerritt Canyon (12.76 million tonnes at 8.33 gm Au/tonne).

The ore bodies exhibit a variety of geometries, such as tabular zones concordant with or cutting across the bedding, or may be confined to fault zones. High angle faults are important controls of ore-fluid plumbing. Ore body sites tend to be controlled by the intersection of such faults, or fold structures, with favourable carbonate unit host rocks. These orebodies can also be considered as distal, low temperature equivalents of metasomatic skarn deposits, and the formation of replacement bodies of jasperoid is a feature of some.

Mineralization occurs as microscopic to sub-microscopic particles of gold and silver. These occur primarily in association with As, Sb and Hg as fracture fillings and coatings on pyrite grains, and to a lesser extent with organic material, hydrothermal silica and introduced sulphides. The uppermost portions of many orebodies have been subjected to varying intensities of acid leaching and are strongly altered and oxidized. The rocks in this zone consist mainly of fine-grained quartz and illite, with lesser kaolinite, sericite, and minor montmorillonite and iron oxides. Gold in this material occurs as tiny particles (up to 10 microns diameter) contained either in quartz or associated with iron oxides or clay minerals. Generally it is the oxidized portion of the deposits that is mined although unoxidized carbonaceous deposits can be treated by including a preoxidation step in the milling process.

There is a persistent geochemical association of Au, Ag, As, Hg, Sb and Tl, and locally of F, W and Ba. This is of considerable importance in geochemical prospecting for deposits of this type. Methods of geochemical exploration and recognition criteria important for the discovery of these deposits have been considered in this dissertation.

It is concluded that potential exists for deposits of this type in a variety of geological settings. Similar deposits may be expected to occur anywhere igneous activity has developed a hydrothermal system within thick sections of carbonate rocks.

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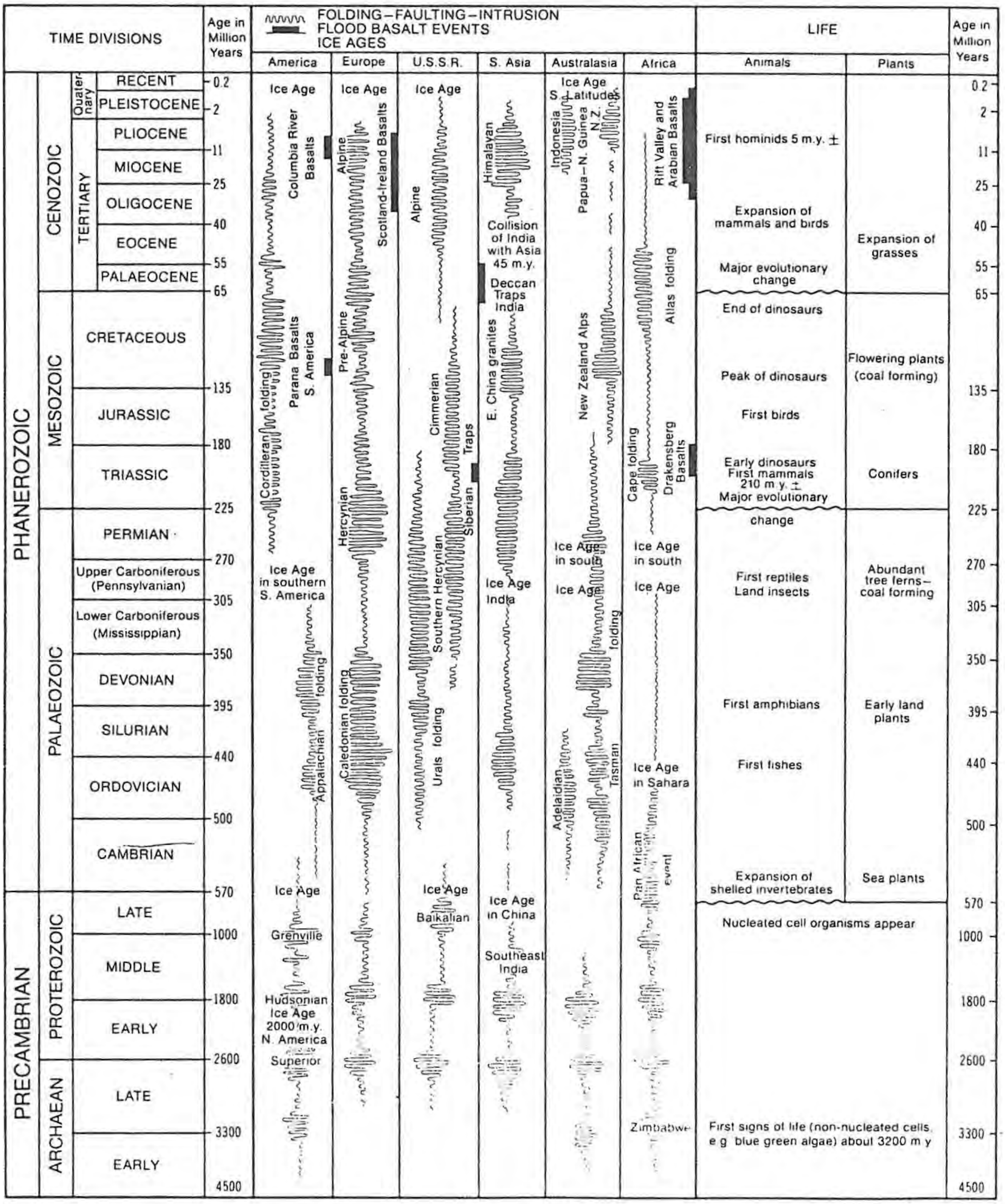
APPENDIX A



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