

**GEOLOGICAL CHARACTERISTICS OF SELECTED DISSEMINATED
SEDIMENT-HOSTED GOLD DEPOSITS IN NEVADA, U.S.A
IN SEARCH OF AN EXPLORATION MODEL**

by

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ABSTRACT

Sediment-hosted disseminated gold deposits in Nevada, western United States are major gold sources and contain reserves in excess of 1 500 metric tons of gold (Percival et al., 1988). Discovery of these deposit types continues at a pace, with Placer Dome announcing a major discovery, Pipeline, to the south of the Gold Acres Mine, along the Battle Mountain - Eureka Trend in 1994 (The Northern Miner, 1994).

Host sediments favoured for disseminated gold mineralisation are thinly bedded silty limestones, carbonate debris flows and to a lesser extent shale, chert and sandstone. The distribution of mineralisation is controlled essentially by the intersection of high-angle faults, which acted as conduits for hydrothermal fluids, with favourable host lithologies, anticlines, low-angle faults and other high-angle faults. Geochemical signature for these deposits is simple being Au, Ag, As, Sb, Hg, Tl, Te, F and Ba, but individual element concentrations vary greatly between and within deposits. Age of mineralisation is cause for considerable debate, and ages ranging between isotopic dates of approximately 117 Ma to early to mid-Tertiary (30-40 Ma) are proposed.

Most of these deposits are situated along three major trends namely the Carlin, Battle Mountain - Eureka and Getchell trends. The Battle Mountain - Eureka trend and, to a lesser extent the Carlin trend, are defined by major linear aeromagnetic and gravity anomalies, which are believed to reflect deep-seated structures. Most deposits are hosted in autochthonous Devonian, thinly bedded, silty limestones that occur as windows through what is believed to be allochthonous Ordovician siliciclastic sediments, which were transported from west to east along the Roberts Mountains thrust during the late-Devonian Antler Orogeny. However, recent fossil dating of what were thought to be Ordovician siliciclastic sediments, gives a Devonian age. This questions the age of Ordovician sediments at the other deposits and the interpretation of the structural windows in which deposits are located. Fault-bounded, proximal, carbonate debris-flow breccias are now recognised as a major host to mineralisation. These debris flow breccias, together with interbedded carbonate and siliciclastic sediments, carbonaceous sediments and soft sediment deformation are all characteristics of lithologies in pull-apart basins which develop along a major strike slip faults.

It is proposed that sediment-hosted disseminated gold mineralisation is controlled by the distribution of deep-seated long-lived, predominantly right-lateral strike-slip faults. It is along these strike-slip faults that syn-sedimentary pull-apart basins developed, within which sediments favoured by epigenetic gold mineralisation were deposited. These pull-apart basins were then overprinted by post-depositional extensional structures, such as negative flower structures. Igneous intrusions and hydrothermal cells have exploited these extensional structures in both compressional and extensional regional tectonic regimes. This model explains the characteristics of the host sediment at many of the deposits, the spatial relationship between igneous intrusion and mineralisation, spanning the period Cretaceous through to mid-Tertiary, the distribution of deposits as districts along major regional trends and why hydrothermal activity is noted between deposit districts but with no complementary mineralisation. Mineralisation is controlled predominantly by high angle structures and although the recent age for mineralisation at the Betze/Post deposit is ~ 117 Ma (Arehart et al., 1993a), placing it in the compressional Sevier Orogeny, these high-angle structures would be developed within local extensional tectonic domains as described above. This model can, and should, be applied to other areas of the world where similar geological features exist.

In exploring for these deposits in Nevada the distribution of Ordovician siliciclastic sediments should be reviewed, especially where spatially associated with deep regional structures. Ordovician sediments have historically been regarded as unfavourable, hence large areas for potential exploration have been ignored but with new ages for these sediments this opens large areas for potential discoveries.

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1. INTRODUCTION

Invisible, dispersed, bulk-minable, disseminated and Carlin-type gold deposits are all different names which have been given to the major gold deposits being developed predominantly in Nevada, U.S.A. Currently the favoured description of these deposits and what is used in this dissertation is "sediment-hosted disseminated gold deposits". Although the bulk of the production from sediment-hosted disseminated gold deposits comes out of Nevada, U.S.A., similar deposit types are now being recognised other states within the U.S.A, Mexico, China and from around the Pacific Rim, specifically Irian Jaya, Indonesia.

Bagby and Berger (1985) and Tooker (1985) collated all existing data pertaining to sediment-hosted disseminated gold deposits and formulated descriptive empirical models that emphasized the geologic-, geochemical- and geophysical-occurrence. However, these empirical models were based on data that was collected from the oxide ores which was the focus of mining in the 1970's to mid- to late 1980's. With advances in technology in treating low grade refractory ores, mining depths have increased to include unoxidised ore bodies. Current geological research has shifted to these unoxidised ores that have not been modified by supergene processes. This research is important in understanding the distribution and primary characteristics that control hydrothermal, sediment-hosted disseminated gold mineralisation.

Exploration programmes for sediment-hosted disseminated gold mineralisation should be based on a sound ore-occurrence model that should be modified and updated as field and academic research data on both regional geological and deposit scale becomes available. The aim of this dissertation is to develop an ore-occurrence model for the sediment-hosted disseminated gold deposits based predominantly on recent literature and to a lesser extent older literature. Twenty three deposits were studied, ten, nine and four along the Carlin, Battle Mountain-Eureka, Getchell trends respectively. The characteristics of the deposits are summarised in Appendices A, B, and C, and from these characteristics an ore-occurrence model has been established. This ore-occurrence model should help in focussing an exploration programme to the most suitable areas likely to contain hydrothermal mineralisation and ultimately a deposit, not only in Nevada, U.S.A., but elsewhere in the world where similar settings are suspected..

2. REGIONAL GEOLOGY

Sediment-hosted disseminated gold deposits occur throughout the U.S.A but the majority lie within the Great Basin which covers most of Nevada, southern California and Oregon, and western Utah (Fig. 1). The regional geology of Nevada is described in detail by Stewart (1980) and other workers and the following section serves only as an introduction and to put local deposit scale geology into perspective.

Nevada lies almost entirely within the Great Basin region of the Basin and Range physiographic province, a region characterised by a series of generally north to northeast trending mountain ranges separated by deep alluvial valleys (Fig's 1 and 2).

The oldest rocks exposed in Nevada are the Proterozoic shallow water sediments deposited on a continental shelf. These thicken westwards along the then, western margin, of the American Precambrian craton (Fig's. 3 and 4), (Stewart, 1980). Although the Precambrian craton edge is not exposed in north central Nevada, it is inferred from the position of Mesozoic and Tertiary granitic intrusions which have initial $^{87}\text{Sr}/^{86}\text{Sr}$ compositions of 0.708 (Farmer and Depaolo, 1983) and 0.706 (Kistler, 1983), (Fig. 5). The inferred Precambrian craton edge, based on isotopic data, trends roughly north to north-northeast through central Nevada (Fig. 5). A paleothermal anomaly is roughly coincident with the 0.706 isotopic line (Cunningham, 1988), (Fig. 4). The Proterozoic rocks are divided into two depositional provinces, one of quartzite and the other of siltstone, carbonate and quartzite (Stewart, 1980). These rocks are not known to host mineralisation but have been inferred to be possible source rocks of gold and related metals for the Carlin-type deposits by Seedorf (1991).

The Paleozoic stratigraphic section is defined by thick sequences of three facies equivalent sedimentary provinces which were deposited from the Ordovician to late Devonian (Fig's 3 and 4). These provinces, from east to west, are; (1) the eastern, carbonate facies comprised predominantly of limestone, dolomite and silty limestone deposited on the continental shelf, (2) transitional facies sediments comprising mixed siliceous, clastic and carbonate sequences deposited on the outside edge of the shelf margin to the slope (3) western facies, fine grained

siliciclastic sediments interbedded with intermediate to basic volcanics deposited in deep water (Fig. 4), (Stewart, 1980; Rota, 1991).

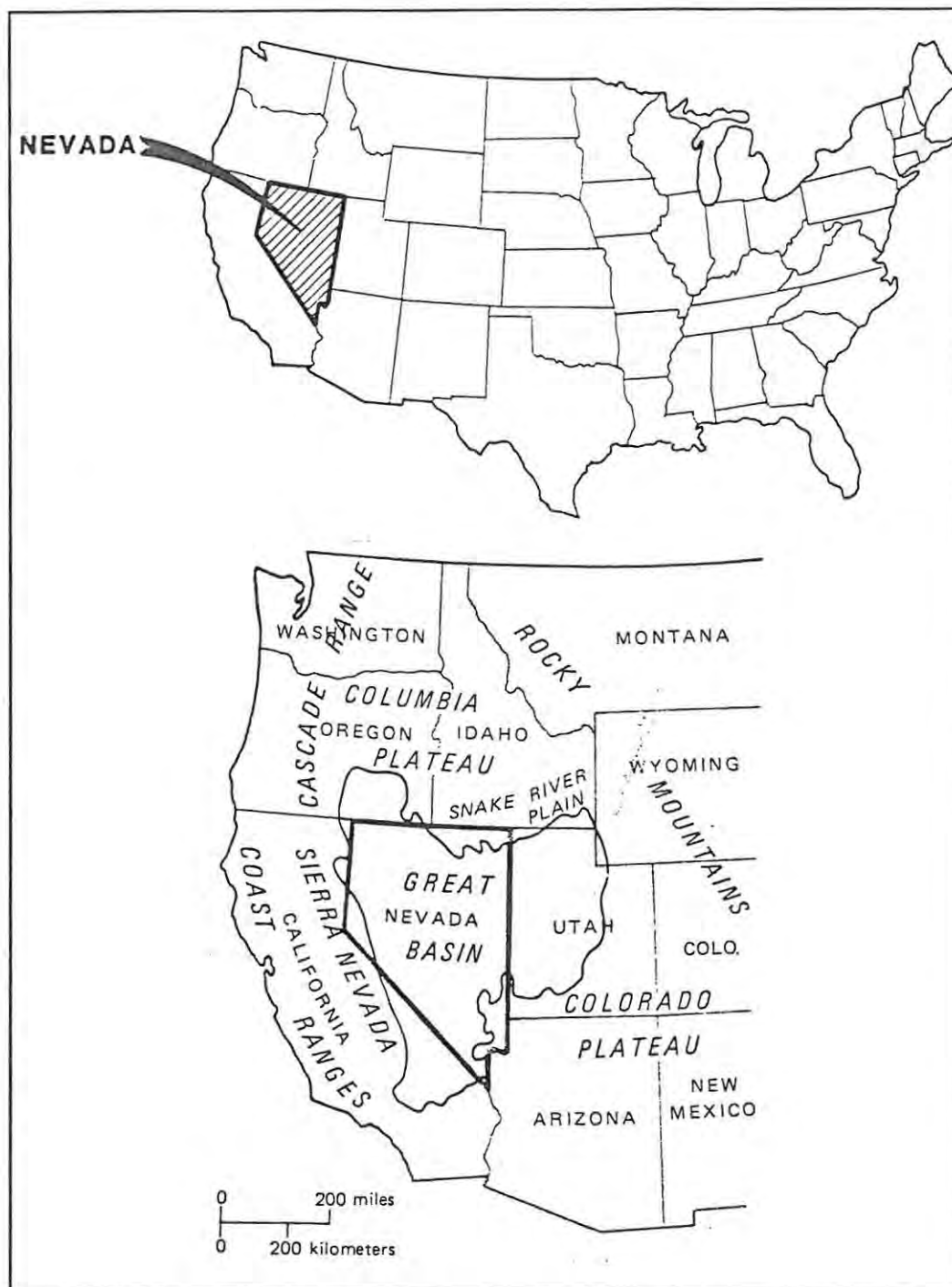


Figure 1. Location map of Nevada and the major physiographic features of the western United States (modified from Stewart, 1980 and Struhsacker, 1986).

From the late Devonian through to late Tertiary, the Great Basin has undergone many different tectonic orogenies, intrusive and metamorphic cycles. In the late Devonian to early

NEWMONT EXPLORATION LIMITED



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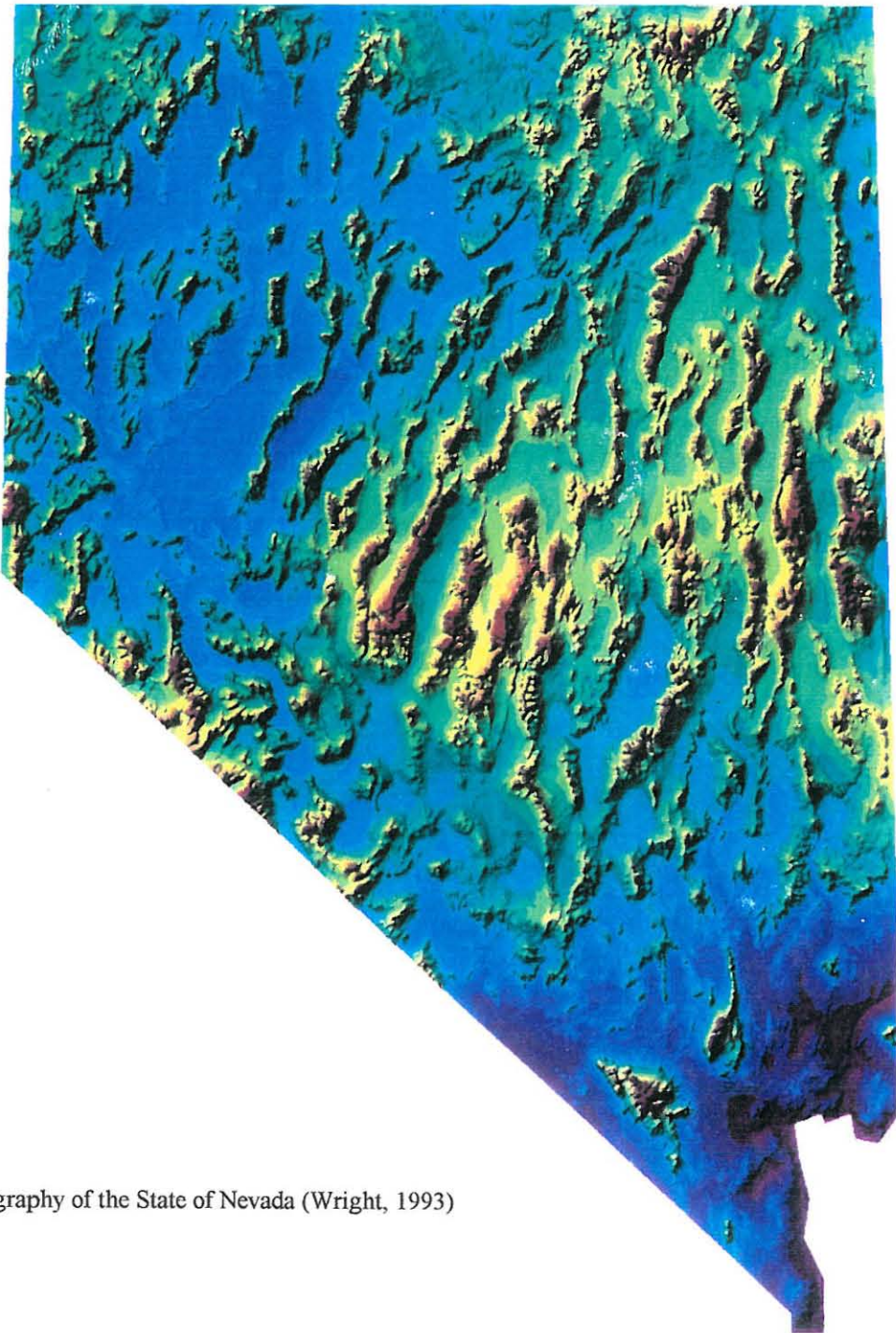


Figure 2. Topography of the State of Nevada (Wright, 1993)

Illumination: Decl. 31S, Incl. 50
Coloration: Linear
Units: ft

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TOPOGRAPHY
STATE OF NEVADA
Scale 1:3,750,000

Mississippian the western facies siliciclastic rocks were thrust over the eastern facies carbonate rocks along the Roberts Mountains Thrust (hereafter RMT) during the Antler orogeny (Fig. 4), (Roberts, 1966, Stewart, 1980). The transported western facies rocks are also described in the literature as eugeosynclinal rocks, the Roberts Mountains allochthon, allochthonous western facies sediments, upper plate rocks, while the carbonate rocks are referred to as miogeosynclinal rocks, autochthonous eastern facies and lower plate rocks. The western siliceous facies rocks are thought to have been transported as much as 145 kilometres over coeval carbonate lithologies (Stewart, 1980). The positive identification of the RMT is, in fact problematical in that it varies from a lithological contact to a breccia zone 15 metres thick in the Carlin trend (Rota and Hausen, 1991). On most regional maps the RMT is shown and regarded by many American geologists as a single thrust plane rather than a thrust fault zone comprised of many discrete thrust faults. Smith et. al., (1991), in a palinspastic restoration of Cenozoic extension of central and eastern portions of the Basin and Range Province have shown that silicified and breccia fault zones previously mapped as the RMT are in fact moderate to high angle normal faults and are actually post- early Cretaceous in age. Thorman et. al., (1991) also believe that many of the faults previously mapped as RMT are actually representative of middle Mesozoic and younger tectonics and not the late Devonian - early Mississippian Antler orogeny. In the northern Simpson Park Range and in the Cortez Range, the RMT has been placed arbitrarily at the contact between carbonate and siliceous rock and subsequent drilling as revealed the contact to be high angle faults. Schull (1991) believes that the transition from carbonate to siliceous facies in the northern Carlin trend is part of a normal sedimentary cycle and not what is commonly believed and described to be a structural contact. Because of the competency contrast between siliceous and carbonate rocks, stress will be taken up along this plane, leading some workers to interpret movement as part of the RMT event, although the lithologies are part of a normal sedimentary sequence. The positive identification of the RMT thrust is important in exploration in that; (1) what was previously mapped as thrusts may actually be high faults which are known to be important controls on mineralisation and (2) what was thought to be Ordovician lithologies may actually be Devonian in age and the favoured host for mineralisation may only be buried at a shallow depth.

The compressive Antler orogeny produced the Antler highland, which had a north-northeast trend through central Nevada, from which sediment was shed eastward into the Antler Flysh

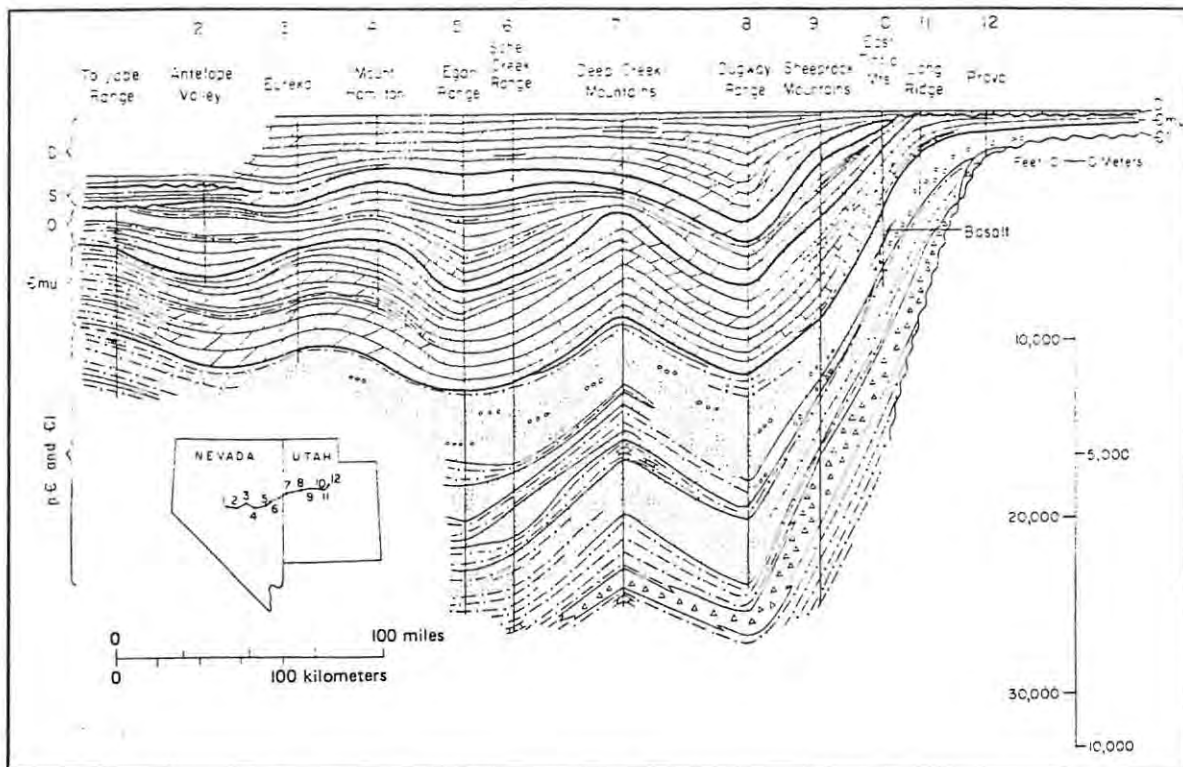


Figure 3. Cross section of Proterozoic and Paleozoic rocks across central Nevada. ps and ε1 = Proterozoic and lower Cambrian rocks, smu = middle to upper Cambrian rocks; O = Ordovician rocks; S = Silurian rocks; D = Devonian rocks (from Stewart, 1980).

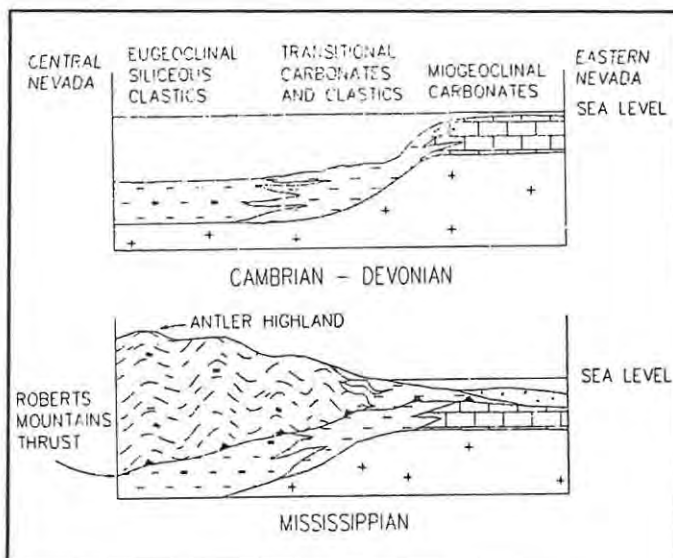


Figure 4. Generalised cross section showing distribution of Paleozoic sedimentary rocks and depositional environments, top, and the Antler highland formed during late Devonian - early Mississippian orogeny, bottom (from Rota and Hausen, 1991).

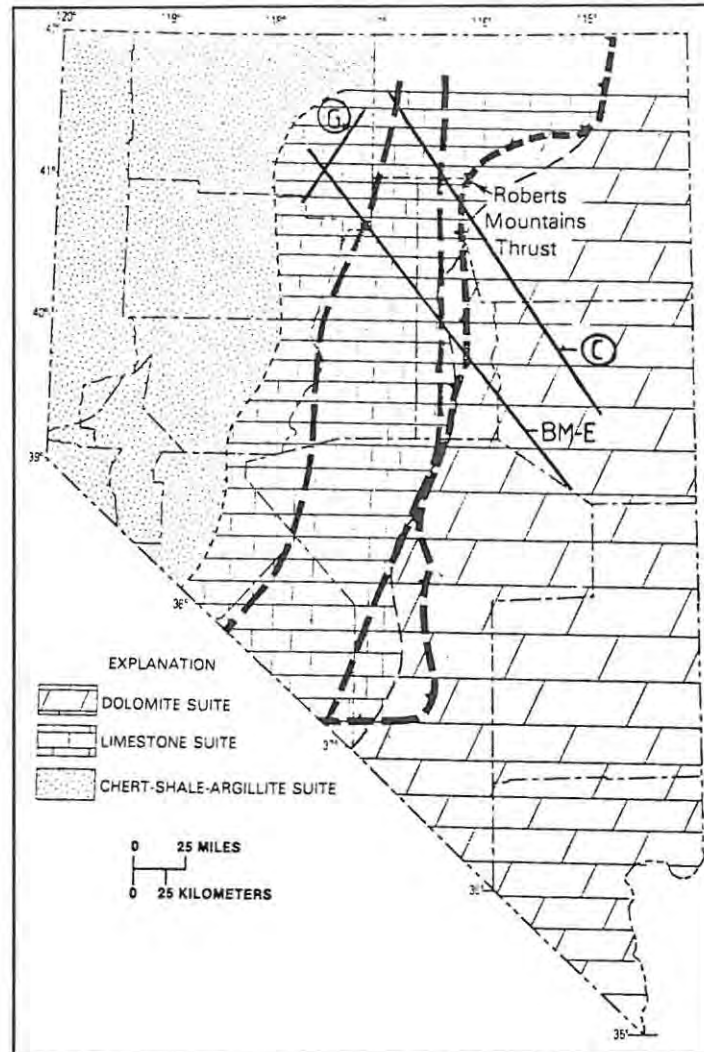


Figure 5. Palinspastic map of Nevada showing distribution of Paleozoic rocks, the approximate distribution of the RMT, the approximate zone containing Mesozoic to Tertiary plutons thought to represent the western Precambrian craton edge, and the mineral trends. Dashed line with ticks = RMT, western dashed line = $^{87}\text{Sr}/^{86}\text{Sr} = 0.706$ isotopic line, eastern dashed line = $^{87}\text{Sr}/^{86}\text{Sr} = 0.708$ isotopic line, solid black lines C, BME and G the Carlin, Battle Mountain - Eureka and Getchell trends respectively (modified from Cunningham, 1988 and Adams and Putman, 1992).

Basin, up to 4 500 metres thick in places, during the Mississippian-Permian times on top of the Paleozoic carbonate platform sediments, (Fig. 4), (Poole et. al., 1983). Sediment deposited during the Mississippian-Permian times is known as the Mississippian Permian Overlap Sequence (Stewart, 1980). Some rock units within the Mississippian Permian Overlap Sequence are important hosts of Carlin-type mineralisation. They include the Pilot shale, Joanna Limestone, Chainman shale, Havallah Sequence and the Etchard Formation (Table 1), (Appendices 1, 2 and 3).

Following the Antler orogeny, Ketner (1977) describes the Pennsylvanian orogeny which essentially comprises further uplift of the Antler highland (Stewart, 1980). There are no major structures associated with this orogeny, only major unconformities as sediment was shed to the west and east of this highland (Ketner, 1977; Stewart, 1980).

During the late Permian to early Triassic, an east-verging thrust-and-fold belt formed during the Sonoma orogeny juxtaposing clastic terranes of the upper Havallah Sequence against rocks of the Roberts Mountains allochthon and Mississippian Permian Overlap Sequence along the Golconda thrust (Stewart, 1980). A south verging fold-and-thrusting belt has been described in the northern Independence Range by Daly et. al., (1991) and they believe that this southward directed tectonics is part of the Sonoma orogeny. Oldow et. al., (1989) believe that the tectonic events, from the Antler through to the Sonoma orogeny, all belong to the same extended event.

Widespread plutonism, mid-crustal metamorphism and eastward as well as westward directed thrusting took place late Jurassic and early Tertiary (Fig. 6), (Thorman et. al., 1991). Eastward directed thrusting, folding, crustal thickening and metamorphism took place during the Sevier orogeny in eastern Nevada and western Utah. Thrusting related to this orogeny has been described to span the period from the late Jurassic (Wiltschko and Dorr, 1983) to Paleocene (Villien and Kingfield, 1986), (Fig. 6). However, most workers date the Sevier orogeny as late Cretaceous (Fig. 6), (Thorman et. al., 1991).

A major plutonic event, comprising of granite to granodiorite, took place early- late Jurassic (Fig. 6), (Stewart, 1980; Morton et. al., 1977; Thorton et. al., 1991). Many of these intrusives are spatially associated with sediment-hosted deposits. Examples are the Goldstrike Stock at Betze/Post and Blue Star/Genesis and the Mill Stock at Cortez (Table 1). Intrusives have been documented to occur in the early Cretaceous and in the late Cretaceous (Fig. 6), (Stewart, 1980). Early Cretaceous dykes intrude the Carlin and Meikle deposits along the Carlin trend (Bettles and Lauha, 1993a; Myers, 1993). The Osgood Mountain (90 Ma) and a quartz monzonite stocks (150 Ma) along the Getchell and Battle Mountain - Eureka trends pre-date gold mineralisation but are spatially related to it (Hays and Foo, 1991; Bloomstein et. al., 1991).

Three metamorphic events have been documented by Thorman et al., (1991) to occur in the Mesozoic, (1) a thermal event at ± 163 Ma, (2) a regional metamorphic event at ± 110 Ma and (3) a thermal event at ± 85 Ma (Fig. 6). The thermal metamorphic events have occurred prior to intrusives while there is no documentation on intrusives accompanying the regional metamorphic event at ± 110 Ma for the ranges studied by Thorman et al., (1991), (Fig. 6). The thermal metamorphic event at ± 110 Ma may be important in the genesis of some of the deposits as recent dates for mineralisation span the period 110 Ma to 117 Ma (Arehart, 1993a).

The Cenozoic was dominated by two extensional tectonic regimes, the first initiated as early as 45 Ma, culminating at ± 20 Ma and is characterised by high angle normal faults, normal listric faults, the second initiated at ± 20 Ma with accelerated extension occurring after 10 Ma (Thorman et al., 1991; Daly et al., 1991; Stewart, 1980). The second extensional regime is dominated by fairly closely spaced high angle listric faults which account for the present day Basin and Range Province and the tilting of the strata (Fig. 2), (Stewart, 1980).

Mid-crustal metamorphic core complexes, derived from depths of between 14 km and 15 km were juxtaposed against shallow crustal rocks in eastern Nevada during Cenozoic crustal extension (Stewart, 1980; Smith et al., 1991). Smith et al., (1991), in a palinspastic reconstruction across a 400 kilometer section of the central and eastern Basin and Range Province, determined that the Cenozoic extension averaged approximately 55% and was spread homogeneously over the whole section, although some basins did have slightly more or less extension than adjacent basins. Significant strike slip faulting accompanied the Cenozoic extension, the most prominent being the right lateral Walker Lane trend on the south western border of Nevada. This is thought to overprint an older structural zone and to have started at ± 15 Ma (Stewart, 1980). Putnam and Hendriques (1991) believe that the Battle Mountain - Eureka and Carlin trends are synthetic R_1 shears, part of the regional Walker Lane and San Andreas shear zones.

During the Cenozoic, lacustrine and fluvial deposits and ashflow tuffs dominated the first period of extension while alluvial fan gravels, rhyolite and basalt to basaltic andesite were

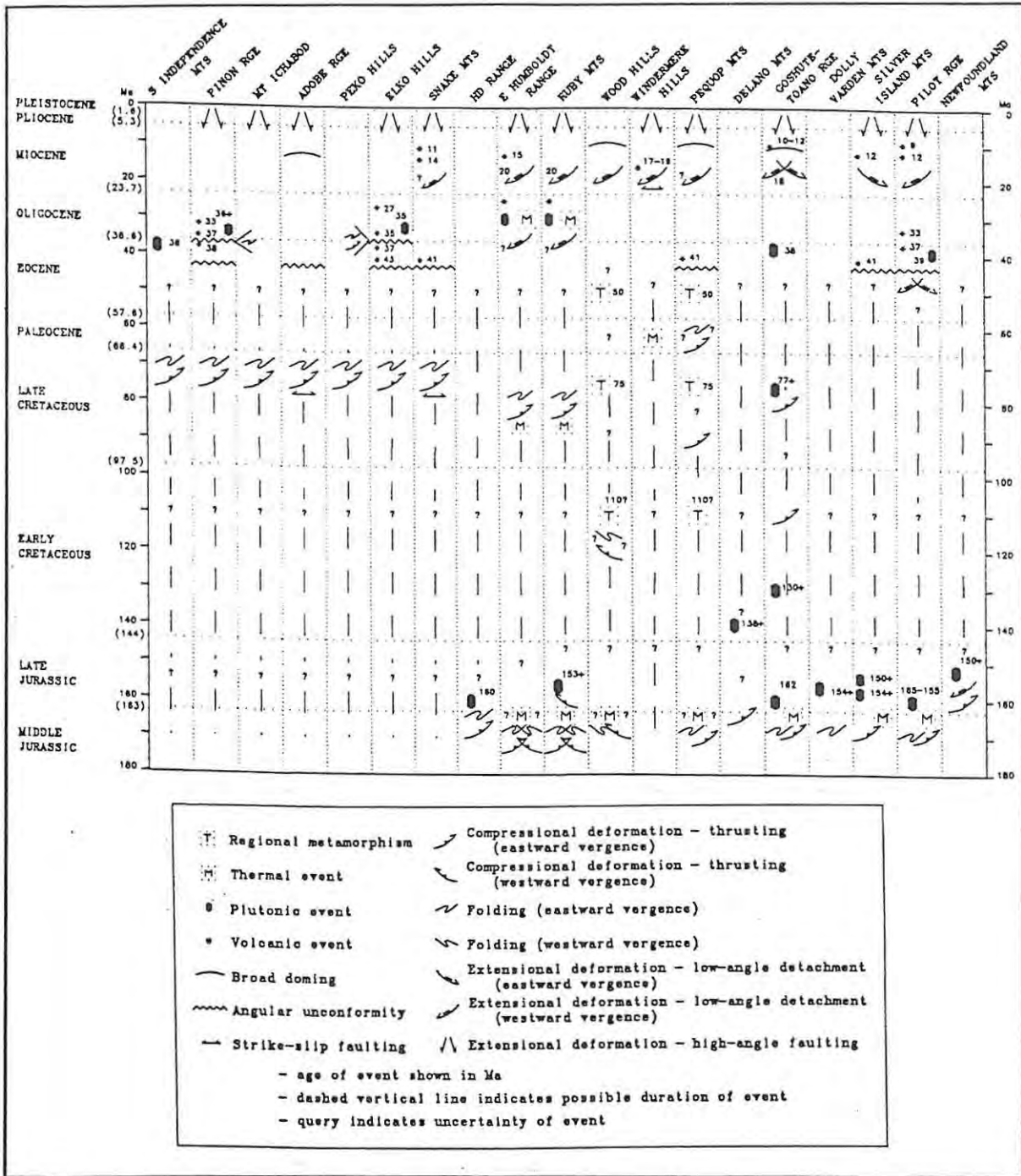


Figure 6. Diagram showing Paleozoic and Cenozoic tectonics of a few ranges in north-central Nevada. The placement of symbols denoting deformation events of questionable age is arbitrary and may bias the visual interpretations of the timing of events. Dashed vertical lines indicate the time span within which events most likely occurred (from Thorman et. al., 1991).

deposited during the second extensional period (Stewart, 1980). A major igneous event, responsible for ashflow tuffs, occurred at ± 36.6 Ma (Fig. 6), (Mckee and Silberman, 1970).

Basalts and basaltic andesites were extruded along the north central Nevada Rift at ± 16 Ma (Stewart, 1980). In the process of exploration for sediment-hosted, disseminated deposits in Nevada it is important that the stratigraphic, intrusive and structural history be documented (Figure 6) for individual ranges because mineralised "trends" clearly cross cut stratigraphic, intrusive and tectonic provinces (Fig's. 2, & 5). It is only by systematically documenting the regional geological parameters that subtleties can be noted which may be important in localised control of mineralisation.

3. DEPOSIT TRENDS

Roberts (1966) was the first to recognise the north west alignment of mineralised windows of eastern facies carbonate rocks which he defined as the Carlin and the Battle Mountain - Eureka trends (Fig's. 7 & 8). Since then, exploration companies have focussed most of their exploration for Carlin type mineralisation along the Carlin and Battle Mountain - Eureka trends as well as the Getchell and Jerrit Canyon trends (Bagby and Berger, 1985; Percival et. al., 1988).

The Carlin trend is approximately 65 kilometres long, extending from Dee in the north to South Bullion in the south and is approximately 8 kilometres wide (Fig's, 7 & 8), (Christensen, 1994). Some workers (Bagby and Berger, 1985) regard the Vantage deposits, at Alligator Ridge, as the southern extension of the Carlin trend (Fig's. 7 & 8). The trend is further defined by regional linear gravity and magnetic anomalies, interpreted as Mesozoic and Tertiary intrusions, while in the northern part of the trend by a north-west trending anticline (Fig's 9 & 10). No single, near surface, through going structure has been located or is known to control mineralisation in the Carlin trend (Christensen, 1993). Most of the high angle faults that do control mineralisation are at a high angle to the trend (Rota, 1991; Rota 1994) (Table 1).

Putnam and McFarlane (1990) have suggested that the trend is defined by a series of *en-echelon* conjugate faults, components of a right lateral transcurrent fault system. Most workers have associated the Carlin trend with high angle faults which are Mesozoic and younger in age. Indirect evidence of structural activity, dates back to at least synsedimentary Devonian-Silurian age, and is given by, (1) Schull (1991), transition of lithologies from

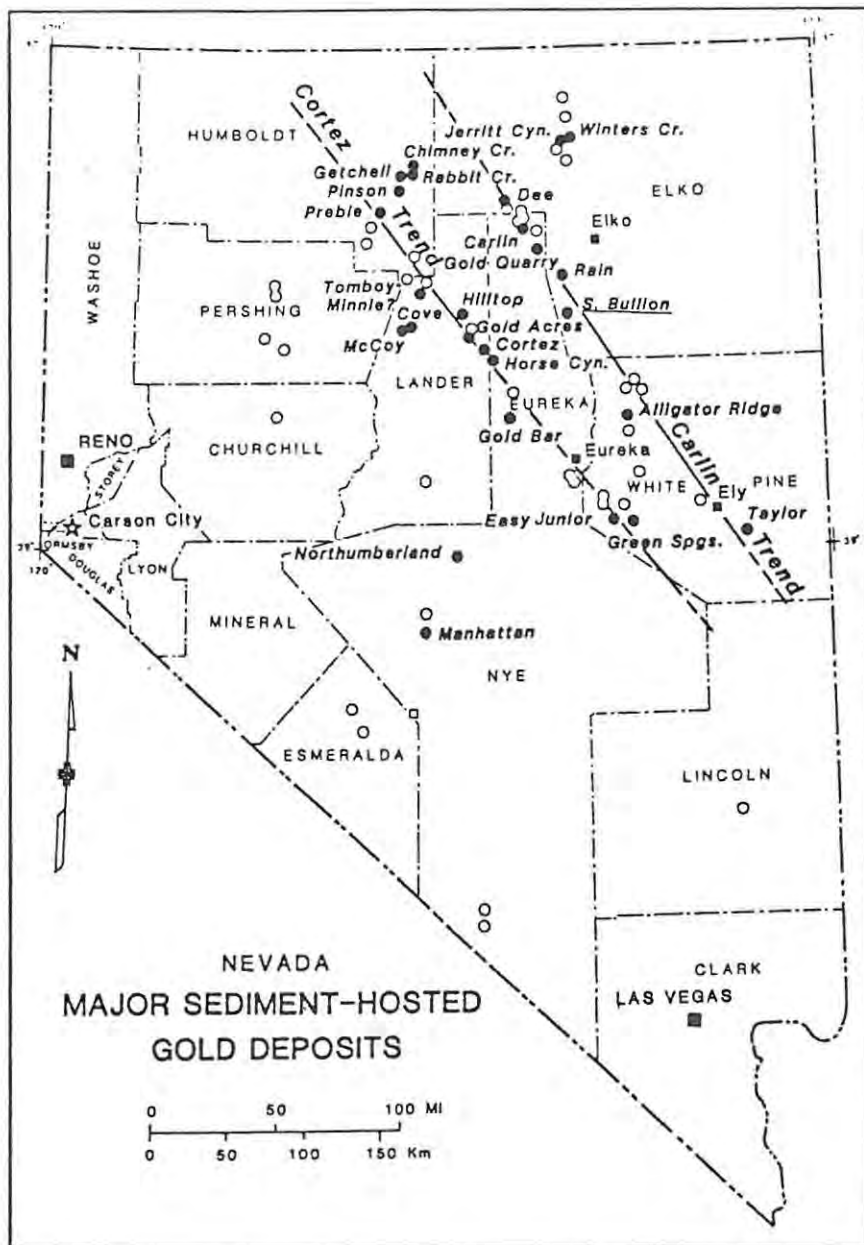


Figure 7. Location of sediment-hosted deposits in Nevada (Adams and Putman, 1992).

carbonate to siliciclastic in localised small basin controlled by synsedimentary faults, (2) Williams (1994) abundant carbonate debris flow breccias within deep water siliciclastic sediments in localised basins proximal to carbonate ledges, (3) Rota and Hausen (1991) soft sediment deformation indicating rapid loading in the Gold Quarry deposit and (4) Rota and Hansen (1991) who argue that the identification of the RMT depends on whether the Rodeo Creek is Ordovician or Devonian in age. These factors point to characteristics of varied and

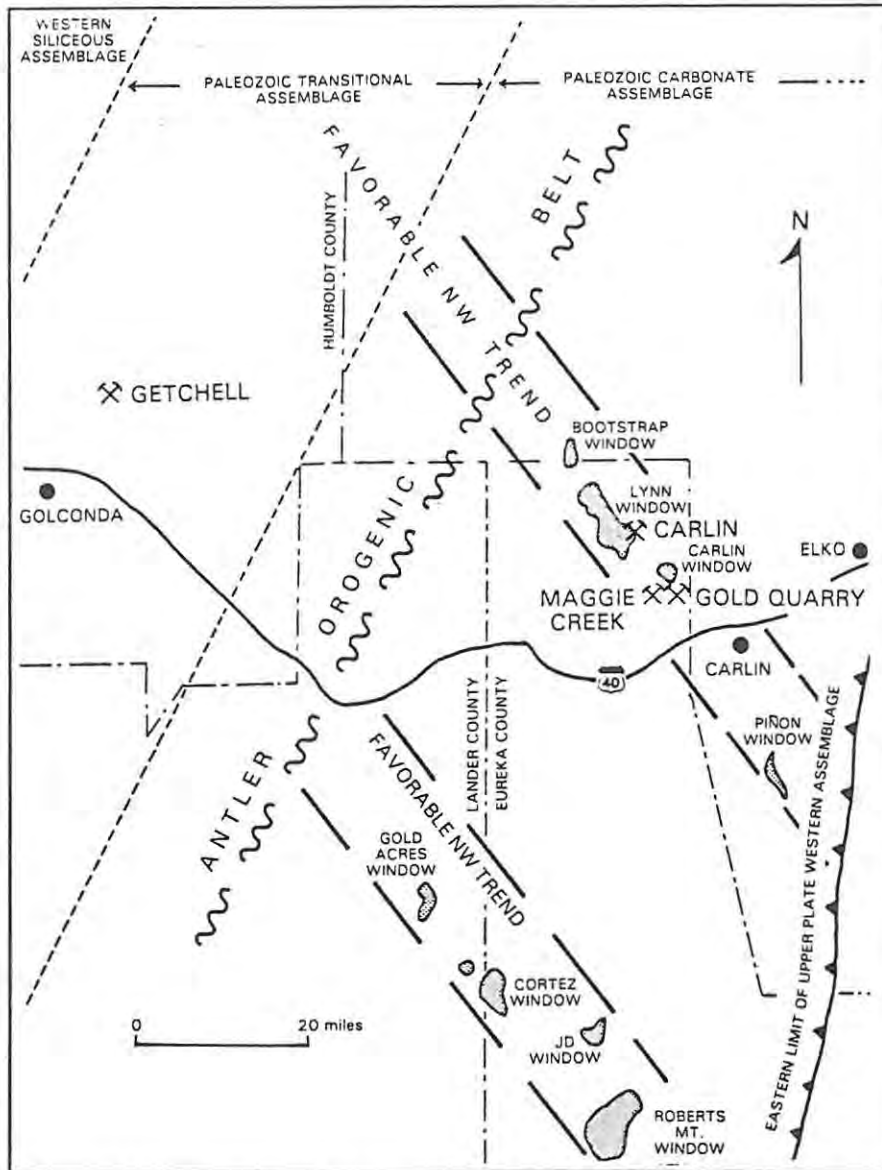


Figure 8. Map showing some of the carbonate windows in the Roberts Mountains thrust sheet along the Carlin and Battle Mountain - Eureka trends (Ekburg, 1986).

complex geology associated within small pull apart basins related to strike slip tectonics. This interpretation is not fully developed in existing literature. The Battle Mountain trend was originally defined by the Gold Acres, Cortez, Horse Canyon and Tonkin Springs deposits (Fig's. 7 & 8), (Bagby and Berger, 1985). The trend is now known to extend south-east to include Gold Bar, Easy Junior and Green-Spring deposits and to the north-west to include Hilltop, Marigold and Lone Tree deposits (Fig. 7). The trend is approximately 200 kilometres long and between 10 and 12 kilometres wide. The Battle Mountain - Eureka deposit trend is oblique to the Central Nevada Rift which is defined by an anomalous magnetic and gravity

zone manifest by Miocene basaltic rocks (Fig's 7, 8, 9 & 10). The deposits along the Battle Mountain - Eureka trend are a series of clusters within the trend and not as confined to a linear belt as those deposits along the Carlin trend (Fig's. 7 & 8). As in the Carlin trend, there is confusion as to the positive identification of the RMT and the age of siliciclastic lithologies in the Gold Acres deposit (Hays and Foo, 1991). Intrusives along the Battle Mountain trend have Mesozoic to Tertiary ages.

The Getchell trend was originally defined by the NNE alignment of the Preble, Pinson-Mag, Getchell and Chimney Creek deposits (Fig. 11), (Percival et. al., 1988; Bagby and Berger, 1985). These mines lie along the northeastern flank of the Osgood Range and the Osgood stock (Fig 11). Recently the Getchell trend has been "widened" to accommodate the Rabbit Creek deposit which lies directly south of Chimney Creek (Fig's 7 & 11), (Hoover et. al., 1988). However, Rabbit Creek lies along a regional N-S trending structure, known as the Rabbit suture, along strike from the Chimney deposit (Bloomstein et. al., 1991). Bloomstein et. al., (1993) suggest that the Lone Tree deposit also lies along the N-S trending Rabbit Suture (Fig. 11). It appears that with continuing exploration success, the once well defined Getchell trend is slowly degenerating (Fig. 7 & 11). Seedorf (1991) suggests that the trends are biased, created by limited exposure of bedrock and preservation of favourable host rocks and that the distribution of Carlin type deposits ranges from "seemingly well defined (though internally complex) trends to broad, almost arbitrary clusters, to practically isolated occurrences" (Fig. 7). There is no denying that most of the sediment-hosted gold deposits lie within a trend controlled by some deep and most probably long lived structure. The seemingly isolated deposit may also lie within a yet undefined trend and regional exploration techniques such as detailed LANDSAT imagery, but more specifically airphoto interpretations, may help in defining regional structural controls in the location of a new unknown deposit. This is clearly demonstrated in the discovery of the Rabbit Creek deposit which does not lie on the Getchell trend. The north-south Rabbit suture may become a new deposit trend in Nevada. Another important factor to consider in exploration is the removal of post deposit structural overprints in order to try to define regional mineralising controlling structures. Once a favourable target has been selected it must be remembered that structures controlling mineralisation are, in most cases, at high angles to the "trend".

NEWMONT EXPLORATION LIMITED



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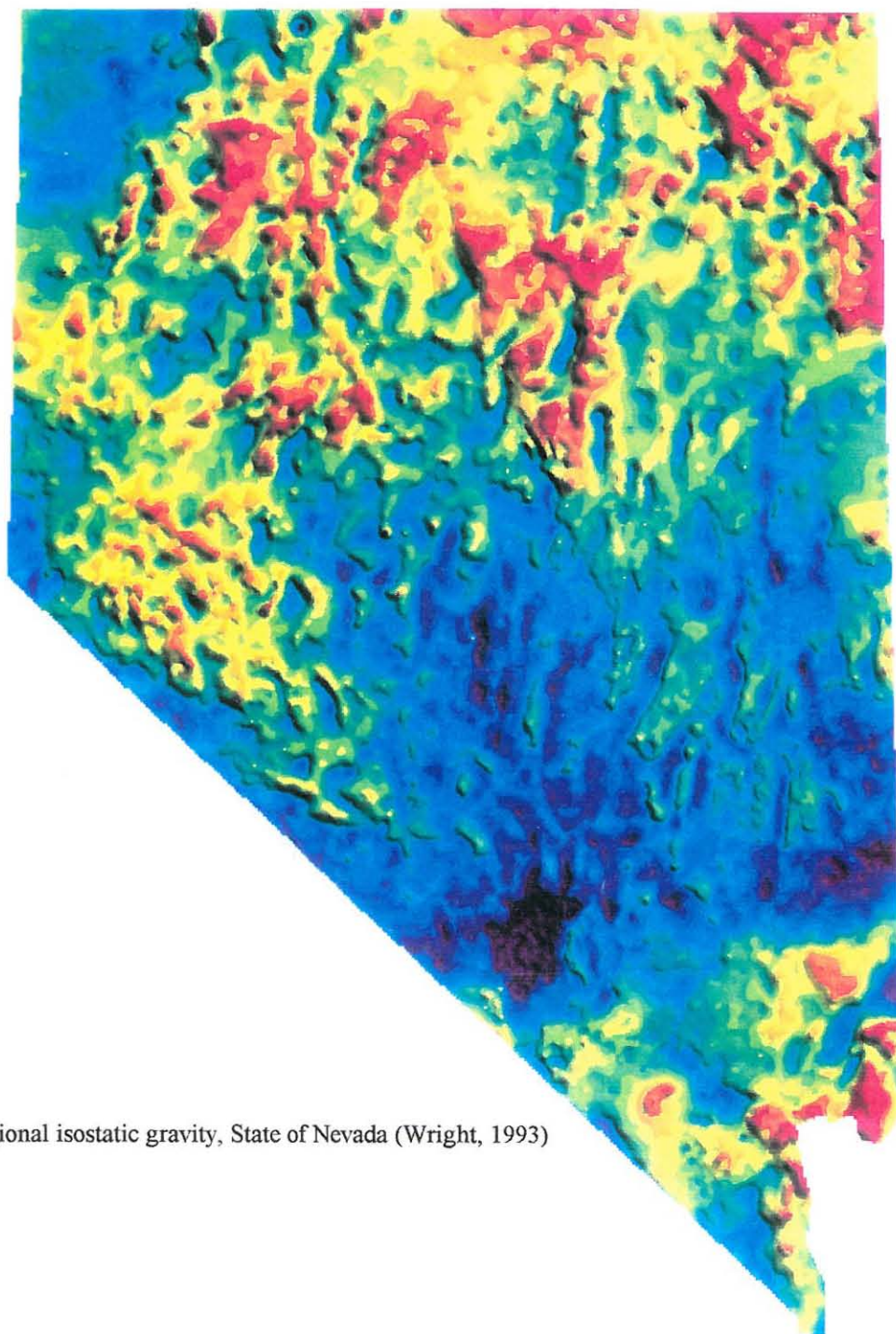


Figure 9. Regional isostatic gravity, State of Nevada (Wright, 1993)

Illumination: Decl. 42, Incl. 52
Coloration: Linear
Units: mgals

200000 E 300000 E 400000 E 500000 E 600000 E 700000 E 800000 E

ISOSTATIC GRAVITY
STATE OF NEVADA
Scale 1:3,750,000

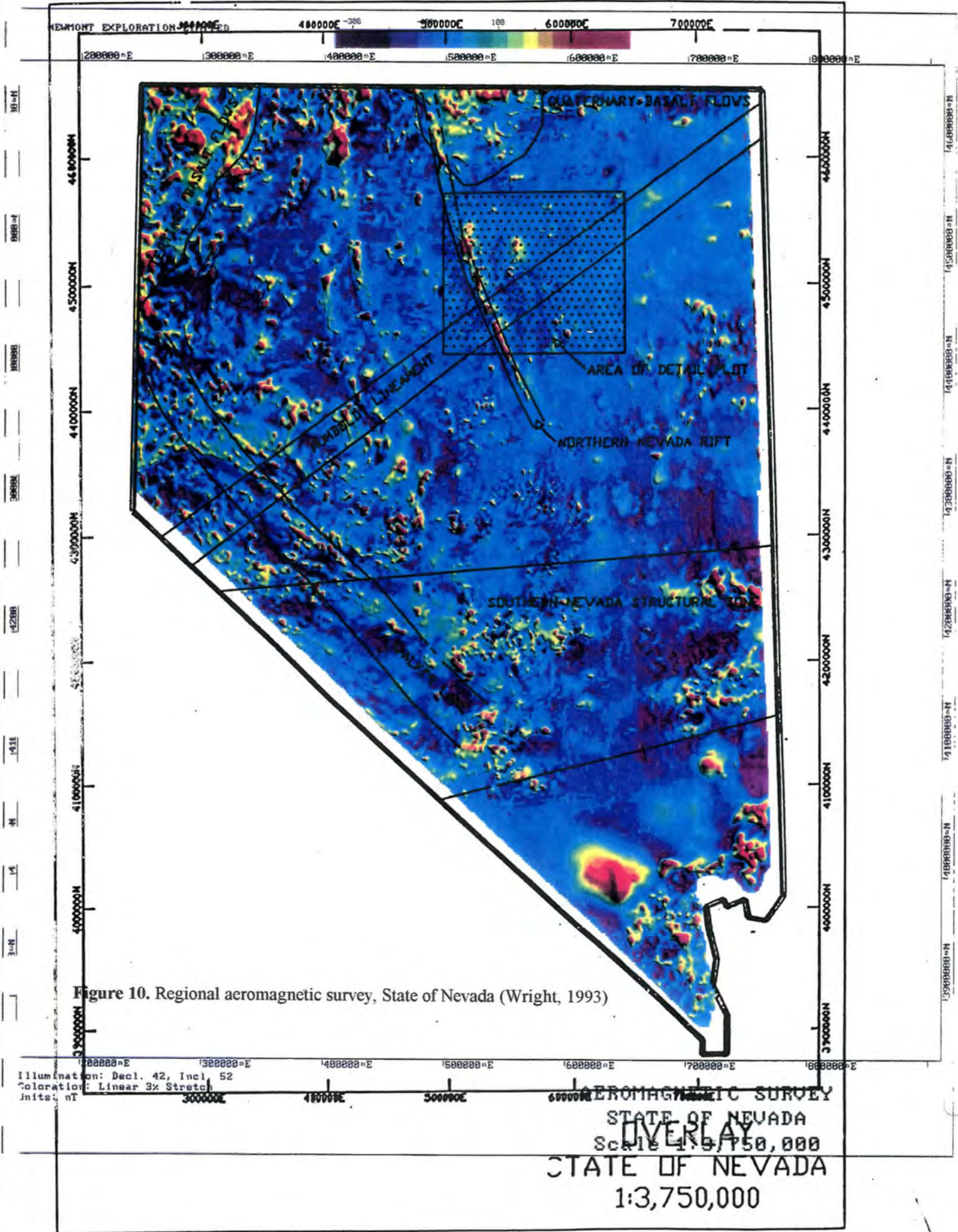
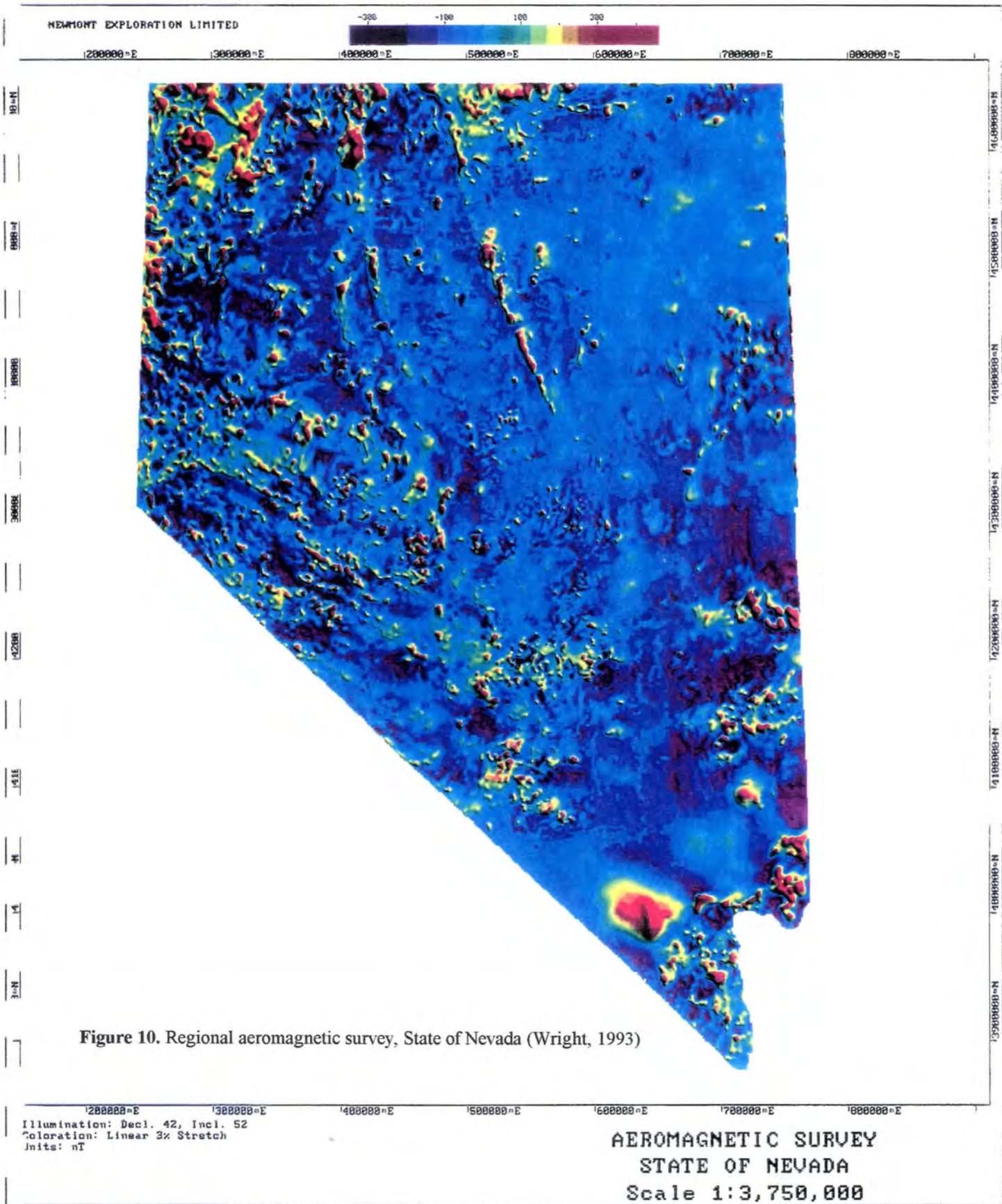


Figure 10. Regional aeromagnetic survey, State of Nevada (Wright, 1993)



An intriguing feature of the Carlin and Battle Mountain - Eureka trends is that they cross cut all described structural features from; (1) the isotopically inferred Precambrian craton margin, (2) the Antler orogeny tectonics as defined by the RMT, (3) the Sonoma orogeny tectonics as defined by the Golconda thrust and (4) the Tertiary Basin and Range extension (Fig's 2 and 5).

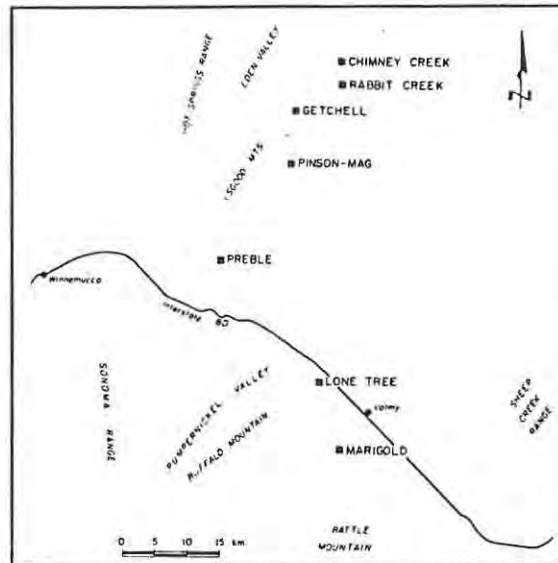


Figure 11. Location of mines along the Getchell trend and the northern part of the Battle Mountain - Eureka trend (Seedorf, 1991).

Most earth scientists involved in studying and exploring the Great Basin believe that the high angle faults are Tertiary in age, formed at the onset of Tertiary extension (Rota pers. comm., 1993). Historically, crustal shortening associated with compressional tectonics is taken up along thrust planes resulting in overthrust terrains (Oldow et. al., 1989). Recent advances in the understanding of kinematics of continental accretion reveal that there is a significant space problem with simple two dimensional reconstruction of accreted terrains (Oldow et. al., 1989). Paleomagnetic, biostratigraphic and stratigraphic data and three dimensional modelling of accreted terranes in the Cordillera indicate that there has to be significant strike-slip displacement together with thrust faulting (Oldow et. al., 1989). Strike-slip displacement in accreted terranes also accounts for the space problems in the two dimensional reconstruction of accreted terranes. Oldow et. al., (1989) argue that contractional structures and coeval strike-slip systems are spatially segregated in most cases but are products of one displacement field (Fig. 12). Oldow et. al., (1989) believe that the thrust faults and coeval strike-slip fault share a common basal decollement and propose that the basal decollement is at the mid to deep

crust, maybe even upper-mantle levels (Fig. 12). Many workers believe that the Carlin and Battle Mountain - Eureka trends are along, long lived, deep structural features and the model proposed by Oldow et. al., (1989) accomodates all the features of these trends (e.g., long lived, deep) and the spatial relationship between thrust faults and high angle inferred strike-slip faults. These faults have been reactivated through time but the critical feature in understanding genesis of these deposits is the timing of mineralisation which on present data, occurs over a time span from late Mesozoic to late Tertiary.

The Getchell trend is subparallel to the inferred western margin of the Precambrian craton and parallel to the Tertiary extensional tectonic fabric (Fig's 5 & 11). Therefore it can be concluded that the primary first order structures controlling the distribution of deposit settings may have formed at different times throughout the evolution of the Great Basin and that some of the first order structures have had long repeated structural, intrusive and mineralisation history.

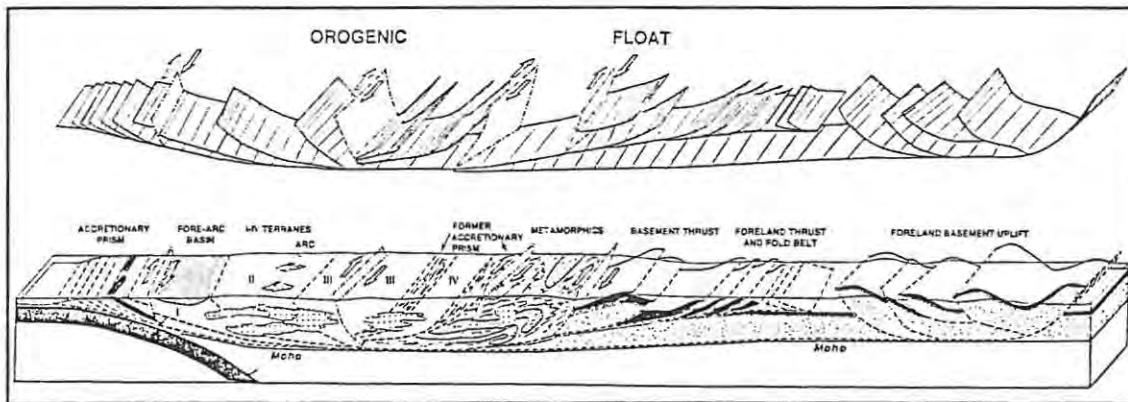


Figure 12. Conceptual diagram of a Cordilleran-type transpressional orogenic float. The top diagram shows major decoupling systems stripped of the rock units involved in the deformation. From a deep decoupling zone at the base of crust emanates a hierarchy of compressional decoupling levels within the basement, at the base of crust. Segments bound by strike-slip faults moved from out of the plane of section into the plane of section (from Oldow et. al., 1989).

4. GEOLOGICAL CHARACTERISTICS OF DEPOSITS

4.1. Host Sediment Lithologies

Gold mineralisation along the Carlin, Battle Mountain - Eureka and Getchell trends is hosted in a wide variety of sedimentary rocks types of varying Paleozoic ages. (Tables 1, 2 and 3). They can be divided into three broad subgroups comprising of (1) autochthonous, miogeosynclinal

carbonate and carbonate - siliciclastic sequences, (2) allochthonous, eugeosynclinal siliciclastic sequences and (3) Antler Overlap Sequence (Tables 1, 2 and 3).

4.1.1. The Carlin Trend

Along the Carlin trend, the autochthonous host rocks include the Silurian - Devonian Roberts Mountains, Popovich, Rodeo Creek and Bootstrap and Siliceous Sequence Formations (Fig's 13 and 14; Table 1), (Baker, 1991; Lauha and Bettles, 1993a and b; Paul et. al., 1993; Meyers, 1993; Doyle-Kunkel, 1993; Rota, 1991 and 1993). The upper Roberts Mountains Formation consists of medium to thinly bedded, platy, carbonaceous, silty limestone, calcareous siltstones and minor interbedded chert (Rota 1991 and 1993; Meyers 1993). The Roberts Mountains Formation at the Post/Betze deposit is described as being dolomitic limestones and siltstones

(Table 1), (Lauha and Bettles;1993a). The mineralogy of the upper unaltered, laminated, Roberts Mountains Formation, based on 246 samples collected throughout north-central Nevada, is 30 to 50 percent calcite (by volume), 15 to 35 percent dolomite, 20 to 30 percent quartz silt, 5 to 15 percent illite, 2 to 4 percent K feldspar, 0.2 to 1 percent pyrite and 0.2 to 0.45 percent organic matter (Mullens, 1979, 1980).

The contact between the Roberts Mountains and Popovich Formations is gradational (Fig's 13 and 14). Lithologies of the Popovich Formation are essentially similar to the underlying Roberts Mountains Formation in that they consist of thin to medium bedded, calcareous, carbonaceous siltstone, silty limestone, mudstone, minor calcarenites and minor to common noncalcareous siltstone (Table 1), (Baker, 1991; Lauha and Bettles, 1993a and b; Paul et. al., 1993; Meyers, 1993; Doyle-Kunkel, 1993; Rota, 1991 and 1993). The Popovich Formation has a higher silt content than the underlying Roberts Mountains Formation and it increases up through the sequence (Rota, 1991; and 1993). Abundant coarse carbonate debris flows occur towards the base of the Popovich Formation at the Betze/Post, Meikle, Genesis/Blue Star and Gold Quarry deposits (Lauha and Bettles, 1993a and b; Paul et. al., 1993; Doyle-Kunkel, 1993; Rota, 1991 and 1993). The debris flows are important in the controls of mineralisation at these mines in that they are highly reactive (comprised predominantly of aragonite) to

mineralising hydrothermal fluids and have high primary porosities and permeabilities (Williams, 1994).

The contacts between Popovich and the Rodeo Creek Formations as seen in the field vary from stratigraphic to structural (Fig's 13 and 14), (Lauha and Bettles, 1993a and b; Paul et. al., 1993; Rota, 1991 and 1993). The Rodeo Creek Formation comprises interbedded siliceous mudstone, siltstone and fine grained sandstone at the Betze/Post deposit (Lauha and Bettles, 1993a and b). At the Gold Quarry deposit, Rota (1991 and 1993) describes the Rodeo Creek Formation as interbedded silty limestone, chert and siltstone while at the Carlin deposit, Myers (1993) describes it as interbedded argillite, siltstone and mudstone. The age and sedimentary setting of the Rodeo Creek Formation is cause for considerable controversy. Geologists from America Barrick Gold Company, who own the Betze and Upper Post deposit, believe that the Rodeo Creek Formation, the Lower Argillite Member, is part of the allochthonous, eugeosynclinal sequence which was thrust over the miogeosynclinal carbonate rocks during the Antler Orogeny (Fig. 14), (Lauha and Bettles, 1993a and b). Newmont geologists on the otherhand, believe that the Rodeo Creek Formation is a transitional Devonian lithological sequence (Fig. 13) (Rota 1991 and 1993). Volk and Zimmerman (in Lauha and Bettles, 1993a) have described fossils which date the Rodeo Creek Formation, in the Betze/Poste deposit, as middle Ordovician, therefore indicating that it is of the allochthonous, eugeosynclinal sequence. Rota (pers. comm., 1993) suggested that Newmont has fossil evidence dating the Rodeo Creek Formation as Devonian.

The major host of gold mineralisation in the Vantage deposit is autochthonous Devonian-Mississippian Pilot Shale, consisting of thinly laminated calcareous siltstone (Illchik et. al., 1986; Illchik 1990).

Allochthonous, eugeosynclinal host rocks along the Carlin trend are the Ordovician Vinini and Valmy Formations which are a sequence of interbedded siliciclastic, carbonaceous siltstones, shales, cherts and minor limey siltones (Rota, 1991 and 1993, Paul et. al., 1993). These siliciclastic rocks are the major host to mineralisation at Gold Quarry (Table 1), (Rota and Hausen, 1991; Rota, 1993).

Table 1. PRINCIPLE CHARACTERISTICS OF MINES ON THE CARLIN TREND, NEVADA.

Deposit	Tonnage/Grade	Formation	Host Rocks Lithology	Age	Faults	Folds	Alteration	Igneous Rocks
Bootstrap/Capstone (1)	14.6 Mt @ 1.92 g/t	Siliceous Sequence Bootstrap Roberts Mountain	Calcareous sandy siltstone Thin interbedded calcareous siltstone, limestone Calcareous thinly bedded, laminated silty limestone	Devonian Devonian Silurian-Devonian	N-S dominant, NW, NE, E-W	n.d.	Silicification Argillisation	Highly altered dykes intruding high angle faults. Thought to be granodiorite - tonalite in composition
Melkje (2)	6.52 Mt @ 21.4 g/t	Popovich (major)	Interbedded noncalcareous siltstones, silty limestones. Debris flows common towards base of formation	Devonian	RMT + post RMT thrusting event. NW + NE dominant high angle faults	n.d.	Decalcification, Silicification, Argillisation.	Monozite dykes 36.4 +/- 1.8 Ma K/Ar Monozite porphyry 147 +/- 4.0 Ma Latic dykes and sills
Betze/Post (3)	136 Mt @ 5.96 g/t	Rodeo Creek (major) Popovich (major) Roberts Mountain (major)	Interbedded siliceous mudstone, siltstone and fine grained sandstone. Interbedded calcareous, carbonaceous siltstone, silty limestone and abundant debris flows. Interbedded dolomitic siltstone and limestone	Devonian Devonian Silurian-Devonian	RMT Post- Goldstrike Intrusive thrusting, NW, N to NNW, NE high angle faults.	Dominant NW trending anticline, post second thrusting event.	Pre-mineralisation skarn and contact metamorphism related to Goldstrike Intrusive. Decalcification, silicification, argillisation, pyritisation, oxidation (supergene and hypogene?)	Biotite feldspar porphyry 39 Ma (dykes, plugs and sills). Post- Au mineralisation, Quartz monozite porphyry 110 Ma sills and dykes. Goldstrike Intrusive 160.6 Ma.
Genesis/Blue Star (4)	67.58 Mt @ 1.1 g/t	Rodeo Creek Popovich Valmy	Thinly bedded siltstones, carbonaceous mudstones and argillites. Thin bedded carbonaceous, slightly calcareous siltstone, mudstone, argillites and minor calcarenites Thin bedded siliclastic siltstone and chert	Devonian Devonian Ordovician	RMT with numerous imbricate thrusts in Vinnini Formation. Post- Goldstrike Intrusive thrusting. N-S, NW, NE high angle faults	NW trending Tusooza Spur antiform, pre- Au mineralisation.	Pre-mineral skarn (Goldstrike intrusion) Decalcification, Argillisation, Silicification, Oxidation (supergene, hypogene?)	Altered Biotite Feldspar Porphyry dykes, 28.3 +/- 0.7 Ma K/Ar Goldstrike Intrusive 160.9 Ma. Lamprophyre dykes, age unknown.
Carlin (5)	12.7 Mt @ 9.2 g/t* 8.27 Mt @ 0.96 g/t**	Rodeo Creek (minor) Popovich (minor) Roberts Mountain (major)	Interbedded argillite, siltstone and mudstone. Interbedded calcareous siltstone, silty limestone and limestone. Thin bedded silty, carbonaceous limestones.	Devonian Devonian Silurian-Devonian	RMT NW, NE, WNW striking high angle faults.	NW trending anticline	Decalcification, Silicification, Argillisation, Oxidation (supergene)	Highly altered dykes of different composition, no cross-cutting relationships observed for the different dykes. Date 123.31 +/- 0.7Ma
Tusc (6)	12.1 Mt @ 2.12 g/t	Rodeo Creek (minor) Roberts Mountain (major)	Interbedded mudstone, chert and siltstone. Thin bedded silty limestone and limestone.	Devonian Silurian-Devonian	RMT with numerous imbricate thrusts. NW, NE high angle faults.	NW trending anticline.	Decalcification, Argillisation, Silicification, Oxidation (supergene).	n.d.
Gold Quarry (7)	163 Mt @ 1.4 g/t	Rodeo Creek (major) Popovich (major) Roberts Mountain (major) Vinnini (major)	Interbedded silty limestone, chert, shale and siltstone. Massive bedded dolomitic limestone, silt increases upwards. Thin, platy silty limestone Siliclastic interbedded carbonaceous shales, siltstones and minor limy siltstones	Devonian Devonian Silurian-Devonian Ordovician	RMT (problematic as it varies from lithological contact to breccia zone 15 m thick. NW and NE high angle faults. Numerous ill-defrict high angle faults thought to be related to decalcification, formed as a result of volume loss.	NE trending anticline.	Decalcification, Silicification, Alunisation, Argillisation, Baritisation, Oxidation (hypogene and supergene)	Altered and mineralised quartz porphyry dyke in Maggie Creek. Believed to be Juro-Cretaceous in age.
Rain (8)	35.1 Mt @ 1.5 g/t	Kinderhookian Webb (major) Devils Gate (minor)	Weakly calcareous mudstone grading upwards into siltstones, sandstones and quartzites Medium bedded micritic limestone	Mississippian Devonian	NE, NW, WNW, E-W high angle faults.	N-S trending dome	Decalcification, Dolomitisation, Silicification, Baritisation, Argillisation.	Argillised quartz porphyry dyke and quartz latite dykes. Nearby Bullion granodiorite stock 36 Ma.
South Bullion (9)	18.1 Mt @ 0.89 g/t	Chairman (minor) Webb (major)	Interbedded sandstone, siltstone and shale. Thin bedded carbonaceous siltstone, siliceous and/or calcareous mudstone. Debris flows common towards base of sequences	Mississippian Mississippian	NW, WNW, N-S, NNW high angle faults.	N to NNW anticline	Decalcification, Silicification, Argillisation, Oxidation (supergene).	Weakly altered rhyolite? dykes and sills. Fine grained disseminated pyrite and marcasite in intrusives.
Vantage (10)	5.8 Mt @ 4.9 g/t	Pilot Shale (major) Devils Gate (trace)	Thinly laminated calcareous siltstone. Lower dolostone and upper limestone.	Devonian - Mississippian Devonian	N to NE and NE striking high angle faults.	Broad anticline parallels N to NE striking fault.	Decalcification, Silicification Oxidation (hypogene + supergene)	n.d.

Source: (1) Baker, 1991. (2) Lauha and Bettles, 1993. (3) Lauha and Bettles, 1993a; Lauha and Bettles, 1993b; Thoreson, 1993. (4) Paul, Jr and Kunkel, 1993. (5) Myers, 1993; Keuhn and Rose, 1992. (6) Doyle-Kunkel, 1993. (7) Rota, 1991 & 1993; Rota and Hausen, 1991. (8) Jory, 1992. (9) Putman and Henriques, 1991. (10) Ilchik, 1991 and 1986.

* Mined out reserves. ** Current reserves.

Table 2. PRINCIPLE CHARACTERISTICS OF MINES ON THE BATTLE MOUNTAIN - EUREKA TREND, NEVADA.

Deposit	Tonnage/grade	Host Rocks		Age	Faults	Folds	Alteration	Igneous Rocks
		Formation	Lithology					
Lone Tree (1)	47.63 Mt @ 2.1 g/t	Havallah Overlap Sequence Valmy	chert, basalt, shale, calcareous sandstone, sandy sandstone conglomerates, sandstone, siltstone, quartzites, chert, basalts, argillites interbedded quartzite, chert, minor basalt & argillites	Pennsylvanian-Permian Pennsylvanian Ordovician	RMT thrust - Antler Golconda thrust - Sonoma Dominant N-S high angle, minor NE & NW high angle faults	N-S east verging folds in Valmy Fm	Pre- Au Skarn Pb-Zn → Cu+Zn. Silicification pre-, syn- Polassic syn-, post Argillic, confined to structures.	Tertiary feldspar dykes in NE, N-S faults (K/Ar 36-39 Ma)
Hilltop (2)	5.23 Mt @ 2.7g/t	Valmy (major)	predominantly chert interbedded with shale, quartzite, greenstone and minor limestone	Ordovician	RMT thrust - Antler, numerous imbricate thrust parallel RMT High angle N-S, W-E faults	n.d.	Silicification (1) chalcidonic quartz + quartz veining; (2) coarsely crystalline quartz + major sulphides	Oligocene (33-35 Ma) rhyolite plugs and dykes - cut dacite porphyry Eocene (38.1 Ma) dacite porphyry - dykes, sills and plugs
Gold Acres (3a, b)	1.99 Mt @ 3.67 g/t	Slaven chert (minor) Valmy (minor) Wenban (minor) Roberts Mountain (major)	thick bedded chert thin to medium interbedded quartzite, sandstone, shale, siltstone medium to thick bedded silty to crystalline limestone. thin to medium bedded, carbonaceous silty limestones	Devonian Ordovician?? (Devonian?) Devonian Silurian-Devonian	RMT N30W/20-30SW, imbricate parallel sole thrust. Ore body lies within imbricate thrust N-S, NE high angle faults	NE trending antiform	Pre-ore Cu-Mo-Pb-Zn skarn. Decalcification in carbonate rocks. Carbonisation, dominant type. Fracture & bedding controlled. Silicification, in upper & lower plate, peripheral to Au zone in upper plate. Argillisation	Tertiary (~66 Ma) quartz porphyry altered dykes Quartz monozonite stock 120 m below deposit (K/Ar 98.9 +/- 2 Ma).
Cortez (4)	3.2 Mt @ 9.8 g/t	Wenban (minor) Roberts Mountain (major)	thick bedded limestones thin to medium bedded, carbonaceous silty limestones	Devonian Silurian-Devonian	RMT Low angle structural contact between Wenban & Roberts Mountain? N-S to NNW, NW, ENE high angle faults.	NW trending anticline NW ore trend	Decalcification, silicification, carbonisation, argillisation of fesc intrusives	Pliocene (10-16 Ma) basaltic andesite & rhyolite flows Oligocene (34 Ma) pre-ore quartz porphyry dykes & sills, Caetano tuff. Mill quartz monozonite stock (K/Ar 150 +/- 3 Ma)
Horse Canyon (5)	2.99 Mt @ 4.91g/t	Wenban (major) Valmy/Virvini (major)	thin - medium bedded limestone thin bedded cherty siltstone, argillaceous-carbonaceous siltstone	Devonian Ordovician	NW striking RMT NNW, N-S, E-W & NW high angle faults, NNW dominant	Large & small recumbant folds. RMT recumbantly folded, axial plane N-S	Decalcification in carbonates silicification, argillisation, carbonisation,	Altered Oligocene? dykes and sills
Tonkin Springs (6a, b)	n.d.	Nevada (minor) Valmy (major)	Massive limestone interbedded chert, shale, silty limestones	Devonian Ordovician	RMT and numerous smaller thrusts N to NW, N-S, NE, E-W high angle faults	n.d.	Decalcification, silicification, carbonisation,	Numerous altered porphyritic intermediate dykes and sills. Thought to be late Mesozoic early Tertiary in age.
Gold Bar (7)	4.36 Mt @ 2.87 g/t	Denay Limestone	interbedded limestones & calcareous siltstones	Devonian	NW, E-W, NE, N-S high angle faults, NW & N-S dominant	NW trending antiform, ore trends	decalcification, silicification (fault-bedding jasperoids), carbonisation, argillisation,	
Ratio Canyon (8)	n.d.	Dunderberg (major) Hamburg (trace)	Fissile claystone interbedded with limestone Massive dolomite, minor lenses of limestone	Cambrian Cambrian	E-W tear faults related to E-W compression, N to NW, E-W, NE high angle faults	N-S trending fold axis later folded by E-W folds resulting in doubly plunging fold axes	Sanding/decalcification, silicification, argillisation restricted to Dunderberg shales	No igneous rocks near mineral occurrence
Nighthawk Ridge (9)	6.33 Mt @ 0.87 g/t	Chainman (75% host) Joanna (25% host)	Carbonaceous shale interbedded with silty & limy lenses lower orthoquartzite, middle siltstone and shale, upper limestone with chert interbeds	Carboniferous Late Devonian-early Carboniferous	Thrust N15E NE, WNW-ESE high angle faults NE dominant, feeder	N15E open folds	Decalcification silicification, argillisation, carbonisation	No igneous rocks near deposit

(1) Bloomstein et. al., 1993. (2) Lisle et. al., 1988. (3a) Hays et. al., 1991. (3b) Cartwright, 1988. (4) Erikson, 1985. (5) Foo et al., 1987. (6a) Gesick, 1987. (6b) Hardisty, 1983. (7) Broili et. al., 1988. (8) Steiniger et. al., 1987. (9) Carden et. al., 1991.

Table 3. PRINCIPLE CHARACTERISTICS OF DEPOSITS ON THE GETCHELL TREND, NEVADA.

Deposit	Tonnage/grade	Formation (host)	Host Rocks Lithology	Age	Faults	Folds	Alteration	Igneous Rocks
Chimney Creek (1)	53 Mt @ 1.8 g/t	(North pit) Etchard Formation (Upper member) (Middle member) (minor) (Lower Member) (major) (South Pit) Valmy (Upper member) (Lower member)	dolomitic siltstone, argillite and calcareous massive dolomite, calcareous sandstones, sandy sandstone, minor conglomerate basal conglomerate, interbedded dolomite, calcareous sandstone and sandy limestone, capped by massive limestone thin bedded chert, shale and minor greenstone/volcanics quartzite, chert, shale, abundant greenstone	Pennsylvanian-Permian Ordovician	(North Pit) Complex structural setting Faults N40°-60°E/60°-80°E control mineralisation - left lateral displacement Fault N10°W - left lateral displacement Faults N40°-60°E control mineralisation Cut by N75°E and E-W trending faults	 Dominated by overturned anticline - axis N20°-30°W plunge 8°-10°NW	(North Pit) Decalcification → Silicification → Argillisation Silicification → Argillisation	(North Pit) Spatially related to Osgood Mountain Porphyry (790 Ma) Dacite sills intruded between Lower and Middle Members (thought to be related to Osgood Mountain Porphyry) which argillised and mineralised in places Ordovician basalts
Rabbit Creek (2)	53 Mt @ 2.4g/t	Comus (major) (Upper Member) (major) (Lower member) (major)	interbedded basalts, hydroclastic tuffs and breccias, siltstone, chert and shale interbedded volcanic and shales and mudrock	Early Ordovician	Prominant feature is the north-south right lateral Rabbit Suture with related anti- and synthetic reidel shears	Large N-S striking anticline with numerous parasitic folds	Decalcification in slightly calcareous lithologies Silicification - numerous silicification events Dolomitisation - accompanies early silicification Argillisation - widespread but confined to volcanic rocks	n.d.
Getchell (3a, b)	8.43 Mt @ 5.82 g/t	Comus Preble Formation	interbedded carbonaceous siltstone, shale and limestone interbedded carbonaceous siltstone, shale and thin bedded limestone	Ordovician Cambrian	Major N10°-15°W/45°-75°E fault that flanks the Osgood Porphyry that host mineralisation Paragenesis E-W > NW > NW + NE	Lithologies highly folded between the major NW trending fault and the Osgood Stock	Pre-ore proximal tungsten-garnet-diopside skarn and a distal wollastonite skarn. Decalcification in carbonate rocks. Carbonisation, dominant type. Silicification numerous phases with jasperoids being developed in feeder faults Argillisation illite after biotite + kaolinite Paragenesis Decalcification > decarbonisation > numerous phases of silicification > argillisation.	Cretaceous (98.8 / 2 Ma) granodioritic stock and dacite dykes intruding along high angle faults which are argillised and mineralised
Preble (4)	n.d.	Valmy Formation (none) Comus Preble (Upper member) (Middle member) (Major host) (Lower member)	shale and chert thin bedded carbonate, shale, dolomite, siltstone, minor chert phyllitic shale and minor sandy shale and carbonaceous beds limestone, carbonaceous and calcareous shale, phyllitic shale and sandstone sandy shale, quartzitic shale, phyllitic shale	Ordovician Ordovician Cambrian Lower Cambrian	Paleozoic E-W directed thrusting NE striking high angle fault flanking granodiorite stock - primary control on mineralisation	n.d.	Pre-gold mineralisation skarn development Silicification, very subtle Decarbonisation Argillite confined to dacite sills	Cretaceous granodiorite stock (98.8 / 2 Ma) Olivine basalts (717 Ma)

Source: (1a) Atkin, 1992, (1b), Thomas 1992. (2) Bloomstein et. al., 1991. (3a) Nanna et. al., 1987, (3b) Tooker, 1985. (4) Kretschmer, 1987.
(major) - major host to gold mineralisation. n.d. - no data.

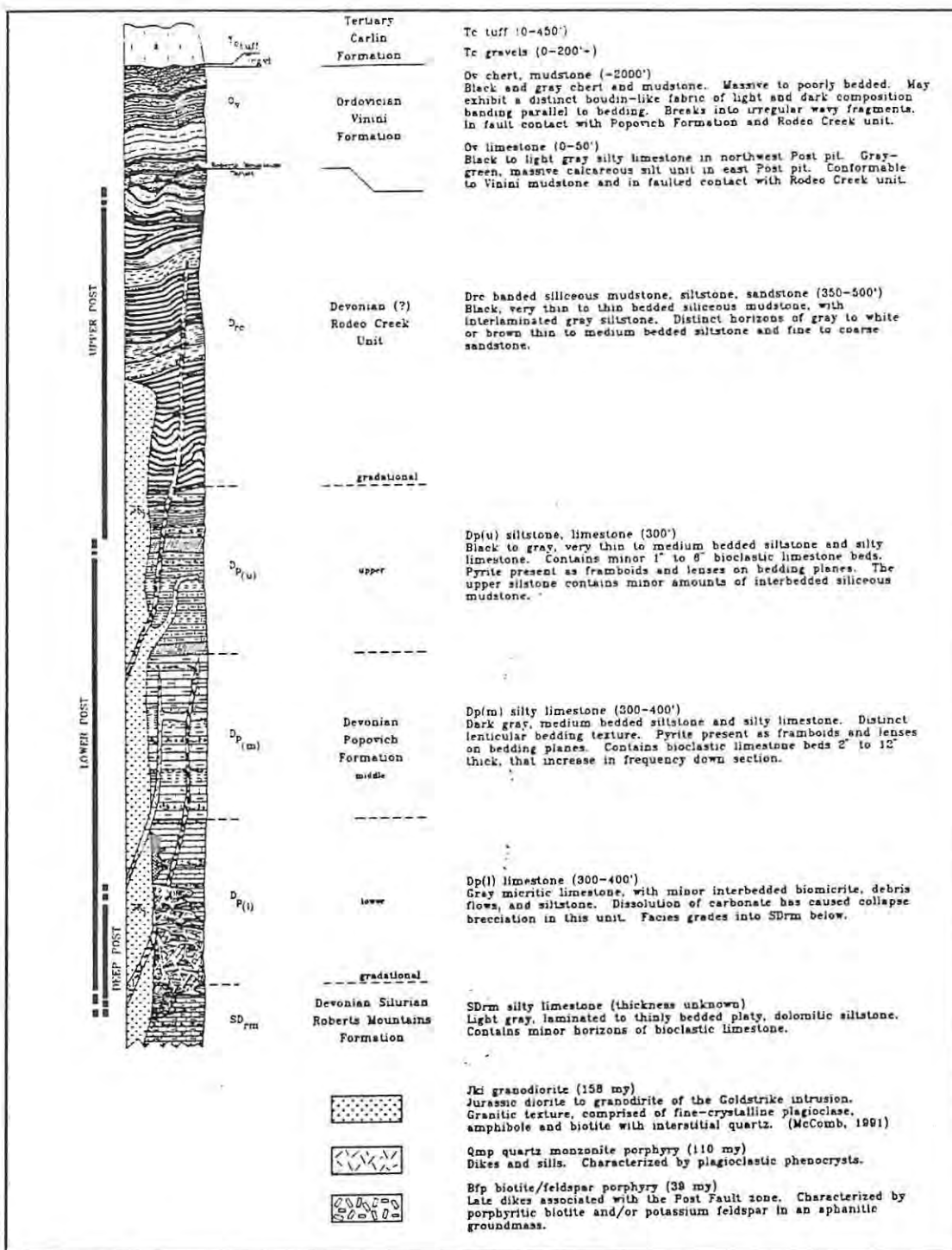


Figure 13. Generalised stratigraphic column for mines along the northern part of the Carlin Trend (Thoreson, 1993).

Formations of the Antler Overlap Sequence which host gold mineralisation, include the Chainman and the Kinderhookian Webb Formations (Table 1) (Jory, 1992; Putnam and Henriques, 1991). The Kinderhookian Webb Formation is a sequence of thinly bedded carbonaceous, siltstone, sandstones and siliceous and calcareous mudstones (Jory, 1992;

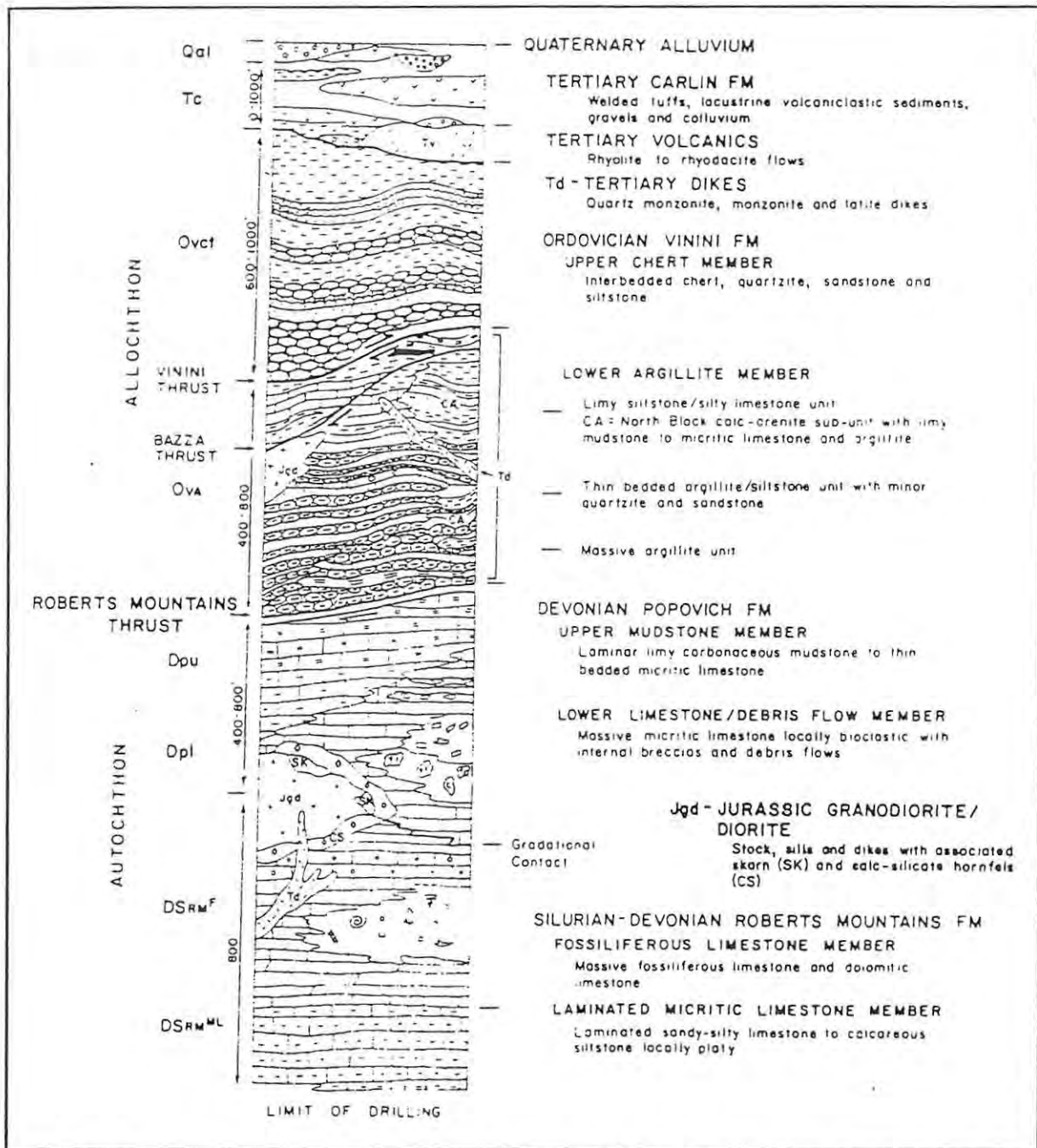


Figure 14. Stratigraphic column for the American Barrick Goldstrike Mines along the Carlin Trend (Bettles and Lauha, 1993).

Putnam and Henriques, 1991). At the Rain and South Bullion deposits, debris flows are common towards the base of the Kinderhookian Webb Formation (Jory, 1992; Putnam and Henriques, 1991; Williams, 1994).

In summary, formations which host gold mineralisation in the Carlin trend are predominantly thin bedded, carbonaceous and calcareous and silty rocks (Table 1). Carbonate debris flows are now recognised as a major host lithology (Table 1).

4.1.2. Battle Mountain - Eureka Trend

A generalised stratigraphic column for deposits along the Battle Mountain - Eureka trend is shown in figure 15. Autochthonous, miogeosynclinal host rocks along the Battle Mountain - Eureka trend include the Cambrian Hamburg and Dunderburg Formations, Silurian-Devonian Roberts Mountains Formation, Devonian Wenban and Denay Formations, late Devonian- early Carboniferous Joanna and the Carboniferous Chainman Formations (Table 2) (Hays and Foo, 1991; Cartwright, 1988; Erikson, 1985; Radtke et. al., 1987; Broilli et. al., 1988; Steinberger et. al., 1987; Carden, 1991). The Roberts Mountains Formation is similar to that described for the Carlin trend (Table 1 and 2). The Wenban Formation consists of thin to massive bedded limestone (Table 2). A thin bedded, carbonaceous limestone, in the Wenban Formation at Horse Canyon deposit is the major host, while the thick bedded, indurated, limestone at Cortez is a minor host, acting more as an impermeable cap to gold bearing hydrothermal fluids (Table 2), (Radtke et. al., 1987; Erikson, 1985). The Chainman, Joanna, Dunderberg Formations are comprised predominantly of thin shale and claystone with minor silty and limey lenses (Table 2), (Steinberger et. al., 1987; Carden et. al., 1991).

Allochthonous, eugeosynclinal host rocks included the Ordovician Valmy and Vinini Formations, which consists of thin to medium bedded chert, quartzite, sandstone, minor basalts, siltstone and shale (Table 2), (Bloomstein et. al., 1993; Lisle et. at., 1988; Hays and Foo, 1991; Cartwright, 1988; Erikson, 1985; Foo et. al., 1987; Gesick, 1987; Hardisty, 1983). Minor limestone beds are common towards the base of many of the Ordovician lithologies exposed at the various mines. The Devonian Slaven Chert at the Gold Acres Deposit overlies the Ordovician Valmy Formation. However, recent fossil dating of the lithologies historically described as Ordovician Valmy Formation, are actually Devonian in age (Wrucke, in Hays and Foo, 1991). This age discrepancy, like that observed in the Carlin trend, is a crucial element in understanding the regional setting, and more importantly, the genesis of sediment hosted

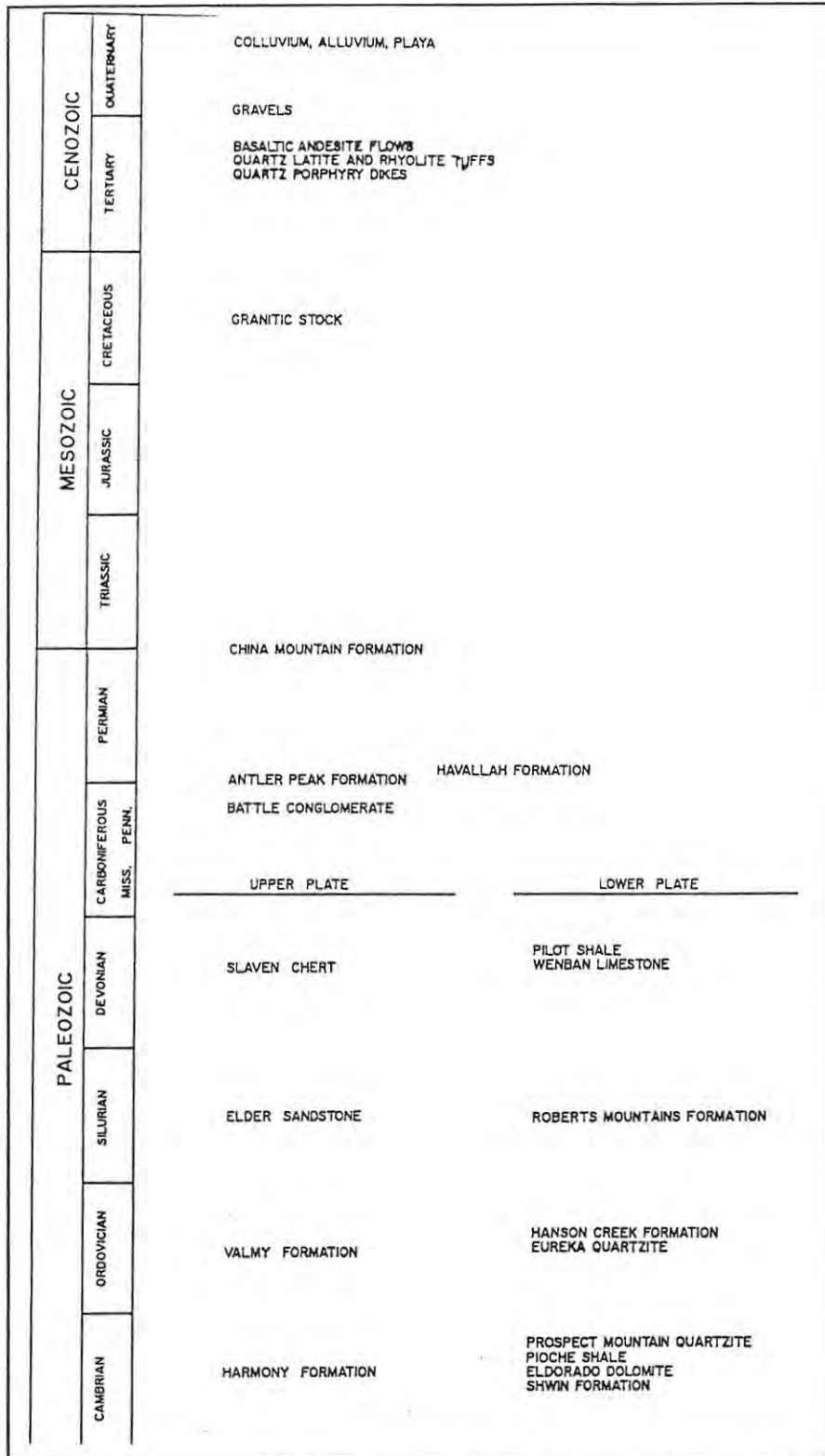


Figure 15. Stratigraphic column for deposits along the northern portion of the Battle Mountain - Eureka Trend (Hays, Jr. and Foo, 1991).

deposits. It therefore has important implications in regional exploration for hydrothermal deposits in Nevada (See Sections 9 & 10).

Antler Overlap Sequence host rocks included the Havallah, and Overlap Sequence at the Lone Tree Mine (Table 2), (Bloomstein et. al., 1993). These rocks are comprised of interbedded conglomerate, sandstone, shale, chert, argillites and minor basalts (Table 2), (Bloomstein et. al., 1993). Mineralisation, like that along the Carlin trend, is hosted in thin to medium bedded lithologies of calcareous, carbonaceous siltstone and shale as well as silty limestone.

4.1.3. The Getchell trend

Host rocks along the Getchell trend are predominantly the deep water "eugeosynclinal" Cambrian Preble Formation, Ordovician Comus, Valmy Formations (Table 3). These formations are dominated by shales, cherts sandstones and basalts (Table 3). Carbonates form only a minor portion of the lithological host sequence.

The lower member of the Pennsylvanian-Permian Etchard Formation, which is part of the Overlap Sequence deposited during the erosion of the Antler highland formed during the Antler orogeny contains significant carbonate host rocks (Table 3), (Atkin, 1992).

Most of the deep water sediments of the Ordovician formations are not regarded as ideal host rocks in Nevada but there has been intense structural deformation flanking the Osgood and other Cretaceous granodiorite stocks, creating a favourable sites for gold deposition. The volcanic lithologies have acted as caps to gold-bearing hydrothermal fluids an important control in the localisation of gold mineralisation.

4.2. Igneous Rocks

Igneous intrusive rocks are clearly associated with fourteen of the nineteen deposits studied along the Carlin and Battle Mountain - Eureka Trends (Tables 1 and 2). Most of the intrusives are dykes and sills, intruded along high and low angle faults (Table 1 and 2). One of the major problems in understanding the genetic relationship between the igneous intrusives and gold

mineralisation is the lack of suitable minerals to date, as hydrothermal alteration affects both intrusives and country rock. Further complicating the subject is the extensive supergene oxidation overprint (Arehart et. al, 1992; Keuhn and Rose, 1992).

4.2.1. The Carlin Trend

In the Carlin trend intrusives which have been dated fall into three broad age groups, (1) middle- late to late Jurassic (± 160 Ma), (2) early Cretaceous (± 90 to 110 Ma) and (3), mid-Tertiary (28 to 39 Ma), (Table 1). The oldest intrusive spatially related to gold mineralisation is the Goldstrike stock, dated 160 ± 2.1 Ma: K/Ar and 165 Ma (Arehart et. al., 1989; Arehart et. al., 1992). The Betze/Post and Genesis/Blue Star deposits occur immediately adjacent to it (Thoreson, 1993; Bettles and Lauha, 1993a and b; Paul et. al., 1993). The stock is diorite to granodiorite in composition and is responsible for extensive skarn and hornfels development which extends several thousand metres from the intrusive (Thoreson, 1993; Bettles and Lauha, 1993a and b; Paul et al., 1993). The stock is only weakly mineralised by the younger gold bearing hydrothermal system but is responsible for pre-gold base metal mineralisation (Bettles and Lauha, 1993a and b). At the Betze/Post deposit numerous dykes and sills extend from the Goldstrike stock and formed impermeable barriers for hydrothermal solutions (Bettles and Lauha, 1993a and b). The development of skarns by the older intrusive event may have played a critical part, in this case, in developing a very permissive host.

A later intrusive event of quartz monzonite dykes and sills occurs at both the Meikle deposit, dated 147 ± 4.0 Ma, and the Betze/Post deposit, dated 110 Ma (Arehart et. al., 1992). The quartz monzonite dykes and sills have suffered varying degrees of alteration and are only weakly mineralised (Thoreson, 1993; Bettles and Lauha, 1993a and b; Paul et. al., 1993). Highly altered dykes of varying composition, but with no known cross-cutting relationships have been observed at the Carlin deposit, with a single age date of 123.31 ± 0.7 Ma: K/Ar (Keuhn, 1989). At the Maggie Creek deposit, adjacent to the Gold Quarry deposit, there is a highly altered and mineralised quartz porphyry dyke, believed to be late Jurassic - early Cretaceous in age (Rota, 1991).

Highly brecciated quartz monzonite dykes, 36.4 ± 1.8 Ma: K/Ar (Arehart et. al., 1992) , intrude in the Meikle deposit and host up to 15 percent of the mineralisation (Bettles and Lauha, 1993a and b). Biotite quartz porphyry dykes and sills, dated 39 Ma (Arehart, 1992) intrude in the Betze/Post Deposit (Bettles and Lauha, 1993a and b). These biotite quartz porphyry dykes crosscut and, thereby, post date mineralisation (Bettles and Lauha, 1993a and b; Arehart et. al., 1992). A granodiorite stock, dated 36 Ma, intrudes within one kilometer of the Rain Deposit (Smith and Ketner, 1975).

Biotite feldspar porphyry dykes and sills, dated 28.3 ± 0.7 Ma: K/Ar, intrude the Genesis/Blue Star deposit (Paul et. al., 1993).

4.2.2. Battle Mountain - Eureka Trend

Along the Battle Mountain - Eureka trend, the oldest intrusive spatially related to gold mineralisation is the Mill quartz monzonite stock at the Cortez Mine, dated 150 ± 3 Ma: K/Ar (Armstrong, 1970). A quartz monzonite stock, dated 98.9 ± 2 Ma: K/Ar (Wrucke and Armbrustmacher, 1975) occurs 120 m below the Gold Acres Deposit and is responsible for pre- gold Cu-Mo-Pb-Zn skarn mineralisation (Hays et. al., 1991).

A major intrusive episode occurred during the late- Eocene - Oligocene period (Table 2). These intrusives have been documented at Lone Tree Deposit (feldspar dykes, 36 - 39 Ma: K/Ar), Hilltop Deposit (dacite porphyry dykes and sills, 38.1 Ma and rhyolite plugs and dykes, 33 - 35 Ma), Cortez Deposit (quartz porphyry dykes and sills, 34 Ma), Tonkin Springs and Horse Canyon Deposit (Bloomstein et. al., 1993; Lisle et. al., 1988; Hays et. al., 1991; Erikson, 1985; Radtke et. al., 1987; Hardisty, 1983). The younger felsic intrusives (33 - 35 Ma) are most likely related to the thick sequence of welded and water-laid rhyolitic tuffs, the Caetano Tuff, which has been dated 31.5 Ma (Gilluly and Masursky), 32.3 Ma (Naeser and McKee, 1970) and 33.6-31.0 Ma (McKee and Silberman, 1970). The quartz porphyry dykes and sills are weakly altered and mineralised at the edges and mineralisation is thought to be related to this igneous event (Erikson, 1985).

4.2.3. Getchell Trend

The deposits along the Getchell trend are spatially related to the Osgood Mountain granodiorite stock dated 98.8 ± 2 Ma: K/Ar (Silberman et. al., 1974). The Osgood Mountain granodiorite stock is responsible for extensive skarn and hornfels development which extends up to 3 000 m from the intrusive and minor pre-gold base metal mineralisation (Kretschmer, 1987; Nanna et. al., 1987). The Twin Creek deposit consists of the Rabbit and Chimney Creek deposits. These are the only known deposits which occur outside the contact metamorphic aureole of the Osgood Mountain stock (Atkin, 1992; Thomas, 1992; Bloomstein et. al., 1991). A dacite sill intrudes the Chimney Creek deposit and is thought to be related to the Osgood Mountain stock (Atkin, 1992). Highly altered Ordovician basalts and basaltic andesites occur in the Chimney and Rabbit Creek Deposits and act as impermeable caps to hydrothermal fluids (Bloomstein et. al., 1991; Atkin, 1992).

4.3. STRUCTURE

4.3.1. Thrust Faults

The (RMT) has been spatially linked to twelve of the twenty three deposits studied (Tables 1, 2 and 3). It is the oldest major structure described for the Carlin, Battle Mountain - Eureka and Getchell trends (Rota, 1991; Radtke, et. al., 1987; Atkin, 1992).

It is along discrete thrust planes, which make up the RMT, that Palaeozoic siliciclastic eugeosynclinal sediments were thrust eastwards over Palaeozoic carbonate - siliciclastic miogeosynclinal sediments during the late Devonian - early Mississippian Antler Orogeny (Stewart, 1980). Subsequent erosion of the over thrustsed siliciclastic eugeosynclinal sediments has exposed numerous windows of mineralised and non-mineralised miogeosynclinal carbonate sediments along the Carlin and Battle Mountain trends through the RMT (Fig's. 4 & 8).

The RMT in the Carlin trend varies from a lithological contact to a breccia zone 15 m wide so that current field evidence indicating large scale transposition is unequivocal (Rota, 1991). The uncertainty surrounding the age of siliciclastic rocks (Devonian or Ordovician) at Gold Acres

deposit, along the Battle Mountain - Eureka trend, also cast uncertainty on the positive identification of the RMT (Hays et. al., 1991).

The Golconda thrust, related to the late Permian - early Triassic Sonoma, is spatially related to gold mineralisation at the Lone Tree deposit (Bloomstein et. al, 1993).

Lauha and Bettles (1993a, b) have described a thrust which post dates the RMT and the 160 Ma old Goldstrike stock. This compressional phase has not been assigned to an orogenic event. Although not described in the literature, abundant bedding parallel faults occur in the deposits in the Carlin and Battle Mountain - Eureka trends visited during 1993.

4.3.2. High Angle Faults

High angle faults, pre-, syn- and post-hydrothermal mineralisation, occur in all twenty three deposits studied (Tables 1, 2 and 3). The orientation of pre-ore high angle faults in the various deposits is consistent, generally being NW, N to NNW, NE and E-W (Tables 1, 2 and 3). Of these orientations the NW and NE trending high angle faults are the predominant faults in many of the deposits (Table 1, 2 and 3).

The relative ages of faults controlling mineralising have been difficult to interpret. Most of the high angle faults have many episodes of movement with the extensive Tertiary Basin and Range event being the last structural overprint. Extensive hydrothermal alteration, especially silicification, has obliterated many fault traces. At Carlin and Betze/Post, the age sequence of high angle faults is NW → NE + NNW (Lauha and Bettles, 1993a and b; Meyers, 1993). The high angle fault sequence at Genesis/Blue Star deposit is N-S → NW → NE (Paul et. al., Kunkel, 1993). Along the Battle Mountain - Eureka trend, high angle fault paragenesis varies greatly from deposit to deposit (Appendix 2). The pre-ore, high angle fault paragenesis for some of the mines along the Battle Mountain - Eureka trend are (1) Horse Canyon, N to NNW → E-W, (2) Tonkin Springs, N to NNW → N-S → NE → E-W, (3) Gold Bar, E-W → N to NNW → NE → N-S and (4) Ratto Canyon, N to NNW → E-W → NE (Radtke et. al., 1987; Gesick, 1987; Broili et. al., 1988; Steinberger et. al., 1987). The apparent multiplicity of events

for the Battle Mountain trend is greater than that for the Carlin trend. However this may be a function of more detailed structural interpretation rather than greater structural complexity.

Most of the high angle faults have been described as being normal and reverse (Appendices 1 - 3). However, the Chimney and Rabbit Creek deposits on the Getchell trend and the Lone Tree deposit on the Battle Mountain trend all occur within a large right lateral shear zone, known as the Rabbit suture (Bloomstein et. al., 1991, 1993). Numerous anastomosing faults (reidel shears) within the N-S trending structure control mineralisation (Bloomstein et. al., 1991, 1993). High angle faults at the Gold Quarry deposit are related to two structural events. The earliest are translational and the later, extensional (Cole in Rota, 1993). The translation event is driven by a NNE principle stress direction and is responsible for a large right lateral shearing along the Carlin trend (Rota, 1993; Putnam and McFarlane, 1990). The NE and NW trending faults have 60 degree angular separation which conforms to the angular separation of synthetic and antithetic shears within a strike-slip fault (Rota, 1993). The translation event is pre-gold mineralisation (Rota, 1993). Extensional tectonics reactivated the earlier high and low angle faults during the Basin and Range event (Rota, 1993).

At Rain, Carlin, Betze/Post, Genesis/Blue Star and Gold Quarry Deposits, there are many discontinuous, randomly orientated, high angle faults which formed as a result of volume loss due to decalcification of the underlying host carbonate lithologies (Williams, 1994).

Along the Getchell trend there are two important regional, high angle structures controlling gold mineralisation distribution, one flanking the north-east trending Cretaceous granodiorite stocks, and the other, the north-south trending Rabbit suture (Table 3). These are both major structures which can be traced with Lansat images and air photographs (Bloomstein et. al., 1991). The Rabbit Suture is a large right lateral fault zone and in this shear zone gold mineralisation is controlled by anti- and synthetic reidel shears (Bloomstein et. al., 1991). The Lone Tree, Rabbit and Chimney Creek deposits are located within the Rabbit Suture (Table 2 and 3). Both these faults, the Rabbit Suture and the one flanking the north-east trending granodiorite stock, display the importance of structure in hydrothermal systems as the host lithologies, predominantly shales and cherts, are not regarded as favourable for gold

mineralisation in Nevada yet adequate structural preparation created a favourable plumbing system thereby increasing secondary permeability.

4.3.3. Folds

Many of the deposits, especially the mines along the Carlin trend, are spatially associated with large open NW, NE and N-S trending anticlines (Tables 1, 2 and 3). The Tuscora Spur anticline, a large NW trending anticline with an undulatory axis, developed during deformation in the Late Triassic to Late Jurassic times. The Betze/Post, Genesis/Blue Star, Carlin and Tusc deposits are spatially linked to the Tuscora anticline (Radtke, 1985; Madrid and Bagby, 1986a; Lauha and Bettles, 1993a and b; Thoreson, 1993, Paul et. al., 1993; Meyers, 1993; Doyle-Kunkel, 1993). The orebodies of these various deposits have long dimensions which roughly parallel the axis of the anticlines, except for the Carlin deposit (Lauha and Bettles, 1993a and b; Thoreson, 1993, Paul et. al., 1993; Meyers, 1993; Doyle-Kunkel, 1993). The Gold Quarry deposit occurs within a large NE trending anticline and the orebody parallels the fold axis (Table 1), (Rota, 1991 and 1993). The large NW trending antiform at the Betze/Post deposit post date the second thrusting event (Lauha and Bettles, 1993a, b). The anticlines pre-date gold mineralisation and probably acted as petroleum traps prior to gold mineralisation (Poole et. al., 1983; Keuhn, 1989).

Large anticlines are the dominant structural features in the Rabbit and Chimney Creek deposits, Getchell trend (Table 3). In Rabbit Creek, high grade ore is located in parasitic fold anticlines where host-sediment is capped by volcanics

4.3.4. Breccias

Breccia bodies are a common feature in most of the sediment hosted hydrothermal gold deposit in Nevada (Appendices, 1, 2 and 3). For continuity sake, all breccia types are discussed in this portion of the dissertation. Most of the information discussed here was presented by Cindy Williams in a talk to the Nevada Geological Society in Reno, Nevada in January, 1994, entitled, "Breccia bodies in the Carlin trend: Classification, interpretation and their role in ore formation". Understanding the genesis and distribution of breccias within a

hydrothermal system appears critical in directing exploration to the heart of mineralisation within a hydrothermal system.

Williams has documented four breccia types occurring in the Carlin trend, namely: (1) carbonate debris flow breccias, (2) collapse breccias, (3) fault breccias and (4) fluidised hydrothermal breccias.

4.3.4.1. Carbonate debris flow breccias

Carbonate debris flow breccias are common towards the base of the Popovich Formation, minor in the upper Roberts Mountains and Rodeo Creek Formations (Fig. 13). Debris flows are characterised by: (1) being bedding conformable, (2) individual flows being encapsulated by thin bedded, deep water, siliciclastic facies sediments, (3) having scour bases and planar to undulatory tops, (4) base of flows having coarse fragments orientated subparallel to each other grading upwards into finer, less orientated, fragments and (5), heterolithic clasts comprised predominantly of carbonate. Individual debris flows vary from 30 centimetres to several metres in thickness and tend to occur in groups of flows. An important criterion in distinguishing debris flow breccias from other breccia types in the Carlin trend, is that both the matrix and the clasts are cut by stylolites. Williams describes the debris flows as being fault bounded and shed from carbonate platforms, which are common along the Carlin trend, into local deep basins adjacent to the platform.

Carbonate debris flows are important in the control of mineralisation along the Carlin trend because they have higher initial permeability than surrounding rocks, and are essentially comprised of aragonite and magnesium carbonate which is highly susceptible to hydrothermal decalcification, thereby increasing secondary permeability. Carbonate debris flows have been described at the Meikle, Betze/Post, Genesis/Blue Star, Rain and Rabbit Creek deposits (Lauha and Bettles, 1993a, b; Paul, Jr. and Kunkel, 1993; Rota and Hausen, 1991; Rota, 1993; Jory, 1992; Bloomstein et. al., 1991). At the Betze/Post deposit, debris flows at the Roberts Mountains - Popovich Formation contact are up to 213 metres thick (Williams, 1994).

4.3.4.2. Collapse breccias

Collapse breccias are characterised by: (1) having a great variety of geometric forms, pipe to funnel shaped or irregular shaped branching bodies, (2) association with decalcified host rock, (3) very angular and delicate fragments, an indication of minimal transport, (3) monolithic fragments of the same composition as the surrounding host rocks, (4) matrix commonly comprised of insoluble residue of clay and silt and hydrothermal products such as quartz and barite, (5) commonly matrix supported. Bedding parallel collapse breccias can often be traced along strike into non-brecciated sediments and are commonly half the thickness of the original bedding, a result of volume loss due to decalcification. At the Gold Quarry deposit, Williams noted that the collapse breccias at the peripheries of the deposit had a higher percentage of hydrothermal cement and are indurated as opposed to those collapse breccias in the centre of the deposit which are unconsolidated with little or no hydrothermal cement.

Collapse breccias are formed as a result of volume loss by carbonate dissolution. At Carlin and Gold Quarry deposits, between 50 and 60 percent volume loss is thought to have occurred during decalcification (Rota, pers comm., 1993; Bakken, 1990). During decalcification voids are created causing overlying host rocks to settle into these voids. The formation of collapse breccias in host rocks susceptible to decalcification enhances the secondary permeability thereby increasing the size of the orebody if the hydrothermal fluids are mineralised. The process of the overlying lithologies settling into voids created by decalcification of carbonate lithologies further increases structural preparation of the overlying rocks, in the form of many small, discontinuous, randomly orientated normal faults. This further increases secondary permeability. This is especially evident in the Gold Quarry deposit where large collapse breccias are formed in the carbonate lithologies underlying siliciclastic, unreactive, host rocks (Rota, 1993). The unreactive siliciclastic rocks, which host the Main orebody, have been structurally prepared by the formation of collapse breccia at depth, and are characterised by numerous small discontinuous, randomly orientated normal faults. Osterberg and Guilbert (1991), showed that by systematically measuring the density and orientation of fractures over the Chimney Creek deposit, the ore body can be successfully delineated. This could be a powerful tool in project scale exploration programs.

4.3.4.3. Fault breccias

Fault breccias are often silicified and are the most common surface expression of alteration and/or structure of hydrothermal systems (Appendices 1, 2 and 3). Fault breccia characteristics are: (1) tabular geometry of any orientation, (2) planar to undulatory contacts, (3) steeply zoned from the edges towards the centre; edges of fault breccias have little matrix (<3 per cent), this increases rapidly towards the centre; increase in rounding of fragments from the edges to the centre; decrease in fragment size from the edges to the centre.

Fault breccias often show repeated movement, brecciation and silicification and host significant mineralisation especially at the intersection of faults (Appendices, 1, 2 and 3). Silicified fault breccias are commonly interpreted as relic conduits to hydrothermal fluids.

4.3.4.4. Hydrothermal breccias

Hydrothermal breccias are characterised by: (1) subangular to well rounded fragments - indication of transport, (2) many different shapes, (3) fragments varying from monolithic to heterolithic and (4) abundant quartz veins. Hydrothermal brecciation is believed to be caused by the sealing of the hydrothermal system, a buildup of pressure until over pressure causes an explosive hydrothermal brecciation event. Most deposits have been described to have had several phases of hydrothermal brecciation (Appendices 1, 2 and 3). These repeated pulses of sealing, over pressuring and hydrothermal brecciation could be critical in the upgrading of the deposit with each event.

4.3.4.5. Crackle breccias

Crackle breccias are usually highly silicified host rock found on the peripheries of hydrothermal breccias. Crackle breccias are characterised by: (1) highly silicified host rock on the peripheries of hydrothermal brecciation, (2) minor movement of individual fragments which can be restored to the original setting, much like a slightly expanded jigsaw puzzle.

4.4. ALTERATION

The distribution and zonation of alteration associated with hydrothermal gold mineralisation in sediment hosted deposits is controlled primarily by the interplay between faults, the permeability of host rocks and the crest of folds. The most common types of hypogene alteration described for the various deposits are decalcification, silicification and argillisation (Tables 1, 2 and 3). The intensities of these three alteration types varies dramatically between deposit to deposit and within individual deposits (Appendices 1, 2, 3). Paragenesis of alteration is commonly as follows; decalcification → silicification → argillisation → oxidation (hypogene?) → oxidation (supergene) (Appendices 1, 2, and 3).

Keuhn and Rose (1992), did a detailed study of alteration zonation in unoxidised ore at the Carlin deposit. Most of the previous studies of hydrothermal alteration at Carlin (Radtke, 1985; Rye, 1985) had been based on oxidised exposures in the upper portions of the mine (Keuhn and Rose, 1992). The mineral assemblage zonation from distal, unaltered Roberts Mountains Formation to the proximal, jasperoid fault conduits is: (1) quartz + dolomite + calcite + illite + K-feldspar + pyrite → (2) quartz + dolomite + calcite + illite + pyrite → (3) quartz + dolomite + illite-K mica + pyrite → (4) quartz + illite-K mica + pyrite → (5) quartz + kaolinite-dickite + pyrite (Fig. 16). Gold mineralisation is associated with mineral assemblages three and four (Fig. 16), (Keuhn and Rose, 1992).

4.4.1. Decalcification

Decalcification, usually the first alteration phase, has been documented by chemical, mineralogical and petrographic data at Carlin (Radtke, 1985; Bakken and Einaudi, 1986, Bakken, 1990; Keuhn and Rose, 1992), at Cortez (Wells et. al., 1969) and at the Vantage deposits (Ilchik, 1990). Decalcification is characterised by the removal of calcite, and to a lesser extent dolomite, by acidic hydrothermal fluids in the pyrite stability field (Bakken, 1990; Keuhn and Rose, 1992). The intensity of decalcification is usually greatest near high angle faults, which were conduits to hydrothermal fluids, and gradually decreasing away from them (Fig's. 16 & 17), (Keuhn and Rose, 1992). Carbonate host rocks which have been decalcified have a significant reduction in their bulk density (Fig. 16).

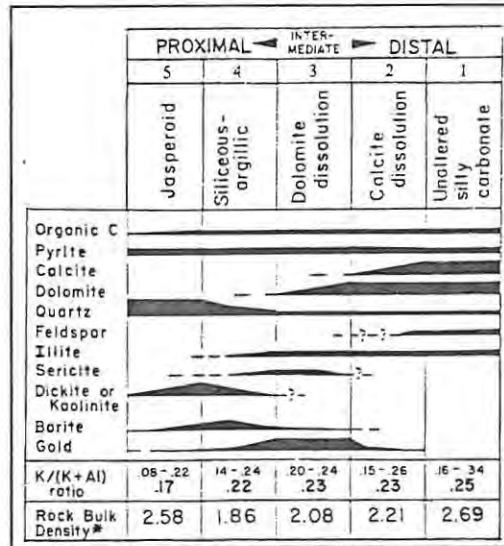


Figure 16. Zonation of alteration at the Carlin deposit as defined by mineralogical stabilities and spatial relationship to conduits of hydrothermal fluids (Keuhn and Rose, 1992).

Decalcification forms a large halo around gold mineralisation both proximal and distal to conduit faults, although the intensity differs, being greatest in proximal host rocks (Fig. 17). Above the orebody at Carlin, moderate decalcification extends up to 60 meters (200 feet), (Fig. 17). Calcite veining is minimal in the decalcified rocks, hosting mineralisation, proximal to structural conduits, while distal decalcified host rocks have abundant calcite veins throughout the ore zone (Fig. 17), (Keuhn and Rose, 1992). Calcite removed from the decalcified zone is precipitated on the peripheries of the hydrothermal system. This can be seen in the intensity of calcite veins above the main orebody in the Carlin deposit (Fig. 17), (Keuhn and Rose, 1992). The distribution of calcite veining can be a useful tool in exploration as a vector pointing to the heart of mineralisation and/or the hydrothermal system. At the Carlin deposit, between 50 and 60 percent volume loss in carbonate lithologies has been attributed to decalcification (Bakken, 1990; Bakken and Einaudi, 1986). Rota and Hausen (1991) have described a similar volume losses to have occurred at the Gold Quarry deposit while Keuhn and Rose (1992) have inferred 30 to 40 percent volume loss at the Betze/Post deposit. Indicators of volume loss as a result of decalcification are collapse breccias, thickness changes of altered vs. unaltered beds and flattening of fossils and worm burrows (Keuhn and Rose, 1992; Williams, 1994). Volume loss as a result of decalcification can result in the formation of many, randomly orientated, normal faults and pervasive extensional fractures with random

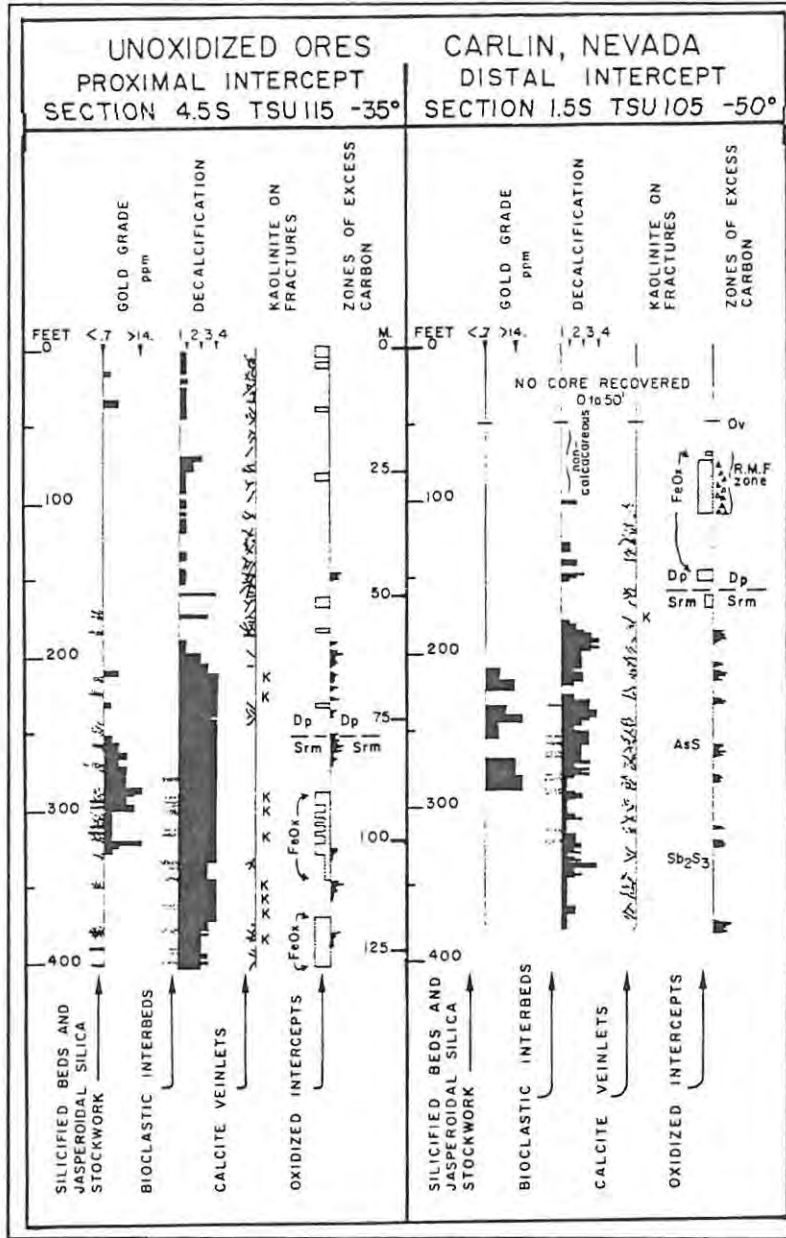


Figure 17. Spatial relationships between typical proximal and distal alteration features and Au mineralisation in unoxidized ore intercepts at Carlin. Decalcification is based on reaction with dilute HCL: <1 = slightly decalcified or dolomitic, 1 to 2 = mildly decalcified, 2 to 3 = moderately decalcified, 3 to 4 = very decalcified, and >4 = total lack of reaction. "Excess carbon" indicates introduced organic matter and hydrocarbon veining. Dp-Srm = Devonian Popovich Formation-Silurian Roberts Mountains Formation contact, Ov = Vinini Formation, R.M.T. = Roberts Mountains thrust fault, K = kaolinite (Keuhn and Rose, 1992).

orientation in the hanging wall to mineralisation (Williams, 1994, Bakken, 1990; Rota, 1993; Keuhn and Rose, 1992). Keuhn and Rose (1992) describe calcite veins and microfaults, in the hangingwall to mineralisation, having slight normal displacement in response to structural adjustment to the volume loss. All the above features are valuable clues in directing exploration

geologists to mineralisation and should be systematically recorded during an exploration program.

Carbonate units at the Betze/Post deposit having lesser amounts of detrital material had sufficiently low initial permeabilities to resist porosity increase due to decalcification, whereas porosities and permeabilities were enhanced in silty units with initially higher permeabilities (Arehart et. al., 1993). Lithologies that are preferentially decalcified are the thin to medium bedded, platy, calcareous, silty limestones, siltstones and mudrocks which host the majority of mineralisation in Nevada (Tables 1, 2, and 3). Carbonate debris flows, common in the lower Popovich Formation in deposits along the northern part of the Carlin trend, are strongly decalcified because of initial primary permeability and the highly reactive nature of these flows (Williams, 1994). At the Betze/Post deposit unaltered, stacked debris flow breccias which are 213 metres thick at the peripheries of the deposit can be traced into the centre of the deposit. There the sequence is 96 metres thick, attribute to volume loss due to decalcification (Williams, 1994).

4.4.2. Silicification

Silicification is the most complex form of hypogene alteration in sediment hosted gold deposits as silica is deposited during different stages in the lifetime of a hydrothermal system (Fig. 16), (Appendices 1, 2, 3), (e.g. Rota, 1991 and 1993; Lisle et. al., 1988; Lauha and Bettles, 1993a, b). Silicification is the most common alteration type observed in exploration programmes because silicified host rocks are resistant to weathering, forming low ridges and hills.

Silicification occurs in a number of ways, including pervasive replacement of limestone and dolomite, known as jasperoids (Lovering, 1972), deposition of fine to coarse grained euhedral quartz, silica veins and veinlets and late stage drusy, chalcedonic and hyaline quartz (Pervival et. al., 1988; Lauha and Bettles, 1993). Although detailed paragenesis of silica deposition varies from deposit to deposit, a common thread runs throughout, this being: (1) an early pre-ore pervasive silicification, (2) silicification associated with gold mineralisation and usually accompanied by brecciation (this stage can have multiple events such as described in the Lone Tree, Rabbit Creek, Meikle, Gold Quarry and Betze/Post deposits), (3) quartz veins and

veinlets accompanied by stibnite, realgar and cinnabar mineralisation and (4) late stage quartz veinlets/veins, drusy, chalcadonic and hyaline quartz lining fractures (Appendices 1, 2, and 3). Gold and sulphide mineralisation is known to accompany all stages of mineralisation (Radtke, 1985; Madrid and Bagby, 1986).

Jasperoid bodies in sediment hosted gold deposits can be divided into two types: (1) those restricted to pre-existing structural zones which are usually characterised by intense brecciation and (2) roughly stratabound jasperoids, controlled by host rock reactivity, porosity, permeability and impermeable lithological and/or structural barriers (Rota and Hausen, 1991).

At most of the deposits studied structural jasperoids occur along high angle feeder faults and it is these jasperoids at surface which have directed exploration programmes and most deposits have a "discovery jasperoid" (e.g. Broili et. al., 1988; Ilchik, 1990; Meyers, 1993; Rota and Hausen, 1991).

At the Gold Quarry deposit, large stratabound jasperoids occur at the contact between the lower carbonate and upper siliciclastic lithologies, the latter acting as an impermeable cap, "ponding" ascending hydrothermal fluids (Rota and Hausen, 1991). At the South Bullion deposit, mineralisation is hosted in jasperoids which occur in the hinge of an anticline, at the unconformity between Devonian Devils Gate and Mississippian Webb Formations (Puntman and Henriques, 1991). On the other hand, stratabound jasperoids at the Gold Bar deposit along the Battle Mountain - Eureka trend, occur below the deposit at the contact between lower massive impermeable limestones and upper thinly interbedded limestones and siltstones (Appendix, 2), (Broili et. al., 1988). A similar jasperoid to that described for Gold Bar occurs at the Vantage deposit (Appendix, 1), (Ilchik, 1990).

Rota and Hausen (1991), describe seven phases of quartz veining with the following paragenesis; (1) quartz micro-veinlets → (2) carbon-rich black quartz veinlets → (3) quartz-vein microbreccia → (4) quartz-alunite veins → (5) quartz-barite veinlets and veins → (6) vuggy quartz veins → (7) milky-white quartz veins and fracture filling. All the vein stages contain some gold mineralisation, but stages 2 through to 5 accompany main stage gold deposition (Rota and Hausen, 1991).

Silification in the siliciclastic host rocks is generally more subtle, occurring as quartz overgrowths on sedimentary derived quartz, quartz veinlets/veins and coating fractures (Lisle, et. al., 1988; Rota and Hausen, 1991; Rota, 1993).

4.4.3. Argillisation

Argillic alteration has been described for most deposits, varying from minor to pervasive (Tables 1, 2 & 3), (Appendices 1, 2, and 3). Argillic alteration in carbonate host rocks, such as those at Cortez, Gold Acres, Bootstrap/Capstone, Gold Quarry deposits, is confined to fractures and faults (Hays et. al., 1991; Erikson, 1985; Baker, 1991; Rota and Hausen, 1991). Minerals that form the argillic alteration suite are illite (sericite), kaolinite, montmorillonite and allophane. Argillisation is the most pervasive alteration type at the Tusc deposit (Doyle-Kunkel, 1993). Here kaolinite and illite occurs as veinlets and fracture coatings with kaolinite and sericite (illite), the dominant clay minerals, in the deeper and upper portions of the orebody respectively (Doyle-Kunkel, 1993). Although montmorillonite has been described to occur at the Carlin deposit (Bakken, 1990; Evans and Peterson, 1986), and Keuhn and Rose (1992) found no evidence of montmorillonite, based on XRD studies of 100 samples. Dickite was found to be a common phase in argillically altered dykes at Carlin (Keuhn and Rose, 1992). Keuhn and Rose (1992) noted that the kaolinite on fractures was greater proximal to structural conduits while distal mineralisation had only trace amounts of kaolinite lining fractures (Fig. 17).

Illite occurs as a primary sedimentary mineral in unaltered host rocks, 5 to 15 percent in the upper Roberts Mountains Formation (Mullens, 1979, 1980) and as a product of hydrothermal alteration (e.g. Bakken, 1990; Hauff et. al., 1991; Keuhn and Rose, 1992). Illite is temperature sensitive and occurs in a number of polytypes with the less ordered 1M and the ordered 2M polytypes being the most common (Hauff et. al., 1991). Hauff et. al.(1991), in a study at the Carlin and Preble deposits, showed that the structure of illite varied systematically from less ordered 1M on the peripheries of these deposits to the ordered 2M polytype within the deposits. X-ray diffraction is the most efficient way to analyse illite but Hauff et. al. (1991) showed that visible/near infrared spectral measurements using a field-portable reflectance spectrometer identified the various illite polytypes. This technique could be an extremely

powerful component in guiding an exploration programme to hydrothermal gold mineralisation, particularly since clay alteration can be outlined by appropriate ratioing of TM data.

Argillic alteration in deposits where carbonate rocks are the dominant host, has often been confused with intense decalcification, resulting in a friable rock comprised of residual, micron sized silt and dolomite (Ilchick, 1990).

Argillic alteration is better developed in deposits where host rocks are shales, basalts and igneous intrusives as at Lone Tree, Rabbit and Chimney Creek and Meikle (Bloomstein et. al., 1993; Atkin, 1992; Bloomstein et. al., 1991; Lauha and Bettles, 1993a). Argillisation is usually peripheral to silicification.

4.4.4. Carbonisation

Carbonisation is defined by the presence of anomalous, mature hydrocarbon within the deposit related to rocks from surrounding regions (Edison and Hallager, 1986). Carbonisation occurs as black, sooty mature hydrocarbon (pyrobitumen) lining fracture, fault and bedding planes, and as carbon rich quartz veins and veinlets. Carbonisation has been reported from Betze/Post, Genesis/Blue Star, Carlin, Gold Quarry, Gold Acres, Horse Canyon, Tonkin Springs, Gold Bar and NightHawk Ridge deposits (Appendices, 1 and 2).

Carbonisation is the dominant alteration at the Gold Acres deposit along the Battle Mountain - Eureka trend (Hays, Jr. and Foo, 1991). Here, carbon occurs as black sooty material lining fracture, fault and bedding planes and in places occurs as much as 3 percent by volume. A significant amount of disseminated pyrite is associated with carbon at Gold Acres (Hays, Jr. and Foo, 1991). At the Horse Canyon, Tonkin Springs, Gold Bar and Nighthawk Ridge deposits, carbonisation occurs as black, sooty material lining fracture and fault planes (Radtke, et. al., 1987; Gesick, 1987; Broili et. al., 1988; Carden et. al., 1991). At Gold Bar, carbon lined fault and fracture planes are greatest adjacent to the structural conduits to hydrothermal fluids whereas at Nighthawk Ridge these fracture and fault planes are peripheral to the deposit (Broili et. al., 1988; Carden et. al., 1991).

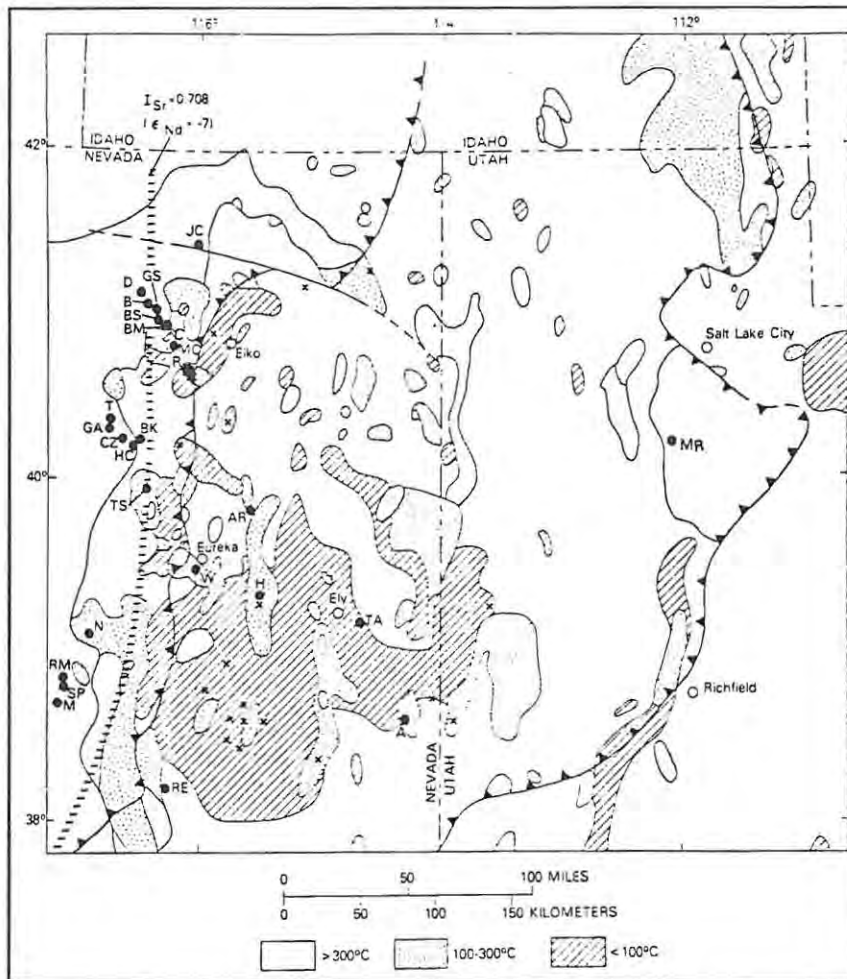


Figure 18. Spatial relationship between sediment-hosted disseminated gold deposits and geothermal gradient of Paleozoic rocks. The dashed line indicates the location of initial $^{87}\text{Sr}/^{86}\text{Sr} = 0.708$ and $^{143}\text{Nd}/^{144}\text{Nd} + -7$ isotopic composition in granites - believed to be craton edge. Western thrust is the late Devonian Antler RMT and the eastern thrust the Sevier thrust system of Cretaceous age. Deposits: JC = Jerrit Canyon, B = Bootstrap, GS = Gold Strike, BS = Genesis/BlueStar, BM = Bullion Monarch, C = Carlin, MC = Maggie Creek/Gold Quarry, D = Dec, R = Rain, T = Tenabo, GA = Gold Acres, CZ = Cortez, HC = Horse Canyon, BK = Buckhorn, TS = Tonkin Springs, AR = Alligator Ridge/Vantage, W = Windfall, N = Northumberland, RM = Round Mountain, SP = Shale Pit, M = Manhattan, RE = Reveille, H = Hamilton, A = Atlanta and MR = Mercur. X indicates the position of wells and outcrop containing oil.

It has been shown at the Carlin deposit that hydrocarbon maturation occurred under P-T conditions of approximately $155 \pm 20^\circ\text{C}$ and 0.6 to 1.4 kbars and was wholly a pre-ore event, unrelated to gold mineralisation (Keuhn and Rose, 1992). Hydrocarbons are thought to have been introduced into the NW trending Tuscora anticline which was formed during Late Triassic to Late Jurassic (Keuhn and Rose, 1992). Organic maturation culminated during the Mesozoic when granodiorite stocks and dykes were emplaced. Organic matter was

subsequently redistributed by the hydrothermal activity responsible for gold mineralisation and later supergene oxidation (Keuhn and Rose, 1992). Rota and Hausen (1991) and Rota (1993) describe carbon rich quartz veins and veinlets accompanying the earlier stages of gold

mineralisation. Nelson (1991) believes that hydrothermal gold mineralisation and hydrocarbons have concentrated in the same lithological and/or structural traps. Cunningham (1987) showed that there is a clear relationship between thermal maturity of organic carbon in sediments that host disseminated gold deposits in Nevada (Fig. 18). Most of the deposits fall within sediments whose organic material is classified as supermature ($>300^{\circ}\text{C}$) and a lesser number in the mature to supermature category ($100\text{-}300^{\circ}\text{C}$) (Fig. 18). Thermal maturation of organic matter has been caused by several different geological events such as, deep burial of lower to middle Paleozoic sediments during early Mesozoic, late Jurassic intrusion, mid- and late-Cretaceous, metamorphic and thermal events respectively (Thorman et. al., 1991) and Tertiary intrusive events and higher geothermal gradient related crustal thinning due to extensional tectonics. Although gold mineralisation is not related to all the thermal events, given the close spatial relationship of areas of increased thermal maturation and sediment-hosted disseminated gold deposits regional maturation studies could be an effective regional exploration tool (Fig. 18).

Ilchik et al., (1986), in a study of the organic matter at the Vantage deposits, concluded that the organic matter within the deposits was of a marine sedimentary origin and that the total organic carbon of mineralised and background material is similar. This indicates that no organic matter was introduced during hydrothermal activity and that hydrothermal activity increased the organic matter maturation (Ilchik, et. al., 1986). Maturation studies can be a useful practical tool in prospect scale exploration providing quantitative vectoring.

4.4.5. Oxidation

Oxidation of sediment hosted, hydrothermal gold deposits has led to the characteristic buff-tan coloured rocks in the upper parts of many of the deposits (e.g. Broili et. al., 1988; Rota and Hausen, 1991). In contrast, unoxidised rocks are grey-black in colour.

The question of whether or not oxidation is a result of hypogene and/or a supergene processes has raised considerable debate (Ilchik, 1990; Radtke, 1985; Rye, 1985; Rota and Hausen, 1991; Rota, 1993; Keuhn and Rose, 1992). The argument centers around the mineral alunite, and whether it is formed from descending, supergene, secondary oxidized fluids, or from primary, ascending, oxidised hypogene, hydrothermal fluids. At the Vantage deposits both hypogene and supergene oxidation processes have been described to occur (Ilchik, 1990). Based on isotopic studies of alunite, and the fact that alunite occurs in veins intergrown with barite, Ilchik (1990) argues that alunite was deposited from ascending, oxidised hypogene, hydrothermal fluids. Hypogene oxidation at the Vantage deposits has resulted in the near complete destruction of the sulphides and organic matter and is confined to the orebody shell (Ilchik, 1990). Supergene oxidation is confined to the upper portions of the orebody with the oxidation front mimicking the erosional paleosurface (Ilchik, 1990). Ilchik (1990) also describes field relations where oxidised rocks underlie reduced rocks, interpreted as hypogene ascending oxidation.

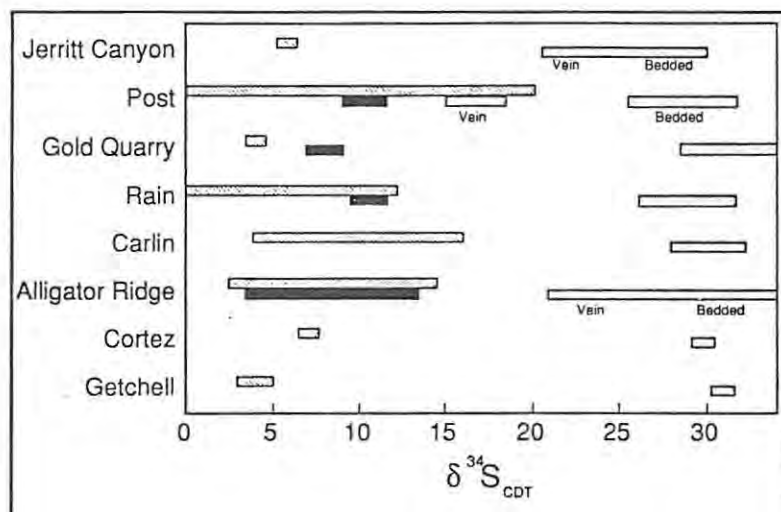


Figure 19. Compilation of sulphur isotope data of sulphides and sulphates from various sediment-hosted micron gold deposits. (From Arehart et. al., 1992). Chevron = primary sulphides, black = alunite/jarosite, grey = barite.

Rota and Hausen (1991) and Rota (1993) cite the presence of alunite and hematite in the deeper portions of the Gold Quarry deposit as an indication that some of the oxidation is hypogene in origin. At Carlin, oxidised pyrite encased by silica has been cited as evidence of hypogene oxidation (Radtke, 1985).

Sulphur, oxygen and hydrogen isotope studies of alunite, from deep within the Post deposit by Arehart et. al., (1992), indicate that the alunite was formed in a supergene environment. Arehart et. al., (1992) point out that the barite occurring in association with alunite in veins is enriched in ^{34}S relative to ^{34}S of alunite (Fig. 19). Therefore, although both minerals occupy the same vein, their isotopic differences indicate different origins and dates. Arehart et. al., (1992) also point out that Ilchik (1990) describes similar differences in the ^{34}S isotopic composition for barite and alunite occurring in the same vein (Fig. 19). They conclude that the argument used by Ilchik, that the occurrence of alunite and barite in the same vein is an indication of hypogene oxidation, is invalid. Alunite at both the Post and Vantage deposits has been described to overgrow barite (Arehart et. al., 1992; Ilchik, 1990).

5. ORE CONTROLS

The shapes and sizes of sediment-hosted hydrothermal gold deposits are a result of a complex interplay between structures (high and low angle faults), nature of host lithologies, unconformities and anticlines. Table 4, is a summary of the controls on mineralisation of the 23 deposits studied, as described by the various authors, in order to prioritise these controls in order to aid exploration.

5.1. High angle faults

High angle faults and reactive carbonate host lithologies are the primary controls of mineralisation in 14 of the 23 deposits studied (Table 4). High angle faults are conduits to ascending hydrothermal fluids and it is at the intersection of high angle faults with low angle faults, suitable host rocks, unconformities and other high angle faults that are major controls to mineralisation on both a regional and local scale (Fig. 20). At the Carlin deposit, it is the intersection of high angle faults and favourable host rocks which forms the local high grade ore zone (Fig. 20a). At the Gold Quarry deposit, it is the intersection of major NE and N to NNW faults which is the major control, in that structural preparation has created a highly permeable plumbing system (Rota, 1993). The orebodies at the Meikle, Deep Post, Lone Tree, Preble, Getchell and Rabbit Creek deposits are all hosted within brittle shear zones which have undergone multiple episodes of movement creating a favourable plumbing system for

Table 4. Ore Controls of Sediment-Hosted Gold Deposits along the Carlin, Battle Mountain - Eureka and Getchell Trends, Nevada.

Deposit	Faults			Unconformities	Folds (Anticlines)	Lithology				Impermeable Caps
	Thrust Faults	High Angle Faults	Fault Intersections			Carbonate	Siliciclastic	Debris Flows	Transitional Lithologies	
Bootstrap/ Capstone		P - SP, C	P			m - LP			✓	
Meikle	m - SP	P - SP, C	L - SP, L			S - LP	m	✓, S	✓	
Betze/Post	m - SP	P - SP, C	L - SP, L	✓?	R, L	P - LP	m	✓, S	✓?	Sills, marble, massive limestone
Genesis/ Blue Star	m - SP	P - SP, C	P - SP, L		R, L	S - LP		✓, m	✓	
Carlin		m - SP, C	m - SP, L		R	P - LP	m - SP		✓	L, Siliciclastic sediments
Tusc		P - SP, C	P - SP		m - L	P - LP			✓	
Gold Quarry	m - SP	P - SP, C	P - SP		m -L, R	P - LP	S	✓, m	✓	L, Siliciclastic sediments
Rain		m - SP, L, C	m - SP, L	P - LP	m, R	P - LP				
South Bullion	m - SP	m - SP, L, C	m - SP	P - LP		P - LP				
Vantage		S, C	m		m - L	P - LP			✓	
Lone Tree		P - SP, L & R, C	S - SP, L			m				
Hilltop	P - SP	m - SP, C	S, L - SP				✓			
Gold Acres	S - SP	S - SP, C	S - SP			P - LP	✓, m			Thrust faults, skarn
Cortez	m - SP	S - SP, C	S - SP		R & L	P - LP				Massive limestone
Horse Canyon	S - SP	S - SP, C	S - SP		S	P - LP	P - SP			
Tonkin Springs	P - SP	P - SP, C				m - LP	P - SP			Thrust and sills
Gold Bar		P - SP, C	S - SP, L			P - LP				
Ratto Canyon	m - SP	S - SP, C	S - SP, L		R & L	P - LP				Thrust
Nighthawk Ridge		P - SP, C	S - SP, L		P, R & L	P - LP				
Chimney Creek		P & S - SP, R & L, C	S - SP, L		P, R & L	P - LP				Argillised basalt, siliciclastics sediments
Rabbit Creek		P - SP, R & L, C	S - SP, L		P, R & L	S - LP		✓, m		As Above
Getchell		P - SP, R & L, C	P - SP, L		m, L	m - LP			✓	
Preble		P - SP, R & L, C	S - SP, L		R, m - L	S - LP	m - SP		✓	
TOTAL	P = 2; S = 2; m = 7	P = 14; S = 5; m = 4	P = 4; S = 11; m = 4	P = 2		P = 14; S = 4; m = 4	P = 2; S = 1; m = 4	5	10	

P - Primary Control; **S** - Secondary Control; **m** - minor Control; **C** - Conduit for hydrothermal fluids; **SP** - Structural Preparation; **LP** - Lithological Preparation; **R** - Regional Control; **L** - Local Deposit Control. ✓ = Present in the mine.

hydrothermal fluids. Tertiary intrusives have intruded many of these high angle faults and the intrusives are mineralised and brecciated themselves (Fig. 20), (i.e. Bootstrap and Meikle deposits), (Baker, 1991; Bettles and Lauha, 1993b).

5.2 Thrust faults

Although many deposits are spatially related to the RMT, only two deposits can be attributed to thrusts being the primary control of mineralisation, Hilltop and Tonkin Springs, both hosted in eugeosynclinal siliciclastic sediments (Table 4). At Hilltop the thrust fault has undergone multiple episodes of movement, creating a permeable breccia up to 15 metres thick (Fig. 21). (Lisle et. al., 1988). The ore bodies at Tonkin Springs, on the other hand, are thin stacked, flat lying, ellipsoidal bodies with local high grades occurring at the intersection of high angle and low angle faults (Gesick, 1987). Thrust faults are secondary or minor controls of mineralisation at 9 of the deposits studied, in that they provide varying degrees of structural preparation (Table 4). Thrust faults at Ratto Canyon and Tonkin Springs deposits are aquitards which impede the rise of hydrothermal fluids (Gesick, 1987; Steinberger et. al., 1987). This could also be the case for the major mines along the Carlin trend depending on the interpretation of the position of the RMT, either at the base or the top of the Rodeo Creek Formation (Fig's 13 and 14). Adams and Putnam (1992) suggest that with the spatial relationship between many deposits and thrust faults and the interpretation of fluid mixing as a major control of mineralisation, thrust faults could have been important in controlling meteoric fluid flow. However, thrust faults are defined as low angle faults ($<45^\circ$) and with lithostatic pressure being vertical, are not envisaged to be highly permeable, open spaced fractures conducive for circulating meteoric and or hydrothermal fluids.

5.3. Folds

Antiforms are spatially associated with 15 of the 23 deposits studied, suggesting a genetic relationship (Table 4). Betze/Post, Genesis/Blue Star and Carlin deposits are all spatially related to the Tuscora antiform (Table. 4), (Christensen, 1993). The long axis of the Gold Quarry deposit is parallel to the axis of a large NE trending anticline with localised structurally controlled, high grade zone trending N to NNW (Rota, 1993). Controls which antiforms

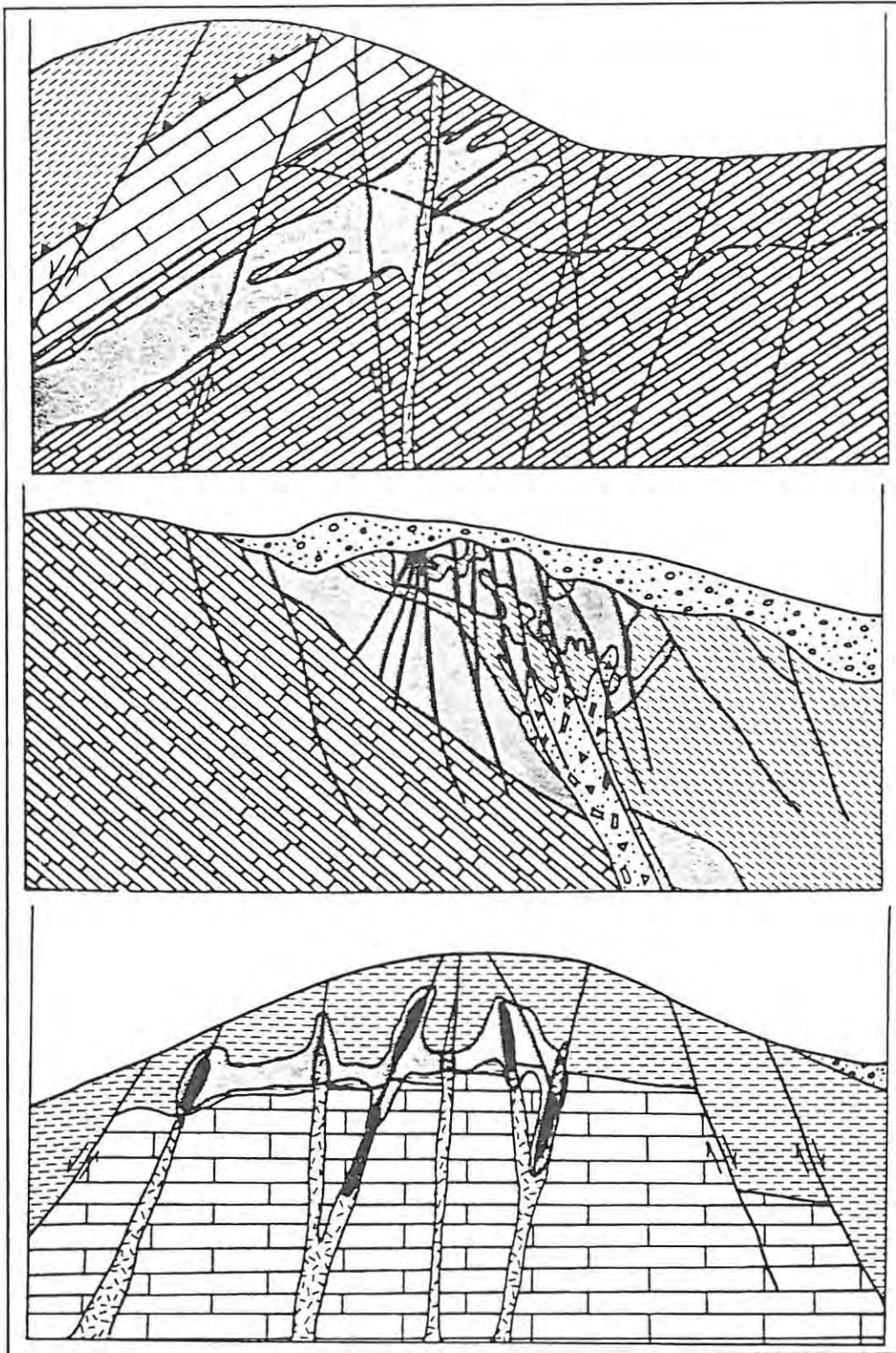


Figure 20. Styles and controls of mineralisation in Carlin trend gold deposits: (a) Carlin deposit stratabound replacement style mineralisation; (b) Bootstrap and Meikle type high-grade vein-like mineralised structures; (c) Gold Quarry deposit with east-dipping stratabound Deep West zone and overlying Main Zone structural stockwork (Christensen, 1993)

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invoke on hydrothermal systems are that they provide impermeable caps to mineralisation, especially where argillised igneous rocks or mudstone overlie permeable host rocks, doubly plunging fold axes restrict flow along the fold axis and axial planar cleavage in the hinges of folds enhance secondary permeability. Nelson (1991), Poole et. al., (1983) and Keuhn, (1989) suggest that the anticlines were petroleum traps prior to gold mineralisation and that both commodities favoured the same structural and/or lithological traps. In the Rabbit Creek deposit, hinges of antiforms are areas of localised high grade ore, especially where impermeable lithologies such as argillised basalts and mudrocks, overlie more permeable lithologies (Bloomstein et. al., 1991).

Understanding the genetic relationship between antiforms and gold mineralisation is important in exploration, especially in extrapolating trends under younger cover.

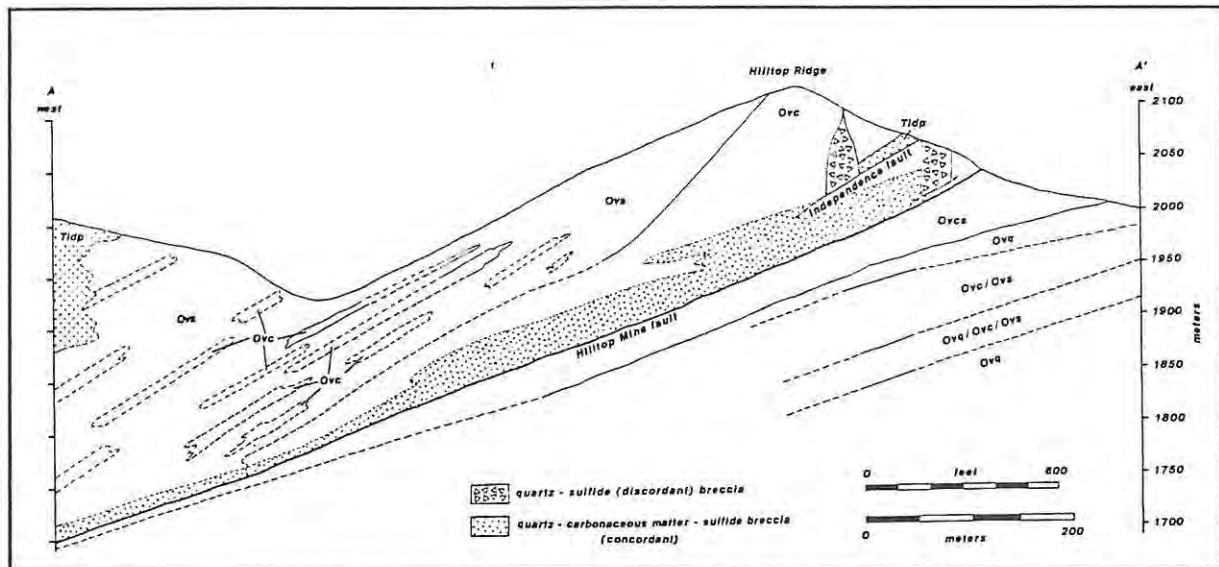


Figure 21. Mineralised concordant breccia in the hangingwall of a low angle fault - Hilltop deposit, Battle Mountain - Eureka trend, Nevada (from Lisle and Desrochers, 1988).

5.4. Unconformities

Unconformities are the primary control on mineralisation at the Rain and South Bullion deposits (Table 4). At both of these deposits, fluids have ascended high angle faults before spreading out laterally into porous and permeable host rocks above the unconformity. If fluid mixing of ascending gold bearing hydrothermal fluids, with meteoric waters, is an important control on gold precipitation, then regional unconformities would be an important control on mineralisation as they could act as large scale aquifers. Regional unconformities could be

important controls on mineralisation if lithologies above the unconformity are impermeable to ascending fluids, ponding these fluids in underlying favourable host lithologies.

5.5. Lithology

Host lithologies play a critical role in the controls of mineralisation in sediment-hosted gold deposits. Although mineralisation is hosted in a variety of lithologies, the favoured lithologies are medium to predominantly thin, calcareous, carbonaceous silty limestone, siltstone and to a lesser extent limestone (Tables 1, 2, 3 & 4). At the Carlin deposit mineralisation has favoured bioclastic silty limestone beds (Fig. 17), (Keuhn and Rose, 1992). Lithologies such as silty limestones and calcareous siltstones which have higher primary porosities and permeabilities are more conducive to alteration by acidic hydrothermal fluids than those lithologies with low initial primary porosities (Keuhn and Rose, 1992). Nelson (1991) states that hinges of anticlines which were fossil petroleum reservoirs, are favourable sites for hydrothermal gold mineralisation while anticline hinges devoid of petroleum did not host gold mineralisation, although similar lithologies are encountered in both. Although hydrocarbons may have a role in the precipitation and/or buffering of gold from hydrothermal fluids, hence a genetic relationship, primary controls such as porosity and permeability, critical for both hydrocarbon and hydrothermal fluid flow, can just easily explain this sympathetic relationship. Hydrocarbons and hydrothermal gold-bearing fluids have therefore exploited the same porous and permeable aquifers and deposition sites.

Carbonate debris flows are important controls on mineralisation because of their extremely high primary porosities and permeabilities. They are comprised, predominantly, of Mg-carbonate which is highly susceptible to alteration by acidic hydrothermal fluids (Williams, 1994). Debris flows are important hosts in Meikle, Betze/Post, Genesis/Blue Star, Gold Quarry and Rain deposits (Table 4).

Transitional lithologies, defined as interbedded carbonate and siliciclastic rocks, appear to be the favoured host rocks for mines in the Carlin trend and at Preble and Getchell deposits (Table 4). Two reasons for these transitional lithologies being favoured host rocks are: (1) competency contrast between many thinly interbedded carbonate and siliciclastic lithologies

provide structural planes along which deformation can take place, hence, enhancing secondary, structurally induced permeability and (2), volume loss due to decalcification of carbonate beds results in collapse breccias, which in turn form high angle microfaults in the hangingwall lithologies, siliciclastic beds, increasing permeabilities in otherwise unreactive host rocks. Gold Quarry and Betze/Post deposits are the biggest mines, tonnage and in situ gold respectively, and are both hosted in transitional lithologies with carbonate debris being a significant component of the transitional lithologies. Systematic and careful observations of lithologies, noting organic carbon content, primary porosity and sedimentary features of individual sedimentary units, are all features which are important to describe, both in the regional and project scale exploration.

5.6. Igneous Rocks

The spatial relationship between sediment-hosted gold deposits and intrusive igneous rocks is striking (Tables 1, 2 and 3). Great controversy surrounds the genetic relationship between intrusive igneous rocks and gold deposits, and this is based in turn on the controversy surrounding the age of mineralisation.

Pre-gold mineralisation intrusives such as the Osgood Mountain (90 Ma), Goldstrike (160.9 Ma) and the Mill (150 Ma) stocks, associated with deposits along the Getchell, Carlin and Battle Mountains trends respectively are important controls to mineralisation. Accompanying these intrusion would have been a localised complex structural regime creating favourable plumbing systems for post-intrusion, ascending hydrothermal fluids. These large intrusives have also acted as rigid bodies in post intrusive tectonics resulting in complex structures further enhancing structural permeability in the vicinities of the intrusives (Bettles and Lauha, 1993a, b; Nanna, et. al., 1987; Kretschmer, 1987). This is especially evident at the Getchell, Preble and Betze/Post deposits where localised high grade zones occur where major faults change orientation around intrusives and sediments are caught up between the intrusive and the stocks (Bettles and Lauha, 1993a, b; Nanna, et. al., 1987; Kretschmer, 1987).

Sillitoe and Bonham (1990) believe that intrusive are the source for gold and pathfinder elements and that the sediment-hosted disseminated gold deposits are distal products of

magmatic-hydrothermal fluids. They cite Bingham Canyon deposit in Utah as an example where the whole range of mineralisation from Cu-Mo porphyry through base metal skarn to distal sediment-hosted gold mineralisation can be observed. Many of the sediment-hosted disseminated gold deposits are associated with with intrusive that have base metal skarn mineralisation (Tables 1, 2 and 3). However, all mine geologist on mines where base metal skarn mineralisation is developed, told and showed the author that gold mineralisation post dates the skarn mineralisation based on cross-cutting mineralisation and structural relationships.

At the Meikle deposit, an intrusive dyke, (36.4 Ma), along a high angle fault, which hosts 15 per cent of mineralisation, has undergone repeated episodes of structural brecciation before mineralisation creating an ideal plumbing system (Bettles and Lauha, 1993b). Igneous sills and Ordovician volcanics are important controls in that they act as aquitards to rising gold bearing hydrothermal fluids forming localised high grade zones such at the Rabbit Creek and Betze/Post deposits (Bloomstein et. al., 1991; Bettles and Lauha, 1993a).

6. Age of Mineralisation

The age of sediment-hosted disseminated gold mineralisation in Nevada is controversial. Dating is frustrated by the lack of coarse grained hydrothermal minerals, lack of exposed, unoxidised ore and the controversy whether or not alunite, the mineral dated in many deposits, is hypogene or supergene in origin (Arehart et. al., 1992; Arehart et. al., 1993). Two approaches are used to date the various deposits; (1) direct isotopic dating of minerals (Silberman and McKee, 1971; Berger and Tylor, 1980; Bonham, 1985; Osterberg, 1990; Arehart et. al., 1992; Arehart et. al., 1993; Ilchik, 1990) and (2) indirect methods based on cross-cutting geological relationships (Radtke, 1985; Rota and Hausen, 1991; Rota, 1993; Bakken and Enaudí, 1986; Seedorf, 1991; Putnam and Henriques, 1991).

The author regards the resolution of the ages of these deposits as an important factor in understanding the genesis of these deposits and their tectonic setting in which they were formed. This in turn, it is hoped, will aid exploration models in the Great Basin.

Table 5, is a summary of the published isotopic dates of sediment-hosted disseminated gold deposits in this study. Ages of mineralisation range from 10 Ma for the Vantage deposits to 123 Ma for the Carlin deposit (Table 5), (Ilchik, 1990; Morten et. al., 1977). The younger Miocene dates for the Vantage and Rain deposits and the Oligocene date for Gold Quarry are all alunite dates (Table, 5), (Ilchik, 1990; Arehart et. al., 1992; Rota and Hausen, 1991). Alunite dates from the Meikle mine vary from 8.48 to 9.58 Ma (Arehart in Bettles and Lauha, 1993b). Alunite is believed to be hypogene in origin by Ilchik (1990) and Rota and Hausen (1991) and these authors feel that these ages represent the age of mineralisation. Arehart et. al., (1992), based on isotopic studies of alunite showed that the alunite at Betze/Post and Gold Quarry deposits is supergene in origin and the age dates of alunite reflect an oxidising weathering event. Arehart et. al., (1992) argues that the isotopic composition of alunite at the Vantage deposit, as described by Ilchik (1990), is very similar to that at the Betze/Post and Gold Quarry deposits and, therefore, is most likely of supergene origin. The age date of between 10 and 12 Ma years is most likely reflect a weathering event related to the onset of Basin and Range extensional tectonic, and not a hydrothermal event (Arehart et. al., 1992). These young dates do however place a minimum age on mineralisation.

At the Betze/Post deposit, Arehart et. al., (1993a) bracketed the age of mineralisation by dating an unaltered pre-ore Goldstrike stock and a post-ore sill at 158 and 39 Ma respectively. Dating sericite, apatite and zircon from high grade hydrothermally altered sediments and adjacent igneous intrusives using K/Ar, $^{40}\text{Ar}/^{39}\text{Ar}$ and fusion track techniques, Arehart et. al., (1993) suggest that gold mineralisation is approximately 117 Ma (Table 5). If this age reflects the timing of gold mineralisation, mineralisation occurred during the compressional regime in the hinterland part of the Sevier overthrust belt (Stewart, 1980). Geologists at the American Barrick Betze/Post deposit believe mineralisation is much younger, probably mid-Tertiary, based on cross-cutting geological relationships (Larry Kornze, pers. comm., 1994). A pre-ore altered dyke has a sericite date of 134 Ma at the Carlin deposit giving a maximum age on mineralisation (Morton et. al., 1977).

The sericite date of between 95 and 101 Ma (Silberman and McKee, 1971) for the altered quartz monzonite stock 152 metres below the Gold Acres deposit, does not reflect the age of gold mineralisation (Foo pers. com., 1993). The stock is responsible for pre-gold Cu-Mo-Pb-

Table 5. PUBLISHED ISOTOPIC AGES FOR SEDIMENT-HOSTED DISSEMINATED GOLD DEPOSITS ALONG THE CARLIN, BATTLE MOUNTAIN - EUREKA AND GETCHELL TRENDS (modified from Arehart et. al., 1993a).

Deposit	Age (Ma)	Description and comments
Betze/Post	117	K/Ar and $^{40}\text{Ar}/^{39}\text{Ar}$ stepheating on sericite and fusion track on apatite and zircon (Arehart et. al., 1993a)
Carlin	58	K/Ar on sericite in dyke adjacent to main pit (Morton et. al., 1977)
Carlin	123	$^{40}\text{Ar}/^{39}\text{Ar}$ stepheating on sericite from altered dyke (Keuhn, 1989 in Arehart et. al., 1993a)
Carlin	134	K/Ar on altered dyke, Carlin pit; most likely pre-ore - therefore maximum age of mineralisation (Morton et al., 1977)
Gold Quarry	25-30	K/Ar on alunite considered to be hypogene (Rota and Hausen, 1991; Arehart et.al. 1992)
Rain	20	K/Ar on alunite considered to be hypogene (Arehart et. al., 1992)
Vantage	10-12	K/Ar on alunite considered to be hypogene (Ilchik, 1990)
Gold Acres	95-101	K/Ar on sericite in altered quartz monzonite from core 152 m below the pit - relationship with ore uncertain; upper age is from biotite in main stock (Silberman and McKee, 1971)
Cortez	36	K/Ar on biotite and sanidine from altered, mineralised felsic porphyry (Morton, 1977)
Getchell	92	K/Ar on sericite from altered, mineralised granodiorite from south pit (Berger and Taylor, 1980)
Chimney Creek	90-130	K/Ar on sericite and alunite considered to be primary alteration minerals (Osterberg, 1990 in Arehart et. al., 1993a)
Rabbit Creek	15	Alunite from fault zone (Bloomstein et. al., 1992)

Zn skarn mineralisation (Table. 5), (Hays and Foo., 1991). Altered and mineralised felsic porphyry dykes having a biotite/sandine K/Ar date of 36 Ma, occur at the Cortez deposit in the Battle Mountain - Eureka trend (Table 5). McKee and Silberman, (1970) have dated the extensive welded and water-laid rhyolitic Caetano Tuff at 33.6 Ma. Erikson (1985) believes that the altered felsic porphyry dykes and sills, occurring in numerous deposits along the Battle Mountain - Eureka trend, are related to the same igneous event responsible for the Caetano Tuff.

The Chimney Creek and Getchell deposits, along the Getchell trend, have sericite dates of between 90 and 130 Ma (Table. 5). The Rabbit Creek deposit has an alunite date of 15 Ma (Table 5), (Bloomstein et. al., 1992). However, dacite and other felsic dykes related to the Cretaceous granodiorite stock (98[±] 2 Ma) are altered and mineralised at the Getchell deposit (Nanna et. al., 1987). Again cross-cutting geological relationships suggest mineralisation is younger than that those based on isotopic dating.

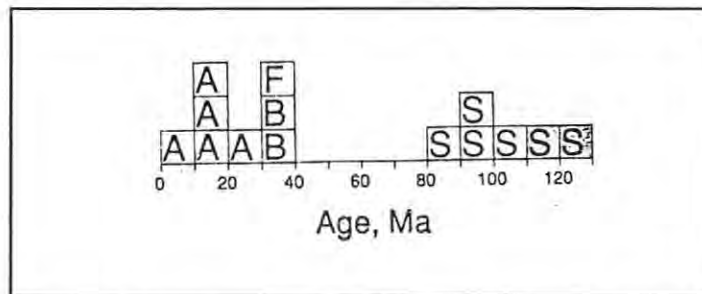


Figure 22. Histogram of published ages of minerals associated with sediment-hosted disseminated gold deposits. A = alunite, B = biotite, F = K feldspar, S = sericite. Shaded sericite blocks dates are from the Post and Carlin deposits, unshaded sericite blocks represent sericite that has an uncertain relationship with gold mineralisation (Arehart et. al., 1993).

Published isotope dates, cited as possible ages for hydrothermal mineralisation, plotted on a histogram, reveal two discrete age populations based on the minerals dated (Fig. 22), (Arehart et. al., 1993). Dates of alunite, feldspar and biotite range from 10 to 40 Ma while the sericite dates range from 80 to 130 Ma (Fig. 22). This age discrepancy has serious implications for the tectonic setting at the time of mineralisation as the older date occurs within the compressive Sevier orogeny while the younger dates fall within the Tertiary extensional regime.

Because the deposits are located within the Basin and Range Province which experienced significant extension, igneous and hydrothermal activity during the Tertiary, researchers such as Rota and Hausen (1991), Radtke (1985) Seedorf (1991) and Putnam and Henriques (1991) believe mineralisation is Tertiary in age. In many of the deposits high angle faults, which post-date thrust faults, are primary controls of mineralisation and/or conduits for ascending hydrothermal mineralisation indicating that mineralisation is post Sevier compression (Appendices 1, 2, and 3) (Rota and Foo pers. comm., 1993).

Seedorf (1991) proposes a model whereby the hydrothermal systems responsible for sediment-hosted disseminated gold deposits were driven by regional crustal heating caused by thinning of the crust during early Eocene - Oligocene extension (30 - 40 Ma). High angle faults, formed as a result of this extension, were able to penetrate deep into Proterozoic and lower Palaeozoic sediments, the proposed source of Au, As, Sb, Ag and Hg, and acted as conduits to ascending mineralised hydrothermal fluids (Seedorf, 1991).

Putnam and Henriques (1991) believe the age of mineralisation to be linked to the onset of wrench tectonics related to the San Andreas and Walker Lane right lateral fault systems. They propose that the NW trending Carlin and Battle Mountain - Eureka trends are synthetic, right lateral R_1 shears, related to the San Andreas and Walker Lane fault systems (Fig. 23). These synthetic R_1 shears are first order structures. The NW trending synthetic R_1 shears exert their own localised stress field with N to NNW and NE trending second order synthetic and antithetic R_1 and R_2 shears respectively (Fig. 24), (Putnam and Henriques, 1991). This is consistent with the paragenesis of high angle faults in many of the deposits, being, NW (1st order R_1 shear) → N to NNW (2nd order R_1 shears) + NE (2nd order R_2 shears), (Appendices, 1, 2 and 3). However, the onset of Walker Lane right lateral faulting is disputed, varying from late Jurassic (Speed, 1978) to as young as 15 Ma (Fleck, 1970). The favoured date is mid-Tertiary (Stewart, 1980).

Igneous activity related to the subduction along the western margin of the United States has migrated throughout the western United States with time (Fig. 25), (Oldow et. al., 1986). If igneous intrusions are heat sources driving hydrothermal systems, it is interesting to note that igneous activity in north-central Nevada was greatest during the 80 to 70 and 40 to 20 Ma

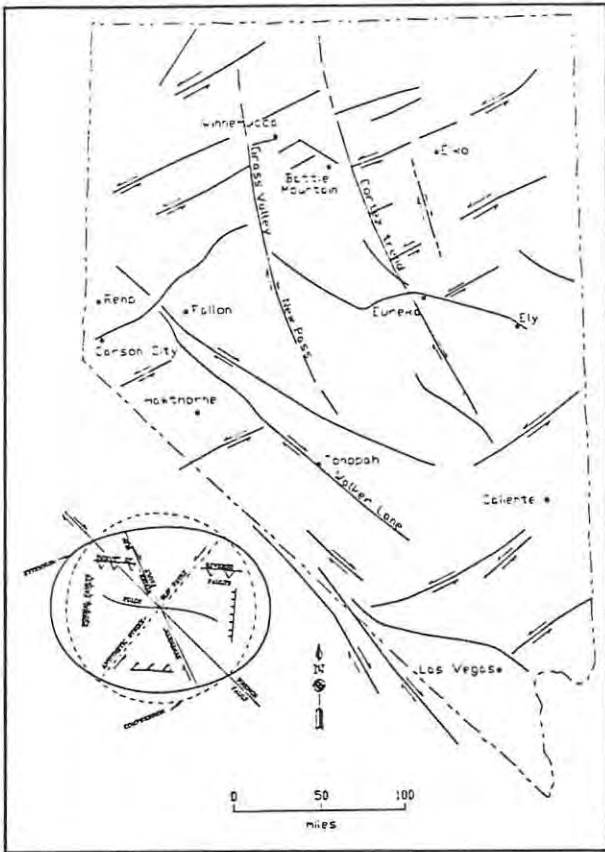


Figure 23. Map of Nevada showing transverse lineaments. Walker Lane Lineament parallel to principle stress (After Putman and Henriques, 1991)

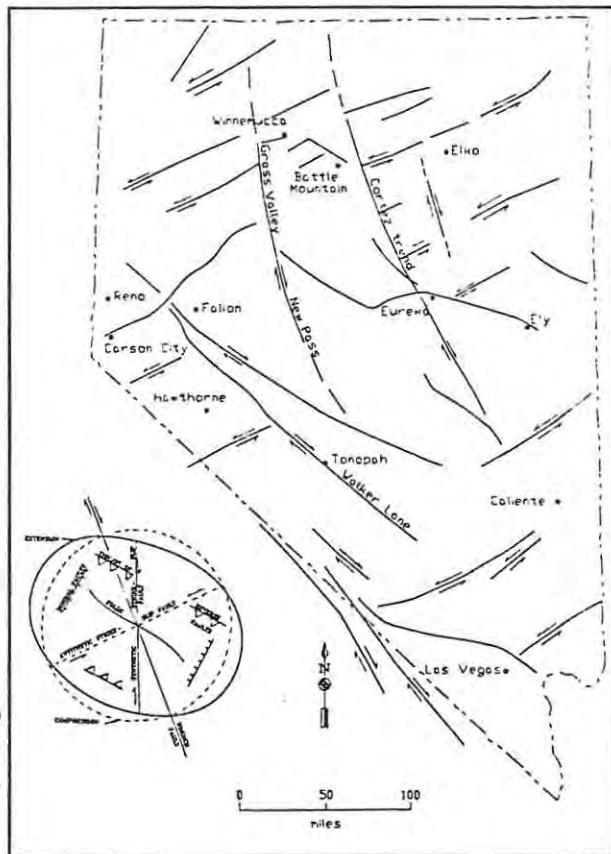


Figure 24. Map of Nevada showing strike-slip structures. Principle stress axis parallel to Battle Mountain - Eureka (Cortez) trend (After Putman and Henriques, 1991)

periods (Fig. 25). No published ages of mineralisation fall within the 80 to 70 Ma period while many deposits have been dated to fall within the 40 to 20 Ma, albeit alunite, biotite, feldspar or indirect dating methods. Note that there is no igneous activity in north-central Nevada for the period 120 to 80 Ma, the period Arehart et. al., (1993a) proposed for mineralisation, based on sericite dates of ± 117 Ma. However the Mill quartz monzonite stock, dated 98.9 ± 2 Ma, below the Gold Acres deposit falls within the period, 80 to 120 Ma, of no igneous activity in north-central Nevada (Fig. 25).

Arehart et. al., (1993a) believe that regional crustal heating could not have been the source of energy to drive the Betze/Post hydrothermal system dated ± 117 Ma. However, Thorton et al., (1991) describe a major thermal metamorphic event at approximately 110 Ma (Fig. 6). From late Devonian through to the early Tertiary the Great Basin was undergoing crustal thickening as a result of the Antler and Sevier compressional orogenies. This would have been a period heating and dewatering of the lower to mid-Paleozoic sediments. Fluids derived from this dewatering event may have been responsible for mineralisation dating at approximately 117 Ma. On the otherhand, there is abundant evidence that regional crustal heating was the energy source of hydrothermal, mineralised and unmineralised, systems during the Tertiary extensional tectonics (Seedorf, 1991; Struhsacker, 1986).

7. GEOCHEMISTRY AND SULPHIDE PARAGENESIS

7.1. Geochemistry

The geochemical makeup of sediment-hosted disseminated gold deposits is a function of the interaction between host sediment and hydrothermal fluids. Hydrothermal systems responsible for gold mineralisation in Nevada have relatively simple geochemical makeup but there has often been confusion on the amounts of element introduced and removed from the system.

Historically, it was thought that significant Si, Fe_(total), K and Al were introduced and Ca, Mg and CO₂ removed (Percival et. al, 1988). Keuhn and Rose (1992), in a detailed geochemical study of the Carlin deposit, showed that by using ratios between relatively immobile elements such as Al and Ti, extensive amounts of Ca, Mg and CO₂ were removed and Si, with trace

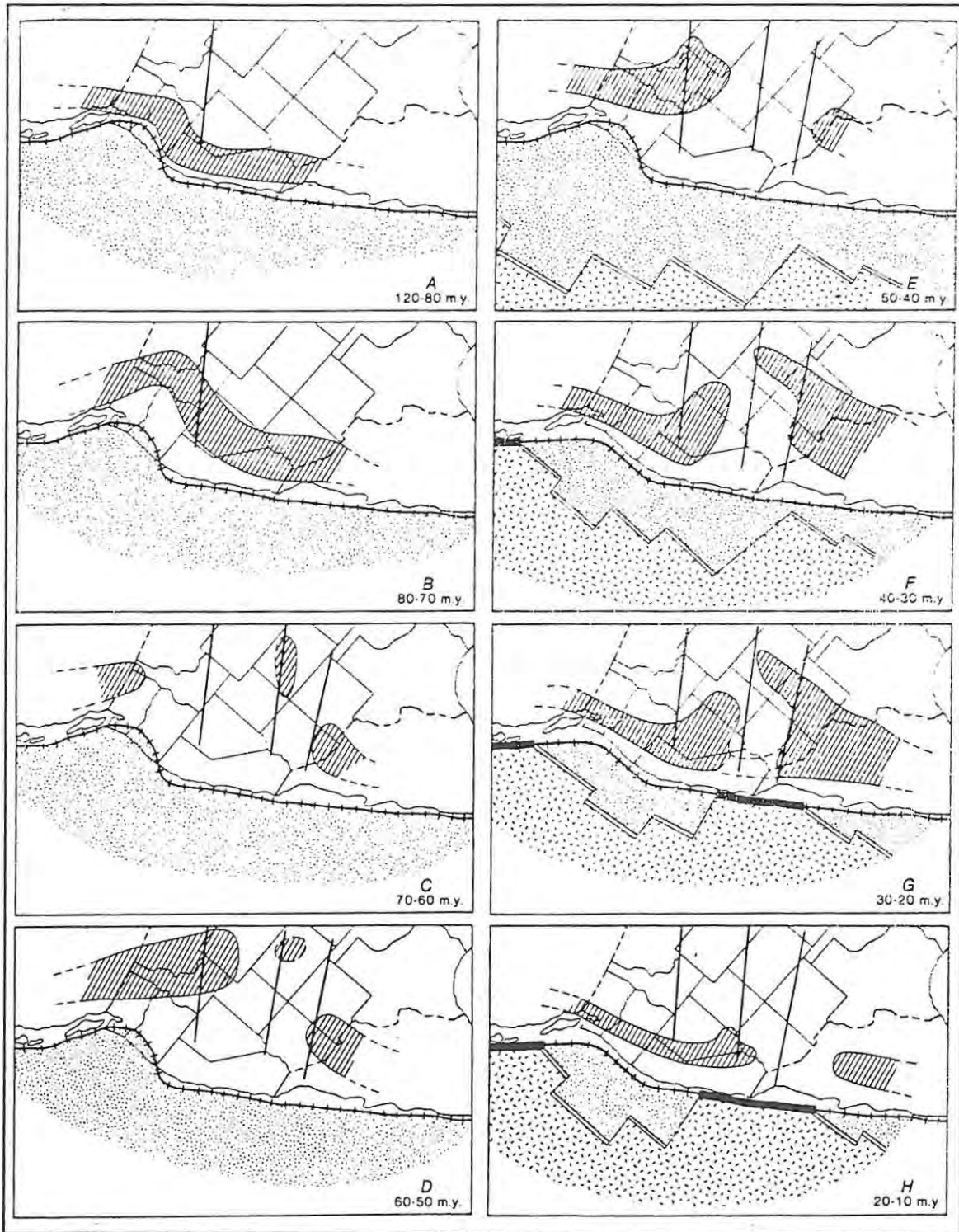


Figure 25. Generalised distribution in the western United States of predominantly andesitic volcanic suites, inferred to be related to subduction. Ruled fields represent the distribution of active volcanism during a particular time frame. From the north to south, the northeast trending lines mark the approximate traces of the Snake River - Yellowstone zone, the Colorado mineral belt, and the Springerville - Raton zone (Oldow, 1989).

elements such as Au, As, Sb, Hg, and Ba, were introduced (Fig. 26). Figure 26 shows plots of TiO_2 , K_2O , SiO_2 and Fe_2O_3 versus Al_2O_3 of unaltered, altered and various mineralised rocks. Plots of K_2O and TiO_2 versus Al_2O_3 have a strong linear relationship across the various sample types, indicating that these elements are relatively immobile in a hydrothermal system (Keuhn and Rose, 1992). Except for leached, barren, footwall rocks and pyritic ore which have low and high Fe_2O_3/Al_2O_3 ratios respectively, there is a strong linear correlation between Fe_2O_3 and Al_2O_3 for most sample types, an indication that Fe is relatively immobile and that most Fe is pre-ore (Fig. 26), (Keuhn and Rose, 1992). Most of the pyritized samples are siliceous but can occur across the entire spectrum of carbonate removal, and are thought to be closely related to fluid conduits (Rose and Keuhn, 1992). Iron does appear to have been leached from the leached footwall rocks, being redistributed in the intermediate zones of alteration in the form of pyrite \pm marcasite or ferroan rims on dolomite (Fig. 26), (Keuhn and Rose, 1992).

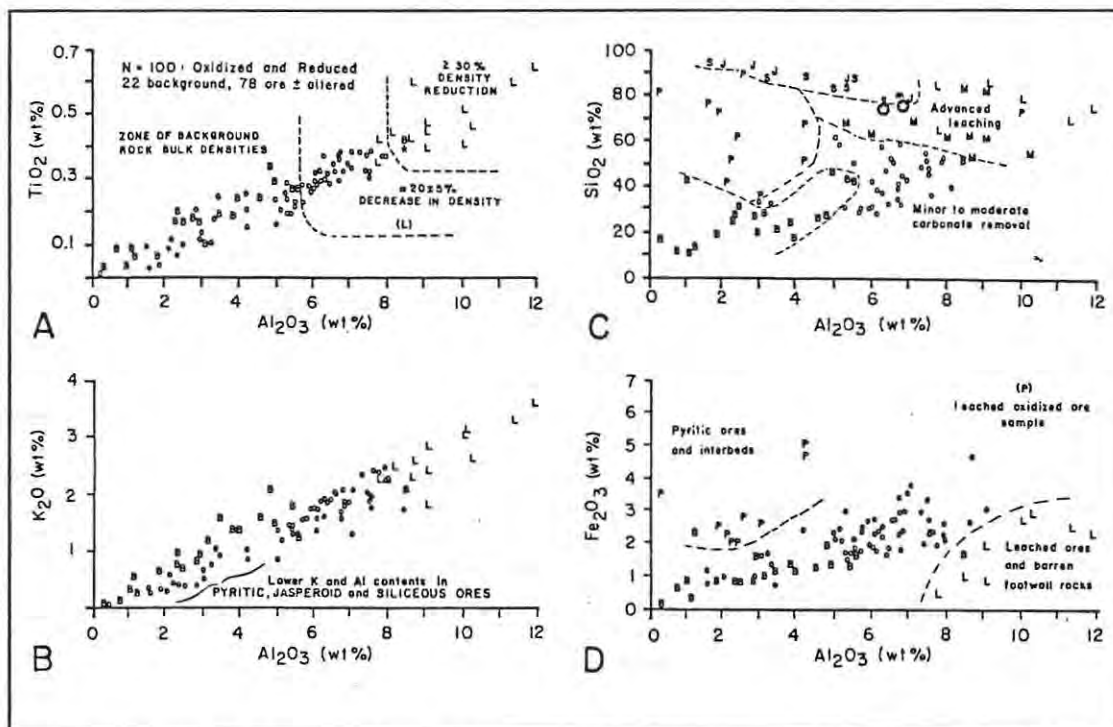


Figure 26. Plots of Ti, K, Si, vs. Al for 78 mineralised and altered, oxidised, and unoxidized rocks at the Carlin deposits and 22 background samples within the district. B = background samples, J = barren jasperoids, L = leached barren footwall rocks and leached ores including unoxidized samples, M = leached, proximal ores, o = all other ore types including "normal", "arsenical" and "carbonaceous". P = pyritic ores and interbeds and S = siliceous ores. Starred points "a" and "m" in C are average and median values for deep reduced ores (From Rose and Keuhn, 1992).

There is a close association between Au and As, Sb, Hg, Tl, Ba and, to a lesser extent, Fl and Ba (Table 6). The abundances (in ppm) of trace elements associated with Au mineralisation are: As (0.1 - 1000), Sb (1 - 10 000), Hg (0.1 - 1000), Ba (10 - 10 000), Tl (<1 - 1 500), Ag

(<0.1 - 100) and F (10 - 10 000) (Table 6), (Percival et. al., 1988). Trace element geochemistry varies greatly between deposits, i.e., Hg is low in both the Carlin and Gold Quarry deposits, restricted to the Genesis/Blue Star orebody and forms a big halo at the Nighthawk Ridge deposit (Table 6). It is therefore important in the evaluation of geochemical data that all the trace elements associated with gold mineralisation be used mutually as the large distribution differences between deposits of a single trace element are too great to be used in isolation in defining gold mineralisation.

Arsenic occurs as arsenian pyrite, realgar and orpiment and, more rarely, as arsenopyrite. Native As has been described to occur at the Cortez, Carlin and Betze/Post deposit but is probably more widespread as it is difficult to recognise in carbonaceous ore (Radtke, 1985). Sb and Hg occur coating pyrite grains but more predominantly as stibnite and cinnabar respectively. Ba occurs as barite, which is a late stage hydrothermal mineral, and as bedded sedimentary barite. Minor amounts of base metals, Cu-Mo-Pb-Zn, have been described to occur with gold mineralisation but are more commonly associated with, pre-gold, skarn mineralisation accompanying intrusive events (Appendices 1, 2, and 3).

7.2. Sulphide and sulphate paragenesis

Based on paragenetic sulphide studies of the Getchell, Chimney Creek, Rabbit Creek, Carlin, Cortez, and Betze/Post deposits, a generalised sequence is shown in figure 27, although varying slightly from deposit to deposit. Pre-ore minerals include pyrite, pyrrhotite and bedded sedimentary barite (Fig. 27). Based on Fe/Al ratios, Keuhn and Rose (1992) showed that a considerable amount of pre-ore pyrite is diagenetic in origin (Fig. 26).

Main stage ore is arsenic rich and minerals include arsenian pyrite, marcasite and native gold, while late-main stage ore minerals are realgar and orpiment (Fig. 27). Post-ore, an antimony rich event, is dominated by stibnite and barite usually in the form of crosscutting veins and late stage calcite veins (Fig. 27). This is followed by a waning barren event comprising marcasite, pyrite and barite (Fig. 27). The paragenetic sequence described also reflects the gross aspect of mineral zoning from arsenopyrite in the deepest core of the hydrothermal system, outwards to arsenian pyrite to realgar and orpiment (Arehart et. al., 1993b).

Table 6. Trace Element Geochemistry of Sediment-Hosted Gold Deposits along the Carlin, Battle - Mountain and Getchell Trends, Nevada

Deposit	Au : Ag Ratio	As (ppm)	Sb (ppm)	Hg (ppm)	Tl (ppm)	Ba (ppm)	Te (ppm)	Base Metals	
Bootstrap/ Capstone	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.		n.d.	
Meikle	1:2.9	D - 1684	D - 82	D - 0.34 - 6.7	n.d.	D- elevated		D - elevated Cu, Pb, Zn	
Betze/Post	1:3 to 1:6	RXC - 336 - 850	RXC - 12 - 114	RXC - 0.34 - 6.7	RXC - 5 - 19	n.d.		Pre-Au Cu, Zn, Pb, Mo	
Genesis/ Blue Star	n.d.	D - + 1000 large halo outward of Au mineralisation	D - +100 restricted to orebody	D - 1 - 30 restricted to orebody	n.d.	n.d.		As Above	
Carlin	n.d.	Elevated	Elevated	Elevated	Elevated	n.d.		n.d.	
Tusc	n.d.	D - + 500 halo	Elevated	Very Low	D - 0.5 - 25	n.d.	D - 0.5 - 25	Cu 100 - 400, Zn - 4%	
Gold Quarry	n.d.	Elevated	Elevated	Low	n.d.	n.d.	n.d.	Elevated Zn, Pb, Cu.	
Rain	10:1	D - 500 = 0.34 Au	D - 123 = 0.34 Au	D - 63	D - 12	n.d.	n.d.	n.d.	
South Bullion	n.d.	Max - 2 600	Max - 1 190	Max - 7	Max - 14	n.d.	n.d.	Mo, Max - 17	
Vantage	1:1	< 5000	< 700	< 0.1	n.d.	n.d.	n.d.	n.d.	
Lone Tree		1 350 - 7 130	37 - 131	0.3 - 10		Depleted	n.d.	Pre-Au Pb-Zn & Cu-Zn	Sc, 15 - 75
Hilltop	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
Gold Acres	n.d.	Elevated	Elevated	Elevated	Elevated	n.d.	n.d.	Pre-Au Cu, Pb, Zn, Mo	
Cortez	n.d.	Elevated	Elevated	Elevated	Elevated	n.d.	n.d.	n.d.	Elevated, W and Ag
Horse Canyon	n.d.	Elevated	Elevated	Elevated	Elevated	n.d.	n.d.	n.d.	
Tonkin Springs	1:2	Elevated	Elevated	Elevated	Elevated	Elevated	n.d.	n.d.	
Gold Bar	n.d.	> 100	> 20	> 1000 ppb	n.d.	n.d.	n.d.	n.d.	
Ratto Canyon	n.d.	Elevated	Elevated	Elevated	n.d.	n.d.	n.d.	n.d.	
Nighthawk Ridge	n.d.	Elevated	Elevated, big halo	> 1 ppm, widespread	> 50, in conduit	n.d.	n.d.	0 - trace	
Chimney Creek	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
Rabbit Creek									
Getchell	n.d.	Elevated	Elevated	n.d.	Elevated	n.d.	n.d.	Elevated pre-Au Mo, W	Elevated Fl
Preble	n.d.	Elevated	Elevated	Elevated	Elevated	n.d.	n.d.	n.d.	Elevated Fl

D - Drilling data.

RXC - Rock chip data

At the Hilltop deposit, two gold depositional events are described by Lisle and Desrochers (1988), (Fig. 28). The first gold depositional event was accompanied by weak base metal mineralisation (Fig. 28). The second, and major, gold depositional event is similar to that described for other sediment-hosted deposits. Gold is deposited initially with arsenic followed by antimony and subsequent barren events (Fig. 28). Major fault movement has been inferred to have occurred between the two gold depositional events while lesser fault movement is inferred to have occurred between the arsenic, antimony and barren events (Fig. 28). Porphyry Cu-Mo mineralisation occurred prior to gold mineralisation (Lisle and Desrochers, 1988), (Fig. 28).

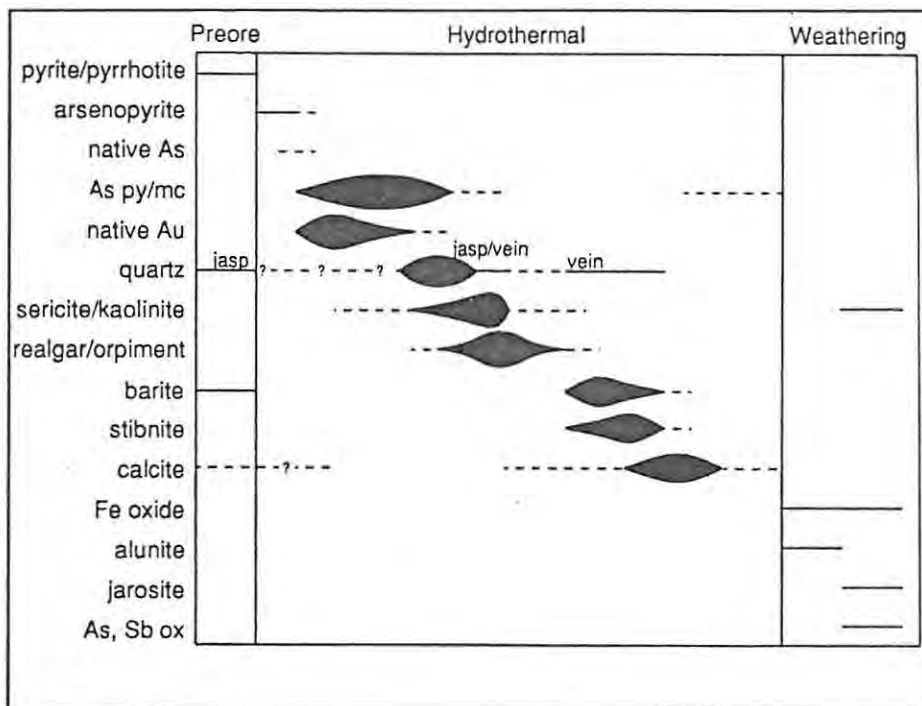


Figure 27. Generalised paragenetic sequence for Chimney Creek, Rabbit Creek, Getchell, Carlin, Betze/Post and Cortez deposits. Mineral abbreviations: As py/mc = arsenian pyrite/marcasite, As - Sb ox = arsenic and antimony oxides, jasp = jasperoidal quartz (from Arehart et. al., 1993b).

7.3. Gold Distribution

The distribution of gold within sediment-hosted disseminated gold deposits has been contentious because of the fine grained nature of gold and the earlier limited resolution of analytical equipment. Gold grains are generally < 5 microns in diameter (Percival et. al., 1988).

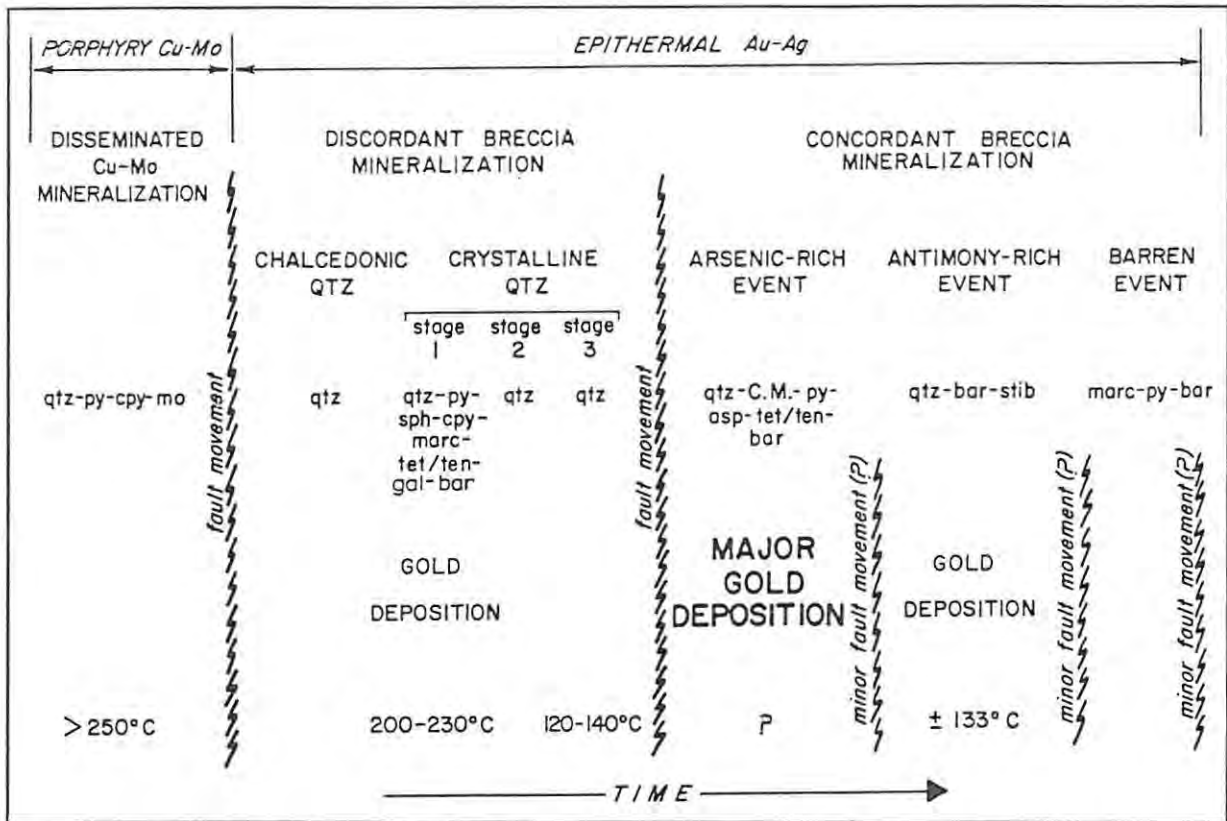


Figure 28. Diagram temporally relating mineralising events in the formation of the Hilltop deposit. Abbreviations are qtz = quartz, py = pyrite, cpy = chalcopyrite, mo = molybdenite, sph = sphalerite, marc = marcasite, tet = tetrahedrite, ten = tennantite, gal = galena, bar = barite, C.M = carbonaceous matter, asp = arsenopyrite and stib = stibnite (Lisle and Desrochers, 1988).

Radtke (1985) believed that significant gold was present in organic matter but Hausen et. al., (1987) showed that there was no significant correlation between gold and organic matter which is a passive wallrock constituent (Kettler, 1990).

Wells and Mullins (1973) were the first to recognise that a significant amount of Au and As occurs in rims of arsenian pyrite on cores of unmineralised pyrite. Microprobe, optical and scanning electron microscopy studies of ore samples from the Chimney Creek, Gold Quarry, Gold Acres, Betze/Post and Rain deposits by Arehart et. al., (1993b) revealed that the majority of the gold occurs in arsenian rich rims overgrown on unmineralised pre-ore pyrite. Minor gold is associated with realgar and orpiment (Arehart et. al., 1993b) and illite (Bakken, 1990). No gold was found to be associated with arsenopyrite, where found, although it is a pre-ore mineral (Arehart et. al., 1993b). The bulk of the arsenic within these deposits is associated with realgar and orpiment (Fig. 27), (Arehart et. al., 1993b). The auriferous arsenian rims vary in width from <1µm to a maximum of 25 µm. It is interesting to note that the thicker arsenian

rims occur in the Gold Quarry, Chimney Creek and the Betze/Post deposits which are some of the largest deposits, tonnage wise. On the otherhand, the smaller tonnage deposits such as Rain. Carlin, Cortez and Gold Acres have arsenian rims $\leq 1 \mu\text{m}$ thick (Arehart et. al., 1993b). This variation in the width of arsenian pyrite rims could be a function of the size of the hydrothermal system responsible for gold mineralisation, and could be a useful tool in project scale exploration when trying to determine the size of the system, although more research is needed to validate this correlation. The thicker arsenian pyrite rims have both simple and complex zoning with As enriched on the inner zones, rapidly decreasing outwards. This zonation of As in auriferous arsenian pyrite rims from rich to poor with time, is in contrast to the As evolution within the hydrothermal system as a whole in that main arsenic bearing minerals, realgar and orpiment, although overlapping with main stage gold precipitation, generally post-date gold precipitation (Fig. 27). This relationship suggests that the pre-ore pyrite can be critical in the precipitation of Au and As.

Gold content in the arsenian pyrite rims varies between 45 and 62 ppm while the pre-ore pyrite cores have Au contents varying between 2.5 and 4.8 ppm (Arehart et. al., 1993b). Gold size in the arsenian pyrite rims varies between 20 to 200 Å and only rarely is native Au observed. Arehart et. al (1993b) believe that due to the strong correlation between Au and As, these two elements enter the pyrite structure as coupled substitution in one of two forms: (1) $(\text{Au}^{+3}_{0.5}\text{As}^{+5}_{0.5})\text{S}_2$ where Au and As substitute for the two Fe sites or (2) $(\text{Au}^{+3}_x\text{Fe}^{+2}_{1-x})([\text{AsS}^{-3}]_x[\text{S}^{-2}]_{1-x})$, where Au and As substitute for the Fe and S sites respectively (Arehart et. al., 1993a). Arehart et. al., (1993b) favour the second form of substitution where Au in the +3 state is substituted in the Fe site and As in the S. Native gold seen in some samples is thought to be related to the exsolution of Au from metastable arsenian pyrite after deposition.

Ainsworth (1982), in a study of the Vantage deposits, noted that optically visible gold in the oxidised ore appears to have been deposited very late in the evolution of the hydrothermal system as it is found to line the centre of still open veins/fractures. This is in direct conflict with most other sediment-hosted deposits where gold is usually deposited early in the evolution of the hydrothermal system (Fig. 27). This optically visible, late stage gold could be a result of gold remobilisation in a weathering, oxidised environment, hence the coarser nature.

Because of the direct correlation between As and Au, As is used as a pathfinder element in the exploration for sediment-hosted gold mineralisation. However, there are many hydrothermal systems in Nevada which have an anomalous As signature but no correlating Au anomaly (Taylor and Bowden pers. comm, 1994). Anomalous As in these cases is most likely derived from realgar and orpiment which are known to have very little associated gold. Arehart et. al., (1993b) have shown the strong correlation between As and Au in arsenian pyrite rims on pre-ore pyrite. Therefore, it may be critical, early in an exploration program, to try to identify whether or not there is pre-ore pyrite development, and if so, determine whether these pyrite grains have arsenian pyrite overgrowths or not. Systematic microscopic reflected light studies of alteration and mineralisation, especially during initial drilling programs of targets, is another exploration tool in determining whether the hydrothermal system is auriferous, or not. If the hydrothermal system is As rich but gold poor and is overprinted by a barren late stage pyrite mineralisation event, this late stage, pyrite mineralisation will not have any arsenian pyrite overgrowths.

One of the mechanism cited for gold precipitation, if Au is transported as a bisulphide complex in a hydrothermal fluid, is the sulphidation of host rock (Hofstra et. al., 1991). Au will precipitate if the bisulphide ion reacts with Fe in the host rock to form pyrite. This process can be documented by measuring the degree of pyritisation (DOP) of fresh, unweathered rocks (Hofstra et. al., 1991). $DOP = \frac{Fe_{pyrite}}{(Fe_{pyrite} + Fe_{reactive})}$. Sources of reactive Fe are magnetite, hematite, ilmenite, oxyhydroxides, amorphous iron oxide, iron bearing phosphates, and montmorillonite (Hofstra et. al., 1991). In a study at the Jerritt Canyon deposit Hofstra et. al., (1991) were able to demonstrate that there is a positive correlation between Au, As and DOP. DOP values of unoxidised mineralised samples at Jerritt Canyon ranged between 0.7 and 0.95 whereas normal marine shales have values around 4. As the reaction front of the hydrothermal system moves through the host rock Au, As and pyrite will be precipitated until sulphur in the hydrothermal fluid is used up (Hofstra et. al., 1991). Sulphidation of host rocks having a high reactive Fe content (>2%) will form a high grade narrow ore body while host rocks with low reactive Fe content (<0.5%) will form broad low grade deposits (Hofstra et. al., 1991). This may be one of several factors explaining why the Meikle deposit is a narrow high grade deposit while Betze/Post, Genesis/Blue Star and Gold Quarry are large low grade deposits, although these deposits are hosted in similar host rocks (Table 1). The downfall of applying DOP as an

exploration technique is that it has to be performed on fresh unweathered rocks. However, it can be applied in a drilling program, especially in the deeper holes and will help in trying to establish the size of the mineralised halo which in turn helps in defining drill spacing. Systematic thin section microscopic studies of host rocks will help in trying to establish lithologies having a higher content of minerals which source reactive Fe.

7.4. Source of gold and related metals

The source of gold and related metals remains problematical, but an understanding of the likely provenance may be important in exploration if it can lead the program to new favourable areas. Two possible sources of gold and related metals have been cited, a magmatic source by Sillitoe and Bonham (1990), and a sedimentary source by Nelson (1991) and Seedorf (1991).

Likely sediment sources are divided into two subgroups. Seedorf and Nelson respectively propose that, (1) the deeper Proterozoic and lower Cambrian sediments, and (2) siliciclastic rocks of the Ordovician Vinini and Valmy Formations which are spatially associated with many deposits, are sources of gold and related metals.

Seedorf argues that there is no need for magmas to supply metals for sediment-hosted gold deposits. He cites isotopic evidence from Radtke et. al., (1980), Rye, (1985), Hofstra et. al., (1991) and Ilchik, (1991), that sulphur in sediment-hosted deposits has a similar $\delta^{34}\text{S}$ signature to that found in Proterozoic and Palaeozoic sediments in Nevada. Average pelitic rocks have a moderate Au content and above average As, Sb, and Hg contents, the elements associated with gold mineralisation, and could be possible source rocks (Table 7), (Seedorf, 1991). Seedorf cites examples of ore-related, high angle, normal faults in the Egan and Cherry Creek ranges, which have penetrated Proterozoic and lower Cambrian source rocks in Nevada (Fig. 29). All of the sediment-hosted deposits in Nevada and western Utah occur where Proterozoic sediments are thicker than 5 000 feet (1 524 m) with the majority occurring where these sediments are thicker than 20 000 feet (6095 m), (Fig. 30). Seedorf believes that these deposits were formed during Eocene to Oligocene (30 - 40 Ma) extension which affected Nevada, south-eastern California, western Utah, Arizona, New Mexico and Mexico (Fig. 30). However, sediment-hosted disseminated gold deposits are only located where Proterozoic and lower

Cambrian sediments rocks are thicker than 5 000 feet (1 524 m). Therefore, source sediment thickness could be regarded as another critical factor in the location of these deposits. There is abundant evidence of hydrothermal activity in western Utah, in similar hosts and with similar geochemical signatures, to those deposits in Nevada, yet no discovery has been made in this region despite extensive exploration (Seedorf, Bowden, Conway pers. comm., 1994). Only a single sediment-hosted disseminated gold deposit, Amelia, has been found in Mexico, but the thickness of the Proterozoic sediments is uncertain in the Sonora due to structural complexities (Seedorf, 1991).

Table 7. Average Element Abundances of Potential Source Rocks (from Seedorf, 1991)

Average Elemental Abundances of Potential Sources Rocks 1,2							
	Au	Ag	As	Sb	Hg	Tl	S
Crust	0.003	0.07	1.8	0.2	0.02	0.8	300
Granite	0.002	0.004	1.5	0.2	0.03	1.2	300
Basalt	0.004	0.1	2.	0.2	0.01	0.2	300
Shale	0.004	0.19	12.	1.5	0.3	1.2	400
Sandstone	0.005	0.25	1.2	1.0	0.03	N. D. ³	240

1 Values in parts per million
 2 Sources of data: Rose et al. (1979) and Krauskopf (1979)
 3 N. D. = No data

This deep source rock model of Seedorf is not unrealistic. Struhsacker (1986), in a study of the active Beowawe hydrothermal hot spring system which lies between the Carlin and Battle Mountain - Eureka trend, concludes that the heated fluids are being derived from a depth of approximately 7 kilometres. The Proterozoic and lower Cambrian source rocks lie between 3 and 5 kilometres below ideal host rocks in Nevada, well within the limits of known hydrothermal cells (Fig. 29).

Nelson (1991) believes that the Vinini and Valmy Formations, which are spatially associated with many of the deposits, are possible source rocks for gold and related metals (Fig. 31). The Vinini and Valmy Formations both have metalliferous black shales and are known sources of petroleum (Poole et. al., 1985). At the Rabbit Creek deposit, an 8 metre thick, pre-gold mineralisation lens of massive sulphide occurs in deep water siliciclastic sediments (Bloomstein

et. al., 1991). The Vinini and Valmy Formations therefore, contain ample source metals for sediment-hosted disseminated gold deposits. However, these rocks generally overlie host rocks at the various deposits in the Carlin, Battle Mountain - Eureka and Getchell trends (Table 1). At these various deposits, alteration of the Vinini and Valmy is limited and is proximal to the deposits. If these rocks were the source, one would expect a larger halo of alteration.

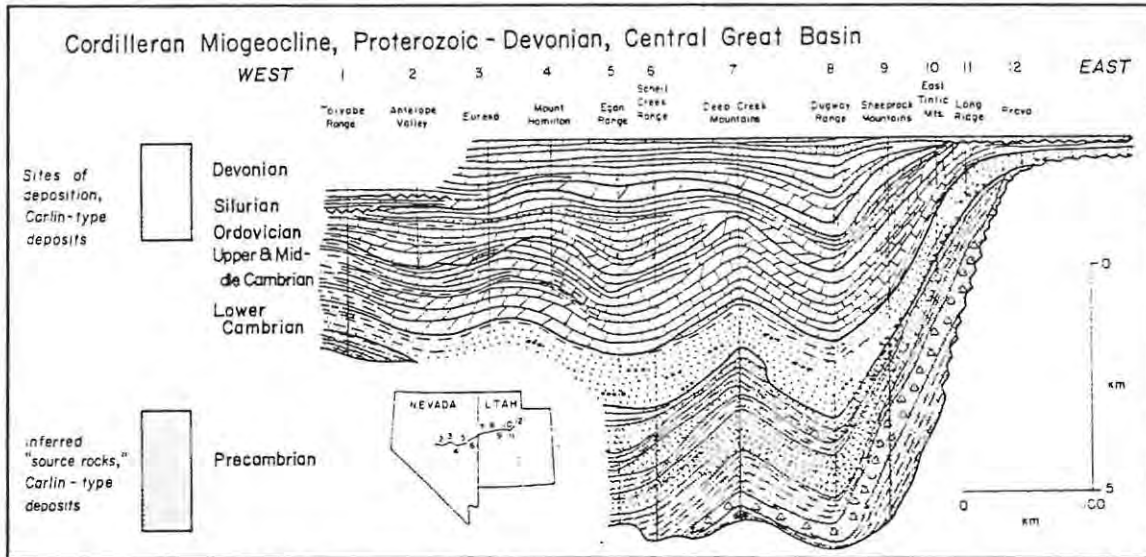


Figure 29. Stratigraphic cross section of Devonian and older rocks across the central Great Basin, showing occurrence of upper Proterozoic and clastic rocks that are the proposed source of sulphur, Au and related metals for Carlin-type deposits (modified from Sedorf, 1991).

Sillitoe and Bonham (1990) propose that sediment-hosted disseminated gold deposits in Nevada are distal products of magmatic-hydrothermal systems. They cite examples such as Bingham Canyon, Utah, and the Bau District, Sarawak in Malaysia as examples where one can observe the zonation from Cu-Mo porphyries outwards to distal sediment-hosted Au-As systems. Typical zonation around and intrusion-centered porphyry would be porphyry Cu-Mo-Au grading outwards through Cu-Au and/or W-Mo skarns to Au- and/or Ag-bearing Zn-Pb skarns to distal sediment-hosted Au deposits that are deficient in base metals but carrying abundant As and Sb (Fig 32), (Sillitoe and Bonham, 1990). Not all these mineralisation zones may be developed for a single intrusion and may also be telescoped. This zonation from porphyry to the distal sediment-hosted Au mineralisation may be up to five kilometres (Sillitoe and Bonham, 1990). Associated with many of the sediment-hosted gold deposit cited by Sillitoe and Bonham are porphyritic felsic intrusions. Many of the sediment-hosted disseminated gold deposits in Nevada have the characteristics cited by Sillitoe

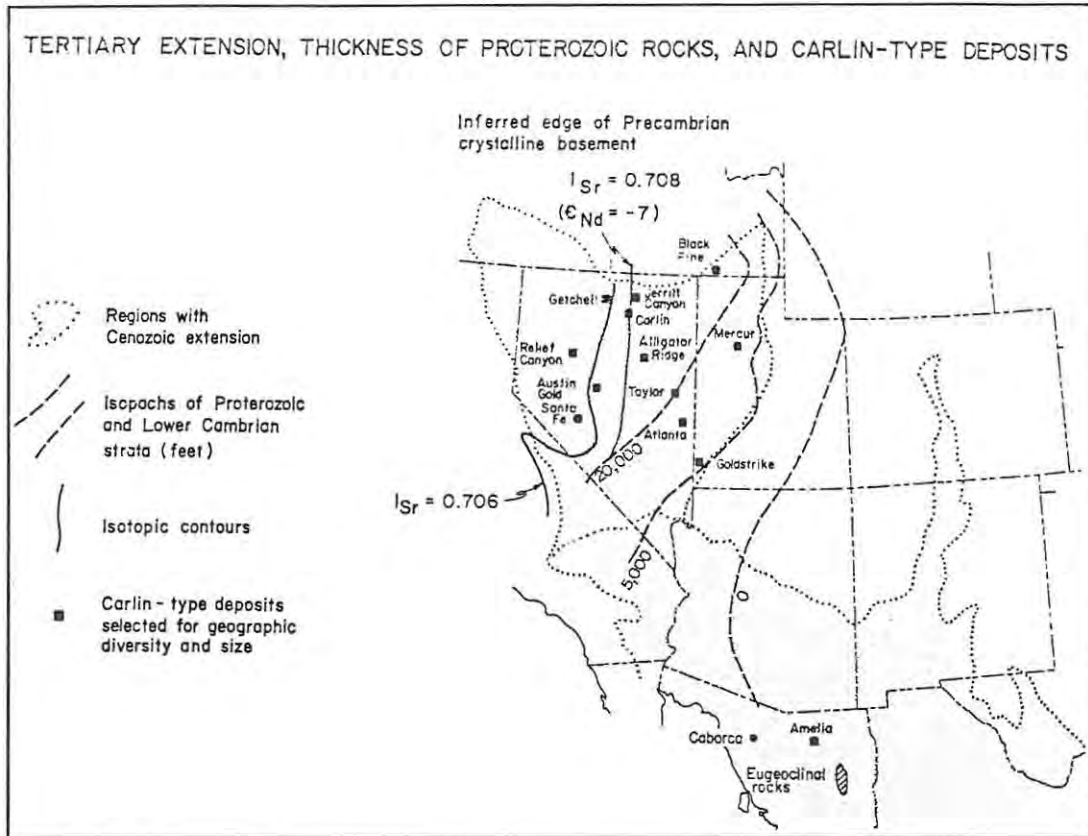


Figure 30. Tertiary extension, thickness of possible source rocks for gold in Carlin-type deposits, inferred Precambrian basement from isotopic contours, and location of some sediment-hosted deposits (from Seedorf, 1991).

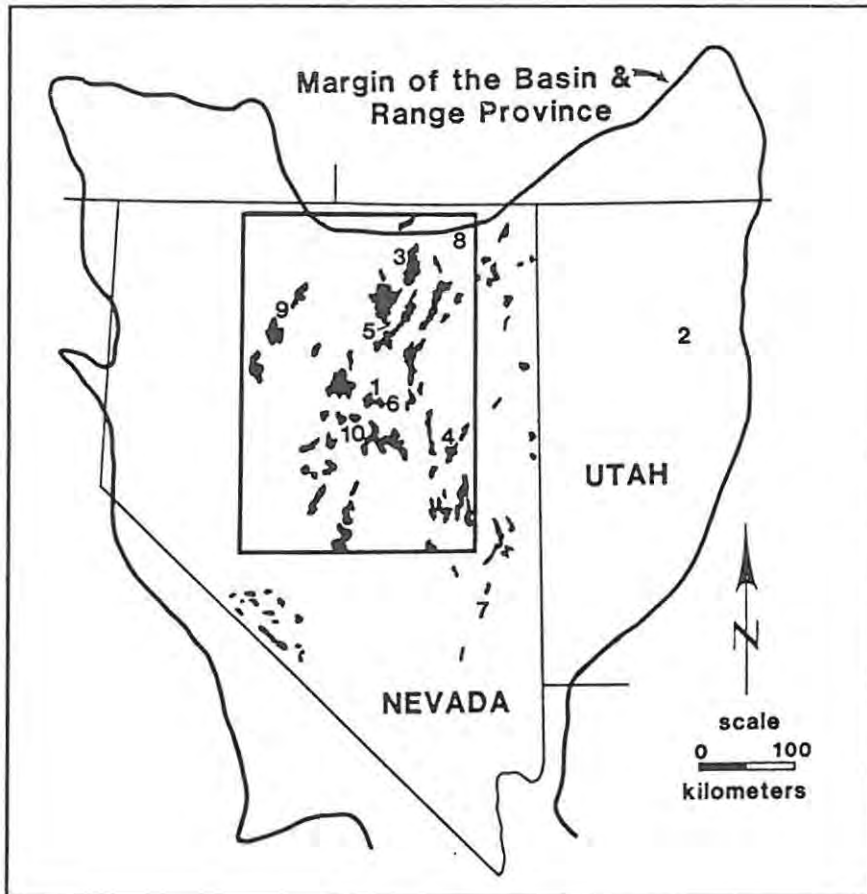


Figure 31. Location and distribution of metalliferous marine black shales of the Valmy, Vinini, Comus and Woodruff Formations within the Basin and Range Province. 1 = Cortez, 2 = Mezur, 3 = Jerritt Canyon, 4 = Vantage, 5 = Carlin, 6 = Horse Canyon (Nelson, 1991).

and Bonham being: (1) spatial relationship with large intrusive, (2) often located within or adjacent to skarn mineralisation and (3) felsic dyke intrusions within the deposit. However, many of the mine geologist at the sediment-hosted gold deposit, visited in 1993/4 believe that the gold mineralisation event post-dates both Cu-porphyry and skarn mineralisation based on cross-cutting geological relationships.

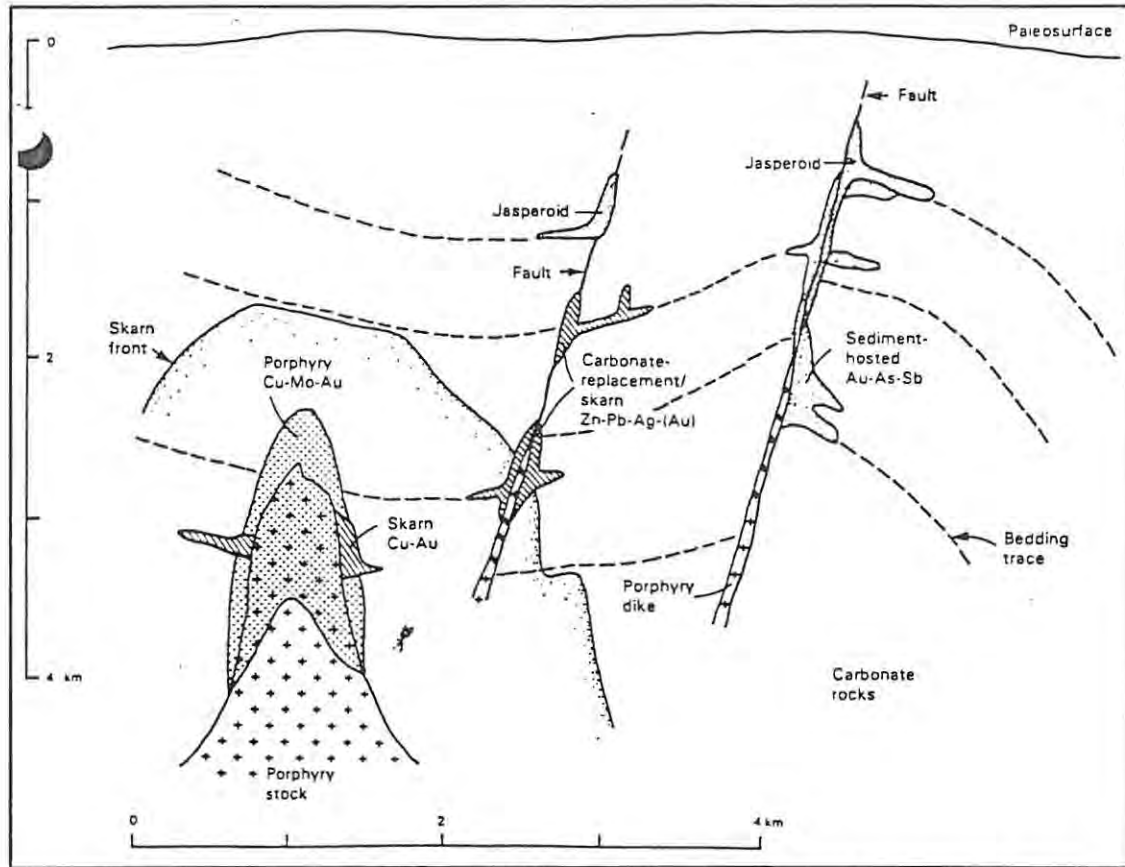


Figure 32. Schematic model to illustrate typical position of sediment-hosted gold deposits on peripheries of intrusion-centered base- and precious metal districts (after Sillitoe and Bonham, 1990)

8. TRANSPORT AND DEPOSITION OF GOLD AND RELATED METALS

Understanding the chemical behaviour of gold and related metals in hydrothermal systems is critical to developing genetic models for the formation of hydrothermal deposits. Limits on geochemical environment of ore formation within favourable structural and host rock settings can be established if the mechanisms of metal transport and deposition are understood.

Processes controlling the transport and deposition of precious metals in hydrothermal systems involve a complex set of equilibrium relationships between minerals in the host rock aqueous

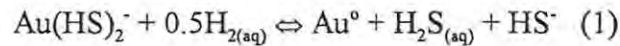
solutions and often the vapour phase. These equilibrium relationships in turn are governed by variations in temperature, pressure, pH of the solution, the activities of oxygen, sulphur and other volatile components and the concentration of dissolved salts such as sodium chloride in solution.

There are numerous ligands which form stable complexes with Au being, Cl^- , Bi^- , I^- , HS^- , S^{2-} , $\text{S}_2\text{O}_3^{2-}$, SnO_6^{2-} , $\text{As}_3\text{S}_6^{3-}$, $\text{Sb}_3\text{S}_6^{3-}$, Te_2^{2-} , NH_3 , OH^- , CN^- , SCN^- (Seward, 1973). The most common complexes involved in the transport of Au in hydrothermal systems are chlorite and bisulphide complexes (Romberger, 1991; Schenberger). However, this may be a function of most experimental data being restricted to chloride and bisulphide complexes. Gold is known to be transported as a tellurium complex (Saunders, 1986), and as a thioarsenide complex (Grigoryeva and Sukneva, 1981). Gold transport as a thioarsenide is consistent with the common association of As and Au in many different hydrothermal settings.

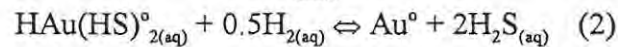
Although sediment-hosted gold deposits occur over a wide geographical area in Nevada, they all have a common geochemical and isotopic signature where studied. These are low to no base metal association, variable Au:Ag ratios (ranging from 1 to 20, but mostly above 10), low salinity (ranging from 1-6 equivalent weight percent NaCl), fluid inclusion homogenisation temperatures of $175^\circ\text{C}\pm 25^\circ\text{C}$, common geochemical signature of As, Sb, Hg and Te (Radtke et. al., 1980; Bagby and Berger, 1985; Keuhn and Rose, 1992). The hydrothermal fluids responsible for gold mineralisation in most of the sediment hosted deposits had to be slightly acidic to acidic in order to remove carbonate from host lithologies. Oxidation of most of the deposits is supergene in origin rather than hypogene (See Section 4.4.5). Arehart et. al., (1993b) showed that most of the Au is located together with As in arsenian pyrite rims on pre-mineralised pyrite. All the above mentioned parameters place constraint on the type of transport and deposition mechanisms of gold in hydrothermal systems.

Romberger (1991) showed that gold is soluble as a chlorite or a bisulphide complex and that the parameters such as pH, salinity, chlorite activity, oxygen activity, sulphur activity, and temperature determine which ligand is the dominant in complex in transporting gold and related metals. Chlorite complexes are only important in the transport of gold at higher temperatures ($>300^\circ\text{C}$), and if the hydrothermal fluid is oxidized. Because of the high Au:Ag

ratio, the general absence of base metals and that oxidation is regarded to be a supergene process in most sediment-hosted deposits in Nevada, chloride complexes are not believed to have contributed significantly to the transport of gold. Bisulphide complexing of Ag occurs in hydrothermal fluids under neutral to slightly alkaline conditions, conditions not believed to have prevailed in these deposits (Romberger, 1991). Ballyntyne and Moore (1988) believed that the fluids responsible for gold mineralisation in sediment-hosted deposits in Nevada were extremely reduced. Seward (1973) showed that under neutral to slightly acidic conditions, Au was transported as the bisulphide complex, $\text{Au}(\text{HS})_2^-$ in hydrothermal fluids (reaction 1). Under even lower pH and reducing conditions the bisulphide complex, $\text{HAu}(\text{HS})_2^0$, may be even more important (Hayashi and Ohmoto, 1991) (reaction 2):

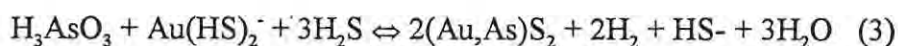


and

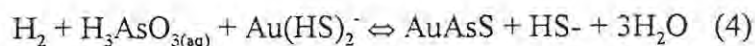


Thioarsenide species such as HAsS_2 and/or H_3AsS_3 are thought to be responsible for transport of As under extreme reducing conditions (Ballyntyne and Moore, 1988). Sillitoe and Bonham (1990) suggest that sediment-hosted gold deposits are the distal products of a magmatic-hydrothermal system. They suggest that base metals, Cu, Mo, Zn, Pb and Ag which are deposited proximal to intrusions are carried as chloride complexes in fluids at higher temperatures. As the fluids cool and interact with meteoric fluids the chloride complexes become unstable, precipitation base metals. With increased mixing of magmatic and meteoric fluids and cooling bisulphide complexes become the important ligands transporting gold until conduit faults intersect favourable permeable horizons and precipitate gold and related pathfinder elements.

Arehart et. al., (1993b) clearly showed that gold is deposited together with arsenic in arsenian pyrite rims on pre-mineralised pyrite (See Section 7.3). Arehart et. al., believe that gold and arsenic are transported in the +1 and +3 states and, on deposition, are respectively oxidised to the +3 and reduced to +1 states. According to Arehart et. al., (1993b) reactions which would precipitate gold and arsenic in arsenian pyrite are:



and



In reaction three Au and As are both deposited in the Fe site of arsenian pyrite while in reaction four Au and As are deposited in the Fe and S sites respectively. Arehart et. al., favour reaction four.

Mechanisms which have been proposed for the deposition of metals from hydrothermal solutions are (1) pH changes, (2) reduction, (3) oxidation, (4) pressure changes, (5) temperature changes, and (6) decrease in the activity of H_2S .

Seward (1973) and Shenberger and Barnes (1989) showed that the solubility of Au increased with increasing temperature for both chlorite and bisulphide complexes, hence cooling should be an adequate mechanism of precipitating Au. Romberger (1991) believes that it is difficult to determine the role of temperature in the deposition of Au in hydrothermal solutions because it affects other solution parameters such as oxygen and sulphur activities and pH. He went on to show that temperature changes are not a viable mechanism of metal deposition at 200°C. At the Beowawe, water dominated, geothermal system which lies just to west of the town of Carlin, Nevada, Cole and Ravinsky (1984) demonstrated that gold was being deposited from non-boiling fluids at between 200°-250°C. Drill cuttings from a borehole down to a depth of 1 750 m had all the geochemical signatures, Au, As, Sb, Te, of sediment-hosted disseminated gold deposits but not in significant quantities to form an ore deposit (Cole and Ravinsky, 1984). A feature also noted at the Beowawe geothermal system, is the lack of hydrothermal brecciation which is common in sediment-hosted disseminated gold deposits. Hydrothermal brecciation (pressure loss) is thought to play a critical role in the upgrading of an ore deposit (Bakken, pers. com., 1994). Therefore it appears that the build up of pressure, followed by the subsequent sudden drop in pressure and boiling, are important factors in the deposition of gold where economic concentrations of gold are found.

Oxidation and a decrease in H_2S activity have been shown to be important controls in the deposition of Au from hydrothermal fluids where bisulphide complexes are the transporting agent (Romberger, 1991). Boiling, solution mixing and wall rock interaction are the three most

important factors in lowering the temperature, decreasing H₂S activity and oxidizing the fluid (Romberger, 1991).

9. DISCUSSION

The two unresolved problems which are critical to exploration in Nevada, are the positive identification of the RMT and the age of the interbedded siliciclastic and carbonate rocks which occur in the hanging wall to the positively identified Devonian-Silurian carbonate lithologies such, as the Roberts Mountains Formation. The RMT has a very definitive genetic implication in that the RMT plane, or planes, is a plane whereby the deep water, Ordovician, siliciclastic lithologies were thrust over Silurian to Devonian platform shelf carbonates, during the late Devonian to early Mississippian Antler orogeny (Roberts, 1966). Rota (1991) points out that the RMT, in the northern section of the Carlin trend, varies from a lithological contact to a breccia zone more than 15 m wide. In the author's experience, while carrying out field work in Nevada during 1993/4 and discussions with Rota (1993/4), the RMT has been arbitrarily placed at the contact between siliciclastic and carbonate lithologies with little regard to sedimentary processes accounting for these facies changes. In most instances there is bedding parallel deformation at the contact between carbonate and siliciclastic lithologies, but it must be borne in mind that the Great Basin has been under compression from the late-Devonian through to the early Tertiary. Any deformation, due to compressional tectonics, is likely to take place along bedding planes, where a competency contrast exists between lithologies, (Ramsay and Huber, 1989). Therefore, not all bedding parallel structures and/or siliciclastic - carbonate lithological contacts are necessarily the RMT.

Recent palaeontological dating, of what was thought to be the allochthonous deep water, Ordovician siliciclastic sediments, at some of the deposits such as Gold Quarry and Gold Acres, indicate that these sediments are in fact autochthonous late Devonian sediments. Schull (1991) believes that the transition from carbonate to siliciclastic lithologies, along the northern part of the Carlin trend, is part of a normal sedimentary cycle and is not due to structural juxtapositioning. Williams (1994) describes carbonate, debris flow breccias, now recognised as an important and significant host in many of the deposits, as proximal to carbonate platforms shed into local second and third order deep water basins. This is further evidence of the deep

water sediments being autochthonous and not allochthonous and there appears to have been some structural control on the distribution of the carbonate debris flow breccias and Devonian siliciclastic lithologies. Rota (1991) describes soft sediment deformation features in the Gold Quarry deposit, within the Popovich Formation, and attributes these features to rapid loading. Many of the sediment-hosted deposits in Nevada have reduced, black shale horizons. All the above factors described can be interpreted as siliclastic sediments at many of these deposits being deposited in second and third order, often reducing, basins, which were subjected to periodic influxes of carbonate debris flows from nearby carbonate platforms. These characteristics, complex interplay between carbonate and siliciclastic sediments, proximal debris flows and reducing basins, are all hallmarks of a pull apart basins associated with a strike-slip fault system. The interbedded carbonate and siliciclastic lithologies, here proposed to have been deposited in syn-sedimentary second and third order basins, must not be confused with the Paleozoic transitional assemblages deposited on the continental slope (Fig's 4 & 8).

Oldow et. al., (1989) showed that in order to accommodate space problems in three dimensional reconstruction of accreted terranes, strike-slip faults are an integral part of the tectonics in a compressional tectonic setting (Fig. 12). Oldow et. al., propose that these strike-slip faults are derived from mid- to deep crustal, and possibly even upper mantle, levels. The Carlin and Battle Mountain - Eureka trends are possible examples of deep seated strike-slip faults situated near the craton edge which formed at the onset of the Antler orogeny during late-Devonian times. It is proposed that it is along these strike-slip faults that second and third order pull apart basins developed into which deep water Devonian siliciclastic sediments were deposited together with carbonate debris flows. Oldow et. al., propose that the strike-slip faults developed in the western U.S.A, as a result of plate collision, are right lateral due to oblique east-north-east directed collision (Fig. 12). Putnam and Hendriques (1991) believe that the Carlin and Battle Mountain - Eureka trends are right lateral, R_1 , reidel shears which are part of a much larger right lateral shear couple related to the San Andreas and Walker Lane trends initiated at ± 15 Ma (Fig's. 23 & 24). Interpretation of the structural setting controlling mineralisation in many of the deposits, is attributed strike-slip faulting (See section 4.3.2). It is clear that the Carlin and Battle Mountain - Eureka trends are long lived, deep seated predominantly right lateral fault systems. These deep seated structures have also controlled the distribution of igneous intrusions and hydrothermal mineralisation from

Cretaceous through to present. There is evidence that pull-apart basins were developed during the waning phases of Paleozoic sedimentation. These paleo-pull apart most likely would have been overprinted by structures such as negative flower structures that develop in jog zone of strike-slip faults (Ramsay and Huber, 1989). Negative flower structures are essentially similar to those found in pull apart basins except that the former structures are developed in consolidated rock.

The deposits along both the Carlin and Battle Mountain - Eureka trends tend to be grouped together in distinct areas along the respective trends (Fig. 8). This distinct grouping of deposits along the trends has been attributed to Devonian autochthonous, platform carbonate lithologies exposed as windows through Ordovician allochthonous, deep water siliciclastic sediments. However, as described above, the siliciclastic sediments at many of the deposits are in fact, Devonian in age. Therefore, the "windows" along the trends may be surface expressions of pull-apart basins and/or negative flower structures and not necessarily windows in the context of thrust tectonics and erosion thereof. However, this does not mean that the RMT and tectonic windows do not exist, but, rather that careful geological observation and interpretation should prevail before taking this for granted.

In Nevada there is an abundance of silicified faults, which have anomalous Au, As, Hg, Sb, Tl and Ba geochemical signatures similar to those of known sediment-hosted disseminated gold deposits. These geochemically anomalous and silicified fault zones are interpreted as conduits to a hydrothermal system and are often the only surface expression of hydrothermal activity and/or mineralisation. Hence these silicified and geochemically anomalous fault zones attract considerable exploration activity. However, more often than not, drilling proves that these silicified fault zones prove to be nothing more than thin tabular silicified bodies, which one sees at surface. In a study of the Beowawe-White Canyon geothermal system, Struhsacker (1986) describes a hydrothermal system which is currently active, depositing anomalous Au, As, Ag, Hg, Sb and Tl at temperatures of approximately 215°C, conditions similar to those described for sediment-hosted disseminated gold deposits. The Beowawe-White Canyon geothermal system is situated between the Battle Mountain - Eureka and Carlin trends, and is active along Tertiary range front faults. This hydrothermal system has caused extensive silification of both the Tertiary volcanics and the siliciclastic Ordovician Valmy Formation (Struhsacker, 1986).

Extensive silicification extends for two and half kilometres along the range front fault which this hydrothermal system is exploiting (Struhsacker, 1986). The hydrothermal system is only active at one end of this zone of silicification (Struhsacker, 1986). This system has been drilled down to a depth of 2 915m for both gold mineralisation and geothermal energy. To date no hydrothermal brecciation has been intersected in drilling or noted in surface exposure (Struhsacker, 1986). Struhsacker believes that as silica is deposited and seals a portion of an open fault system the hydrothermal system simply follows the path of least resistance and moves along the fault, leaving a trail of silicification. Hydrothermal brecciation has been described in all the deposits studied (Appendices A, B and C) and is believed to play a critical role in upgrading the gold mineralisation. Therefore, a hydrothermal system has to have a plumbing system conducive to hydrothermal convection, but at same time must have the ability to seal itself with no possible route for migration. This will cause the build up of pressure resulting in overpressuring, hydrofracturing and precipitation of silica and metals before the process repeats itself. As mentioned before, there are many anomalous, silicified fault zones within the Carlin and Battle Mountain trends which do not have associated deposits. This is especially the scenario between deposit districts along the Carlin and Battle mountain - Eureka trends (Rota pers. comm., 1994). Evidence indicates that mineralised hydrothermal cells migrated along strike-slip faults leaving a trail of silicification and anomalous geochemical signature. The migration of these hydrothermal cells is halted at the intersection of faults within local paleo-pull apart basins and/or negative flower structures developed along the major strike-slip faults. This allowed for overpressuring and hydrofracturing to take place, all critical factors in upgrading anomalous hydrothermal settings to economic ones. It is therefore critical to distinguish between tectonic and hydrothermal breccias, within a silicified fault zone, in order to determine if one is in the right area for the development of a sediment-hosted ore body. This raises the question as to whether geochemical studies could be applied when trying to determine in which direction a paleo-hydrothermal system has migrated?. If so, this will help in vectoring an exploration program in the right direction.

Although mineralisation occurs in a wide variety of sediments (Table 1, 2 and 3) certain lithologies are favoured. Along the Carlin trend favourable host rocks are thinly bedded silty limestones, carbonate debris flow breccias and interbedded carbonate and siliciclastic lithologies (Table 1). Carbonate lithologies are a minor host to mineralisation along both the Battle

Mountain - Eureka and Getchell trends while siliciclastic lithologies are the major host (Table 2 and 3). It is interesting to note that deposits hosted in carbonate lithologies generally tend to form low grade - high tonnage deposits while those hosted in the siliciclastic lithologies are high grade - low tonnage deposits (Tables 1, 2 and 3). This relationship could be the result of a number of factors. Carbonate lithologies, especially the thinly bedded silty carbonates, are prone to decalcification by slightly acidic fluids, thereby increasing secondary permeability. This allows for greater penetration of mineralised hydrothermal fluids from the feeder/conduit faults. On the other hand, siliciclastic rocks are not prone to decalcification, hence the secondary permeability is almost solely reliant on structurally induced permeability, as with, the deposits along the Getchell trend, especially the Rabbit and Getchell deposits. However, the Rabbit Creek deposit is a low grade - high tonnage deposit because it is located within a highly complex structural zone (Table 3). Hofstra et. al., (1991) showed that the reactive Fe within the host rock is also important in determining the tonnage and grade of a deposit. Host lithologies with a high (>2%) or with a low (<0.5%) reactive Fe content will form low tonnage - high grade and high tonnage - low grade deposits respectively. This may be one factor explaining the difference in tonnage and grade between the Betze/Post (136 Mt @ 5.96 g/t) and Meikle (6.52 Mt @ 21.4 g/t) deposits although hosted in the same lithologies. Shaw (1991) believes that the difference in tonnage between the Carlin and Battle Mountain - Eureka trends may be a function of erosion. Tertiary volcanics and sediments as well as Ordovician siliciclastic sediments, are better developed along the Battle Mountain - Eureka trend than along the Carlin trend. Shaw (1991) believes that the level of erosion along the Carlin trend is deeper exposing Devonian-Silurian carbonate lithologies. There is, therefore, the potential for large tonnage gold deposits to exist, at depth, along the Battle Mountain - Eureka trend (Shaw, 1991). The width of arsenian pyrite rims on pre-ore pyrite, in which most of the gold is situated, appears to vary according to the tonnage of the deposit. In larger deposits such as the Betze/Post, Gold Quarry and Rabbit Creek the arsenian pyrite rims are $>1\pm\mu\text{m}$ thick whereas in the smaller deposits the rims are $<1\pm\mu\text{m}$ thick (See Section 7.3), (Arehart et. al., 1993b). This may reflect the size of the hydrothermal system responsible for mineralisation, hence the differences in tonnage.

Arehart et. al., (1993b) showed conclusively that gold is situated in arsenian pyrite rims on unmineralised pre-ore pyrite. One of the likely settings to form diagenetic pyrite is in a

reducing environment within second and third order basins. Many of the deposits have reduced carbonaceous shale horizons which can be interpreted as sediments deposited in second and third order, basins under reducing conditions.

Three sources for gold and related metals have been proposed, being: (1) Proterozoic sediments underlying the Paleozoic Great Basin (Seedorf, 1991), (2) allochthonous deep water Ordovician Vinini and Valmy Formations Nelson (1991) and (3) an igneous source (Sillitoe and Bonham, 1990). The allochthonous Ordovician sediments are not envisaged to be source rocks as most of these lithologies are not hydrothermally altered, which one would expect if the sediments were leached of possible source metals. Alteration of the Ordovician sediments is restricted to the immediate vicinity where these sediments host gold mineralisation (Fooler pers. com. 1993).

There is a spatial relationship between igneous intrusions and many of the sediment-hosted disseminated gold deposits and it is tempting to infer that igneous rocks were the source of gold and related metals (Tables 1, 2 and 3). Sillitoe and Bonham (1991) believe that the sediment-hosted disseminated gold deposits in Nevada are products of distal magmatic-hydrothermal systems. They cite the Bingham Canyon Cu-Mo porphyry as an example, where the whole range from Cu-Mo porphyry through Cu-Au, Pb-Zn skarns to distal sediment-hosted gold, exists. Lone Tree and Gold Acres are two deposits where there is a spatial relationship between Cu-Mo porphyry, skarn, distal sediment-hosted gold mineralisation and porphyritic, 38 Ma old intrusions. However, isotopic and fluid inclusion data of Hofstra et al., (1988) Keuhn, (1989) and Illchik (1990) all indicates that the fluids responsible for mineralisation had isotopic characteristics of highly exchanged meteoric waters. The source of sulphur, based on sulphur isotope studies, is from Proterozoic and Paleozoic sediment and not igneous intrusions (Keuhn, 1989). However, an igneous source cannot be ruled out given the number of igneous events spanning from Cretaceous through to present day in Nevada.

Seedorf (1991) considers that the most likely source is the Proterozoic and lower Paleozoic underlying the Great Basin (Fig's. 29 & 30). Seedorf points out that the sediment-hosted deposits occur where the Proterozoic sediments are greater than 20 000 feet (6 095 m) thick. Regionally produced "metamorphic" fluids were responsible for transporting the metals from

the source to the site of deposition (Seedorf, 1991). Seedorf believes that the fluids were transported along high angle faults which were formed during Tertiary extensional tectonics. Seedorf considers that sediment-hosted disseminated gold mineralisation is Tertiary (30-40 Ma) in age because of the higher geothermal gradient during extensional tectonics. This age of mineralisation agrees with the indirect age determinations based on geological cross-cutting relationships (See section 6). This model does not require an igneous source for the metals or to drive the hydrothermal system. Seedorf's deep source rock model is not unrealistic as Struhsacker (1986) has shown that at the Beowawe-White Canyon geothermal system, hydrothermal fluids at surface have temperatures of 215°C. Based on a geothermal gradient of 30°C/km, these fluids have to be derived from a depth of 7 km in order to attain these surface temperatures. The vertical distance between the upper Proterozoic source rocks and host rocks is well within the limits of the Beowawe - White Canyon hydrothermal cell (Fig. 30). There does not appear to be any igneous intrusion at depth, based on geophysical interpretation, driving the Beowawe-White Canyon geothermal system (Struhsacker, 1986). However, Seedorf's model for the source of metals and origin of "metamorphic fluids" can be valid for the older (110 Ma) isotopic age of mineralisation, if the model where the Carlin and Battle Mountain - Eureka trends are regional right lateral strike slip faults which developed at the onset of the compressive Antler Orogeny, during late Devonian, is correct. Dewatering of fluids from both the Proterozoic and Paleozoic sediments would commence at the onset of the compressional Antler Orogeny, and if the fluids have the right chemistry and temperature, would scavenge and transport gold and related metals. Fluids would then be channelled into and extensional structures, such as high angle structures within pull apart basins and/or negative flower structures, which occur within an overall compressive event. These fluids would rise until they encountered favourable host rocks and structural environment whereby the system can seal itself, overpressure, leading to hydrofracturing. This combined model of Seedorf and the author does not require an igneous event to drive the hydrothermal system or to be a source for metals. This fits well with the regional picture as there was no igneous activity occurring in north central Nevada during the period 110 to 90 Ma (Fig. 25). However, the author is of the opinion, based on this literature research and field work carried out in 1993/4, that sedimentary hosted gold mineralisation occurred episodically from mid-Cretaceous through to present day. All mineralisation appears to have been controlled by

extensional structures, be it localised or regionally, within a regional compressive or extensional tectonic settings respectively.

The age of mineralisation is divided into camps: being mid- to late-Cretaceous (90 to 117 Ma) and early- to mid- Tertiary (30 to 45 Ma), (See Section 6). It is interesting to note that it was during the late Cretaceous (80 Ma) that the Laramide Cu-porphyry mineralisation peaked in southern Arizona while at the other end of the spectrum, mid-Tertiary (38 Ma), the Bingham Canyon Cu-Mo- Au-Pb-Zn mineralisation in Utah occurred. Although there was no major igneous activity in the mid- to late Cretaceous (120 - 80 Ma) in north-central Nevada (Fig. 25) a regional metamorphic and thermal event occurred at 110 Ma and 85 Ma respectively (Thorton et. al., 1991). This raises an interesting question as to whether sediment-hosted disseminated gold mineralisation in Nevada is linked to the mineralising events in Arizona and Utah?

An interesting aspect of the Carlin and Battle Mountain trends, is that they cross-cut the Tertiary Basin and Range extensional tectonics (Fig. 2, 8 & 9). It can be argued, based on cross-cutting relationships, that mineralisation is younger than the 12 Ma old Basin and Range extensional tectonics. Effimoff and Pinezich (1986), based on seismic studies, showed that the basins within the Basin and Range Province were asymmetrical and that the ranges were the apex of tilted rotated blocks and the basins, the down tilted part (Fig's. 33 & 34). Most deposits are located in the ranges, areas that would have little lateral displacement, so the trend does not appear to be severely disturbed by Tertiary Basin and Range extensional tectonics. In a palinspastic reconstruction across the Cu-porphyry district in southern Arizona and New Mexico, Nielsen (1979), showed that the distribution of Laramide (\pm 80 Ma) porphyry copper intrusions in southern Arizona and New Mexico are aligned along regional fractures after removing Basin and Range extensional tectonics. This greater apparent displacement of the copper porphyries, as a result of Basin and Range, is a function of the level of erosion. The erosion level is deeper for the porphyry district, hence greater dislocation of pre-Basin and Range mineralisation trends, whereas for the sediment-hosted deposits in Nevada, erosion is not as deep therefore, dislocation of the trends is less apparent.

Cunningham (1987) showed that the larger sediment-hosted disseminated gold deposits are spatially related to the Precambrian craton edge (Fig. 18). The higher paleothermal anomaly defined by supermature (>300°C) organic material parallels the inferred Precambrian craton edge (Fig. 18). The Precambrian craton edge together with other geological features discussed is important in the controlling the distribution of structures, hydrothermal systems and sediment-hosted gold mineralisation.

Percival et. al., (1987), Seedorf (1991) believe that the sediment-hosted disseminated gold deposits were formed in a mesothermal environment ranging between 500 m and 5 000 m. This is not unrealistic as the Betze/Post deposit has a vertical range of known mineralisation of over a kilometer (Seedorf pers. com., 1993/4). Mineralisation extends beyond the limits of current drilling.

10. EXPLORATION

10.1. Remote Sensing

Nevada and the Great Basin is dominated by an arid to semi-arid environment, making this terrain amenable to remote sensing exploration techniques. LANDSAT imagery will be useful in delineating regional structural trends, structural domains and alteration patterns around hydrothermal systems. Although most argillic alteration has been attributed to supergene rather than hypogene processes, it is nevertheless spatially associated with the high density of fractures/faults occurring within mineralising hydrothermal systems (Rota, pers. com., 1994). Using band ratioing of LANDSAT data, argillic alteration can be enhanced.

Aerial photography studies in conjunction with LANDSAT images, is a powerful tool in the construction of basic geological plans, especially in the ranges. The Rabbit Creek deposit was discovered by detailed interpretation of the Rabbit Suture from aerial photographs (Bloomstein et. al., 1991). From aerial photograph studies, anticlines, high angle faults and distribution of carbonate lithologies should be noted as they are all important in the distribution of mineralisation.

Although Nevada is a semi- to arid terrain, outcrop is generally poor. Infrared imagery could be a powerful tool in exploration in carbonate lithologies, delineating subsurface structures which contain meteoric water. Nevada winters are characterised by heavy snowfalls and early spring runoff should enhance structures which are conduits to fluids, hence helping in determining the structural history of the area of interest.

10.2. Geophysical Techniques

Geophysical techniques, which are the direct detectors of sulphide mineralisation, have not been very successful in the location of sediment-hosted disseminated gold mineralisation due to the low content and disseminated nature of sulphides within the ore bodies. Indirect techniques, which respond to a geological environment rather than a particular mineral suite, are used more as a mapping tool than an anomaly finder. Within a body of rock affected by a hydrothermal system, alteration and/or mineralisation assemblages may vary widely in intrinsic properties from silicic (high resistivity, low chargeability) to advanced argillic(?) (low resistivity, high chargeability). However, sulphide mineralisation is only sometimes a significant component of an anomaly. It is for these reasons that a geophysical program should be carefully planned, using a number of different geophysical techniques, but always intergrated with other geological techniques.

Gravity surveys will help in locating subcropping stocks and plutons which have been shown to be an important control in the distribution of sediment-hosted disseminated gold deposits. Regional gravity data has been used to outline regional structures which have been intruded by various igneous bodies (Fig. 10). Many deposits, Betze/Post, Getchell, Cortez, are located at the edges of these Cretaceous intrusions. In the last five years, exploration has shifted towards targets buried by Tertiary pediment, developed in basins of the Tertiary Basin and Range Province. Gravity surveys have been used in attempt to determine the depth of pediment in the Tertiary basins. However, in the authors experience in drilling these buried targets, gravity has not proved to be a succesful technique because of the variability of the alluvium density due to compaction, grain size, water saturation and intercalated Tertiary volcanic flows.

Regional aeromagnetic surveys will help mapping the extent of the Tertiary volcanic cover, which covers large tracts of ground in Nevada, which is not conducive to locating low grade bulk tonnage deposits. Regional aeromagnetic surveys are useful in delineating regional deep structures along which plutonic and volcanic rocks have intruded and extruded respectively (Fig. 9). Within limits, aeromagnetic surveys will help in locating depth and susceptibility contrast of buried intrusives. This has especially been successful at the Betze/Post deposit where there is a strong spatial relationship between mineralisation and intrusive (Bettles and Lauha, 1993b). Ground magnetic surveys are a logical follow up to regional magnetic anomalies. Ground magnetics has proven to be an extremely useful tool in delineating the distribution of volcanic units on exploration properties where outcrop is poor. Ground magnetic surveys were successful in defining structures which bound or offset the contact between Silurian-Devonian sediments and Tertiary pediment at the Betze/Post deposit (Bettles and Lauha, 1993b).

Electrical geophysical techniques which have been proved to be useful in the search of sediment-hosted disseminated gold deposits have been, (1) controlled source audio-frequency magnetotellurics (CSAMT), (2) induced polarization (IP) and (3) transient (or time-domain) electromagnetics (TEM, or TDEM), (Zonge and Hughes, 1990). CSAMT, an electromagnetic sounding technique measuring resistivity variations in the ground, has proved to be an excellent tool in mapping silicification, faults, argillic alteration, clay and graphite zones and structural/lithological relationships in precious metal exploration targets.

Bettles and Lauha (1993b) found that interpretation of IP data with a pole-dipole array was complicated by the presence of diagenetic pyrite, barren hydrothermal pyrite and carbonaceous sediments. As a result, multi-frequency IP (complex resistivity) surveys are becoming popular in exploration programs as they are used to distinguish between sulphides, clays and graphite (Fritz, pers. com., 1993).

10.3. Host Rock Studies

Resolving the age of the siliciclastic lithologies spatially related to many of the deposits is important in understanding the distribution of sediment-hosted gold mineralisation. If the

siliciclastic lithologies are Devonian in age this supports the model that mineralisation may be controlled by paleo-pull apart basins. If this model is proved correct it opens up large areas of exploration, especially along regional, long lived structures.

Although sediment-hosted gold deposits in Nevada occur in a number of different lithological types the tonnage and grade vary considerably, depending on the geochemistry of the host rock (Tables 1, 2, and 3). Pre-ore pyrite and reactive Fe within host sediments appear to play a critical control in mineralisation. On a prospect which shows favourable signs of hydrothermal mineralisation, determining the quantity and distribution of both pre-ore pyrite and reactive Fe may help in determining the morphology and size of the mineralised envelope. This will help in determining sample parameters and drill hole spacing.

Cunningham (1988) has shown that most of the sediment-hosted disseminated gold deposits are associated with Paleozoic lithologies are submature, 100-300°C, while the larger deposits are developed in supermature (>300 °C) sediments (Fig, 18). Regional scale organic matter maturation studies such as conodont colour alteration, pyrolysis, such as measured by Rock-Eval techniques, and vitrinite reflectance will help in determining regional paleothermal gradient. This should help in further delineating the areas of exploration interest.

Illite occurs both as a primary sedimentary mineral and as a product of hydrothermal alteration. It is known to be temperature sensitive and XRD studies should help in vectoring in on the heart of the hydrothermal system.

10.4. Structural Studies

Structure is regarded as the first order control on the distribution of hydrothermal systems. Therefore, a good understanding of structural regimes, both on the regional and prospect scale, is paramount in exploration for sediment-hosted disseminated gold deposits. The first and most obvious structure which needs clarification is the RMT, which has often been arbitrarily placed at contacts between carbonate and siliciclastic lithologies (See section 4.3.1). Where the RMT has been interpreted to occur, large areas of potential exploration have been written off simply because siliciclastic rocks have been lumped together as allochthonous Ordovician sediments,

regarded as unfavourable host rocks. Recent dating of host rock is proving that the siliciclastic rocks, initially interpreted as allochthonous Ordovician rocks, are in fact autochthonous and Devonian in age. This opens up large areas for exploration, especially along regional, long lived, deep structures.

Most of the deposits are associated with, and controlled by, high angle faults which are believed to be part of strike slip fault systems. It is proposed that the "windows" of mineralisation along both the Carlin and Battle Mountain - Eureka trends could represent paleo-pull-apart basins, that may be overprinted by negative flower structures associated with younger strike-slip tectonic events. These areas of paleo-pull apart and/or negative flower structures are favourable sites for hydrothermal systems and igneous activity because of localised extensional tectonics within both regional compressional and extensional tectonic environments. Whereas, between these "windows", faults are not conducive to hydrothermal systems as there are no open structures to be exploited. It is in the author's opinion that small pull-apart paleo-basins and/or negative flower structures are critical in stemming the migration of the hydrothermal system, resulting in overpressuring which leads to hydrothermal brecciation. This is regarded as critical in upgrading the mineralisation.

On prospect scale exploration, detailed attention should be paid to mapping the density and orientation of micro-fractures and faults, especially where there is silicification in faults. A zone of high density and randomly orientated micro-faults/fractures may indicate that decalcification has taken place in the underlying lithologies, resulting in volume loss and the formation of collapse breccias. This has been proved a useful technique in delineating the ore body at Rabbit Creek (Osterberg and Guilbert, 1991).

In recent years, exploration for Paleozoic sediment-hosted disseminated gold mineralisation has shifted from the ranges to Paleozoic rocks buried beneath gravels in Tertiary basins. The Chimney Creek and Gold Quarry deposits are two examples of deposits buried beneath Tertiary gravels on the edges of basins (Bloomstein et. al., 1991; Rota, 1991 and 1993). Recently, Placer Dome have announced a major discovery, the Pipeline deposit (34.21 Mt @ 4.1 g/t), situated south of the Gold Acres deposit that is buried beneath Tertiary gravels (Fig. 7), (The Northern Miner, 1994).

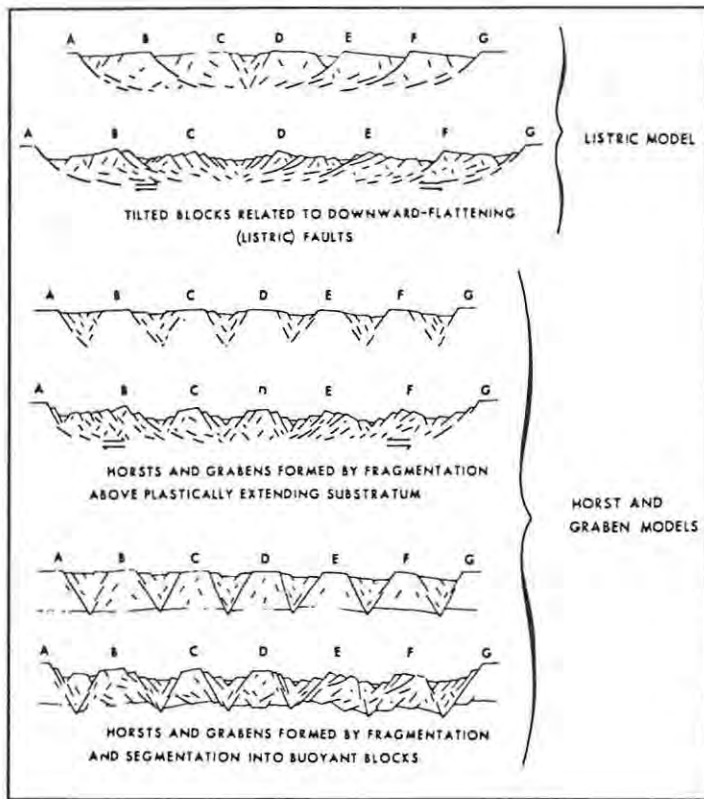


Figure 32. Two general models for basin and range structural development showing early and late stage development (After Effimoff and Pinezich, 1986).

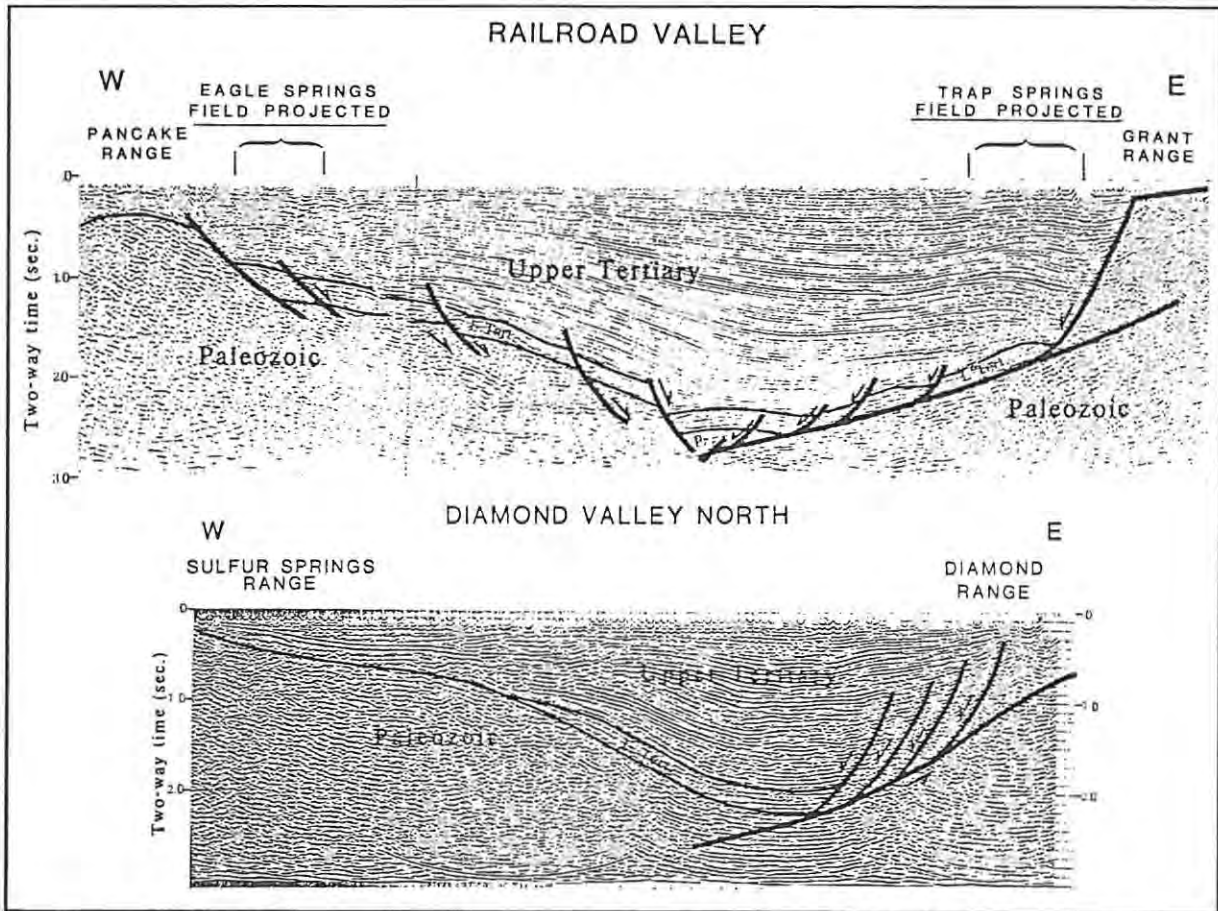


Figure 33. Two-way time seismic sections across Railroad and Diamond Valleys showing listric nature of Basin and Range faulting (After Effimoff and Pinezich, 1986).

To explore for disseminated gold deposits beneath gravels in Tertiary basins it is critical to understand the structural development of the Tertiary Basin and Range tectonics. The two general models for basin and range structural development are; listric and horst and graben (Fig. 33), (Effimoff and Pinezich, 1986). Basins in northeastern Nevada have been extensively studied for oil plays and good quality seismic data exists across some of the valleys. Seismic dip profiles across the Diamond and Railroad Valleys (Fig. 34), clearly show that the basin has an asymmetrical profile (Fig. 34). The eastern margins of these valleys are bound by listric faults, which have displaced Paleozoic sediments between 3 000 and 4 500 metres, while the western flanks are defined by gentle east-dipping ramps (Fig. 34), (Effimoff and Pinezich, 1986). The listric model is favoured for basin and range structural development, where the uplifted part of the blocks forms the ranges and the down tilted part forms the grabens (Fig. 34), (Effimoff and Pinezich, 1986).

The Gold Quarry, Chimney Creek and Pipeline deposits are all located on the edge of the basin, on gentle southeast-dipping ramps. It would be futile to explore for gold mineralisation in basins adjacent to listric, range front faults as these faults have displacements of 3 000 metres or greater (Fig. 34). Airphotograph studies and regional mapping of ranges will quickly determine the direction of tilt and position of the range front faults, helping to determining the optimum position for exploration within the adjacent basin, if the adjacent ranges show indications of mineralised hydrothermal activity.

10.5. Geochemical Techniques

10.5.1. Lithochemical Techniques

Rock chip sampling has been used extensively in sediment-hosted disseminated gold mineralisation in Nevada. Often, silicified fault zones are the only prominent outcrop on exploration properties, attracting considerable attention and rock chip sampling at the expense of surrounding outcrop. Because mineralisation and alteration is subtle, mineralised lithologies adjacent to silicified fault zones are often overlooked. At both Carlin and Chimney Creek deposits, mineralisation was detected in samples which were regarded as "background" samples for nearby silicified outcrop (Rota and Atkin, per comm., 1993). It is therefore important that a systematic rock chip sampling program be designed over the property of

interest in order to try to nullify visual biased data collection. The following pathfinder elements should be analysed for As, Ag, Hg, Sb, F and Tl. However, gold is its own best pathfinder.

10.5.2. Stream Sediment Techniques

Stream sediment geochemistry has proved to be an excellent tool in delineating anomalous gold mineralisation. The bulk leach extractable gold (BLEG) sampling technique has proved to be the best technique for defining anomalous low grade gold mineralisation because of the large sample size (3-5 kg) and courser fraction (-1 mm). BLEG sampling is used in regional surveys to sample streams (washes) at the base of ranges. This method quickly determines whether the ranges are anomalous in gold. Care should be taken in interpreting gold anomalies, in streams originating from ranges, as raised, preserved, pediments which often have placer gold mineralisation unrelated to hydrothermal sediment-hosted gold deposits. Cu and Au are the elements which are analysed in BLEG sampling program. An orientation study should be done in streams draining from known mineralisation, in order to determine the optimum sample size and mesh fraction on commencement of an exploration program.

10.5.3. Soil Geochemical Surveys

Soil geochemical surveys are important in exploration for sediment-hosted disseminated gold mineralisation in Nevada, because of the lack of outcrop and the subtle features of this type of mineralisation. Pathfinder elements, As, Ag, Sb, Hg, F, Tl and Au should be analysed and should all be used in interpretation of data because of the great variability of individual elements within, and between, known deposits.

10.5.4. Synthesis of Data

Once all the regional structural, geophysical, host rock, igneous intrusion, geothermal and geochemical data has been collected it must be compiled into plans and tabulated as in figure 6. This will help in defining the geology of individual ranges and prioritise ranges for follow up exploration.

11. CONCLUSIONS AND SUMMARY

The model proposed here is that sediment-hosted deposits are located within strike-slip basins located along regional, deep seated and long lived structures which define trends along which the deposits are located. Geological evidence indicates that these strike-slip faults and related pull apart basins were initiated at the onset of the eastward directed compressional Antler Orogeny, during the final stages of the sedimentary evolution of the Paleozoic Great Basin. Evidence includes proximal, fault bounded, carbonate debris flows enclosed in deep water, thinly bedded siliciclastic sediments, a complex relationship between thinly bedded carbonate and siliciclastic lithologies, soft sediment deformation interpreted to be a result of rapid loading and conjugate high angle faults which have the correct geometry perceived for pull apart basins. Putnam and Henriques (1991) believe that the Carlin and Battle Mountain - Eureka trends are right lateral, R_1 , synthetic reidel shears, related to the right lateral wrench faults of the Walker Lane and San Andreas fault systems.

Sediment-hosted disseminated gold deposits tend to occur in groups along the trends. This was, and still is thought, to be a function of autochthonous Devonian-Silurian carbonate lithologies, exposed as windows through allochthonous Ordovician siliciclastic lithologies being transported along RMT. However, recent fossil dating indicates the once believed to be Ordovician siliciclastic sediments are actually Devonian in age. This is further evidence that deep water sediments were deposited in local second and third order basins, adjacent to carbonate platforms. If the positive identification of Devonian siliciclastic sediments, especially where spatially associated with long lived deep seated structures, can be established, this opens large areas for exploration in Nevada.

Pull apart basins are favourable sites for igneous intrusions, hydrothermal activity and mineralisation as they are sites of extension within both regional compressional and extensional structural terraines. Pull apart basins are not only the structures conducive to circulating hydrothermal fluids, but also prevent the hydrothermal system from migrating along strike, resulting in sealing of the system, overpressuring and hydrofracturing, all critical factors in upgrading an anomalous occurrence to an economic one. Host rocks, carbonate debris flow breccias, thinly bedded silty limestones and interbedded silty carbonates and siliciclastic

lithologies, developed within these pull apart basins, are preferred host rocks for disseminated gold deposits. The reasons being: (1) thinly bedded, silty carbonates are susceptible to decalcification by slightly acidic to acidic fluids, increasing secondary porosity and permeability and (2) the competency contrast between thinly interbedded siliciclastic and carbonate lithologies is conducive to producing secondary structurally induced permeability. Strike-slip faults related to compressional tectonics according to Aldow et al., (1986) are derived from deep within the crust and even possible the upper mantle (Fig. 12). These structure would be exploited by ingeous intrusion especially in jog zone where pull-apart basins and/or negative flower structure develop.

The tonnage and grade of the individual deposits are a function of the type of host rock, geochemistry of the host rock, structural preparation, depth of erosion and size of the hydrothermal cell.

Alteration types commonly described in sediment-hosted disseminated gold deposits are decalcification, silicification, carbonisation, argillisation, oxidation and, to a lesser extent, alunite and barite. Decalcification is usually the first alteration process to occur whereby calcite and dolomite are removed by slightly acidic fluids. Up to 60% of carbonate has been described to have been removed from deposits such Carlin and Gold Quarry (Rota, 1991; Bakken, 1990). Silicification is more complex and is deposited throughout the evolution of a hydrothermal system. Carbonisation occurs in varying amounts and is usually a late stage alteration feature. Carbon is thought to be remobilised from carbonaceous sediments in the immediate surrounds of a hydrothermal cell, or within structural and lithological traps which the hydrothermal fluids are exploiting. There are two schools of thought on the origin of argillisation and oxidation alteration types these being a supergene and/or a hypogene. Arehart et. al., (1992) showed that oxidation and argillisation processes are a result of supergene weathering processes based on isotopic studies of alunite and barite.

Geochemistry of these deposits is fairly simple comprising Au, As, Sb, Hg, Tl. In evaluation of rock chip, soil and stream sediment geochemistry, all these geochemical variables must be taken into account due to the large variability of individual elements within and between deposits. Arehart et al., (1993b) showed that most of the gold is deposited together with

arsenic, in arsenian pyrite rims, on pre-ore diagenetic pyrite. Therefore, diagenetic pyrite is a critical component in the deposition of gold. This may explain why some hydrothermal systems with all the right pathfinder elements in anomalous quantities, have no gold mineralisation.

Three sources for gold and pathfinder elements have been proposed, (1) Ordovician carbonaceous siliciclastic sediments (Nelson, 1991), (2) Proterozoic and lower Paleozoic sediments underlying the Great Basin (Seedorf, 1991) and (3) igneous intrusions (Sillitoe and Bonham, 1990). The Ordovician sediments are not regarded as a potential source, based on the lack of alteration which would accompany large scale scavenging of gold and pathfinder elements. Isotopic studies on sulphur indicate that the isotopic signatures of sulphur within the deposits, is similar to that of the sulphur within sediments in Nevada, hence no magmatic input of sulphur or related metals is required, but can, never the less, not be ruled out. Seedorf showed that the thickness of the Proterozoic rocks is critical in determining the distribution of the sediment-hosted disseminated gold deposits in Nevada and therefore proposes these sediments as a potential source.

Age of mineralisation is divided into two camps based on direct and indirect dating techniques. Isotopic dates of mineralisation range between 95 and 123 Ma and between 25 and 38 Ma (Morton et. al., 1977; Arehart et. al., 1993; Keuhn, 1989). Isotopic dates of alunite are divided into two groups being: those dates younger than 15 Ma and those greater than 20 Ma (Table 5). The younger dates, 10 to 15 Ma, probably represent the onset of supergene processes (Arehart et. al., 1992) which accompanied the uplift associated with the Basin and Range extensional tectonics at ± 12 Ma (Stewart, 1980). The alunite dates of between 20 and 30 Ma are consistent K/Ar dates of 30 to 36 Ma of biotite and sanidine and is believed to reflect the younger age limit for mineralisation for sediment-hosted gold deposits in Nevada. Most of the Newmont and American Barrick mine geologists believe that mineralisation is early- to mid-Tertiary, based on cross cutting geological features and because this period was dominated by crustal extension with an elevated geothermal gradient and igneous activity. The author believes that gold mineralisation spans the entire period from the early Cretaceous to mid-Tertiary, with two periods of intense mineralisation at either end of this period.

Fluid inclusion and isotopic studies indicate that the hydrothermal fluids were slightly saline and acidic and that metals were deposited at temperatures of $200 \pm 25^\circ\text{C}$. Gold is transported predominantly as a bisulphide complex under these conditions and deposition occurs due to a number of processes, mixing of hydrothermal fluids with meteoric water, temperature and pressure changes, as well as pH oxygen and fugacity changes.

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APPENDIX A

Characteristics of Sediment-Hosted, Disseminated Gold Deposits along the Carlin Trend.

Deposit	Page No.
Bootstrap/Capstone	1
Meikle	2
Betze/Post	4
Genesis/Blue Star	7
Carlin	9
Tusc	11
Gold Quarry	13
Rain	16
South Bullion	19
Vantage	21

n.d. = not described

A. Deposit:	BOOTSTRAP/CAPSTONE		Capstone; Silicification of carbonate and siliciclastic sediments → argillic alteration accompanying Au mineralisation.
B. Tonnage/Grade:	14.66 Mt @ 1.92 g/t.		
C. Shape/Dimension:	n.d.	6. Ore Controls:	Bootstrap; lens shape vein like orebodies in N-S striking faults. Repeated movement on fault increased permeability. Capstone; steep N25W and N35E, west dipping faults intruded by igneous dykes, lesser extent lithological ore controls. Intersection of faults main structural control.
D. Deposit Attributes:			
1. Stratigraphy/Host Rocks:	<u>Devonian Siliceous Sequence;</u> Calcareous sandy siltstone, siliceous mudstone. <u>Devonian Bootstrap Limestone;</u> Upper; thick beds of oolitic limestone, minor silty to sandy detritus, debris flow assemblages in upper limestone beds. Middle; thin, bedded and laminated calcareous siltstone to silty limestone. Lower; laminated, platy calcareous silty limestone, limestone. <u>Silurian-Devonian Roberts Mountains Formation;</u> Calcareous thinly bedded and laminated silty limestone.	7. Ore/Gangue Mineralogy:	n.d.
		8. Sulphide Paragenesis:	
		9. Mineralisation:	n.d.
		10. Geochemistry:	n.d.
		11. Fluid Inclusions:	n.d.
		12. Isotope:	n.d.
2. Igneous Rocks:	Highly altered dykes intruding high angle faults. Thought to be granodiorite - tonalite in composition.	13. Source:	Baker, 1991.
		14. Remarks:	Was a stibnite producing area prior to Au.
3. Age of mineralisation:	n.d.		
4. Structure:	N-S dominant → NW + NE → E-W high angle faults, repeated movement on faults through time, all pre-mineral.		
5. Alteration:	<u>Bootstrap; Silicification</u> along fault and joint planes grading outwards to argillic alteration.		

A. Deposit:	MEIKLE (also known as Purple Vein)		Note; Barrick include the Rodeo Creek Formation into the Vinini Formation based on fossil evidence (Lauha et. al., 1993).
B. Tonnage/Grade:	6.52 Mt @ 21.4 g/t.		
C. Shape/Dimension:	Three Orebodies; 1. Flat Sector 31 m thick, 250 to 345 m below surface, 2. Central Dipping Sector; 47 m thick, dips 70°, 250 to 625 m below surface. 3. Southern Sector, equidimensional body, 281 to 656 m below surface.	2. Igneous Rocks:	Monzonite dykes along high angle faults. In ore zone the monzonite dykes have been brecciated altered and mineralised. Sericite date of 36.4 ±1.8 Ma: K/Ar. Monozite porphyry dated; 147 ± 4.0 Ma: K/Ar. Latite dykes and predominantly sills which have intruded along thrust faults. Monzonite and latite intrusives host 15% of the ore.
D. Stratigraphy/Host:	Devonian Rodeo Creek Formation; well bedded and banded siliceous mudstone interlaminated with thin bedded siltstone and fine to medium-grained sandstone. Contact structural, RMT (Barrick) Devonian Popovich Formation; HOSTS orebody . Upper; medium-bedded siltstone and silty limestone, clay-rich carbonaceous zone in the upper Popovich Formation. Middle; massive-bedded siltstone and silty limestone, bioclastic beds common towards the base. Lower; interbedded bioclastic limestone, debris flow and interbedded siltstone. Debris flow breccias common at base of Popovich Formation. Silurian-Devonian Roberts Mountains Formation; thin bedded, platy dolomitic siltstone with interbeds of bioclastic limestone. Ordovician Vinini Formation; deformed siltstone, chert, mudstone and limestone, abundant low-angle structures.	3. Age of Mineralisation: 4. Structure: 5. Alteration:	n.d. But > 36 Ma. RMT - Antler Orogeny; Lower imbricate thrust important in structural ore controls. A post- RMT thrust event important in structural ore controls especially in the footwall portion of the thrust slices. High angle faults are the major control for development of secondary permeability and deep feeders. Dominant trend N20-30W and N40-70E. Decalcification; important in creating secondary porosity and permeability. Silicification; the dominant alteration type, four stages of silicification recognised; (1) barren early stage of silica flooding, (2) silicification associated with Au mineralisation, (3) late stage chalcocenic quartz associated with mercury mineralisation and (4) very late stage hyaline silica on fractures. Higher grades associated with an increase in sulphides and where multistage hydrothermal brecciation overprints other breccia types.

	<p>HOST most of the Au mineralisation.</p> <p>Argillisation; minor in Meikle deposit and mostly confined to monzonite and latite intrusives and structural zones peripheral to silicification.</p> <p>Dominant clay mineral illite and minor kaolinite, montmorillonite and sericite.</p>		
6. Ore Controls:	<p>Dominant control high angle faults and intersection of these faults. Repeated brecciation along faults.</p> <p>Intersection of thrust faults and high angle faults.</p> <p>Intersection of high angle faults and the reactive permeable lithologies.</p> <p>Lithological controls less important, debris flow breccias and decalcified carbonate lithologies.</p> <p>Breccias, debris flow, fault and hydrothermal breccias very important in controlling most of mineralisation.</p>	<p>11. Fluid Inclusions:</p> <p>12. Isotope:</p> <p>13. Source:</p>	<p>Hg same as Post/Betze,</p> <p>Ba is highly elevated,</p> <p>Elevated Cu, Pb and Zn.</p> <p>Lauha and Bettles, 1993.</p>
7. Ore/Gangue Mineralogy:	<p>Pre- Au mineralisation tennantite-tetrahedrite.</p> <p>Syn- mineral pyrite, marcasite, stibnite trace realgar and orpiment. Quartz, calcite, barite.</p>		
9. Mineralisation:	<p>Au (0.002-0.01 microns) is located in rims of arsenian pyrite rims on arsenian poor pyrite cores.</p> <p>Pyrite divided into equal portions of coarse (200 micron) and fine (10-20 microns) grains with the fine grained having higher Au- grades.</p> <p>Au grade increases with sulphide content, degree of brecciation and silicification.</p> <p>Mineralisation structural and vein controlled, minor replacement orebodies.</p>		
10. Geochemistry.	<p>Higher Au and Ag grades than Post/Betze deposit.</p> <p>Au:Ag ratio = 1: 2.9.</p> <p>As- 1684 ppm (twice as high as Post/Betze),</p> <p>Sb- 82 ppm (half that of Post/Betze),</p>		

A. Deposit:	BETZE, POST (UPPER, LOWER AND DEEP).	Ordovician Vinini Formation; deformed siltstone, chert, mudstone and limestone, abundant low-angle structures. Note; Barrick include the Rodco Creek Formation into the Vinini Formation based on fossil evidence (Lauha et. al., 1993).
B. Tonnage/Grade:	Post; (Combined) 136 Mt @ 5.96 g/t.	
C. Shape/Dimensions:		
D. Deposit Attributes:		
1. Stratigraphy/Host Rocks:	<p>Devonian Rodeo Creek Formation; well bedded and banded siliceous mudstone interlaminated with siltstone, thin bedded siltstone and fine to medium- grained sandstone. HOSTS the Upper Post Deposit. Contact transitional (Newmont); Structural, RMT (Barrick). Devonian Popovich Formation; Upper; medium-bedded siltstone and silty limestone, clay-rich carbonaceous zone in the upper Popovich Formation. HOSTS Upper Post and Betze Deposits . Middle; massive-bedded siltstone and silty limestone, bioclastic beds common towards the base. HOSTS Lower Post Deposit (Refractory leach grade, 0.21 - +1.71 g/t). Lower; interbedded bioclastic limestone, debris flow and interbedded siltstone. Debris flow breccias common at base of Popovich Formation. HOSTS higher grade Lower Post Deposit (+3.42 g/t) and higher grade Deep Post deposit (+6.85 g/t). Transitional contact. Silurian-Devonian Roberts Mountains Formation; thin bedded, platy dolomitic siltstone with interbeds of bioclastic limestone. HOSTS Betze Deposit.</p>	<p>2. Igneous Rocks:</p> <p>Biotite Feldspar Porphyry dykes, porphyritic biotite and/or feldspar in aphanitic groundmass. Dated 39 Ma (Archart, 1992). Post-mineral, cuts Deep Post orebody. Quartz Monozite Porphyry dykes and sills, quartz latite in composition with phenocryst of altered plagioclase, biotite and quartz. Dated 110 Ma (Archart, 1992). Goldstrike Intrusive, granodiorite to diorite in composition, weakly mineralised. Dated 160.6 ± 2.1 Ma (Archart and Kesler, 1989).</p> <p>3. Age of Mineralisation: Pre- 39 Ma - Post- 110 Ma.</p> <p>4. Structure: Roberts Mountains Thrust - Antler Orogeny - Vinini highly fractured and folded. Post- Goldstrike intrusive thrusting. Dominant structure NW anticline, plunges to SE. Post-second thrusting event. High angle N25W, N to NNW and NE faults. Paragenesis; NW → NE + N to NNW.</p> <p>5. Alteration: Pre-mineral skarn/hornfels alteration, skarn alteration extent 940 m from Goldstrike Intrusive. All Au-deposits within the contact metamorphic aureole. Decalcification; stratigraphically controlled by silty carbonate lithologies in Roberts Mountains, Popovich and to a lesser extent in the Rodeo Creek Formations.</p>

Silicification; early, sulphide- and Au-poor, pervasive silicification flooding of permeable decalcified sediments. Later silicification event accompanied hydrothermal brecciation, numerous quartz veins, veinlets and stockwork veinlets. Au and sulphide mineralisation accompanied this event.

Argillisation; post dates silicification and is associated with faults and fractures. Kaolinite dominant at Post/Betze deposit, illite thought to be sedimentary.

Pyritisation; found in both silicified and argillised zones, up to 5% sulphides in sulphide orebodies.

Carbonisation; carbon (pyrobitumen) occurs in ore zone but more commonly peripheral to orebodies.

Oxidation; Supergene and possible hypogene oxidation, pyrite converted to Fe-oxides. Minerals goethite, hematite, jarosite, alunite, jarosite. Oxidation depth varies from 25 m in the stock to 187 m in the sediments. Supergene alunite dates 8.48 to 9.58 Ma: K/Ar (Arehart in Lauha et. al., 1993).

6. Ore Controls:

Upper Post; Mineralisation and alteration stratigraphically controlled in bleached and argillised siltstones, sandstones. Structurally controlled mineralisation occurs as stockwork quartz veins and in silicified fault breccia.

Lower Post; Stratigraphically controlled forming a bedding-parallel body hosted in laminated, carbonaceous, pyritic mudstones-siltstones and silty limestones of Popovich Formation and silty limestones of the Roberts Mountains Formation. The debris flow breccias, decalcified bioclastic limestones at base of Popovich host the high grade ore due to primary permeability and reactive nature

of the host rock. Average sulphide content 4 to 5%.

Deep Post; A high grade (+6.85 g/l) structurally controlled orebody at base of orebody within a N50W high angle fault along the margins of the Goldstrike intrusion.

The goldstrike intrusion thought to have added in structural ore controls in creating initial fracture and faults at time of intrusion and more important acted as a rigid body within a structural regime creating complex faulting/fracturing around the edge of the deposit.

The sills extending from the Goldstrike Intrusion acted as caps to the Au bearing fluid as did massive limestones, marble and argillites creating local high grade orebodies.

Intersection of high angle NE and N to NNW faults and the intersection of these faults with permeable lithologies are major controls on mineralisation distribution and size of orebodies. Minor deposits are located in low angle fractures thought to be cooling joints.

7. Ore/Gangue Mineralogy:

Pyrite, marcasite, realgar, orpiment, stibnite, pyrrhotite, arsenopyrite and chalcopyrite. Trace earlier base metal sulphides, sphalerite, galena, molybdenum and stibnite.

Quartz, calcite, kaolinite and minor illite.

8. Sulphide paragenesis:

n.d.

9. Mineralisation:

Au is associated with Au bearing arsenian pyrite and marcasite and both sulphides are divided into: (1) 50% coarse grained (1/- 200 micron in diameter) and (2), 50% fine grained (10 to 20 microns in diameter). Au, 0.002 to 0.01 microns in

diameter, occurs as globules in arsenian pyrite and marcasite. 20 to 30 % of Au occurs in fine grained sulphides, 10 to 20% as free Au and the rest in coarse sulphides. Sulphides + Au mineralisation accompany second phase of silicification.

10. Geochemistry:

Post/Betze deposit rock chip composites;

Au- 0.23 - 0.33 ppm,

As- 336 - 850 ppm,

Sb- 12 - 114 ppm,

Hg- 0.34 - 6.7 ppm,

Tl- 5 - 19 ppm,

Low levels of Ag. Au:Ag 1:3 (oxide) to 1:6 (refractory).

Trace base metals, Cu, Zn, Pb and Mo related to Goldstrike Intrusive.

11. Fluid Inclusion:

12. Isotope:

13. Source:

Bettles and Lauha, 1993a.

Bettles and Lauha, 1993b.

Thoreson, 1993.

- A. Deposit: **GENESIS/BLUE STAR**
- B. Tonnage/Grade: 67.58 Mt @ 1.1 g/t (Genesis, Blue Star, Beast & SOLD included in reserve).
- C. Shape/Dimension: Elongated N to NNW (Genesis and Bluestar pits combine).
1 875 m * 325 - 780 m.
- D. Deposit Attributes:
1. Stratigraphy/Host Rocks:

Devonian Rodeo Creek Formation; Thinly bedded siltstones, carbonaceous mudstone and argillite; minor calcarenite at base; minor, medium bedded-calcareous siltstone higher in sequence.
Conformable contact.

Devonian Popovich Formation; thinly bedded carbonaceous mudstone and argillites, minor calcarenites occur towards the base and medium bedded-calcareous siltstones higher in the section.

Ordovician Vinini Formation; medium to thin bedded, laminated, siltstone and chert, local interbeds of calcareous siltstone.
In structural contact with both the Popovich and Rodeo Creek Formations.
 2. Igneous Rocks:

Biotite feldspar porphyry (28.3 ±0.7: K/Ar date of biotite), biotite and to a lesser extent feldspar phenocryst, altered, bleached with kaolinite-sericite masses, occurs as dykes.

Goldstrike Stock (158 Ma), fine to medium grained granodiorite, propylitically altered and may contain abundant disseminated pyrite.

Lamprophyre 1 to 1.5 m dykes, contain hornblende, biotite and feldspar, age uncertain.
 3. Age of Mineralisation: n.d. <158 Ma - >28.3 Ma.

4. Structure:

Palaeozoic thrusting - RMT, numerous imbricate thrust in Vinini Formation, Post Goldstrike Stock age thrusting, NW trending Tuscarora Spur antiform - pre-mineral, High-angle N-S → NW → NE → Basin and Range faulting.
N-S faults, apparent reverse and normal offset - strike slip?, pre-mineral and served as a conduit, NW fault set, prominent, southwest dipping normal, step faults, some control on mineralisation, NE fault set, dominant in places, biotite feldspar porphyry intrudes along this set, mineralisation strongly controlled by this set. Basin and Range fault, N to NW steep dipping faults.
5. Alteration:

Pre-mineralisation skarn alteration associated with the Goldstrike Stock, orebody within the skarn; Skarn minerals diopside, quartz, calcite, montmorillonite, minor garnet, tremolite and wollastonite. Siliclastic rocks undergone some hornfels development.

Argillisation; - sericitisation and decalcification? spatially linked to Au mineralization.

Silicification; - most common, quartz veins and veinlets and pervasive quartz flooding, quartz flooding commonly exceeds 70% in orebody.

Decalcification; seldom seen but regarded as important.

Oxidation; supergene, possibly hypogene, jarosite and scorodite.
6. Ore Controls:

Structural ore controls dominant control, intersection of NW and NE faults, limb of the Tuscarora anticline, in low and high angle structures. Almost exclusively within the

pre-mineralisation metamorphic rocks.

7. Ore/Gangue Mineralogy: Pyrite, As-pyrite. Quartz, calcite, chlorite.
8. Sulphide paragenesis: n.d.
9. Mineralisation: Au micron-size. Au together with As and Sb are concentrated in the auriferous pyrite rims.
10. Geochemistry: Large As halo, + 1000 ppm extent outward of Au mineralisation, Sb, + 100 ppm restricted to orebody, Hg 1-30 ppm restricted to orebody but does not correlat with Au.
11. Fluid Inclusion:
12. Isotope:
13. Source: Paul, Jr. and Kunkel, 1993.
14. Remarks: Hydrothermal breccia in southern Genesis Pit.

Deposit:	CARLIN		dykes of different compositions. Erratically mineralised. One age date of 123.31 ± 0.91 Ma (Kuchn, 1989)
B, Tonnage/Grade:	Past Production; 12.7 Mt @ 9.2 g/t. Current Reserves; 8.27 Mt @ 0.96 g/t.		
C. Shape/Dimensions:	Tabular orebody.	3. Age of Mineralisation:	Not well constrained, post 123 Ma - pre- Tertiary Carlin Formation (5 Ma).
D. Stratigraphy/Host:	<u>Devonian Rodeo Creek Formation</u> ; interbedded argillite, mudstone, and siltstone. Minor thin sandstone interbeds. Minor HOST to structurally controlled mineralisation. Gradational to faulted contact. <u>Devonian Popovich Formation</u> ; Upper; interbedded calcarenite and massive bioclastic limestone. Middle; grades upwards from thin-medium bedded laminated silty limestone to massive beds of micrite and limestone. Lower; Massive beds of micrite and limestone with occasional silty limestone interbeds. Minor HOST to structurally controlled mineralisation. Gradational contact. <u>Devonian-Silurian Roberts Mountains Formation</u> ; interbedded thin, platy, carbonaceous, silty limestone, dolomitic limestone and calcareous siltstone. Grades downwards to medium to thick beds of coarse grained silty to sandy limestone. Major HOST to mineralisation in the upper 90 to 130 m. <u>Ordovician Vinini Formation</u> ; interbedded mudstone, siltstone, chert and minor pillow basalts.	4. Structure:	RMT - Antler Orogeny, Ordovician Vinini Formation thrust over Popovich, Rodeo Creek and Roberts Mountains Formations. High angle structures, paragenesis NW → NE → WNW NW. Most high angle faults are normal faults, WNW striking fault right lateral strike-slip fault. NE strike faults also have right lateral movement.
		5. Alteration:	<u>Decalcification</u> ; host most of mineralisation in the upper Roberts Mountains Formation below the Popovich contact. Bakken (1990) showed that decalcification resulted in 40 to 60% volume loss. This resulted in an increased permeability and porosity. <u>Silicification</u> ; host minor Au mineralisation in fault zones and adjacent to feeder faults. Feeder faults are defined by large brecciated jasperoids. <u>Argillisation</u> ; localised within and adjacent to intrusive dykes. Alteration paragenesis; unoxidized unaltered host rock (1) quartz + dolomite + calcite + illite + K-feldspar + pyrite → (2) quartz + dolomite + calcite + illite + pyrite → (3) quartz + dolomite + illite-K mica + pyrite → (4) quartz + illite-K mica + pyrite → (5) quartz + kaolinite-dickite + pyrite (adjacent to feeder faults), (Keuhn and Rose, 1992). Au associated with 3 & 4.
2. Igneous Rocks:	Highly altered dykes intruding along high angle structures. No crosscutting relationship between		

- Oxidation:** Keuhn and Rose (1992), show that oxidation is supergene
6. Ore Controls: Lithological; reactive host rock of the upper Roberts Mountains Formation subjected to decalcification forming a tabular orebody. Massive limestones at base of Popovich acted as an impermeable cap. Structural control by high angle faults that served as feeder faults. Local high grade zones at fault intersections and at fault - reactive lithology intersections. Mineralisation hosted in structures in the unreactive lithologies of the overlying Popovich, Rodeo Creek and Vinini Formations.
7. Ore/Gangue Mineralogy: Pre-Au ore minor galena +/- sphalerite; Syn - Au ore Au + pyrite + realgar + orpiment + stibnite; Post- Au ore, stibnite + oxidation of pyrite. Pre- Au ore, barite, quartz; Syn- Au ore, carbonate removal → quartz jasperoids → quartz veinlets + calcite & dolomite veinlets + barite, calcite, quartz lining fractures and vugs in jasperoids; Post- Au ore, travertine + hyaline opal + calcite veins.
8. Mineralisation: Au occurs as micron to submicron- sized particles associated with quartz, pyrite and clays in siltstone. Au not found in contact with native arsenic, cinnabar, realgar, orpiment and stibnite. Au associated with outer rims of arsenian rich pyrite.
9. Sulphide paragenesis: Pre- Au- Pb-Zn → pyrite + native arsenic → realgar → orpiment + realgar + stibnite → Post Au- stibnite stibiconite + native sulphur.
10. Geochemistry: Elevated As, Hg, Sb and have a strong spatial relationship with Au.
11. Fluid Inclusion:
12. Isotopes:
13. Source: Myers, 1993. Keuhn and Rose, 1992.

A. Deposit:	TUSC	All faults thought to be pre-ore, with multiple episodes of movement pre-, syn- and post-ore deposition.
B. Tonnage/Grade:	12.15 Mt @ 2.12 g/t	
C. Shape/Dimension:		5. Alteration: Four principle alteration types Paragenesis; decalcification → silicification → argillisation → supergene oxidation (+alunite). Decalcification ; principle alteration type, predate Au introduction, nearly all of 50 to 60% of calcite removed. Argillisation ; second most pervasive alteration type, clay minerals predominantly kaolinite and illite occurring as clay veinlets and fracture coatings, kaolinite in deeper portions of the orebody while sericite (illite) in the upper portions. Advanced argillic alteration spatially associated with decalcification and Au mineralisation. Silicification ; limited to elongated pods and lenses within the alteration halo in the Good Hope Fault Zone, minor bedding replacement jasperoids. Oxidation ; complete destruction of organic matter and sulphides by descending acidic supergene fluids. Alunite appears to be related to advanced argillic and late supergene oxidation. Alunite±kaolinite±silica deposited by descending fluids along open fractures and joints.
D. Deposit Attributes:		
1. Stratigraphy/Host Rocks:	<p>Devonian Limestone (Unnamed) Popovich equivalent? Laminated massive silty limestone and siltstone with interbeds of massive micritic limestone. Devonian - Mississippian Rodeo Creek Formation; siliceous, interbedded mudstone, chert and siltstone that is highly structurally disturbed. HOSTS 15% of the ore. Nature of contact not described. Silurian - Devonian Roberts Mountains Formation; laminated thin bedded silty limestone and interbedded limestone. HOSTS 85% of ore.</p>	
2. Igneous Rocks:	n.d.	
3. Age of Mineralisation:	35 - 40 Ma.	
4. Structure:	<p>RMT and abundant imbricate thrust in the Rodeo Creek Formation, the unnamed Devonian Limestone and the Vinini Formation. NW striking Good Hope Fault (reverse fault, right lateral movement has been inferred), with three subparallel splays form the main feeder for hydrothermal fluids, intense zone of crushed and sheared rock exist between some of the splays with multiple episodes of brecciation. NE striking faults constrain mineralisation.</p>	6. Ore Controls: Primary control is the structurally prepared Good Hope Fault Zone, intersections of NW and NE faults. Fracture, joints and minor folds are secondary structure controls especially in the siliciclastic Rodeo Creek Formation. Lithological control in the decalcification of carbonate lithologies in the Roberts Mountains and Rodeo Creek Formations.
		7. Ore/Gangue Mineralogy: n.d. Barite - trace

8. Sulphide Paragenesis: n.d.
9. Mineralisation: n.d.
10. Geochemistry: Three element association; (1) Au+As+Sb±Ag, (2) Cu+Bi+Mo+Se+Cd and (3) Te+Tl+Zn.
Large As halo >500 ppm surrounds alteration and mineralisation, Tl & Te anomalies, 0.5 - 25 ppm, conformable and/or below ore deposit,
Good Hope Fault Zone has 100-400 ppm Cu and up to 4 wt% Zn.
Hg very low.
11. Fluid Inclusions: n.d.
12. Isotope: n.d.
13. Source: Doyle-Kunkel, 1993.

A. Deposit:	GOLD QUARRY	3. Age of Mineralisation:	Probable age, Oligocene (34-20 Ma) related to felsic extrusive volcanics. Alunite dates 28-30 Ma - late hypogene, early supergene; minimum age of deposit. Possible age: Cretaceous (140-110 Ma).
B. Tonnage/Grade:	163 Mt @ 1.4 g/t	4. Structure:	Compressional tectonics; RMT: Antler Orogeny. However RMT is problematic as it varies from lithological contacts to 15 m wide breccia zones (Rota & Hausman, 1991). Post RMT pre-mineral large NE trending anticlines; ore trends NE. Pre-mineral translational tectonics; Major & minor, subsidiary NE and NW high angle faults. Thought to be related to a large right lateral shear zone. Gold Quarry (R ₁) and Good Hope Faults (R ₂) are the major NE and NW trending faults. Compression NNE. Syn-mineral high angle faulting due to decalcification and collapse of Roberts Mountains & Popovich carbonate lithologies. Post-mineral extension tectonics; Basin & Range faulting.
C. Shape/Dimension:	Orebody strikes NE, 1845 m long, 1200 m wide 200 m deep.	5. Alteration:	5 types of alteration; paragenesis; decalcification → silicification + mineralisation → alunization → argillisation → baritization. Decalcification ; in silty carbonate lithologies, increased permeability and porosity, collapse breccia due to volume loss (50-60% volume loss). this lead to vertically vectored fracturing and faulting further increasing permeability. Fluids thought to be part of prograde expansion of hydrothermal system. Sha (in Rota, 1993) suggests, based on fluid inclusion studies that CO ₂ rich fluids responsible for decalcification as opposed to boiling.
D. Deposit Attributes:			
1. Stratigraphy/Host Rocks:	<p>Ordovician Vinini Formation; interbedded carbonaceous shale, siliceous shale, chert, siltstone, quartzite, minor limy siltstone; mat belong to Transitional assemblage (Rota, 1993). Lower part HOSTS Main orebody.</p> <p><u>Ordovician-Silurian-Devonian Transitional Assemblage (Rodco Creek-Devonian);</u> Interbedded siltstone, silty limestone, shale, chert. HOSTS Main Orebody. Structural? and/or transitional contact?.</p> <p><u>Devonian Popovich Formation;</u> Massive bedded fossiliferous, dolomitic limestone, silt content increases upwards. HOSTS Deep West Orebody. Transitional contact.</p> <p><u>Silurian-Devonian Roberts Mountains Formation;</u> Platy, silty, dolomitic limestone, base 1 - 3 m thick dolomite & locally sandy limestone. Upper part HOST Deep West Orebody. Transitional contact.</p> <p><u>Silurian-Devonian Hanson Creek Formation;</u> Grey-black dolomite with quartz veining.</p>		
2. Igneous Rocks:	Andesite flows. Intrusive quartz porphyry dyke in Maggie Creek. Believed to be Juro-Cretaceous in age, altered and Au+As mineralised.		

Silicification; multiple events with multi-episodic veining and brecciation throughout mineralisation. Quartz found as (a) replacement of fine grained matrix, (b) overgrowths of detrital quartz, (c) veinlets, <1mm wide, (d) veins, (e) subrounded fragments in hydrothermal breccia, (f) replacement of barite in hydrothermal breccia

matrix (g) late stage supergene, fibrous chalcedonic quartz in breccia matrix.

Quartz veins paragenesis; 1- quartz micro-veinlets → 2- carbon-rich black quartz veinlets & veins → 3- quartz-vein microbreccia → 4- quartz-alunite veins → 5- quartz-barite veinlets & veins → 6- vuggy quartz veins → 7- milky-white quartz veins and fracture filling. All vein stages contain some Au, stages 2, 3, 4 & 5 are main stage Au deposition. Structural jasperoids in the upper Main deposit and bedding jasperoids in the Deep West deposit

Alunitization; controversy whether alunite is supergene and/or hypogene; Rota (pers. comm) found alunite in Deep, unoxidised orebody, it is not replaced by any other mineral and is believed to be the waning phase of hydrothermal activity. Archart (1992) based on O, H, S isotope studies believes alunite in Main orebody is supergene.

Argillisation; accompanies alunite in late stage hydrothermal phase, kaolinite associated with alunite, kaolinite & illite corrode quartz grains. Sericite along vein margins with pyrite, vein and breccia filling, in quartz veins with kaolinite, QSP alteration thought to pre-date Au mineralisation.

Baritization; Barite throughout deposit, Ba transport occurred in reducing conditions in absence of sulphate.

Oxidation; hydrothermally related, extensive along main feeders, hematite abundant (unstable below 55°C).

Supergene oxidation; acid sulphate system. Ore Controls: Primary Control; Structure along NW and NE structures and the intersection of these structures. Intersection of high angle and low angle structures. Secondary high angle structures related to the volume loss and formation of collapse breccias in deeper carbonate lithologies. this lead to increased permeability in upper siliciclastic rocks. NE trending anticline, main orebody trends NE, local high grade zones trend NW.

Secondary control; lithology (1) silty carbonates susceptible to decalcification, (2) impermeable siliciclastic cap rocks creating ponding.

7. Ore/Gangue Mineralogy:

Au associated with pyrite & minor marcasite Arsenopyrite, stibnite, stibiconite - hydrothermal suite.

Pre-mineral suite; galena, sphalerite, cerussite, bindheimite, monimolite, plumbogummitite, mimetite, malachite.

Quartz, alunite, Fe-oxide, barite, illite, kaolinite, carbon, pyrite, calcite.

8. Sulphide paragenesis:

n.d. a. Inferred - Base metals sulphides → pyrite + marcasite.

9. Geochemistry:

As best correlates with Au.

As, Sb, Hg elevated but generally confined to structures.

Major trace elements: Ag, Pb, Zn, Cu, widespread but associated with structures, no correlation with Au, these major trace elements are higher than at Carlin Mine;

Minor Trace elements, Mo, W, V, Se, Cd.

10. Fluid Inclusion:

12. Isotope:

Rota, 1991 & 1993.

13. Source:

Rota and Hauscn, 1991.

A. Deposit: **RAIN** (only producing mine),
EMIGRANT SPRINGS,
GNOME, (too deep, uneconomic),
SNOW PEAK, (too narrow, large strip ratios)

SOUTHERN MINERALISED ZONE (SMZ) (to be mined late 1994),

B: Tonnage/Grade: Rain - 35.1 Mt @ 1.5 g/t.
Emigrant Springs - 27 Mt @ 0.72 g/t.
SMZ - 1.44 Mt @ 0.65 g/t.
Gnome - 2.4 Mt @ 1.6 g/t.
Snow Peak - 3.6 Mt @ 0.69 g/t.

C. Shape/Dimensions: Rain - 1 524 m * 183 m * 30 - 91 m,
Emigrant Springs - 3 000 m * 610 m * 15 m,
SMZ - 183 m * 122 m * 30 m,
Gnome - 244 m * 152 m * 30 m.

D. Deposit Attributes:

1. Stratigraphy/Host Rocks:

Permian Diamond Peak Formation; quartz-pebble - quartz-chert conglomerate.
Unconformity.
Mississippian - Chainman Formation; Coarsen upwards from siltstone - sandstone to sandstone - quartzite - conglomerates.
Transitional contact.
Mississippian - Kinderhookian Webb Fm:
HOST Au mineralisation,
Weakly calcareous mudstones grading upwards into siltstone, sandstone and quartzites.
Unconformity.
Devonian Devils Gate Formation;
Medium bedded micritic limestone.
Conformable contact.

Devonian Telegraph Formation; medium bedded dolomite.

Ordovician Woodruff Formation; interbedded cherts, shale quartzites.

Note; no transitional lithologies of mixed carbonate and siliclastic as seen at Gold Quarry to the north.

2. Igneous Rocks:

Argillised quartz porphyry dyke at Emigrant Springs and a quartz latite dyke at immigrant Rain.

Both pre mineral dykes.

Nearby Bullion granodiorite stock (36 Ma, Smith and Kctner, 1975).

3. Age of Mineralisation.

n.d. Favoured age 36 - 38 Ma based on age of Bullion stock and time of crustal extension.

4. Structure:

Two important features are Palaeozoic carbonate windows thought to be stable buttresses and major bounding high angle faults which served as

feeders.

Emigrant Springs window is a broad dome with N-S axis.

Rain window a NE trending dome.

High angle faults NE and NW the most dominant + WNW, NNW and E-W striking faults. Most high angle faults have significant horizontal displacement. Faults acted as conduits for hydrothermal fluids.

5. Alteration:

5 types in decreasing abundance; Silicification → argillisation → baritisation → dolomitisation → decalcification.

Paragenesis; decalcification → dolomitisation → silicification → baritisation → argillisation

Decalcification; dominant high grade alteration in the Main orebody at Rain

Silicification; most pervasive, superimposed on mudstone, siltstone & sandstone as quartz overgrowths, replacement of carbonate in lower Webb Formation. Au deposition is nearly always associated with weak to pervasive silicification. Quartz veining common, microscopic to 1 cm widths, vuggy quartz veins, milky quartz veins, quartz-barite veins, quartz vein microbreccia.

Argillisation; Penetrates several cm's into silicified rocks, strongly developed in fault zones.

Baritisation; developed throughout district but concentrated near faults, isotope evidence indicates hypogene origin.

Dolomitisation; common in Devils Gate limestone adjacent to faults, calcite veining is ubiquitous, sandy texture.

Supergene alteration; alunite dates between 18 & 22 Ma, strong acid leaching, argillic alteration characterised by alunite, kaolinite and halloysite, best developed along NW & NE striking faults. Acidic fluids percolated downwards until reaching unconformity between Webb & Devils Gate Formations, limestone of Devil Gate buffered acidic solutions forming a 3 m to 9 m thick clay zone at unconformity. Basal clay enriched in As (0.4%), Hg (5.6%), Co (122 ppm), Cu (54 ppm), Fe (6%), Mn (5%), Ni (877 ppm), Zn (0.45%)

6. Ore Controls:

Structurally controlled by high angle faults especially at intersections, intersection of high angle and low angle faults, intersection of high angle faults and reactive lithologies of lower Webb Formation just above unconformity. Unconformity is a horizontal stratigraphic control. At Rain high grade at intersection of NE and NW striking faults

immediately above unconformity in the hangingwall.

7. Ore/Gangue Mineralogy:

pyrite, marcasite, sphalerite, arsenopyrite, disulfide, realgar, orpiment, cinnabar. Quartz, barite, calcite, F-oxides.

8. Sulphide paragenesis:

n.d.

9. Geochemistry:

Elevated As, Sb, Hg, Tl.

Au:Ag ratio > 10:1.

As best pathfinder, average @ Rain 805 ppm, 500 ppm As contour = 0.34 ppm Au.

Sb average @ Rain 123 ppm Sb contour = 0.34 ppm Au.

Hg average @ Rain 63 ppm, Hg 7 ppm contour = 0.34 Au contour.

Tl average @ Rain = 12 ppm.

10. Ore Types at Rain:

Siliceous, quartz > 40%, barite <30%,

Siliceous/baritic, 30 to 40% barite,

Baritic, > 40% barite,

Carbonaceous, high organic content. > 0.5% pyrite,

Argillaceous, clay content > 40%,

Calcareous, predominantly carbonates, calcite.

11. Genetic model at Rain:

By Williams in Jory, 1992.

Stage 1; Right lateral movement on Rain fault, stable carbonate buttress, Rain fault conduit for hydrothermal solutions, passive silicification, biotite, quartz, arsenian pyrite, sphalerite.

Stage 2. Boiling @ 290°C, hydrothermal brecciation, multiple boiling and brecciation events, stage 1 veins, quartz, arsenian pyrite, sphalerite, Au, calcite, barite.

Stage 3. Boiling focussed in conduits forming pipe-like accretionary lapilli crosscutting hydrothermal breccia.
Stage 4. Post mineral faulting.
Stage 5. Supergene leaching/collapse breccia formation.

12. Fluid Inclusions:

13. Isotope:

14. Source: Jory, 1992.

A. Deposit:	SOUTH BULLION		
B. Tonnage/Grade:	18.14 Mt @ 0.89 g/t.		
C. Shape/Dimension:	Elongate NW trend. 1435 m * 586 m * +/- 20 m.	5. Alteration:	Decalcification; Forms a halo around silicified orebody, 6 to 10 m thick zone above orebody, has numerous cross-cutting calcite veinlets. Silicification; Au mineralisation is hosted in jasperoids that are developed just above the unconformity between Devils Gate and Webb Formations. Jasperoids are stratabound within the anticline, strongly brecciated, varying amounts of hydrothermal barite, stibnite, pyrite, hematite and calcite. Barite content increases with increasing jasperoid thickness as does Au. Silicification resulted in replacement of carbonate, development of quartz overgrowths, in filling fractures and vugs, pervasive flooding along zones of secondary porosity and permeability. Silicified fault breccias in Chainman shales. Argillization; Weak, dispersed hydrothermal clays, "not thought to be related to Au hydrothermal event".
D. Deposit Attributes:			
1. Stratigraphy//Host Rocks:	Mississippian Chainman Formation; "Flysh" and turbidite sequences typical, interbedded sandstone, siltstone and shale, upward coarsening. HOSTS minor structurally controlled mineralisation. Contact transitional to abrupt. Mississippian Webb Formation; Thin bedded carbonaceous siltstone, siliceous and calcareous mudstone, calcareous mudstone dominant towards the base of sequence. Debris flow breccias common towards base of sequence. Major HOST to mineralisation at unconformity. Unconformity - Paleokarst surface. Devonian Devil Gate Formation; Dominantly thick bedded massive limestone, minor thin sandy limestone beds.	6. Ore Controls:	complex structural history N20°W faults (1) 10° - 30° dips, (2) 50° - 90° dips, both dip sets have oblique to strike slip and dip slip movement,
2. Igneous Rocks:	Weakly altered rhyolite dykes and sills with disseminated fine grained pyrite and marcasite.		Structural control along high and low angle NNW, N to NNW and N-S faults. The intersection with basal calcareous shales of Webb Formation. Lateral spread just above unconformity. Lithological controls - decalcification - increased porosity and permeability - primary porosity + permeability in debris flow breccias.
3. Age of mineralisation:	n.d. Thought to be mid-Tertiary.		
4. Structure:	Most dominant feature N to NNW anticline, plunges to SSE @ 30°. High angle faults; N70°W - reverse; brecciated baritic jasperoid, one of several conduits, N-S reverse faults with	7. Ore/Gangue Mineralogy:	Pyrite, marcasite, quartz, barite, stibnite, calcite, hematite.

8. Sulphide Paragenesis: n.d.
9. Mineralisation: Gold accompanied pervasive silicification. Silicification stratabound. Minor Au mineralisation in silicified high angle faults in hangingwall Chainman Shales.
10. Geochemistry: As - maximum - 2 600ppm,
Hg - maximum - 7 ppm,
Ag - maximum - 49 ppm,
Sb - maximum - 1190 ppm,
Tl - maximum - 14 ppm,
Mo - maximum - 17 ppm.
An enriched 2 to 7 m zone of As, Sb & Hg between unsilicified calcareous rocks and mineralised jaspicoid.
11. Fluid Inclusion:
12. Isotope:
13. Source: Putman and Henriques, 1991.

A. Deposit:	VANTAGE I, II & III (also known as Alligator Ridge)	3. Age of Mineralisation:	Based on "hypogene" alunite 11.5 ± 0.7 Ma (Ilchik, 1990).
B. Tonnage/Grade:	5.8 Mt @ 4.9 g/t.	4. Structure:	Main structural feature the N to NE striking Vantage normal fault, a 20 to 30 m wide structural zone, feeder fault. Broad anticline parallel to the Vantage fault. NE striking, south dipping normal faults. Numerous breccias associated with faults.
C. Shape/Dimensions:	Vantage I and III are nearly circular in plan 120 to 150 m in diameter and up to 75 m thick. Vantage II is 120 m by 270 m in plan, elongated in a NW direction. All orebodies have a flat bottom.	5. Alteration:	Three events; (1) decalcification and silicification, (2) hypogene oxidation and (3) supergene oxidation. Decalcification: removal of calcite from lower Pilot shale and Devils Gate Limestone, contact between calcareous and noncalcareous siltstone is sharp as is Au grade. Numerous hydrothermal calcite veins peripheral to the deposit. Silicification: Underlying Devils Gate Limestone and fault zones are pervasively silicified forming jasperoids (>95 wt % quartz), Pilot shale passively silicified, (30-65 wt % illite, 5-10 wt % kaolinite, 25-60% wt % quartz, 5 wt % pyrite, 1-5 wt % organic hydrocarbon, <5 wt % calcite). Silicification occurs throughout the ore zone in the Pilot Shale. Veins of euhedral quartz, kaolinite and stibnite accompany silicification. Dickite in some veins. Hypogene oxidation: confined to the orebody, complete destruction of sulphides and organic matter, accompanied by alunite and/or barite veins, hematite lines fractures in places. Supergene oxidation, mimicks, and is up to 30 m below, erosional surface, locally deeper along fractures. Abundant goethite and jarosite.
D. Deposit Attributes:			
1. Stratigraphy/Host:	Mississippian Chainman Shale; lower thin bedded carbonaceous limestone and upper pyritic carbonaceous mudstone. Mississippian Joanna Limestone; thin to medium bedded bioclastic limestone and chert. Minor disconformable contact. Mississippian - Devonian Pilot Shale; thinly laminated calcareous siltstone divided into, Upper, siltstone that as up to 55% calcite, Middle six meter thick chert band, Lower laminated, calcareous and carbonaceous siltstone, Siltstone composition, 30-45 wt % dolomite, 35-50 wt % illite, 14 wt % detrital quartz, 5 wt % pyrite, 1.5 wt % organic matter, 0-3 wt % kaolinite. HOSTS mineralisation. Conformable contact. Devonian Devils Gate Formation; comprised of lower dolostone and upper limestone. Devonian Nevada Formation; medium grey saccharoidal dolomite.		
2. Igneous Rocks:	n.d.		

6. Ore Controls: High angle Vantage Fault Zone acted as feeder. Au- bearing hydrothermal fluids spread laterally at Devils Gate Limestone - Pilot Shale contact, altering both but mineralising Pilot Shale only. Local controls, fault and bedding intersections - fracture intersections.

7. Ore/Gangue Intersections: Pyrite, arsenian pyrite, stibnite, orpiment, realgar. Quartz, kaolinite, barite, dickite, hematite, alunite.

8. Sulphide paragenesis: n.d.

9. Mineralisation: Mineralisation accompanies decalcification silicification. Minor low grade mineralisation associated with jasperoids. Most of Au mineralisation hosted in the Pilot Shale.

10. Geochemistry: Au:Ag ratio 1:1 - carbonaceous, unoxidised ore.
 Au:Ag ratio 5:1 - oxidised ore.
 Au:Ag ratio 9:1 - oxidised ore (Klessig, 1994)
 Elevated As, Ag and Sb.
 As < 5 000 ppm,
 Sb < 700 ppm.
 Hg < 0.1 ppm.

11. Fluid Inclusion: **Calcite Veins;**
 Homogenisation Temperature 205 to 230°C,
 average 215°C.
 Salinity, < 1 wt percent.

12. Isotope:

Rock Type/Alteration	$\delta^{18}\text{O}$ (per mil)	$\delta^{13}\text{C}$ (per mil)	$\delta^{34}\text{S}$ (per mil)
Unaltered Pilot shale	+24.4	-1.3	
Unaltered Devils Gate Limestone	+23.7	+0.7	
Devils Gate Jasperoid	+15.9 - +18.2		
Joanna Limestone Jasperoids	+15.6 - +20.2		
Chainman Shale Jasperoid	+17.7 - +23.2		
Vein quartz	+16.1 - +20.1		
Background unaltered rock, whole-rock			+0.8 (syn- genetic pyrite)
Altered whole-rock average			< +11
Stibnite			+5.5 - +10
Orpiment			+2.5 - +12.3
Barite (disseminated)			+25.9 - +47.1 Most samples >+35
Barite (vein)			+21.0 - +29.2
Alunite			+3.8 - +13.4

13. Source: Ilchik, 1990.
 Ilchik, 1986.

APPENDIX B

Characteristics of Sediment-Hosted, Disseminated Gold Deposits
along the Battle Mountain - Eureka Trend.

Deposit	Page No.
Lone Tree	1
Hilltop	3
Gold Acres	5
Cortez	7
Horse Canyon	8
Tonkin Springs	9
Gold Bar	11
Ratto Canyon	13
Nighthawk Ridge	14

A. Deposit:	LONE TREE GOLD DEPOSIT	3. Age of Mineralisation:	< 38 Ma. Post dates skarn mineralisation.
B. Tonnage/Grade:	47, 638 Mt @ 2.1 g/t. Oxide Ore Heap Leach; 8.975Mt @ 3.5 g/t Refractory Ore; (1) Sulphide Mill ore 8.355 Mt @ 5.3 g/t (2) Run-of -mine reserves 30.307 Mt @ g/t.	4. Structure:	Paleozoic Antler thrusting in Vinini Formation. Sonoma Orogeny thrusting in Havallah Sequence. Main structural feature is N-S trending Waynes Fault Zone, comprised of numerous anastomosing N-S, NW and to a lesser extent NE brittle fault. Thought to be a large strike slip fault with late dip slip component. Minor east-west structures. WNW striking faults. All structures have multiple episodes of movement. Most mineralisation hosted in N-S striking faults 3 to 30 m wide (Powerline fault), local higher grade at intersection with NE & NW striking faults & at dilational jogs and bends within N-S fault. Mineralisation along NE & NW faults narrow.
C. Shape/Dimensions:	Strikes N-S 1250 m * 50 - 120 m * open.		
D. Deposit Attributes:	<u>Pennsylvanian-Permian Havallah Sequence;</u> Deep water oceanic sequence of chert, basalt grading up through shale, mudstone, calcareous sandstone, sandy limestone; structurally deformed by abundant low angle faults of Sonoma Orogeny Age? <u>Pennsylvanian Antler Overlap Sequence;</u> autochthonous sequence, basal 1 -6 m conglomerate overlain by coarse lithic arenite and siltstone and sandstone; structurally not disturbed. <u>Ordovician Valmy Formation;</u> Interbedded quartzites, chert, minor basalts, argillites. N-S, east verging folds; Bedding N-S/30-70W.	5. Alteration:	Intense pre-mineral skarn alteration. Pb, Zn outer zone → Cu + Zn inner zone → 36-40 Ma porphyry crops out south of deposit. <u>Silicification (1):</u> Pre-mineral silicification in sandy limestone and faults, sealed faults. Renewed faulting resulted in brittle failure of silica sealed faults increasing permeability. <u>Silicification (2):</u> vein filling and matrix alteration. <u>Potassic alteration:</u> Syn- to post silicification <u>Argillic alteration:</u> Upper Lone Tree deposit argillic alteration confined to fractures and faults
1. Stratigraphy/Host Rocks:	Tertiary feldspar porphyry dykes intruded along NW & N structures. K/Ar 36 - 39 Ma (Biotite & amphibole). Similar to age of intrusive responsible for the Fortitude Cu-skarn deposit to south (Theodore & Hammerstrom, 1991) .		
2. Igneous Rocks:			

	Minerals quartz, kaolinite, dickite, jarosite, alunite. Jarosite replaces kaolinite. Alunite (sulphur isotope data; $\delta^{34}\text{S} = +2.4$ per mill) is of supergene variety. Paragenesis: Skarn alteration → pre- mineral silicification → silicification + late syn potassic alteration → potassic alteration → argillisation.	Se ranges from 15 to 75 ppm. Ba depleted .
6. Ore Control:	Structural preparation. Complex and repeated movement along N-S faults and to a lesser extent NW, NE and E-W striking faults. Pre- mineral silicification sealed N-S faults and subsequent brittle failure increased permeability.	
7. Ore/Gangue Mineralogy:	Skarn minerals; clinopyroxene, K-feldspar, actinolite, sphene, clinozoisite. Ore: galena, sphalerite, chalcopyrite, pyrite, arsenopyrite, Cd-Co-Ni-rich pyrite. Silicification (1); massive silica flooding, Ore; galena-sphalerite. Silicification (2) + Potassic alteration; quartz, adularia, sericite, calcite, pyrite, rutile gold bearing pyrite arsenopyrite.	
8. Sulphide paragenesis:	n.d.	
9. Mineralisation:		
10. Geochemistry:	Pre-Au mineralisation event of base metal mineralisation ppt Pb-Zn & Cu-Zn. As correlates best with Au, ranges from 1350 to 7130 ppm. As principle component in Au-hydrothermal fluid. As highs at fault intersections. Sb moderately anomalous, 37 to 131 ppm. Hg ranges from 0.3 - 10 ppm. Hg poor system.	
	11. Fluid Inclusions:	n.d.
	12. Isotope:	
	13. Source:	Bloomstein et. al., 1993.

A. Deposit:	HILLTOP MINE		Discordant Breccia: located in hangingwall to Hilltop Fault, located along N-S trending faults parallel to steep limbs of Antler Orogeny age isoclinal fold, angular to subangular fragments, fragments comprised of chert, shale, breccia dyke material.
B. Tonnage/Grade:	5.23 Mt. @ 2.7 g/t		Fragments of discordant breccia occur in concordant breccia N-S normal faults
C. Shape/DimensionsL*B*T:	488 m * ? m * 2-59 m.		
D. Deposit Attributes:			
1. Stratigraphy/Host Rock:	Ordovician Valmy Formation; predominantly chert interbedded with noncalcareous shale, quartzite, greenstone, minor limestone.	5. Alteration:	Silicification; 1 ST Phase - chalcedonic quartz + quartz veining with minor sulphides. 2 ND Phase - coarsely crystalline quartz with abundant sulphides. Quartz veins (N-S/steep dip to W), 2.5 cm to 30 cm thick, cockscomb texture.
2. Igneous Rocks:	HOST. Oligocene (33-35 My?) rhyolite plugs and dykes that cut dacite porphyry. Breccia dykes with shale, chert and dacite porphyry fragments. Eocene (38.1 My?) dykes, sills and plugs of dacite porphyry.	6. Ore Control:	Structural ore control along low and to a lesser extent high angle faults. Grade and ore thickness increase at structural intersections.
3. Age of Mineralisation:	<38.1 My.	7. Ore/Gangue Mineralogy:	Pyrite, chalcopyrite, galena, tetrahedrite, Au, minor barite + rare fluorite occurs with quartz. Barite concentrated near the top of deposit. Sulphides increase with increasing quartz crystal size. Sulphides intergrown with coarsely crystalline quartz.
4. Structure:	Compressive Antler Orogeny (RMT) Hilltop Fault (N-S/20°-30°W), varies from a fault plane to gouge zone 15 m thick. Slickenlines indicate normal movement. Concordant breccia in hanging wall to Hilltop fault. Saddle Fault (W-E/90°), north of saddle fault only hanging wall lithologies to the Hilltop Fault altered whereas south of Saddle Fault both hanging and footwall lithologies to the Hilltop Fault are altered. Concordant Breccia; limited to hangingwall of Hilltop Fault, 2-59 m thick, fragment to matrix supported, fragments comprised of shale, chert, dacite porphyry.	8. Sulphide paragenesis:	Pyrite pseudomorphing? marcasite → chalcopyrite → sphalerite → galena → tetrahedrite. Au paragenesis not determined.
		9. Mineralisation:	Three distinct and overlapping events. 1 ST Event; Quartz, carbonaceous matter, pyrite, arsenopyrite, tennantite/ tetrahedrite-Au (arsenic rich) phase that constitutes the majority of the

ore, coats and fills fractures, replaces breccia matrix, pyrite-arsenopyrite veinlets.
Paragenesis; pyrite after marcasite + arsenopyrite + barite + alunite → tennantite + tetrahedrite → drusy quartz → orpiment[±] - realgar.
Au micron to submicron inclusions in sulphides.
2ND Phase; Chalcedonic quartz, euhedral barite + stibnite + Au & Ag form matrix of breccia. Barite and stibnite veinlets.
3RD Phase; Marcasite, pyrite, barite cement breccia and contains fragments of the first two mineralisation phases. Coarsely crystalline pyrite and vugs lined with barite.

10. Geochemistry: n.d
11. Fluid Inclusion: NaCl = 5.4 - 7.3%. Homogenisation Temperature = 160 - 185
12. Isotope: n.d.
13. Source: Lisle et. al., 1988.

A. Deposit:	GOLD ACRES MINE	4. Structure:	RMT N30°W/20°-30°SW, imbricate sole thrust parallel to RMT, orebody lies within the imbricate thrust. NE high angle faults 30 m throws smaller NE faults within the ore body, throws 1 - 6 m N-S faults local control on ore distribution.
B. Tonnage/ Grade:	1.99 Mt. @ 3.67 g/t		
C. Shape/ Dimensions (m):	n.d		
D. Deposit Attributes:			
1. Stratigraphy/Host:	<p><u>Devonian Slaven Chert</u>; thick bedded chert <u>Devonian Wenban Formation</u>; medium to thick bedded silty to crystalline limestone. Tectonically interleaved with lenses of Ordovician Valmy Formations. Transitional contact. <u>Devonian-Silurian Roberts Mountains Formation</u>; dark grey, carbonaceous, thin to medium bedded finely laminated calcareous silty limestone. Major HOST <u>Ordovician Valmy Formation</u>; thin to medium bedded, interbedded, quartzite, sandstone, shale,, siltstone, greenstone +/- limestone. Thick sequences of siltstone & sandstone horizons do not host mineralisation. Fossil evidence suggest that what is believed to be the Valmy Formation is actually Devonian in age.</p>	5. Alteration:	<p><u>Decalcification</u> - in carbonate lithologies of Srm, minor in Dw and limestones of the Ov, increase permeability. <u>Carbonisation</u> - dominant alteration type both in lower & upper plate lithologies. Sooty mature carbon concentrated along fractures & bedding planes, significant carbon and up to 3% pyrite associated with carbonisation. <u>Silicification</u> - in both upper & lower plate lithologies, peripheral to Au zone in upper plate rocks, wanes from N to S. <u>Argillisation</u> - Confined to Srm and to fractures, illite the dominant clay. Skarn - two skarns associated with intrusive, replace Dw and Srm.</p>
2. Igneous Rocks:	Tertiary (<66 My) quartz porphyry dykes intruding along high angle normal faults. Quartz monzonite stock 120 - 180 m below deposit. K/Ar 98.8 +/- 2 My (Bt), 1% pyrite + biotite No Au mineralisation in stock.	6. Ore Control:	Structural ore control by older imbricate thrusts and younger high angle faults. Permeable interbedded silty limestones. Upper skarn acted as impermeable cap to hydrothermal fluids. High angle faults acted as conduits to porphyry and hydrothermal fluids which spread laterally into thrust fault and permeable lithologies.
3. Age of Mineralisation:	Mid Cretaceous? < 66 Ma.	7. Ore/Gangue Mineralogy:	Skarn - chlorite, tremolite, epidote, calcite, quartz, illite, nontronite, smithsonite, pyrite,

- pyrrhotite, chalcocite, sphalerite, arsenopyrite, galena.
 Upper skarn - Pb-Zn+/-Cu,
 Lower Skarn - Cu-Mo.
 Hydrothermal suite - pyrite/calcite, quartz, melanterite, azurite, jarosite, realgar
 Base metal suite → pyrite + quartz
 veins → calcite veins.
8. Sulphide paragenesis:
9. Mineralisation: Earlier base metal mineralisation associated with Mesozoic intrusive and skarn development.
 Later hydrothermal Au mineralisation event.
10. Geochemistry: Base metal suite; Ag, Cu, Pb, Zn & Mo.
 Hydrothermal suite; Au, As, Sb, Hg, Tl, SO₄, S²⁻, organic C. Au correlates best with Tl. No correlation with base metals and Au.
 Heat for skarn formation >500 C, at this temperature Tl and Hg would be driven off, therefore hydrothermal event later than porphyry mineralisation.
11. Fluid Inclusion: Quartz veins - Homogenisation Temp = 150 - 185C
12. Isotope: n.d.
13. Source: Hays et. al., 1991.
 Cartwright, 1985.

A. Deposit:	CORTEZ GOLD MINE		Silicification - weak to pervasive jasperoids, mineralisation hosted in weak to moderate silicification
B. Tonnage/Grade:	3.2 Mt. @ 9.8 g/t		Argillic - argillisation of felsic porphyry dykes to montmorillonite.
C. Shape/Dimension:	Irregular to tabular, NW strike.		
D. Deposit Attributes:		6. Ore Control:	Structural ore control by both high and low angle faults. Structural and lithological contact between Dw & Srm acted as an impermeable cap. Mineralisation in hinge of large scale antiform. High angle faults feeders and low angle faults and permeable lithologies lateral migration of Au bearing hydrothermal fluids.
1. Stratigraphy/Host:	Devonian Wenban Formation; thick bedded limestones, minor ore host Silurian Roberts Mountain Formation; thin to medium bedded, finely laminated calcareous, moderately to strongly carbonaceous silty limestone. HOSTS mineralisation.	7. Ore/Gangue Mineralogy:	Pyrite, native Au, As-, Au-, Sb-, Hg-bearing pyrite. Quartz, calcite minor barite
2. Igneous Rocks:	Pliocene (10-16 My) basaltic andesites and rhyolite flows Oligocene (34 My) Caetano rhyolite tuff and felsic quartz porphyry dykes, sills that crosscut mineralisation and structures Jurassic Mill quartz monzonite stock K/Ar 150 +/- 3 My (Bt).	8. Sulphide paragenesis:	n.d.
3. Age of Mineralisation:	150 My > mineralisation < 34 My.	9. Mineralisation:	Au mineralisation accompanying silicification.
4. Structure:	NW30 - 40 SW oriented high angle normal faults, conduits to mineralising fluids, E-W high angle faults. Contact between Dw and Srm structural (pers. comms Placer Dome geologists, 1992). Minor low angle faults. Large NW striking anticline. Abundant minor folds.	10. Geochemistry:	Elevated, As, Sb, Hg, Tl, W, Ag.
5. Alteration:	Decalcification - removal of calcite in silty limestone, increased permeability.	11. Fluid Inclusion:	
		12. Isotope:	n.d.
		13. Source:	Erikson, 1985.
		14. Remarks:	Old Ag-Pb-Zn vein hosted mineralisation.

A. Deposit:	HORSE CANYON MINE		sedimentary structures preserved, multiple brecciation events and resilicification. Silicification pre- and post ore.
B. Tonnage/grade:	2.99 Mt @ 4 .91 Mt		<u>Argillisation</u> ; best developed along fault zones. Illite the dominant clay, localised kaolinitic pods developed along structures.
C. Shape/Dimension:	Strikes NW, irregular tabular body.		<u>Carbonisation</u> ; sooty organic carbon concentrated along fractures, bedding planes and in fold hinges.
D. Deposit Attributes:			
1. Stratigraphy/Host:	<u>Devonian Wenban Formation.</u> Thin - medium bedded limestone, weak to moderately carbonaceous, calcite veins and euhedral pyrite throughout. HOSTS mineralisation in North Pit. <u>Ordovician Valmy Formation</u> ; Thin bedded cherty siltstone and shaly interbeds shale + thin to medium bedded laminated argillaceous, very carbonaceous silstone. HOSTS mineralisation in South Pit.		6. Preparation: Ore best developed at intersection of high angle NNW striking faults and permeable lithologies (Dw) and/or structurally prepared lithologies (Ov) adjacent to RMT. In siliciclastic Ov localised ore in hinges of fold axis due to increased permeability. Higher grades and more oxidised ore at intersection of E-W to ENE and NNW striking faults.
2. Igneous Rocks:	Altered and mineralised Oligocene felsic dykes.		7. Ore/Gangue Mineralogy: Epigenic fine grained pyrite/calcite, quartz, crystalline jarosite, hematite, rare barite, alunite.
3. Age of Mineralisation:	Syn- post Oligocene (<36 My).		8. Sulphide paragenesis: n.d.
4. Structure:	Roberts Mountains Thrust, NW strike. Large and small overturned recumbant folds, RMT has been recumbantly folded. Recumbant fold axis strikes N-S, axial plane overturned to the east. High angle normal faults; NNW to N-S → E-W → NW (post mineralisation). NNW dominant and were main conduits to hydrothermal fluids.		9. Mineralisation: Au mineralisation accompanying silicification, Au within epigenic pyrite, disseminated and within quartz veins.
5. Alteration:	<u>Decalcification</u> ; preferential in silty limestones, very poorly developed in indurated limestones. <u>Silicification</u> ; structurally controlled brecciated jasperoids in high angle faults, stratiform in Ov and Dw, better developed in the latter,		10. Geochemistry: Elevated As, Sb, Hg & Tl, Au & Tl have the best correlation.
			11. Fluid Inclusion: n.d.
			12. Isotope: n.d.
			13. Source: Foo et. al., 1987.

A. Deposit:	TONKIN SPRINGS	5. Alteration:	Decalcification: Restricted to Nevada Fm limestones and the silty carbonates in the Ov; increasing permeability. Silicification: varies from weak to pervasive (jasperoids in the Nevada Fm limestones and Ov silty limestone beds); drusy quartz lining open voids, quartz veining. Carbonisation: Sooty carbon lining fractures. Argillisation: minor - restricted to fractures and fault planes. Paragenesis: decalcification → silicification jasperoid development → silicification, silica veinlets with sulphide and Au → calcification with realgar, cinnabar and barite → microfracturing, carbonisation (Hardisty, 1983).
B. Tonnage/Grade:	n.d.	6. Ore Control:	Predominantly structural ore control. At intersection of NW & NE structures and at intersection of high angle structures with thrust and low angle structures and permeable lithologies.
C. Shape/Dimensions:	Regional N to NNW strike,, local N to NNE strike.	7. Ore/Gangue Mineralogy:	Pyrite. Realgar, cinnabar, barite, calcite, organic carbon.
D. Deposit Attributes:		8. Sulphide Paragenesis:	n.d.
1. Stratigraphy/host:	<u>Ordovician Valmy Formation:</u> Coils Member - pure quartzite, shale, siltstone, laminated shaley limestone. Rooster Member - interbedded shales, cherts, argillites, siltstones and laminated silty limestone, capped by Nevada Formation limestones that form jasperoids, structural contact (RMT). Host most of Au mineralisation. Telephone Member - Upper black, calcareous, carbon shales interbedded with thin slabby limestones; Lower thin to medium bedded sandy to silty carbonates.	9. Mineralisation:	Au mineralisation accompany the quartz veining and pyrite.
2. Igneous Rocks:	Oligocene basaltic andesites. Late Eocene - early Oligocene rhyolite welded and waterlain tuffs. Late Mesozoic - early Tertiary (?) porphyritic, propylitized intermediated dykes and sills. Most of ore mined has been adjacent to intrusive bodies.	10. Geochemistry:	Elevated As , Hg, Sb, Ba, Tl. Au:Ag ratio = 1:2.
3. Age of mineralisation:	≤ 66 My (?).		
4. Structure:	Roberts Mountains Thrust, Numerous smaller low angle faults and thrust within deposits. High angle structures; N to NW → N-S → NE → E-W.		

Au:Ag ratio = 1:2.

11. Fluid Inclusion:

n.d.

12. Isotope:

n.d.

13. Source:

Gesick, 1987.
Hardisty, 1983.

A. Deposit:	GOLD BAR MINE	5. Alteration.	Decalcification/sanding; calcite and carbon removal → increased permeability.
B. Tonnage/Grade:	4.36 Mt @ 2.87 g/t.		Silicification; jasperoids and quartz veining, jasperoids developed in NW striking feeder fault and at base of deposit between impermeable massive limestones & interbedded limestones and siltstones, jasperoids commonly brecciated, clast supported, monolithic. Matrix and vugs composed of drusy quartz. Most alteration migrated up dip of feeder structure.
C. Shape/ Dimension:	NW striking ore body, roughly tabular. 910 m * 60 - 120 m * 15 - 76 m.		Carbonisation; black sooty carbonaceous material lines fractures, greatest along feeder fault.
D. Deposit Attributes:			Carbonate; Calcite veining peripheral to silicification.
1. Stratigraphy/Host:	<u>Tertiary Tuffaceous Agglomerates.</u> Unconformity. <u>Devonian Nevada Formation;</u> <u>Devonian Denay Limestone;</u> Upper- thick to medium bedded limestone with local layers of silty limestone. Middle- a 115 m thick thin bedded intercalated limestone, calcareous siltstone and finely laminated mudstone, HOST mineralisation. Lower- basal medium to thick bedded fossiliferous limestone with trace amounts of chert and cherty limestone.		Argillisation; Rare, Illite → montmorillonite + allophane, confined to fractures.
2. Igneous Rocks:	Rhyolite tuffaceous agglomerate (23.8 Ma) Volcanics are altered and mineralised.	6. Ore Control:	Structural ore control along NW striking faults and at intersections of NW and NE striking faults. Lithological ore control increased permeability in silty limestone due to decalcification.
3. Age of mineralisation:	24 Ma or younger.	7. Ore/Gangue Mineralogy:	See 9.
4. Structure:	Paleozoic thrusting (RMT). Large open NW striking anticline in carbonate lithologies; siliciclastic lithologies isoclinally folded. High angle fault paragenesis E-W → N to NW → NE → N-S; NW and N-S faults the dominant set. Bedding NW/15 -30 NE.	8. Sulphide paragenesis:	n.d.
		9. Mineralisation:	Three types of ore: (1) Oxide ore: the major ore type, weak to pervasive decalcification/sanded, calcite, clay, quartz, relict pyrite, hematite pseudomorph after pyrite, limonite, disseminated free Au, trace barite, Mn oxide minerals, stibiconite, Au 1 - 10 microns.

(2) Jasperoid ore: minor ore type, pyrite and calcite line fractures, Au occurs as free gold in quartz veinlets and on fractures.

(3) Carbonaceous ore: Deeper part of orebody, authigenic pyrite, abundant carbon, realgar, orpiment, higher grade 6.1 g/t, Au micron size and occurs as free Au.

Paragenesis; Sanding/decalcification, carbon removal + calcite carbon veining → Calcite removal + introduction of minor pyrite + quartz veining → pyrite and quartz veining + silicification → Au + arsenic mineral precipitation + calcite veining → quartz veining.

10. Geochemistry: Hg largest halo (>1000ppb),
Hg increases above ore body,
As (100 ppm) & Sb (>20 ppm) haloes close to
Au orebody and elevated above ore body.
11. Fluid Inclusion: n.d.
12. Isotope: n.d.
13. Source: Broili et. al., 1988.

A. Deposit:	RATTO CANYON GOLD OCCURRENCE		
B. Tonnage/Grade:	n.d.		
C. Shape/Dimensions:	n.d.		
D. Deposit Attributes:			
1. Stratigraphy/Host:	<p><u>Cambrian Dunderberg Formation;</u> Fissile claystone interbedded with limestone, limestone is medium grey, blue grey. HOST most of mineralisation.</p> <p><u>Cambrian Hamburg Formation;</u> Massive dolomite with irregular lenses of limestone.</p>	6. Ore Control:	<p>brecciated, late stage quartz veining, most of Au hosted in silicified zone and/or in adjacent argillic alteration.</p> <p>Argillisation; restricted to the Dunderberg shale, peripheral to silicification, illite → kaolinite + sericite. Au mineralisation present in argillic alteration but not always.</p>
2. Igneous Rocks:	Eocene intermediate tuffs, flows and minor porphyrotic dykes and sills (36 My).		
3. Age of Mineralisation:	Thought to be related to the Eureka mineralisation.	7. Ore/Gangue Mineralogy:	Structural prepared lithologies along N to NW faults at intersection of NW and NE high angle structures, at intersection of high and low angle structures, at intersection of high angle and permeable lithologies and up dip into anticlines. Contact between Dunderberg shale and Hamburg dolomite. Thrust planes form cap to mineralisation. Carcarous argillaceous sediments.
4. Structure:	<p>E-W compression resulting in N-S striking fold axis and thrust fault + E-W tear faults.</p> <p>N-S compression resulting in broad E-W folds with fold striking E-W. N-S striking fold axes plunge to the north and south.</p> <p>High angle faults; N to NW → E-W → NE.</p> <p>Feeder fault N-S.</p>	8. Sulphide paragenesis:	Au deposited as free gold in quartz veinlets, quartz, realgar, pyrite.
5. Alteration:	<p><u>Sanding/decalcification;</u> confined to dolomites, located in proximity to silicification, calcite matrix removed, minor Au.</p> <p><u>Silicification;</u> concentrated along high angle normal faults and at intersections of high and low angle faults, destroys sedimentary features,</p>	9. Mineralisation:	n.d.
		10. Geochemistry:	Oxide ore; remobilisation and deposition of Fe-oxide on fractures, realgar increases with increasing Au, highest grade in argillic zone adjacent to silicification.
		11. Fluid Inclusions:	Unoxidised ore; Free Au in quartz veinlets.
		12. Isotope:	Positive correlation between Au & As, Hg & Sb form halo around Au zone.
		11. Source:	n.d.
			n.d.
			Steiniger et. al., 1987.

A. Deposit:	NIGHTHAWK RIDGE		Silicification; liesegang banding in Chainman Formation; Jasperoid widespread in Joanna limestone, chalcedonic, matrix supported monolithic breccia, clay + barite cement + line fractures, limonite in upper portions while hematite common in lower silicified zone.
B. Tonnage/Grade:	6.33 Mt @ 0.87 g/t.		Argillisation; 25% of ore body, near main feeder.
C. Shape/Dimensions:	n.d.		Carbonisation; carbonaceous material driven from feeder to peripheries of deposit.
D. Deposit Attributes:	Carboniferous Chainman Formation; Carbonaceous shale interbedded with silty and limey lenses. Host 75% of ore.		Silicification and oxidation emulate the anticline.
1. Stratigraphy/Host Rocks:	Late Devonian - early Carboniferous Joanna Formation. Host 25 % of ore. Upper - light grey, sparry crinoidal, porous, permeable with lenses and nodules of chert, increasing interbeds of silt and shale up through the sequence. Lower - orthoquartzite.	6. Ore Control:	Ore body hosted in anticline. NE fault main conduit. Structural ore control along NE fault and at intersection of NE - WNW faults. Increase permeability in silty and calcareous shales.
2. Igneous Rocks:	No igneous rocks near deposit.	7. Ore/Gangue Mineralogy:	Free Au, pyrite/quartz, limonite, hematite, anatase.
3. Age of mineralisation:	n.d.	8. Sulphide paragenesis:	n.d.
4. Structure:	Open style folding, axis N15E, plunge SW Reverse faults - Strike N 15E, NE/80W major shear zone on west limb of anticline, primary conduit. Ore thickness and grade closest to NE/80W fault and at intersection of NE & WNW-ESE faults, WNW-ESE faults minor but increase structural ore control dramatically.	9. Mineralisation:	Au grain size 1- 5 microns, intergranular + disseminated.
5. Alteration:	Decalcification - in silty limestones and calcareous shales.	10. Geochemistry:	Ag depleted, Hg > 5 ppm restricted to feeder fault, Hg > 1ppm widespread Tl > 50 ppm in feeder zone, Sb - elevated, good dispersion halo, As - elevated adjacent and up dip of feeder Base metals - 0 to trace.

11. Fluid Inclusions:

n.d.

12. Isotope:

n.d.

13. Source:

Carden, 1991.

APPENDIX C

Characteristics of Sediment-Hosted, Disseminated Gold Deposits
along the Getchell Trend.

Deposit	Page No.
Chimney Creek	1
Rabbit Creek	4
Getchell	6
Preble	8

A. Deposit: **CHIMNEY CREEK**

B. Tonnage/Grade: 53 Mt @ 1.8 g/t.

C. Shape/Dimension: Divided into three pits along a north south trend.

D. Deposit Attributes:

1. Stratigraphy/Host Rocks:

North Pit;
Pennsylvanian to Permian Etchard Formation, siliciclastic & carbonate units of a regressive shallow shelf sequence.
Upper Member - dolomitic siltstone, argillite & calcareous sandstone;
Middle Member - minor **HOST** at base, upper massive dolomite and lower calcareous & sandy sandstones, minor conglomerate;
Lower Member - major **HOST**, basal conglomerate overlain by interbedded dolomite, sandy dolomite, calcareous sandstone & sandy limestone, capped by thick massive limestone.
Lower Mississippian Goughs Canyon Formation; greenstone sequence of mafic volcanics.

South Pit;
Ordovician Valmy Formation:
Upper unit; dark, thin bedded chert, shale and minor greenstone/volcanics.
Lower unit; pure quartzite, dark chert, siliceous shale and abundant greenstone.

Both upper and lower units structurally deformed and argillised.

2. Igneous Rocks:

North Pit; Dacite sill intruded along contact between Lower and Middle Members, mineralised where in contact with Lower Member sandstone. Dacite porphyry thought to be related to Osgood Mountain Porphyry exposed near Getchell Mine (Age +/- 90 Ma).
South Pit; Ordovician basalts.

3. Age of Mineralisation:

North Pit; < 90 Ma.
 South Pit; n.d.

4. Structure:

North Pit; Extremely complex tectonic & structural setting, (1) Paleozoic overthrusting (2) Basin and Range extension.
 Regional joint set N40-60E/60-80E, faults that partially control mineralisation have same orientation with left lateral displacement (pre- & postdates mineralisation) → Fault striking N10W (left lateral oblique slip); small weakly mineralised jasperoid development along fault → N30E range front fault.
 Bedding N60E/20-30E.

South pit; Dominant overturned anticlinal fold, fold axis - N20-30W, plunge 8-10NW, asymmetrical, upper limb dip 30SW, lower limb 60SW, many small folds, soft sediment deformation abundant. Age of folding Devonian Antler Orogeny. Faults; dominant N-S set, steeply dipping; minor but important ore control N40-60E set of faults; N75E to E-W set cut mineralisation.

5. Alteration:

North Pit;

Decalcification; prior to mineralisation, developed in calcareous sandstone & sandy limestone, calcite leached → collapse breccia → increased permeability; decalcified sandstone extremely friable; fluids migrated updip.

Silicification; bedded jasperoids, developed within ore zone at contacts between decalcified horizons and overlying non-decalcified rocks (dolomite, mudrocks, altered intrusives), at base of sedimentary horizon in contact with footwall greenstones. Cross-cutting jasperoids developed along faults, replacement of primary carbonates and as sugary grains in quartz-hematite-limonite matrix.

Argillisation; in argillaceous sediments and intrusives, illite → sericite + kaolinite + dickite + alunite + natroalunite. Dacite intrusive have extensively sericitized and argillised, phyllic assemblage partially replaced by smectite & kaolinite.

South Pit; Hypogene and supergene alteration.

Argillisation the most common, clay and plagioclase altered to sericite.

Supergene; kaolinisation of sericite, alunite common in veinlet and replacing kaolinite. Minor illite, smectite, goethite, celadonite, scorodite, arsenopyrite & francolite.

6. Ore Controls:

North Pit; decalcification of sandy limestones and calcareous sandstone primary control. Feeder N-S faults, NE faults local controls; dolomite, non-calcareous claystone and siltstone and dacite intrusive acted as impermeable caps to hydrothermal fluids. Mineralisation stratiform.

South Pit; Large overturned anticlinal fold the most important structural ore control; fluids percolated into extensively structurally prepared siliciclastic sediments and were trapped by argillised basalt layers. Mineralisation stratiform. N-S faults second, less important control on mineralisation within the deposit.

Regionally the N-S structure the primary control on mineralisation occurrences - Rabbit Structure.

7. Ore/ Gangue Mineralogy:

North Pit; n.d.

South Pit; Pyrite, marcasite, stibnite, getchellite, orpiment.

8. Sulphide Paragenesis:

North Pit; n.d.

South Pit; Syngenetic pyrite → pyrite + Au + marcasite + orpiment.

9. Mineralisation:

North Pit; n.d.

South Pit; Au is within diffuse rims or overgrowths of sulphide on early euhedral pyrite. Pyrite and marcasite contain Au. Sulphide ranges from massive coarse grained to ultra fine disseminated, veinlets & agglomerates.

- 10. Geochemistry:
 - North Pit; n.d.
 - South Pit; n.d.
- 11. Fluid Inclusions:
 - n.d.
- 12. Isotopes:
 - n.d.
- 13. Source:
 - Alkin, 1992.
 - Thomas, 1992.

A. Deposit:	RABBIT CREEK	3. Age of Mineralisation:	Alunite date 15.1 +/- 0.6 Ma (Supergene). Post 90 Ma - Pre- 15.1 Ma.
B. Tonnage/Grade:	53 Mt @ 2.4 g/t.	4. Structure:	Prominant feature is the N-S striking Rabbit Suture along which Chimney Creek, Rabbit Creek and possibly Lone Tree deposits are aligned. Rabbit Suture thought to be a right lateral shear zone. Large N-S striking anticline with numerous parasitic folds. Numerous high angle NE striking faults which in places form 90 m wide breccia zone. NE fault have dextral strike-slip displacement. Minor N-S to NNW high angle faults.
C. Shape/Dimension:	There are numerous zone within the orebody; North Central area, n.d. HGO Zone, 340 m * 180 m * 6-37 m, stratiform, SWS Zone, 180 m * 6-30 m thick * 150 m downdip, Main Chert Zone, 90m thick, LGO Zone, 460 m * 210 m * 80 m, Upper Sill Zone, 340 m * 150 m * 6-55 m, DZ Zone, n.d.	5. Alteration:	<u>Decalcification</u> ; prominant in the lower member slightly calcareous shales and siltstones. increased porosity and permeability, collapse breccias. <u>Silicification</u> ; numerous silicification episodes, Main Chert Zone is an orebody hosted in a jasperoid, numerous quartz-orpiment-pyrite, quartz-stibnite veinlets accompany massive silicification. <u>Dolomitisation</u> ; accompanys early silification. <u>Argillisation</u> ; widespread and confined essentially to volcanic rocks.
D. Deposit Attributes:	Tertiary alluvium, 12 to 200 m thick overlies the deposit. <u>Early Ordovician Comus Formation</u> ; divided into upper and lower members, Upper Member; interbedded basalts, hydroclastic tuffs and breccias, coarse volcanoclastic rocks, siltstones, cherts and shales. Sedimentary - volcanic rock ratio 1:1. Sedimentary rocks, thinly bedded, slightly calcareous, dolomitic with up to 1,5% organic carbon. Lower Member; interbedded volcanic and sedimentary rocks. Sedimentary - volcanic rock ratio 2:1. Sedimentary rocks comprised of thinly bedded, fissile, shales and mudrock. Both Upper and Lower Members HOST mineralisation.	6. Ore Controls:	Structural Control; First order control is the N-S Rabbit Suture. Orebodies in hinges of anticlines especially where argillised volcanic rocks overlie permeable sedimentary rocks. Large NE faults zones
1. Stratigraphy/Host Rocks:	n.d.		
2. Igneous Rocks:	n.d.		

where rocks have been intensely brecciated increasing permeability. Lithological control; decalcification of calcareous mudstones and siltstones, sedimentary breccias and argillised volcanics acting as an impermeable cap in the hinges of anticlines - stratiform orebodies.

7. Ore/Gangue Mineralogy: Pyrite, arsenopyrite, stibnite, orpiment, cinnabar, minor sphalerite and getchellite (AsSb, S₃).
Quartz, barite, calcite.
8. Sulphide paragenesis: n.d.
9. Mineralisation: Au- micron size adjacent to cubic pyrite surrounded by orpiment.
10. Geochemistry: See Table.
11. Fluid Inclusion: n.d.
12. Isotope: n.d.
13. Source: Bloomstein et. al., 1991.

A. Deposit:	GETCHELL DEPOSIT	5. Alteration:	Pre-mineral skarn proximal tungsten - garnet - diopside skarn and distal wollastonite skarn and marble. Affects both the hanging and footwall rock of main NE striking fault.
B. Tonnage/Grade:	8.43 Mt @ 5.82 g/t		<u>Decarbonisation</u> ;
C. Shape/Dimension:	4 pits over a strike length of 4 km striking N10-15W. Individual deposits 300-400 m * 4 - 15 m * 300 - 600 m (open).		<u>Decalcification</u> ; minor in thin interbedded limestones.
D. Deposit Attributes:			<u>Silicification</u> ; numerous phases of silicification with each phase being brecciated prior to flooding, jasperoid development along feeder faults.
1. Stratigraphy/Host Rocks:	<u>Ordovician Comus Formation</u> ; thinly interbedded carbonaceous siltstone, shale and limestone. <u>Cambrian Preble Formation</u> ; thinly interbedded carbonaceous siltstone, shales and thin bedded limestone. Transitional facies rocks, cherts, shales, and distal facies carbonate turbidites.		<u>Argillisation</u> ; illite after biotite, kaolinite in argillaceous units. Paragenesis; decalcification + decarbonation → numerous pulses of silicification and brecciation → argillisation.
2. Igneous Rocks:	Cretaceous granodiorite stock and porphyritic dacite intruded along Getchell and other high angle faults. Dacite porphyry dykes altered and mineralised. Age 98.8 +/- 2 Ma.	6. Ore Controls:	Structural prepared reactive host rocks especially where host rock forms wedges between main NE fault and granodiorite; at intersections of NE and NW faults, where NE faults bends around stock, in nose of folded host rock. Mainly confined to NE fault. Repeated silicification and brecciation increased permeability.
3. Age of Mineralisation:	< 98 Ma.		
4. Structure:	Major N10-15W/45-75E fault that flanks the eastern side of granodiorite stock host mineralisation. High angle fault paragenesis E-W → NW → NW + NE. Intersection of fault host high grade mineralisation as well as where main N10-15W striking fault bends around intrusive. Lithologies highly folded into tight folds.	7. Ore/Gangue Mineralogy:	Native Au, realgar, orpiment, stibnite, minor cinnabar. Quartz, pyrite, marcasite, arsenopyrite, fluorite, calcite, dolomite, barite.
		8. Sulphide paragenesis:	Au + pyrite + arsenopyrite → Au + pyrite + realgar + orpiment + calcite → calcite + barite.

9. Mineralisation: Au associated with in rims of pyrite and arsenopyrite, associated with quartz.
10. Geochemistry: Elevated As, Sb, Tl, F. Pre-mineral elevated Mo, W.
11. Fluid Inclusion: n.d.
12. Isotope: n.d.
13. Source: Nanna et. al., 1987.
Tooker, 1985.

A. Deposit:	PREBLE	3. Age of Mineralisation:	n.d., but < 98.8 +/- Ma.
B. Tonnage/Grade:		4. Structure:	Paleozoic thrusting. Getchell Fault flanks the eastern margin of the granodiorite stock. Getchell Fault is fault zone comprised of sub-parallel enechelon faults with NE strike/ easterly dip. Fault zone 15 - 30 m wide. Primary conduit for Au-hydrothermal fluids. Dykes intruded along Getchell fault zone.
Shape/Dimension:	Strikes NE, irregular elongated deposit within Getchell Fault Zone with tongues of mineralisation into calcareous sediment.		
C. Deposit Attributes:		5. Alteration:	<u>Silicification</u> ; very subtle, quartz overgrowths <u>Argillic</u> ; strongly altered sill. <u>Decarbonisation</u> ; thought to be by acidic solutions as a result of oxidizing sulphides.
1. Stratigraphy/Host Rocks:	Antler Sequence (autochthonous) <u>Ordovician Valmy Formation</u> , <u>Ordovician Comus Formation</u> ; thin bedded carbonate, shale, dolomite siltstone, minor chert. <u>Cambrian Preble Formation</u> ; Upper - phyllitic shale with minor sandy shale & carbonaceous beds. Middle - HOST , limestone, carbonaceous and calcareous shale, phyllitic shale, quartzitic sandstone. Lower - sandy shale, quartzitic shale, phyllitic shale. <u>Lower Cambrian Osgood Mountain Quartzite</u> .	6. Ore Controls:	Structural ore controls in 15 - 30 m wide Getchell fault zone; mineralisation at intersection of Getchell fault and carbonaceous & calcareous sediments.
2. Igneous Rocks:	Olivine basalt +/- 17 Ma. Mid-Tertiary volcanic rocks. Late Cretaceous Granodiorite Stock (98.8 +/- 2 Ma, Silberman et. al., 1974). Numerous dykes and sills of granodiorite, andesite porphyry, dacite porphyry and aplites related to the stock. Stock responsible for irregular skarn up to 3000 m from intrusive. Pinson and Getchell Mines lie within skarn development.	7. Ore/Gangue Mineralogy:	Oxide Zone; Au + limonite + pyrite + quartz, limonite intergrowths of goethite + lepidochrosite. Unoxidised Zone: quartz + pyrite + arsenopyrite + minor marcasite + chalcopyrite + sphalerite; 2 -3% sulphides.
		8. Sulphide paragenesis:	n.d.
		9. Mineralisation:	Au - 2 microns associated with quartz and to lesser extent rims of pyrite. Pyrite syn- & epigenetic.

10. Geochemistry: Elevated As, Hg, Ba, Sb, Tl, F.
Au correlates well with As.
11. Fluid Inclusions: n.d.
12. Isotope: n.d.
13. Source: Kretschmer, 1987.