DESCRIPTIVE MODEL OF CARLIN-TYPE GOLD DEPOSITS

Albert H. Hofstra

US Geological Survey, P. O. Box 25046, Denver, CO 80225, USA

1. INTRODUCTION

The goal of this study is to provide a list of the physical and chemical attributes of Carlin-type gold deposits useful for prospect evaluations and mineral resource assessments. The information is compiled from the literature and my own research. Although some of the information is controversial, most is generally accepted.

2. OVERVIEW

Carlin-type deposits are epigenetic, disseminated, gold deposits that are typically hosted in calcareous sedimentary rocks. The deposits are known mainly in northern Nevada and northwestern Utah where they are arranged in clusters and belts (Fig. 1). The deposits in this region are estimated to contain about 5000 tons of gold, more than half of which resides in the Carlin Trend (~3100 tons). Approximately 1500 tons of gold has been produced. Carlin-type deposits are frequently called as sediment-hosted disseminated gold, sediment-hosted micron gold or invisible gold as synonyms.

They are spatially associated with syngenetic barite deposits and related base-metal occurrences, porphyry Cu-Mo-Au deposits, volcanic-hosted precious-metal deposits, or epithermal mercury, stibnite, or barite vein occurrences. Temporally associated deposit types include porphyry Cu-Mo-Au deposits and volcanic-hosted epithermal Au-Ag deposits.
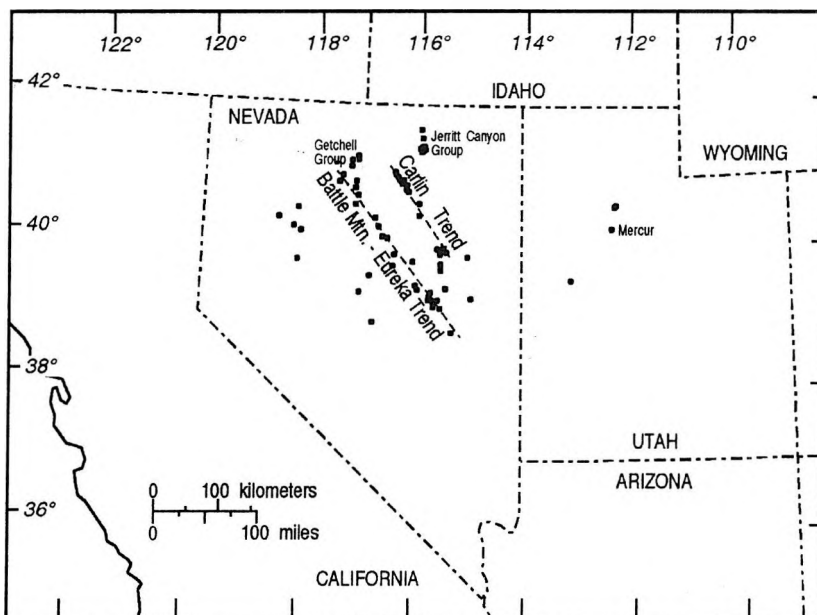

Fig. 1: Location map

Two ore types, the refractory ore and the oxide ore are exploited. Most of the gold in refractory ore occurs in arsenian pyrite, arsenian marcasite, or arsenopyrite. The sulfides are oxidized in the mill so that gold can be recovered by cyanide carbon in leach methods. Some of the ore is refractory because it contains organic carbon that can rob gold from cyanide solutions in which case the carbon must be deactivated before entering the carbon in leach circuit in the mill. Natural weathering and oxidation of refractory ores results in the formation of oxide ores with low sulfide and organic carbon contents that are suitable for gold recovery by cyanide heap leach methods.

Average ore grades in individual deposits range from 0.6 to 22 g/t. The lowest grades are in open pit mines that exploit oxide ore. Underground mines have higher average grades because of the higher costs associated with development of underground workings and processing of refractory ores. The ore tonnage of discrete deposits may range over 200,000,000 t or less than 100,000 t, and may contain as much as 1000 t of gold or less than 1 t of gold. Most of the deposits contains between 10 and 100 t of gold.

The host rocks of the deposits are Cambrian to Triassic in age, although more than half of the deposits is in Devonian sediments. Most of the deposits are in platform margin or intraplatform calcareous sediments, but some are hosted in oceanic deep marine siliciclastic sequences. Ore locally occurs in Jurassic to Mid–Tertiary igneous rocks and contact metamorphic rocks. Fig. 2 shows the distribution of gold ore through the stratigraphic sequence in the Carlin Trend.

The age of the deposits is very difficult to estimate because they contain few datable minerals, cogenetic with the gold. The age constraints are mainly of two types, those provided by cross cutting relationships with dated igneous rocks, and those provided by isotopic dates on sericite. Sericite separated from mineralized sedimentary and igneous rock yields a wide range of old dates that at best place an older limit on gold mineralization. These dates are not very meaningful because they are from incompletely reset pre-ore micas or from mixtures of pre-ore and ore-stage mica. The isotopic dates from igneous rocks constrain the age of several deposits to between 42 and 32 Ma. Hydrothermal adularia from one deposit has been dated at 42.0 Ma. Supergene alunite is 30 Ma or younger. The deposits are therefore Mid–Tertiary in age (42-30 Ma).

Concerning the tectonic setting of the deposits regional scale tectonic and magmatic processes were required to drive these systems. The deposits are located in the backarc of the North American Cordillera; a region that in the Mid–Tertiary was characterized by high regional heat flow, widespread calcalkaline magmatism, and crustal extension. However, there is not a one-to-one spatial correspondence between the deposits and volcanic centers or epizonal plutons which has made it difficult to determine the relation between the deposits and magmatism.
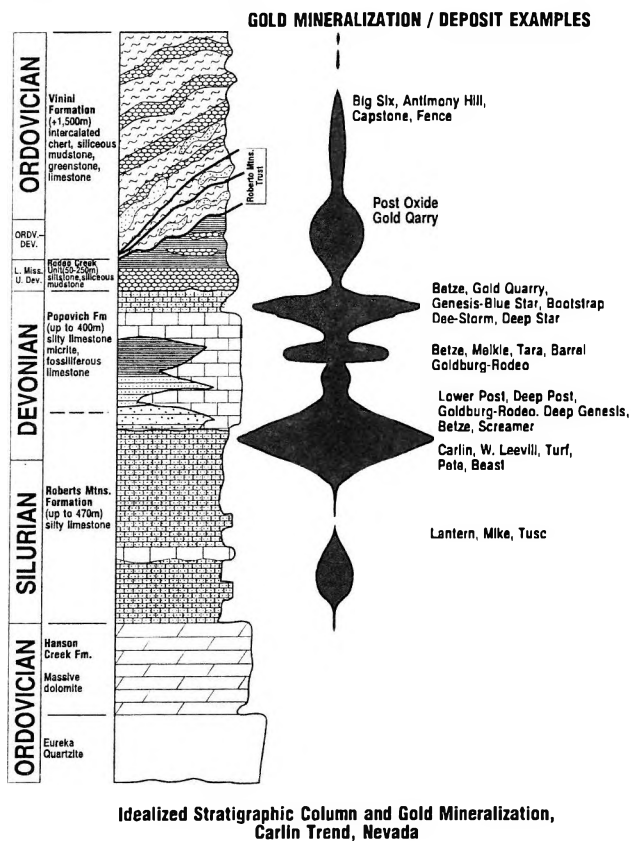

Idealized Stratigraphic Column and Gold Mineralization, Carlin Trend, Nevada

Fig. 2: Idealized stratigraphic column and gold mineralization, Carlin Trend Nevada (TEAL and JACKSON 1997)

The NNW striking Carlin Trend is 60 km long and is defined by more than 40 gold deposits. The Battle Mountain-Eureka Trend also strikes NNW is more than 80 km long and is defined by over 20 gold deposits. At the surface, the trends are manifest by a complex array of faults, folds, and igneous intrusions suggesting that they are zones of weakness in the crust. Gravity gradients and Sr and Pb isotopic variations of granitic intrusions in the region indicate that the trends developed along major crustal discontinuities. Magnetotelluric surveys across the trends show that they are underlain by deep penetrating fault zones. These faults may have originated as normal faults during late Proterozoic rifting of the continental margin and appear to have influenced subsequent patterns of sedimentation, deformation, magmatism, and hydrothermal activity. Most of the deposits in the Carlin Trend, Battle Mountain–Eureka Trend, and Jerritt Canyon district are in the lower plate of the Roberts Mountains thrust that placed oceanic deep marine siliciclastic rocks on top of silty carbonate rocks of the platform margin. The deposits are exposed in tectonic windows through the allochthon. The windows commonly reflect antiformal structures or tilted fault blocks. Recent discoveries adjacent to the windows have been found by drilling through the allochthon.

The ore deposits are preferentially localized in permeable and reactive rocks that focused fluid flow. The primary permeability controls are faults and fault intersections that were feeders for ascending hydrothermal fluids. Secondary permeability controls influenced flow away from feeders and include permeable strata, breccias, thrust faults, joint sets, anticlines, and igneous intrusions. Breccia types include sedimentary debris flows and breccias, solution collapse breccias, and fault breccias. The deposits are commonly overlain by less permeable rocks that acted as a caprock (e.g. Roberts Mountains allochthon). Chemically favorable host rocks are those that contain carbonate and iron-bearing minerals. Dissolution of carbonate increases permeability allowing continued influx of ore fluids. Sulfidation of reactive iron-bearing minerals consumes H_2S causing gold to precipitate. Many deposits are localized along faults where ascending ore fluids encountered less permeable caprocks and were forced to move laterally through permeable and reactive rocks below the cap rock. Fig. 3 shows the distribution of ore deposits in the northern Carlin Trend relative to major faults and Jurassic intrusions. Ore controls for several deposits in the Carlin Trend are illustrated on Figs. 4–10; Fig. 11 summarizes the relative importance of various ore controls on deposits in the Carlin Trend.
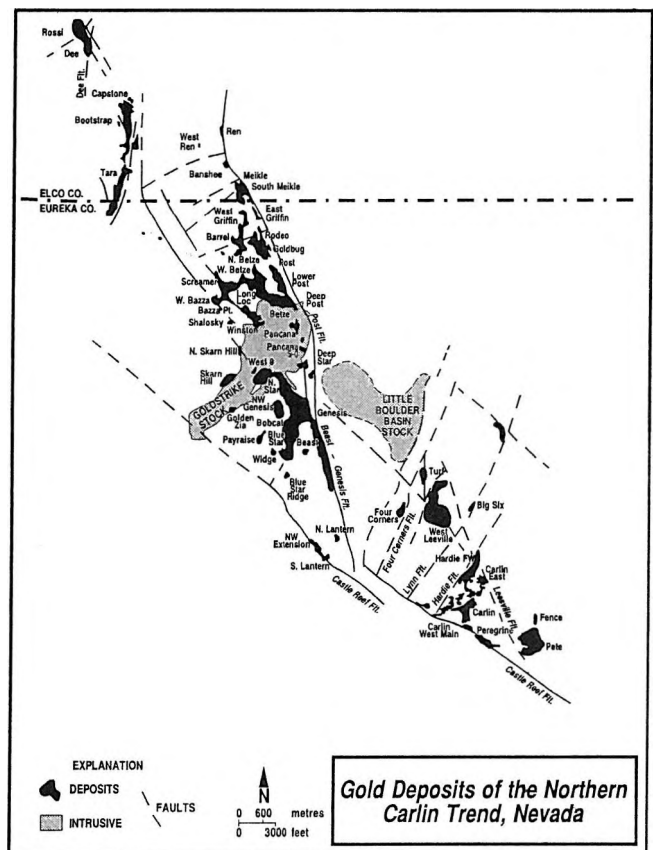

Fig. 3: Gold deposits of the Northern Carlin trend (TEAL and JACKSON 1997)

The geometry of the ore deposit varies as a function of the predominant ore controls (e.g. stratigraphy=tabular and stratiform, fault=tabular discordant, breccia pipe =carrot shaped, joint sets=irregular stockwork)

4. MINERAL ASSOCIATION AND TRANSFER

The hydrothermal mineral assemblege of the ores consists of ore minerals (arsenian pyrite, arsenian marcasite, arsenopyrite, realgar, orpiment, stibnite, cinnabar and thallium sulfides with native gold and arsenic), accompanied by silicates (quartz, kaolinite, illite-smectite, montmorillonite, rare adularia), carbonates (calcite, dolomite, ± ankerite, ± siderite), phosphates (rare apatite), sulfates (barite), oxides (rutil, leucoxene) and some halides (fluorite).

The supergene ore minerals are composed of goethite, hematite, pyrolusite, scorodite, stibiconite and native gold in association with silicates (halloysite and other clay minerals), phosphates (variscite, wawellite and others), sulfates (alunite, jarosite, gypsum and melanterite).
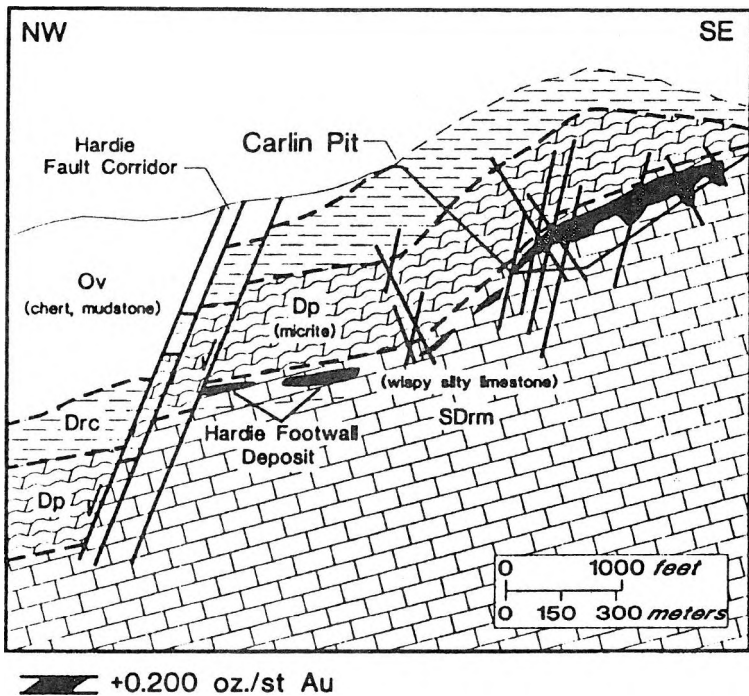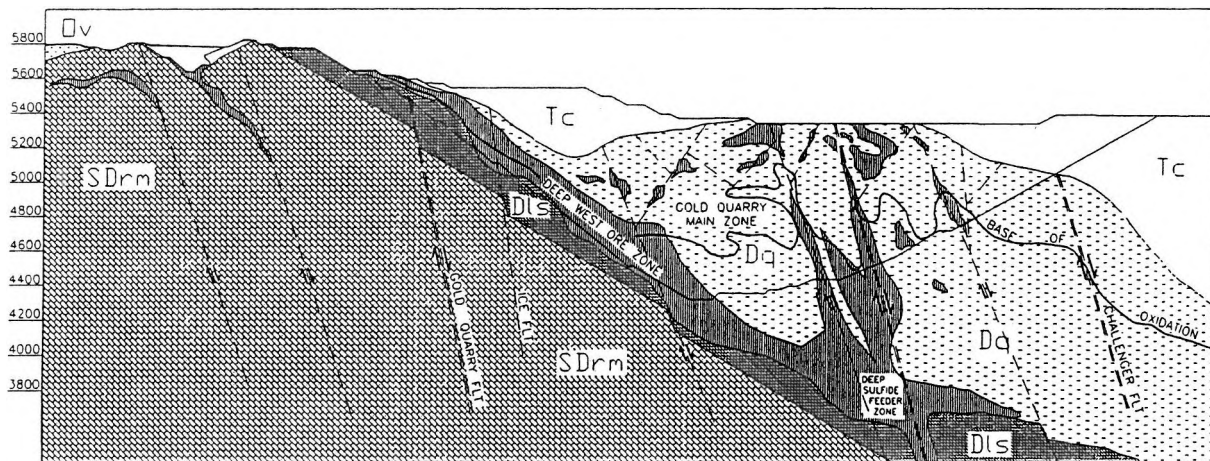

Fig. 4: Cross section of the Carlin and Hardie Footwall deposit (TEAL and JACKSON 1997) Tc=Tertiary cover; Ov=Vinini Formation; Dp=Popovich Formation; Drc=Rodeo Creek Formation; SDrm=Roberts Mountains Formation

Fig. 5: Cross section of the Gold Quarry deposit (TEAL and JACKSON 1997) (Legend see on Fig. 4)
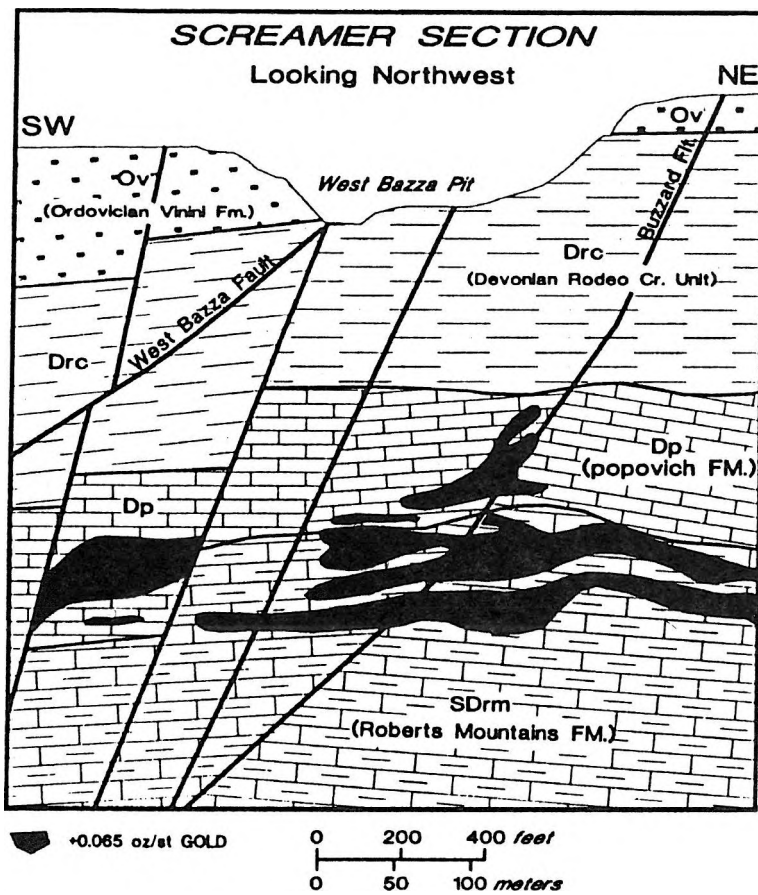
SCREAMER SECTION
Looking Northwest

SW

NE

Ov

Ov
(Ordovician Vinini Fm.)

West Bazza Pit

Drc
(Devonian Rodeo Cr. Unit)

West Bazza Fault

Buzzard Flt.

Drc

Dp
(popovich FM.)

Dp

SDrm
(Roberts Mountains FM.)

+0.065 oz/st GOLD

0 200 400 feet

0 50 100 meters

Fig. 6: Cross section of the Screamer deposit (TEAL and JACKSON 1997)

DEEP STAR
Looking North

W

E

Ov

Jki

Ov
(siliclastic rocks)

Ov
(siliclastic rocks)

Jki
(diorite)

Jki

GEN FAULT

RMT

Dp

Ov
(siliclastic rocks)

DEEP STAR FAULT ZONE

Dp
(calc-silicate hornfels)

RMT

1768m

1646m

1524m

1402m

DEEP STAR ORE BODY

(calc-silicate hornfels)

Jki
(diorite)

Ov.

0 200 400 feet

0 50 100 meters

Quartz, Clay,
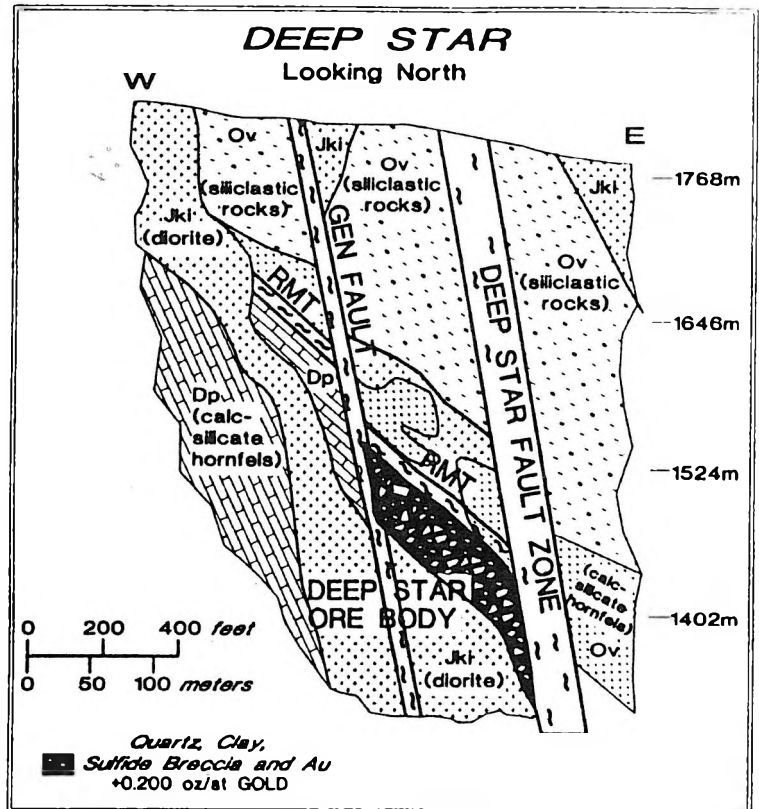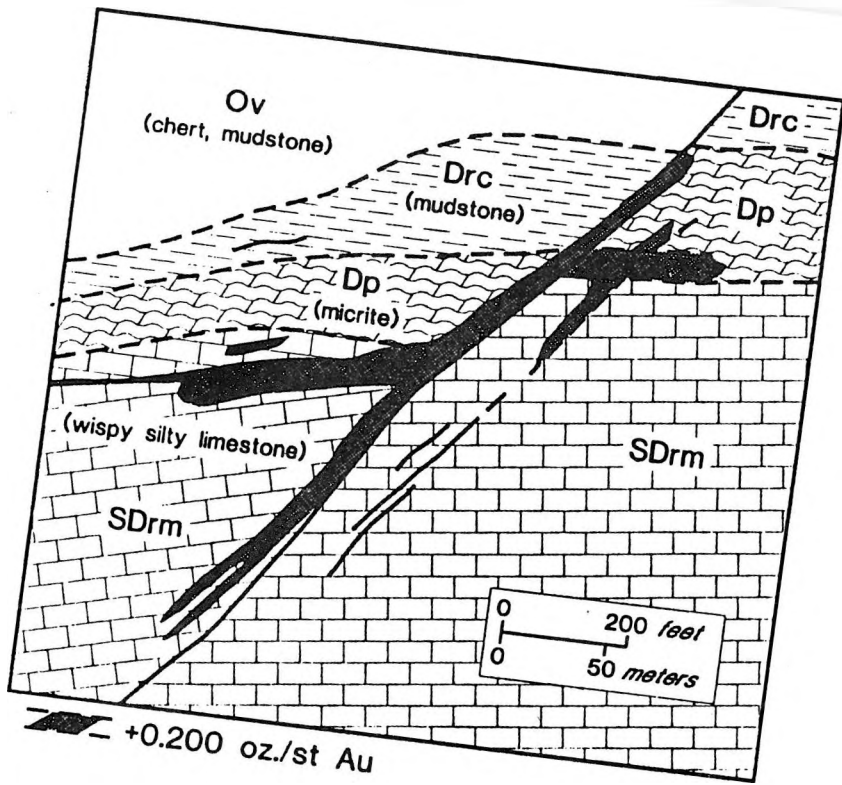Sulfide Breccia and Au
+0.200 oz/st GOLD

Fig. 7: Cross section of the Turf deposit
(TEAL and JACKSON 1997)
(Legend see on Fig. 4)

141

Fig. 8: Cross section of the
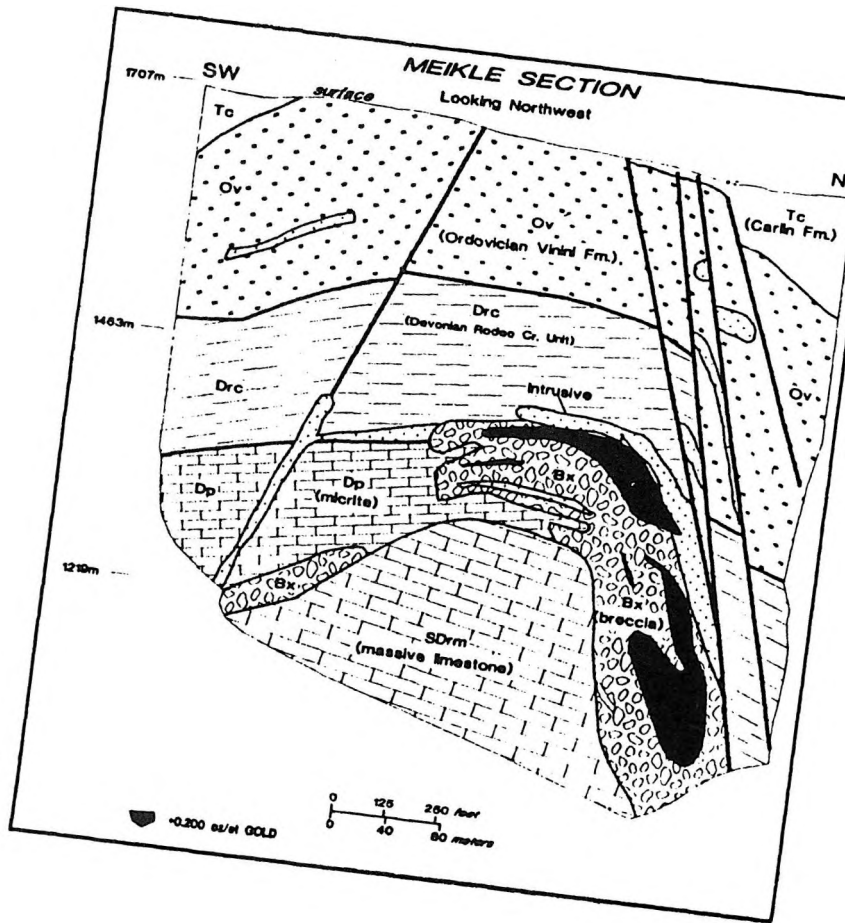(TEAL and JACKSON 1997)
(Legend see on Fig. 4)

Ov
(chert, mudstone)

Drc
(mudstone)

Drc

Dp

Dp
(micrite)

(wispy silty limestone)

SDrm

SDrm

SDrm

0 ___ 200 *feet*
0 ___ 50 *meters*

◼ ◼ +0.200 oz./st Au

Fig. 9: Cross section of the Deep Star de-
posit (TEAL and JACKSON 1997)
(Legend see on Fig. 4)

MEIKLE SECTION

1707m — SW   *surface*   Looking Northwest   N

Tc

Ov

Ov
(Ordovician Vinini Fm.)

Tc
(Carlin Fm.)

1463m

Drc
(Devonian Rodeo Cr. Unit)

Drc

Ov

Intrusive

Dp

Dp
(micrite)

Bx

1219m

Bx

Bx
(breccia)

SDrm
(massive limestone)

◼ +0.200 oz/st GOLD

0 ___ 125 ___ 260 *feet*
0 ___ 40 ___ 80 *meters*

142

Fig. 10: Cross section of the Rain deposit (TEAL and JACKSON 1997)
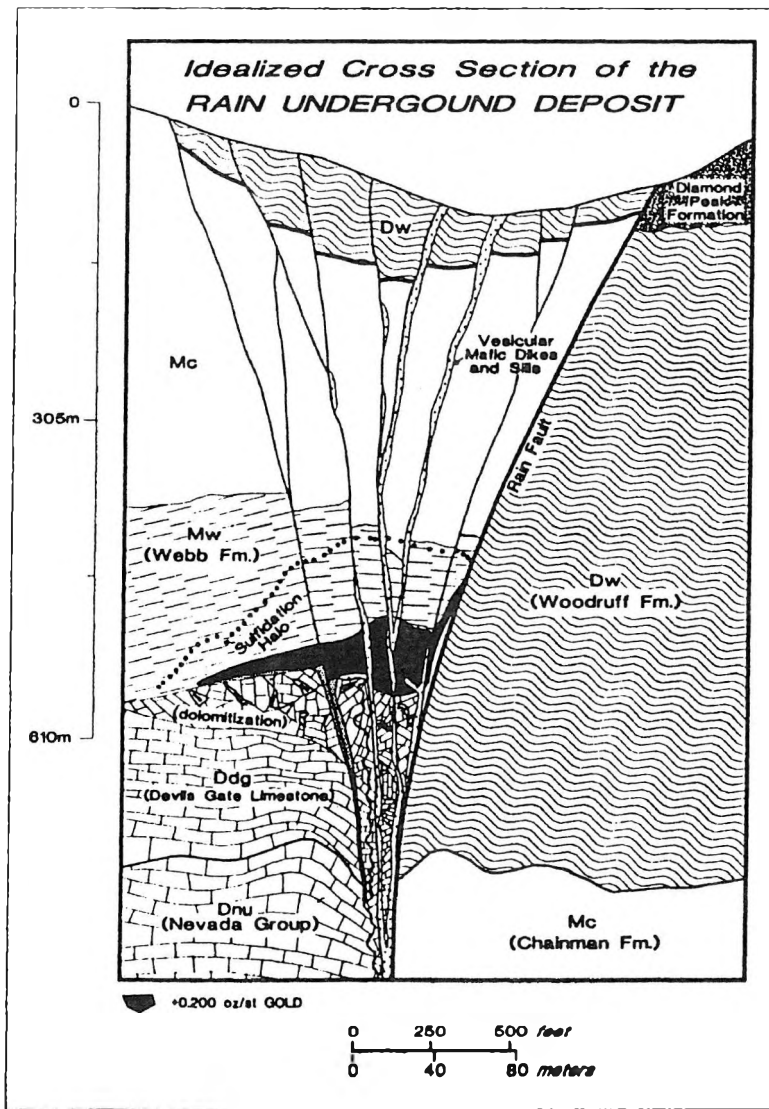
The mineral texture is represented by ore stage pyrite, marcasite, and arsenopyrite which in the deposits usually occur as small 1 mm to 1 micron disseminations or overgrowths on preexisting diagenetic pyrite. Orpiment, realgar, stibnite, cinnabar, calcite, and barite generally fill open spaces in fractures and breccias. Late botryoidal pyrite and marcasite line open spaces in fractures and breccias.

The gold is invisible and occurs primarily in arsenian pyrite as submicron sized grains of native gold and as Au in the pyrite lattice. Arsenian pyrite also contains elevated concentrations of thallium, antimony, and mercury. Gold and trace elements occur in a similar fashion in arsenian marcasite and arsenopyrite. The ores contain 0.5 to 10% pyrite (marcasite or arsenopyrite) with gold concentrations of 200 to 5,000 ppm. Gold has also been observed in quartz, dolomite, clays, organic carbon, cinnabar, and barite. In oxidized ores native gold is larger and usually occurs as 1 micron to 1 mm sized grains in limonite.

The host rocks of the deposits locally contain several percent organic carbon. The carbon is either indigenous to the host rock or was introduced as liquid petroleum. In some deposits, the organic carbon was metamorphosed into cryptocrystalline graphite with 30-150 angstrom crystal domains prior to gold mineralization. Both types of carbon are concentrated by dissolution of the carbonate host rocks. In rocks that contain immature organic matter, the thermal maturity of organic carbon increases in ore zones. In rocks that contain thermally mature carbon, the thermal maturity of organic carbon is the same within and outside the deposit. There is no consistent relationship between the amount of carbon in the host rocks and gold grades. Organic carbon does not appear to have played a major role in mineral precipitation.
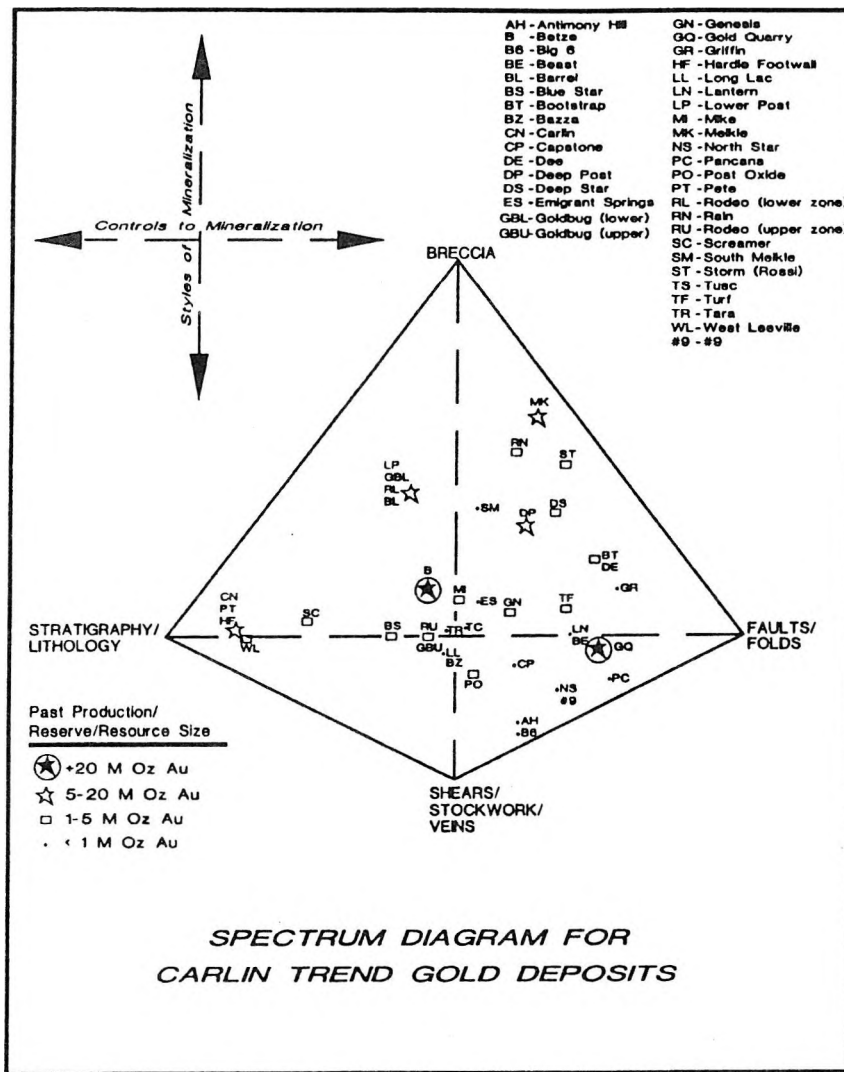
Fig. 11: Factors of ore control, Carlin Trend gold, Nevada (TEAL et al. 1997 in TEAL and JACKSON 1997)

Styles of Mineralization

Controls to Mineralization

BRECCIA

AH - Antimony Hill
B - Betze
B6 - Big 6
BE - Beast
BL - Barrel
BS - Blue Star
BT - Bootstrap
BZ - Bazza
CN - Carlin
CP - Capstone
DE - Dee
DP - Deep Post
DS - Deep Star
ES - Emigrant Springs
GBL- Goldbug (lower)
GBU- Goldbug (upper)

GN - Genesis
GQ - Gold Quarry
GR - Griffin
HF - Hardie Footwall
LL - Long Lac
LN - Lantern
LP - Lower Post
M - Mike
MK - Meikle
NS - North Star
PC - Pancana
PO - Post Oxide
PT - Pete
RL - Rodeo (lower zone)
RN - Rain
RU - Rodeo (upper zone)
SC - Screamer
SM - South Meikle
ST - Storm (Rossi)
TS - Tusc
TF - Turf
TR - Tara
WL - West Leeville
#9 - #9

STRATIGRAPHY/ LITHOLOGY

FAULTS/ FOLDS

SHEARS/ STOCKWORK/ VEINS

Past Production/ Reserve/Resource Size

✪ +20 M Oz Au
☆ 5-20 M Oz Au
□ 1-5 M Oz Au
• < 1 M Oz Au

SPECTRUM DIAGRAM FOR
CARLIN TREND GOLD DEPOSITS

The main alteration types are silicification, argillization, carbonate dissolution and sulfidization of iron-bearing minerals. Sometimes K-metasomatism of silicates also may occur. The silicification of carbonates is common, but its spatial correlation to mineralization is erratic. In some deposits silicification is best developed in feeder zones while in others it can occur above, below, beside, in, or away from ore zones. Igneous rocks are less often silicified. Argillization of silicates is best developed in igneous rocks, hornfels, skarn, and sedimentary rocks containing detrital feldspar. Preexisting illite in the host rocks is relatively resistant to argillization and often persists when other silicate minerals are argillized. The carbonate dissolution is very common resulting in increased porosity, volume loss, concentration of insoluble minerals, and formation of solution collapse breccias. The sulfidization of iron-bearing minerals is very important and results in the formation of disseminated arsenian pyrite, arsenian marcasite, or arsenopyrite which contain the bulk of the gold in the deposits. Ferroan calcite and dolomite are probably the principle iron-bearing minerals in the host rocks although iron bearing clays, phosphates, and oxides may also be sulfidized. The K-metasomatism of silicates is rare and was manifested by the presence of adularia only in one single district.

The minerals are distributed in proximal to distal zoning which is reflected in the following (proximal → distal). Carbonates: carbonate absent → dolomite → calcite±siderite±ankerite. Silicates: dickite or kaolinite → illite/smectite, ±illite → montmorillonite → feldspars, amphibole, biotite, pyroxene. Organic matter: mature → immature. Sulfides: arsenian pyrite or marcasite → arsenopyrite → iron bearing carbonates, silicates, phosphates, oxides, and pyrrhotite. Sulfates: preexisting barite is relatively unaffected by ore fluids. Phosphates: diagenetic apatite is dissolved in proximal ore zones, igneous apatite is resistant to ore fluids. Oxides: leucoxene → preexisting ilmenite and Ti-bearing silicates.

The introduced elements of the mass transfer are represented by ±Si, S, Au, As, Sb, Hg, Tl, Ag, Ba, ±Te, ±Se and ±W, while CO_3, Ca, Sr, Na, ±Mg, ±K are considered to be depleted. Among the inmobile elements (Al, Ti, ±Fe, ±Si, ±K) plays the Fe an important role in the setting of introduced Au, As, and sulfur. This indicates that the disseminated iron sulfides formed by sulfidation of host rock iron. Sulfidation decreases the H_2S concentration of the ore fluids causing gold to precipitate.

5. METHODS OF EXPLORATION

Geochemical assaying is generally applied as first step on exploration. Beside the main elements of Au and Ag, pathfinder elements like As, Sb, and Hg are ubiquitous, with ±Tl, ±W. Reconnaissance stream sediment sampling is used to discriminate between areas of high and low potential. In stream sediments, As, Sb, and Hg are usually more widespread than Au. The major districts and trends are readily outlined by As anomalies in stream sediments. Rock chip and soil surveys are used to define surface mineralization and detect mineralized structures and stratigraphy. In soil and rocks chips, As, Sb, and Hg usually form broader higher contrast anomalies than Au. Ground water in the vicinity of the deposits has elevated concentrations of As, and other trace elements.

Geophysical methods can be used in delineation of the trends and ore districts. Regional gravity data indicates that the Battle Mountain–Eureka trend lies along a major crustal discontinuity. Magnetotelluric surveys across the Carlin Trend and Battle Mountain–Eureka Trend indicate that both trends are underlain by deep penetrating structures. These structures served to localize intrusions of Jurassic, Cretaceous, and Tertiary age; some of which are apparent on regional areomagnetic maps. Geophysical methods generally cannot be used to directly detect gold ores. However, satellite and airborne multispectral data are helpful in defining major lithologic boundaries, structural zones, and areas of hydrothermal alteration (e.g. silicification). Ground magnetic and various electromagnetic methods may be used to map high or low angle faults, fractures, and highly permeable altered zones that may have served as conduits for ore fluids. Electrical resistivity methods are able to delineate hydrothermal alteration and fault zones as a resistivity low and silicification as a high. Electrical and seismic methods can be employed to determine the depth to bedrock or the location of permeable and impermeable beds. The organic carbon in the host rocks is the dominant source of anomalies observed by electrical methods. The induced polarization method can be used to estimate the percent sulfide in the ores if the carbon content is low. It can also be used to locate the boundary between oxide and refractory ores due to the lack of organic carbon and sulfide in the oxide ores.

6. GENESIS AND MODEL OF THE DEPOSITS

Fluid inclusions data indicate temperatures from 150° to 250 °C of the ore fluids, having a salinity 0 to 6 eq. wt. % NaCl. Among the gas phases CO_2 is predominant (1-10 mole %), H_2S minor but ubiquitous (10^{-2} to 10^{-1} molal), with ±N_2 and ±CH_4 in minor quantity. Estimated pressure ranges between 1 to 3 kbars, corresponding to a depth of 1 to 5 km.

Moderately acidic pH (4.0 to 5.5) of ore fluids is indicated by the presence of marcasite and kaolinite and by the dissolution of dolomite. High H_2S-concentrations (log fH_2S = –1 to–2) in ore fluids are shown by the common occurrence of high sulfidation state minerals such as orpiment and realgar. Mass transfer studies prove that sulfur was one of the most abundant elements introduced by the hydrothermal fluids, while gas analyses of fluid inclusions indicate that the fluids contained 10^{-1} to 10^{-2} m H_2S. Low fO_2 (log fO_2 = –39 to –43) is indicated by the predominance of CO_2 over CH_4, the presence of graphitic carbon, the absence of magnetite and hematite, the narrow fO_2 for realgar and orpiment at the given fH_2S, and the low SO_4 content of ore stage fluids.

Stable isotope studies on fluid inclusions and clay minerals show that Mid-Tertiary meteoric water in this region had δD values between –160 and –120‰ and $\delta^{18}O$ values of –21 to –16‰. In most deposits, hypogene kaolinite and water extracted from fluid inclusions have δD values between –160 and –110‰ and $\delta^{18}O$ values of –20 to 10‰. The low δD and variable $\delta^{18}O$ values are consistent with a meteoric origin for the water. However, the deposits in the Getchell district have an enormous range of δD values between –155 and –40 ‰ and $\delta^{18}O$ values of –20 to +15‰. The high δD and $\delta^{18}O$ values require the presence of a deep sourced magmatic or metamorphic fluid. *Quartz* – The $\delta^{18}O$ compositions of ore stage jasperoid and quartz veins range from 1 to 26‰. The broad range of values requires mixing between a high $\delta^{18}O$ fluid and low $\delta^{18}O$ unexchanged meteoric water. Gold was transported by the high $\delta^{18}O$ fluid. Fluid mixing was probably common in these systems and took place where as-

cending ore fluids displaced indigenous ground waters in the host rocks. *Organic matter* – The organic carbon in the host rocks has low $\delta^{13}C$ values of –34 to –21‰ that are typical of sedimentary organic matter. Bitumen has $\delta^{13}C$ values a few permil less than the indigenous organic matter in the rocks. *Calcite and dolomite* – Calcite and dolomite in unaltered host rocks have a broad range of $\delta^{13}C$ and $\delta^{18}O$ compositions between about –8 to 3‰ and 22 to 28‰ respectively. The $\delta^{13}C$ and $\delta^{18}O$ values of calcite and dolomite in strongly altered rocks are restricted to a much narrower range between –4 to 2‰ and 7 to 13‰ respectively. Ore stage calcite veins have $\delta^{13}C$ values of –5 to 3‰ and extend to $\delta^{18}O$ values as low as 1‰. The high $\delta^{13}C$ values of ore related carbonates indicate that only a very small proportion of the CO_2 in ore fluids could have been derived from oxidation of organic matter or hydrocarbons. The data permit that the ore fluid consisted of isotopically evolved meteoric water but cannot exclude other possibilities. *Barite* – The $\delta^{34}S$ and $\delta^{18}O$ values for barite cover a huge range from 5 to 40‰ and –7 to 15‰. The large range requires more than one source of sulfate. The sulfate in the isotopically heavy barites was probably derived from dissolution of the sedimentary barite in the rocks. The lower $\delta^{18}O$ values are indicative of meteoric water. The lower $\delta^{34}S$ values suggest that some of the sulfate was derived from either the oxidation of H_2S in ore fluids or from the oxidation of preexisting sedimentary or hydrothermal sulfides. Many samples have intermediate $\delta^{34}S$ values and probably contain mixtures of sulfate derived from each end member. *Sulfides* – The $\delta^{34}S$ composition of ore stage pyrite, marcasite, and arsenopyrite is mainly between 0 and 24‰. Orpiment, realgar, and stibnite are mainly between –3 and +17‰. The calculated isotopic composition of H_2S in the ore fluids using a temperature of 225 °C is between 0 and 20‰ with a mode at 10‰. This range is within that of sedimentary pyrite and organosulfur sources in lower Paleozoic sedimentary rocks. The highest $\delta^{34}S$ values suggest that some H_2S came from thermochemical or inorganic reduction of sedimentary sulfate; barite being the most abundant and likely source of sulfate in the rocks. The entire range of $\delta^{34}S$ values from the deposits is consistent with derivation of H_2S from sedimentary or metasedimentary sources. The lowest $\delta^{34}S$ values allow (but do not require) that some H_2S came from magmatic fluids or from preexisting magmatic sulfides. The source of H_2S is very important because gold was transported as a bisulfide complex.

Processes and model of ore formation will be outlined in the following. Ascending ore fluids were apparently impeded by impermeable caprocks at depths of 1 km or more where they moved laterally away from feeder zones and were dispersed into local ground water. Increased interactions between the acidic CO_2- and H_2S-rich ore fluids and the host rocks in these zones resulted in carbonate dissolution, volume loss, increased porosity, argillization of silicate minerals, sulfidation of host rock iron to form arsenian pyrite, arsenian marcasite, or arsenopyrite, and precipitation of gold. Cooling of fluids resulted in silicification of carbonates and precipitation of orpiment and realgar in open spaces. Mixing with indigenous ground waters with elevated iron content may also have contributed to gold precipitation. The CO_2 liberated by dissolution of carbonate may have lead to transient fluid over pressures, boiling, and precipitation of calcite in open spaces. Precipitation of gold may also have been promoted by boiling.

To concentrate ~5,000 tons of gold from the background levels in the crust requires the development of large hydrothermal systems. The energy required to drive these systems is also large. Regional scale tectonic and magmatic processes were probably required. The large number of similarities among Carlin-type deposits suggests they have common origins and formed in response to a single event. The most reliable isotopic dates constrain the age of many deposits to between 42 and 30 Ma. The deposits probably formed over a period of about 10 Ma soon after the onset of extension and magmatism in northern Nevada and NW Utah. The increased permeability and high heat flow in this setting may have provided the drive for deep circulation of meteoric water and development of Carlin-type deposits in fracture systems that focused fluid flow. If these structures penetrated to mid-crustal levels, they may also have tapped metamorphic fluids generated in the middle crust or magmatic fluids released from deep intrusions or batholiths. However, if extensional faulting and regional magmatism were all that was required to produce Carlin-type deposits they should be present in similar tectonic settings to the north and south. As yet, none have been recognized. Apparently additional factors were critical to the formation of Carlin-type deposits. Current research is directed towards improving constraints on the age of the deposits and identifying the critical factors that led to their formation.

7. BIBLIOGRAPHY

ALBINO, G. V. 1994: Geology and lithogeochemistry of the Ren gold prospect, Elko County, Nevada – the role of rock sampling in exploration for deep Carlin-type deposits. — Journal of Geochemical Exploration, 51: 37–58.

AREHART, G. B. 1996: Characteristics and origin of sediment-hosted disseminated gold deposits: a review. — Ore Geology Reviews, 11: 383–403.

AREHART, G. B.–ELDRIDGE, C. S.–CHRYSSOULIS, S. L.–KESLER, S. E. 1993a: Ion microprobe determination of sulfur isotope variations in iron sulfides from the Post/Betze sediment-hosted disseminated gold deposit, Nevada, USA. — Geochimica et Cosmochimica Acta, 57: 1505–1519.

AREHART, G. B.–FOLAND, K. A.–NAESER, C. W.–KESLER, S. E. 1993b: $^{40}Ar/^{39}Ar$, K/Ar, and fission track geochronology of sediment-hosted disseminated gold deposits at Post/Betze, Carlin Trend, northeastern Nevada. — Economic Geology, 88: 622–646.

AREHART, G. B.–KESLER, S. E.–O'NEIL, J. R.–FOLAND, K. A. 1992: Evidence for the supergene origin of alunite in sediment-hosted micron gold deposits, Nevada. — Economic Geology, 87: 263–270.

BAGBY, W. C.–BERGER, B. R. 1985: Chapter 8, Geologic characteristics of sediment-hosted, disseminated precious metal deposits in the western United States. — Reviews in Economic Geology, 2: 169–202.

BAKKEN, B. M.–HOCHELLA, M. F. JR.–MARSHALL, A. F.–TURNER, A. M. 1989: High-resolution microscopy of gold in unoxidized ore from the Carlin mine, Nevada.— Economic Geology, 84: 171–179.

BAKKEN, B. M.–EINAUDI, M. T. 1986: Spatial and temporal relations between wall rock alteration and gold mineralization, main pit, Carlin gold mine, Nevada, USA. — in MACDONALD, A. J. (ed.): Proceedings of Gold '86, an International Symposium on the Geology of Gold: Toronto, Canada: 388–403.

BERGER, B. R.–BAGBY, W. C. 1990: The geology and origin of Carlin-type gold deposits. — in FOSTER, R. P. (ed.): Gold Metallogeny and Exploration, Blackie and Son Ltd, Glasgow, Scotland.

BIRAK, D. J.–HAWKINS, R. J. 1985: The geology of the Enfield Bell mine and Jerritt Canyon district, Elko County, Nevada. — US Geological Survey Bulletin 1646: 95–105.

BIRAK, D. J. 1986: Exploration and geologic development of the Jerritt Canyon gold deposits, Elko County, Nevada, USA. — in MACDONALD, A. J. (ed.): Proceedings of Gold '86, an International Symposium on the Geology of Gold: Toronto, Canada: 488–496.

BIRAK, D. J.–DOE T. C.–STEVENS D. L. 1992: North Generator Hill gold deposit, Jerritt Canyon district, Nevada. — in HARTMAN H. L. (ed.): SME Mining Engineering Handbook, 2nd Edition: Society for Mining, Metallurgy, and Exploration, Inc., Littleton, Colorado, 1: 366–377.

BLAKELY, R. J.–JACHENS, R. C. 1991: Regional study of mineral resources in Nevada: Insights from three-dimensional analysis of gravity and magnetic anomalies. — Geological Society of America Bulletin, 103: 795–803.

BROOKS, R. A.–BERGER, B. R. 1978: Relationship of soil mercury values to soil type and disseminated gold mineralization, Getchell mine area, Humboldt County, Nevada. — Journal of Geochemical Exploration, 9: 183–194.

CHRISTENSEN, O. (ed.) 1993: Gold Deposits of the Carlin Trend, Nevada. — SEG Guidebook Series, 18: 105 p.

COYNER, A. R.–FAHEY, P. L. (eds.) 1996: Geology and Ore Deposits of the American Cordillera, Symposium Proceedings. — Geological Society of Nevada, Reno, Nevada: 1747 p.

CUNNINGHAM, C. G.–ASHLEY, R. P.–CHOU, I.–ZUSHU, H.–CHAOYUAN, W.–WENKANG, L. 1988: Newly discovered sedimentary rock-hosted disseminated gold deposits in the People's Republic of China. — Economic Geology, 83: 1462–1467.

DONGSHENG, L.–YUNJIN, T.–JIANYE, W.–LUANLING, L. 1991: Carlin-type gold deposits in China. — Brazil Gold '91, E.A. Ladeira, ed., Balkema, Rotterdam: 80–93.

DREWES–ARMITAGE, S. P.–ROMBERGER, S. B.–WHITNEY, C. G. 1996: Clay alteration and gold deposition in the Genesis and Blue Star deposits, Eureka County, Nevada. — Economic Geology, 91: 1383–1393.

ERICKSON, R. L.–MARRANZINO, A. P.–ODA, U.–JANES, W. W. 1964: Geochemical Exploration near the Getchell mine, Humbolt, county, Nevada. — US Geological Survey Bulletin 1198–A: 26 p., 2 pl.

ERICKSON, R. L.–VAN SICKLE, G. H.–NAKAGAWA, H. M.–McCARTHY, J. H. JR.–LEONG, K. W. 1966: Gold geochemical anomaly in the Cortez district Nevada. — US Geological Survey Circular 534.

FLEET, M. E.–MUMIN, A. H. 1997: Gold-bearing arsenian pyrite and marcasite and arsenopyrite from Carlin Trend gold deposits and laboratory synthesis. — American Mineralogist, 82: 182–193.

GRANEY, J. R.–KESLER, S. E.–JONES, H. D. 1991: Application of gas analysis of jasperoid inclusion fluids to exploration for micron gold deposits. — Journal of Geochemical Exploration, 42: 91–106.

GRAUCH, V. J. S.–JACHENS, R. C.–BLAKELY, R. J. 1995: Evidence for a basement feature related to the Cortez disseminated gold trend and implication for regional exploration in Nevada. — Economic Geology, 90: 203–207.

GRIMES, D. J.–FICKLIN, W. H.–MEIER, A. L.–McHUGH, J. B. 1995: Anomalous gold antimony, arsenic, and tungsten in ground water and alluvium around disseminated gold depsoits along the Getchell Trend, Humboldt County, Nevada. — Journal of Geochemical Exploration, 52: 351–371.

GROFF, J. A.–HEIZLER, M. T.–MCINTOSH, W. C.–NORMAN, D. I. 1997: $^{40}Ar/^{39}Ar$ dating and mineral paragenesis for the Carlin-type gold deposits along the Getchell Trend, Nevada: Evidence for Cretaceous and Tertiary Gold mineralization. — Economic Geology, 92: 601–622.

HAUSEN, D. M.–PARK, W. C. 1986: Observations on the association of gold mineralization with organic matter in Carlin-type ores. — in DEAN, W. C. (ed.): Organics and Ore Deposits, proceedings of the Denver Region Exploration Geologists Society: 119–136.

HAUSEN, D. M.–KERR, P. F. 1968: Fine gold occurrence at Carlin, Nevada. — in RIDGE, J. D. (ed.): Ore Depsoits of the United States, 1933–1967, v. 1, New York, AIME: 908–940.

HERAN, W. D.–MCCAFFERTY, A. M. 1986: Geophysical surveys in the vicinity of Pinson and Getchell mines, Humboldt County, Nevada. — US Geological Survey Open-File Report 86–432.

HERAN, W. D.–SMITH, B. D. 1984: Geophysical surveys at the Getchell and Preble disseminated gold deposits, Humboldt County, Nevada. — US Geological Survey Open-File Report 84–795.

HOEKSTRA, P.–HILD, J.–BLOHM, M. 1989: Geophysical surveys for precious metals exploration in the Basin-and Range, Nevada. — in BHAPPO, R. B.–HARDEN, R. J. (eds.): Gold Forum on Technology and Practices – World Gold '89: Society of Mining Engineering, Proceedings: 69–75.

HOFSTRA, A. H.–LEVENTHAL, J. S.–NORTHROP, H. R.–LANDIS, G. P.–RYE, R. O.–BIRAK, D. J.–DAHL, A. R. 1991: Genesis of sediment-hosted diseminated gold deposits by fluid mixing and sulfidization: Chemical-reaction-path modeling of ore-depositional processes documented in the Jerritt Canyon district, Nevada. — Geology, 19: 36–40.

HOFSTRA, A. H.–DALY, W. E.–BIRAK, D. J.–DOE T. C. 1992: Geologic framework and genesis of Carlin-type gold deposits in the Jerritt Canyon district, Nevada, USA. — in LADEIRA, E. A. (ed.): Brazil Gold '91, Rotterdam, A.A. Balkema: 77–87.

HOFSTRA, A. H.–SNEE, L. W.–RYE, R. O.–FOLGER, H. W.–PHINISEY, J. D.–NAESER, C. W.–STEIN, H. J.–LORANGER, R. J.–DAHL, A. R.–LEWCHUK, M. in press: Age constraints on Jerritt Canyon and other Carlin-type gold deposits in the western United States. – Relation to mid–Tertiary extension and magmatism. — Economic Geology.

HOLLAND, P. T.–BEATY, D. W.–SNOW, G. G. 1988: Comparitive elemental and oxygen isotope geochemistry of jasperoid in the northern Great Basin; evidence for distinctive fluid evolution in gold-producing hydrothermal systems. — Economic Geology, 83: 1401–1423.

HOOVER, D. B.–PIERCE, H. A.–MERKEL, D. C. m 1986: Telluric traverse and self potential data release in the vicinity of the Pinson mine, Humboldt County, Nevada. — US Geological Survey Open-File Report 86–341.

ILCHIK, R. P.–BARTON, M. D. 1997: An amagmatic origin of Carlin-type gold deposits. — Economic Geology, 92: 269–288.

ILCHIK, R. P. 1990: Geology and geochemistry of the Vantage gold deposits, Alligator Ridge–Bald Mountain minning district, Nevada. — Economic Geology, 85: 50–75.

ILCHIK, R. P.–BRIMHALL, G. H.–SCHULL, H. W. 1986: Hydrothermal maturation of indigenous organic matter at the Alligator Ridge gold deposits, Nevada. — Economic Geology, 81: 113–130.

JEWELL, P. W.–PARRY, W. T. 1987: Geology and hydrothermal alteration of the Mercur gold deposit, Utah. — Economic Geology, 82: 1958–1966.

JEWELL, P. W.–PARRY, W. T. 1988: Geochemistry of the Mercur gold deposit, Utah, USA. — Chemical Geology, v. 69: 245–265.

JORALEMAN, P. 1951: The occurrence of gold at the Getchell mine, Nevada. — Economic Geology, 46: 276–310.

KUEHN, C. A.–ROSE, A. R. 1992: Geology and geochemistry of wall-rock alteration at the Carlin gold deposit, Nevada. — Economic Geology, 87: 1697–1721.

KUEHN, C. A.–ROSE, A. R. 1995: Carlin gold deposits, Nevada: Origin in a deep zone of mixing between normally pressured and over pressured fluids. — Economic Geology, 90: 17–36.

LANDIS, G. P.–HOFSTRA, A. H. 1991: Fluid inclusion gas chemistry as a potential minerals exploration tool: Case studies from Creede, CO, Jerritt Canyon, NV, Coeur d'Alene district, ID and MT, southern Alaska mesothermal veins, and mid-continent MVT's. — Journal of Geochemical Exploration, 42: 25–59.

LEVENTHAL, J.–HOFSTRA, A. 1990: Characterization of carbon in sediment-hosted disseminated gold deposits, north central Nevada. — in HAUSEN, D. M.–HALBE, D. N.–PETERSEN, E. U.–TAFURI, W. J. (eds.): Gold '90, Proceedings of the Gold '90 Symposium, Salt Lake City, Utah, Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO: 365–368.

LOVERING, T. G. 1972: Jasperoid in the United States–Its characteristics, origin, and economic significance. — U.S. Geol. Survey Prof. Paper 710: 164 p.

MAHER, B. J.–BROWNE, Q. J.–McKEE, E. H. 1993: Constraints on the age of gold mineralization and metallogenesis in the Battle Mountain–Eureka mineral belt, Nevada. — Economic Geology, 88: 469–478.

MAO, S. H. 1991: Occurrence and distribution of invisible gold in a Carlin-type gold deposit in·China. — American Mineralogist, 76: 1964–1972.

NELSON, C. E.: Comparitive geochemistry of jasperoids from Carlin-type gold deposits of the western United States. — Journal of Geochemical Exploration, 36: 171–195.

ONEIL, J. R.–BAILEY, G. B.: Stable istope investigation of gold-bearing jasperoid in the central Drum Mountains, Utah. — Economic Geology, 74: 852–859.

RADTKE, A. S.–SCHEINER, B. J. 1970: Studies of hydrothermal gold deposition (I). Carlin gold deposit, Nevada: The role of carbonaceous materials in gold deposition. — Economic Geology, 65: 87–102.

RADTKE, A. S.–RYE, R. O.–DICKSON, F. W. 1980: Geology and stable isotope studies of the Carlin gold deposit, Nevada. — Economic Geology, 75: 641–672.

RADTKE, A. S. 1985: Geology of the Carlin gold deposit, Nevada. — US Geological Survey Professional Paper 1267: 124 p.

RAINES, G. L.–LISLE, R. E.–SCHAFER, R. W.–WILKINSON, W. H. (eds.) 1991: Geology and Ore Deposits of the Great Basin. — Symposium Proceedings, Geological Society of Nevada, Reno, Nevada: 1251 p.

ROBERTS, R. J. 1960: Alinement of mining districts in north-central Nevada. — US Geological Survey Professional Paper 400-B: B17–B19.

ROBERTS, R. J.–RADTKE, A. S.– COATS, R. R.–SILBERMAN, M. L.–McKEE, E. H. 1971: Gold-bearing deposits in north-central Nevada and southwestern Idaho, with a section on periods of plutonism in north-central Nevada. — Economic Geology, 66: 14–33.

ROMBERGER, S. B. 1986: Ore deposits #9. Disseminated gold deposits. — Geoscience Canada, 13: 23–31.

RYE, R. O. 1985: A model for the formation of carbonate-hosted disseminated gold deposits based on geologic, fluid inclusion, geochemcial, and stable isotope studies of the Carlin and Cortez deposits, Nevada. — in TOOKER, E. W. (ed.): Geologic Characteristics of Sediment- and Volcanic-Hosted Disseminated Gold deposits--Search for an Occurrence Model, US Geological Survey Bulletin 1646: 35–42.

RYTUBA, J. J. 1985: Geochemistry of hydrothermal transport and deposition of gold and sulfide minerals in Carlin-type systems. — US Geological Survey Bulletin 1646: 27–34.

SCHAFER, R. W.–COOPER, J. J.–VIKRE, P. G. (eds.) 1988: Bulk Minable Precious Metal Deposits of the Western United States. — Symposium Proceedings, The Geological Society of Nevada, Reno, Nevada: 755 p.

SILBERMAN, M. L.–BERGER, B. R.–KOSKI, R. A. 1974: K-Ar age relations of granodiorite emplacement and W and Au mineralization near the Getchell mine, Humboldt County, Nevada. — Economic Geology, 69: 646–656.

SILLITOE, R. H.–BONHAM, H. F. 1990: Sediment-hosted gold deposits: Distal products of magmatic-hydrothermal systems. — Geology, 18: 157–161.

TEAL, L.–JACKSON, M. 1997: Geologic overview of the Carlin Trend gold deposits and descriptions of recent discoveries. — SEG Newsletter, 31: 1 and 13–25.

THORMAN, C. H.–CHRISTIANSEN, O. D. 1991: Geologic settings of gold deposits in the Great Basin, western United States. — in LADEIRA, E. A. (ed.): Brazil Gold'91, Balkema, Rotterdam.

TINGLEY, J. V.–BONHAM, H. F. eds. 1986: Sediment-Hosted Precious-Metal Deposits of Northern Nevada. — Nevada Bureau of Mines and Geology Report 40: 103 p.

TOOKER, E. W. ed. 1985: Geologic Characteristics of Sediment- and Volcanic-Hosted Disseminated Gold deposits. – Search for an Occurrence Model. — US Geological Survey Bulletin 1646.

TURNER, S. J.–FLINDELL, P. A.–HENDRI, D.–HARDJANA, I.–LAURICELLA, P. F.–LINDSAY, R. P.–MARPAUNG, B.–WHITE, G. P. 1994: Sediment-hosted gold mineralization in the Ratatotok district, North Sulawesi, Indonesia. — Journal of Geochemical Exploration, 50: 317–336.

VIKRE, P.–THOMPSON, T. B.–BETTLES, K.–CHRISTENSEN, O.–PARRATT, R. eds. 1997: Carlin-Type Gold Deposits Field Conference — SEG Guidebook Series, 28: 287 p.

WANG, K.–ZHOU, Y. 1994: Mineralogy of the Carlin-type Dongbeizhai and Jinya gold deposits, southwestern China. — International Geology Review, 36: 194–202.

WELLS, J. D.–MULLINS, T. E. 1973: Gold-bearing arsenian pyrite determined by microprobe analysis, Cortez and Carlin gold mines, Nevada. — Economic Geology, v. 68: 187–201.

WELLS, J. D.–STOISER, L. R.–ELLIOTT, J. E. 1969: Geology and geochemistry of the Cortez gold deposit, Nevada. — Economic Geology, 64: 526–537.

WILLIAMS, C. 1993: Northeastern Nevada breccia bodies. — Symposium proceedings, Elko Chapter-Geological Society of Nevada.

WILSON, P. N.–PARRY, W. T. 1990: Mesozoic hydrothermal alteration associated with gold mineralization in the Mercur district, Utah. — Geology, 18: 866–869.

WILSON, P. N.–PARRY, W. T. 1995: Characterization and dating of argillic alteration in the Mercur gold district, Utah. — Economic Geology, 90: 1197–1216.

WRUCKE, C. T.–ARMBRUSTMACHER, T. J. 1975: Geochemical and geologic relations of gold and other elements of the Gold Acres ope pit mine, Lander County, Nevada. — US Geological Survey Professional Paper 860: 27 p.