Metalliferous Marine Black Shales and Fossil Petroleum Reservoirs – Source Rock and Host Environment for Carlin-Type Gold Deposits

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Abstract

Six Carlin-type (CT) gold deposits and four barren CT systems are compared using geochemical data for 45 major and minor elements. Variability in gold relates not only to the well-known epithermal suite (As, Sb, Hg, Ba, Tl), but also to a suite of elements which are enriched in metalliferous marine black shales (Li, P, Mn, Ba, Mo, Cr, Co, V, Cd, Ni, U, Zn and Pb).

Metalliferous marine black shales in the Great Basin are found in western assemblage rock units such as the Vinini and the Valmy Formations. The outcrop distribution of western assemblage rock units is similar to that of CT gold deposits. This observation supports a link between CT gold deposits and metalliferous marine black shales. The Vinini Formation and equivalent western assemblage units may represent the source of gold for CT deposits.

Samples of ore and altered host rock in CT deposits are enriched in hydrocarbon relative to unaltered host rock. Petrographic and fluid inclusion studies indicate that hydrocarbon enrichment occurred before hydrothermal alteration and before gold mineralization. Some deposits contain evidence for an associated brine. Carlin-type deposits may form by mixing of hydrothermal fluids enriched in gold with fossil petroleum reservoirs.

Introduction

Carlin-type gold discoveries in the Great Basin of the western United States are currently adding close to 200 tonnes (6.5 million ounces) of new reserves every year. Past production plus published reserves at 33 CT deposits total over 1800 tonnes (60 million ounces). The variably oxidized orebodies contain micron-size gold and disseminated pyrite. Host rocks include argillized and silicified carbonaceous limestones, dolomites, siltstones and shales.

Data are presented in Table 1 for 381 rock samples collected at six CT orebodies and four barren systems. The gold orebodies include Alligator Ridge, Carlin, Cortez, Horse Canyon, Jerritt Canyon, and Mercur. The barren systems are Black Cliff, Hot Creek, Iron Point and McCluskey Peak. As many as 60 drill holes in each of the four barren systems failed to reveal more than trace amounts of gold mineralization.

This paper deals with the genetic implications of the database, particularly the source of gold and the environment of deposition. A companion paper (Nelson, 1990) uses the same data to derive a discriminant function which distinguishes jasperoids sampled at CT ore deposits from those sampled at barren CT systems.

Host Rocks

Host rock types at the six orebodies include limestone, silty dolostone, silty limestone and shale. Carlin, Cortez and Hot Creek are hosted by the Silurian-Devonian Roberts Mountains Formation, a thin to medium-bedded, calcareous siltstone with minor carbonaceous material and early diagenetic pyrite (Radtke el al., 1980, Wells et al., 1969). Jerritt Canyon is hosted by the Roberts Mountains Formation and by the underlying Ordovician-Silurian Hanson Creek Formation (Birak and Hawkins, 1985). Alligator Ridge and Black Cliff are hosted by the lower member of the Devonian-Mississippian Pilot Shale, a fissile carbonaceous shale to siltstone with minor carbonate cement (Tapper, 1986). Mercur is hosted by a shale member of the Great Blue Limestone (Lenzi, 1973).

Several of the deposits are hosted by upper plate and overlap assemblage rock units (dominantly siliceous rocks that were emplaced during the Antler orogeny over autochthonous carbonates). Horse Canyon occurs in the Devonian Wenban Limestone and the Ordovician Vinini Formation (Coppinger, 1986). McCluskey Peak is hosted by the Devonian Denay Limestone and the Vinini Formation. Iron Point is hosted by the Ordovician Comus and Vinini Formations and the Cambrian Preble Formation (Erickson and Marsh, 1974).

Fossil Petroleum Reservoirs

Unoxidized portions of the six orebodies sampled are enriched in carbon relative to the background carbon

Table 1.
Geochemical Data for Six Carlin-Type Gold Deposits and Four Barren Carlin-Type systems.

Element	258 samples from 6 Carlin-type ore deposits			123 samples from 4 barren Carlin-type systems		
	Mean	Std. Dev.	Range	Mean	Std. Dev	Range
SiO2 pct	68.500	26.146	95.490	70.238	31.564	96.500
Al2O3 pct	4.410	3.238	15.470	2.693	2.284	16.620
Na2O pct	.076	.055	.317	.060	.055	.415
MgO pct	1.907	2.821	11.570	.910	1.597	8.420
CaO pct	8.142	11.823	51.950	8.328	15.590	54.400
K2O pct	1.045	.909	4.195	.634	.768	5.305
TiO2 pct	.172	.146	.880	.131	.138	.625
P ppm	628.968	684.829	5569.560	1117.303	2455.263	25097.400
Total C	2.206	2.726	10.310	2.024	3.362	10.930
Carbonate	9.748	13.893	51.615	8.971	17.305	54.715
LOI	9.489	10.917	41.780	8.683	13.359	41.940
Total S	.514	1.338	10.030	.570	2.128	12.660
Sulfate	.965	3.677	28.434	1.380	6.008	35.895
Sulfide	.232	.527	2.494	.130	.252	1.847
Total Fe	1.834	1.996	22.554	1.998	3.082	21.067
FeO pct	.223	.132	.650	.226	.346	3.750
Fe2O3 pct	1.603	1.980	21.225	1.854	3.215	21.025
Au ppb	1934.961	9053.937	93737.500	41.077	107.745	737.500
Ba ppm	10528.620	51839.610	469977.000	12256.240	71775.880	569997.000
Hg ppb	8927.529	41537.300	489997.500	8209.634	36269.600	299995.000
Sr ppm	221.041	436.724	4417.500	193.374	344.455	2368.000
As ppm	374.076	895.875	9697.500	188.679	547.204	4597.500
Zn ppm	96.136	157.628	1097.500	119.386	565.369	6159.500
Sb ppm	259.963	1361.947	19997.500	58.598	122.078	1137.500
V ppm	81.339	103.159	770.500	75.256	208.517	2147.500
Rb ppm	27.578	30.671	197.500	17.797	26.158	174.500
Tl ppm	10.169	29.920	279.750	.813	1.360	9.750
Ag ppm	2.370	9.168	108.090	5.083	34.691	369.750
Zr ppm	107.122	69.859	342.500	80.134	73.713	467.500
Cr ppm	109.793	84.953	370.500	109.650	119.253	602.500
Ni ppm	24.880	28.056	227.500	18.768	20.899	123.500
Mo ppm	6.236	9.039	73.500	10.573	24.825	209.500
Cu ppm	14.302	16.378	118.500	23.622	59.279	396.500
Pb ppm	18.376	37.330	524.500	44.728	236.469	2412.500
Cd ppm	1.273	2.417	24.500	2.217	12.545	137.500
Co ppm	3.826	3.971	24.500	3.183	5.304	35.500
U ppm	4.389	3.636	26.995	3.311	3.025	15.995
Se ppm	4.529	6.799	94.500	6.415	8.443	52.500
Te ppm	6.163	4.837	62.000	6.350	3.068	13.000
W ppm	4.321	3.442	22.995	6.128	12.315	97.995
Nb ppm	10.510	4.512	24.500	10.341	5.214	30.500
Li ppm	19.766	11.865	74.500	29.280	22.429	97.500
Bi ppm	1.554	1.673	14.000	2.154	2.799	20.000
Be ppm	.792	.578	2.500	1.142	.848	3.500
Mn ppm	196.200	285.733	2755.500	962.293	.292	35386.000

content of unaltered host rock. Carbonaceous ores typically run 1 to 5 percent carbon with local enrichments to as much as 20 percent. Carbon was not observed in veinlets in any of the jasperoid samples suggesting that hydrocarbon enrichment occurred before hydrothermal alteration.

Several paragenetic and fluid inclusion studies (Kuehn and Gize, 4 1985 and Hausen and Park, 1986) provide additional evidence for pre- hydrothermal carbon enrichment. Paragenetically early quartz veins at Carlin contain immiscible hydrocarbon globules (petroleum) and were formed at depths of several kilometers (Kuehn and Rose, 1987).

Evidence for pre-hydrothermal carbon enrichment is also reported by Levanthal et al. (1987) for Jerritt Canyon, where fluid inclusions from jasperoids contain as much as 10 equivalent weight percent NaCl (Hofstra et al., 1987). No high salinity fluid inclusion measurements have yet been reported for the Carlin deposit

(Kuehn and Rose, 1987; Rose and Kuehn, 1987).

Organically-derived hydrocarbon enrichment, immiscible petroleum globules, and local high salinity fluids suggest that CT gold deposits are also fossil petroleum reservoirs. Petroleum generation took place during the Mesozoic (Poole et al., 1983), at which time present-day northeastern Nevada was buried by several kilometers of overlying sediment (Kuehn and Bodnar, 1984). Hydrocarbons and associated brines accumulated in structural traps such as the faulted crest of the Tuscarora anticline.

Gold was introduced by Tertiary hydrothermal fluids which mixed with fossil petroleum reservoirs. Mixing of dilute gold-bearing hydrothermal fluids with a saline petroleum reservoir provides an appropriate mechanism for calcite dissolution, quartz replacement and gold mineralization.

Discoveries of very large CT deposits (e.g. Gold Quarry) and merging deposits in the Carlin trend indicate that mineralization can affect rock volumes approaching a cubic kilometer. Deep CT ore deposits such as Post and Cove contain drill intercepts several hundred vertical meters of continuous mineralization. These large altered rock reservoirs may be fossil petroleum fields.

Metalliferous Marine Black Shales

Most CT deposits are spatially associated with the Ordovician Vinini Formation and the correlative Valmy Formation (Figs. 1 and 2). The Valmy-Vinini sequence includes argillite, quartzite and chert with lesser greenstone, tuff and feldspathic quartzite. Syngenetic mineralization includes minor stratabound lead-zinc (Ketner, 1983), and bedded barite. Both formations contain metalliferous marine black shales (Poole and Desborough, 1985) and both are established sources of petroleum (Poole et al., 1983).

The Mississippian Chainman Shale was deposited in a flysch trough and pro-delta basin east of the Antler orogenic highland. Rock types vary from mudstone and calcareous shale to siltstone and metalliferous marine black shale. The Chainman Shale contains no greenstones or stratabound base metal sulfides such as those found in the Vinini, Valmy and Woodruff Formations but, it is a recognized source of petroleum in the Great Basin (Poole et al., 1983). Few CT gold deposits are spatially related to the Chainman Shale (Fig. 2).

The Chainman Shale was deposited relatively quickly. Concentration of metals from seawater is favored by deep

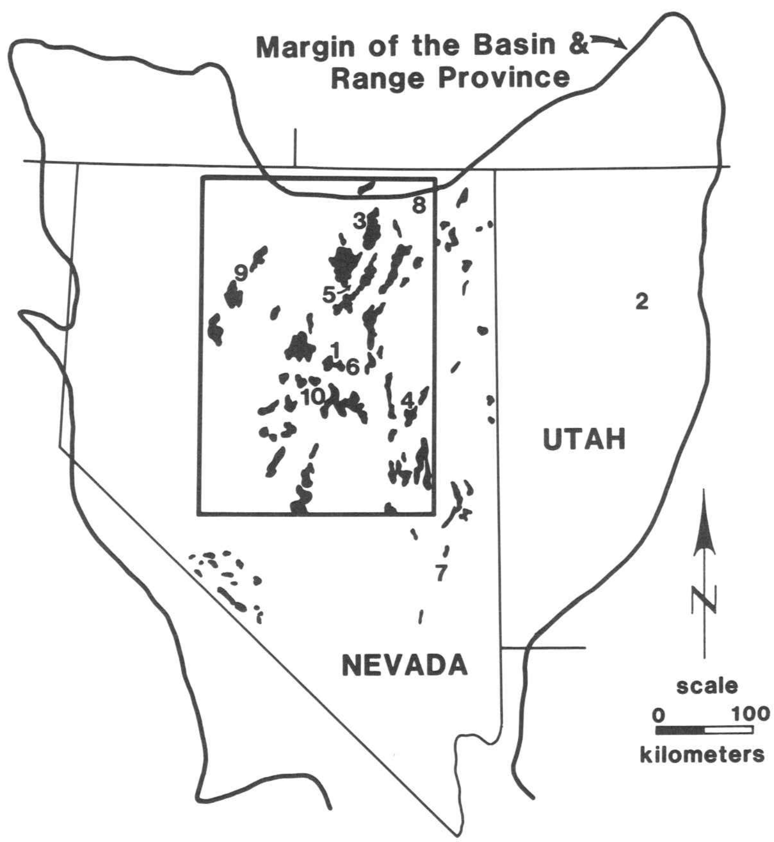

Fig. 1. Location map showing the distribution of rock units in the Basin and Range Province which are reported to contain metalliferous marine black shale. Locations of Carlin-type orebodies sampled for this study are numbered as follows: Cortez (1), Mercur (2), Jerritt Canyon (3), Alligator Ridge (4), Carlin (5), and Horse Canyon (6). Locations of barren Carlin-type systems sampled for this study are numbered as follows: Black Cliff (7), Hot Creek (8), Iron Point (9), and McCluskey Peak (10). Outcrop pattern for the Valmy, Comus, Vinini and Woodruff Formations and the Chainman Shale is taken from 12 the 1:500,000 scale geologic map of Nevada compiled by Stewart and Carlson (1978). A rectangular box outlines the area shown in Fig. 2.

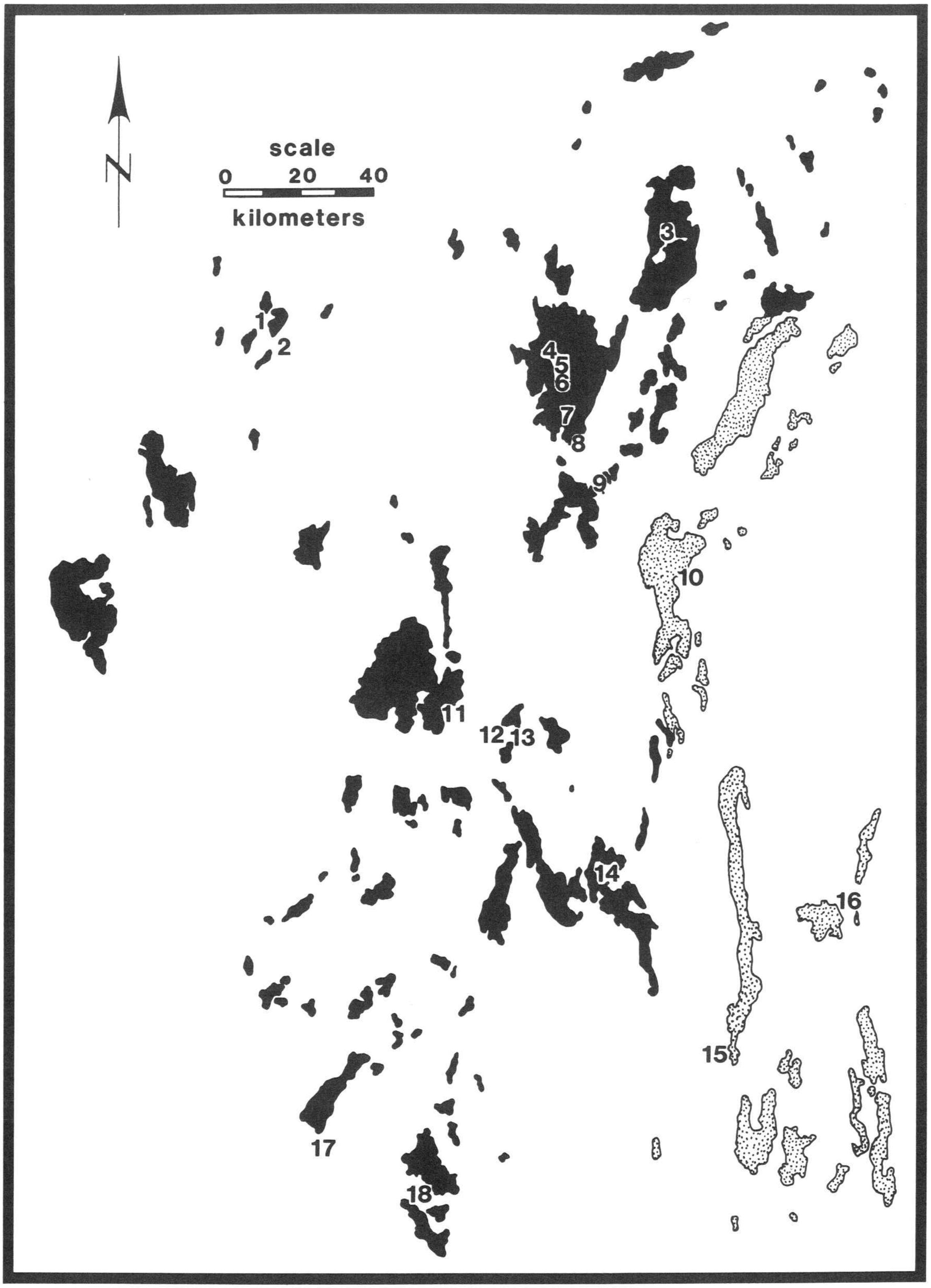
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Fig. 2. Outcrop distribution of rock units which contain metalliferous marine black shales in northeastern Nevada. Western assemblage rock units including the Valmy, Comus, Vinini, and Woodruff Formations are shown in a solid pattern. The Chainman Shale is shown in a stippled pattern. Carlin-type ore deposits are numbered as follows: Getchell (1), Pinson (2), Jerritt Canyon (3), Dee (4), Bootstrap (5), Goldstrike (6), Post and Bluestar (7), Carlin (8), Gold Quarry and Maggie Creek (9), Rain (10), Gold Acres and Robertson (11), Cortez (12), Horse Canyon (13), Tonkin Springs (14), Windfall (15), Alligator Ridge (16), Victorine (17), and Northumberland (18).

water environments where sedimentation rates are slow. The Vinini, Valmy, and Woodruff Formations are deep water sediments and contain much more metal than eastern assemblage shelf carbonates such as the Chainman. Large CT deposits will probably not be discovered where source rocks are absent (e.g. southeastern Nevada and western Utah).

Mercur, located far to the east of most CT orebodies, may have derived its gold from the Lower Mississippian Deseret Limestone, a locally metalliferous, phosphatic shale deposited in a starved basin along the western margin of the Mississippian carbonate platform.

Hydrothermal leaching of gold and associated elements from a rock sequence containing metalliferous marine black shales results in a fluid capable of forming a gold orebody. A permeable reservoir enriched in organically-derived hydrocarbon provides a favorable environment for gold precipitation. Barren systems may simply lack a pre-existing petroleum reservoir.

Conclusions

This study suggests that gold in CT deposits is derived from a stratigraphic section containing metalliferous marine black shales. Hydrothermal solutions which circulate through a favorable source rock sequence leach gold plus a distinctive suite of minor elements. Hydrothermal fluids which do not circulate through a favorable source rock form barren systems.

This study also suggests that CT deposits were once petroleum reservoirs. Hydrothermal fluids which encounter fossil petroleum reservoirs may form CT orebodies. Hydrothermal fluids which do not encounter fossil petroleum reservoirs, or which contain no gold to begin with, form barren systems.

The proposed source of gold in CT deposits is supported by 1) the observation that CT orebodies are spatially related to rock units which contain metalliferous marine black shales, and 2) the observation that a metalliferous marine black shale geochemical suite can be used to distinguish jasperoids sampled at barren CT systems from jasperoids sampled at CT orebodies (Nelson, 1990).

The host environment is supported by 1) petrographic and fluid inclusion evidence for pre-hydrothermal enrichment of saline, petroliferous fluids, and 2) the similarity in structural setting for petroleum fields and CT gold deposits.

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