

0.40 percent or a factor of 40. The efficacy of chlorine content of biotites as a mineral exploration tool has not yet been demonstrated, due to lack of sufficient analyses for statistical validity. However, the close correlation between chlorine content of biotite with copper content and the established relationship between copper content of biotites and ore deposits suggests chlorine content may serve as an effective exploration tool.

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W. T. PARRY

DATA ON MAJOR AND MINOR ELEMENTS IN HOST ROCKS AND ORES, CARLIN GOLD DEPOSIT, NEVADA*

The purpose of this communication is to summarize and make available a large amount of data on the content of major and minor elements in the host rocks and ores of the Carlin gold deposit and to show the changes in the abundance of these elements as a result of hydrothermal mineralization and subsequent oxidation. Other aspects of the study of minor elements in the Carlin deposit, including the correlation between elements in various types of ore and the influence of geologic features on spatial distribution, will be presented in a later paper. The Carlin gold deposit is located about 33 miles northwest of Elko, Nevada (Fig. 1).

The deposit is characterized by large disseminated replacement-type ore bodies in the upper beds of the Silurian Roberts Mountains Formation. Several of these ore bodies are currently exposed in the West, Main, and East Pit areas of the mine. Although detailed information on the depth of gold deposition and the geometry of individual ore bodies cannot be disclosed (by agreement with Newmont Mining Corporation), the host rocks have been hydrothermally altered in some parts of the deposit to a depth of 800+ feet. Small amounts of gold are scattered throughout this depth, and larger amounts, concentrated in several zones, make up the ore bodies.

The host rocks for the ore bodies are dark- to medium-gray, thin-bedded, siliceous, argillaceous, dolomitic limestones. Mineralogically the rocks are made up of large and widely varying amounts of calcite, dolomite, illite, and quartz, plus minor kaolin, montmorillonite (?), chlorite, K-feldspar, plagioclase, pyrite, zircon, barite, rutile, sphene, and carbonaceous materials. Complete chemical analyses of the fresh

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carbonate rocks are given by Hausen (1967), Hausen and Kerr (1968), and Radtke and Scheiner (1970).

Gold and the other associated elements were deposited from an acid hydrothermal solution which introduced significant amounts of silica and barite and removed large amounts of carbonate from the limestone host rock. The primary gold ores are made

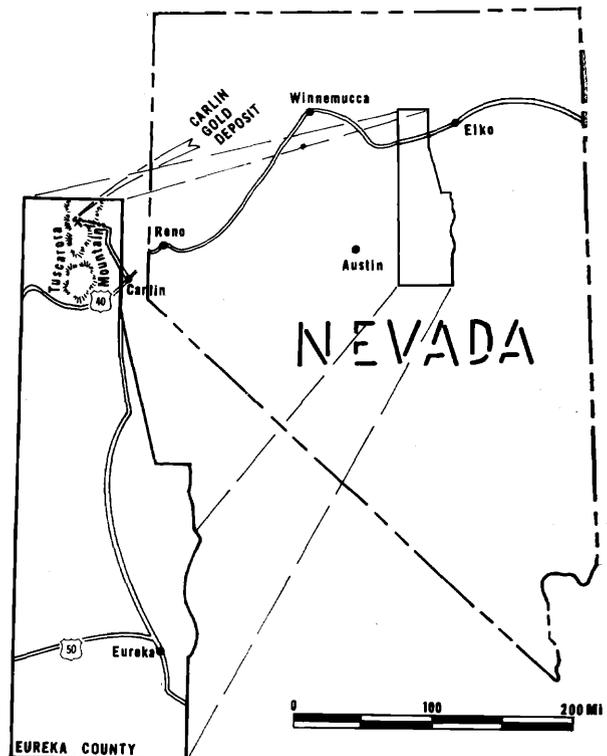


FIG. 1. Index map showing the location of the Carlin gold deposit in north-central Nevada.

Table 1. Major and minor elements in carbonate host rocks and primary and oxidized ores.

[Si, Al, Fe, Ca, Mg, K, Na, P, S and C are in parts per million. Elements sought but not found in spectrographic analysis along with sensitivity (shown in parenthesis), include: Bi (7), Eu (50), Ge (7), Hf (50), Li (200), P (5,000), Pd (1), Pt (10), Re (15), Ta (50), Th (150), and U (500). N signifies not determined or not calculated. Where only part of the total number of samples contained detectable amounts of an element, the average was calculated by assuming the content of the element in those samples was half-way between the limit of detection and zero.]

Element	Sensitivity	Samples with de- tectable amounts/number		Fresh carbonate host rocks		Mineralized carbonate rocks		Oxidized mineralized rocks		Method ^{1/} of Analysis		
		Range	Median	Average ^{1/}	Range	Median	Average ^{1/}	Range	Median		Average ^{1/}	
Si (percent)		10/10	9-18	12.5	13	30/30		18/18	15-40	26	29	R
Al do.		10/10	0.7-2.9	1.2	1.5	30/30		18/18	1.7-5.6	3.9	4.2	R
Fe do.		10/10	0.3-0.9	0.6	0.6	30/30		18/18	0.5-3	1.4	1.5	R
Ca do.		10/10	18.8-29.8	22.1	22.9	30/30		18/18	0.2-10	4.1	3.5	R
Mg do.		10/10	1-4	2.4	2.6	30/30		18/18	0.3-3.7	2.0	2.2	R
K do.		10/10	0.2-1.1	0.65	0.7	30/30		18/18	0.4-2.3	1.7	1.9	R
Na do.		10/10	0.01-0.1	0.02	0.02	29/30		18/18	0.01-0.15	0.03	0.03	R
P do.		7/10	<0.01-0.05	0.01	0.02	29/30		18/18	0.01-0.9	0.04	0.05	R
S do.	0.005	7/7	0.05-0.26	0.14	0.13	44/44		1/4	N	N	N	X
C do.		40/40	0.11-0.95	0.25	0.3	60/60		45/45	0.03-0.15	0.07	0.08	LC
(organic)												
Ag (ppm)	0.7	0/40	N	N	N	75/120		88/250	<0.7-2	<0.7	0.4 ?	S
As do.	10	2/15	<10-10	N	N	60/60		50/50	40->10,000	320	450	X,C
Au do.	0.02	2/40	<0.02-0.06	N	N	120/120		250/250	0.06-125	11	12	A
B do.	7	22/40	<7-70	15	15 ?	118/120		250/250	7-300	70	80	S
Ba do.	10	40/40	27-1,000	200	150	120/120		250/250	200-100,000	1,500	2,300	X,S
Be do.	1	1/40	<1-1	N	N	30/120		130/250	<1-3	1	1	S
Cd do.	50	0/40	N	N	N	2/120		0/250	N	N	N	S
Ce do.	70	0/40	N	N	N	2/120		22/250	<70-300	N	N	S
Co do.	2	4/40	<2-7	N	N	114/120		243/250	<2-150	7	7	S
Cr do.	1	40/40	7-70	30	30	120/120		250/250	15-700	50	60	S
Cu do.	1	40/40	2-30	15	9	120/120		250/250	7-200	50	45	S
Ga do.	2	30/40	<2-15	3	5	115/120		248/250	<2-30	10	10	S
Hg do.	0.01	40/40	0.02-0.24	0.07	0.08	120/120		250/250	0.2-130	21	20	V,A
La do.	20	2/40	<20-30	N	N	94/120		183/250	<20-200	30	35	S
Mn do.	1	40/40	70-200	100	125	120/120		250/250	7-700	150	180	S
Mo do.	2	5/40	<2-5	N	N	104/120		220/250	<2-50	7	7	S
Nb do.	1	1/40	<7-7	N	N	47/120		150/250	<7-20	7	7	S
Ni do.	1	1/30	1-30	10	12	120/120		250/250	1.5-500	30	45	S
Pb do.	7	6/40	<7-15	N	N	115/120		243/250	<7-200	20	30	S
Sb do.	0.5	9/15	<0.5-3	0.5	0.8	60/60		50/50	5-450	110	125	X,C
Sc do.	2	16/40	<2-7	N	3	115/120		250/250	3-30	10	10	S
Se do.	1	0/10	N	N	N	45/100		75/250	<1-40	N	1 ?	A
Sn do.	7	0/40	N	N	N	1/120		3/250	<7-20	N	N	S
Str do.	5	40/40	150-2,000	500	625	120/120		250/250	20-2,000	100	140	S
Te do.	0.2	0/10	N	N	N	9/100		29/250	<0.2-0.4	N	N	A
Ti do.	2	40/40	70-2,000	850	810	120/120		250/250	300-5,000	1,500	1,700	S,R
Tl do.	50	0/40	N	N	N	4/120		22/250	<50-150	N	N	S
V do.	3	40/40	10-500	70	100	120/120		250/250	50-1,500	100	140	S
W do.	20	0/15	N	N	N	13/100		23/250	<20-400	N	14 ?	C
Y do.	10	35/40	<10-30	15	15	120/120		250/250	10-70	20	25	S
Yb do.	10	32/40	<1-2	1	2	118/120		250/250	1-7	2	2.5	S
Zn do.	5	10/10	8-27	11	14	50/50		10/50	10-620	130	110	X,A
Zr do.	5	40/40	30-150	100	90	120/120		250/250	30-300	150	150	S

^{1/}Average is the arithmetic mean.
^{2/}Values for shallow unoxidized ore.
^{3/}Values for deep unoxidized ore.
^{4/}Calculated average does not include one or more anomalously high values.
^{5/}R = Rapid rock analysis; S = Semiquantitative spectrographic analysis; A = Atomic absorption; X = X-ray fluorescence; V = Instrumental mercury meter; LC = Ieco combustion system.

up of widely varying amounts of quartz, illite, calcite, dolomite, and barite, the same minor accessory minerals present in the host rocks, plus pyrite, pyrrhotite, arsenopyrite, realgar, orpiment, stibnite, chalcopyrite, sphalerite, galena, cinnabar, molybdenite, and several sulfosalt minerals. The primary ores may be divided into several distinct types based on the form and associations of gold, the content of silica and organic carbon, and the abundance of the various hydrothermal minerals present. For the purpose of this paper the data for mineralized carbonate rocks (primary ores), as summarized in Table 1, include analyses of samples of all the various types of unoxidized ores.

The upper parts of the ore bodies have undergone oxidation induced by shallow oxygen-bearing meteoric waters. This resulted in the destruction of sulfide minerals and carbonaceous materials, removal of more carbonate, development of zones of weathered pyritic alteration, and bleaching the rocks light gray to tan. Values for the major chemical constituents in oxidized mineralized rocks are given by Hausen (1967) and Hausen and Kerr (1968), and data on minor elements are included in these papers and in publications by Hardie (1966) and Akright, Radtke, and Grimes (1969). Most of the values for individual elements reported in these papers correspond reasonably well to the data summarized in Table 1. The notable exception is the data for mercury in fresh rocks of the Roberts Mountains Formation. This was erroneously reported by Akright, Radtke, and Grimes (1969) to range from 10 to 40 ppm (parts per million) and to average 20 ppm, whereas the correct values are 0.02 to 0.2 ppm and the average is 0.08 ppm.

Data reported in Table 1 were obtained from various types of analyses of 40 samples of fresh Roberts Mountains Formation, 120 samples of unoxidized mineralized limestone, and 250 samples of oxidized mineralized rock. Semiquantitative spectrographic analyses were run on all the samples. Other types of analyses were performed on selected samples (see Table 1). The samples of fresh limestone represent part of a suite of hand specimens collected in both the Lynn and Carlin windows, as well as composite 5-foot intervals in rotary drill holes in various areas west and south of the Carlin deposit and at least half a mile away from the deposit. Most, but not all, of these samples probably were collected from the upper beds of the Roberts Mountains Formation within the same general stratigraphic interval containing the gold ore bodies at Carlin. Samples of mineralized limestone, including various types of carbonaceous ores, were collected from exposed faces in the East Pit area, as well as cuttings from composite 5-foot intervals in deeper parts of rotary drill holes in both the East and Main Pit areas. Oxidized

samples were taken from exposed faces in the West and Main Pit areas and from drill cuttings from shallow parts of the same areas.

In terms of the amount of material involved, the most important change in the rocks during mineralization was the removal of calcite and dolomite and the introduction of silica. The apparent increase in aluminum probably principally reflects residual enrichment resulting from the removal of carbonate. This relationship is indicated by: (1) the relatively constant ratio of $Al:K + Na + P$ in the mineralized and fresh rocks; (2) the obvious increases in rock porosity; and (3) the absence of any significant amounts of introduced kaolin and other aluminum-bearing minerals. The increase in iron reflects the introduction of pyrite and smaller amounts of pyrrhotite and arsenopyrite. Aside from silica and iron, the average abundances of important elements introduced into the limestone by the ore solution to form the primary unoxidized ores are, in decreasing order, barium (2,200 ppm), arsenic (480 ppm), zinc (185 ppm), antimony (130 ppm), boron (70 ppm), copper (35 ppm), lead (30 ppm), lanthanum (30 ppm), mercury (25 ppm), tungsten (18 ppm?), gold (11 ppm), molybdenum (7 ppm), selenium (2 ppm?), and silver (0.4 ppm?). Approximate enrichment factors for these elements in the primary ores vs. the fresh host rocks are gold ($> 550 \times$), mercury ($> 300 \times$), antimony (160 \times), arsenic ($> 50 \times$), barium (15 \times), zinc (13 \times), boron (5 \times) molybdenum ($> 4 \times$), lead ($> 4 \times$), copper (4 \times), and selenium ($> 2 \times$). Silver, tungsten, and lanthanum were also enriched, but the data sets available preclude the calculation of meaningful enrichment factors.

As a result of the removal of carbonate during postore oxidation, the shallow oxidized ores underwent residual enrichment in such elements as silicon, aluminum, potassium, sodium, phosphorus, barium, titanium, and zirconium. Although the average content of gold remained about the same, the average abundance of most of the other elements introduced during mineralization decreased after oxidation.

The authors wish to acknowledge the help and assistance of the numerous individuals who carried out the various types of analyses. Rapid rock analyses were performed under the direction of Leonard Shapiro, U. S. Geological Survey, Washington, D. C. Spectrographic analyses and X-ray fluorescence analyses for sulfur, arsenic, barium, antimony, and zinc were done in the U. S. Geological Survey laboratories at Menlo Park, Calif. Atomic absorption analyses for selenium, tellurium, zinc, and gold, colorimetric analyses for arsenic, antimony, and tungsten and instrumental mercury meter analyses for mercury were done in U. S. Geological Survey

laboratories at Denver, Colorado. Additional data on gold were provided by Carlin Gold Mining Company. The Mines Experiment Station, U. S. Bureau of Mines, Reno, Nevada, generously supported the work by performing analyses for mercury using the Lemaire sniffer atomic absorption method, and analyses for organic carbon by the Leco combustion method.

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APPLICATION OF REGRESSION ANALYSIS TO THE STUDY OF BACKGROUND VARIATIONS IN TRACE METAL CONTENT OF STREAM SEDIMENTS

The first step in the interpretation of regional geochemical data is recognition of normal or background variations in trace metal content. In the case of drainage sediments these variations, although predominantly influenced by bedrock geology, commonly reflect a variety of factors. Although orientation surveys might suggest sampling or analytical techniques whereby background variation can be minimized or even used to advantage, fluctuation of metal content of sediments unrelated to mineralization will still present problems in interpretation. Routine measurement of all parameters known to influence metal content of sediments is not practical and in some remote regions even basic geological data are lacking. Consequently, it would be useful if a few simple parameters, measured either in the field or on the sediments, could be used to account for observed variations in trace metal content. A group of such easily measured parameters are applied to interpretation of stream sediment samples in this communication. These include percentage of fines, loss on ignition, pH of stream water and iron and manganese content of sediments.

In Pennsylvania, Rose and Suhr (1971) and Rose et al. (1970) have used regression analysis to investigate relationships between trace elements as dependent variables and independent variables such as bedrock geology, and physical, chemical or mineralogical composition of the sediments. Having established a regression equation, predicted and actual metal values can be compared and anomalous

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samples, with marked positive differences between these values (residuals), noted for follow-up. A similar approach has been used in the present study to investigate trace element content of a set of sediments from central British Columbia.

Sample Collection and Analysis

Forty stream sediment samples were collected in the summer of 1971 in an area of 120 square miles covering a quartz monzonite intrusion about 25 miles south of Prince George, British Columbia. Apart from the quartz monzonite, less abundant rock units which contribute to the sediments include granites and country rock consisting of micaceous quartzites and phyllites, and locally derived glacial deposits. Active sediments were collected a short distance above access roads. Stream water pH, measured in the field with BDH Liquid Universal Indicator, was found to vary between 5.7 and 7.9.

All samples were air-dried, disaggregated and sieved to minus 80-mesh for analysis. Copper, zinc, iron, manganese and nickel were determined by atomic absorption after digestion with a 4:1 mixture of nitric and perchloric acids. Results for nickel were corrected for background absorption which would otherwise result in spuriously high reading (Fletcher, 1970). Analytical precision, based on duplicate analyses, is generally better than ± 15 percent at the 95 percent confidence level.

Loss on ignition, which is probably due largely to organic matter and H₂O, was determined for all