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GEOCHEMISTRY OF SELECTED ROCK SAMPLES: COLADO GEOTHERMAL AREA, NEVADA

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ABSTRACT

This report presents the results of the chemical analysis of 30 surface rock samples from the Colado geothermal area. The samples represent a variety of materials affected by several hydrothermal events which have formed Au, Sb and clay deposits within the area. The active geothermal system is currently being evaluated for electrical power production.

The elements As, Sb, Au, Ag, Li and Hg have been concentrated during more than one of the hydrothermal events which have affected the Colado area. Distinct chemical signatures do not exist for any particular event, instead, it appears that this suite of elements has been repeatedly remobilized, probably in response to similar physical and chemical conditions and processes. Delineation of geochemical zoning related to the active geothermal system is possible only because it is spatially separated from the older hydrothermal deposits.

The chemical similarity between the older hydrothermal events and the present hydrothermal system suggest that the Sb and Au mineralization formed at shallow depths in a boiling geothermal environment. It is suggested that new ore zones may be discovered in the Willard mining district if the geothermal model is applied to exploration.

INTRODUCTION

The Colado geothermal area lies in south-central Pershing County, Nevada, about 10 km northeast of Lovelock on the western flank of the West Humboldt Range. The geothermal potential of the area for electrical power production is currently being evaluated by Getty Oil Company in cooperation with the Division of Geothermal Energy of the U.S. Department of Energy through the Industry Coupled Case Study program.

The geology of the Colado area has recently been mapped and reviewed by Sibbett and Bullett (1980) and the multielement geochemistry of temperature gradient hole cuttings evaluated by Christensen (1980). During geologic mapping of the area, numerous rock samples were collected for petrographic and geochemical studies. This report presents the results of the chemical analyses and evaluates these results within the context of the chemical model developed from the geochemistry of the gradient hole cuttings.

Thirty rock samples were prepared and analyzed for 38 elements by inductively-coupled plasma emission spectroscopy (ICP) as described by Christensen (1980) and Christensen and others (1980). Statistical reduction or analysis of chemical data was not performed since (1) the number of values is insufficient and (2) the analyzed samples represent a variety of materials and thus do not constitute a valid statistical population.

DISCUSSION

The collection locations of samples are shown on Figure 1, sample descriptions are presented in Table 1, and sample geochemistry is tabulated in Table 2. The samples represent a variety of materials collected from throughout the geothermal area.

The Colado geothermal area has been the center of several previous hydrotnermal events (Sibbett and Bullett, 1980). These events produced the Sb and Au deposits east of the present geothermal system, and the clay deposits and Cu prospects in tributaries of Coal Creek which collectively are included in the Willard mining district (Johnson, 1977). Au ore from the Willard group of mines (Figure 1) apparently consists of free-milling gold and silver in Cu-stained quartz veins containing galena, sphalerite, and garnet. Cu prospects on the south side of Coal Canyon apparently explore similar veins (Johnson, 1977).

The Sb mines have been developed on quartz-stibnite veins that strike nearly parallel to bedding within the metasedimentary host rocks. Stibnite occurs as pods and individual crystals in quartz and calcite veins and within fractures in bedrock. Reported assays show Sb, Ag, and traces of Au (Johnson, 1977).

The clay deposits occur in Tertiary volcanic units where hydrothermal alteration of vitric and tuffaceous rocks has been intense. Montmorillonite is the principal clay mineral; impurities include cristobalite, quartz, feldspar, calcite, zeolites, and gypsum.

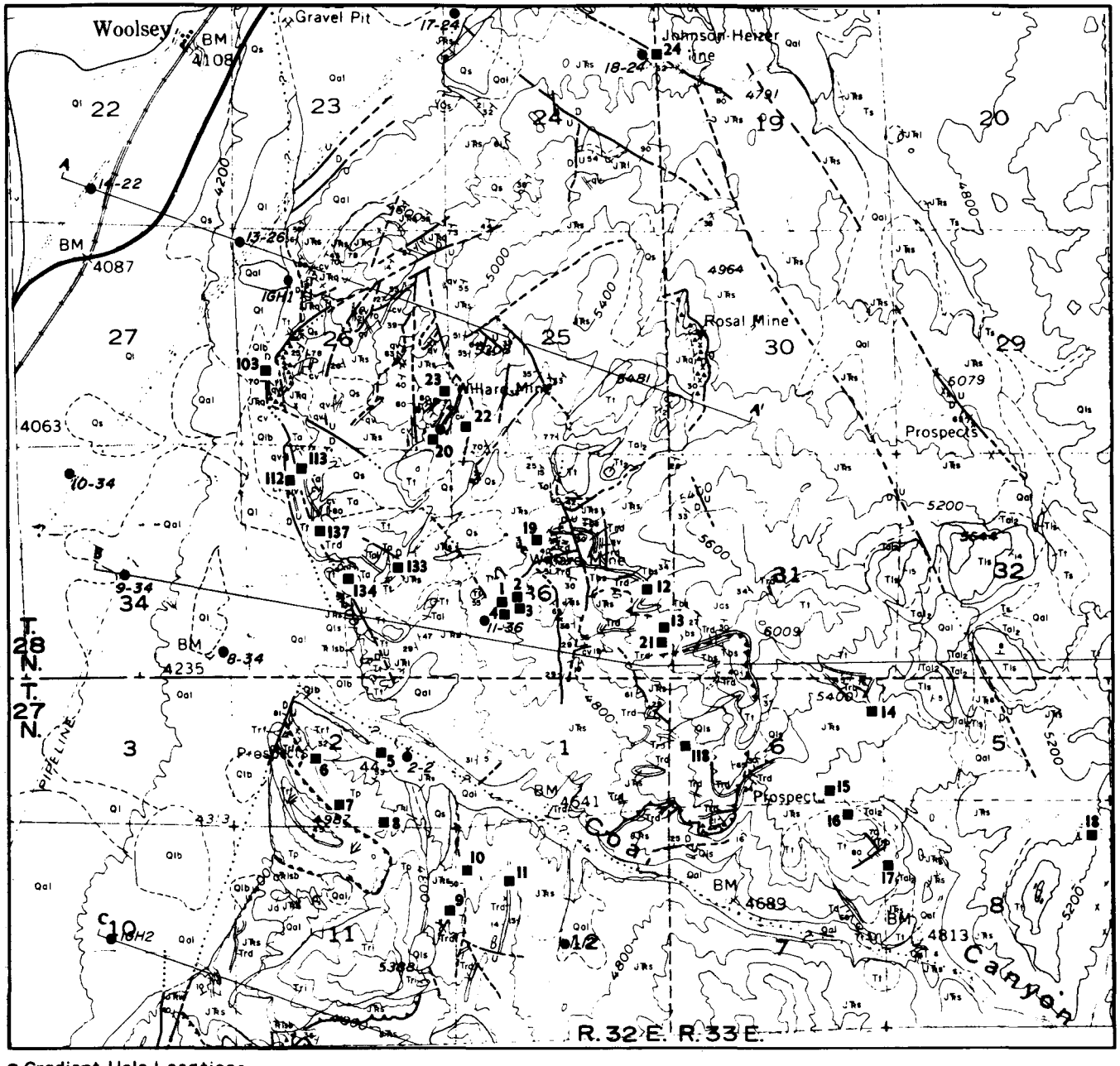

Figure 1. SAMPLE LOCATIONS

GEOLOGIC BASE FROM SIBBETT AND BULLETT (1980)

The present geothermal system is centered beneath alluvium along the western edge of the West Humboldt Range. Thermal waters probably rise along a major fault intersection in the Mesozoic rocks then spread out in a shallow aquifer in the alluvium (Sibbett and Bullett, 1980). Christensen (1980) has shown that enrichments of As, Li, Hg and Be are associated with the present geothermal system.

The samples discussed here were collected in part to evaluate the chemical signatures associated with each type of mineralization. Samples collected from prospect pits, mine dumps and quartz veins in the vicinity of the Willard Mine include numbers 1, 2, 3, 4, 13, 19, 20, 22 and 23. Sample 24 was collected at the Johnson-Heizer mine, the largest Sb mine in the district. Samples 5, 6, 7, 8, 14, 16, 17 and 18 represent clay materials associated with volcanic units. Brecciated and altered materials associated with range-front faults include numbers 103, 112, 113, 134, and 137. The remaining samples are of a variety of rocks types and veins from throughout the area. For comparative purposes, a summary of geochemical data from the gradient hole samples investigated by Christensen (1980) is included as Table 3.

Although the effects of the different periods of mineralization are recognizably distinct, the suite of characteristic trace elements is largely the same for all hydrothermal events including the present geothermal system. Materials associated with the precious metal mineralization of the Willard mines are characterized by consistently high concentrations of Li, Cr, Cu, Hg and As, and some high concentrations of Pb and Ag. Concentrations of As up to 1250 ppm are especially noted. Vein material from the Johnson-Heizer Sb mine

is characterized by unusually large concentrations of Sb, Au and As. Samples collected from clay pits in altered Tertiary volcanic rocks have notably high concentrations of Au and Be and occasionally of Hg. The brecciated material associated with range-front faults has anomalous concentrations of As, Sb, Hg and Au.

The elements As, Sb, Au, Ag, Li and Hg were remobilized and concentrated during more than one of the hydrothermal events which have affected the Colado thermal area. Distinct chemical signatures do not exist for any event. Instead, it appears that this suite of elements has been repeatedly remobilized, probably in response to similar physical and chemical conditions extant during the sequential hydrothermal events.

Christensen (1980) has shown that a distinctive zoning of As, Hg, Li and Be exists in gradient hole cuttings from the Colado geothermal area. Enrichments of these elements outline an area coincident with a thermal anomaly related to fluid flow within the active geothermal system. Geochemistry has been shown to be a useful exploration tool in this situation where the chemical record of the active system is developed upon the chemically homogeneous alluvial matrix. Had the present geothermal system and the gradient holes been coincident with the older mineralization, it is doubtful that the chemical distributions related to the multiple events could be distinguished. Such a coincidence of hydrothermal events and geochemical signatures has been described for the Cove Fort-Sulphurdale area in Utah (Ross and others, 1981).

The chemical similarity between the older hydrothermal events and the

present geothermal system strongly suggests that the Sb and Au mineralization formed at shallow depths in a boiling geothermal environment. Deposition of metals probably occurred as a direct result of boiling or flashing of hydrothermal fluids, as has been described for modern geothermal systems (Weissberg, 1969; White and others, 1971; Weissberg and others, 1980). Recognition of this genetic relationship suggests that additional ore bodies may exist at depth, vertically stacked along fluid-flow controlling structures.

The geothermal model proposed for deposits of the Willard mining district is essentially that described by Buchanan (1980) for the Guanajuato mining district, Mexico. This model requires an anomalously high geothermal gradient which acts as a driving force behind a convecting hydrothermal system. Hydrothermal fluids become heated, leach alkalies and metals from rocks along their flow path, and rise toward the surface. The water rises past the depth where hydrostatic pressure is insufficient to prevent boiling and boiling occurs, resulting in significant chemical and physical changes in the solutions and precipitation of ore and gangue minerals.

Mineral precipitation frequently results in a self-sealing of fluid channels, effectively stopping the discharge of fluids upward. Fracturing of the sealing cap due to tectonic or thermal stress may cause a sudden reduction in pressure and flashing of the fluid column below the base of the sealing cap to a depth dependent on the temperature profile and fluid composition. This flashing may lead to mineral precipitation deeper in the system. Thus, two types of boiling are recognized: hydrostatic boiling and flashing

(Buchanan, 1980). Two or more levels of mineralization, not necessarily connected, may be developed.

It is suggested that new ore production zones may be discovered beneath the Willard district if the geothermal model is applied. Alteration and fluid inclusion studies may serve as useful drilling guides.

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TABLE 1

Sample Descriptions

Sample Number	Description
NVC80-1	Mudstone-siltstone from mine working
NVC80-2	Stained and altered mudstone from prospect pit
NVC80-3	Stained and altered mudstone from prospect pit
NVC80-4	Mudstone-siltstone with quartz veining from adit entrance
NVC80-5	Clay from altered rhyolite
NVC80-6	Clay from altered rhyolite
NVC80-7	Perlite
NVC80-8	Clay from altered rhyolite
NVC80-9	Quartz vein in siltstone from adit
NVC80-10	Quartz vein in siltstone
NVC80-11	Rhyolite sill intruding mudstone/shale
NVC80-13	Mine dump sample: mudstone with quartz veining
NVC80-14	Clay from altered rhyolite
NVC80-15	Quartz vein in shale; trench cut
NVC80-16	Clay prospect; hematite stained
NVC80-17	Altered ash-flow tuff: clay prospect
NVC80-18	Altered rhyolite tuff: clay prospect
NVC80-19	Fracture-filling quartz vein in mudstone at Willard Mine, south area
NVC80-20	Quartz vein material from dump of north Willard Mine
NVC80-21	Altered rhyolite dike
NVC80-22	Quartz vein in mudstone from north Willard Mine dump
NVC80-23	Quartz and calcite vein, north Willard Mine

NVC80-24	Quartz vein in siltstone, Johnson Heizer Mine
NVC80-103	Silicified breccia in fault zone
NVC80-112	Kaolinite near range-bounding fault
NVC80-113	Altered and hematite-stained andesite between quartz and calcite veins
NVC80-118	Siltstone
NVC80-133	Conglomerate
NVC80-134	Altered andesitic flow
NVC80-137	Hematite-stained quartz breccia from fault zone

TABLE 2 GEOCHEMISTRY OF SAMPLES

	1	2	3	4	5	6	7	8
Na_2O, %	.116	.052	.088	.055	1.73	2.87	2.98	3.06
K_2O, %	2.04	1.44	2.40	2.64	2.80	2.71	2.76	3.57
CaO, %	1.02	6.13	.413	.252	4.94	6.21	.850	1.09
MgO, %	.447	.692	.547	.442	.788	.374	.114	.232
Fe_2O_3, %	3.03	2.35	2.11	1.00	1.30	1.08	1.24	1.40
Al_2O_3, %	6.97	5.16	7.74	7.33	14.41	12.53	12.54	12.26
TiO_2, %	.262	.261	.341	.309	.064	.056	.062	.109
P_2O_5, %	.439	.165	.108	.050	.131	<.002	<.002	.063
Sr, ppm	254	117	66	55	129	86	45	289
BaO, %	.106	.065	.188	.176	.021	.012	.017	.025
Cr, ppm	67	37	67	38	<2	<2	<2	8
MnO_2, %	.012	.011	.002	.002	.054	.035	.029	.020
Co, ppm	67	25	17	18	2	5	17	7
Ni, ppm	29	11	11	<5	<5	<5	<5	<5
Cu, ppm	39	11	13	26	8	<5	<5	<5
Pb, ppm	25	10	13	<10	26	27	24	26
Zn, ppm	137	60	51	22	57	49	55	60
Ag, ppm	23	9	2	46	<2	<2	<2	<2
Au, ppm	<4	<4	<4	<4	6	<4	<4	<4
As, ppm	1250	550	200	425	6	4	3	6
Sb, ppm	81	39	<30	48	<30	<30	<30	<30
Sn, ppm	<5	<5	<5	<5	13	<5	<5	<5
Li, ppm	104	106	74	94	9	3	9	13
Be, ppm	1.6	1.0	1.7	1.3	4.0	3.5	4.0	10
Zr, ppm	29	20	26	31	109	108	122	119
La, ppm	17	15	20	16	21	21	21	10
Ce, ppm	28	19	31	23	31	33	23	19
Hg, ppb	45	70	25	15	550	25	10	<5

Table 2 continued

	9	10	11	13	14	15	16	17
Na_2O, %	.520	.038	.397	.831	.757	4.50	.449	1.30
K_2O, %	1.12	2.44	2.02	1.77	4.98	2.00	2.54	3.05
CaO, %	12.84	6.68	1.11	2.51	1.99	1.74	.302	2.38
MgO, %	1.47	2.04	.116	1.58	.917	.184	.276	.177
Fe_2O_3, %	1.89	3.83	.380	5.44	1.10	2.01	.903	.791
Al_2O_3, %	5.51	10.07	12.32	13.01	12.49	11.15	16.67	10.73
TiO_2, %	.220	.364	.066	.737	.171	.278	.213	.133
P_2O_5, %	1.75	.279	.008	.234	.077	.147	.009	.047
Sr, ppm	286	119	87	257	98	97	68	233
BaO, %	.102	.281	.085	.120	.089	.024	.055	.094
Cr, ppm	33	27	<2	99	11	10	5	4
MnO_2, %	.032	.047	.008	.038	.038	.027	.068	.044
Co, ppm	19	35	24	24	10	24	18	19
Ni, ppm	16	21	<5	36	<5	6	9	<5
Cu, ppm	48	13	<5	50	6	67	8	<5
Pb, ppm	<10	<10	22	17	26	11	78	26
Zn, ppm	239	140	49	84	18	29	49	18
Ag, ppm	4	<2	<2	4	<2	<2	<2	<2
Au, ppm	<4	4	<4	<4	<4	<4	<4	4
As, ppm	6	45	10	110	12	70	28	50
Sb, ppm	30	<30	<30	<30	<30	47	<30	<30
Sn, ppm	<5	11	<5	6	<5	<5	<5	<5
Li, ppm	21	46	90	59	61	19	74	73
Be, ppm	1.0	1.7	2.1	3.2	2.4	1.2	3.0	2.2
Zr, ppm	32	39	111	96	92	73	122	94
La, ppm	26	19	21	27	33	<5	26	34
Ce, ppm	37	25	40	43	52	<10	50	52
Hg, ppb	120	100	55	110	220	45	240	140

Table 2 continued

	18	19	20	21	22	23	24
Na_2O, %	1.04	.022	.020	.018	.031	.017	.474
K_2O, %	3.82	1.68	1.28	2.43	1.50	.767	.523
CaO, %	1.73	7.55	2.56	.228	21.80	13.50	2.43
MgO, %	.621	.500	.388	.373	.642	.158	1.42
Fe_2O_3, %	1.58	1.75	1.16	.567	1.62	.624	3.35
Al_2O_3, %	15.31	5.07	4.64	11.32	5.64	2.43	4.63
TiO_2, %	.159	.174	.182	.053	.234	.067	.134
P_2O_5, %	.003	.104	.053	.003	.122	.018	.070
Sr, ppm	455	189	22	29	81	105	95
BaO, %	.055	.071	.101	.016	.121	.035	.010
Cr, ppm	2	20	27	<2	27	11	13
MnO_2, %	.241	.052	.015	.002	.068	.156	.057
Co, ppm	6	28	35	18	22	29	43
Ni, ppm	<5	9	18	5	14	<5	11
Cu, ppm	8	52	21	<5	32	16	11
Pb, ppm	39	<10	<10	20	<10	30	15
Zn, ppm	54	53	71	49	282	76	76
Ag, ppm	<2	<2	<2	<2	<2	<2	<2
Au, ppm	10	5	<4	<4	<4	4	5
As, ppm	2	450	65	81	175	75	300
Sb, ppm	<30	35	<30	<30	<30	<30	576
Sn, ppm	<5	<5	<5	<5	<5	<5	<5
Li, ppm	5	101	74	224	43	188	32
Be, ppm	3.0	1.7	1.3	1.9	2.2	1.6	1.0
Zr, ppm	117	15	10	102	23	<5	16
La, ppm	42	15	11	18	9	7	14
Ce, ppm	74	13	13	35	13	<10	18
Hg, ppb	10	45	2200	100	170	65	70

Table 2 continued

	103	112	113	118	133	134	137
Na_2O, %	.038	.429	.424	.219	.042	2.07	.069
K_2O, %	.051	.019	1.36	.126	.657	2.18	.066
CaO, %	.616	.022	.455	.096	40.30	9.85	.415
MgO, %	.059	.027	.652	.090	.457	1.81	.053
Fe_2O_3, %	.120	1.14	4.17	.528	7.19	7.25	10.76
Al_2O_3, %	4.46	31.88	8.80	13.83	3.86	14.82	7.16
TiO_2, %	.025	.332	.310	.067	.182	.824	.063
P_2O_5, %	.048	.014	.111	.005	.078	.293	.012
Sr, ppm	202	34	526	13	176	332	305
BaO, %	.111	.003	.684	.008	.062	.169	.600
Cr, ppm	7	4	12	<2	21	347	<2
MnO_2, %	.001	<.001	.010	.003	.162	.256	.006
Co, ppm	29	4	18	15	27	37	14
Ni, ppm	<5	<5	5	<5	50	122	<5
Cu, ppm	5	<5	104	<5	17	50	7
Pb, ppm	<10	65	12	17	17	19	16
Zn, ppm	<5	<5	59	20	664	65	<5
Ag, ppm	<2	<2	2	<2	<2	<2	<2
Au, ppm	<4	8	<4	<4	5	10	<4
As, ppm	125	90	45	6	50	2	50
Sb, ppm	40	<30	<30	<30	<30	<30	58
Sn, ppm	<5	<5	<5	<5	10	<5	<5
Li, ppm	28	20	50	126	18	89	32
Be, ppm	<0.5	0.6	2.4	1.2	1.7	1.9	1.8
Zr, ppm	<5	194	57	122	31	98	36
La, ppm	5	22	6	13	<5	19	18
Ce, ppm	<10	51	13	32	20	33	32
Hg, ppb	55	750	45	220	490	25	550

TABLE 3

Summary of Geochemical Data from Gradient Hole Cuttings

Element	Minimum	Maximum	Mean	Standard Deviation
Na, ppm	340	29800	8410	6670
K, ppm	9120	34600	21000	6220
Ca, ppm	2190	132000	52400	25200
Mg, ppm	1830	59900	10300	8010
Fe, ppm	9970	40500	22600	6550
Al, ppm	32500	84700	56400	11000
Ti, ppm	1260	3250	2180	443
P, ppm	413	3420	956	563
Sr, ppm	19	428	189	111
Ba, ppm	262	2890	969	786
V, ppm	< 150	< 150	< 150	-
Cr, ppm	12	72	38	12
Mn, ppm	45	1180	388	173
Co, ppm	13	875	41	83
Ni, ppm	8	50	24	8
Cu, ppm	9	279	28	26
Mo, ppm	< 50	< 50	< 50	-
Pb, ppm	< 10	37	-	-
Zn, ppm	33	2000	150	219
Cd, ppm	< 5	10	-	-
Ag, ppm	< 2	20	-	-
Au, ppm	< 4	7	-	-
As, ppm	9	275	47	49
Sb, ppm	< 30	173	-	-
Bi, ppm	< 100	< 100	< 100	-
U, ppm	< 2000	< 2000	< 2000	-
Te, ppm	< 50	< 50	< 50	-
Sn, ppm	< 5	< 25	-	-
Li, ppm	20	96	48	32
Be, ppm	1.5	3.0	2.1	0.3
Zr, ppm	11	107	56	25
La, ppm	14	33	22	11
Ce, ppm	23	57	40	9
Th, ppm	< 150	< 150	< 150	-
Hg, ppb	10	3300	265	417

As determined colorimetrically, Hg by gold film detector, all other elements by ICP.

Si lost during sample digestion; W and B contaminated during sample preparation and analysis.