INITIAL INVESTIGATION OF SOIL
MERCURY GEOCHEMISTRY AS AN AID TO
DRILL SITE SELECTION IN GEOTHERMAL SYSTEMS

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Date Published - December, 1978

Prepared for the
DEPARTMENT OF ENERGY
DIVISION OF GEOTHERMAL ENERGY
UNDER CONTRACT EG-78-C-07-1701

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ABSTRACT

A mercury-in-soil survey was conducted at the Roosevelt Hot Springs Known Geothermal Resource Area (KGRA), Utah, to evaluate mercury soil geochemistry as a method of selecting exploration well sites in a hot-water geothermal system. Samples of -80 mesh soil were collected at 30.5 m intervals along traverses crossing known structures, surficial geothermal alteration, and exploration well sites, and were analysed using a Model 301 Gold Film Mercury Detector (Jerome Instrument Corp., Jerome, Arizona).

Strong mercury anomalies occur at locations along known structures in close proximity to subsurface thermal activity; examples include areas over hot spring deposits and near a shallow producing well. In contrast, background mercury concentrations are present in nearby locations with little or no indication of subsurface thermal activity, such as areas around deep marginal producing wells and dry wells, and areas lacking hot spring deposits. These results indicate that mercury geochemical surveys can be useful for identifying and mapping structures controlling fluid flow in geothermal systems and for delineating areas overlying near-surface thermal activity. Soil mercury geochemistry thus provides information which may aid in the cost-effective selection of exploratory well sites.

INTRODUCTION

Mercury geochemistry as a method of regional scale exploration for geothermal resources has been studied by several workers. Matlick and Buseck (1976), and Phelps and Buseck (1978) conducted regional mercury surveys in

several areas of geothermal activity and found broad mercury anomalies outlining the geothermal areas. Their surveys involved collecting A horizon soils on a 1.6 km grid and analyzing them in the field with a portable gold film mercury detector (McNerney, Buseck, and Hanson, 1972). Klusman et al. (1977), and Klusman and Landress (1978) sampled A and B horizon soils over geothermal areas using a 0.4 km interval and analysed the soil mercury after decomposition with 50% hydrogen peroxide and sulfuric acid using flameless atomic absorption. Their results also defined regional mercury highs in soils over geothermal areas. These studies demonstrate a general association of mercury anomalies with areas containing thermal activity and indicate that regional scale mercury soil surveys may define broad areas having potential as geothermal resources.

Detailed mercury surveys over areas of known subsurface thermal activity have shown mercury anomalies associated with faults (Klusman and Landress, 1977; Parry, Benson, and Miller, 1976). This is an expected result since mercury is known to partition strongly into the vapor phase flashed from hot geothermal waters (Robertson et al., 1978). The mercury-bearing vapor will migrate to the surface through permeable zones that connect with or that in themselves constitute aquifers for thermal waters. Thus, strong mercury soil anomalies are likely to be specific indicators of structures that communicate with the geothermal resources at depth. Delineation of such structures can aid in the selection of drill sites for exploration wells.

The object of this study is to provide an initial evaluation of mercury soil geochemistry as a method of selecting exploration well sites within a

hot-water geothermal system. Roosevelt Hot Springs KGRA was selected for this initial study because it is a small- to medium-sized thermal resource, well defined by exploratory drilling, to which the geochemical data could be related. In addition, geological and geophysical data are available for the area and might be usefully compared with the geochemical results.

GEOLOGIC SETTING OF STUDY AREA

Roosevelt Hot Springs KGRA is located in Beaver County, Utah on the western flank of the Mineral Mountains (Fig. 1). The geothermal system at Roosevelt Hot Springs is a structurally controlled hot-water system. Four major fault trends are described in the area by Nielson et al. (1978). These include a large scale north-south trending, low-angle, normal fault dipping west, numerous steeply dipping northwest-trending faults that are present only in the hanging wall of this low-angle normal fault, and steeply dipping, east-west trending and north-northeast trending normal faults that cut both the hanging and foot walls of the low-angle normal fault and extend to an unknown depth.

Two major structures occur in the study area: the Opal Mound Fault, in the northern half of T27S, R9W, is a north-northeast trending, east dipping, normal fault; and the Negro Mag Wash Fault, in the northeast corner of T27S, R9W, is an east-west trending fault. Hot spring deposits in the form of siliceous sinter and silica-cemented alluvium are localized along both faults, and fumarolic activity occurs along the trend of the Negro Mag Wash Fault, indicating that these faults are or have been zones of fluid discharge from a hot-water hydrothermal system. Berge, Crosby, and Lenzer (1975) have

Geology modified by J. B. HULEN from Liese, 1957; Hintze, 1963, 1975; Petersen, 1975; Evans et al, 1977

FIGURE 1

suggested that the Opal Mound Fault is a major structural control on the subsurface hydrologic regime in the area. Because of its apparent importance in controlling the configuration of the present geothermal system at Roosevelt Hot Springs, the Opal Mound Fault was chosen as the focus of this study.

METHODS

Sample Traverses

Three major traverses were sampled in the study area and are shown in Figure 1. All traverses are parallel to one another and cross the Opal Mound Fault nearly perpendicular to its trend. Traverse A-A' crosses the Opal Mound Fault in an area of prominent hot spring deposits and also passes near producing well TP72-16 and somewhat near the marginal producing well PP25-15. This traverse is 3,962 m long and was designed to permit comparison of mercury levels over and away from the fault and geothermal well sites. Traverse B-B', which is 1,280 m long, crosses the Opal Mound Fault in an area lacking hot spring deposits and passes near dry well PP9-1 and producing well PP13-10. Traverse C-C', which is 1,523 m long, crosses the Opal Mound Fault where there are also prominent hot spring deposits.

Location coordinates for the traverses and individual samples are referenced to the southeast corner of section 9, T27S, R9W. Traverses A-A', B-B', and C-C', are located at 366 m S, 1173 m N, and 2210 m N respectively. Other mercury-in-soil traverses completed in the study area by Parry, Benson, and Miller (1976), who used a similar sampling and analytical technique, include UU1, UU2, and UU3 located at 290 m S, 2350 m N, and 3330 m N respectively (Fig. 1).

Sampling

Soil samples were collected at 30.5 m intervals from a depth of 15 to 18 cm. This sample depth was chosen based on variations of mercury concentration with depth measured at several locations (Appendix). Minus 80 mesh material was separated with a stainless steel sieve and immediately sealed in airtight glass vials. Wet samples, of which there were only two, were dried overnight at room temperature and then sieved and sealed in glass vials.

Analytical Procedure

All samples were analysed within 72 hours of collection using a Model 301 Gold Film Mercury Detector (Jerome Instrument Corp., Jerome, Arizona). In this method of mercury analysis the sample is heated to greater than 600°C with a propane torch to release mercury vapor. The mercury is collected on a gold film and the quantity is measured by the resultant change in electrical resistance of the gold film.

Reproducibility

Precision of the mercury detector under field conditions is greater than 1 ppb (Matlick and Buseck, 1976). The major error in analysis is introduced by using a calibrated scoop to measure the sample amount for each analysis. Buseck (1977) found that this introduces a relative error in sample weight of $\pm 31\%$ (95% confidence level, determined by weighing 20 randomly chosen samples).

To determine the overall reproducibility of mercury-in-soil results, a 610 m section of traverse A-A' was resampled (set 2, Table 1) approximately 15 days after and within a meter of the original sample sites (set 1, Table 1).

Soil profile 2 was similarly resampled (Appendix). Although there is considerable variation between the two traverse data sets, the results show the area of anomalous mercury to be virtually the same for both sets and therefore equivalent for purposes of exploration. Comparing the results on a sample for sample basis reveals differences ranging from 0 to 670 ppb Hg, with an average difference of 75 ppb. Possible causes of these differences are variations in the mercury concentration of the soil during the 15 day period or a systematic error in sample analysis or collection. In Matlick and Buseck's (1976) work little or no diurnal variation in mercury concentrations of the soils was found in their study area. Whatever the cause of the concentration variations, it is important to note that it does not affect the validity of this method in defining areas of anomalous mercury.

Geochemical Background and Threshold Calculations

Statistical methods employed in the calculation of the local background and threshold values for mercury concentrations in the study area are those discussed by Levinson (1974) and Sinclair (1974). A background population of 0-70 ppb mercury was determined based on the change in slope on a log ppb mercury cumulative frequency diagram using the data from traverse A-A'. From this background population, a threshold value of 53 ppb and a background value of 24 ppb were assigned. Anomalous values greater than two times threshold, 106 ppb, are referred to as high anomalous and those less than 106 ppb as low anomalous.

Since the study was located entirely within an area overlying a subsurface geothermal resource, the background and threshold values may be

positively biased. Therefore they should be considered local values even though traverse A-A' extends beyond the area of surficial thermal activity and alteration.

RESULTS AND DISCUSSION

Mercury concentrations measured in soils along traverse A-A', B-B', and C-C' are included in Figures 2, 3, and 4 and Tables 2, 3, and 4. High anomalous mercury concentrations were obtained along these traverses in soils covering areas of known thermal activity, i.e., near producing wells and hot spring deposits. In areas lacking hot spring deposits or where non-producing or marginally producing wells have been drilled, background mercury concentrations were obtained.

Traverses A-A', C-C', and their coincident traverses, UU1 and UU2 (Parry, Benson, and Miller, 1976) cross the Opal Mound Fault in areas where there are associated hot spring deposits. On these traverses, high anomalous mercury concentrations were measured in the Opal Mound Fault area, suggesting that these segments of the fault have relatively direct access to subsurface hydrothermal activity. In contrast, the central section of the fault characteristically lacks mercury anomalies (traverse B-B', Fig. 3) and associated hot spring deposits (Fig. 1), suggesting that this section of the fault is relatively impermeable or lacks direct access to the thermal resource. Geophysical data also supports this concept; a resistivity low which parallels the Opal Mound Fault narrows significantly in the vicinity of traverse B-B' (Ward and Sill, 1976).

FIGURE: 2 MERCURY TRAVERSE A-A' (366M S)

FIGURE: 3 MERCURY TRAVERSE B-B' (1173M N)

FIGURE: 4. MERCURY TRAVERSE C-C' (2210M N)

East of the Opal Mound Fault, from approximately 300 to 500 m, there is another area of extremely high anomalous mercury concentrations on both traverse A-A' and C-C' (Fig. 2 and 4), and a low anomalous concentration on traverse B-B' (Fig. 3). These data suggest that a subsurface fracture zone may exist east of and parallel to the Opal Mound Fault that is also carrying thermal fluids. Along this anomalous zone, the occurrence of two producing wells TP72-16 (depth 382 m, Geothermex Inc., 1977) near A-A' and PP13-10 (depth 1631 m, Geothermex Inc., 1977) near B-B' supports this suggestion. The existence of this fracture zone can also be inferred from the TP72-16 well log data (Geothermex Inc., 1977) and surface mapping (Nielson et al., 1978) which suggest the presence of a series of shallow fracture zones which lack surface exposure, and from geophysical data (Ward and Sill, 1976) which define an area of low resistivities just east of and parallel to the Opal Mound Fault. Thus strong mercury anomalies correlate well with the location of shallow producing well TP72-16 and apparently define the trace of a north-south structural zone with additional potential for production.

Another possible interpretation of this eastern anomaly on A-A' and B-B' is that it is partly due to contamination generated during the drilling and testing of wells TP72-16 and PP13-10, similar to mercury contamination noted in soils around a coal-fired power plant (Klein and Russell, 1973). To evaluate this possibility for the eastern anomaly on traverse A-A', traverses D-D' and E-E' (Fig. 1, 5 and 6, Tables 5 and 6) were sampled. These data show a decrease in mercury concentrations with increased distance to the north and south of TP72-16 along the inferred permeable zone, indicating that contamination from TP72-16 may be partly responsible for this anomaly. The results of

FIGURE: 5 MERCURY TRAVERSE D-D' (396M S)

FIGURE: 6 MERCURY TRAVERSE E-E' (183M S)

traverse UU1 (Parry, Benson, and Miller, 1976), which was sampled prior to the drilling of TP72-16, however, show a mercury high of 400 ppb near TP72-16's present location. Thus, anomalous mercury occurred in the vicinity of TP72-16 before well testing although well activity apparently has enhanced the anomaly.

Further east, along traverses A-A' and C-C', mercury concentrations decrease to background. A relatively deep well which is a marginal producer (PP25-15, depth approximately 2286 m, Geothermex Inc., 1977) had been drilled 533 m south of A-A'. The concomitant lack of good production from this well and the lack of mercury anomalies along several possible faults in the area (Nielson et al., 1978) further support the potential usefulness of mercury geochemistry in defining exploration well drilling priorities.

Intermediate depth producing wells PP3-1 (depth 831 m, Geothermex Inc., 1977), and PP54-3 (depth 878 m, Geothermex Inc., 1977), which are located 380 m N and 520 m N of traverse C-C', respectively, are not readily related to mercury anomalies. No particular significance is attached to this observation, however, since production in these wells is probably related to thermal activity along the Negro Mag Wash Fault to the north and associated mercury anomalies would most likely occur further to the north.

Several zones of anomalous mercury concentrations occur west of the Opal Mound Fault. Traverse A-A' extending 2000 m west of the fault area crosses several weak anomalies (Fig. 2) which may relate to possible fracture zones (Nielson et al., 1978) or may be a result of mercury dispersion by ground or surface waters from the Opal Mound Fault area. Traverse B-B', extending 600 m

west in the central area of the Opal Mound Fault, transects an area with mostly background concentrations (Fig. 3). A dry well, PP9-1 (depth 2099 m, Geothermex Inc., 1977) drilled 90 m north of B-B' in this area, provides another example of correspondence between low mercury geochemistry and a lower probability of drilling success. Traverse C-C' has nearly continuous high anomalies extending up to 600 m west of the fault (Fig. 4), suggesting the presence of an undocumented fracture zone and associated near-surface thermal activity.

Since automobile traffic might be a cause of spurious mercury anomalies, locations of the most frequently used graded dirt roads in the study area are shown on the topographic profiles in Figures 2, 3, and 4. All samples collected near these frequently used roads show mercury concentrations consistent with the values around them. It is concluded, therefore, that automobile traffic did not affect the results of this survey.

CONCLUSIONS AND RECOMMENDATIONS

At Roosevelt Hot Springs, mercury anomalies occur mainly at locations along known structures in close proximity to subsurface thermal activity; examples include areas over hot spring deposits and near the shallow producing well TP72-16. In contrast, nearby locations with little or no indication of subsurface thermal activity, such as areas near the dry well PP9-1, the marginal producing well PP25-15, and the central area of the Opal Mound Fault that lacks hot spring deposits, display background mercury concentrations. Anomalous soil mercury therefore suggests the presence of thermal activity at (shallow?) depth and provides a useful criterion for determining sites for

initial exploration wells. Conversely, background mercury concentrations establish lower priority areas. These results indicate that mercury geochemical surveys can be useful for identifying and mapping structures controlling fluid flow in geothermal systems and for delineating areas overlying near-surface thermal activity. Mercury-in-soil data thus provides information which will aid in the cost-effective selection of initial exploratory well sites.

Further work is necessary to provide an adequate data base for interpretation of soil mercury geochemistry in geothermal systems. It is important to better determine the degree to which the magnitude and extent of an anomaly relate to proximity to a geothermal resource rather than proximity to permeable structures only. Temporal variations of mercury in soil anomalies should be evaluated to determine if the magnitude of an anomaly might be used to distinguish between inactive and active thermal systems. Parallel studies should be conducted over vapor-dominated, low-temperature and inactive geothermal systems, and over non-geothermal areas with either seismically active or inactive faults to fully document the distribution of mercury relative to these features.

ACKNOWLEDGEMENTS

This report has benefited from the suggestions and assistance of a number of the Earth Science Laboratory staff. Special thanks are given to Odin Christensen and Dennis Nielson for their valuable suggestions and review of this report, to Carol Withrow for programming of the computer graphics, and to Jeff Hulen for compilation of the geologic base map. Drafting for the report was done by Connie Pixton and Doris Cullen, typing and report preparation by Susan Keller and Sue Moore.

Special acknowledgements go to Les McFadden at the University of Arizona for consultation on the soil properties of the field area, and to C. Wayne Lowe and Darin Malchus, who aided as field assistants.

Funding was provided by the Division of Geothermal Energy, DOE, in the form of a subcontract to ESL/UURI under contract EG-78-C-07-1701.

REFERENCES

- Berge, C. W., Crosby, G. W., Lenzer, R. C., 1975, Geothermal exploration of the Roosevelt KGRA, Utah, in *New Concepts of Exploration in the Rockies: A.A.P.G. and S.E.P.M. 25th Ann. Mtg.*, no. 66, p. 52-53.
- Buseck, P. R., 1977, Geothermal Exploration: Arizona State Univ. Semi-Annual Technical Report II, Geothermal Research Program, U.S. Geol. Survey, grant no. 14-08-001-G-383, 5 p.
- Evans, S. H., et al., 1977, Geologic map of the central and northern Mineral Mountains, Utah: Dept. Geol. and Geophy., Univ. Utah.
- Fang, S. C., 1978, Sorption and transformation of mercury vapor by dry soil: *Environ. Science Technol.*, v. 12, p. 285-288.
- Geothermex Inc., 1977, Geothermal potential of the lands leased by Geothermal Power Corporation in the northern Mineral Mountains, Beaver and Millard Counties, Utah: report for Geothermal Power Corp., 43 p.
- Hintze, L. F., 1963, Geologic map of southwestern Utah, Utah State Land Board.
- Hintze, L. F., 1975, Geologic highway map of Utah: Brigham Young University, Special Publ. 3.
- Klein, D. H., and Russell, P., 1973, Heavy metals: Fallout around a power plant: *Environ. Science Technol.*, v. 7, p. 357-358.
- Klusman, R. W., Cowling, S., Culvey, B., Roberts, C., and Schwab, A. P., 1977, Preliminary evaluation of secondary controls on mercury in soils of geothermal districts: *Geothermics*, v. 6, no. 1/2, p. 1-8.
- Klusman, R. W., and Landress, R. A., 1977, Nature of the occurrence of mercury in soils of geothermal areas: Colo. School of Mines, Dept. Chem. and Geochem., Final Report, U.S. Geol. Survey grant no. 14-08-0001-G-335, 116 p.
- Klusman, R. W., and Landress, R. A., 1978, Secondary controls on mercury in soils of geothermal areas: *Jour. Geochemical Exploration*, v. 9, no. 1, p. 75-91.
- Levinson, A. A., 1974, *Introduction to Exploration Geochemistry: Applied Publishing Ltd.*, Calgary, Canada, 612 p.
- Liese, H. C., 1957, Geology of the northern Mineral Range, Millard and Beaver Counties, Utah: Univ. Utah, Unpub. M.S. Thesis, 88 p.
- Matlick, J. S. III, and Buseck, P. R., 1976, Exploration for geothermal areas using mercury: a new geochemical technique, in *Proc. 2nd U.N. Symposium on Development and Use of Geothermal Resources*, Pezzotti, C., ed.: U.S. Govt. Printing Office, v. 1, p. 785-792.

- McNerney, J. J., Buseck, P. R., and Hanson, R. C., 1972, Mercury detection by means of thin gold films: *Science*, v. 178, p. 611-612.
- Nielson, D. L., Sibbett, B. S., McKinney, D. B., Hulen, J. B., Moore, J. N., Samberg, S. M., 1978, *Geology of Roosevelt Hot Springs KGRA, Beaver Co., Utah: Univ. Utah Research Inst., Earth Science Laboratory Report no. 12, DOE contract no. EG-78-C-07-1701.*
- Parry, W. T., Benson, N. L., and Miller, C. D., 1976, *Geochemistry and hydrothermal alteration at selected Utah hot springs: Dept. of Geol. and Geophy., Univ. Utah, Final Report: v. 3, Natl. Sci. Found. contract no. GI-43741, 131 p.*
- Petersen, C. A., 1975, *Geologic map of the Roosevelt area, Beaver County, Utah: Utah Geology, v. 2.*
- Phelps, D. W., and Buseck, P. R., 1978, Natural concentrations of Hg in the Yellowstone and Coso geothermal fields: *Geothermal Resources Council, Transactions, v. 2, p. 521-522.*
- Robertson, D. E., Fruchter, J. S., Ludwick, J. D., Wilkerson, C. L., Crecelius, E. A., and Evans, J. C., 1978, Chemical characterization of gases and volatile heavy metals in geothermal effluents: *Geothermal Resources Council, Transactions, v. 2, p. 579-582.*
- Sinclair, A. J., 1974, Selection of threshold values in geochemical data using probability graphs: *Jour. Geochemical Exploration, v. 3, p. 129-149.*
- Trost, P. B., and Bisque, R. E., 1972, Distribution of mercury in residual soils, in *Environmental Mercury Contamination*, Hartung, R., and Dinman, B. D., eds.: Ann Arbor Science Publishers, p. 178-196.
- Ward, S. H., and Sill, W. R., 1976, Dipole-dipole resistivity surveys, Roosevelt Hot Springs KGRA: *Dept. of Geol. and Geophy., Univ. Utah, Final Report: v. 2, Natl. Sci. Found. contract no. GI-43741.*

APPENDIX

Determination of Optimum Sampling Depth or Soil Horizon

To determine the optimum depth or soil horizon for sample collection, six mercury profiles were sampled in areas of anomalous, intermediate, and background mercury concentrations along traverse A-A'. These holes were sampled to depths of 45 to 50 cm, using a 5 cm sampling interval. The results of these mercury profiles and a cursory examination of the soils in the study area showed a large variation in degree of soil development and a non-uniform mercury concentration distribution within the A and B soil horizons.

In non-anomalous to low anomalous zones, mercury shows little change in concentration with depth (Profiles 1, 2a, and 3, Fig. 7 and 8). However, in high anomalous zones mercury shows a significant increase in concentration with depth (Profiles 4 and 5, Fig. 8). Comparable profiles completed by Buseck (1977) showed similar results. The soils in the non-anomalous profiles 1, 2a, and 3 are clay deficient and show little change from the A to B horizons, while the anomalous profiles 4 and 5 have red clay-rich B horizons which are the zones of increasing mercury. Profile 2b, in contrast to this general trend, shows decreasing mercury with depth, with the anomalous mercury concentrations being in the A soil horizon (Fig. 7). Profile 2b was sampled within 1 m and 15 days prior to profile 2a and has the same clay-deficient soil as profiles 1, 2a, and 3.

A cursory comparison of the soils in the study area shows varying degrees of soil development and of mercury concentration by the A and B soil horizons. Trost and Bisque (1972) and Fang (1978) found that both organic materials and

clay minerals in soils sorb mercury, although organics sorb much greater amounts per unit weight than clays. Since the soils of the study area are not organic rich, it is reasonable that mercury is more concentrated where clay-rich soil horizons have developed as a result of hydrothermal alteration or soil forming processes. The occurrence of anomalous concentrations in the A horizon of the clay-deficient soil of profile 2b is probably a function of its organic concentration. A consistent overall correlation between anomalous mercury concentration and clay-rich soils, or any other obvious soil parameter, was lacking at Roosevelt Hot Springs. Work completed by Klusman and Landress (1978) demonstrated that a mercury anomaly of high magnitude would overwhelm any variations resulting from secondary soil parameters. These results suggest that collection of soils from any specific horizon would be superfluous to determining a zone of anomalous mercury concentrations in the study area.

Based on the above considerations, a compromise depth for sample collection of 15 to 18 cm was chosen rather than collecting from a specific soil horizon as other workers have done (Matlick and Buseck, 1976, Klusman et al., 1977, and Klusman and Landress, 1978). This depth, which is often close to the transition zone between the A and B soil horizons, provides adequate detection of mercury anomalies in the various soil-forming environments described above.

MERCURY PROFILES

MERCURY IN SOIL (PPB)

1, 2A, AND 2B

LOCATED ON TRAVERSE A-A'

MERCURY PROFILES

3, 4, AND 5

LOCATED ON TRAVERSE A-A'

FIGURE 8

MERCURY IN SOIL (PPB)

Table 1. Duplicate Samples of a Section of Traverse A-A' (366 m S),
Sample Locations and Mercury Concentrations

Location			Hg (ppb)			
Direction	Meters	Feet	1	2	Difference	Average
W	610	2000	47	47	0	47
W	640	2100	510	260	250	390
W	671	2200	28	70	42	50
W	701	2300	120	95	25	110
W	732	2400	75	110	35	93
W	762	2500	130	800	670	470
W	792	2600	140	200	60	170
W	823	2700	140	230	90	190
W	853	2800	100	110	9	110
W	884	2900	110	140	30	130
W	914	3000	52	120	68	86
W	945	3100	140	190	50	170
W	975	3200	69	71	2	70
W	1006	3300	17	27	10	22
W	1036	3400	150	200	50	180
W	1067	3500	32	98	66	65
W	1097	3600	41	30	11	36
W	1128	3700	24	37	13	31
W	1158	3800	21	30	9	26
W	1189	3900	24	28	4	26

Table 2. Mercury Traverse A-A' (366 m S),
Sample Locations and Mercury Concentrations

Location			Mercury
Direction	Meters	Feet	ppb
E	914	3000	13
E	884	2900	17
E	853	2800	15
E	823	2700	22
E	792	2600	22
E	762	2500	15
E	732	2400	17
E	701	2300	15
E	671	2200	13
E	640	2100	19
E	610	2000	9
E	579	1900	21
E	549	1800	16
E	518	1700	22
E	488	1600	25
E	457	1500	18
E	427	1400	24
E	396	1300	22
E	366	1200	23
E	335	1100	30
E	305	1000	33
E	274	900	15
E	244	800	27
E	213	700	17
E	183	600	13
E	152	500	17
E	122	400	6
E	91	300	6
E	61	200	9
E	30	100	22
	0	0	35

(Cont.)

Location			Mercury
Direction	Meters	Feet	ppb
W	30	100	31
W	61	200	44
W	91	300	38
W	122	400	40
W	152	500	74
W	183	600	910
W	213	700	800
W	244	800	480
W	274	900	990
W	305	1000	930
W	335	1100	410
W	366	1200	270
W	396	1300	190
W	427	1400	63
W	457	1500	110
W	488	1600	62
W	518	1700	44
W	549	1800	35
W	579	1900	190
W	610	2000	47
W	640	2100	390
W	671	2200	50
W	701	2300	110
W	732	2400	93
W	762	2500	470
W	792	2600	170
W	823	2700	190
W	853	2800	110
W	884	2900	130
W	914	3000	86
W	945	3100	170

Table 2. Traverse A-A' (Cont.)

Direc- tion	Location		Mercury
	Meters	Feet	ppb
W	975	3200	70
W	1006	3300	22
W	1036	3400	180
W	1067	3500	65
W	1097	3600	36
W	1128	3700	31
W	1158	3800	26
W	1189	3900	26
W	1219	4000	21
W	1250	4100	43
W	1280	4200	32
W	1311	4300	48
W	1341	4400	29
W	1372	4500	24
W	1402	4600	30
W	1433	4700	22
W	1463	4800	40
W	1494	4900	38
W	1524	5000	24
W	1554	5100	29
W	1585	5200	33
W	1615	5300	25
W	1646	5400	24
W	1676	5500	76
W	1707	5600	50
W	1737	5700	50
W	1768	5800	41
W	1798	5900	38
W	1829	6000	43
W	1859	6100	35
W	1890	6200	75

(Cont.)

Direc- tion	Location		Mercury
	Meters	Feet	ppb
W	1920	6300	56
W	1951	6400	40
W	1981	6500	60
W	2012	6600	26
W	2042	6700	48
W	2073	6800	35
W	2103	6900	20
W	2134	7000	15
W	2164	7100	11
W	2195	7200	13
W	2225	7300	16
W	2256	7400	9
W	2286	7500	8
W	2316	7600	47
W	2347	7700	40
W	2377	7800	24
W	2408	7900	24
W	2438	8000	34
W	2469	8100	21
W	2499	8200	22
W	2530	8300	68
W	2560	8400	30
W	2591	8500	20
W	2621	8600	19
W	2652	8700	20
W	2682	8800	45
W	2713	8900	42
W	2743	9000	95
W	2774	9100	17
W	2804	9200	15
W	2835	9300	18

Table 2. Traverse A-A' (Cont.)

Location			Mercury
Direction	Meters	Feet	ppb
W	2865	9400	14
W	2896	9500	18
W	2926	9600	19
W	2957	9700	20
W	2987	9800	16
W	3018	9900	12
W	3048	10000	9

Table 3. Mercury Traverse B-B' (1173 m N),
Sample Locations and Mercury Concentrations

Location			Mercury
Direction	Meters	Feet	ppb
E	379	1245	23
E	349	1145	26
E	319	1045	28
E	288	945	16
E	258	845	22
E	227	745	17
E	197	645	18
E	166	545	21
E	136	445	18
E	105	345	17
E	75	245	23
E	44	145	18
E	14	45	16
W	17	55	56
W	47	155	25
W	78	255	16
W	108	355	23
W	139	455	31
W	169	555	12
W	200	655	11
W	230	755	15
W	261	855	23
W	291	955	17
W	322	1055	28
W	352	1155	32
W	383	1255	22
W	413	1355	30
W	443	1455	10
W	474	1555	28
W	504	1655	59
W	535	1755	19

(Cont.)

Location			Mercury
Direction	Meters	Feet	ppb
W	565	1855	29
W	596	1955	18
W	626	2055	25
W	657	2155	22
W	687	2255	25
W	718	2355	14
W	748	2455	14
W	779	2555	17
W	809	2655	14
W	840	2755	11
W	870	2855	13
W	901	2955	20

Table 4. Mercury Traverse C-C' (2210 m N),
Sample Locations and Mercury Concentrations

Location			Mercury
Direc- tion	Meters	Feet	ppb
E	914	3000	24
E	884	2900	23
E	853	2800	23
E	823	2700	30
E	792	2600	23
E	762	2500	23
E	732	2400	14
E	701	2300	20
E	671	2200	17
E	640	2100	15
E	610	2000	20
E	579	1900	19
E	549	1800	14
E	518	1700	25
E	488	1600	33
E	457	1500	1500
E	427	1400	1500
E	396	1300	390
E	366	1200	1000
E	335	1100	220
E	305	1000	1400
E	274	900	87
E	244	800	110
E	213	700	200
E	183	600	140
E	152	500	530
E	122	400	1200
E	91	300	200
E	61	200	1400
E	30	100	910
E	0	0	260

(Cont.)

Location			Mercury
Direc- tion	Meters	Feet	ppb
W	30	100	210
W	61	200	39
W	91	300	160
W	122	400	1100
W	152	500	240
W	183	600	310
W	213	700	270
W	244	800	530
W	274	900	280
W	305	1000	210
W	335	1100	90
W	366	1200	43
W	396	1300	110
W	427	1400	110
W	457	1500	57
W	488	1600	110
W	518	1700	110
W	549	1800	130
W	579	1900	110
W	610	2000	68

Table 5. Mercury Traverse D-D' (396 m S),
Sample Locations and Mercury Concentrations

Location			Mercury
Direction	Meters	Feet	ppb
W	152	500	69
W	183	600	89
W	213	700	110
W	244	800	180
W	274	900	210
W	305	1000	140
W	335	1100	52
W	366	1200	110
W	396	1300	48
W	427	1400	22
W	457	1500	19

Table 6. Mercury Traverse E-E' (183 m S),
Sample Locations and Mercury Concentrations

Location			Mercury
Direction	Meters	Feet	ppb
W	213	700	35
W	244	800	190
W	274	900	75
W	305	1000	56
W	335	1100	230
W	366	1200	130
W	396	1300	34
W	427	1400	51
W	457	1500	15

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