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TRENDS IN MERCURY ANOMALY AMPLITUDE ALONG FAULTS WITHIN THE NORRIS-MAMMOTH-LA DUKE CORRIDOR, IN AND ADJACENT TO YELLOWSTONE NATIONAL PARK, WY AND MT.

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ABSTRACT

Hg anomalies occur in soils over mapped faults at thermal areas and at intermediate locations along faults that interconnect them. Using established criteria for anomaly threshold identification, we find significant anomalies as large as 180 and as small as 20 ppb in the north boundary area between Mammoth Hot Springs and La Duke Spring.

Anomaly amplitudes vary along faults in a way that suggests depletion of Hg in aquifers associated with the faults, and amplitude trends suggest flow directions that are in agreement with those inferred by other investigators. Hg depletion is large along fault segments where gas venting is observed, and it is small on segments that lack visible surface manifestations.

In several cases we observe discrete amplitude increases in the inferred "downstream" direction. Such augmentation north of Mammoth appears to reflect input of Hg- bearing water from intersecting faults "upstream". South of Mammoth a similar increase is attributed to an unmapped fault.

INTRODUCTION

The association between hydrothermal aquifers and free Hg anomalies in overlying soil has been documented by White (1967), Matlick and Buseck (1976), and Phelps and Buseck (1978). Identification of Hg anomalies as an indicator of faults associated with geothermal reservoirs has been widely applied in geothermal exploration (e.g. Capuano and Bamford, 1978; Varekamp and Buseck, 1983; and Williams, 1985).

In earlier work in Yellowstone, Phelps and Buseck (1980) attributed low concentrations of soil Hg at Mammoth Hot Springs to vapor loss (or dilution) during long-distance transport of the water from the Norris area, where Hg was abundant (Locations are shown in Figure 1.). Our work began with an assessment of soil Hg on mapped faults between Norris and Mammoth (Colvard and Hamilton, 1987). Interest arose from the need to better understand geothermal systems in boundary areas subject to possible geothermal development nearby. Subsequently, we turned our attention to faults crossing the park boundary north of Mammoth (Conn et al., 1988). We present here a summary of National Park Service research ongoing since 1986 and described in detail by Hamilton, et al. (1990).

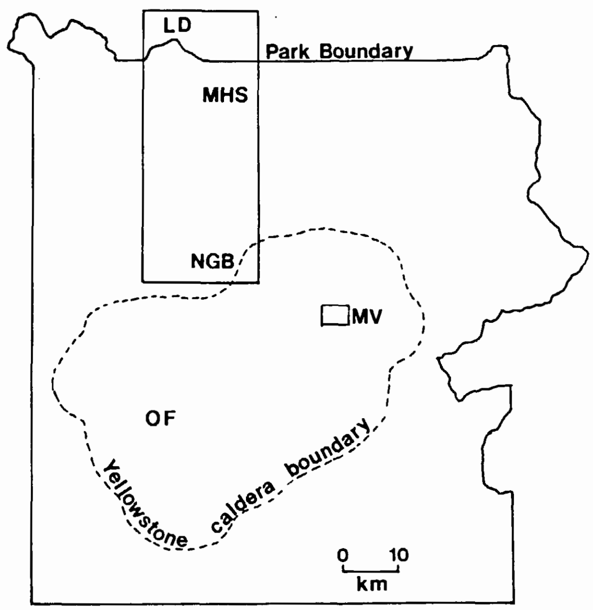

Figure 1. Map of Yellowstone National Park, showing: the outline of the Yellowstone caldera; the study area, with locations of Norris Geyser Basin (NGB), Mammoth Hot Springs (MHS), and La Duke spring (LD). The Mud Volcano (MV) and Old Faithful areas are also shown.

METHODS

Sampling traverses were laid out to cross mapped faults at approximately right angles (Fig. 2). Sample spacing along traverses (averaging approximately 15 m) is evident in plots of data shown below. Sampling and analytical protocols for the Jerome Model 301 gold film analyzer were like those used by Phelps and Buseck (1980) , except that our soil combustion temperature is 350 C. Sampling depth was approximately 15 cm. We found no relationship between background Hg concentration and regolith type as mapped by Pierce (1973 a, b).

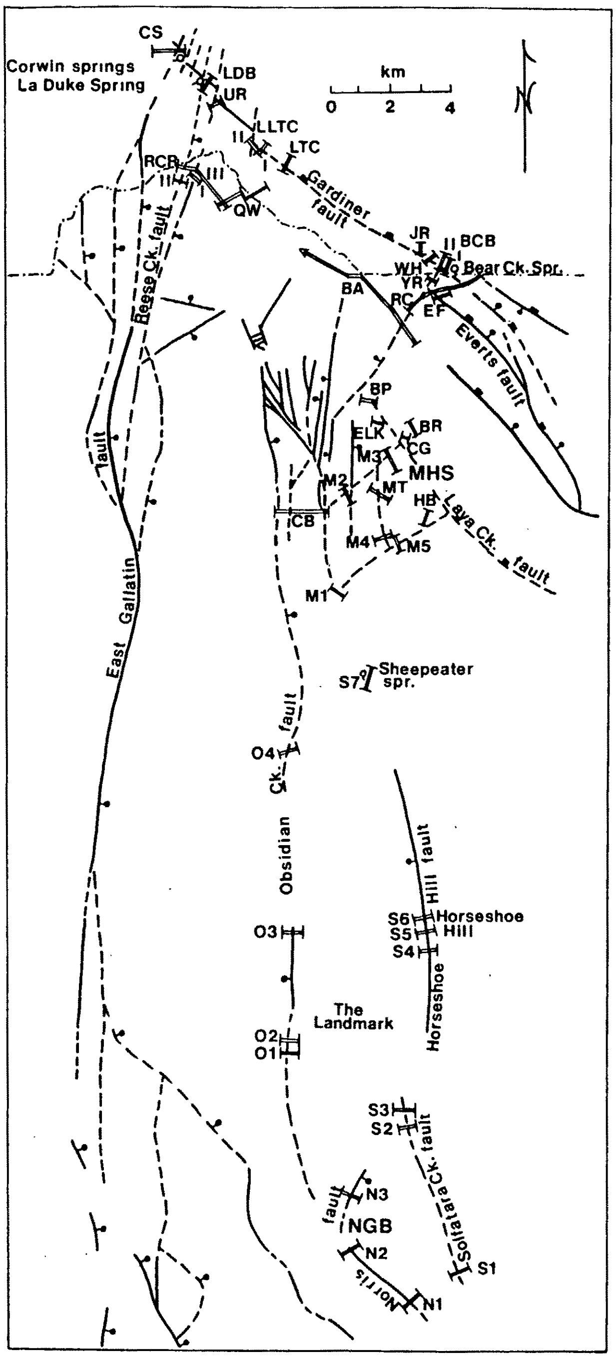

Figure 2. Map of the Norris - Mammoth - La Duke corridor study area showing faults in the park from USGS (1972). Faults north of the park boundary are from Struhsacker (1976) and Fraser et al. (1969). Traverse locations are indicated by double lines ending in bars with name labels. Selected hot springs are shown by small circles. Traverse name abbreviations are explained in the text. Length of shorter traverses is not to scale.

Results of comparative analysis on splits of sieved soil samples are presented in Table I.

Data presented here represent 60+- 30 percent of the yield by cold vapor AAS (USGS, 1989), probably showing mostly loosely-bound, elemental Hg. Analytical precision is shown by error bars (+- one sigma) in the plots of data below.

Table I

Sample YPSL No.	Mercury Concentration (ppb) Tuva I	Tuva II	AAS	Diff. from AAS	
CB 84	15.5+-4.3	32.2+-0.2	40	-24.5	-7.8
CB 26	46.4+-0.4	54.0+-0.4	50	-3.6	4.0
BA 109	19.2+-4.4	54.4+-3.0	70	-50.8	-15.6
CB 20	14.9+-0.1	15.6+-0.3	20	-5.1	-4.4
BA 37	59.1+-0.7	61.0+-3.6	60	-0.9	1.0
BA 206	6.8	34.2+-2.0	30	-23.2	4.2
BA 220	102.7+-14.5		210	-107.3	
BA 220s	151.0+-0.8	117.1			
CB 75b	62.2+-1.9	70.4+-5.0	80	-17.8	-9.6

All samples listed in Table I were sieved to <180 um except BA 220s, which was <125. Sample CB 75b was ground in a mortar. CB signifies Clagett Butte, and BA samples came from the Black Arrow traverse. Tuva I and II refer to gold film analytical methods discussed in Hamilton et al. (1990). All data presented here are Tuva I except the CB traverse in Fig 7, which are Tuva II. Note that the combined precision of our Tuva II analyses (2 or more runs) is better than 4 percent while for Tuva I it is <10 percent.

RESULTS

Norris - Mammoth Corridor

Hg data from nineteen traverses crossing mapped faults between Norris Geyser Basin and Mammoth Hot Springs are summarized in Figures 3 and 4. These data were acquired between July, 1986 and August, 1987. Along the Norris and Obsidian Creek fault zones (informal names) background and anomaly amplitude descend northward and southward of a broad high near Obsidian Cliff. Exceptions to this trend are noted immediately north and south of the Norris area. A very strong anomaly at N3 occurs with low background, but at N2 the high anomaly is so broad that we probably did not sample background.

Figure 4 shows results on traverses crossing the Solfatara Creek - Horseshoe Hill fault system (informal names). Here we observed much higher anomalies, but the trends are similar to those shown in Figure 3. High anomalies and background are seen in the Horseshoe Hill area (about 4 km east of Obsidian Cliff), trending to lower values north and south of this area. The exception to this trend is the marked increase in anomaly amplitude at Golden Gate. This may represent augmentation from an intersecting unmapped fault from the south.

The inferred flow direction, northward from the Horseshoe Hill - Obsidian Cliff area toward Mammoth, is in agreement with flow suggested by Truesdell and Fournier (1976): "...the high partial pressure of CO_2 and large Ca contents of

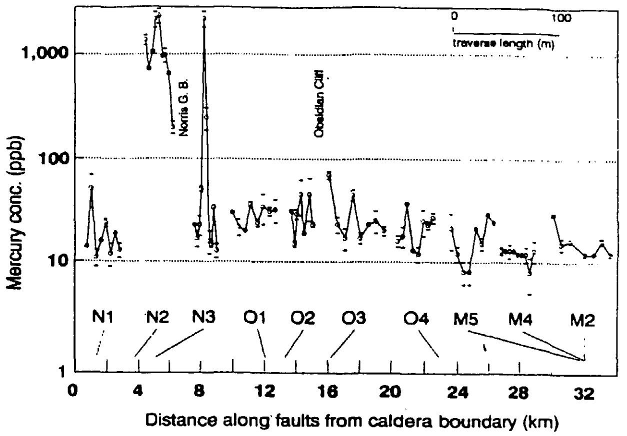

Figure 3. Soil Hg data for traverses crossing the Norris (N) and Obsidian Creek (O) faults and selected faults in the Mammoth area (M). Traverses (Fig. 2) are plotted against distance north of the caldera boundary. Error bars here and in figures to follow represent one sigma. All traverses, except M4, are thought to intersect anomalies associated with faults. A major Hg source is evident at Norris Geyser Basin, and a smaller source is inferred near Obsidian Cliff.

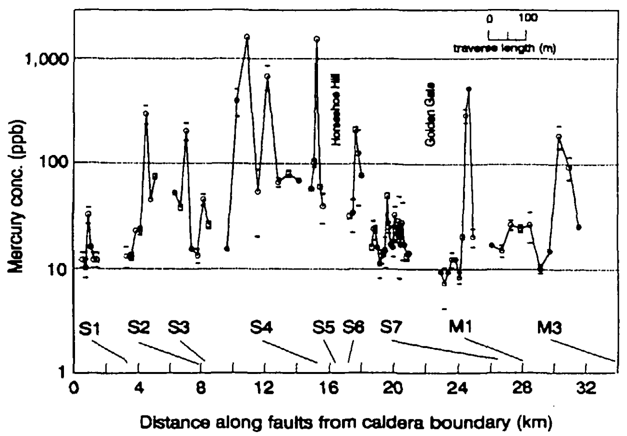

Figure 4. Soil Hg data for traverses crossing the Solfatara Creek and Horseshoe Hill fault zones (S) and faults in the Mammoth area (M). A major Hg source is seen in the Horseshoe Hill area east of Obsidian Cliff. M1 is near Golden Gate, and M3 is located in front of the Visitor Center at Mammoth.

Mammoth Hot Spring probably result from reaction of Norris acid chloride waters moving northward along a fault zone with sediments consisting in part of limestone." More specifically it is in agreement with the flow model proposed by Clark and Turekian (1990) with regard to a source near Obsidian Cliff and seems to reflect the deep upwelling proposed by White et al. (1988).

Mammoth Hot Springs Area

Locations of Hg traverses and faults in the Mammoth Hot Springs area are shown in Figure 5. The travertine hot spring terrace area was extensively sampled, as shown, by Phelps and Buseck (1980) in 1977, but the route of ingress of Hg-bearing waters to the Mammoth springs was not clearly identified. Highest anomalies found in 1977 were at locations identified as C, D, and E in the figure. Phelps and Buseck (1980) noted that these anomalies aligned with a buried fault mapped by Christiansen and Blank (1972), but because this fault lies east and downslope from the highest concentration of hot springs we believe it more likely represents the aquifer feeding several lower springs in the area. We informally call it the Cemetery fault for purposes of discussion here.

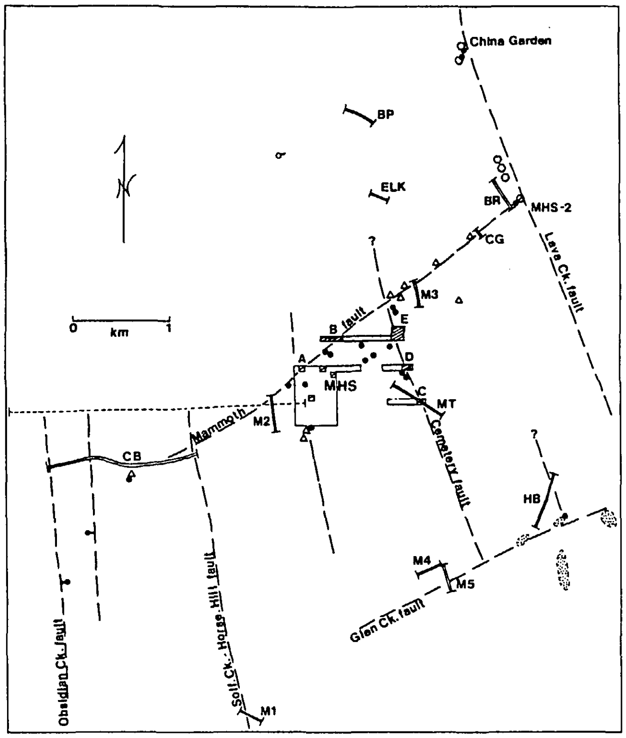

Figure 5. Map of faults in the Mammoth Hot Springs area based on USGS (1972) mapping with locations adjusted to match mercury anomalies and to avoid areas where anomalies were not found. Faults are shown with bold dashed lines. Hg traverses are shown by double lines ending in bars with identification labels found in the text. Vapor and gas vents are shown by triangles. Selected hot springs are indicated by closed circles. Areas sampled for Hg by Phelps and Buseck (1980) are outlined by solid lines in rectangular array at the Mammoth Terraces. Their areas giving [Hg]>20 ppb are shaded and labeled as A, B, C, D, and E. Travertine deposits near the Gardner high bridge are stippled.

Hg traverse data along faults between Golden Gate and the Beaver Pond trail north of Mammoth Hot Springs, including the Cemetery fault, are illustrated in Figure 6. The modest northward decrease in anomaly amplitude suggests that it is plausible to consider flow from Golden Gate into the Cemetery fault as far as the intersection with the Mammoth fault, but the marked decrease in amplitude at the Beaver Pond traverse implies that the fault does not contain much hot water at this point.

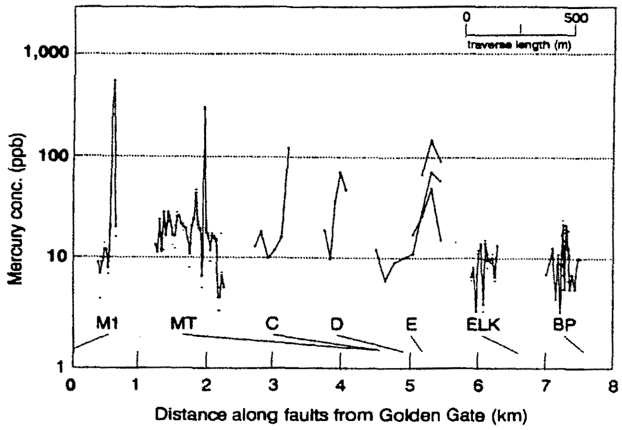

Figure 6. Hg concentrations on traverses at Golden Gate and on the Cemetery fault as far as the Beaver Pond (BP) traverse. The Cemetery fault has large anomalies in Mammoth, but it may not contribute to spring discharge in the upper terrace area. The Elk Plaza (ELK) traverse probably missed the fault.

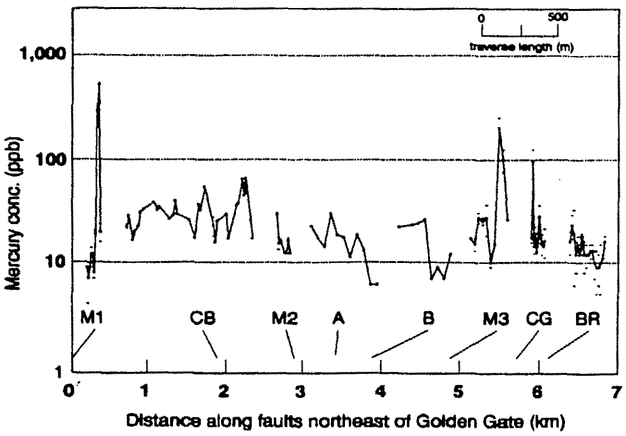

Figure 7. Hg concentrations on traverses at Golden Gate and along the Mammoth fault from Clagett Butte to hot spring MHS-2, near Hot River. Modest anomalies suggest that little Hg-bearing water is associated with the Mammoth fault southwest of the intersection with the Cemetery fault. Northeast of that point the fault has higher anomalies. Clagett Butte analyses were by the Tuva II method (see Table I).

Hg data along faults between Golden Gate and the Hot River area northeast of Mammoth are shown in Figure 7 to assess anomalies along the Mammoth fault. The marked reduction in anomaly amplitude between M1 and the east half of the Clagett Butte traverse without apparent gas venting or hot spring discharge suggests to us that there is little flow along this portion of the fault. Moreover, low anomalies at A and B (representing data of Phelps and Buseck from the northwest portion of their sampling area) and at M2 imply little Hg-bearing water in that portion of the Mammoth fault. Downslope from and northeast of the intersection with the Cemetery fault, however, the Mammoth fault exhibits high anomalies at the Albright Visitor Center (M3) and northeast of the Mammoth Campground (CG). An anomaly at the Hot River area (BR) aligns with a travertine-depositing hot spring (MHS-2) on the trace of the Mammoth fault at the Gardner River.

Gardiner Valley

Hg traverses in the Gardiner Valley between the Gardner River and the Corwin Springs area (map locations in Fig. 2) are compiled in Figure 8. These data show Hg anomalies associated with faults entering the valley from the south and, in three cases where traverses cross the valley (Corwin Springs, CS; Queen of the Waters, QW; and Rescue Creek, RC), illustrate anomalies aligned with structures that strike northwest along the valley. The north-south structures are normal faults, with the possible exception of the Rifle Range fault. This fault (informal name) may be an extension of the Lava Creek fault as shown by Christiansen (1973). The northwest-striking structures are associated with the older, complex fold and thrust zone of the Gardiner fault.

The RC traverse clearly shows very small anomalies associated with the Everts thrust (and a nearby, unnamed thrust) as well as the Rifle Range fault. These small anomalies suggest that the valley structures carry very little Hg-bearing water at this point. At the northwest end of the valley, the CS traverse shows modestly high anomalies, perhaps associated with the East Gallatin normal fault and the Gardiner thrust as mapped by Struhsacker (1976). High valley anomalies are found in a zone parallel to the Yellowstone River at the fishing access area (QW) 8 km northwest of Bear Creek. This zone may be associated with the footwall block of the Gardiner thrust, and we propose that the high anomalies are a result of the injection of Hg-bearing waters into the zone from normal faults entering the valley from the south somewhere between the Rescue Creek traverse and the 8 km point.

Several candidates for injection are evident along the Black Arrow (BA) traverse, which shows anomalies associated with the Rifle Range fault and several faults mapped in the Mammoth and Stephens Creek areas (Fig. 2). The amplitudes of these anomalies appear to increase northwestward along the BA line. No gas vents or hot springs are known in the valley between Bear Creek and QW, so Hg depletion may occur gradually in this area.

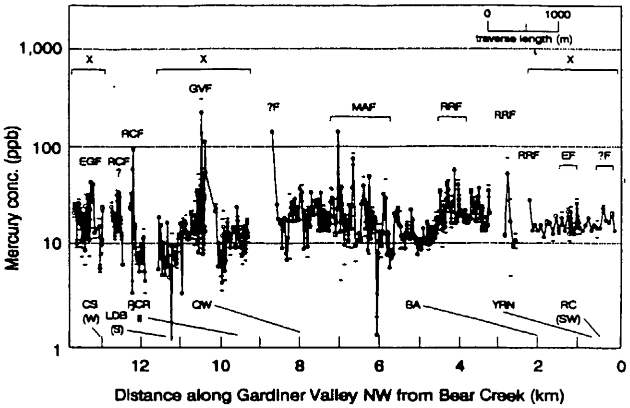

Figure 8. Hg concentration data for traverse segments crossing the Gardiner Valley (CS, QW, and RC) are labeled with an X. Also shown are traverses that account for inputs into the valley from the south (RCR II, BA, and YRN). The large anomalies at QW may be due to inputs from faults encountered on the BA line, showing increasing Hg to the northwest. Fault name abbreviations are: East Gallatin (EGF); Reese Creek (RCF); proposed Gardiner Valley (GVF); Mammoth area faults (MAF); Rifle Range (RRF); Everts (EF); and unnamed or unmapped faults (?F). South, west, and southwest ends of some traverses are indicated by (S), (W), and (SW).

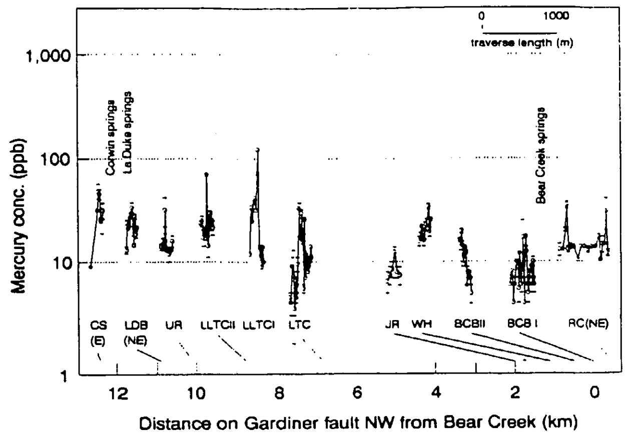

Figure 9. Hg concentration data for all traverses and traverse segments crossing and near the Gardiner fault between the Bear Creek area and the Corwin fishing access area. Assuming flow down-valley to the northwest in the fault zone, the decrease at Bear Creek is attributed to Hg losses with discharge at the springs there. The increase northwest of BCB II may be from injection from the Rifle Range fault (traverse YRN in Fig. 8). The Jardine Road line probably missed the fault. A large increase near the mouth of Little Trail Creek canyon may be attributed to a crosscutting fault mapped at that location by Struhsacker (1976). The small increase northwest of La Duke may be due to input from the Reese Creek fault (RCR II in Fig. 8). East and northeast ends of several traverses are indicated by (E) and (NE).

One of the Reese Creek traverses (RCRII) is shown in Figure 8 (the line giving the highest values), and it is evident that this fault is a significant contributor of Hg-bearing waters to the system near La Duke spring. Where a portion of the Reese Creek fault zone was sampled northeast of the Yellowstone River at La Duke (LDB) anomalies were smaller, presumably because of losses at hot springs along the river at that location.

Gardiner Thrust Zone

Hg data on traverses crossing the Gardiner thrust between Bear Creek and Corwin Springs are shown in Figure 9. One line (Jardine Road, JR) probably missed the fault, and we exclude it from the discussion here. The results give the impression of an overall increase in Hg in the fault zone toward the northwest. The RC data show small anomalies associated with the Gardiner thrust (and a parallel, unnamed thrust) east of Bear Creek hot springs. The Bear Creek Bench (BCB) traverses show even lower anomalies, and this is consistent with northwest flow in the fault zone with Hg loss at the springs. We interpret the increase at traverse WH to injection of Hg-bearing water into the thrust by the Rifle Range fault (see Fig. 8). Moreover, we interpret the increase between the LTC and LLTC (Little Trail Creek) traverses as due to water injected into the Gardiner thrust near the mouth of Little Trail Creek canyon by the normal fault shown at that location by Struhsacker (1976).

The decline in anomaly amplitude between LLTC I and LDB is consistent with northwest flow and relatively rapid Hg depletion. The apparent increase in amplitude northwest of LDB may be a result of misidentification of the fault. As noted above, Struhsacker shows the Gardiner thrust offset to the west by normal faulting here. The anomaly shown in Figure 9 at the east end of the Corwin Springs traverse may actually represent an unnamed normal fault at that location. Thermal anomaly surveys in the area support that interpretation (Chambers and Hamilton, in prep.).

CONCLUSIONS

Using the concept of Hg depletion along faults between the Horseshoe Hill - Obsidian Cliff area and the Mammoth Hot Springs area, we infer a direction of flow that is in agreement with other investigators. Depletion is greater along fault segments where evidence of gas venting and spring discharge is visible.

As a result we propose here that Hg leakage from fault zones provides an assessment of the Hg partial pressure in aquifers associated with the faults. The fault zones are apparently permeable enough, owing perhaps to fracture of mineral precipitates by occasional seismic activity, to permit leakage of Hg vapor to the surface. We think that some associated aquifers may be intersected by faults at depth. In areas of thick valley fill the aquifer may overlie the fault, and some faults themselves may serve as aquifers.

We conclude that a major aquifer can be traced northward to Golden Gate and the Cemetery fault in Mammoth, though portions of the flow path have yet to be located. Northeastward flow through a portion of the Mammoth fault is also inferred.

In the Gardiner Valley north of Mammoth, Hg anomalies associated with a series of normal faults appear to mark aquifers entering the valley from the south. Strong anomalies on two parallel segments of a traverse at the QW area suggest a northwest-striking structure, perhaps associated with the footwall of the Gardiner thrust, being supplied with Hg by normal faults from the south. The depletion of cross-valley Hg northwest of the QW area is consistent with loss with hot spring discharge at the La Duke - Corwin springs area.

Along the Gardiner thrust, on the benches northeast of the Gardiner Valley, augmentation of Hg northwestward suggests that the above-mentioned normal faults are also adding geothermal waters to the thrust zone. Depletion at Bear Creek hot springs is attributed to losses with discharge there. Augmentation at the mouth of Little Trail Creek Canyon may be due to a normal fault intersecting at that point.

Hg anomalies suggest that the Reese Creek fault contributes to the geothermal aquifer at La Duke, but we suspect considerable augmentation from the Gardiner Valley structure to account for the sizeable discharge at La Duke.

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