DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Preliminary Results of Precise Leveling and Trilateration Surveys in Yellowstone National Park, Wyoming, 1983-1984

by

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FOREWARD

This report describes preliminary results of precise leveling and trilateration surveys in Yellowstone National Park in October 1983 and September 1984. A companion report (Dzurisin, Yamashita, and Johnson, 1986) describes results of repeat surveys in September 1985. Each report has its own figures and tables; this one also contains an appendix with descriptions of 50 benchmarks measured during the leveling surveys.

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ABSTRACT

Level surveys in Yellowstone National Park in 1923 and 1975-1977 revealed that parts of Yellowstone caldera rose by more than 700 mm during that interval along an axis connecting the Mallard Lake and Sour Creek resurgent domes, at an average rate of 14 mm/yr. Our surveys in October 1983 and September 1984 show that uplift continued since the 1975-1977 survey at an average rate of 22 mm/yr (180 mm net); we estimate the maximum uplift near LeHardy Rapids since 1923 to be about 980 mm. Because it is not known when the uplift began, it is not yet clear whether the rate of uplift is currently increasing, decreasing, or staying roughly constant. The net volume change inside the caldera since 1923 is conservatively estimated to be 0.75 km^3; the average rate of volume increase is thus about 0.012 km^3/yr. A precise trilateration network consisting of 8 lines 11 to 30 km long spanning the northeast part of the caldera was established in September 1984 to monitor horizontal strain changes associated with the continuing uplift.

INTRODUCTION

Purpose and Scope

This informal report was prepared in order to make available to interested parties the results of precise level and trilateration surveys conducted by U. S. Geological Survey crews in Yellowstone National Park during October 1983 and September 1984. Data reported here are preliminary and subject to revision; final results will be published in the formal literature as appropriate.

With support from the USGS Volcanic Hazards Reduction Program, a series of annual level surveys was initiated in October 1983 and supplemented in 1984 with a precise trilateration network in the northeast part of Yellowstone caldera. The purpose of these surveys is to monitor ground displacements caused by physical processes acting in a large rhyolitic magma reservoir that is known to exist beneath Yellowstone caldera (Eaton and others, 1975). Better understanding of these active magmatic processes is necessary to refine volcanic hazards assessments for Yellowstone, which heretofore have been based on the geologic record of past eruptions (Christiansen, 1984a, b) and on crustal structure beneath Yellowstone caldera inferred from regional geophysical surveys (Smith and Braile, 1982).

A recent compilation of unrest at large calderas worldwide (Newhall, Dzurisin, and Mullineaux, 1984; Dzurisin and Newhall, 1984) suggests that ground displacements and associated seismicity are relatively common at young silicic calderas, implying that results from Yellowstone may be applicable to similar calderas elsewhere.

1984 Schedule and Participants

At the request of the National Park Service, we began our work in Yellowstone Park after Labor Day (September 3, 1984) to avoid the peak tourist season. A crew from the Cascades Volcano Observatory consisting of Steve Brantley, Kathy Cashman, Dan Dzurisin, Dan Johnson, and Ken Yamashita arrived in Yellowstone on September 3 and began the level survey from Canyon Junction to Lake Butte (Figure 1) on September 5. Brantley and Cashman were replaced by Bruce Furakawa on September 15; the level survey was completed on September 21.

While the level survey was in progress, Jim Savage and a USGS contract crew established a precise trilateration network consisting of 8

lines 11 to 30 km long spanning the northeast part of the caldera (Figure 2). A 35 km line from Washburn to Chittenden could not be measured this year owing to high winds; it will be included in future surveys whenever possible. A larger network spanning the entire caldera would have been preferable, but limited funding and problems with obtaining clear lines of sight precluded such an undertaking. We chose to concentrate on the northeast part of the caldera for 3 reasons: 1) we wanted the trilateration network to span the annual level survey from Canyon Junction to Lake Butte; 2) this is the only area with reasonable lines of sight over distances of 10-40 km; and 3) Smith and Braile (1982) have identified a shallow low velocity zone, probably containing partial melt, beneath the northeast part of the caldera near the centroid of the new trilateration network.

The trilateration network was measured to a precision of about 1 part in 10^7 using a Geodilite, a very precise electro-optical distance measuring instrument. Atmospheric refractivity corrections were based on measurements from an aircraft flown along the line-of-sight during ranging; results are listed in Table 1. We plan to repeat the level and trilateration surveys each September for the foreseeable future to establish contemporary strain rates and to correlate possible strain rate changes with changes in seismic, hydrothermal, or other activity in the caldera.

LEVELING RESULTS

Earlier Surveys

Level surveys in the Yellowstone area during 1923-1977 were of variable quality and coverage; Pelton and Smith (1982) discuss the results and limitations of each. One thing is clear from these earlier surveys: broad uplift by more than 700 mm occurred along an axis connecting the Mallard Lake and Sour Creek resurgent domes sometime between 1923 and 1977 (Figure 3), at an average rate of about 14 mm/yr (Pelton and Smith, 1979, 1982). A primary goal of our work at Yellowstone is to monitor vertical and horizontal ground displacements annually to determine whether ground deformation there is continuous or episodic, and whether the rate of deformation is currently increasing, decreasing, or staying roughly constant.

The Route

We chose the pre-existing level line between Canyon Junction and Lake Butte (Figure 1) for annual monitoring for the following reasons: 1) the route is nearly orthogonal to the axis of uplift identified by Pelton and Smith (1979, 1982); 2) it includes several benchmarks established during the first survey in 1923, and thus has a relatively long history of measurement; 3) it includes the benchmark with the largest 1923-1977 uplift reported by Pelton and Smith (B11 1923, 726 mm); and 4) access is relatively easy except in winter along paved National Park Service roads.

Benchmark Descriptions

The 43 km long (33 km straight line distance) Canyon Junction to Lake Butte level line currently includes 57 benchmarks, including 10 established in 1923, 19 in 1976, and 28 in 1984 (Figure 1). Most benchmarks are standard brass caps cemented or epoxied into bedrock or concrete structures; a few of the 1984 benchmarks are of a newer design with a central nipple to facillitate accurate positioning of the level

rod. Descriptions for each of the benchmarks are given in the appendix; those for pre-1984 benchmarks are only slightly modified from Evoy and Smith (1979).

1983 Results

The central 24 km of the level line, from Trout Creek to Indian Pond, was leveled to first order standards during October 13-25. All segments were double run using a Wild N-3 level and Wild GPLE-3 Invar level rods; the N-3 uses a manual spirit level and therefore is not subject to magnetic errors associated with automatic levels using magnetic compensators. Our digital thermometers were calibrated only above 0 degrees Centigrade, so most of the temperature data were acquired with mercury thermometers with a precision of about 0.5 degree Centigrade. The rods had been calibrated at the U. S. Navy Gage and Standards Center in March 1983; the 1983 data in Table 2 include rod and temperature corrections but no corrections for atmospheric refractivity (owing to inadequate temperature data).

Our 1983 results are ambiguous because the survey was not tied to a stable base outside the caldera. Nevertheless, it is clear that a substantial amount of additional uplift had occurred since the line was last surveyed in 1976. Benchmark DA 3 1934 near LeHardy Rapids was uplifted by 81 mm relative to 32 MDC 1976 near Indian Pond, and the pattern of uplift is similar to the 1923-1976 profile of Pelton and Smith (1979, 1982). Extrapolation based on the earlier profile suggests that the total uplift at DA 3 1934 relative to a stable base near Lake Butte was about 160 mm during 1976-1983, at an average rate of 23 mm/yr. This was considerably higher than the average rate for 1923-1976 (14 mm/yr) calculated by Pelton and Smith (1979, 1982), but the comparison is clouded by our inability to tie the 1983 survey to a stable base.

1984 Results

The entire level line from Canyon Junction to Lake Butte was releveled to first order standards in September 1984 using a Wild N-3 level, the same pair of level rods used in 1983, and digital temperature sensors with a precision of 0.1 degree Centigrade. With permission from the National Park Service, we drove P-K masonry nails flush with the road pavement as temporary marks, which yielded better results than the portable turning cups used for the 1983 survey. Data were recorded in the field using a Hewlett-Packard 41-C handheld calculator, then transferred to a DEC VAX 750 at the Cascades Volcano Observatory. Temperatures were measured 0.5 m and 2.5 m above the ground surface at each instrument site, and the level rods were calibrated at the National Bureau of Standards immediately after the Yellowstone survey. Data in Table 2 do not include rod, temperature or refractivity corrections, which are likely to be small compared to the uplift measured since 1976. These corrections might be significant compared to the relatively small uplift since 1983, however, so the 1983-1984 changes should be used with caution.

The central part of the level line, between Trout Creek and Indian Pond, was single run in 1984 unless the result differed from the 1983 survey by more than first order standards. Adjacent benchmark pairs were run in opposing directions to minimize the effect of pin settlement during measurements. The northern and southern parts of the line (from Canyon Junction to Trout Creek and from Indian Pond to Lake Butte,

respectively), last measured in 1976, were double run in 1984. We chose to replace a segment of the route between Indian Pond and Lake Butte with a new segment along the paved road from Fishing Bridge toward the East Entrance. The earlier route follows a dirt road through prime grizzly bear habitat; the road has been abandoned by the Park Service and is subject to frequent bear closures.

The 1984 level survey generally confirmed the inferences drawn from the partial survey in 1983. Benchmark DA 3 1934 was uplifted by 180 mm relative to 36 MDC 1976 during 1976-1984, at an average rate of 22 mm/yr. The shape of the resulting profile is similar to the 1923-1977 profile published by Pelton and Smith (1979, 1982), suggesting that the source of the deformation has not changed. Canyon Junction has seemingly been uplifted by an additional 18 mm relative to Lake Butte since 1976, consistent with the results of earlier surveys (Figure 3). Although this could reasonably be attributed to systematic leveling errors, it is also possible that regional tectonic tilting is responsible. The maximum measured uplift along the line since 1923 is 892 mm at BM B11 1923; extrapolation based on the shape of the 1976-1984 profile suggests that the true maximum near DA 3 1934 has been about 986 mm.

Closures

In 1912 the International Geodetic Association resolved that leveling should be described as of high precision only if the random probable error was less than 1 mm x $d^{1/2}$ and the systematic error less than 0.2 mm x d, where d is the distance leveled in km. In 1948 the Association redefined high precision leveling as having errors less than 2 mm x $d^{1/2}$ (probable) or 3 mm x $d^{1/2}$ (standard), i. e., standard errors less than 3 $mm/km^{1/2}$ for distances greater than several tens of kilometers (Bomford, 1980). Note that the relevant distance for double run leveling is the length of the circuit, twice the one way distance between benchmarks for the segment under consideration.

Final closure information for the 1983 survey and preliminary results for the 1984 survey are provided in Table 3. It is difficult to estimate the magnitude of systematic errors that may exist in these data, except to recall the precautions against such errors that were mentioned earlier. An estimate of the magnitude of random errors can be made by comparing the difference between fore- and back-leveling, i. e., the benchmark-to-benchmark closures for double-run segments. For the 1983 survey, 77% of the closures meet or exceed the strictest definition of first order leveling (1 $mm/km^{1/2}$); none of the closures exceed the acceptable standard error of 2 $mm/km^{1/2}$. The average benchmark-to-benchmark closure is 0.75 $mm/km^{1/2}$.

For those segments that were double run in 1984, the average benchmark-to-benchmark closure is 0.96 $mm/km^{1/2}$. Fifty per cent of the closures meet or exceed the 1 $mm/km^{1/2}$ standard and 87% are better than 2 $mm/km^{1/2}$; only 1 closure exceeded 3 $mm/km^{1/2}$, and that segment was re-run to better than 2 $mm/km^{1/2}$. The 1983 closures are slightly better than those for 1984, probably because a smaller tolerance for acceptable right-left scale differences was used in 1983 (0.03 mm vs. 0.10 mm). The larger tolerance significantly decreases the time required for the survey, however, and is considered to be an acceptable compromise for that reason.

DISCUSSION

The shapes of the 1923-1976, 1923-1983, and 1923-1984 profiles from Canyon Junction to Lake Butte are poorly constrained owing to the small number of 1923 benchmarks that could be recovered during the later surveys. The 1976-1984 profile is much better constrained (Figure 4), and can be used as a model to fit profiles to the other surveys. Although the number of common benchmarks is admittedly small, this procedure yields reasonable fits to the 1923-1976, 1923-1983, and 1923-1984 data (Figure 5). We conclude that the shape of the uplift has not changed significantly since 1923, at least along the profile from Canyon Junction to Lake Butte. Note from Figure 6 that the shape of the uplift bears no resemblance to the topographic profile along the level route, so the uplift is unlikely to be an artifact of systemmatic errors related to topography.

The volume of uplift at Yellowstone since 1923 was estimated from the 1923-1976 contour map of Pelton and Smith (Figure 3), subject to the following assumptions: 1) only the area inside the caldera rim was considered, i.e., ground displacements associated with the 1959 M=7.1 Hebgen Lake earthquake northwest of the caldera were excluded; 2) contours inside the caldera were arbitrarily closed by extrapolating the known shape of the uplift; 3) the 1923-1976 volume was calculated as the sum of stacked horizontal slabs defined by the 100 mm contours; and 4) the result was scaled by 892/726 mm (1984/1976 uplift at B11 1923) to extend the estimate through 1984.

This admittedly crude calculation suggests that the net uplift within Yellowstone caldera during 1923-1984 was about 0.75 km^3; the corresponding average rate of volume change is 0.012 km^3/yr. This is similar to the mean rate of growth of the Hawaiian-Emperor volcanic chain (0.015 km^3/yr; Shaw, Jackson, and Bargar, 1980), and to the value of 0.01 km^3/yr proposed by Smith (1979), Smith and Shaw (1975, 1979), and Shaw (1984) for the average influx rate of mafic magma to the base of active silicic magma reservoirs. It is therefore tempting to conclude that uplift at Yellowstone since 1923 is an expectable manifestation of the long term, steady state influx of basalt from the mantle into a healthy rhyolitic reservoir beneath the caldera. Unfortunately, that is almost certainly an oversimplified view.

SUMMARY

Level surveys in Yellowstone National Park in 1923 and 1975-1977 revealed that the floor of Yellowstone caldera rose by more than 700 mm during that interval along an axis connecting the Mallard Lake and Sour Creek resurgent domes, at an average rate of 14 mm/yr. Our surveys in October 1983 and September 1984 show that uplift continued since the 1975-1977 survey at an average rate of 22 mm/yr; maximum uplift near LeHardy Rapids since 1923 is estimated to be about 98 cm. Because it is not known when the uplift began, it is not yet clear whether the rate of uplift is currently increasing, decreasing, or staying roughly constant. The net volume change inside the caldera since 1923 is conservatively estimated to be 0.75 km^3; the average rate of volume increase is thus about 0.012 km^3/yr.

A precise trilateration network consisting of 8 lines 11 to 30 km long spanning the northeast part of the caldera was established in September 1984 to monitor horizontal strain changes associated with the continuing uplift. The lines were measured to a precision of about 1

part in 10^7 using a Geodolite, a precise electro-optical distance measuring instrument. We plan to repeat the level and trilateration surveys annually to better establish current rates of deformation and to relate future changes in deformation, seismicity, and hydrothermal activity within the caldera.

Acknowledgments

This is a cooperative project involving the U. S. Geological Survey and the National Park Service; we are indebted to the NPS for living accommodations and logistical support during our visit, notably the use of the Utah Dorm and the NPS contract helicopter for reconnaisance purposes. John Varley and Wayne Hamilton were particularly accommodating. Jim Savage, Wil Prescott, Ross Stein, and Bob Castle of USGS advised us on first order level techniques, and Ross loaned us temperature measuring equipment for the 1984 level survey.

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TABLE 1

YELLOWSTONE TRILATERATION NETWORK
September 1984 Results

FROM	TO	DISTANCE Mark-Mark (m)	DISTANCE Sea level (m)
Amethyst	Cone	20591.8633	20582.3674
Amethyst	Trout	30878.4928	30861.5155
Amethyst	Washburn	14615.9699	14607.7777
Chittenden	Cone	11309.1762	11302.7798
Chittenden	Trout	27632.4211	27612.4008
Cone	Trout	25025.5312	25009.7045
Cone	Washburn	25291.8931	25279.2688
Trout	Washburn	21000.5582	20980.0173
Washburn	Chittenden	-	-

TABLE 2

YELLOWSTONE LEVEL DATA
1923-1984

BENCHMARK NAME	ROAD DISTANCE (KM)	PROJECTED DISTANCE (KM)	ELEVATION [1] 1923 (M)	ELEVATION [1] 1976 (M)	ELEVATION [2] 1983 (M)	ELEVATION [3] 1984 (M)	CHANGE 1923-1976 (M)	CHANGE 1923-1983 (M)	CHANGE 1923-1984 (M)	CHANGE 1976-1983 (M)	CHANGE 1976-1984 (M)	CHANGE 1983-1984 (M)	BENCHMARK NAME
11 MDC 1976	0.0	0.0	-	2413.0200	-	2413.0382	-	-	-	-	0.0182	-	11 MDC 1976
CVO 84-1	1.1	0.8	-	-	-	2413.1508	-	-	-	-	-	-	CVO 84-1
LC 58 1977	2.7	1.1	-	-	-	2366.0416	-	-	-	-	-	-	LC 58 1977
J11 1923	1.8	1.3	2377.3269	2377.5324	-	2377.5533	0.2055	-	0.2264	-	0.0209	-	J11 1923
22 MDC 1976	3.8	1.9	-	2346.2685	-	2346.2933	-	-	-	-	0.0248	-	22 MDC 1976
23 MDC 1976	4.5	2.3	-	2340.4325	-	2340.4616	-	-	-	-	0.0291	-	23 MDC 1976
24 MDC 1976	5.9	3.6	-	2344.9191	-	2344.9600	-	-	-	-	0.0409	-	24 MDC 1976
CVO 84-2	6.6	4.2	-	-	-	2342.0852	-	-	-	-	-	-	CVO 84-2
25 MDC 1976	7.8	5.1	-	2340.8244	-	2340.8983	-	-	-	-	0.0739	-	25 MDC 1976
CVO 84-3	8.4	6.1	-	-	-	2341.2057	-	-	-	-	-	-	CVO 84-3
CVO 84-6	9.3	6.9	-	-	-	2369.8569	-	-	-	-	-	-	CVO 84-6
B11 1923	9.8	7.4	2358.2000	2358.6691	-	-	0.4611	-	-	-	-	-	B11 1923
CVO 84-4	10.1	7.7	-	-	-	2345.1061	-	-	-	-	-	-	CVO 84-4
CVO 84-5	11.2	8.5	-	-	-	2343.2465	-	-	-	-	-	-	CVO 84-5
F11 A	12.2	9.5	-	2343.5588	2343.6789	2343.6982	-	-	-	0.1201	0.1394	0.0193	F11 A
E11 A2	13.0	10.2	-	2344.8323	2344.9613	2344.9798	-	-	-	0.1290	0.1475	0.0185	E11 A2
CVO 84-7	13.8	11.0	-	-	-	2369.5943	-	-	-	-	-	-	CVO 84-7
26 MDC 1976	14.7	11.7	-	2364.1762	2364.3440	2364.3614	-	-	-	0.1678	0.1852	0.0174	26 MDC 1976
CVO 84-22	14.7	11.7	-	-	-	-	-	-	-	-	-	-	CVO 84-22
CVO 84-8	16.0	12.9	-	-	-	2354.3922	-	-	-	-	-	-	CVO 84-8
27 MDC 1976	16.9	13.7	-	2351.0709	2351.2297	2351.2484	-	-	-	0.1588	0.1775	0.0187	27 MDC 1976
CVO 84-9	18.2	14.9	-	-	-	2350.7145	-	-	-	-	-	-	CVO 84-9
28 MDC 1976	19.0	15.3	-	2359.0792	2359.2422	2359.2595	-	-	-	0.1630	0.1803	0.0173	28 MDC 1976
DA 3 1934	19.9	16.2	-	2353.1317	2353.2978	2353.3117	-	-	-	0.1661	0.18	0.0139	DA 3 1934
29 MDC 1976	20.4	16.7	-	2368.5925	2368.7563	2368.7706	-	-	-	0.1638	0.1781	0.0143	29 MDC 1976
CVO 84-10	21.2	17.2	-	-	-	2362.8510	-	-	-	-	-	-	CVO 84-10
B11 1923	22.1	17.8	2365.0341	2365.7604	2365.9106	2365.9261	0.7263	0.8765	0.892	0.1502	0.1657	0.0155	B11 1923
CVO 84-11	23.0	18.6	-	-	-	2380.6487	-	-	-	-	-	-	CVO 84-11
30 MDC 1976	23.7	19.3	-	2390.2493	2390.3860	2390.3972	-	-	-	0.1367	0.1479	0.0112	30 MDC 1976
L19 1977	24.2	19.5	-	-	-	2395.1365	-	-	-	-	-	-	L19 1977
A11 1923	25.1	19.9	2374.7207	2375.3398	2375.4726	2375.4821	0.6191	0.7519	0.7614	0.1328	0.1423	0.0095	A 11 1923
CVO 84-23	25.1	19.9	-	-	-	-	-	-	-	-	-	-	CVO 84-23
31 MDC 1976	26.3	21.0	-	2363.8227	2363.9367	2363.9452	-	-	-	0.1140	0.1225	0.0085	31 MDC 1976
7743.43	27.6	22.1	-	2360.4440	2360.5444	2360.5534	-	-	-	0.1004	0.1094	0.0090	7743.43
CVO 84-15	28.8	23.0	-	-	-	2362.2982	-	-	-	-	-	-	CVO 84-15
32 MDC 1976	29.3	23.3	-	2366.0016	2366.0869	2366.0959	-	-	-	0.0853	0.0943	-	32 MDC 1976

TABLE 2 (cont.)

YELLOWSTONE LEVEL DATA

1923-1984

BENCHMARK NAME	ROAD DISTANCE (KM)	PROJECTED DISTANCE (KM)	ELEVATION[1] 1923 (M)	ELEVATION[1] 1976 (M)	ELEVATION[2] 1983 (M)	ELEVATION[3] 1984 (M)	CHANGE 1923-1976 (M)	CHANGE 1923-1983 (M)	CHANGE 1923-1984 (M)	CHANGE 1976-1983 (M)	CHANGE 1976-1984 (M)	CHANGE 1983-1984 (M)	BENCHMARK NAME
CVO 84-12	30.4	23.8	-	-	-	2371.9860	-	-	-	-	-	-	CVO 84-12
CVO 84-27	30.4	23.8	-	-	-	-	-	-	-	-	-	-	CVO 84-27
33 MDC 1976	31.4	24.5	-	2381.6153	2381.6083	-	-	-	-	-	-	-	33 MDC 1976
CVO 84-16	31.7	25.1	-	-	-	2359.2472	-	-	-	-	-	-	CVO 84-16
CVO 84-17	32.7	26.2	-	-	-	2358.3663	-	-	-	-	-	-	CVO 84-17
D12 1923	33.4	26.2	2436.8932	2437.1036	-	-	0.2104	-	-	-	-	-	D12 1923
CVO 84-13	33.9	27.2	-	-	-	2358.8971	-	-	-	-	-	-	CVO 84-13
34 MDC 1976	34.6	27.4	-	2411.7201	-	-	-	-	-	-	-	-	34 MDC 1976
CVO 84-14	35.1	27.4	-	-	-	2366.0042	-	-	-	-	-	-	CVO 84-14
CVO 84-18	35.9	27.9	-	-	-	2376.9184	-	-	-	-	-	-	CVO 84-18
E12 1923	36.4	28.5	2425.0619	2425.1851	-	-	0.1232	-	-	-	-	-	E12 1923
CVO 84-19	37.1	28.9	-	-	-	2360.5252	-	-	-	-	-	-	CVO 84-19
CVO 84-24	38.0	29.7	-	-	-	2360.5465	-	-	-	-	-	-	CVO 84-24
CVO 84-25	38.6	30.3	-	-	-	2379.1234	-	-	-	-	-	-	CVO 84-25
F12 1923	39.8	30.9	2475.9387	2475.9292	-	-	-0.0095	-	-	-	-	-	F12 1923
CVO 84-26	40.0	31.3	-	-	-	2437.8180	-	-	-	-	-	-	CVO 84-26
CVO 84-20	41.0	31.6	-	-	-	2465.6213	-	-	-	-	-	-	CVO 84-20
35 MDC 1976	41.7	31.7	-	2492.5972	-	-	-	-	-	-	-	-	35 MDC 1976
CVO 84-28	41.8	31.7	-	-	-	-	-	-	-	-	-	-	CVO 84-28
CVO 84-21	42.6	32.3	-	-	-	2547.1430	-	-	-	-	-	-	CVO 84-21
36 MDC 1976	43.3	32.9	-	2545.6183	2545.6183	2545.6183	-	-	-	0.0000	0.0000	0.0000	36 MDC 1976

[1] 1923 and 1976 data from Evoy and Smith (1979).

[2] 1983 data includes rod and temperture corrections, not not refractivity corrections.

[3] Preliminary 1984 data does not includes rod, temperature, or refractivity corrections.

TABLE 3

1983 Closure Information

BENCHMARKS (FROM/TO)	ROAD DISTANCE (KM)	ELEVATION DIFFERENCE (M)	CLOSURE (M)	CLOSURE (MM/KM**1/2)	MEAN DIFFERENCE (M)	ELEVATION 1983 (M)
F11 A TO E11 A2	0.8	1.2828	+0.0008	0.63	1.2824	"2343.6788"
E11 A2 TO F11 A		-1.2820				2344.9613
E11 A2 TO 26 MDC 1976	1.7	19.3828	+0.0002	0.11	19.3827	2364.3440
26 MDC 1976 TO E11 A2		-19.3826				
26 MDC 1976 TO 27 MDC 1976	2.2	-13.1136	+0.0014	0.67	-13.1143	2351.2297
27 MDC 1976 TO 26 MDC 1976		13.1150				
27 MDC 1976 TO 28 MDC 1976	2.1	8.0126	+0.0001	0.05	8.0125	2359.2422
28 MDC 1976 TO 27 MDC 1976		-8.0125				
28 MDC 1976 TO DA 3 1934	0.9	-5.9431	+0.0026	1.94	-5.9444	2353.2978
DA 3 1934 TO 28 MDC 1976		5.9457				
DA 3 1934 TO 29 MDC 1976	0.5	15.4582	-0.0006	0.60	15.4585	2368.7563
29 MDC 1976 TO DA 3 1934		-15.4588				
29 MDC 1976 TO B11 1923	1.7	-2.8448	+0.0017	0.92	-2.8457	2365.9106
B11 1923 TO 29 MDC 1976		2.8465				
B11 1923 TO 30 MDC 1976	1.6	24.4760	+0.0012	0.67	24.4754	2390.3860
30 MDC 1976 TO B11 1923		-24.4748				
30 MDC 1976 TO A11 1923	1.4	-14.9133	+0.0001	0.06	-14.9134	2375.4726
A11 1923 TO 30 MDC 1976		14.9134				
A11 1923 TO 31 MDC 1976	1.2	-11.5370	-0.0022	1.42	-11.5359	2363.9367
31 MDC 1976 TO A11 1923		11.5348				
31 MDC 1976 TO 7743.43	1.3	-3.3915	+0.0017	1.06	-3.3923	2360.5444
7743.43 TO 31 MDC 1976		3.3932				
7743.43 TO 32 MDC 1976	1.7	5.5416	-0.0018	0.98	5.5425	2366.0869
32 MDC 1976 TO 7743.43		-5.5434				
32 MDC 1976 TO 33 MDC 1976	2.1	15.5927	-0.0014	0.68	15.5934	2381.6803
33 MDC 1976 TO 32 MDC 1976		-15.5941				

TABLE 3(cont.)

1984 Closure Information

BENCHMARKS (FROM/TO)	ROAD DISTANCE (KM)	ELEVATION DIFFERENCE (M)	CLOSURE (M)	CLOSURE (MM/KM**1/2)	MEAN DIFFERENCE (M)	ELEVATION 1984 (M)
11 MDC 1976 TO CVO 84-1	1.1	0.1121	-0.0010	0.68	0.1126	2413.0382
CVO 84-1 TO 11 MDC 1976		-0.1131				2413.1508
CVO 84-1 TO J11 1923	0.7	-35.5971	+0.0008	0.68	-35.5975	2377.5533
J11 1923 TO CVO 84-1		35.5979				
J11 1923 TO LC 58 1977	0.9	-11.5113	+0.0009	0.67	-11.5117	2366.0416
LC 58 1977 TO J11 1923		11.5122				
LC 58 1977 TO 22 MDC 1976	1.1	-19.7493	-0.0019	1.28	-19.7483	2346.2933
22 MDC 1976 TO LC 58 1977		19.7474				
22 MDC 1976 TO 23 MDC 1976	0.7	-5.8311	+0.0013	1.10	-5.8317	2340.4616
23 MDC 1976 TO 22 MDC 1976		5.8324				
23 MDC 1976 TO 24 MDC 1976	1.4	4.4985	+0.0001	0.06	4.4984	2344.9600
24 MDC 1976 TO 23 MDC 1976		-4.4984				
24 MDC 1976 TO CVO 84-2	0.7	-2.8747	+0.0002	0.17	-2.8748	2342.0852
CVO 84-2 TO 24 MDC 1976		2.8749				
CVO 84-2 TO 25 MDC 1976	1.2	-1.1866	+0.0006	0.39	-1.1869	2340.8983
25 MDC 1976 TO CVO 84-2		1.1872				
25 MDC 1976 TO CVO 84-3	0.6	0.3075	+0.0001	0.09	0.3074	2341.2057
CVO 84-3 TO 25 MDC 1976		-0.3074				
CVO 84-3 TO CVO 84-6	0.9	28.6503	-0.0018	1.34	28.6512	2369.8569
CVO 84-6 TO CVO 84-3		-28.6521				
CVO 84-6 TO CVO 84-4	0.8	-24.7521	-0.0026	2.06	-24.7508	2345.1061
CVO 84-4 TO CVO 84-6		24.7495				
CVO 84-4 TO CVO 84-5	1.1	-1.8587	+0.0019	1.28	-1.8596	2343.2465
CVO 84-5 TO CVO 84-4		1.8606				
CVO 84-5 TO F11 A	1.0	0.4515	-0.0050			
F11 A TO CVO 84-5		-0.4465	0.0004	0.40	0.4517	2343.6982
CVO 84-5 TO F11 A		0.4519				

TABLE 3(cont.)

1984 Closure Information

BENCHMARKS (FROM/TO)	ROAD DISTANCE (KM)	ELEVATION DIFFERENCE (M)	CLOSURE (M)	CLOSURE (MM/KM**1/2)	MEAN DIFFERENCE (M)	ELEVATION 1984 (M)
F11 A TO E11 A2	0.8	1.2816	-	-	1.2816	2344.9798
E11 A2 TO CVO 84-7	0.8	24.6145	-	-	24.6145	2369.5943
CVO 84-7 TO 26 MDC 1976	0.9	-5.2329	-	-	-5.2329	2364.3614
26 MDC 1976 TO CVO 84-8	1.3	-9.9692	-	-	-9.9692	2354.3922
CVO 84-8 TO 27 MDC 1976	0.9	-3.1438	-	-	-3.1438	2351.2484
27 MDC 1976 TO CVO 84-9	1.3	-0.5339	-	-	-0.5339	2350.7145
CVO 84-9 TO 28 MDC 1976	0.8	8.5450	-	-	8.5450	2359.2595
28 MDC 1976 TO DA 3 1934	0.9	-5.9478	-	-	-5.9478	2353.3117
DA 3 1934 TO 29 MDC 1976	0.5	15.4589	-	-	15.4589	2368.7706
29 MDC 1976 TO CVO 84-10	0.8	-5.9196	-	-	-5.9196	2362.8510
CVO 84-10 TO B11 1923	0.9	3.0752	+0.0001	0.07	3.0751	2365.9261
B11 1923 TO CVO 84-10		-3.0751				
B11 1923 TO CVO 84-11	0.9	14.7223	-0.0006	0.45	14.7226	2380.6487
CVO 84-11 TO B11 1923		-14.7229				
CVO 84-11 TO 30 MDC 1976	0.7	9.7513	+0.0037	3.13		
30 MDC 1976 TO CVO 84-11		-9.7476	0.0018	1.53	9.7485	2390.3972
CVO 84-11 TO 30 MDC 1976		9.7494				
30 MDC 1976 TO L19 1977	0.5	4.7395	+0.0004	0.40	4.7393	2395.1365
L19 1977 TO 30 MDC 1976		-4.7391				
L19 1977 TO A11 1923	0.9	-19.6544	-	-	-19.6544	2375.4821
A11 1923 TO 31 MDC 1976	1.2	-11.5369	-	-	-11.5369	2363.9452
31 MDC 1976 TO 7743.43	1.3	-3.3918	-	-	-3.3918	2360.5534

TABLE 3(cont.)
1984 Closure Information

BENCHMARKS (FROM/TO)	ROAD DISTANCE (KM)	ELEVATION DIFFERENCE (M)	CLOSURE (M)	CLOSURE (MM/KM**1/2)	MEAN DIFFERENCE (M)	ELEVATION 1984 (M)
7743.43 TO CVO 84-15	1.2	1.7368	-	-	1.7368	2362.2902
CVO 84-15 TO 32 MDC 1976	0.5	3.8057	-	-	3.8057	2366.0959
32 MDC 1976 TO CVO 84-12	1.1	5.8892	-0.0018	1.21	5.8901	2371.9860
CVO 84-12 TO 32 MDC 1976		-5.8910				
CVO 84-12 TO CVO 84-16	1.3	-12.7375	+0.0026	1.61	-12.7388	2359.2472
CVO 84-16 TO CVO 84-12		12.7401				
CVO 84-16 TO CVO 84-17	1.0	-0.8797	+0.0025	2.50	-0.8809	2358.3663
CVO 84-17 TO CVO 84-16		0.8822				
CVO 84-17 TO CVO 84-13	1.2	0.5310	+0.0004	0.26	0.5308	2358.8971
CVO 84-13 TO CVO 84-17		-0.5306				
CVO 84-13 TO CVO 84-14	1.2	7.1069	-0.0004	0.26	7.1071	2366.0042
CVO 84-14 TO CVO 84-13		-7.1073				
CVO 84-14 TO CVO 84-18	0.8	10.9136	-0.0013	1.03	10.9142	2376.9184
CVO 84-18 TO CVO 84-14		-10.9149				
CVO 84-18 TO CVO 84-19	1.2	-16.3948	-0.0033	2.13	-16.3932	2360.5252
CVO 84-19 TO CVO 84-18		16.3915				
CVO 84-19 TO CVO 84-24	0.9	0.0223	+0.0020	1.49	0.0213	2360.5465
CVO 84-24 TO CVO 84-19		-0.0203				
CVO 84-24 TO CVO 84-25	0.6	18.5775	+0.0012	1.10	18.5769	2379.1234
CVO 84-25 TO CVO 84-24		-18.5763				
CVO 84-25 TO CVO 84-26	1.4	58.6946	+0.0001	0.06	58.6946	2437.8180
CVO 84-26 TO CVO 84-25		-58.6945				
CVO 84-26 TO CVO 84-20	1.0	27.8019	-0.0028	2.80	27.8033	2465.6213
CVO 84-20 TO CVO 84-26		-27.8047				
CVO 84-20 TO CVO 84-21	1.6	81.5205	-0.0024	1.34	81.5217	2547.1430
CVO 84-21 TO CVO 84-20		-81.5229				
CVO 84-21 TO 36 MDC 1976	0.7	-1.5246	+0.0003	0.24	-1.5247	"2545.6183"
36 MDC 1976 TO CVO 84-21		1.5249				

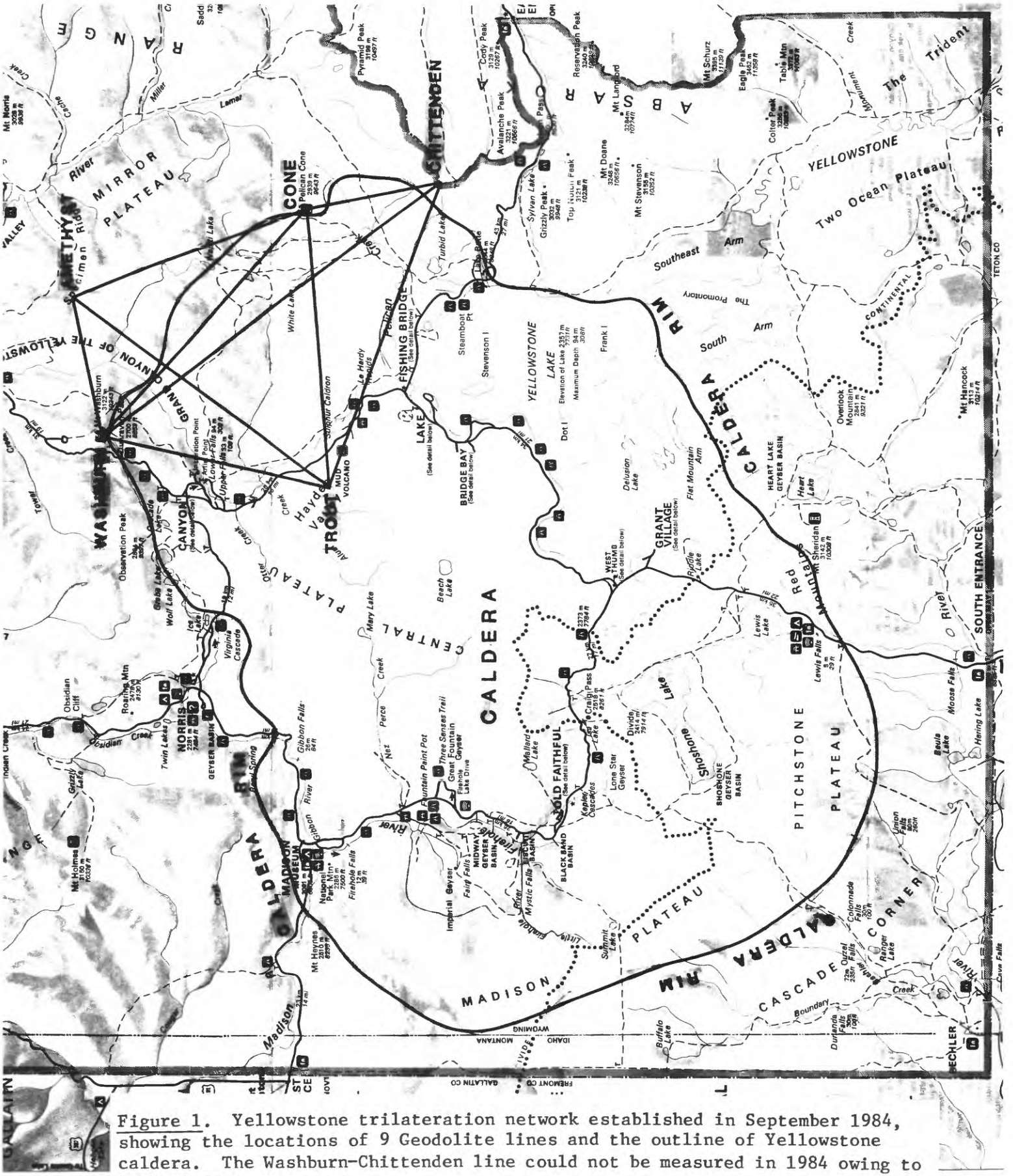

Figure 1. Yellowstone trilateration network established in September 1984, showing the locations of 9 Geodolite lines and the outline of Yellowstone caldera. The Washburn-Chittenden line could not be measured in 1984 owing to high winds.

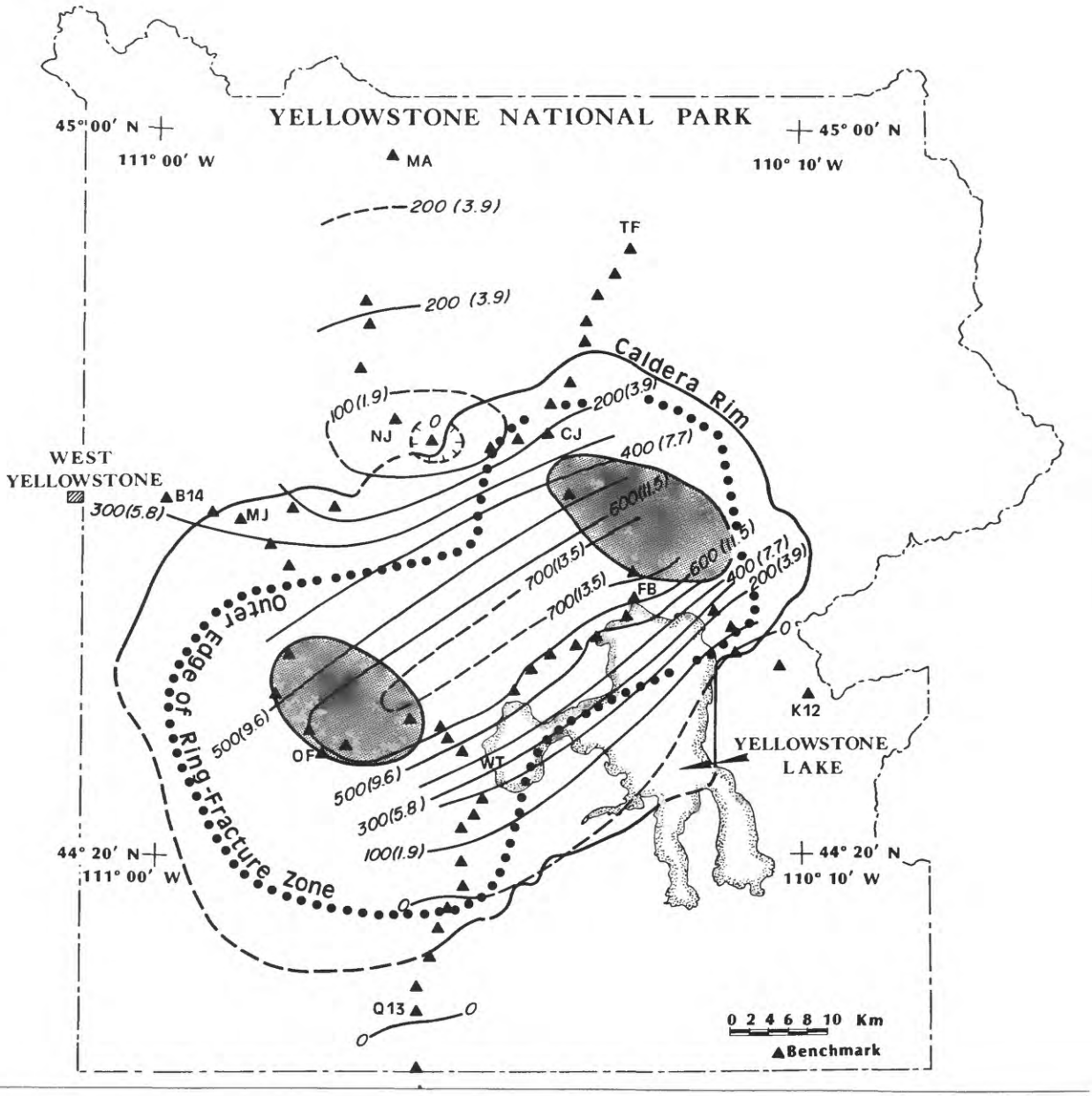

Figure 2. Contour map of Yellowstone elevation changes derived from level surveys in 1923 and 1975-1977 (Pelton and Smith, 1982). Triangles represent 1923 benchmarks; contour interval is 100 mm, with corresponding uplift rates (mm/yr) in parentheses. Stippling marks the locations of the Mallard Lake (lower left) and Sour Creek (upper right) resurgent domes. The level line from Canyon Junction (CJ) to Lake Butte (near K12) was measured in 1923, 1976, 1983 (partial), and 1984; a complete map of current benchmarks is shown in Figure 3.

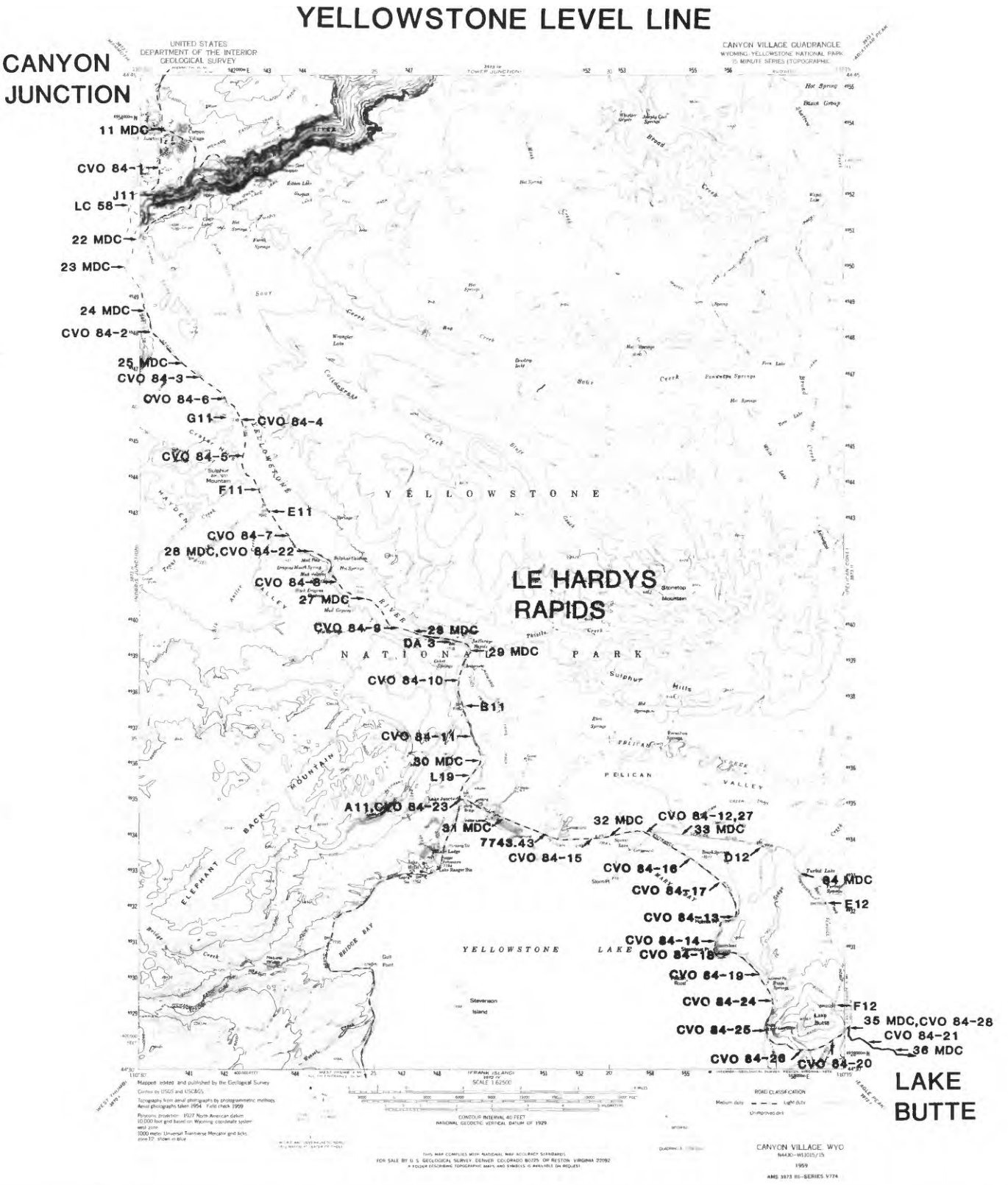

Figure 3. Level line from Canyon Junction to Lake Butte, showing the locations of benchmarks established during 1923-1984. See Appendix for benchmark descriptions.

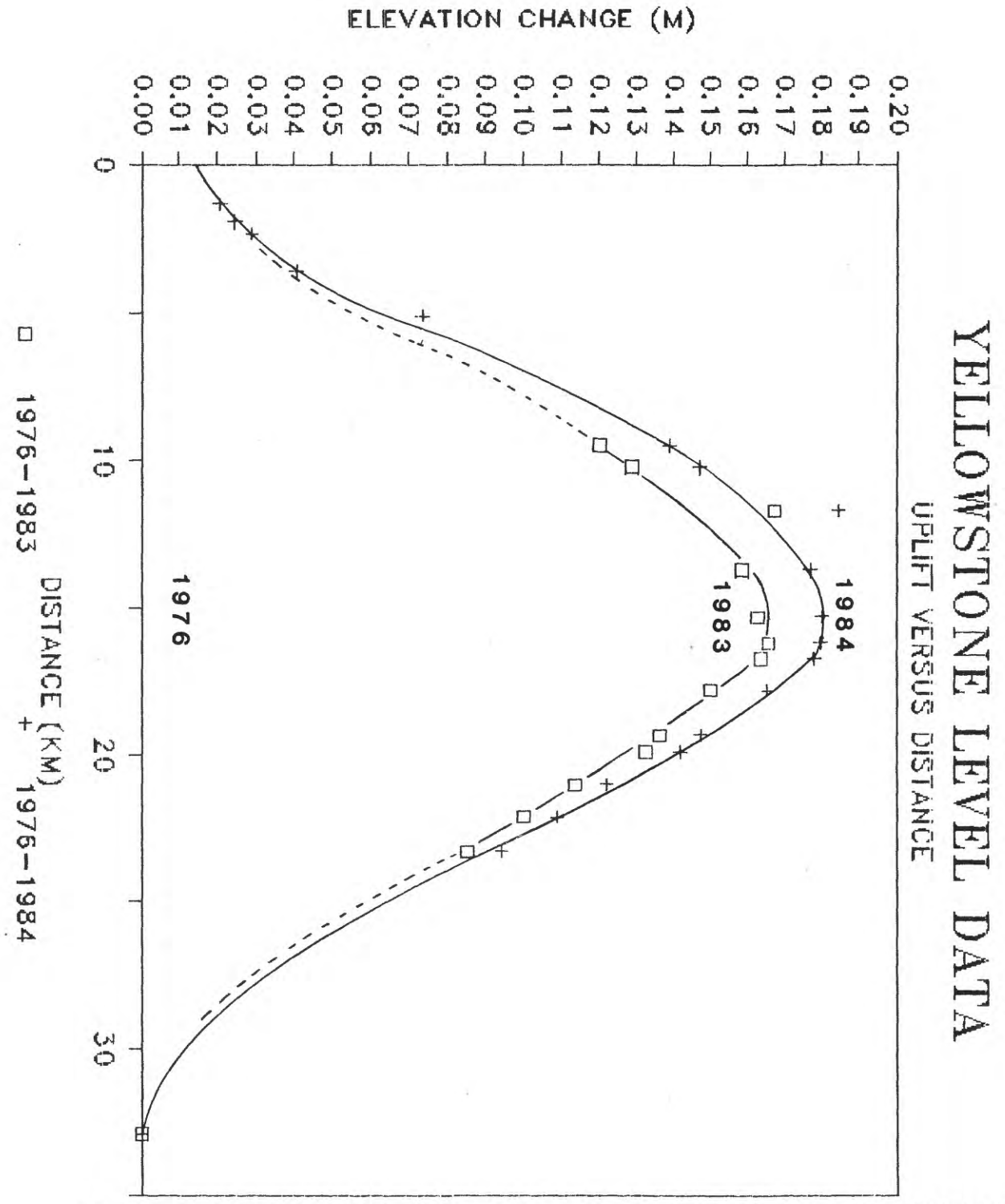

Figure 4. Level profiles along the route shown in Figure 3 for 1976-1983 and 1976-1984 . The 1983 survey was not tied to a stable base outside the caldera; an artificial datum was established by assuming that the 1976-1983 profile is similar in shape to the 1976-1984 profile.

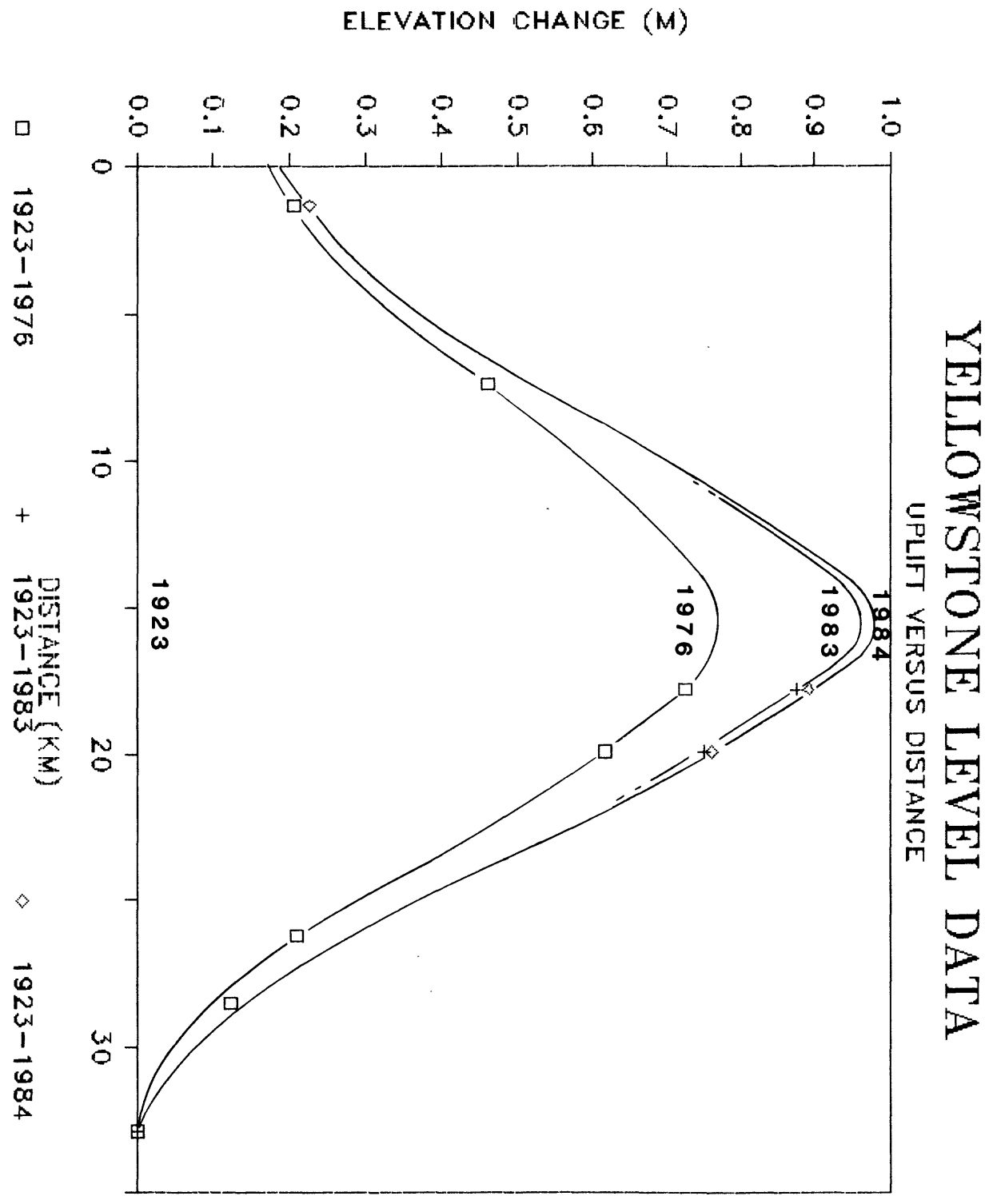

Figure 5. Level profiles along the route shown in Figure 3 for 1923-1976, 1923-1983, and 1923-1984. The 1976-1984 profile served as a model for sketching the other curves.

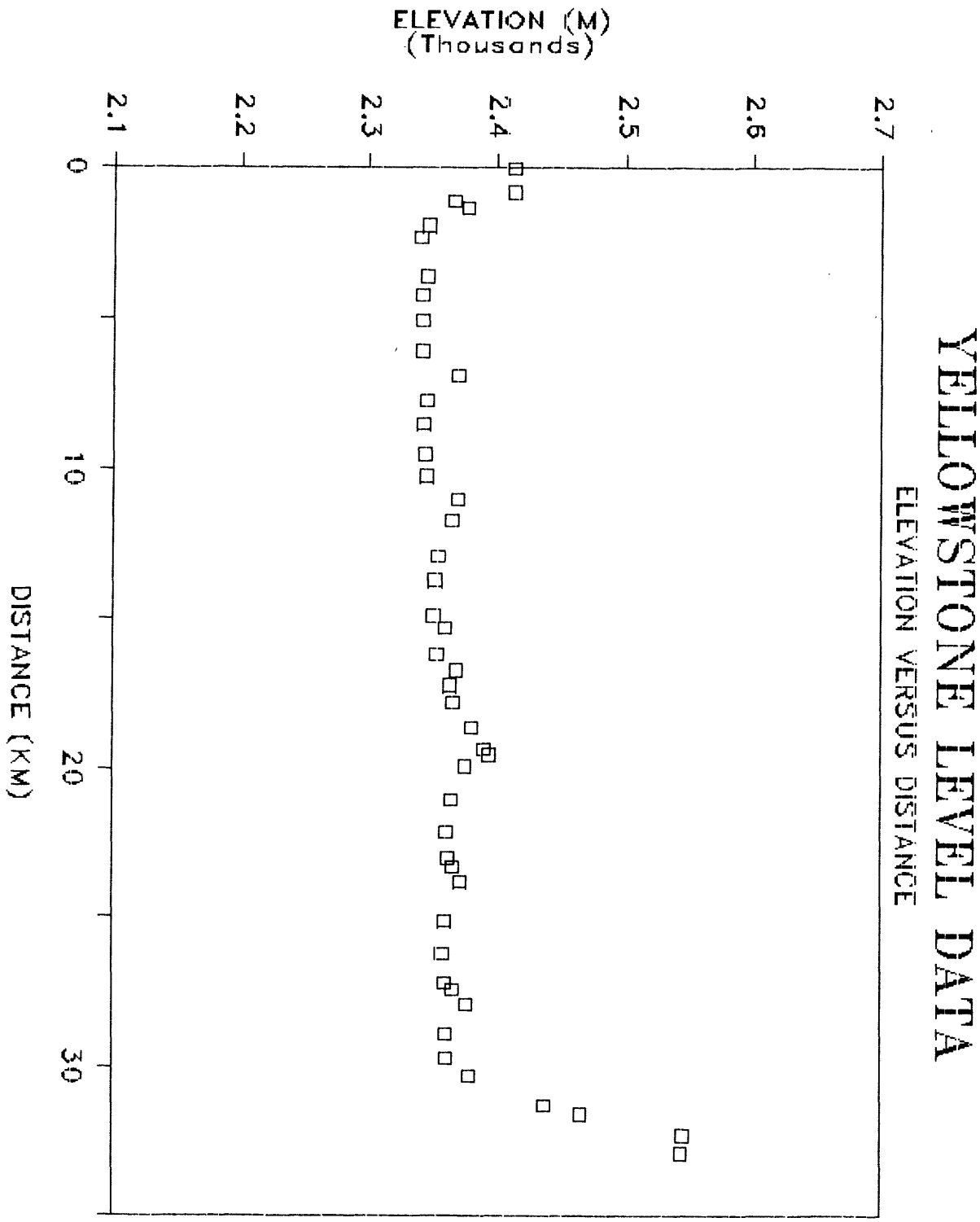

Figure 6. Elevation profile along the level route shown in Figure 3. Note that there is no correlation between elevation and the level changes shown in Figures 4 and 5.

APPENDIX
BENCHMARK DESCRIPTIONS
YELLOWSTONE NATIONAL PARK, WYOMING
CANYON JUNCTION-LAKE JUNCTION-LAKE BUTTE

The following benchmarks along National Park Service roads between Canyon Junction and Lake Butte were installed primarily during level surveys in 1923, 1975-77, and 1984. This NW-SE route is roughly orthogonal to the axis of uplift identified by Pelton and Smith (1979, 1982), and crosses the axis near Le Hardy Rapids on the Yellowstone River. Most of the benchmarks occur in the Canyon Village Quadrangle (15 minute series, 1:62,500 scale); a few near the ends of the route lie in the adjacent Norris Junction and Pelican Cone Quadrangles. The entire route was levelled to first order standards in September 1984 by a crew from the U. S. Geological Survey's Cascades Volcano Observatory; annual surveys are planned in the future. Except for the CVO 84-XX series of benchmarks established in 1984, most of the following descriptions are modified only slightly from Evoy and Smith (1979).

In the following descriptions, "Canyon Junction" refers to the intersection of two paved National Park Service roads: one between Norris and Canyon Village, the other between Canyon Village and Lake Junction. "Lake Junction" refers to the intersection near Fishing Bridge of the paved road between Canyon Village and Bridge Bay with the paved road from Fishing Bridge to the East Entrance of the Park.

NAME	DISTANCE (mi/km)	DESCRIPTION
11 MDC 1976	0.0/0.0	Near Canyon Junction, at service station located on northeast quadrant of intersection: 100 m east of centerline of north-south highway, 50 m north of centerline of west-east highway, 25 m southeast of southeast end wall of brick service station building, 2 m higher than asphalt driveway of station, on top of small knoll; cemented on southwest side of lava outcrop projecting 0.5 m.
CVO 84-1	0.65/1.1	Canyon Junction, 1.1 km (0.65 mi) south of along the highway toward Lake Junction; 7 m west of centerline, cemented on top of solitary boulder projecting 1 m.
J11 1923	1.15/1.8	Canyon Junction, 1.4 km (0.9 mi) south of along the highway toward Lake Junction, thence 0.4 km (0.25 mi) southeast along section of old highway bed; at north end of parking area overlooking "Grand Canyon of the Yellowstone", 3 m west of rim of Canyon, 0.5 m higher than parking area; set on concrete post projecting 0.6 m.
LC 58 1977	1.7/2.7	Canyon Junction, 2.7 km (1.7 mi) south of along the highway toward Lake Junction; 30 m west of highway centerline, 5 m north of center of service road; National Park Service benchmark cemented on top of lava outcrop projecting 2 m above highway level.

NAME	DISTANCE (mi/km)	DESCRIPTION
22 MDC 1976	2.35/3.8	Canyon Junction, 3.8 km (2.35 mi) south of along the highway toward Lake Junction, thence about 0.1 km (0.05 mi) east of center of junction of drive to south rim of "Grand Canyon of the Yellowstone"; at concrete and steel bridge over Yellowstone River; 6 m south of centerline of drive, 0.3 m higher than bridge surface; cemented in top of southwest corner abutment of bridge.
23 MDC 1976	2.85/4.5	Canyon Junction, 4.5 km (2.85 mi) south of along highway toward Lake Junction; at wooden-railed concrete bridge over "Otter Creek"; 5 m west of centerline of highway, 0.3 m higher than highway surface; cemented in top of south end of west concrete headwall of bridge.
24 MDC 1976	3.7/5.9	Canyon Junction, 5.9 km (3.7 mi) south of along highway toward Lake Junction; 0.1 km (0.05 mi) south of south end of turnout on west side of road, at second rock and mason culvert headwall south of turnout; 7 m west of centerline of highway, 0.6 m lower than highway surface; cemented in south end of west headwall of rock and mason culvert.
CVO 84-2	4.1/6.6	Canyon Junction, 6.6 km (4.1 mi) south of along highway toward Lake Junction; at rock and mason culvert headwall, 5 m west of centerline at road level; cemented in south end of culvert headwall.
25 MDC 1976	4.9/7.8	Canyon Junction, 7.8 km (4.9 mi) south of along highway toward Lake Junction; at concrete and mason bridge over "Alum Creek", 5.8 m east of centerline of highway, about level with road surface; cemented in top center of east headwall of concrete and mason bridge.
CVO 84-3	5.25/8.4	Canyon Junction, 8.4 km (5.25 mi) south of along highway toward Lake Junction; at rock and mason culvert headwall, 7 m west of centerline, 3 m lower than road level; cemented in center of culvert headwall.
CVO 84-6	5.8/9.3	Canyon Junction, 9.3 km (5.8 mi) south of along highway toward Lake Junction; at rock and mason culvert headwall, about 100 m north of Wildlife Exhibit pullout, 6 m west of centerline at road level; cemented in north end of culvert headwall.

NAME	DISTANCE (mi/km)	DESCRIPTION
CVO 84-4	6.3/10.1	Canyon Junction, 10.1 km (10.1 mi) south of along highway toward Lake Junction; at rock and mason culvert headwall, 7 m west of centerline, 0.3 m higher than road level; cemented in south end of culvert headwall.
CVO 84-5	7.0/11.2	Canyon Junction, 11.2 km (7.0 mi) south of along highway toward Lake Junction; at rock and mason culvert headwall, 6 m west of centerline, 0.2 m lower than road level; cemented in north end of culvert headwall.
F 11A 1934	7.65/12.2	Canyon Junction, 12.2 km (7.65 mi) south of along highway toward Lake Junction; at concrete and mason bridge over "Trout Creek", 0.3 m higher than road surface; cemented in top center of east headwall of concrete and mason bridge.
E 11A 2 1934	8.1/13.0	Canyon Junction, 13.0 km (8.1 mi) south of along highway toward Lake Junction; at concrete and mason bridge over "Elk Antler Creek", 0.3 m higher than road surface; cemented in top of east headwall of concrete and mason bridge.
CVO 84-7	8.65/13.8	Canyon Junction, 13.8 km (8.65 mi) south of along highway toward Lake Junction; at rock and mason culvert headwall, 6 m west of centerline, 0.2 m lower than road level; cemented in north end of culvert headwall.
26 MDC 1976	9.2/14.7	Canyon Junction, 14.7 km (9.2 mi) south of along highway toward Lake Junction; at turnout labeled "Geology Exhibit"; 19 m northeast of centerline of highway, at concrete platform for exhibit panel "Hayden Valley", 0.3 m west of northeast corner of base of concrete platform; set on 5/8-inch copper-coated rod encased in 6-inch drainpipe.
CVO 84-22	9.2/14.7	Canyon Junction, 14.7 km (9.2 mi) south of along highway toward Lake Junction; at rock and mason culvert headwall, 6 m south of centerline, 0.5 m lower than road level; cemented in east end of culvert headwall; 55 m east-southeast of, on opposite side of road from, 26 MDC 1976.

NAME	DISTANCE (mi/km)	DESCRIPTION
CVO 84-8	10.0/16.0	Canyon Junction, 16.0 km (10.0 mi) south of along highway toward Lake Junction; at rock and mason culvert headwall, 6 m west of centerline, 0.3 m lower than road level; cemented in south end of culvert headwall; about 100 m southeast of southeast end of Mud Volcano Area parking lot.
27 MDC 1976	10.55/16.9	Canyon Junction, 16.9 km (10.55 mi) south of along highway toward Lake Junction; (or Lake Junction, 8.3 km (5.2 mi) north of along highway toward Canyon Junction); at T-road north to Buffalo Ford Picnic Area; 12.8 m west of centerline of T-road north, 10.7 m north of centerline of highway, 1 m south of tree, 0.6 m lower than highway surface; set on 5/8-inch copper-coated rod encased in 6-inch drainpipe.
CVO 84-9	11.35/18.2	Canyon Junction, 18.2 km (11.35 mi) south of along highway toward Lake Junction; (or Lake Junction, 7.0 km (4.4 mi) north of along highway toward Canyon Junction); 15 m west of rock and mason culvert west headwall (top of headwall 2 m lower than road level), cemented in large boulder 20 m west of centerline; boulder projects 1 m above ground level, benchmark about 1 m lower than road level.
28 MDC 1976	11.9/19.0	Canyon Junction, 19.0 km (11.9 mi) south of along highway toward Lake Junction; (or Lake Junction, 6.2 km (3.8 mi) north of along highway toward Canyon Junction); 10 m east of centerline of highway, 1 m higher than highway surface; set on 5/8-inch copper-coated rod encased in 6-inch drainpipe.
DA 3 1934	12.45/19.9	Canyon Junction, 19.9 km (12.45 mi) south of along highway toward Lake Junction; (or Lake Junction, 5.1 km (3.2 mi) north of along highway toward Canyon Junction); about 65 m west of west end of turnout on north side of highway, 11 m south of centerline of highway, 1 m lower than highway surface; set in top of concrete post projecting 0.1 m.
29 MDC 1976	13.8/20.4	Canyon Junction, 20.4 km (13.8 mi) south of along highway toward Lake Junction; (or Lake Junction, 4.6 km (2.9 mi) north of along highway toward Canyon Junction); at south end of pullout on west side of highway, 10 m east of centerline of highway, 0.3 m higher than highway surface; set on 5/8-inch copper-coated rod encased in 6-inch drainpipe.

NAME	DISTANCE (mi/km)	DESCRIPTION
CVO 84-10	13.25/21.2	Canyon Junction, 21.2 km (13.25 mi) south of along highway toward Lake Junction; (or Lake Junction, 3.8 km (2.4 mi) north of along highway toward Canyon Junction); at rock and mason culvert headwall, 6 m west of centerline, 0.3 m lower than road level; cemented in south end of culvert headwall.
B 11 1923	13.85/22.1	Canyon Junction, 22.1 km (13.85 mi) south of along highway toward Lake Junction; (or Lake Junction, 2.9 km (1.8 mi) north of along highway toward Canyon Junction); at parking strip on east side of highway; about 75 m east-southeast of south end of parking strip, in dense timber along edge of old roadbed, cemented in top of boulder projecting 0.5 m.
CVO 84-11	14.4/23.0	Canyon Junction, 23.0 km (14.4 mi) south of along highway toward Lake Junction; (or Lake Junction, 2.0 km (1.25 mi) north of along highway toward Canyon Junction); at rock and mason culvert headwall, 6 m west of centerline, 0.3 m lower than road level; cemented in south end of culvert headwall.
30 MDC 1976	14.85/23.7	Canyon Junction, 23.7 km (14.85 mi) south of along highway toward Lake Junction; (or Lake Junction, 1.3 km (0.8 mi) north of along highway toward Canyon Junction); at turnout on east side of highway; 29.5 m east of centerline of highway from approximately center of turnout, about 0.6 m lower than highway surface; cemented in top of large boulder flush with ground on west side and projecting 0.6 m above ground on east side.
L19 1977	15.1/24.2	Canyon Junction, 24.2 km (15.1 mi) south of along highway toward Lake Junction; (or Lake Junction, 0.8 km (0.5 mi) north of along highway toward Canyon Junction); 8 m west of centerline, 0.3 m lower than road level, on rod projecting 0.1 m, marked by metal fencepost projecting 1 m above ground.
A 11 1923	15.7/25.1	Canyon Junction, 25.0 km (15.7 mi) south of along highway toward Lake Junction; near Lake Junction (T-road intersection about 0.6 km (0.4 mi) west of Fishing Bridge and about 2.4 km (1.5 mi) north of Lake Lodge); 125 m east of center of junction, 35 m northwest of west end of Fishing Bridge parking strip, 26 m north of centerline of highway toward East Entrance (Cody, Wyoming), about level with highway; set in concrete post projecting 0.6 m.

NAME	DISTANCE (mi/km)	DESCRIPTION
CVO 84-23	15.7/25.1	Canyon Junction, 25.0 km (15.6 mi) south of along highway toward Lake Junction; near Lake Junction; 125 m east of center of junction, at rock and mason culvert headwall, 12 m north of centerline of highway to East Entrance; cemented in east end of culvert headwall, 1 m lower than road level, 10 m south of A 11 1923.
31 MDC 1976	16.45/26.3	Canyon Junction, 25.0 km (15.6 mi) south of to Lake Junction, thence 1.3 km (0.8 mi) east-southeast along highway from Lake Junction toward East Entrance; about 150 m east of T-road south entrance to Fishing Bridge Campground; near east end of last parking area on north side of highway, across highway from point where parking area adjoins highway; 7.6 m south of centerline of highway; 0.6 m lower than highway surface; cemented on northwest corner of westernmost of two concrete manhole foundations.
USBPR7743.43	17.25/27.6	Canyon Junction, 25.0 km (15.6 mi) south of to Lake Junction, thence 2.6 km (1.6 mi) east-southeast along highway from Lake Junction toward East Entrance; at wooden-railed concrete bridge over "Pelican Creek"; 4 m south of centerline of highway, 0.3 m higher than highway surface; cemented in top of west end of south concrete sidewall of bridge.
CVO 84-15	18.0/28.8	Canyon Junction, 25.0 km (15.6 mi) south of to Lake Junction, thence 3.8 km (2.4 mi) east-southeast along highway from Lake Junction toward East Entrance; at rock and mason culvert headwall, 6 m south of centerline, 0.2 m lower than road level; cemented in west end of culvert headwall.
32 MDC 1976	18.3/29.3	Canyon Junction, 25.0 km (15.6 mi) south of to Lake Junction, thence 4.3 km (2.7 mi) east-southeast along highway from Lake Junction toward East Entrance; at turnout on south side of highway about in center of south side of turnout; 16 m south of centerline of highway, 0.3 m west of forked tree, about level with highway surface; set on 5/8-inch copper-coated rod encased in 6-inch drainpipe.
CVO 84-12	19.0/30.4	Canyon Junction, 25.0 km (15.6 mi) south of to Lake Junction, thence 5.4 km (3.4 mi) east-southeast along highway from Lake Junction toward East Entrance; near west end of eastern of two turnouts near Indian Pond, 70 m east of Service Road to Turbid Lake, 30 m south of centerline, about 4 m lower than road level, cemented on large boulder projecting 1 m.

NAME	DISTANCE (mi/km)	DESCRIPTION
CVO 84-27	19.0/30.4	Canyon Junction, 25.0 km (15.6 mi) south of to Lake Junction, thence 5.4 km (3.4 mi) east-southeast along highway from Lake Junction toward East Entrance; near west end of eastern of two turnouts near Indian Pond, 70 m east of Service Road to Turbid Lake, at rock and mason culvert headwall, 6 m south of centerline, 0.3 m lower than road level; cemented in west end of culvert headwall.
CVO 84-16	19.8/31.7	Canyon Junction, 25.0 km (15.6 mi) south of to Lake Junction, thence 6.7 km (4.2 mi) east-southeast along highway from Lake Junction toward East Entrance; at rock and mason culvert headwall, 7 m north of centerline, 1 m lower than road level, opposite "Mary Bay" sign; cemented in west end of culvert headwall, 0.4 m east of copper-coated rod projecting 0.4 m.
CVO 84-17	20.45/32.7	Canyon Junction, 25.0 km (15.6 mi) south of to Lake Junction, thence 7.7 km (4.8 mi) east-southeast along highway from Lake Junction toward East Entrance; 10 m north of centerline of highway, 1 m lower than highway surface, in large flat grassland opposite Mary Bay; set on 5/8-inch copper-coated rod encased in 6-inch drainpipe.
CVO 84-13	21.2/33.9	Canyon Junction, 25.0 km (15.6 mi) south of to Lake Junction, thence 8.9 km (5.6 mi) east-southeast along highway from Lake Junction toward East Entrance; near north end of picnic area pullout, 11 m west of centerline of highway, near road level; cemented on large boulder projecting about 1 m above lake shore.
CVO 84-14	21.9/35.1	Canyon Junction, 25.0 km (15.6 mi) south of to Lake Junction, thence 10.1 km (6.3 mi) east-southeast along highway from Lake Junction toward East Entrance; at rock and mason culvert headwall, 6 m east of centerline, 0.5 m lower than road level; cemented in south end of culvert headwall.
CVO 84-18 (unstamped)	22.45/35.9	Canyon Junction, 25.0 km (15.6 mi) south of to Lake Junction, thence 10.9 km (6.8 mi) east-southeast along highway from Lake Junction toward East Entrance; at rock and mason culvert headwall, 6 m north of centerline, 0.3 m lower than road level; cemented in west end of culvert headwall.

NAME	DISTANCE (mi/km)	DESCRIPTION
CVO 84-19	23.2/37.1	Canyon Junction, 25.0 km (15.6 mi) south of to Lake Junction, thence 12.1 km (7.6 mi) east-southeast along highway from Lake Junction toward East Entrance; at wooden-railed bridge over "Sedge Creek"; 4 m northeast of centerline of highway, 0.2 m higher than highway surface; cemented in top of northwest end of northeast rock and mason sidewall of bridge.
CVO 84-24	23.75/38.0	Canyon Junction, 25.0 km (15.6 mi) south of to Lake Junction, thence 13.0 km (8.1 mi) east-southeast along highway from Lake Junction toward East Entrance; 20 m northeast of centerline of highway, near level of highway surface; cemented in prominent bedrock outcrop about 1 m above ground level.
CVO 84-25	24.15/38.6	Canyon Junction, 25.0 km (15.6 mi) south of to Lake Junction, thence 13.6 km (8.5 mi) east-southeast along highway from Lake Junction toward East Entrance; 5 m east of centerline of highway, 0.4 m higher than highway surface; cemented in bedrock at prominent roadcut.
CVO 84-26	25.0/40.0	Canyon Junction, 25.0 km (15.6 mi) south of to Lake Junction, thence 15.0 km (9.4 mi) east-southeast along highway from Lake Junction toward East Entrance; at rock and mason culvert headwall, 0.3 km (0.2 mi) southwest of road to Lake Butte Overlook, 5 m north of centerline, 0.3 m lower than road level; cemented in west end of culvert headwall.
CVO 84-20	25.6/41.0	Canyon Junction, 25.0 km (15.6 mi) south of to Lake Junction, thence 16.0 km (10.0 mi) east-southeast along highway from Lake Junction toward East Entrance; at rock and mason culvert headwall, 0.7 km (0.45 mi) northeast of road to Lake Butte Overlook, 6 m north of centerline, 0.3 m lower than road level; cemented in east end of culvert headwall.
CVO 84-28	26.1/41.8	Canyon Junction, 25.0 km (15.6 mi) south of to Lake Junction, thence 16.8 km (10.5 mi) east-southeast along highway from Lake Junction toward East Entrance; at rock and mason culvert headwall, 140 m east of east end of wooden-railed bridge at former location of 35 MDC 1976, 6 m north of centerline, 0.5 m lower than road level; cemented in west end of culvert headwall.

NAME	DISTANCE (mi/km)	DESCRIPTION
CVO 84-21	26.6/42.6	Canyon Junction, 25.0 km (15.6 mi) south of to Lake Junction, thence 17.6 km (11 mi) east-southeast along highway from Lake Junction toward East Entrance; 15 m north of centerline, 1.5 m higher than highway surface; cemented in west end of bedrock ledge, about 0.6 m above ground level.
36 MDC 1976	27.05/43.3	Canyon Junction, 25.0 km (15.6 mi) south of to Lake Junction, thence 18.3 km (11.45 mi) east-southeast along highway from Lake Junction toward East Entrance; at turnout on south side of highway, about in center of south side of turnout, 17.4 m south of centerline of highway, about 1.5 m lower than highway surface, set on 5/8-inch copper-coated rod encased in 6-inch drainpipe.