

U. S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Descriptions and elevations for First-Order, Class II leveling bench marks,
and Global Positioning System (GPS) coordinates and elevations between
West Yellowstone, Montana. and Old Faithful, Yellowstone National Park, Wyoming.

By

Kenneth M. Yamashita¹, Elliot Endo¹, Maurice Sako², and David Wieprecht¹

Open-File Report 97-57

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards or with the North American Stratigraphic Code. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

¹U.S. Geological Survey
David A. Johnston Cascades Volcano Observatory
5400 MacArthur Blvd.
Vancouver, Washington 98661

²U.S. Geological Survey
Hawaiian Volcano Observatory
P.O. Box 51
Hawaii National Park, Hawaii 96718

Introduction

In August 1996 the Cascades Volcano Observatory (CVO), U.S. Geological Survey (USGS), acquired a Wild® NA3003 digital level. This instrument “reads” a bar code rod (similar to the bar code on grocery items). The infrared spectrum of the light entering the instrument is separated from the visible band. This infrared portion, carrying the light and dark stripes of the rod, is then compared with a stored electronic image of the bar code. The observed image is shifted until it exactly matches the electronic image, yielding a height of the rod to the nearest .0001 m and the stadia distance to 0.01 m. The data can then be automatically stored in a REC module (a RAM module) and downloaded to a PC at a later time or be directed out a serial port to a portable computer. A REC module will store about 1140 height differences (64 K byte).

In 1987 CVO contracted the National Geodetic Survey (NGS) (formerly the U.S. Coast and Geodetic Survey (USC&GS)) to resurvey leveling lines in and around Yellowstone National Park, Wyoming. In September 1996 members of CVO resurveyed a portion of this leveling line from approximately 1.6 km (1 mi) west of the town of West Yellowstone, Montana to approximately 1 km (0.6 mi) southeast of Old Faithful, in Yellowstone National Park, Wyoming. The purpose of this survey was two fold: 1) to detect any possible deformation occurring in the western part of the caldera, and 2) to compare the Wild® NA3003 to the Wild® NA2 with a parallel micrometer, an instrument we have been using for the past 12 years to monitor vertical displacement in the eastern section of Yellowstone caldera. To accomplish this, 9 sections of approximately 15 km (9.3 mi) were single-run with the NA3003 and the circuit closed by running in the opposite direction with the NA2. 4 sections of approximately 7 km (4.3 mi) were double-run with the NA3003, and an additional 4 sections of approximately 7 km (4.3 mi) were double-run with the NA2 to ensure that any differences were not procedural but true instrumental differences. An additional 25 km (15.5 mi) were single run independently with the two instruments. The procedure used during the survey was the same for both instruments in that two readings were taken at each setup resulting in two elevation differences for each setup. The error tolerance for the two height differences for the setup was 0.3mm. All differences greater than 0.3mm were rejected and a new set of readings taken. Stadia balance between foresight and backsight was kept to 5.0 m or less and temperatures were taken at each setup. Corrections for index of refraction, change in length of the invar strip of the leveling rod, collimation error and rod scale error were applied to the data back in the office.

The manufacturer of the NA3003 states a standard deviation over a 1 km (0.6 mi) double-run leveling of 0.4mm, and 0.3 mm for the NA2 when used with the GPM3 parallel plate micrometer. Allowable closure errors for First-Order, Class II surveys are given as $4\text{mm } D^{1/2}$ where D is the total distance in km, forward and back of a closure circuit. Although our observed misclosures were well within first-order, class II standards, they were slightly greater than the manufacturer’s claim. Tables 1 thru 3 demonstrate remarkable consistency for the three methods of comparison. With the limited amount of data collected it is not possible to make a true assessment of the accuracy of the NA3003, but our data indicate that the NA2 and the NA3003 do give acceptable results in double-run loops, and when compared to one another. Further tests are planned in future surveys.

Concurrent with the leveling survey a third crew conducted a rapid static GPS survey on all leveling bench marks. We used a Trimble® 4000 SSI P-code receiver with 8 - 20 minute occupations at each site, while two similar GPS units collected data on known GPS coordinate sites during the entire time that the rapid static survey was underway. The fixed sites (Airport, Harlequin, Nez Perce and Meertens²) were chosen so that stations occupied for the rapid static survey were not more than 10 km away. The GPS survey was carried out between 8 am and 4:30 pm, a time that our mission planning program displayed the best satellite geometry with a minimum of 5 satellites.

This report contains descriptions for all bench marks along the leveling line. Figures 1- 5 show the location of the bench marks along the leveling line, figure 6 the location of the leveling line in relation to the rest of Yellowstone National Park, figure 7 a graph showing the change in elevation from 1987 to 1996 and a cross-section of the topography along the leveling route, and figure 8 a graph showing the difference between the ellipsoidal and the orthometric heights. Table 4 contains bench mark identification, elevation difference between adjacent marks and elevation relative to bench mark B144 which we have held as “fixed”, table 5 contains rapid static GPS coordinates and ellipsoidal heights (subject to change with further processing), and table 6 contains orthometric heights from the leveling survey, GPS ellipsoidal heights, and the difference in elevations between the two heights.

Acknowledgments

The authors would like to thank Edward C. Brown for taking time away from his administration and computer duties to assist us, and special thanks to Stuart Ashbaugh, Nancy L. Daniels, Anna C. Dondero, Chris Harpel, Sophie Leblanc, Ben A. Pauk, and Jason L. Permenter who took time away from friends and family to volunteer their time in the interest of science.

We thank Eugene Iwatsubo and Edward C. Brown for their constructive comments in reviewing this manuscript.

Description for Bench marks along the leveling line starting in West Yellowstone, MT.

- AIRPORT** 0.14 km (0.09 mi) east along Yellowstone Ave. from the Museum of the Yellowstone in West Yellowstone, MT. to the intersection with Canyon St. (Hwy 191), then 3.14 km (1.95 mi) north along Highway 191 to the intersection on the left (west) with the Airport Entrance road. Continue ahead on highway 191 for 2.7 km (1.7 mi) to a road on the west at a sign "Madison Arm Resort". Turn left, then left again and go south parallel to the main highway for 0.4 km (0.25 mi) to a gap in the fence. Continue ahead for 0.6 km (0.4 mi) to a fork at the base of a bluff, bear right and go northwest for 0.3 km (0.2 mi) along the bluff to a dim track road on the left at a gravel pit. Turn left and go southwest, uphill, for 0.2 km (0.1 mi) to the runway perimeter fence. Turn right and go southwest for 0.3 km (0.2 mi) along the fence to the station on the left. Bench mark is attached to a pipe 135 m (443 ft) northeast from the extended line of the threshold lights, 1.45 m (4.7 ft) west from a fence post with brackets, 1.05 m (3.5 ft) northwest from the fence line, and 0.4 m (1.3 ft) southwest from a witness post. Bench mark is a USGS National Center for Earthquake Research (NCER) red brass tablet stamped "Airport 1973".
- B144** 1.67 km (1.05 mi) west along Yellowstone Ave. from the Museum of the Yellowstone in West Yellowstone, MT. to the intersection with Iris St., then 0.08 km (0.05 mi) south along Iris St. to an intersection with a gravel road (the old railroad bed) then 0.65 km (0.4 mi) west along the gravel road to a witness post. Bench mark is set in the top of a 25 cm (10 inch) diameter concrete post, 4 m (13 ft) north of the center of the gravel road, and 10 cm (4 inch) higher than the ground level. Bench mark is a U.S. Coast and Geodetic Survey (USC&GS) brass tablet stamped "B144 1959".
- C566** On the south and west (back) side of the Museum of the Yellowstone. Bench mark is set vertically in the south wall of the museum, 15.6 m (51.2 ft) east of the west end of the museum, 8.7 m (28.5 ft) northeast of the south end of a 1 x 2.5 m (3 x 8 ft) diameter propane tank, 7.5 m (24.6 ft) north of the south edge of the concrete walk, 2.6 m (8.5 ft) north of the north corner of a concrete/stone pier of the museum, and 8.3m (27.2 ft) west of the west side of the south door into the museum. Bench mark is a National Geodetic Survey (NGS) brass tablet stamped "C566 1983".
- W162** 0.30 km (0.20 mi) east along Yellowstone Ave. from the Museum of the Yellowstone in West Yellowstone, MT. to the intersection with Boundary St. and a triangle formed by three roads on the south side and a large stone monument with the Union Pacific railroad logo, 18.6 m (61.0 ft) west of the centerline of the north-south street, 4.1 m (13.5 ft) south of the centerline of a road angling off of Yellowstone Ave., 24.6 m (80.7 ft) south of the centerline of Yellowstone Ave. and 4 m (13.1 ft) southwest of the southwest edge of the stone monument, set on a rod 20 cm (8 inch) below the

ground level. Bench mark is a USC&GS brass tablet stamped " W162 1960" Note: the bench mark has been damaged but seems to be holding its elevation.

- C144** 1.69 km (1.05 mi) east along the Madison junction road from the Museum of the Yellowstone in West Yellowstone, MT. to a paved road leading north, 17.4 m (57 ft) north of the centerline of the Madison Jct. road, 32.5 m (106.6 ft) east of the center of the paved road, and 0.3 m (1.0 ft) west of a metal fence post. Bench mark is set in the top of a 25 cm (8 inch) diameter concrete post, 10 cm (4 inch) higher than the ground level. Bench mark is a USC&GS brass tablet stamped "C144 1959".
- D566** 3.38 km (2.10 mi) east along the Madison junction road from the Museum of the Yellowstone in West Yellowstone, MT. to a barely visible closed off track road leading south, 14.9 m (48.9 ft) south of the centerline of the Madison Jct. road, 8.6 m (28.2 ft) east of the center of the track road, and 2.5 m (8.2 ft) south of a 0.8 x 1 x 0.5 m (2.5 x 3 x 1.5 ft) high boulder. Mark is stainless steel rod enclosed in a concrete pipe with a 12 cm (5 inch) metal cover. The flange of the mark is stamped "D566 1983".
- E130** 4.88 km (3.03 mi) east along the Madison junction road from the Museum of the Yellowstone in West Yellowstone, MT. to the northeast side of a prominent hill, 40.8 m (133.9 ft) south of the centerline of the Madison Jct. road, set in the top of a 0.3 x 1.0 x 0.14 m (1 x 3 x 0.5 ft) high embedded boulder at the base of the hill, and 0.6 m (2 ft) higher than the road and ground level. Bench mark is a USC&GS brass tablet stamped "E130 1959".
- B339** 5.18 km (3.21 mi) east along the Madison junction road from the Museum of the Yellowstone in West Yellowstone, MT. to the west end of a paved road leading into a parking area, 16.1 m (52.8 ft) west of the center of the paved road leading to parking area, 15.7 m (51.5 ft) north of the Madison Jct. road, and 7 m (23.0 ft) northeast of the center of a 0.6 m (2 ft) diameter drainage pipe. Mark is a stainless steel rod enclosed in a concrete pipe with a 12 cm (5 inch) metal cover. The flange of the mark is stamped "B339 1983".
- C14 1923** 6.69 km (4.15 mi) east along the Madison junction road from the Museum of the Yellowstone in West Yellowstone, MT., 8.5 m (27.9 ft) north of the centerline of the Madison Jct. road, 1 m (3 ft) lower than the road level, and cemented in the top of a 0.3 x 0.3 x 0.2 m (12 x 12 x 8 inch) high embedded boulder. Bench mark is a USC&GS brass tablet stamped "C14 1923"
- C339** 6.93 km (4.30 mi) east along the Madison junction road from the Museum of the Yellowstone in West Yellowstone, MT. to a closed off track road leading southeast, at the east-south-east end of a line of boulders that closes the road, 19.2 m (63 ft) south of the centerline of the Madison Jct. road, and 8.2 m (26.9 ft) south of the

center of the track road. Mark is a stainless steel rod set enclosed in a concrete pipe with a 12 cm (5 inch) metal cover. The flange of the mark is stamped "C339 1983". Note: at the time of recovery there were a number of fallen trees covering the mark.

- V158** 8.26 km (5.12 mi) east along the Madison junction road from the Museum of the Yellowstone in West Yellowstone, MT. to a paved road leading northeast, 14.8 m (48.6 ft) northeast of the center of the road leading northeast, 16.7 m (54.8 ft) north of the centerline of the Madison Jct. road, and set in the top of a 25 cm (10 inch) diameter concrete post, set flush with the ground. Bench mark is a USC&GS brass tablet stamped "V158 1960".
- B14 1923** 8.26 km (5.12 mi) east along the Madison junction road from the Museum of the Yellowstone in West Yellowstone, MT. to a paved road leading northeast, leave the main road and follow the side road for 1.5 km (0.9 mi), cemented on a 0.5 x 1.0 x 0.1 m (1.6 x 3 x 0.3 ft) high embedded boulder, 13.9 m (45.6 ft) east of the center of the road, and 32.7 m (107.3 ft) southeast of BM Hull (description follows). Bench mark is a USC&GS brass tablet stamped "B14 1923".
- HULL** 8.26 km (5.12 mi) east along the Madison junction road from the Museum of the Yellowstone in West Yellowstone, MT. to a paved road leading northeast, leave the main road and follow the side road for 1.5 km (0.9 mi), cemented on a 0.3 m (1 ft) embedded boulder set flush with the ground, 47.7 m (155.8 ft) northwest of the center of the road, 3.7 m (12.1 ft) east of the Madison river, and 32.7 m (107.3 ft) northwest of BM B14 (previously described). Bench mark is a NGS brass tablet stamped "HULL 1987".
- U158** 11.16 km (6.92 mi) east along the Madison junction road from the Museum of the Yellowstone in West Yellowstone, MT. to the southwest end of a paved pullout on the north side of the road, cemented in the top of a 25 cm (10 inch) concrete pier, 31.3 m (102.7 ft) north of the centerline of the Madison Jct. road, 9.3 m (30.5 ft) northwest of the center of the road leading to the pullout, and 18.3 m (60 ft) east of the Madison river. Bench mark is a USC&GS brass tablet stamped "U158 1960". Note: At the time of recovery the bench mark was under a fallen tree.
- A14 RESET** 12.73 km (7.90 mi) east along the Madison junction road from the Museum of the Yellowstone in West Yellowstone, MT. to the southeast end of the concrete bridge over the Madison river, cemented on top of the northeast concrete head wall, 5.6 m (18.4 ft) northeast of the centerline of the bridge, and 1.1 m (3.6 ft) higher than the road level. Bench mark is a USC&GS brass tablet stamped "A14 Reset 1958".
- T158** 14.59 km (9.05 mi) east along the Madison junction road from the Museum of the Yellowstone in West Yellowstone, MT. to a curve in the road and a paved pullout on the south side of the road, set on top of a 1 x 1 x 0.5 m (3 x 3 x 1.5 ft) high embedded

boulder, 17.2 m (56.4 ft) north of the centerline of the Madison Jct. road, and 1.5 m (5 ft) higher than the road level. Bench mark is a USC&GS brass tablet stamped "T158 1960".

Z13 1923 16.51 km (10.24 mi) east along the Madison junction road from the Museum of the Yellowstone in West Yellowstone, MT. to a paved side road on the southeast leading to a pullout. Leave the Madison Jct. road and continue 0.30 km (0.2 mi) along the side road. Set on a 1.3 x 2 x 0.5 m (4.3 x 6.5 x 1.5 ft) high embedded boulder, 10.4 m (34.1 ft) north of the side road, and 40.5 m (133 ft) south of the Madison Jct. road. Bench mark is a USC&GS brass tablet stamped "Z13 1923".

S158 17.82 km (11.05 mi) east along the Madison junction road from the Museum of the Yellowstone in West Yellowstone, MT. to a paved pullout on the south side of the road, set in the top of a 25 cm (8 inch) diameter concrete post, 9.4 m (30.8 ft) south of the centerline of the Madison Jct. road, 7.7 m (25.3 ft) northeast of the center of the pullout road, and 1 m (3 ft) southeast of a large boulder, in a line of boulders, and about 0.3 m (1 ft) higher than the road level. Bench mark is USC&GS brass tablet stamped "S158 1960".

Y13 1923 19.43 km (12.05 mi) east along the Madison junction road from the Museum of the Yellowstone in West Yellowstone, MT. to a paved road on the south side of the road, set on the top of a 0.7 x 1.1 x 0.3 m (2.3 x 3.6 x 1 ft) high embedded boulder, 7.2 m (23.6 ft) northeast of the center of the paved road, 40.8 m (134 ft) southwest of the centerline of the Madison Jct. road, 1 m (3 ft) lower than the Madison Jct. road, and 1.2 m (4 ft) higher than the side road. Bench mark is a USC&GS brass tablet stamped "Y13 1923".

HARLEQUIN 20.09 km (12.46 mi) east along the Madison junction road from the Museum of the Yellowstone in West Yellowstone, MT. to a paved road leading to a pullout on the south side of the road, set on a 0.3 x 0.3 x .01 m (1 x 1 x .02 ft) high embedded boulder, on a triangular shaped ridge, 26.6 m (87.3 ft) south of the south edge of the paved pullout, and approximately 30 m (100 ft) west of an area of rock outcrop. Bench mark is a NGS brass tablet stamped "Harlequin 1987".

R158 21.11 km (13.09 mi) east along the Madison junction road from the Museum of the Yellowstone in West Yellowstone, MT., or 1.75 km (1.1 mi) west along the Madison Jct. road from Madison Junction, to a paved road leading to a pullout on the south side of the highway, set on a 25 cm (10 inch) concrete pier, at the northeast end of the pullout, 13.1 m (42.9 ft) southeast of the centerline of the Madison Jct. road, 7.9 m (25.9 ft) northwest of the center of the pullout road, 13.4 m (44.0 ft) south of the southeast end of a metal culvert, 13 m (42.6 ft) north-northeast of a 5 m (16 ft) tall dead tree, and 1 m (3 ft) lower than the main road level. Bench mark is an USC&GS brass tablet stamped "R158 1960".

- D339** 22.87 km (14.18 mi) east along the Madison junction road from the Museum of the Yellowstone in West Yellowstone, MT. to the intersection at Madison Junction. Bench mark is a stainless rod enclosed in a concrete pipe with a 12 cm (5 inch) metal cover, on the northwest side of the intersection, 24.4 m (80 ft) northeast of the centerline of the westbound lanes of the Madison junction highway, 13.3 m (43.6 ft) northwest of the centerline of the southbound lanes of the Norris-Old Faithful highway, and 1.5 m (5 ft) lower than the roadbed. The flange of the mark is stamped "D339 1983". Note: this bench mark is located in the northwest corner of Madison Junction where the roads to West Yellowstone, Norris and Old Faithful converge.
- 1MDC** At Madison Junction, set on a rod enclosed in a 15 cm (6 inch) diameter PVC pipe, 17.2 m (56.4 ft) east of the centerline of the north-bound lanes to Norris/Old Faithful, and 0.5 m (1.5 ft) west of a cluster of 3 trees. Bench mark is a U.S. Geological Survey (USGS) aluminum tablet stamped "1 MDC 1975". Note: this mark is east, across the road, and slightly south of bench mark D339.
- BM6802.32** 0.6 km (0.4 mi) south along the road to Old Faithful from Madison Junction, to the north end of the bridge over the Gibbon river, set on the east walkway of the bridge, 5.7 m (18.7 ft) east of the centerline of the bridge, and 0.3 m (1.0 ft) south of the north end of the east walkway. Bench mark is a Bureau of Public Roads (BPR) brass tablet stamped "6802.32".
- E339** 1.4 km (0.85 mi) south along the road to Old Faithful from Madison Junction to a paved service road leading west, set in the top of a 1 x 1 x 0.5 m (3 x 3 x 1.5 ft) high exposed rock in a road cut, 37 m (121.4 ft) south of the center of the service road, 8.5 m (27.9 m) west of the centerline of the main highway, and 1 m (3 ft) higher than the road level. Bench mark is a NGS brass tablet stamped "E339 1983".
- 40MDC** 2.22 km (1.38 mi) south along the road to Old Faithful from Madison Junction to the north end of a large paved pullout on the west side of the road, set on bedrock on the west side of a small ravine, 16.5 m (54.1 ft) north of the northeast end of the paved pullout, and 0.6 m (2 ft) higher than the road level. Bench mark is a USGS aluminum tablet stamped "40 MDC 1976".
- F339** 2.48 km (1.54 mi) south along the road to Old Faithful from Madison Junction to a small road cut on the east side of the highway, set on bedrock at the north end of a small 5 m (16.4 ft) high road cut, 41.3 m (135.5 ft) northeast of a metal culvert, 6.4 m (21 ft) east of the centerline of the highway, and 0.6 m (2 ft) higher than the road level. Bench mark is an NGS brass tablet stamped "F339 1983".
- Y9 1923** 3.84 km (2.38 mi) south along the road to Old Faithful from Madison Junction to a one-way paved road to the west, set in bedrock 52.7 m (172.9 ft) west of where the paved side road turns north and a foot path meet, 2.1 m (6.9 ft) east of the east bank

of the Firehole river, 1.5 m (4.9 ft) lower than the side road level, and 0.1 m (0.3 ft) above the ground level. Bench mark is a USC&GS brass tablet stamped "Y9 1923".

41MDC Approximately 5.32 km (3.30 mi) south along the road to Old Faithful from Madison Junction to a large 2.3 m (7.5 ft) high boulder on the southwest side of the road, set on the northeast end of the boulder approximately 9.4 m (30.8 ft) southwest of the road center. Bench mark is a USGS aluminum tablet stamped "41 MDC 1976". Note: Re-alignment of the road was in progress between Y9 and 44MDC at the time of the survey. Because all distance would change when the new road is completed, these distances are given as "approximately".

Z9 1923 Approximately 6.92 km (4.29 mi) south along the road to Old Faithful from Madison Junction to a side road to the northeast, set on a 0.5 m (1.5 ft) high concrete pier, and approximately 9 m (29.5 ft) east of the road center. Bench mark is a USC&GS brass tablet stamped "Z9 1923".

CVO94-10 Approximately 6.92 km (4.29 mi) south along the road to Old Faithful from Madison Junction to a side road to the northeast, approximately 24.4 m (80 ft) northeast of the center of the main road, 16.6 m (54.5 ft) southwest of the center of a gravel rod, and set on a rod driven 4.6 m (15 ft), enclosed in a 15 cm (6 inch) PVC pipe. Bench mark is a brass USGS tablet stamped "CVO94-10". Note: In September 1996 a gravel access road was built less than 2 m west of this mark.

42MDC Approximately 8.45 km (5.24 mi) south along the road to Old Faithful from Madison Junction to a short horseshoe shape side road to the west, cemented on the east end of a 1 m (3 ft) round embedded boulder, at the north end of the pullout, approximately 16.7 m (54.7 ft) west of the road center. Bench mark is a USGS aluminum tablet stamped "42 MDC 1976".

NEZ PERCE Approximately 10.15 km (6.29 mi) south along the road to Old Faithful from Madison Junction to the bridge over the Nez Perce river, set in the top of a 1 x 1.8 m (3 x 6 ft) embedded boulder, in a field of boulders, approximately 56 m (184 ft) east of the east end of the bridge, and 11.4 m (37.4 ft) north of the north bank of the creek. Bench mark is a NGS brass tablet stamped "Nez Perce 1987".

V366 Approximately 10.68 km (6.62 mi) south along the road to Old Faithful from Madison Junction to a pullout at the trail head to Mary Lake, a stainless steel rod enclosed in a concrete pipe with a 12 cm (5 inch) metal cover, 33.1 m (108.6 ft) northeast of the center of the road, 6.3 m (20.7 ft) northwest of the center of the pullout, and 0.5 m (1.5 ft) higher than the road level. The flange of the mark is stamped "V366 1987".

43MDC Approximately 12.5 km (7.75 mi) south along the road to Old Faithful from Madison

Junction to a large outcrop and at the south end of a road cut, and set in bedrock approximately 11.9 m (39.0 ft) east of the road center. Bench mark is a USGS aluminum tablet stamped "43 MDC 1976". Note: this bench mark may be destroyed during road construction.

- CVO94-11** Approximately 12.5 km (7.75 mi) south along the road to Old Faithful from Madison Junction to a large outcrop at the south end of a road cut, set in bedrock approximately 28.7 m (94.2 ft) east of the road center, and 18.7 m (61.4 ft) north-northeast of bench mark 43 MDC. Bench mark is a USGS brass tablet stamped "CVO94-11".
- 44MDC** 14.08 km (8.73 mi) south along the road to Old Faithful from Madison Junction, to a swampy area on the east, 12.0 m (39.4 ft) southeast of the centerline of the highway, 12.1 m (39.7 ft) northeast of sign "reduce speed", 4.8 m (15.7 ft) southeast of a stone headwall of a culvert, and set on the top of a rod enclosed in a 15 cm (6 inch) PVC pipe. Bench mark is a USGS brass tablet stamped "44 MDC 1976".
- 45MDC** 15.90 km (9.86 mi) south along the road to Old Faithful from Madison Junction, to a paved road leading southeast to a picnic area, 12.8 m (42 ft) southeast of the center line of the main highway, 12.7 m (41.7 ft) east-southeast of the side road, set on a rod enclosed in a 15 cm (6 inch) diameter PVC pipe, and 0.6 m (2 ft) lower than the road level. Bench mark is a USGS aluminum tablet stamped "45 MDC 1976".
- CV094-12** 17.44 km (10.81 mi) south along the road to Old Faithful from Madison Junction, 28.3 m (92.8 ft) south of the south edge of the pullout pavement edge, 26.0 m (85.3 ft), northwest of a pine tree, 17.5 m (57.4 ft) northeast of a pine tree, 16.8 m (55.1 ft) northeast of the northeast bank of the Firehole river, set on a rod driven 16.8 m (55 ft) and enclosed in a 10 cm (4 inch) PVC pipe with a cap. Bench mark is a USGS brass tablet stamped "CVO94-12".
- THERMAL** 19.08 km (11.83 mi) south along the road to Old Faithful from Madison Junction, to a road leading to the northwest, leave the main road and follow the side road for 0.2 km (0.1 mi) to the end of the road and a bridge over the Firehole river, set in an area of mineral deposit 9.1 m (29.9 ft) northeast of the center of the road over the bridge, 6.8 m (22.3 ft) southeast of the southeast end of the bridge, and 0.4 m (1.3 ft) lower than the road level. Bench mark is a NGS brass tablet stamped "Thermal 1987". Note: deposits accumulating on the bench mark from thermal spring run off makes finding this mark difficult.
- C10 1923** 19.09 km (11.84 mi) south along the road to Old Faithful from Madison Junction, to a road to the northwest. Leave the main road and follow the side road for 0.2 km (0.1 mi) to the end of the road and a bridge over the Firehole river, cemented on top of the southeast abutment of the bridge, and 3.4 m (11.2 ft) southeast of the center of the

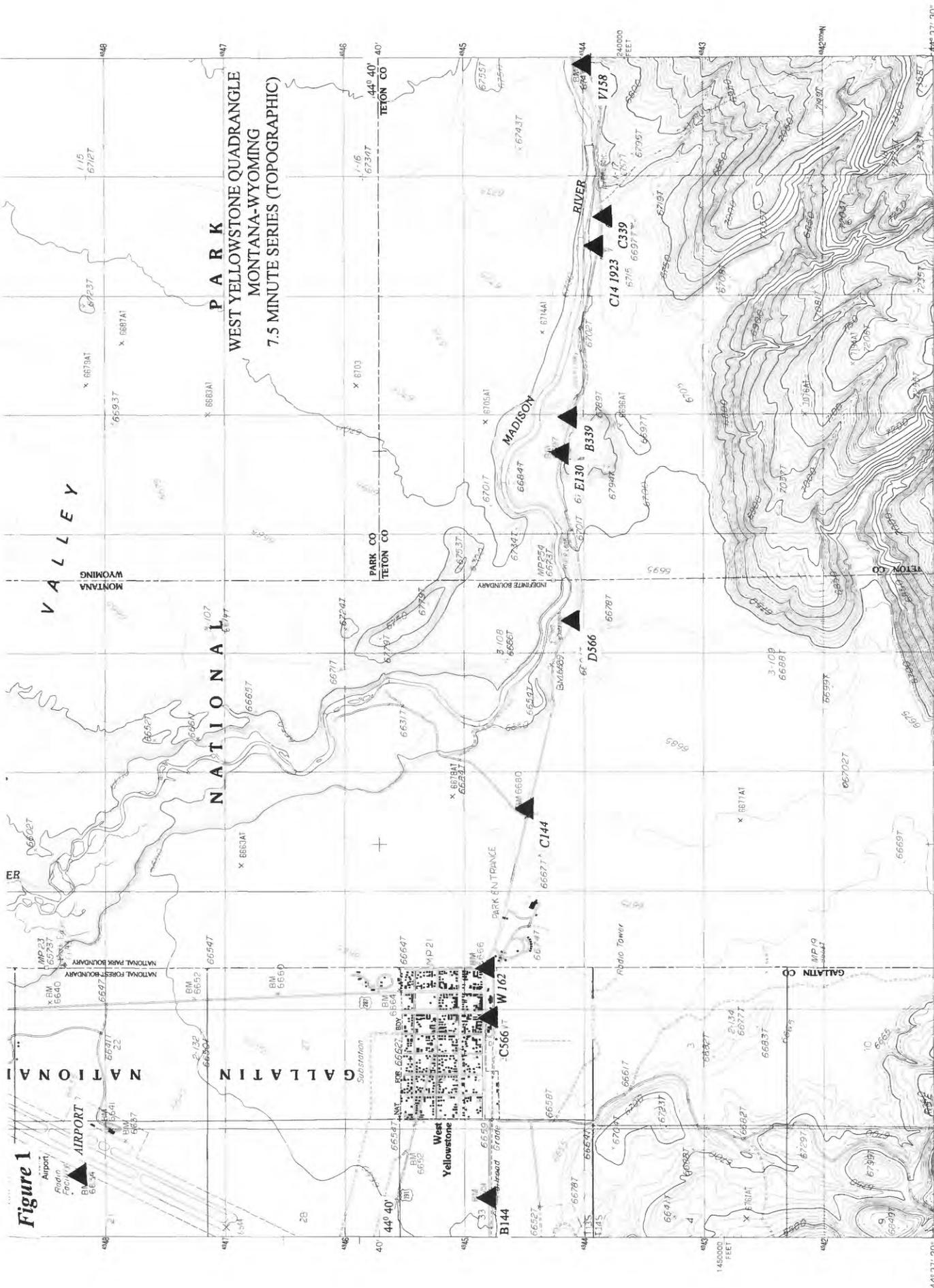
road. Bench mark is a USG&GS brass tablet stamped "C10 1923".

- CVO94-13** 21.14 km (13.11 mi) south along the road to Old Faithful from Madison Junction, to the north end of a paved pullout on the east side of the road, set on a rod driven 7.6 m (25 ft) and enclosed in a 10 cm (4 inch) diameter PVC pipe, 32 m (105.0 ft) north of the north end of the pullout, 17.6 m (57.7 ft) east of the centerline of the highway, and 12 m (39.4 ft) north of pole #WPL 4, which is the last pole in a line that parallels the highway before making a dogleg and turning south (uphill). Bench mark is a USGS brass tablet stamped "CVO94-13".
- X366** 22.4 km (13.90 mi) south along the road to Old Faithful from Madison Junction, to the northeast end of a paved pullout on the east side of the road, a stainless steel rod enclosed in a concrete pipe with a 12 cm (5 inch) metal cover, 17.7 m (58.1 ft) northeast of the centerline of the highway, and 8.8 m (28.9 ft) northeast of the northeast edge of the paved pullout. The flange of the mark is stamped "X366 1987".
- BM7273.15** 23.35 km (14.48 mi) south along the road to Old Faithful from Madison Junction, to the southwest end of the bridge over the Firehole river, cemented on the southwest end of the walkway of the bridge, and 4.1 m (13.5 ft) northwest of the centerline of the bridge. Bench mark is a BPR brass tablet stamped "7273.15"
- 48MDC** 25.05 km (15.53 mi) south along the road to Old Faithful from Madison Junction to paved pullout on both sides of the road, cemented in a 0.3 x 2.4 m (1 x 7.9 ft) exposed outcrop of bedrock, 20.6 m (67.6 ft) southeast of the southeast end of a pullout, 12 m (39.4 ft) northeast of the centerline of the highway, 6.4 m (21.0 ft) southeast of a metal culvert, and across the road from a sign "Old Faithful-Food, Gas, Lodging-Exit 1 mile". Bench mark is a USGS aluminum tablet stamped "48 MDC 1976".
- BMOF4** ON the southwest end of the overpass on the road to Old Faithful, cemented on the concrete walk, 5.2 m (17.1 ft) east of the centerline of the overpass, and 5.2 m (17.1 ft) west of the concrete walk to which the guard rail is attached. Bench mark is a National Park Service (NPS) brass tablet stamped "OF-4 76"
- BMIO2** ON the southwest end of the overpass on the road to Old Faithful, cemented on a 20 cm (8 inch) diameter concrete pier, 5.5 m (18.0 ft) east of the centerline of the overpass, and 2.2 m (7.2 ft) south of the south edge of the concrete sidewalk, and bench mark BM OF4. Bench mark is a Federal Highways Administration (FHA) brass tablet stamped "IO-2 1986"
- Y366** 1.1 km (0.68 mi) south along the highway to West Thumb from the overpass to Old Faithful, to a cross walk and an access road, a stainless steel rod enclosed in a concrete pipe with a 12 cm (5 inch) metal cover, 19.6 m (64.3 ft) northwest of the

centerline of the main road, 11.4 m (37.4 ft) southeast of the southeast corner of a (not a log) cabin (nearest the road/path), and 9.9 m (32.5 ft) west of the road/path. The flange of the mark is stamped "Y366 1987".

MEERTENS 2.48 km (1.54 mi) south along the highway to West Thumb from the overpass to Old Faithful to the northeast end of the bridge over the Firehole River, set on the northeast concrete sidewalk, 4.8 m (15.7 ft) southeast of the centerline of the bridge, and 1.7 m (5.6 ft) southeast of the northwest end. Bench mark is an NGS brass tablet stamped "Meertens 1987".

MEERTENS2 2.48 km (1.54 mi) south along the highway to West Thumb from the overpass to Old Faithful to the northeast end of the bridge over the Firehole River, set on the northeast concrete sidewalk, 5.0 m (16.4 ft) southeast of the centerline of the bridge, 0.7 m (2.3 ft) southeast of the northwest end, and 0.8 m (2.6 ft) northeast of bench mark Meertens. Bench mark is an NGS brass tablet stamped "Meertens 2 1987".



13

ROAD LEGEND

- Improved Road
- Unimproved Road
- Trail
- Interstate Route
- U.S. Route
- State Route

QUADRANGLE LOCATION

Scale: 1:10,000 (MILES), 1:10,000 (FEET), 1:10,000 (KILOMETERS)

CONTOUR INTERVAL 10 FEET
SUPPLEMENTAL CONTOUR INTERVAL 5 FEET

PROVISIONAL MAP

Produced by the UNITED STATES GEOLOGICAL SURVEY
 COMPILED FROM AERIAL PHOTOGRAPHS TAKEN DECEMBER 1967
 FIELD CHECKED 1968
 MAP EDITED 1968
 PROJECTION TRANSVERSE MERCATOR CONFORMAL CONIC
 GRID UNITED STATES TRANSVERSE MERCATOR, SOUTH ZONE
 GRID 30-METER STATE GRID TENS MONTANA, SOUTH ZONE
 WYOMING, WEST ZONE
 UTM GRID DECLINATION 1968
 MAGNETIC NORTH DECLINATION 1968
 VERTICAL DATUM NATIONAL GEODETIC VERTICAL DATUM OF 1929
 HORIZONTAL DATUM 1927 NORTH AMERICAN DATUM
 To place on the projected North American Datum of 1983,
 move the projection lines as shown by dashed corner fields
 (11 meters north and 62 meters east)

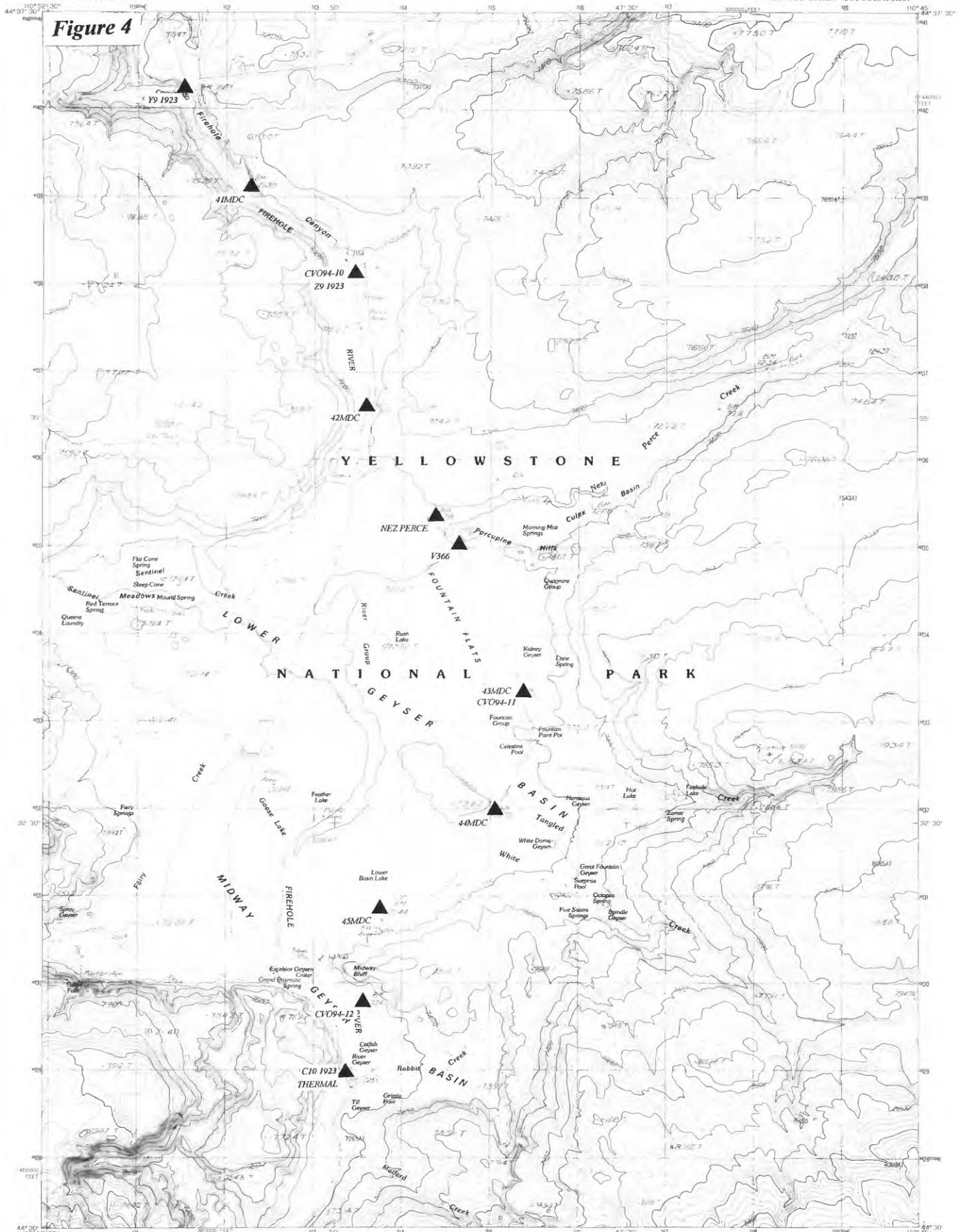


Figure 4

PRODUCED BY THE UNITED STATES GEOLOGICAL SURVEY
CONTROL BY THE UNITED STATES GEOLOGICAL SURVEY
COMPILED FROM AERIAL PHOTOGRAPHS TAKEN IN 1960
FIELD CHECKED BY THE MAP EDITOR
PROJECTION: TRANSVERSE MERCATOR
GRID: UNIFORMED UNIVERSAL TRANSVERSE MERCATOR
ZONE 12
NAD 83 STATE GRID TICS: WYOMING WEST ZONE
UTM GRID DECLINATION: 10°P EAST
MAGNETIC NORTH DECLINATION: 13°P EAST
VERTICAL DATUM: NATIONAL GEODETIC VERTICAL DATUM OF 1955
HORIZONTAL DATUM: 1983 NORTH AMERICAN DATUM
To place on the predicted North American Datum of 1983,
move the projection lines as shown by dashed corner ticks
(1) meters north and (2) meters east.
There may be private inholdings within the boundaries of any
Federal and State Reservations shown on this map.
Land lines have not been established in this area.
All marginal data and lettering generated and positioned by
automated type placement procedures.

PROVISIONAL MAP
Produced from original
manuscript drawings. Informa-
tion shown as of date of
field check. 2



WYOMING
QUADRANGLE LOCATION

1	2	3	4	5	6	7	8
1	2	3	4	5	6	7	8

ABOUNDING 2.5 QUADRANGLE NAMES

ROAD LEGEND
Improved Road
Unimproved Road
Trail
Interstate Route
U.S. Route
State Route

LOWER GEYSER BASIN, WYOMING
PROVISIONAL EDITION 1986

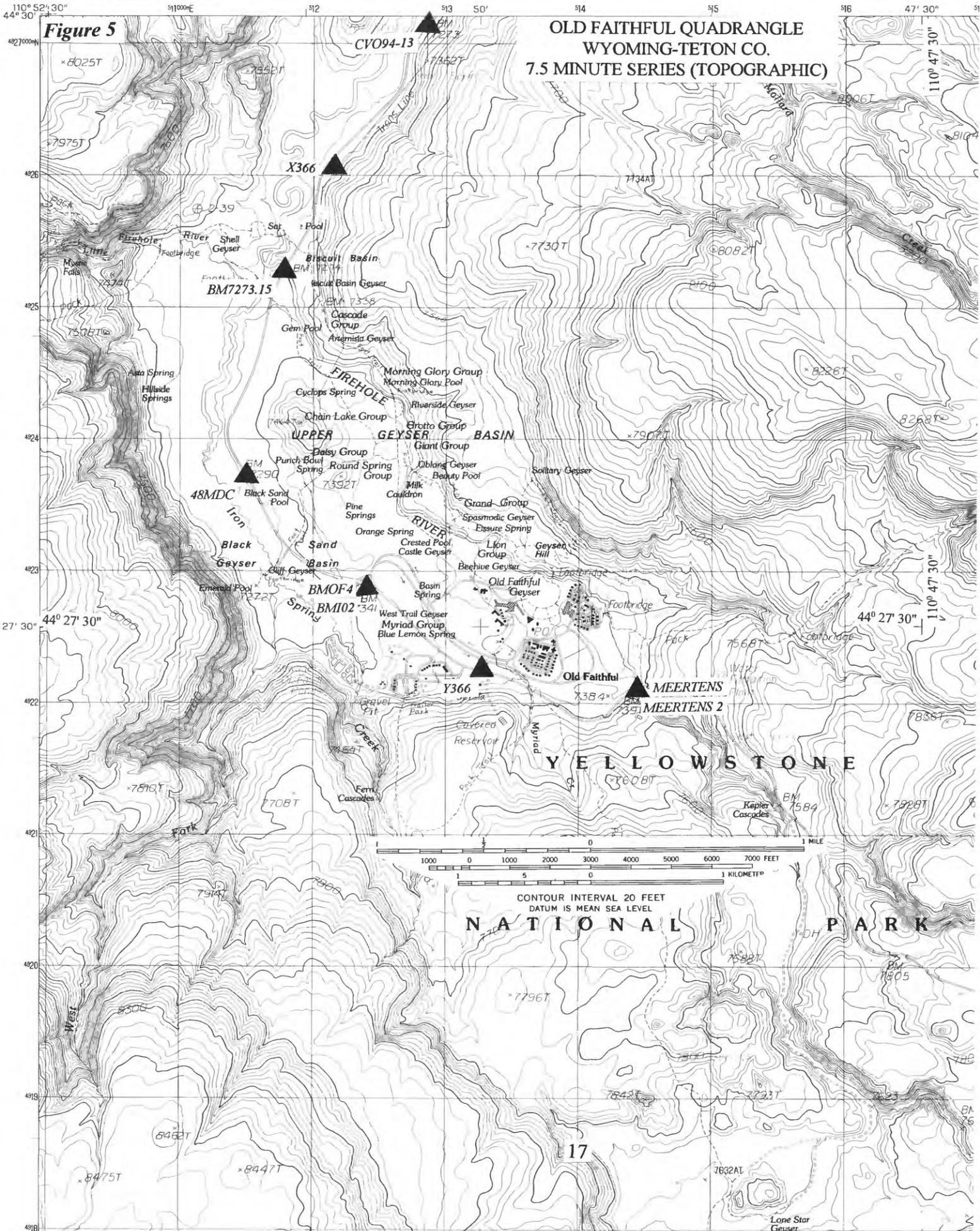


Figure 6. Location map of the Cascades Volcano Observatory's Yellowstone National Park September 1996, first-order leveling and GPS survey.

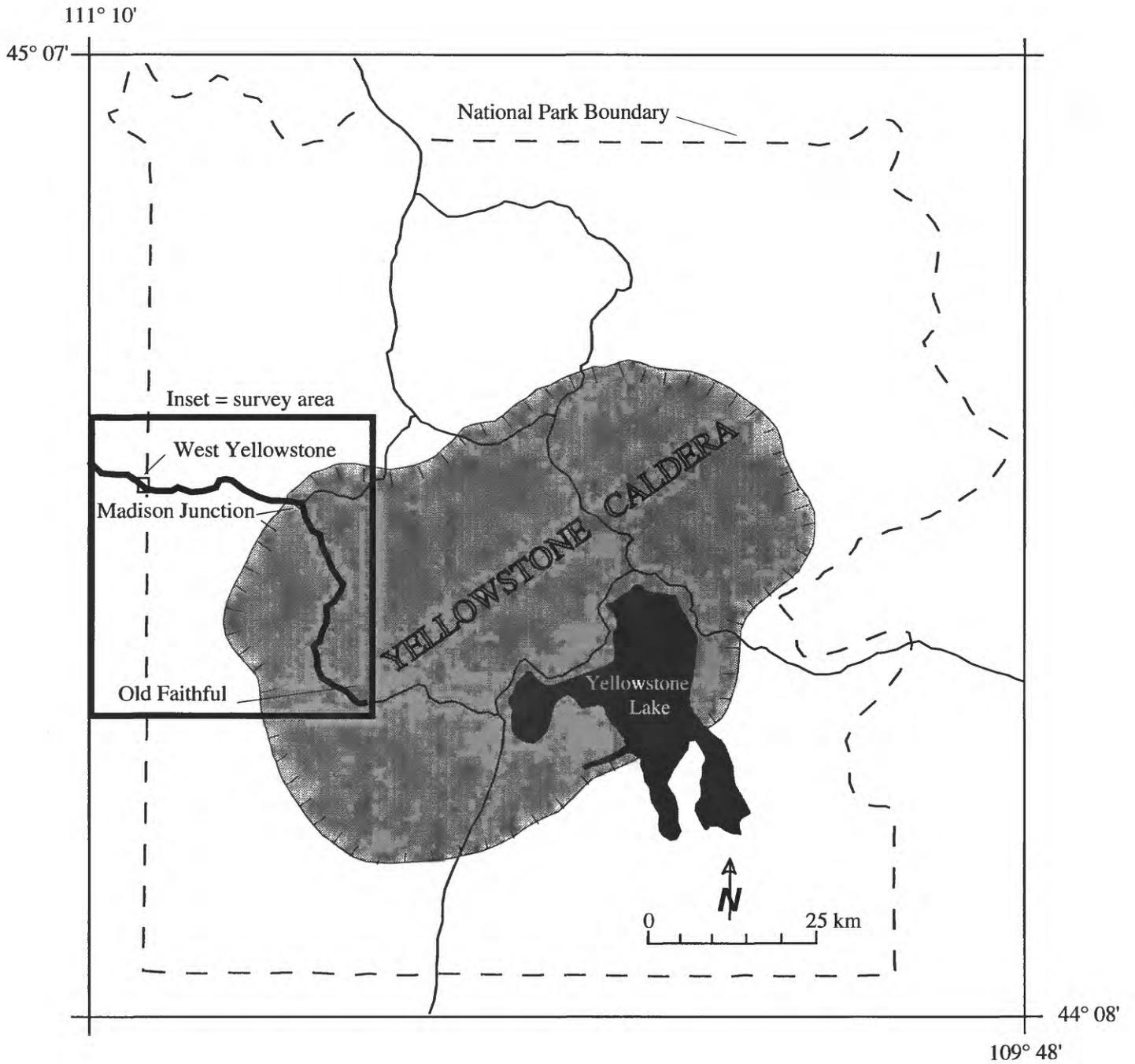


Figure 7

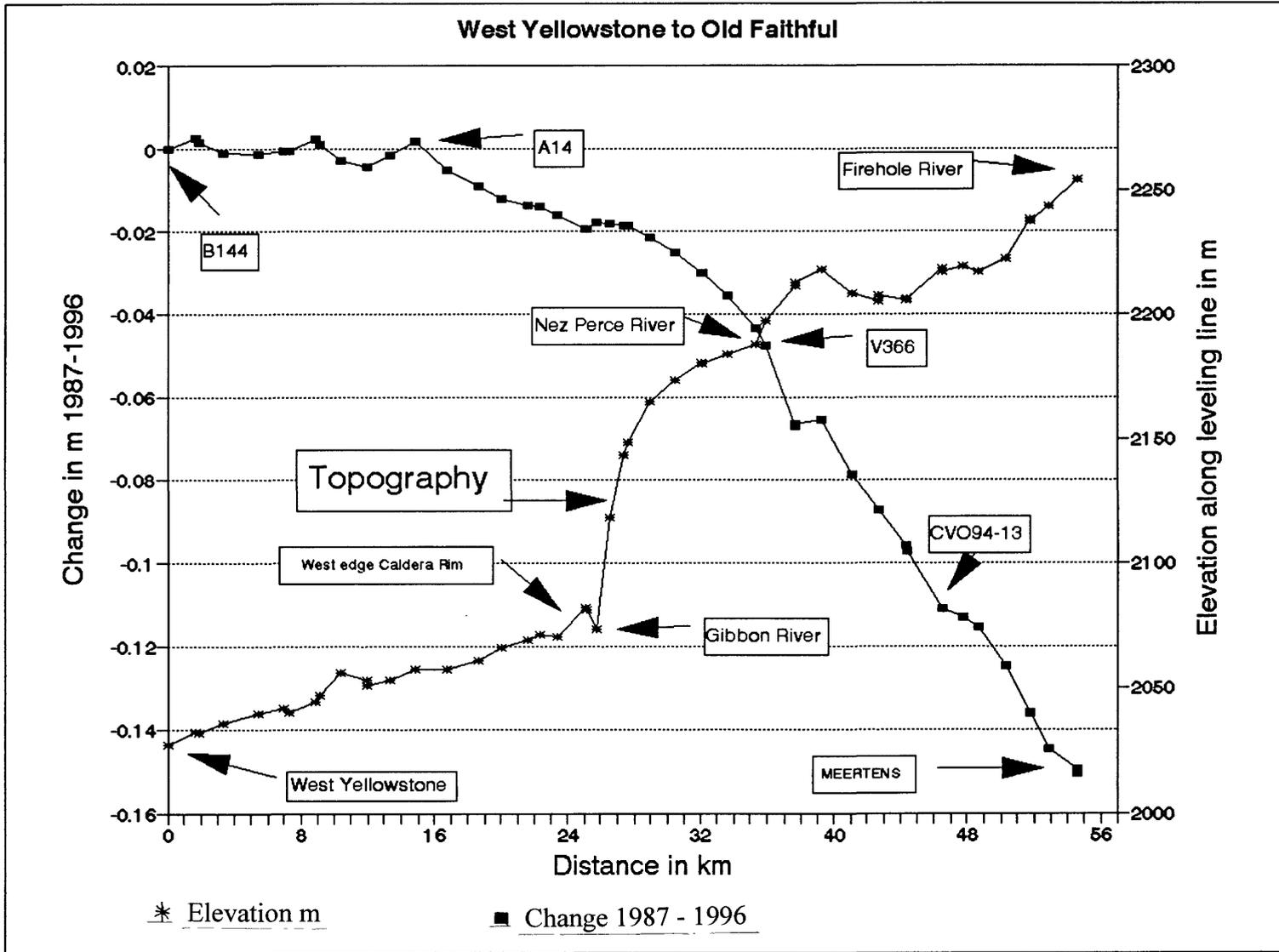


Figure 8

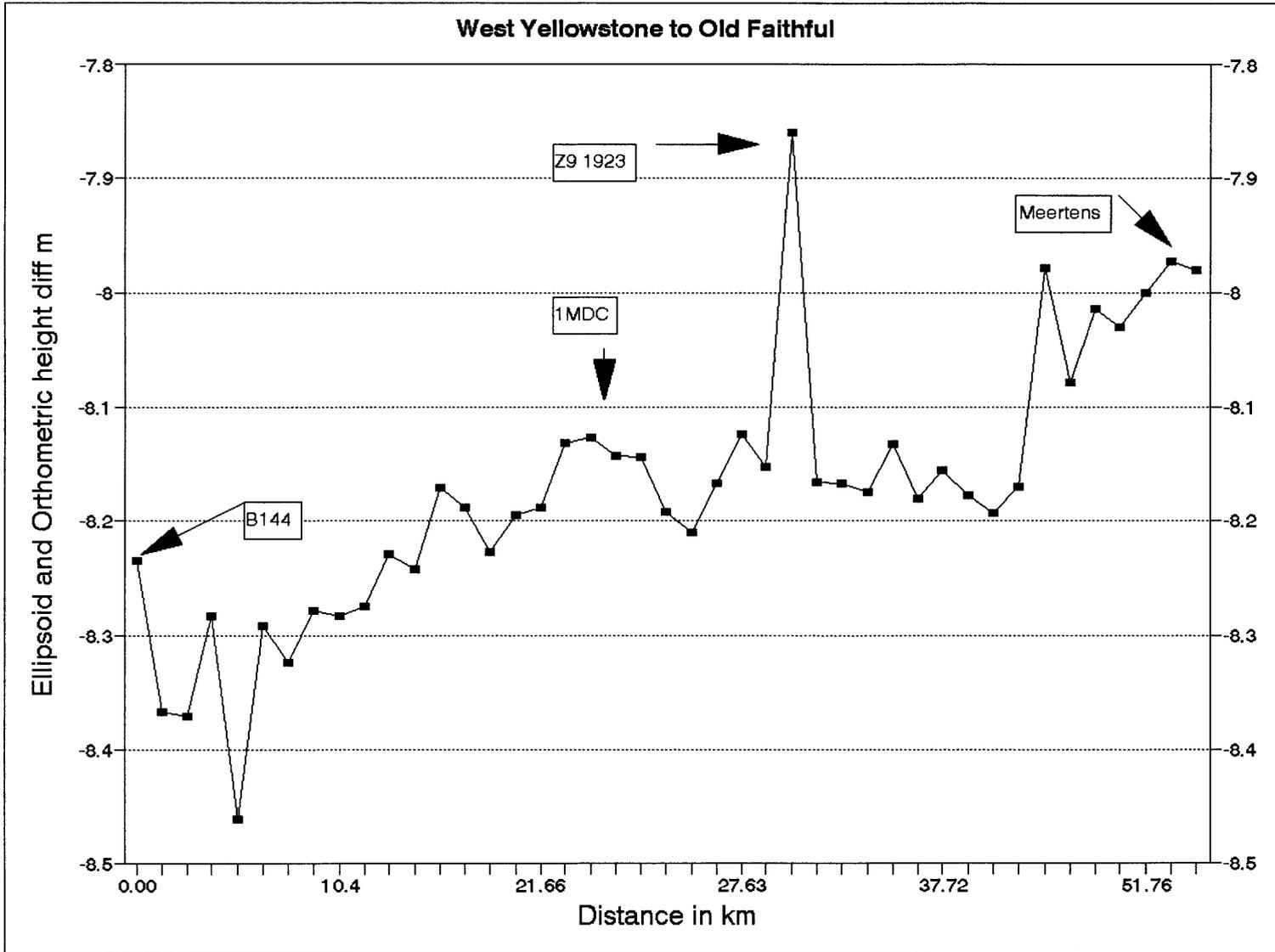


Table 1

The Wild® NA3003 Digital level was used to level in one direction and the Wild® NA2 level with micrometer was used to run in the opposite direction for the data listed in this table.

Elev Diff between BM in m	Circuit of closure loop in km	Allowable closure in mm	Observed closure in mm	Allowable closure mm km ^{1/2}	Observed closure mm km ^{1/2}
16.851	2.72	6.60	-2.07	4.0	-1.25
12.419	3.52	7.50	-0.66	4.0	-0.35
1.6430	1.30	4.56	1.40	4.0	1.23
9.5137	1.06	4.12	-0.11	4.0	0.11
25.036	1.72	5.15	0.36	4.0	0.27
8.008	2.96	11.84	0.13	4.0	0.08
44.802	1.60	5.06	0.65	4.0	0.51
4.165	3.40	7.38	0.30	4.0	0.16
1.103	2.04	5.71	-1.48	4.0	-1.04
Average	1.64	6.43	0.79*	4.0	0.62*

* All values were considered absolute to arrive at these figures

TABLE 2

The Wild® NA3003 Digital level was used to double-run the sections for the data listed in this table.

Elev Diff between BM in m	Circuit of closure loop in km	Allowable closure in mm	Observed closure in mm	Allowable closure mm km ^{1/2}	Observed closure mm km ^{1/2}
3.511	3.22	7.18	0.49	4.0	0.98.
0.463	3.74	7.74	-2.54	4.0	1.08
4.491	3.14	7.09	-0.73	4.0	0.09
4.054	3.84	7.8	3.45	4.0	1.66
Average	3.48	7.45	1.80*	4.0	0.97*

* All values were considered absolute to arrive at these figures

TABLE 3

The Wild® NA2 with parallel micrometer was used to double-run the sections for the data listed in this table.

Elev Diff between BM in m	Circuit of closure loop in km	Allowable closure in mm	Observed closure in mm	Allowable closure mm km ^{1/2}	Observed closure mm km ^{1/2}
9.655	3.64	7.63	1.88	4.0	0.27
11.668	4.10	8.10	-2.19	4.0	1.31
5.311	3.16	7.11	0.16	4.0	0.41
14.223	3.62	7.61	-3.16	4.0	1.76
Average	3.63	7.61	1.85*	4.0	0.94*

* All values were considered absolute to arrive at these figures

TABLE 4

Elevations for the 1987 and 1996 surveys, differences between bench marks and cumulative elevation difference.

BM ID	1996 ELEV M	1987 ELEV M	CUM DIFF 87-96	1996 ELEV DIFF M	1987 ELEV DIFF M
B144	2027.52592	2027.52592	0.00000		
C566	2032.33161	2032.32905	0.00256	4.80569	4.80313
W162	2032.0314	2032.02993	0.00147	-0.30021	-0.29912
C144	2036.2566	2036.25753	-0.00093	4.2252	4.2276
D566	2039.67247	2039.67375	-0.00128	3.41587	3.41622
E130	2041.61367	2041.61399	-0.00032	1.9412	1.94024
B339	2040.15452	2040.15487	-0.00035	-1.45915	-1.45912
C14 1923	2044.47629	2044.47407	0.00222	4.32177	4.3192
C339	2047.14523	2047.14402	0.00121	2.66894	2.66995
V158	2056.54415	2056.54702	-0.00287	9.39892	9.403
B14 1923	2053.19276	2053.19734	-0.00458	-3.35139	-3.34968
Hull	2051.05049	2051.05493	-0.00444	-2.14227	-2.14241
U158	2053.19459	2053.19628	-0.00169	2.1441	2.14135
A14 Reset	2057.68509	2057.68336	0.00173	4.4905	4.48708
T158	2057.22318	2057.22814	-0.00496	-0.46191	-0.45522
Z13 1923	2061.27913	2061.28845	-0.00932	4.05595	4.06031
S158	2066.15276	2066.16517	-0.01241	4.87363	4.87672
Y13 1923	2069.66356	2069.67727	-0.01371	3.5108	3.5121
Harlequin	2071.30725	2071.3214	-0.01415	1.64369	1.64413
R158	2070.205	2070.22099	-0.01599	-1.10225	-1.10041
D339	2082.6244	2082.64398	-0.01958	12.4194	12.42299
1MDC	2081.28136	2081.30079	-0.01943	-1.34304	-1.34319
BM6802.32	2073.41414	2073.43189	-0.01775	-7.86722	-7.8689
E339	2118.21566	2118.23398	-0.01832	44.80152	44.80209
40MDC	2143.25189	2143.27061	-0.01872	25.03623	25.03663
F339	2148.4758	2148.49475	-0.01895	5.22391	5.22414
Y9 1923	2165.32612	2165.34773	-0.02161	16.85032	16.85298
41MDC	2173.33435	2173.35939	-0.02504	8.00823	8.01166
Z9 1923	2180.70856	2180.73854	-0.02998	7.37421	7.37915
CVO94-10	2180.0611	2180.09131	-0.03021	-0.64746	-0.64723
42MDC	2183.6161	2183.65171	-0.03561	3.555	3.5604

Nez Perce	2187.78206	2187.82541	-0.04335	4.16596	4.1737
DA1 *	2188.06894	2188.11229	-0.04335	0.28688	0.28688
V366	2197.29576	2197.34341	-0.04765	9.22682	9.23112
43MDC	2211.51687	2211.5838	-0.06693	14.22111	14.24039
CVO94-11	2212.43482	2212.50149	-0.06667	0.91795	0.91769
44MDC	2217.74553	2217.81084	-0.06531	5.31071	5.30935
45MDC	2208.0918	2208.17059	-0.07879	-9.65373	-9.64025
CVO94-12	2205.13591	2205.22322	-0.08731	-2.95589	-2.94737
46MDC *	2207.3401	2207.42741	-0.08731	2.20419	2.20419
Thermal	2205.87469	2205.97071	-0.09602	-1.46541	-1.4567
C10 1923	2206.23933	2206.33641	-0.09708	0.36464	0.3657
CVO94-13	2217.90854	2218.01943	-0.11089	11.66921	11.68302
47MDC *	2216.88092	2216.99181	-0.11089	-1.02762	-1.02762
X366*	2219.40134	2219.51431	-0.11297	2.52042	2.5225
BM7273.15	2217.14889	2217.26408	-0.11519	-2.25245	-2.25023
48MDC	2222.2895	2222.41397	-0.12447	5.14061	5.14989
BMOF4	2237.68537	2237.82153	-0.13616	15.39587	15.40756
BMIO2	2237.43897	2237.57481	-0.13584	-0.2464	-0.24672
Y366	2243.28565	2243.43033	-0.14468	5.84668	5.85552
Meertens	2253.83556	2253.98498	-0.14942	10.54991	10.55465
Meertens2	2253.8681	2254.01844	-0.15034	0.03254	0.03346

* These bench marks are destroyed

TABLE 5

Rapid static ellipsoidal heights (m) and North Latitude and West Longitude.

Bench mark ID	Ellipsoidal elevation m	N Latitude deg-min-sec Baseline Solution	W Longitude deg-min-sec Baseline Solution
Airport*	2011.2370	44 42 00.74340	111 06 38.84500
B144	2019.17162	44 39 29.59161	111 07 18.43703
W162	2023.79625	44 39 30.48813	111 05 51.16470
C144	2027.88893	44 39 20.04078	111 04 50.29743
D566	2031.30115	44 39 07.28819	111 03 39.49513
E130	2033.33072	44 39 09.40502	111 02 35.02751
B339	2031.69296	44 39 08.50229	111 02 21.38392
C14 1923	2036.18415	44 39 00.55374	111 01 15.18598
C339	2038.82137	44 38 58.64387	111 01 04.63490
V158	2048.26613	44 39 03.85906	111 00 06.15529
B14 1923	2044.91016	44 39 37.14985	110 59 28.50909
Hull	2042.77530	44 39 36.74683	110 59 29.87734
U158	2044.96520	44 40 06.81198	110 58 54.56815
A14 Reset	2049.44293	44 39 48.97001	110 57 54.17817
T158	2049.05175	44 38 59.85319	110 57 14.04263
Z13 1923	2053.09116	44 38 48.84123	110 55 52.33148
S158	2057.92600	44 38 37.46725	110 54 53.10252
Y13 1923	2061.46802	44 38 26.89713	110 53 47.18516
Harlequin*	2063.11900	44 38 22.69320	110 53 19.19100
R158	2062.07221	44 38 30.06173	110 52 35.82104
D339	2074.49648	44 38 44.57583	110 51 30.25388
1MDC	2073.13786	44 38 43.61974	110 51 28.97254
BM6802.32	2065.26946	44 38 26.77648	110 51 39.92459

E339	2110.02359	44 38 07.17368	110 51 30.65387
40MDC	2135.04235	44 37 47.69260	110 51 21.10620
F339	2140.30773	44 37 40.71580	110 51 26.17167
Y9 1923	2157.20183	44 37 01.74026	110 51 20.19437
41MDC	2165.18181	44 36 26.11582	110 50 45.92356
Z9 1923	2172.84921	44 35 53.20383	110 49 52.56555
CVO94-10	2171.89496	44 35 53.59405	110 49 52.05931
42MDC	2175.44893	44 35 04.56687	110 49 47.61733
Nez Perce*	2179.60800	44 34 23.39700	110 49 12.02640
V366	2189.16245	44 34 11.98158	110 48 57.64824
43MDC	2203.33646	44 33 18.46471	110 48 26.45072
CVO94-11	2204.27840	44 33 18.79926	110 48 25.74168
45MDC	2199.91362	44 31 57.83748	110 49 39.28167
CVO94-12	2197.00155	44 31 23.66390	110 49 49.78552
Thermal	2197.71041	44 30 57.94916	110 49 57.48424
C10 1923	2198.06932	44 30 57.67065	110 49 57.92690
CVO94-13	2209.93042	44 29 58.07229	110 50 21.03141
BM7273.15	2209.06983	44 28 58.30743	110 51 09.24044
48MDC	2214.27476	44 28 07.66329	110 51 22.13410
BM0F4	2229.65402	44 27 39.37224	110 50 42.01552
BMI02	2229.43942	44 27 39.0290	110 50 42.02891
Y366	2235.31316	44 27 19.93204	110 50 03.04031
Meertens2*	2245.88700	44 27 14.42220	110 49 08.95020

* Fixed control point

TABLE 6

Elevation difference between ellipsoidal and orthometric heights (m).

Bench mark ID	Ellipsoidal height (m)	Orthometric height (m)	diff ellipsoidal - orthometric height (m)
B144	2019.17162	2027.52592	-8.3543
W162	2023.79625	2032.0314	-8.23515
C144	2027.88893	2036.2566	-8.36767
D566	2031.30115	2039.67247	-8.37132
E130	2033.33072	2041.61367	-8.28295
B339	2031.69296	2040.15452	-8.46156
C14 1923	2036.18415	2044.47629	-8.29214
C339	2038.82137	2047.14523	-8.32386
V158	2048.26613	2056.54415	-8.27802
B14 1923	2044.91016	2053.19276	-8.2826
Hull	2042.77530	2051.05049	-8.27519
U158	2044.96520	2053.19459	-8.22939
A14 Reset	2049.44293	2057.68509	-8.24216
T158	2049.05175	2057.22318	-8.17143
Z13 1923	2053.09116	2061.27913	-8.18797
S158	2057.92600	2066.15276	-8.22676
Y13 1923	2061.46802	2069.66356	-8.19554
Harlequin*	2063.11900	2071.30725	-8.18825
R158	2062.07221	2070.20500	-8.13279
D339	2074.49648	2082.62440	-8.12792
1MDC	2073.13786	2081.28136	-8.1435
BM6802.32	2065.26946	2073.41414	-8.14468

E339	2110.02359	2118.21566	-8.19207
40MDC	2135.04235	2143.25189	-8.20954
F339	2140.30773	2148.48580	-8.17807
Y9 1923	2157.20183	2165.32612	-8.12429
41MDC	2165.18181	2173.33435	-8.15254
Z9 1923	2172.84921	2180.70856	-7.85935
CVO94-10	2171.89496	2180.06110	-8.16614
42MDC	2175.44893	2183.61610	-8.16717
Nez Perce*	2179.60800	2187.78206	-8.17406
V366	2189.16245	2197.29576	-8.13331
43MDC	2203.33646	2211.51687	-8.18041
CVO94-11	2204.27840	2212.50149	-8.22309
45MDC	2199.91362	2208.09180	-8.17818
CVO94-12	2197.00155	2205.13591	-8.13436
Thermal	2197.71041	2205.87469	-8.16428
C10 1923	2198.06932	2206.23933	-8.17001
CVO94-13	2209.93042	2217.90854	-7.97812
BM7273.15	2209.06983	2217.14889	-8.07906
48MDC	2214.27476	2222.28950	-8.01474
BM0F4	2229.65402	2237.68537	-8.03135
BMI02	2229.43942	2237.43897	-7.99955
Y366	2235.31316	2243.28565	-7.97249
Meertens2*	2245.88700	2253.8681	-7.9811

* Fixed control point