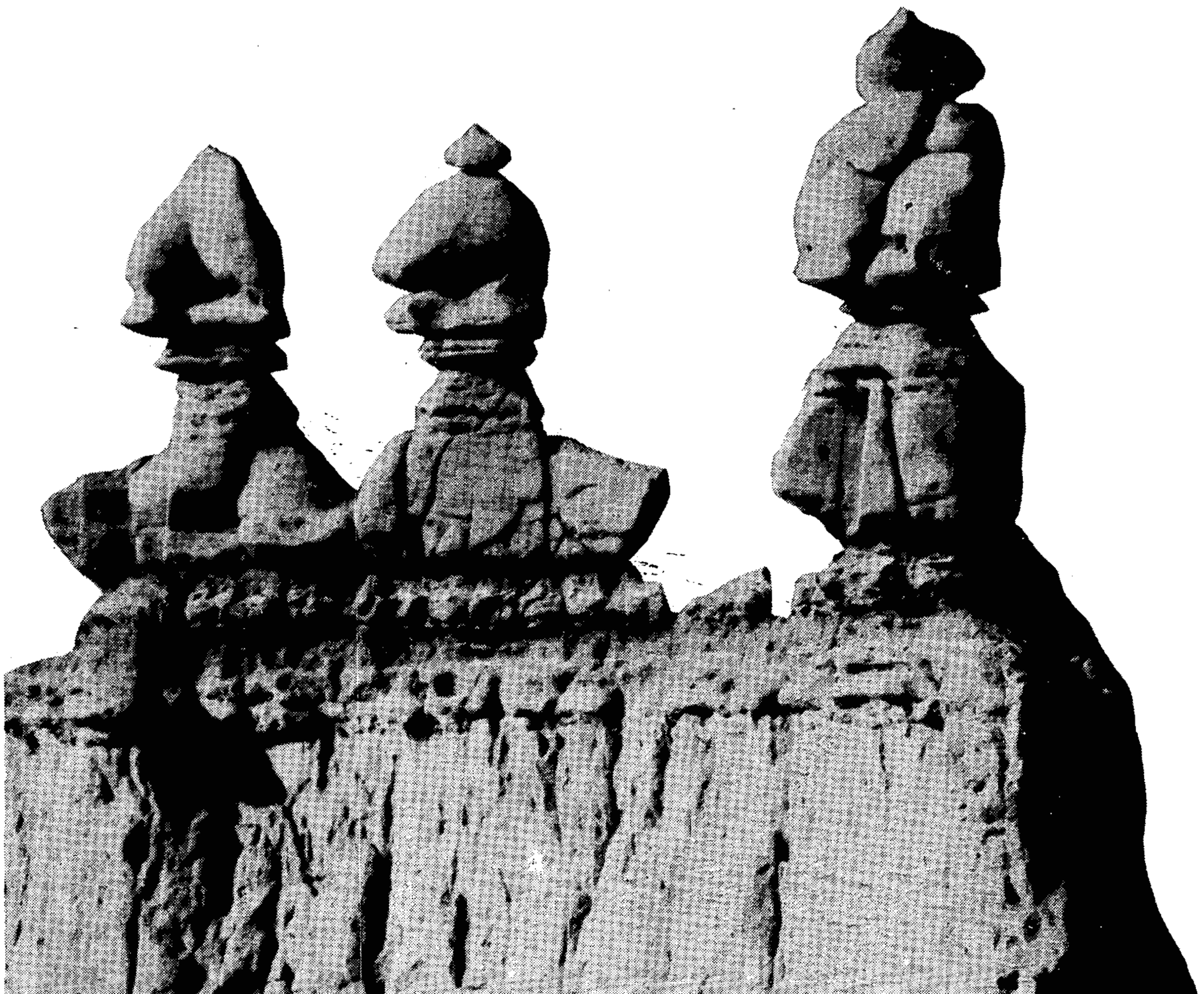
MASTER

DEPARTMENT OF GEOLOGY AND GEOPHYSICS



REPORT: FINAL: Volume 77-9

CONTRACT: EY-76-S-07-1601

AGENCY: DOE/DGE

TITLE: Precision Leveling and Gravity Studies at Roosevelt Hot Springs KGRA, Utah

AUTHORS: Kenneth L. Cook and James A. Carter

DATE: March 1978

UNIVERSITY OF UTAH SALT LAKE CITY, UTAH 84112

DISCLAIMER

FINAL REPORT: VOLUME 77-9

DOE/DGE

EY-76-S-07-1601

WDM

PRECISION LEVELING AND GRAVITY STUDIES AT THE ROOSEVELT HOT SPRINGS KGRA, UTAH

By

Kenneth L. Cook and James A. Carter

CONTENTS

INTRODUCTION

Since 1975 the University of Utah has been involved in precision leveling and gravity studies in the Roosevelt Hot Springs KGRA, Utah (Fig. 1). The objective of the precision leveling and gravity surveys is to provide a baseline for detecting mass reduction or movement (displacement) related to injection or withdrawal of geofluids or to changes in tectonic strain, or both of these effects.

In this report, the precision leveling and gravity data obtained during the period September 1975 through October 31, 1977 are presented, and interpretations of the data are made. If the project is to be continued, it should be emphasized that the interpretations given here are considered preliminary, and subject to revision and correction in the light of future anticipated improved techniques of data reduction and processing.

The project has been conducted with the informal cooperation of the Phillips Petroleum Company, which has authorized the inclusion of some of its data in this report, and the U.S. Geological Survey. However, the authors are solely responsible for the material included in this report.

Figure 1. Map showing Roosevelt Hot Springs area and new leveling lines (A-A' and B-B') of benchmarks installed by USGS during May 1977. Dashed rectangle shows map area covered in Figure 2.

Notes: 1) U.S. National Geodetic Survey (NGS) benchmark R-182 (installed in 1970; not shown in this figure) is located along the Union Pacific railroad tracks about 0.1 mi south of the point of intersection of lines AA' and CC'.

2) U.S. National Geodetic Survey benchmarks Q-182 and K-182 (installed in 1970; not shown in this figure) are located along the Union Pacific railroad tracks about 0.6 mi and 6 1/2 mi, respectively, north of the point of intersection of lines AA' and CC'.

3) Benchmark BM-A (installed prior to 1958; not shown in this figure) is located along the Union Pacific railroad tracks about 1 1/2 mi north of the point of intersection of lines AA' and CC'.

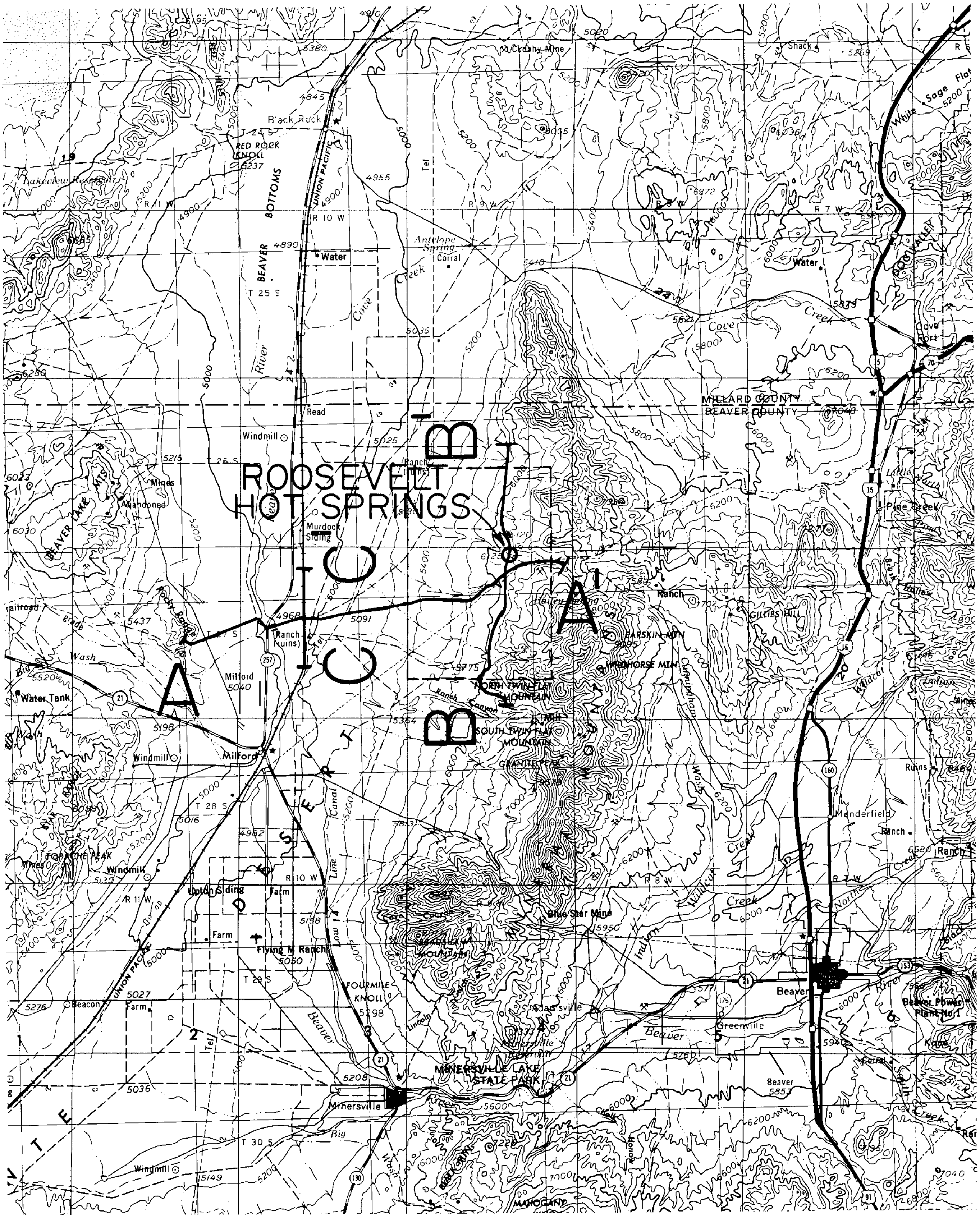

ROOSEVELT
HOT SPRINGS
A
A'
B
B'
C
C'
Black Rock
BEAVER BOTTOMS
Beaver River
Cove Creek
Antelope Spring
Corral
Water
Read
Windmill
Ranch (ruins)
Murdock Siding
Mines
Abandoned
BEAVER LAKE MTS
Water Tank
Milford
Upton Siding
Farm
Flying M Ranch
FOURMILE KNOLL
Beacon
Minersville
MINERSVILLE LAKE STATE PARK
Adamsville
Greenville
Beaver
NORTH TWIN FLAT MOUNTAIN
SOUTH TWIN FLAT MOUNTAIN
GRANITE PEAK
WILDHORSE MTN
BEARSKIN MTN
Blue Star Mine
GILLIES HILL
Cove Fort
Pine Creek
Manderfield
MILLARD COUNTY
BEAVER COUNTY
UNION PACIFIC
Beaver Power Plant No. 1

Figure 1

PRECISION LEVELING SURVEYS

Precision Leveling Survey No. 1

Precision leveling survey No. 1 involved the precise measurements of the elevations and locations of the monuments installed for the Phillips Petroleum Company at drill sites and other locations (Fig. 2 and table 1) in the Roosevelt Hot Springs KGRA. The surveys were made intermittently during the period September 12, 1975 through December 1975 by the Bulloch Bros. Engineering, Inc., Cedar City, Utah, under contract to the Phillips Petroleum Company.

The techniques of the precision leveling survey are given in Appendix 1. The survey was second-order leveling, with an accuracy of 0.05 ft for each horizontal mile of traverse (N. L. Rhodes, 1977, oral communication). It should be noted that 1) the datum used for the survey was U.S. National Geodetic Survey (NGS) benchmark R-182 (originally established in 1970 and located about 0.1 mi <u>south</u> of the point of intersection of lines AA' and CC' (Fig. 1); 2) an elevation value of 4970.978 ft (see table 3) was assigned to NGS benchmark R-182 by Bulloch Bros. Engineering, Inc. (as recommended by the Denver office of the USGS during September 1975 as an "unadjusted value"; and 3) a leveling line of at least 8 mi was required to tie this datum to the monuments in the Roosevelt Hot Springs area (Fig. 1).

It should also be noted that essentially all the monuments were set in concrete posts with a 2-inch-diameter brass disc on top and rise about 8 inches above the surface of the ground. The elevation of the top of each 2-inch-diameter brass disc, as determined by the Bulloch Bros. Engineering, Inc. survey, is given in table 2 in the column labeled "Elev. of Mon. (ft)".

Figure 2 -- Map showing locations of monuments in the Roosevelt Hot Springs area at which precision gravity data have been taken by the University of Utah.

Keys to symbols used for monuments

E 46-10	Phillips Petroleum Co. drill hole (already completed or planned).
USGS PINON	U.S. Geological Survey benchmark. (also University of Utah 12-inch-diameter concrete monument)

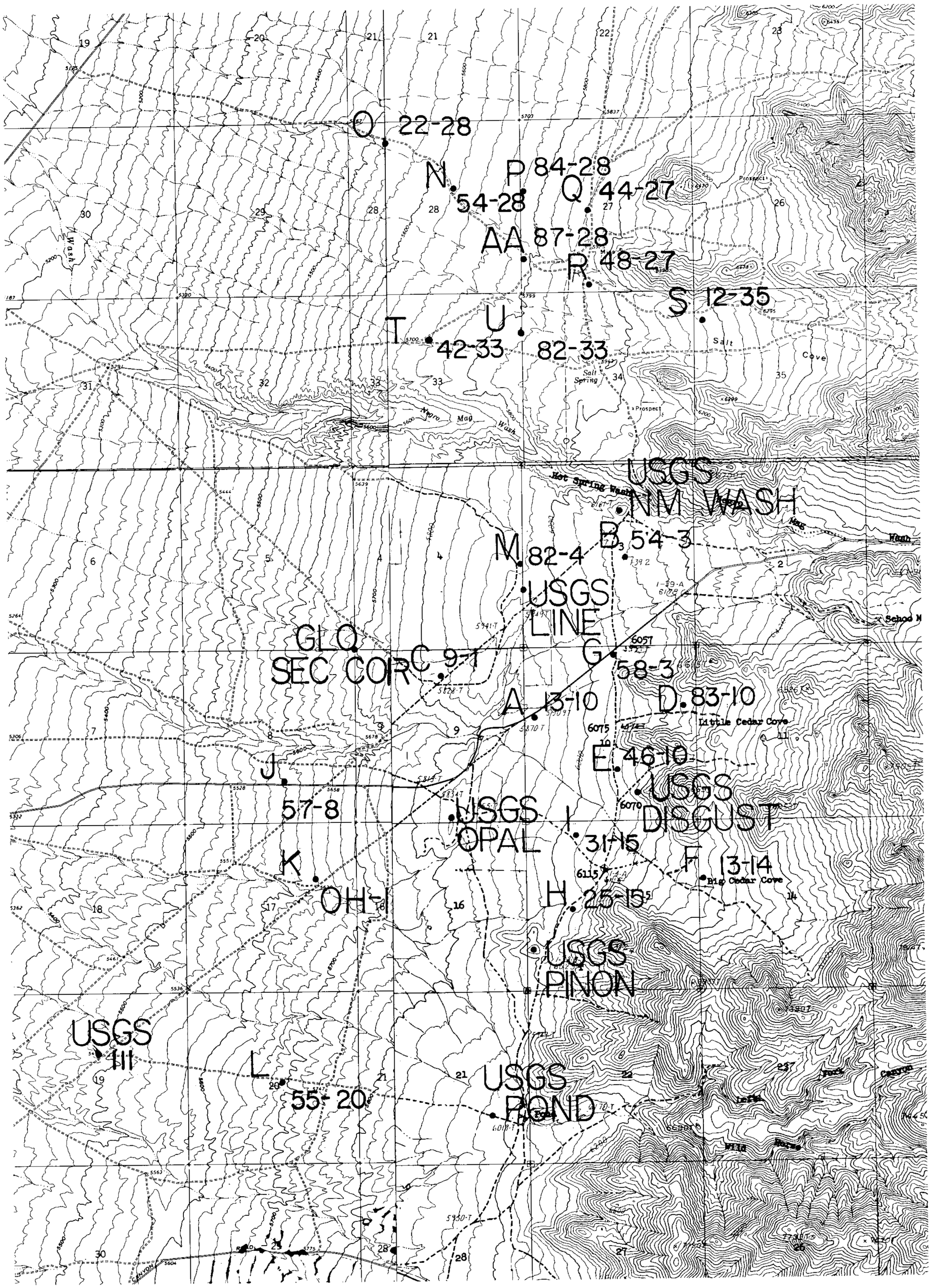

O 22-28
N 54-28
P 84-28
Q 44-27
AA 87-28
R 48-27
S 12-35
T 42-33
U 82-33
Salt Cove
Salt Spring
USGS NM WASH
Hot Spring Wash
B 54-3
M 82-4
USGS LINE
GLO SEC COR
C 9-1
G 58-3
A 13-10
D 83-10
Little Cedar Cove
E 46-10
J 57-8
USGS DISGUST
USGS OPAL
I 31-15
F 13-14
Big Cedar Cove
K OH-1
H 25-15
USGS PINON
USGS 111
L 55-20
USGS POND
Wild Horse

Figure 2

Table 1 -- Monuments (as of Oct. 31, 1977; see Fig. 2)

		No.
1.	At Phillips Petroleum Co. drill holes already completed or currently being drilled 1/	22
2.	At U. S. Coast and Geodetic Survey or USGS permanent benchmarks 1/	5
3.	At USGS benchmarks installed in late August 1976 (includes 4 monuments established nearby by University of Utah) 2/ 3/. These benchmarks are designated DISGUST, LINE, OPAL, PINON, POND, SEC COR, N M WASH, and III (Fig. 2).	8
4.	At new USGS benchmarks installed during May 1977 along 1) an east-west profile (AA', Fig. 1) across Milford Valley between the Rocky Range on the west and the Roosevelt Hot Springs area on the east and 2) a north-south profile (BB', Fig. 1) between Ranch Canyon area on the south and a point about 2 km south of the Millard-Beaver County line on the north (to include 30 monuments to be established nearby by University of Utah) 3/	30
	TOTAL	65

1/ Gravity stations taken at these monuments during: 1) February 4-7, 1976, prior to Phillips Petroleum Co. 4-day withdrawal tests during February 12-16, 1976; 2) February 16-18, 1976, after these tests; 3) August 16-18, 1976; and 4) July 5-6, 1977. Precise leveling of the Phillips monuments was done during September 12, 1975 to December 1975 by Bulloch Bros. Engineering, Inc. under contract to Phillips Petroleum Co.

2/ Gravity stations taken at these monuments during: 1) September 19, 1976, and 2) July 5-6, 1977.

3/ Precise first-order leveling of these USGS benchmarks was done by the USGS during May 1977.

Table 2

ELEVATIONS OF ROOSEVELT KGRA CONCRETE PADS USED IN PRECISION GRAVITY NET

Location (see map)	Station Designation	Elev. of Mon. (ft.)	Elev. Dif. (ft.)	Elev. Pad (ft.)
T26S, R9W, Sec. 28	"O" KGRA-22-28	5527.02	-0.30	5526.72
T26S, R9W, Sec. 28	"N" KGRA-54-28	5645.63	-0.61	5645.02
T26S, R9W, Sec. 28	"P" KGRA-84-28	5765.16	-0.54	5764.62
T26S, R9W, Sec. 28	"AA" KGRA-87-28	5794.95	-0.33	5794.62
T26S, R9W, Sec. 27	"Q" KGRA-44-27	5932.33	-0.26	5932.07
T26S, R9W. Sec. 27	"R" KGRA-48-27	5929.97	-0.33	5929.64
T26S, R9W, Sec. 33	"T" KGRA-42-33	5712.65	-0.20	5712.45
T26S, R9W, Sec. 33	"U" KGRA-82-33	5845.44	-0.62	5844.82
T26S, R9W, Sec. 35	"S" KGRA-12-35	6180.52	-0.78	6179.74
T27S, R9W, Sec. 4	"M" KGRA-82-4	5946.37	-0.20	5946.17
T27S, R9W, Sec. 3	"B" KGRA-54-3	6108.62	-0.39	6108.23
T27S, R9W, Sec. 3	"G" KGRA-58-3	6048.26	-0.48	6047.78
T27S, R9W, Sec. 8	"J" KGRA-57-8	5597.64	-0.14	5597.50
T27S, R9W, Sec. 9	"C" KGRA-9-1	5833.08	-0.86	5832.22
T27S, R9W, Sec. 10	"A" KGRA-13-10	5890.83	-0.42	5890.41
T27S, R9W, Sec. 10	"D" KGRA-82-10	6279.10	even	6279.10
T27S, R9W, Sec. 10	"E" KGRA-46-10	6094.03	-0.38	6093.65
T27S, R9W, Sec. 14	"F" KGRA-13-14	6358.99	-0.19	6358.80
T27S, R9W, Sec. 15	"I" KGRA-31-15	6041.85	-0.63	6041.22
T27S, R9W, Sec. 15	"H" KGRA-25-15	6024.00	-0.19	6023.81
T27S, R9W, Sec. 17	"K" KGRA-OH#1	5647.81	-0.78	5647.03
T27S, R9W, Sec. 20	"L" KGRA-55-20	5712.48	-0.07	5712.41

Precision Leveling Survey No. 2

Precision leveling survey No. 2 involved principally the precise measurements of the elevations and the locations of about 30 new USGS benchmarks erected along lines AA' and BB' (Fig. 1). The benchmarks were spaced along the profiles at intervals of about 0.5 mi in the vicinity of the Roosevelt Hot Springs geothermal area and 1.0 mi elsewhere. In addition, elevation measurements were taken at the following previously established stations:

NGS benchmark Q-182 (established in 1970)

NGS benchmark R-182 (established in 1970)

E(46-10), G(58-3), I(31-15) } Established in 1975 for Phillips Petroleum Co. by Bulloch Bros. Engineering, Inc.

The survey was made by the U. S. Geological Survey, with W. B. Cook as Party Chief, during May 1977, using first-order leveling techniques. The techniques of the survey are given in Appendix 2. The accuracy of first-order leveling is within 1.2 cm for 9 km of horizontal traverse. It should be noted that the datum used for the USGS survey was benchmark Q-182 (originally established in 1970 and located about 0.6 mi north of the point of intersection of lines AA' and CC' (Fig. 1)). It should also be noted that the above-mentioned NGS benchmark R-182, which was used for the datum of precision leveling survey No. 1 by Bulloch Bros. Engineering, Inc., was reoccupied in the USGS survey; and an elevation value of 4970.998 ft (see table 3) was obtained (W. B. Cook, 1977, p. 1).

Accordingly, because NGS benchmark R-182 was assigned an elevation value of 4970.978 ft (see table 3) by Bulloch Bros. Engineering, Inc. for precision leveling survey No. 1, all elevation values of the USGS survey (precision leveling survey No. 2) should be consistently 0.020 ft greater than those of precision leveling survey No. 1.

The elevation values and detailed descriptions of the 30 new USGS benchmarks along profiles AA' and BB" (Fig. 1) have been published (W. B. Cook, 1977), and will not be repeated in this report. However, the elevation values for those stations in precision leveling survey No. 1 that were reoccupied in precision leveling survey No. 2 are given in table 3. In addition to NGS benchmark R-182, these reoccupied stations are (Fig. 2): E (46-10), G (58-3), and I (31-15), which for convenience will be designated henceforth in the report simply as E, G, and I, respectively.

Comparison of precision leveling survey Nos. 1 and 2

Table 3 shows a comparison of the elevation values for those stations in precision leveling survey No. 1 that were reoccupied in precision leveling survey No. 2. In column D of this table is shown an "Adjusted Difference", which takes into account the difference of 0.020 ft in the "assigned" values of the elevation for NGS benchmark R-182 for the two respective surveys. Accordingly, on the assumption that the elevation of NGS benchmark R-182 did not change during the period between the two surveys -- which seems reasonable on the basis of our present knowledge--, the "Adjusted Difference" values in column D, table 3, indicate the following results:

> During the period between (1) September - December 1975 and (2) May 1977, the elevations of stations E, G, and I apparently decreased 0.825 ft, 0.772 ft, and 0.765 ft, respectively, with respect to NGS benchmark R-182.

These relatively large apparent changes in elevation during a 17-month period appear unreasonable. Because the apparent changes in elevation are all of the approximately same order of magnitude (ie., within 0.06 ft), a survey error in leveling may have occurred along the 8-mile-long line between the location of the datum (NGS benchmark R-182 or Q-182) and the monuments in the Roosevelt Hot Springs area. It is not known, however, whether this postulated error was made by Bulloch Bros. Engineering, Inc. or the USGS.

Table 3.--Elevations at monuments.

Station	A Survey No. 1 1/ (Sept.-Dec., 1975) (feet)	B Survey No. 2 2/ May 1977 (feet)	C Difference (A-B) (feet)	D Adjusted Difference (C+0.020 ft) (feet)
R-182 6/	4970.978 3/	4970.998	-0.020	0.000
Q-182 6/	Not occupied	4968.664 4/		
E (46-10)	6094.03	6093.185	-0.845	-0.825
G (58-3)	6048.26	6047.468	-0.792	-0.772
I (31-15)	6041.85	6041.065	-0.785	-0.765
DISGUST 5/		6116.233		
LINE 5/		5999.403		
OPAL 5/		5901.767		
PINON 5/		6074.656		
POND 5/		5976.361		
SEC COR 5/		Not available		
N M WASH 5/		6168.538		
III		Not available		

1/ Data taken by Bulloch Bros. Engineering Co., Cedar City, Utah.

2/ Data taken by U.S. Geological Survey (W. B. Cook, 1977).

3/ This benchmark and elevation were taken as the datum for precision leveling survey No. 1. The elevation value was given to Bulloch Bros. Engineering, Inc. by the Denver office of the USGS during September 1975 as the "unadjusted value" at that time.

4/ This benchmark and elevation were taken as the datum for precision leveling survey No. 2.

5/ Benchmarks established by USGS during late August 1976 for precision horizontal-control survey (Ben Lofgren, 1977, written communication).

6/ NGS benchmark established in 1970.

PRECISION HORIZONTAL-CONTROL SURVEYS

During late August 1976, the U.S. Geological Survey erected and measured the horizontal distances between the following benchmarks in the Roosevelt Hot Springs KGRA for the purpose of establishing an initial baseline for precision horizontal control (Fig. 2):

DISGUST
LINE
OPAL
PINON
POND
SEC COR
N M WASH
III

The elevations of these stations, as obtained by the USGS in May 1977 (W. B. Cook, 1977), are given in table 3.

The field work was under the supervision of Ben Lofgren, Ground Water Division, USGS, Sacramento, California. An electronic reflection-type geodometer was used for the survey. However, because of a malfunction of the electronics of the instrumentation--which was not recognized until after the survey was completed--, there is a question as to the reliability of the results of this first (August 1976) precision horizontal-control survey (Ben Lofgren, 1976, oral communication).

During June 1977, however, a precision horizontal-control survey was repeated by the USGS; and the horizontal distance between the above-listed benchmarks were remeasured accurately. In addition, the horizontal distances between the new 30 USGS measurements (installed during May 1977) were also measured accurately. The results of these precision horizontal-control surveys have not yet been made available.

PRECISION GRAVITY SURVEYS

Continuous-readings gravity survey

A continuous-readings gravity survey was made during a 4-day steam withdrawal test at Phillips Petroleum Company's well #54-3 (Fig. 2) during the period February 12 through 16, 1976. The continuous-readings gravity survey consisted of periodic (at least one reading per hour) gravity readings taken with two different LaCoste and Romberg model "G" gravity meters on a concrete monument [1/] located about 60 m southeast of the steam withdrawal well. Readings were started 2-1/2 hr before steam withdrawal commenced and continued until 3-1/2 hr after steam withdrawal stopped. The gravity readings were adjusted for tidal variation and inspected for anomalies that might have been caused by the withdrawal of steam or ground displacement.

Readings were taken every 30 min on both gravimeters before and during the first 50 hr of the test. As it became apparent that any changes which might be observed were very small and occurring slowly, the interval between readings was increased to 1 hr for the remainder of the test. Two observers worked in shifts while taking the readings. Two complications occurred during the data-gathering phase of the experiment. The first was that one of the gravimeters (G-66) being used had level adjustment problems and had to be replaced. This meant that during the first 25 hr of the test, readings were taken with gravimeter G-264 only. Further, the replacement gravimeter (G-386) had not been "on heat" long enough to stabilize completely, and consequently the readings taken on this gravimeter have a large amount of drift associated with them. The second complication involved a tear of

1/Monument B (54-3) (Fig. 2).

about 0.7 mgal in instrument G-264 at about 02:00 hr UTC, February 14, 1976 (see Fig. 3). This resulted in a period of about 18 hr thereafter when the readings of G-264 were unstable.

Observed readings were converted to milligals (mgal) using a digital computer and the manufacturer's supplied scale constants. Then a computer subroutine by Dr. Robert Jachens of the USGS, which calculates theoretical normal gravity tides in milligals, was used to remove the earth tide effects. These reduced readings were then plotted versus time to show any possible effects of the steam withdrawal test (Fig. 3).

The gravity readings taken at the monument site during the steam test show one anomalous decrease in gravity of about 0.1 mgal after the steam withdrawal began (at about 07:00 hr UTC, February 13, 1976). Unfortunately, only one instrument (G-264) was operational at this time, so verification is not possible as to whether this decrease in gravity was due to physical changes within the rocks at depth or a tear in the instrument. The linear decrease in the readings of G-386 is attributed entirely to drift because the instrument had not been on heat long enough to stabilize. The stable response of G-264, except when the tear occurred, supports this conclusion.

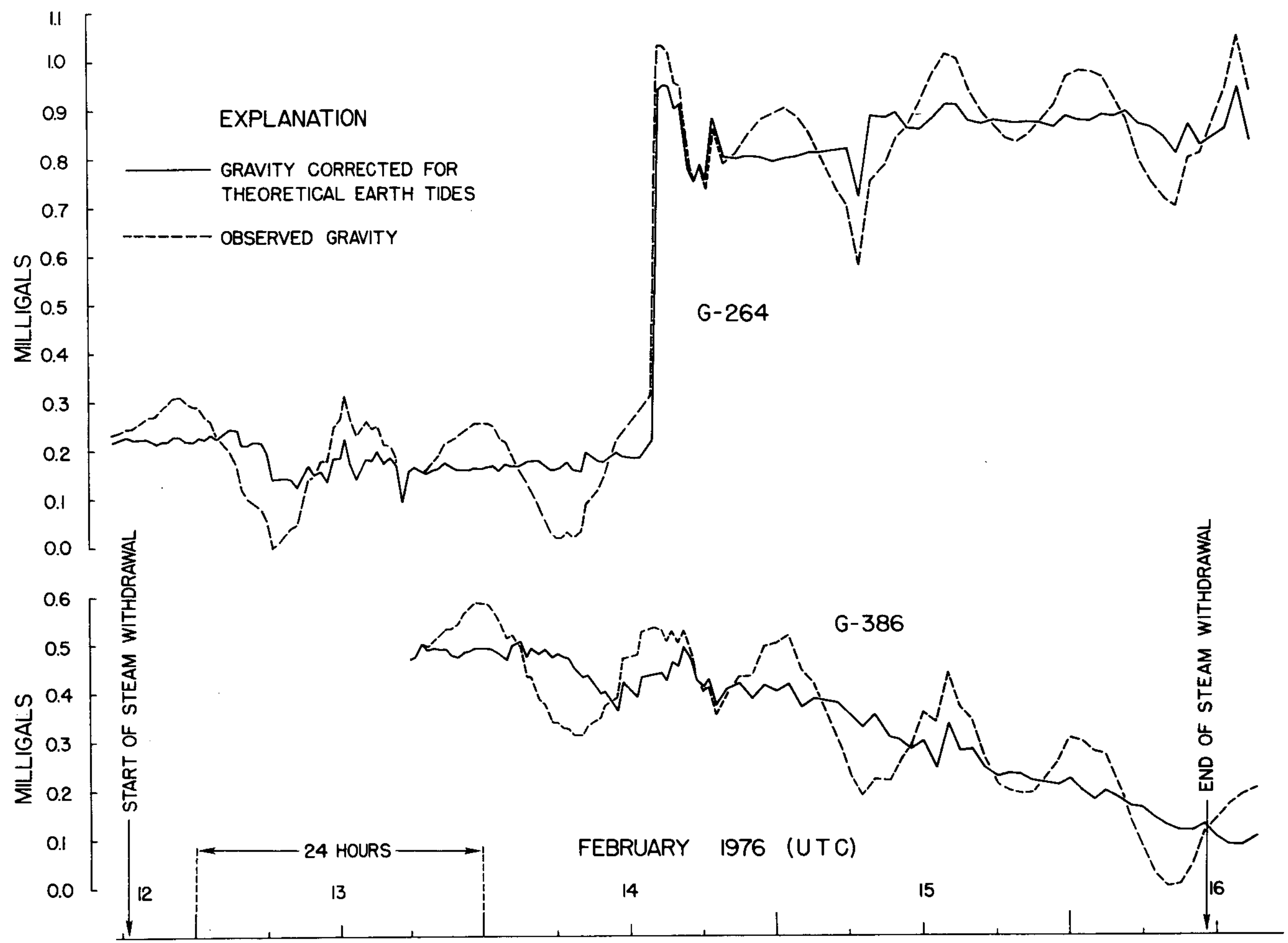


FIGURE 3. Plot of gravity readings taken periodically (at least once an hour) during a steam withdrawal test at Phillips Petroleum Co. well no. 54-3, Roosevelt Hot Springs KGRA, Beaver County, Utah. Upper and lower plots are for La Coste and Romberg gravity meters no. G-264 and G-386, respectively. The indicated date and times are Coordinated Universal Time (UTC).

Regional Precision Gravity Surveys

During the period February 1976 through October 31, 1977, four separate regional precision gravity surveys were made in the Roosevelt Hot Springs KGRA. The dates of the surveys were (table 4): 1) early February 1976, before the steam withdrawal test by the Phillips Petroleum Company; 2) late February, after the steam withdrawal test; 3) August-September, 1976; and 4) July 1977. Each survey consisted of taking gravity readings at stations primarily in the Roosevelt Hot Springs known geothermal area, but also in or near Milford, Utah, which is well outside the area of the known geothermal system.

Instruments used.--The instruments used for the precision gravity surveys, which are listed in table 4, were generally LaCoste and Romberg model G gravity meters. The only instrument used consistently in all four surveys was the LaCoste and Romberg G-264. In the first survey (prior to the 96-hr withdrawal test) two instruments, in addition to G-264, were used: 1) first, LaCoste and Romberg gravimeter G-66 was used; but it was found to have mis-adjusted levels and eventually had to be sent back to the factory for repairs; and 2) next, Worden gravimeter No. 735 was used only to help monitor G-264 to ascertain that the latter instrument did not have any tears during the survey. Accordingly, the readings from the LaCoste and Romberg G-66 and Worden No. 735 gravity meters were not reduced or otherwise processed.

In survey Nos. 2, 3, and 4, the following LaCoste and Romberg gravity meters were used, respectively, in addition to G-264: G-386, G-269, and G-461 (with electronic readout).

Table 4.--Gravity meters used for precision gravity surveys.

Survey No.	Dates	Gravity Meters (LaCoste and Romberg, unless otherwise indicated)	Instrument Operators
1	Feb. 4-7, 1976	G-264 1/ G-66 2/ Worden No. 735 1/	I. Thangsuphanich Craig Davies Craig Davies
-	Feb. 12-16, 1976 (during withdrawal test)	G-264 1/ G-386 2/	I. Thangsuphanich Craig Davies
2	Feb. 16-18, 1976	G-264 1/ G-386 2/	I. Thangsuphanich Craig Davies
3	Aug. 16-19, 1976	G-264 1/ G-269 3/	R. F. Sawyer J. A. Carter
3A	Sept. 19, 1976 4/	G-264 G-269	J. A. Carter J. A. Carter
4	July 5-6, 1977	G-264 1/ G-461 1/ (with electronic readout) 5/	M. E. Halliday J. A. Carter

1/ Instrument owned by University of Utah.

2/ Instrument rented from LaCoste and Romberg, Inc.

3/ Instrument on loan from U.S. Air Force to University of Utah.

4/ Precision gravity survey No. 3A involved gravity measurements at the following new USGS benchmarks installed during late August 1967 for precision horizontal control only at the following stations: DISGUST, LINE, OPAL, PINON, POND, SEC COR, N M WASH, and III.

5/ The LaCoste and Romberg G meter (with electronic readout) provides a greater accuracy of reading than the regular LaCoste and Romberg G meter because the instrument can be nulled by balancing a galvamometer needle (by turning the reading dial). However, the instrument operator must still read the reading dial and record his reading, as is done for the regular G meter.

<u>Procedure</u>.--In each of the precision gravity surveys, readings were taken with two different gravity meters, at essentially the same time, at each of the stations for which 12-inch-diameter concrete monuments (or pads) were available (see table 1). For all gravity surveys, these monuments included 1) those established by the Phillips Petroleum Company in the Roosevelt Hot Springs area (22 monuments, see table 2 and Fig. 2), and 2) certain U.S. National Geodetic Survey (NGS) and/or USGS permanent benchmarks near the town of Milford, Utah, far removed from the known geothermal system monuments (see table 3). Starting with the precision gravity survey No. 2, gravity readings were also taken at 12-inch-diameter monuments erected (by J. A. Carter, University of Utah) at or near the USGS benchmarks installed in late August 1976 under the supervision of Ben Lofgren (Fig. 2). The elevations of these USGS benchmarks and monuments, as measured by W. B. Cook (1977), are included in table 3.

The first three regional precision gravity surveys (including survey No. 3A, table 4) were conducted using a looping method in which each new station was tied successively to a previous station. That is, for stations A, B, C and D, the sequence of readings, starting with the Milford gravity base station M, was MABABCBCDCDM. Two readings were taken with each gravimeter each time a station was occupied, and readings were repeated until the difference between the two readings was not more than 0.004 dial divisions. The initial station in each loop was tied, by at least two readings, to a base station far removed from the Roosevelt Hot Springs geothermal system. The base station chosen was usually the Milford gravity base station, which is in the Utah Gravity Base Station Network (Cook <u>et al</u>., 1971); but at other times one of the following benchmarks, located north of Milford, (at which the Phillips Petroleum Company had erected 12-inch-diameter pads) was used as a base station: BM-A; K-182; and Milford Airport (C-332). This established the gravity at the first station of each loop, and these ties were re-established each time the network of pads was re-read.

The location descriptions and elevations of these benchmarks are given in Appendix 4 (see also Fig. 1).

For the precision gravity survey No. 4 (table 4), the looping technique was modified so that each station was occupied only once by each of the two instruments. That is, for stations A, B, C, and D, the sequence of readings, starting with the Milford gravity base station M, was MABCDM. This modification was required because of the time limitation of the personnel making the survey. As before, two readings were taken with each gravimeter each time a station was occupied, and the same specifications of no more than 0.004 dial divisions variance between successive readings were met; and also the initial station in each loop was tied to a base station far removed from the geothermal system.

Data Reduction.--Using the UNIVAC 1108 digital computer, the data were reduced for each survey by tying the initial station in each looping sequence to the Milford gravity base station, for which the observed gravity value was taken as 979539.86 mgal (Cook et al., 1971). The Milford base station is located far outside the geothermal system and therefore is assumed stable. The gravity value of each station in a looping sequence, relative to the Milford base station, was then calculated by converting the gravimeter reading to milligals, using the manufacturer's supplied dial constants, removing a computer-generated theoretical normal earth-tide component (tide program obtained from Robert Jachens, USGS), and assuming linear instrument drift within each loop. Finally, for each survey the gravity value at each station was obtained in a listing of the computer printout. In addition, the difference in gravity between the Milford base station and each station of the network was calculated and printed out on computer cards.

Results: -- The results of the four precision gravity surveys are presented in two forms: 1) in tables which list the observed gravity value at each station for each of the four surveys; and 2) in a series of gravity contour maps, which show the apparent changes in gravity at each station between the various time intervals of each of the four surveys.

Table 5 shows the observed precision gravity values (in mgal) obtained with LaCoste and Romberg gravity meter G-264 for surveys 1 through 4; and table 6 shows the corresponding values obtained with LaCoste and Romberg gravity meters G-386, G-269, and G-461 for survey Nos. 2, 3, and 4, respectively. It should be noted that for brevity, the first two digits "97" have been consistently omitted for each gravity value in this table. Also included on the right-hand column of each of these two tables, is the mean of the observed gravity values obtained for each station and the root-mean-square error. It will be noted that most of the root-mean-square errors are less than 0.03 mgal, and only one is greater than 0.05 mgal.

Using the method of Draper and Smith (1966), which is described in Appendix 3, the standard deviation of the error for each instrument in each survey was computed, and is listed in table 7.

Table 5.--Observed precision gravity values (in mgal) obtained with LaCoste and Romberg gravimeter G-264 for survey Nos. 1 through 4. 1/

STATION	No. 1	No. 2	No. 3	No. 4	MEAN
A	9498.985	9499.003	9498.998	9498.949	9498.984 ± .024
B	9485.836	9485.859	9485.868	9485.836	9485.850 ± .016
C	9501.608	9501.663	9501.670	9501.597	9501.635 ± .037
D	9473.282	9473.254	9473.313	9473.205	9473.264 ± .046
E	9484.239	9484.216	9484.193	9484.133	9484.195 ± .046
F	9463.330	9463.345	9463.318	9463.264	9463.314 ± .035
G	9489.632	9489.642	9489.630	9489.598	9489.626 ± .019
H	9487.687	9487.707	9487.718	9487.667	9487.695 ± .023
I	9485.696	9485.698	9485.694	9485.645	9485.683 ± .026
J	9510.054	9510.089	9510.085	9510.008	9510.059 ± .037
K	9506.565	9506.600	9506.568	9506.534	9506.567 ± .027
L	9499.407	9499.449	9499.411	9499.389	9499.414 ± .025
M	9494.984	9595.020	9494.984	9494.976	9494.991 ± .020
N	9522.302	9522.327	9522.270	9522.288	9522.297 ± .024
O	9528.058	9528.082	9528.013	9528.036	9528.047 ± .030
P	9516.252	9516.258	9516.195	9516.202	9516.227 ± .033
Q	9506.347	9506.370	9506.339	9506.345	9506.350 ± .014
R	9505.371	9505.397	9505.362	9505.370	9505.375 ± .015
S	9486.632	9486.650	9486.604	9486.617	9486.626 ± .020
T	9514.707	9514.748	9514.676	9514.695	9514.707 ± .030
U	9509.525	9509.572	9509.540	9509.517	9509.539 ± .024
AA	9513.268	9513.276	9513.290	9513.254	9513.272 ± .015
III			9508.395	9508.393	9508.394 ± .001
POND			9485.902	9485.857	9485.880 ± .032
PINON			9484.352	9484.305	9484.329 ± .033
OPAL			9495.154	9495.076	9495.115 ± .055
DISGUST			9483.480	9483.425	9483.453 ± .039
SECOR			9506.758	9506.719	9506.739 ± .028
NM WASH			9484.707	9484.665	9484.686 ± .030
LINE			9494.157	9494.108	9494.133 ± .035
BM-A	9542.111	9542.148	9542.258	9542.152	9542.167 ± .063
K-182	9560.937	9561.157	9561.147		9561.080 ± .124
AIRPORT	9536.966	9536.916	9536.941	9536.924	9536.937 ± .022
Milford base station	9539.86	9539.86	9539.86	9539.86	9539.86 ± .00

1/ For brevity, the first two digits "97" are omitted from each value in this table.

Table 6.--Observed precision gravity values (in mgal) obtained with LaCoste and Romberg gravimeter G-386, G-269, and G-461 for survey Nos. 2, 3, and 4, respectively. 1/

STATION	No. 2 (386)	No. 3 (269)	No. 4 (461)	MEAN
A	9499.003	9498.998	9498.951	9498.984 ± .029
B	9485.853	9485.906	9485.836	9485.865 ± .037
C	9501.697	9501.665	9501.585	9501.585 ± .058
D	9473.291	9473.281	9473.203	9473.258 ± .048
E	9484.211	9484.193	9484.162	9484.189 ± .025
F	9463.376	9463.360	9463.276	9463.337 ± .054
G	9489.645	9489.665	9489.597	9489.636 ± .035
H	9487.759	9487.714	9487.685	9487.719 ± .037
I	9485.741	9485.696	9485.662	9485.700 ± .040
J	9510.117	9510.076	9510.037	9510.077 ± .040
K	9506.619	9506.593	9506.548	9506.587 ± .036
L	9499.450	9499.438	9499.393	9499.427 ± .030
M	9495.013	9495.030	9494.974	9495.006 ± .029
N	9522.327	9522.270	9522.233	9522.277 ± .047
O	9528.079	9528.014	9527.989	9528.027 ± .046
P	9516.309	9516.198	9516.180	9516.229 ± .070
Q	9506.386	9506.303	9506.309	9506.333 ± .046
R	9505.430	9505.326	9505.337	9505.364 ± .057
S	9486.703	9486.590	9486.597	9486.630 ± .063
T	9514.742	9514.653	9514.667	9514.687 ± .048
U	9509.520	9509.458	9509.503	9509.494 ± .032
AA	9513.315	9513.207	9513.231	9513.251 ± .057
III		9508.421	9508.388	9508.405 ± .023
POND		9485.905	9485.888	9485.897 ± .012
PINON		9484.343	9484.324	9484.334 ± .013
OPAL		9495.156	9495.130	9495.143 ± .018
DISGUST		9483.473	9483.443	9483.458 ± .021
SECOR		9506.752	9506.714	9506.733 ± .027
NM WASH		9484.699	9484.682	9484.691 ± .012
LINE		9494.155	9494.109	9494.132 ± .033
BM-A	9542.247	9542.057	9542.172	9542.159 ± .096
K-182	9561.299	9561.204		9561.252 ± .067
AIRPORT	9537.077	9536.942	9536.924	9536.981 ± .084
Milford base station	9539.86	9539.86	9539.86	9539.86 ± .00

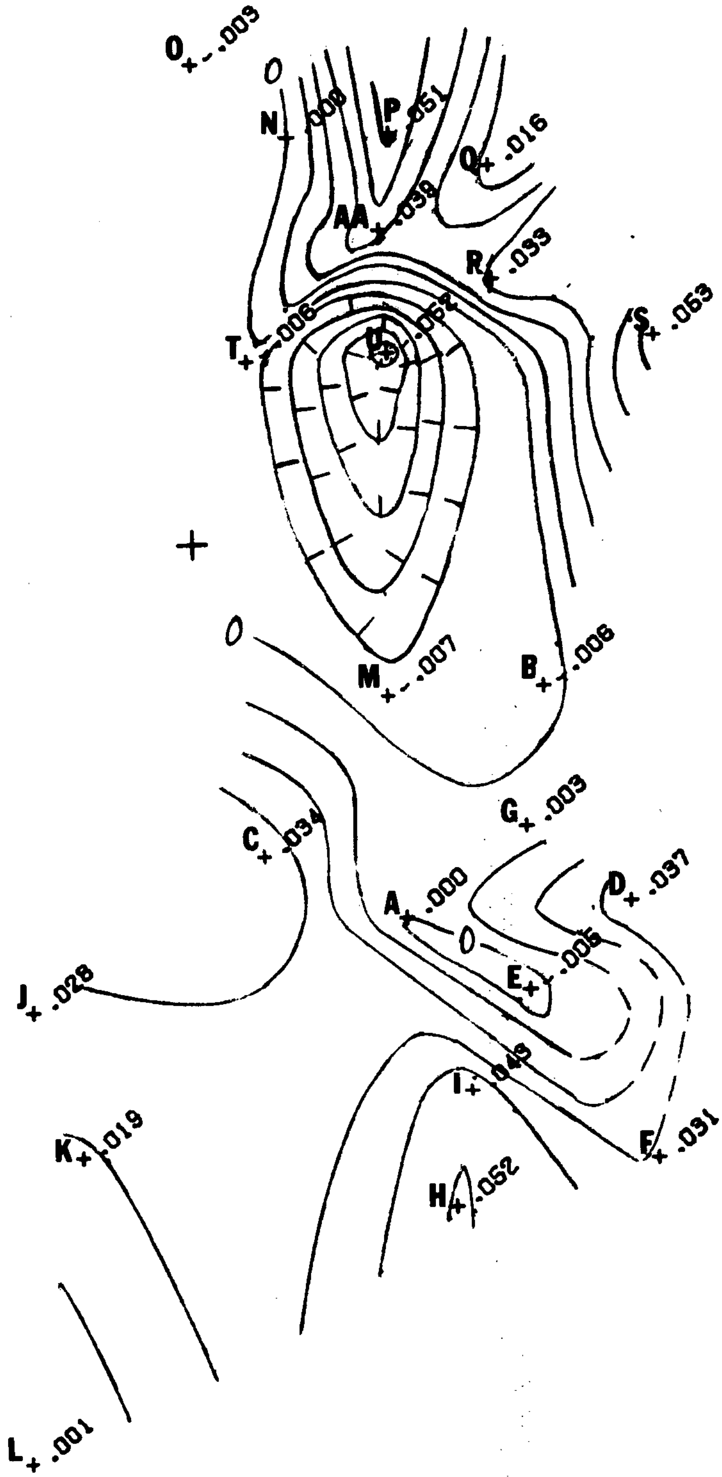
1/ For brevity, the first two digits "97" are omitted from each value in this table.

Table 7. -- Standard deviation of the error (in mgal) for each instrument in each survey (Survey No. is indicated at top of each column).

Instrument No.	1	2	3	3A	4
G-264	0.014	0.004	0.024	0.0004	0.012
G-386		0.011			
G-269			0.009	0.010	
G-461					0.008

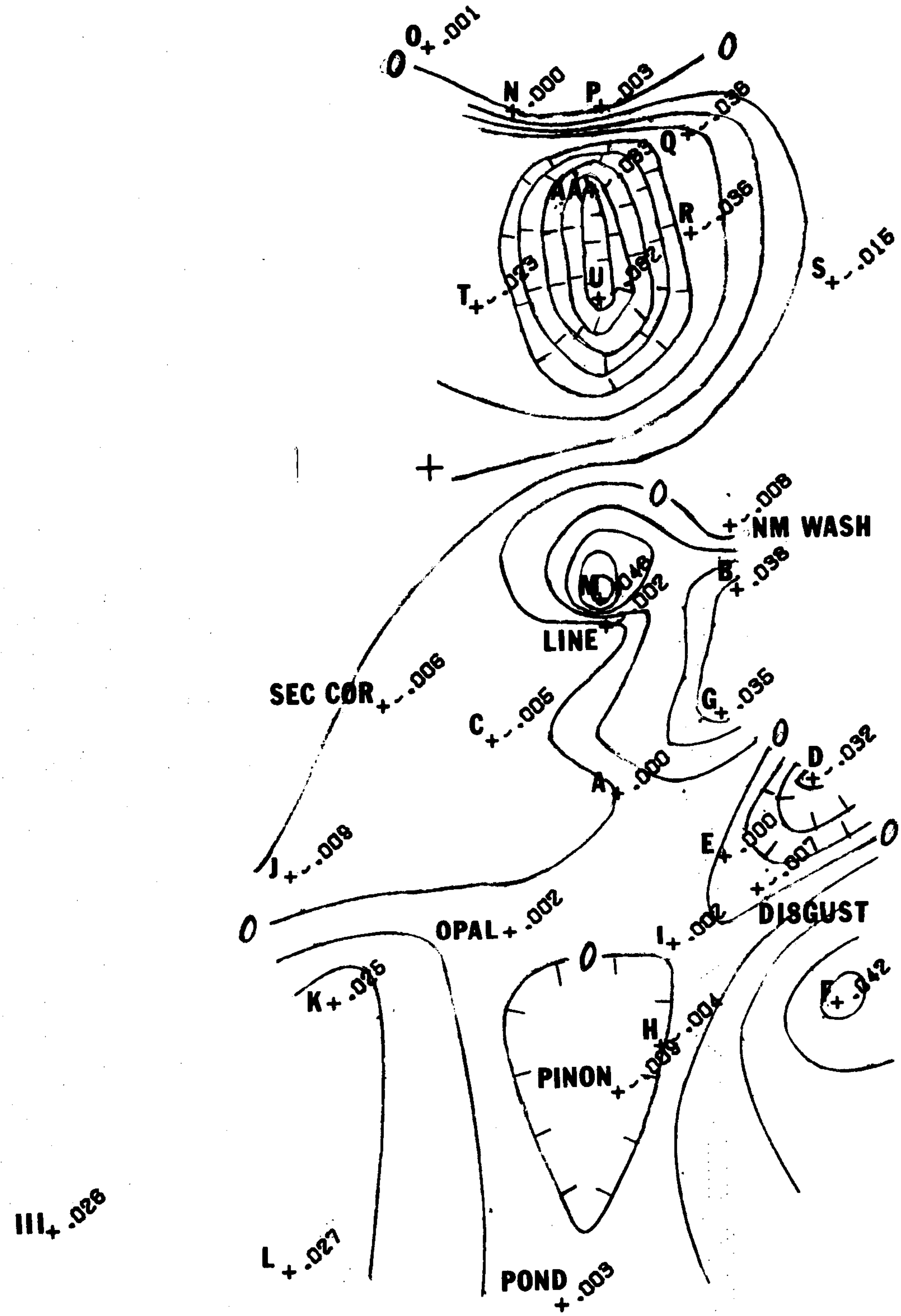
Figures A through M (which for convenience are designated by letters instead of numbers) are contour maps (at the same scale as Fig. 2) which show 1) lines of equal change in observed gravity values between two instruments for the same survey or 2) lines of equal change in observed gravity values between different surveys at various times. The contour interval of each map is 0.01 mgal. The maps provide a pictorial representation of areas where any consistent gravity changes (as represented, for example, by changes in gravity values over several adjacent stations) has occurred. It should be noted that for the map presentation of the data, the gravity values of survey Nos. 3 and 3A were combined, and designated as survey No. 3 only.

Table 8 shows the various permutations and combinations of the gravity instruments and surveys that have been used in compiling the 13 gravity contour maps included in this report.



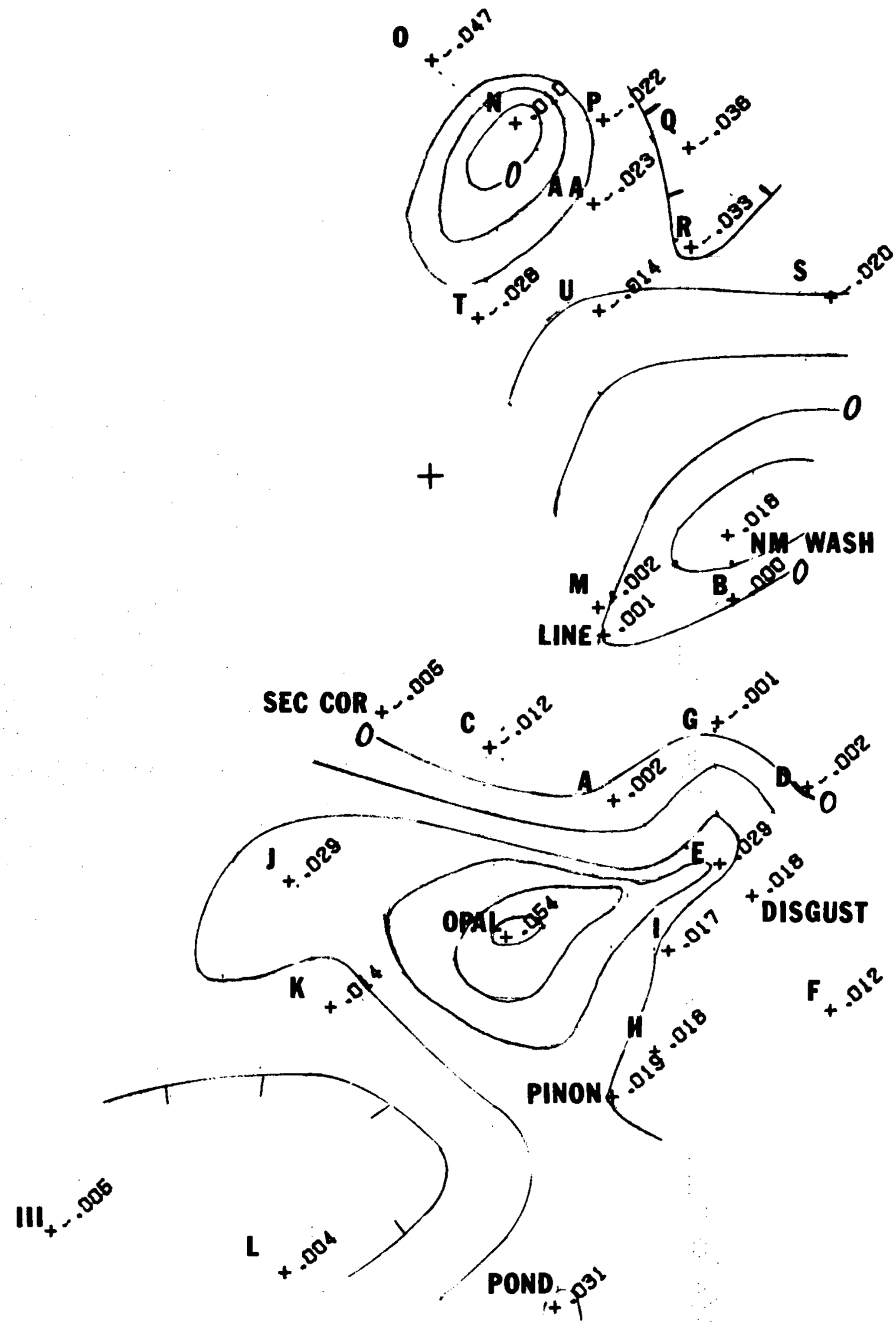
SURVEY TWO(264)-SURVEY TWO(386)

Figure A



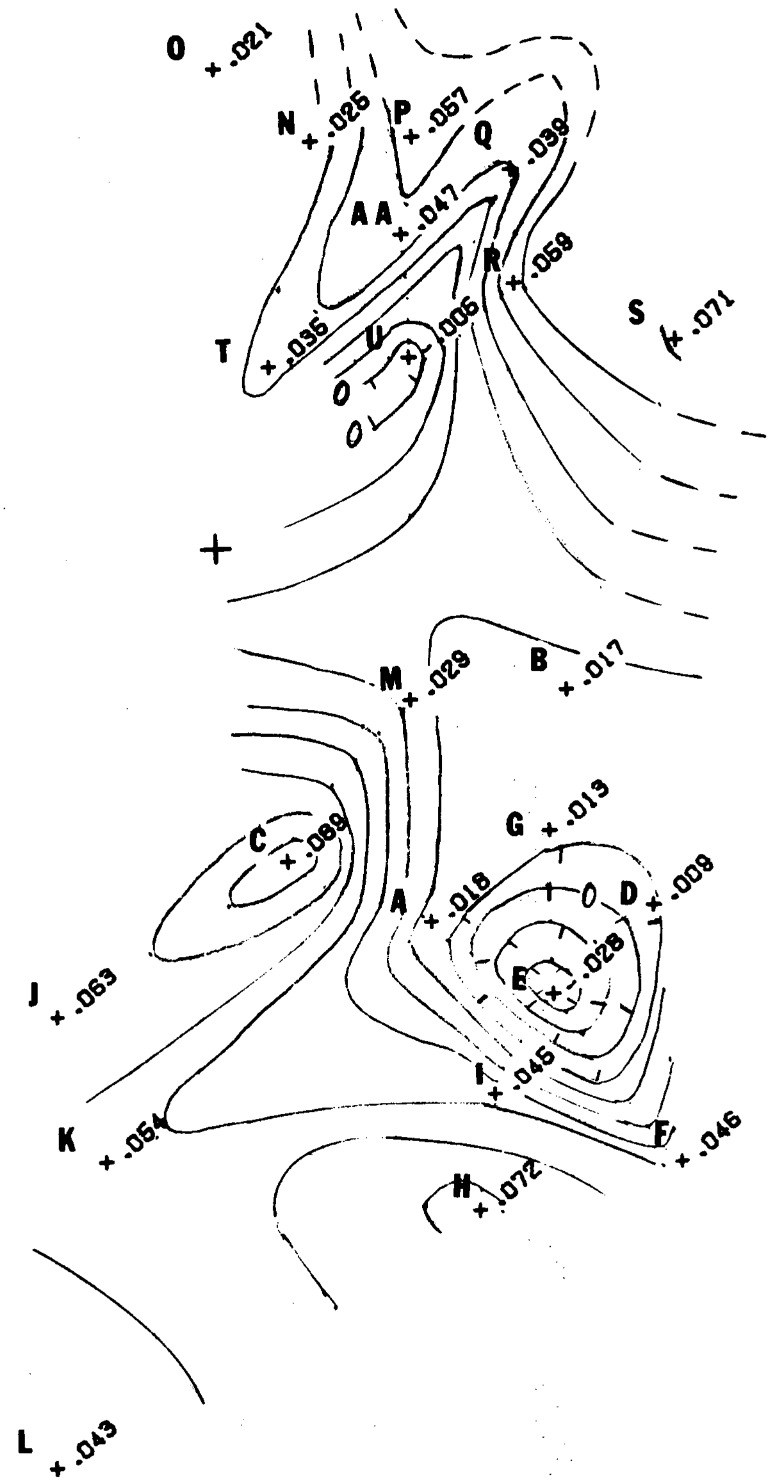
SURVEY THREE(264)-SURVEY THREE(269)

Figure B



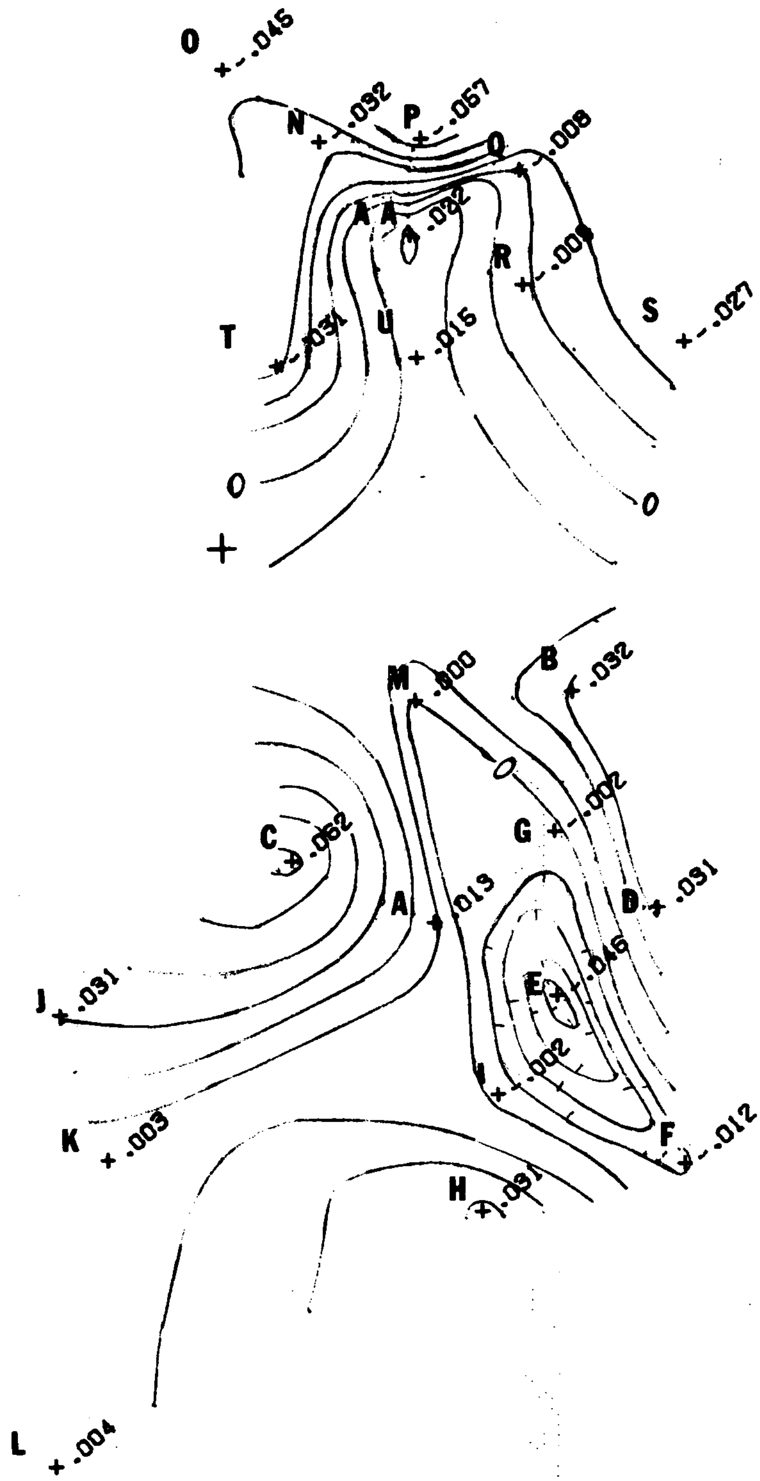
SURVEY FOUR(264)-SURVEY FOUR(461)

Figure C



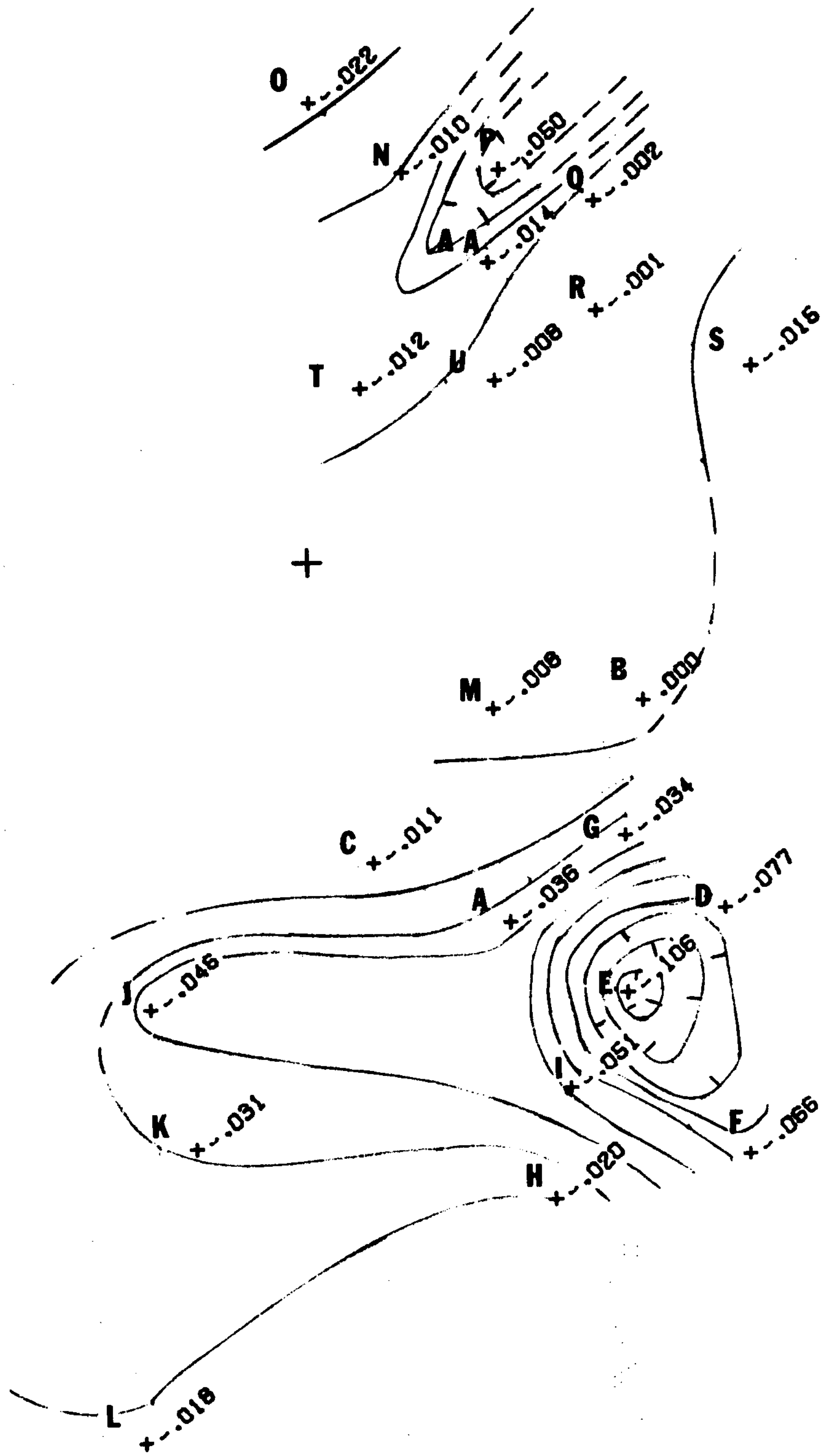
SURVEY ONE(264)-SURVEY TWO(386)

Figure D



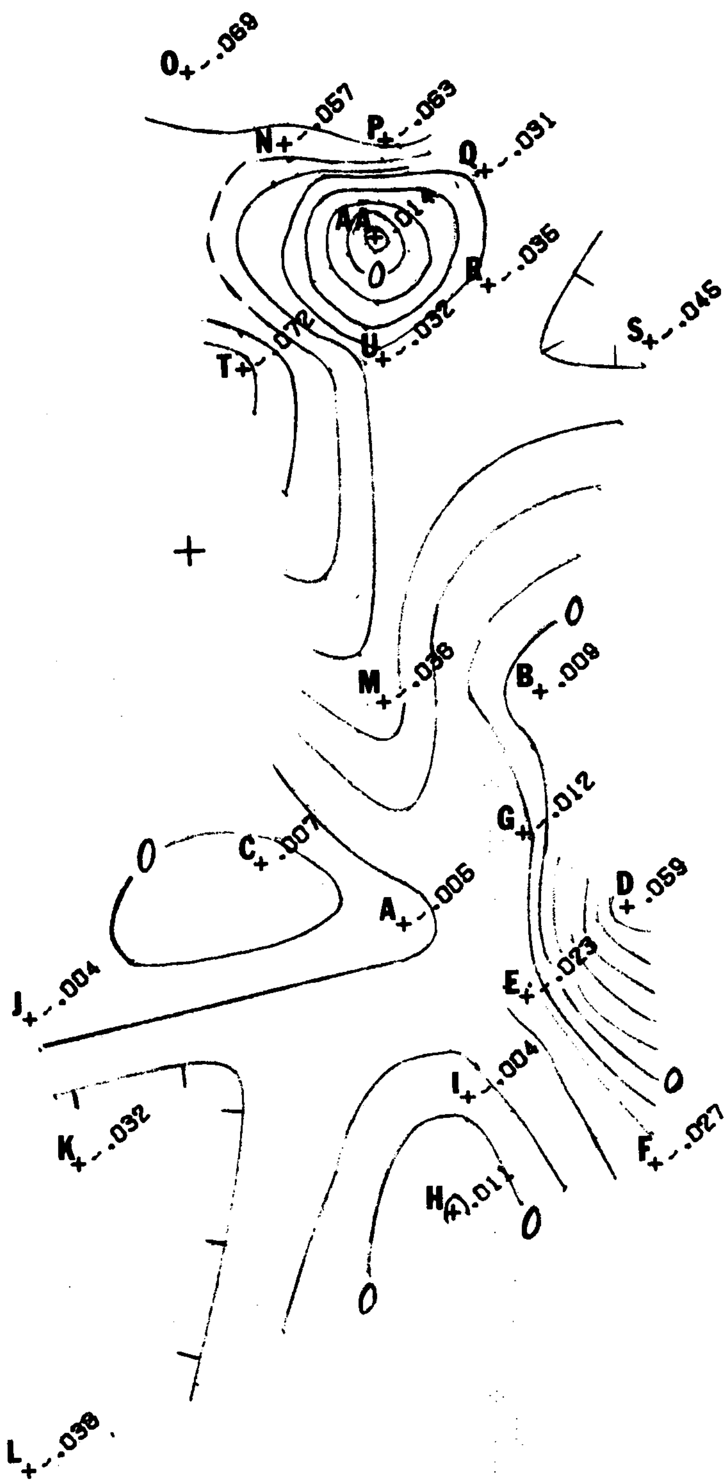
SURVEY ONE(264)-SURVEY THREE(264)

Figure E



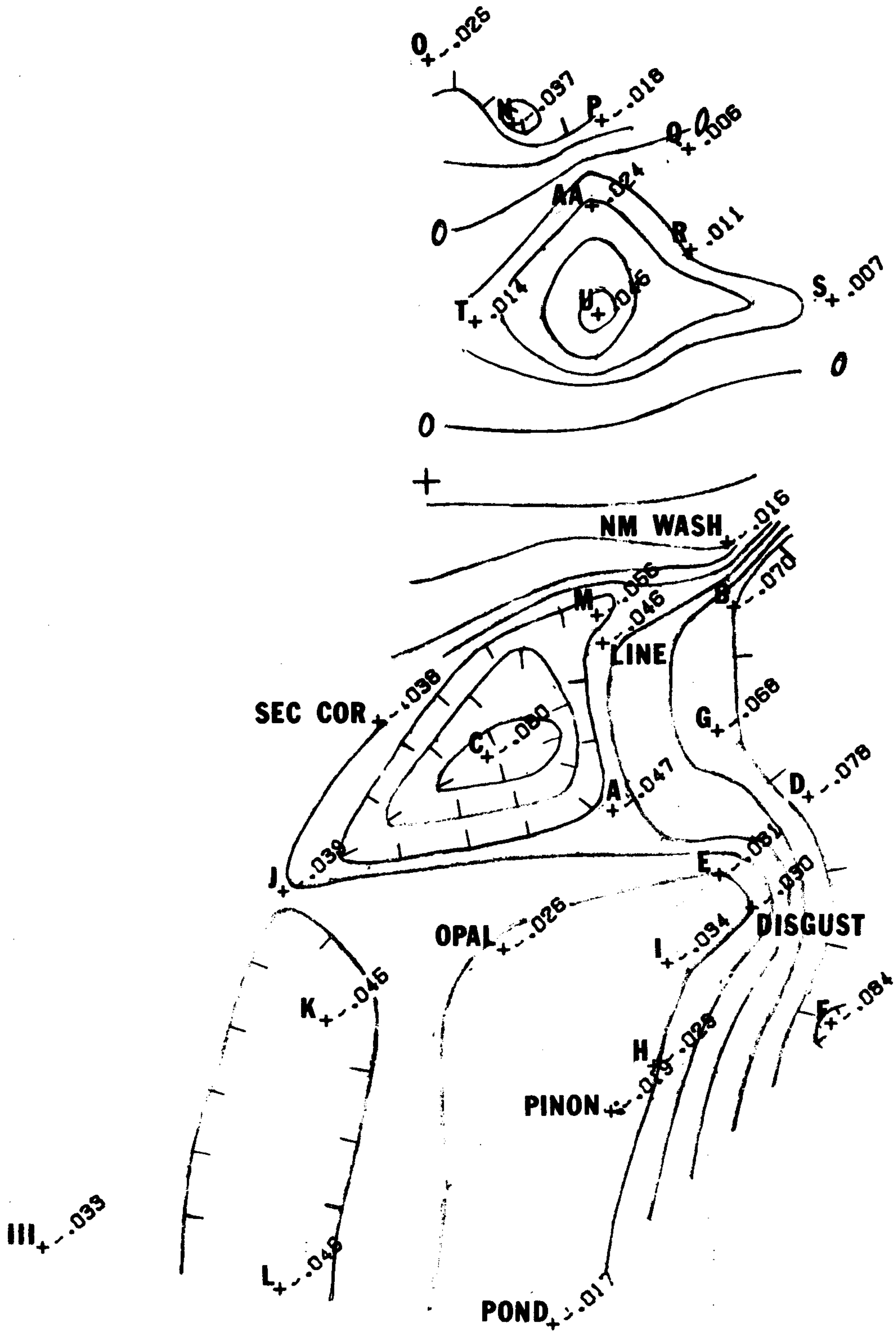
SURVEY ONE(264)-SURVEY FOUR-A(264)

Figure F



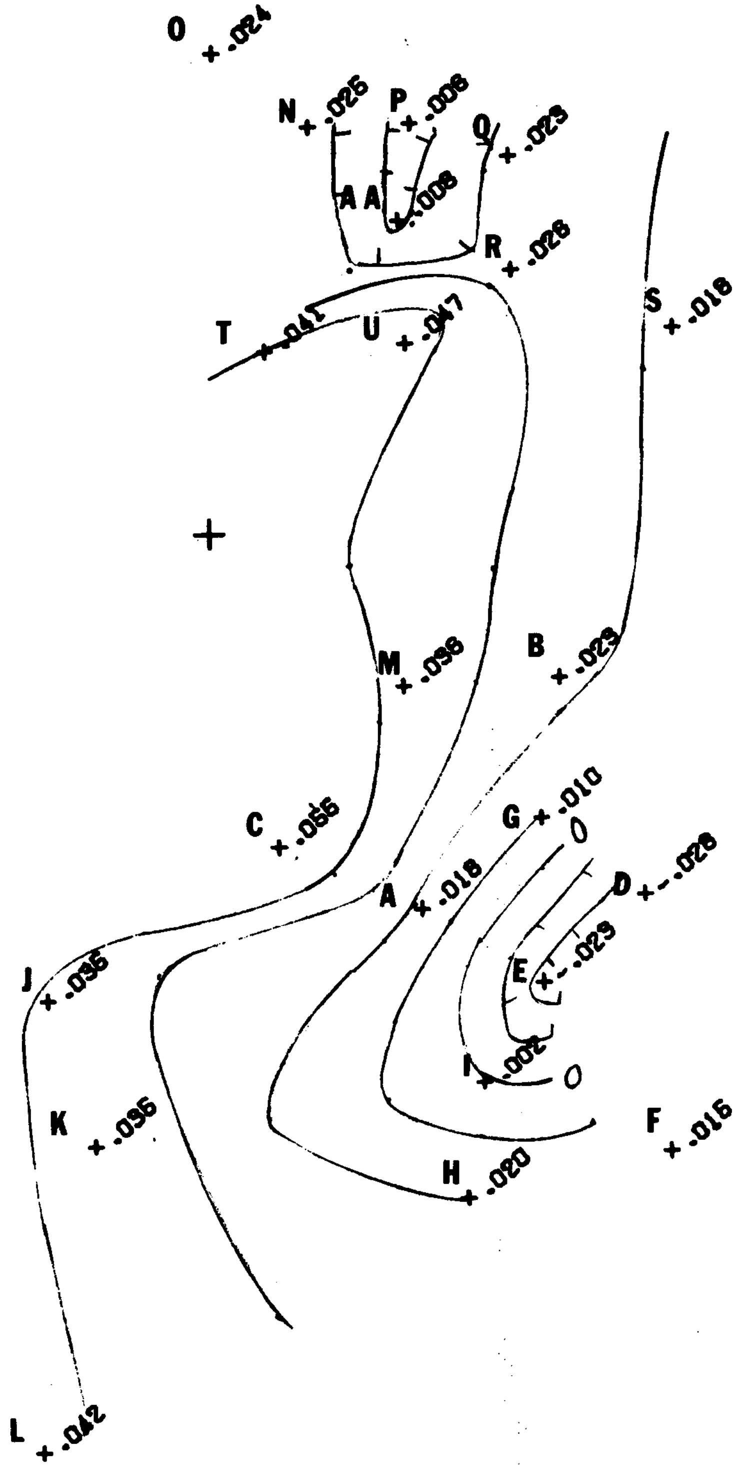
SURVEY TWO(264)-SURVEY THREE(264)

Figure G



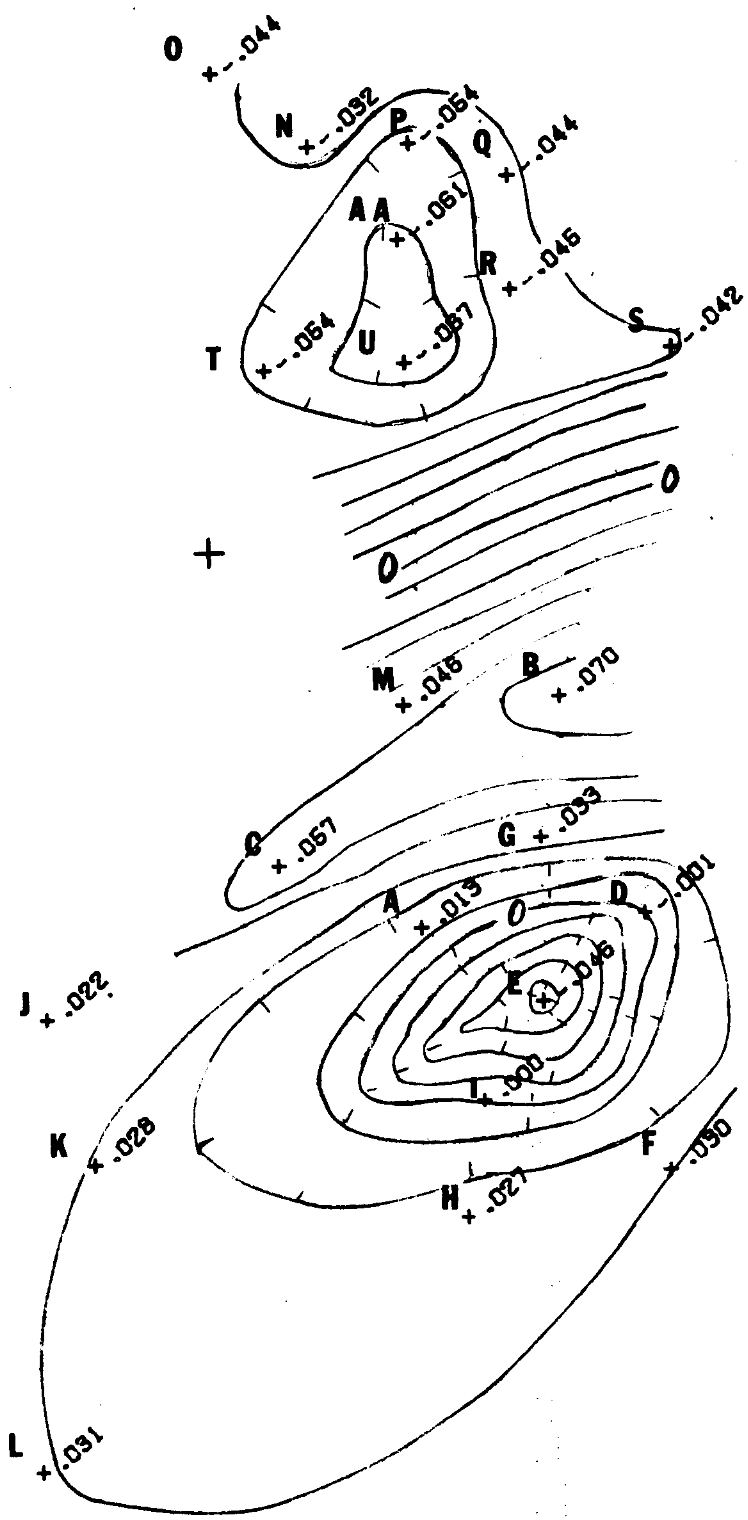
SURVEY THREE A(269)-SURVEY FOUR(461)

Figure H



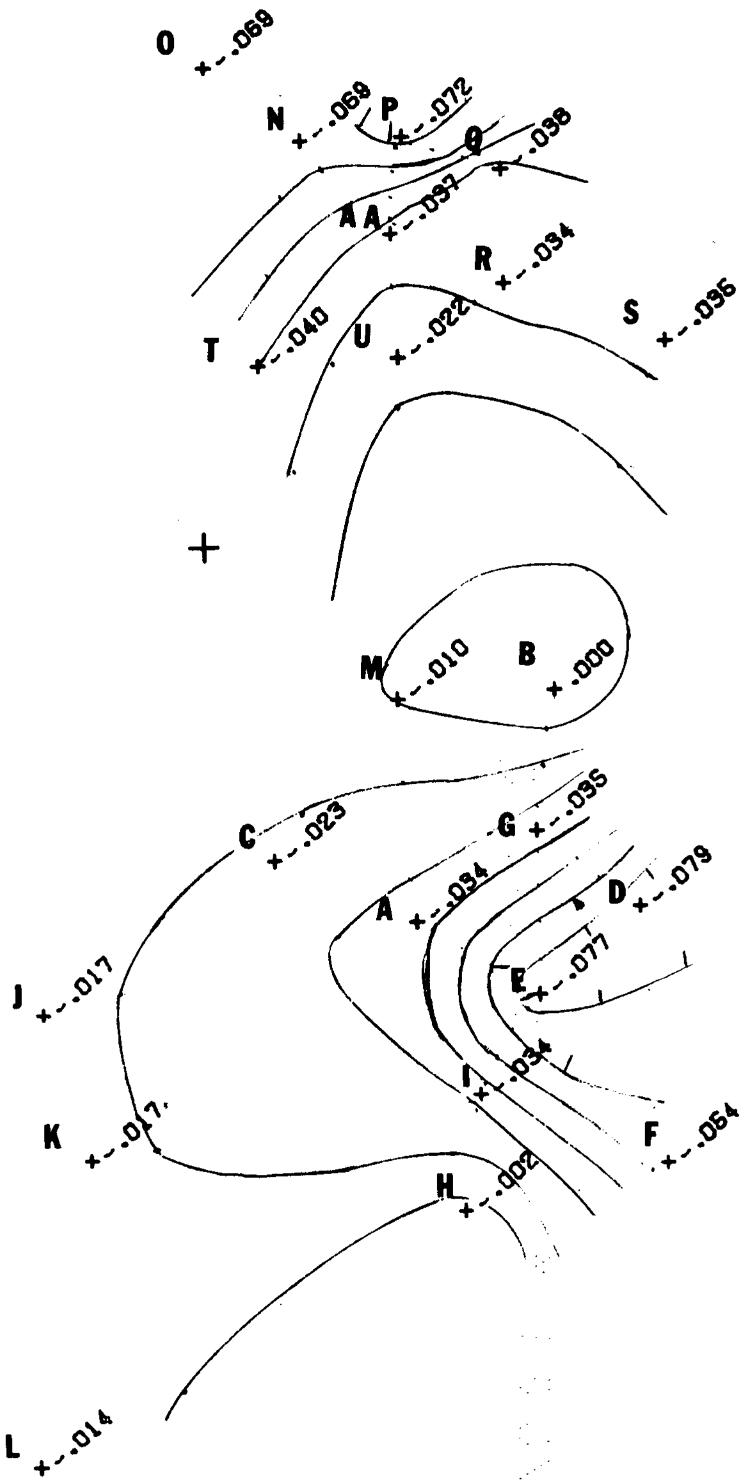
SURVEY ONE(264)-SURVEY TWO(264)

Figure I



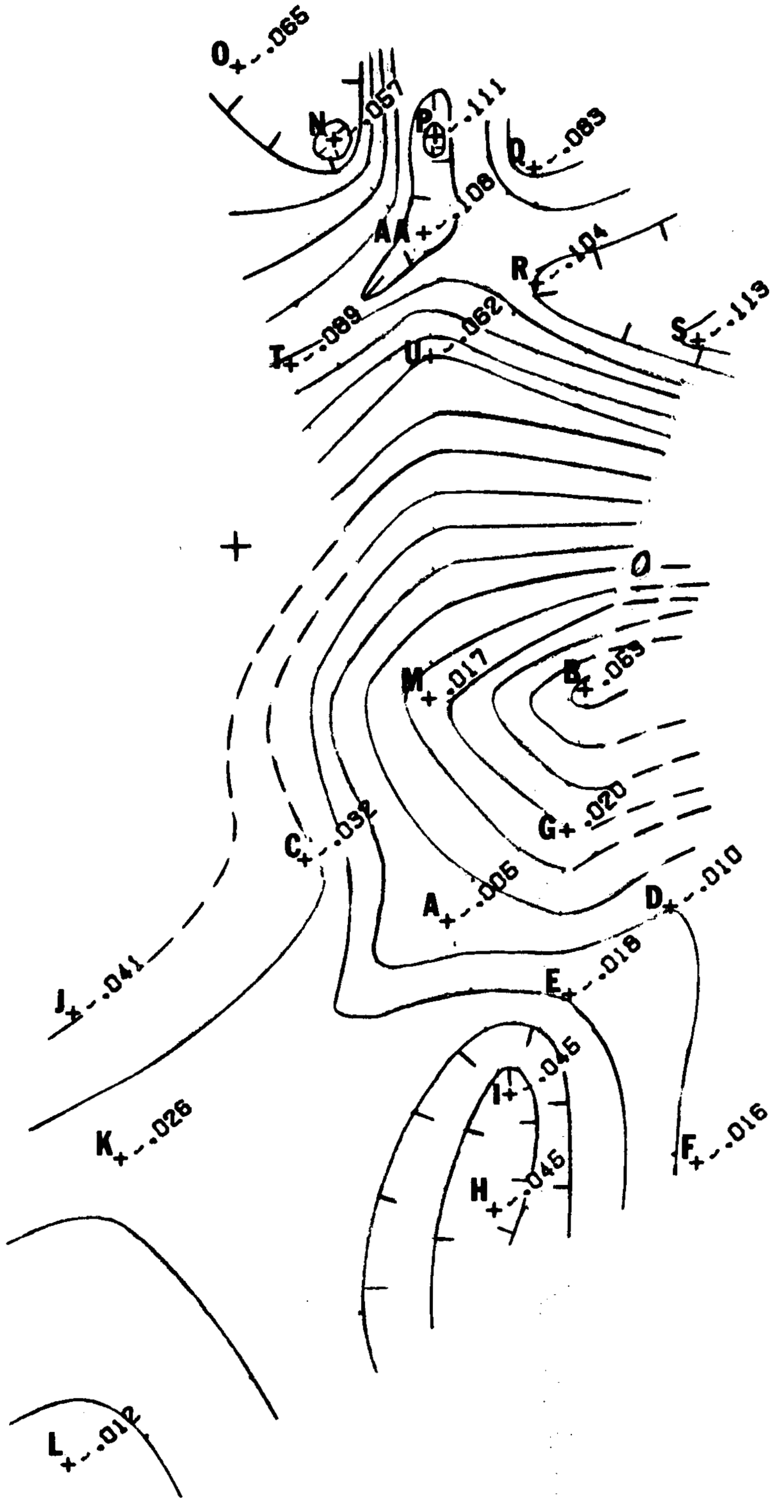
SURVEY ONE(264)-SURVEY THREE(269)

Figure J



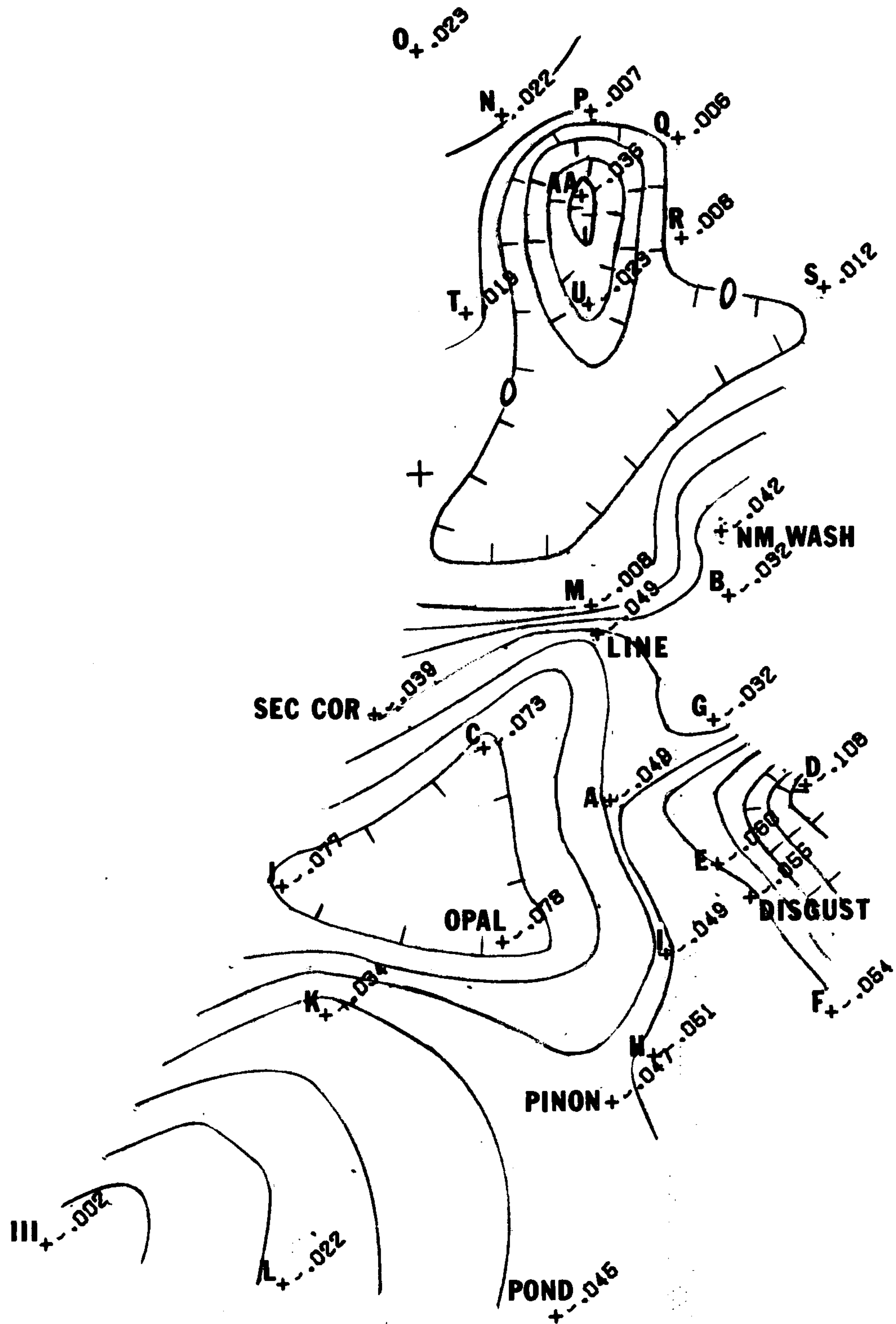
SURVEY ONE(264)-SURVEY FOUR-A(461)

Figure K



SURVEY TWO(386)-SURVEY THREE(269)

Figure L

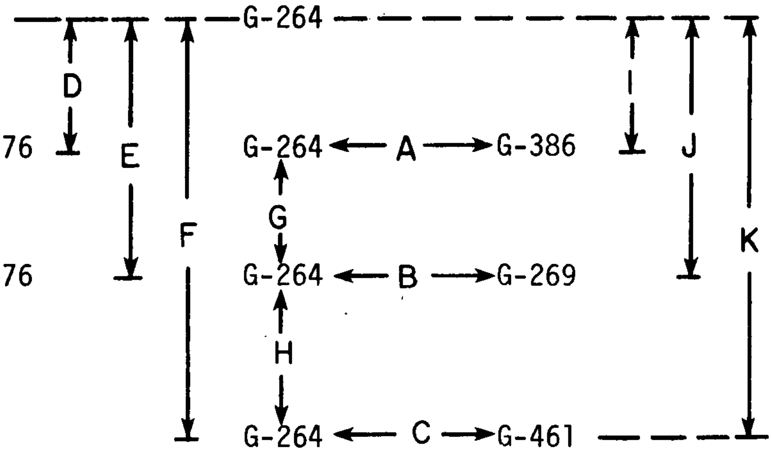


SURVEY THREE A(264)-SURVEY FOUR(264)

Figure M

Table 8. -- Permutations and combinations of gravity instruments and surveys used in compiling the gravity contour maps in Figures A through M (indicated in table by letter designation).

Survey No.	Date of Survey	Gravity Meter
1	Feb. 4-7, 1976	G-264
2	Feb. 16-18, 1976	G-264 ← A → G-386
3	Aug. 16-19, 1976 Sept. 19, 1976	G-264 ← B → G-269
4	July 5-6, 1977	G-264 ← C → G-461



Discussion of results -- In the listings of gravity values in tables 5 and 6, the only significant change in observed gravity values is the apparently persistent decrease in gravity for station E (table 5). The decrease in gravity at station E is 0.106 mgal between survey Nos. 1 and 4 as observed by gravity meter G-264 and 0.049 mgal between survey Nos. 2 and 4 as observed by gravity meters G-368 and G-461. Gravity meter G-264 showed a decrease of 0.083 mgal between survey Nos. 2 and 4. Although these results appear consistent and may indicate an actual decrease in gravity at station E, the magnitude of the change (0.106-mgal decrease, corresponding to an elevation change of more than 1 ft) is so large that much or all of the change is probably fortuitous. The lack of similar changes at nearby stations tends to support this conclusion.

Figures A, B, and C show contour maps which show differences in observed gravity values (in mgal) between the two respective instruments in survey Nos. 2, 3, and 4, respectively. In this case, these maps can be used to help evaluate the accuracy of each survey. In particular, the pronounced peaks or troughs that center around a station (or a group of stations) indicate that the observed gravity value of that station (or stations) probably has a large error. For example, the gravity values at the following stations apparently have large errors:

1) Station U in survey No. 2 (Fig. A).

2) Stations AA, U, and M in survey No. 3 (Fig. B).

3) Station OPAL in survey No. 4 (Fig. C).

It should be emphasized that except for the gravity high that is centered around station OPAL, the lack of pronounced centers on the contour map for survey No. 4 (Fig. C) indicates that the accuracy of this survey was superior to that for survey Nos. 2 and 3. It should be noted that RMS errors for survey No. 4 (table 7) were not significantly different from the errors for the other surveys; and this is attributed to the fact that not many stations were repeated, so the RMS error for survey No. 4 is based on a very small sample of data. Further, the tie interval between repeat readings was larger for survey No. 4, allowing more opportunity for consistent accumulated error to bias the statistics.

Figures D, E, and F show the changes in observed gravity values (in mgal) between survey Nos. 1 and 2, survey Nos. 1 and 3, and survey Nos. 1 and 4, respectively, using the same gravity meter, G-264. The most striking feature of these maps is the persistent decrease (as indicated by the minus sign) in the observed gravity at station E, such that during a 17-month period (between survey Nos. 1 and 4) a total decrease of 0.106 mgal (Fig. F) is indicated.

Figures G and H show the changes in observed gravity values (in mgal) between survey Nos. 2 and 3 and survey Nos. 3 and 4, respectively, using the same gravity meter, G-264. The pronounced changes in observed gravity for station D(-0.108 mgal), E(-0.060 mgal), DISGUST (-0.055 mgal), and F(-0.054 mgal) between survey Nos. 3 and 4 (Fig. H) indicate that these stations (taken in the same loop during each survey) are suspect of an error. It should be noted that because of the suspected error, it is concluded that much of the apparent change in gravity of station E arose here; and that the large change in observed gravity for station E, previously referred to, is probably fortuitous.

Figures I through M are included in this report for completeness, but will not be discussed in detail. However, the persistence of the low center related to station E in Figures I, J, and K should be noted.

The discrepancy between the small standard deviations of individual surveys and the large changes in gravity when two surveys are compared is attributed to one or more of the following causes:

1) There is actual ground motion or mass loss of significant magnitude which is rather erratic in both directions (positive or negative gravity change) and position (station locations affected).

2) The control base stations located outside the net are not as stable as assumed, and there are small gravity changes outside the area of interest which are magnified by small gravity changes inside the net.

3) The statistics calculated for each survey used a sample of errors that was too small to give accurate results.

4) The number of ties between the net in the area of interest and the control base stations were insufficient; and the length of time between these ties was too great. (In several surveys, ties were made only once between the net and the control stations; and the drift corrections for these ties were typically over a longer time period than for adjacent stations within the gravity net).

Of these possible causes, the last appears the most plausible to account for the above-mentioned discrepancy.

SUMMARY AND CONCLUSIONS

Two networks of benchmarks and/or monuments have been established in the Roosevelt KGRA: 1) a network of about 22 monuments by the Phillips Petroleum Company, for which precision leveling was done by Bulloch Bros. Engineering, Inc., in September to December 1975; and 2) a network of about 35 benchmarks, for which precision leveling was done by the USGS in May 1955 and for which precision horizontal control (not yet available) was done by the USGS during August 1976 and July 1977. The USGS precision leveling survey in May 1977 reoccupied only three of the Phillips monuments (E, G, and I), which were found to be about 0.7 to 0.8 feet lower in elevation than the precision leveling survey by Bulloch Bros. Engineering in 1975. Because this difference is about the same for all three stations, it appears unreasonable and is attributed to a possible error in leveling along the 8-mile line between the datum and the Roosevelt Hot Springs geothermal area.

Throughout the 4-day withdrawal test by the Phillips Petroleum Company in hole #54-3 during February 12-16, 1976, precision gravity readings taken at 1-hr intervals with two gravity meters at monument B (54-3) near the drill hole showed no variation in gravity that could be attributed to mass reduction or ground movement (displacement) related to either withdrawal of geofluids or changes in tectonic strain.

During the period February 1976 to July 1977, four separate precision gravity surveys were conducted on about 22 Phillips monuments and 8 USGS benchmarks in the Roosevelt Hot Springs KGRA. No changes in gravity at these stations were observed that can be attributed to either mass reduction or ground movement (displacement) associated with the withdrawal of geothermal fluids. An apparent decrease in observed gravity of about 0.106 mgal at station E during a 17-month period is believed unrealistic, and was probably caused by a fortuitous accumulation of errors involving both reading errors and insufficiently precise field techniques. These techniques are now being improved to assure greater accuracy in the future.

The precision gravity surveys made to date indicate that long-term changes in mass and/or elevation effects on the order of 0.1 mgal [1/] are detectable. Anticipated improvements in procedure, data reduction, and instrumentation should allow detection of smaller gravity changes.

In summary, a network of benchmarks and monuments has been established in the Roosevelt Hot Springs KGRA, and precision leveling data and precision gravity data have been taken to provide an initial baseline to detect mass reduction or changes in ground movement (displacement) related to the withdrawal of geothermal fluid. However, insofar as the precision gravity data are concerned, the baseline is considered to be inadequate until concrete monuments adjacent to the 30 new USGS benchmarks have been erected and precision gravity measurements taken at these monuments.

[1/] Corresponding to an elevation change of more than 1 ft.

RECOMMENDATIONS

Continuation of the precision leveling, precision horizontal control, and precision gravity surveys is recommended in the Roosevelt Hot Springs KGRA. A check precision leveling line should be surveyed as soon as possible between NGS benchmark R-182 and stations E, G, and I in the Roosevelt Hot Springs area. It is recommended that future precision gravity surveys should be made with both a rented LaCoste and Romberg D-type gravimeter and the LaCoste and Romberg gravimeter G-461 (electronic readout) gravimeter owned by the University of Utah.

Creation of a larger, denser network of precision gravity stations both inside and outside the anticipated geothermal production area in the Roosevelt Hot Springs KGRA is also recommended. Specifically, expansion of the gravity network by constructing concrete monuments adjacent to the 30 new USGS benchmarks erected and surveyed by precise leveling in May 1977, is recommended.

Gravity readings of the existing and expanded gravity network should be repeated about every 12 months.

The Phillips Petroleum Company is now carrying on a 6-month flow test of the Roosevelt Hot Springs geothermal reservoir, which started on October 7, 1977 and will terminate in April 1978. Geofluids are flowing out of hole #54-3 and are being reinjected in hole #82-33 (Fig. 2). It is recommended that a precision gravity survey of the existing and expanded gravity network be made following this test.

Proposal submitted to DOE

On November 11, 1977 a research proposal entitled "Environmental Baseline Studies" (with S. H. Ward as Principal Investigator and K. L. Cook as Co-Investigator) was submitted to the Division of University and Manpower Development Programs, Department of Energy, Washington, D. C. The proposal includes a continuation of the precision gravity surveys in the Roosevelt Hot Springs KGRA, as outlined in the above recommendations, during the period October 1, 1977 through September 30, 1978.

REFERENCES

Cook, K. L., Nilsen, T. H., and Lambert, J. F., 1971, Gravity base station network in Utah -- 1967: Utah Geol. and Mineralog. Survey Bull. 92, 57 p.

Cook, W. B., 1977, Benchmark descriptions, field summary; open file listing by U.S. Dept. of the Interior, Geological Survey, July 7, 1977, 14 p.

Draper, N. R. and Smith, H., 1966, Applied Regression Analysis, John Wiley and Sons, Inc., New York, London, Sydney, 407 p.

Hunt, T. M., 1975, Repeat gravity measurements at Wairakei 1961-1974: Report No. III, Geophysics Division, Dept. of Scientific and Industrial Research, Wellington, New Zealand, 26 p.

Hunt, T. M., and Hicks, S. R., 1975, Repeat gravity measurements at Broadlands geothermal field, 1967-1974: Report No. 113, Geophysics Division, Dept. of Scientific and Industrial Research, Wellington, New Zealand, 20 p.

Isherwood, W. F., 1977, Reservoir depletion at the Geysers, California (abstract): Geothermal Resources Council, Transactions, v. 1, p. 149.

APPENDICES

APPENDIX 1

Techniques Used in Precision Leveling Survey No. 1 (N. L. Rhodes, 1977, oral communication) (Survey made under contract to Phillips Petroleum Company)

Name of contractor: Bulloch Bros. Engineering, Inc.

Cedar City, Utah

Note: The survey was made by N. L. Rhodes, engineer employed full-time for this contractor.

Instrument used: Zeiss self-leveling level -- Model NI-2

Accuracy claimed: within 0.05 foot per linear mile of traverse (second-order leveling).

Datum used: U.S. National Geodetic Survey (NGS) benchmark R-182 (originally established 1970), located along Union Pacific railroad tracks about 0.1 mi south of point of intersection of lines AA' and CC' (Fig. 1)

Elevation used: 4970.978 ft

Note: This elevation value was given to N. L. Rhodes during September 1975 by the Denver office of the USGS as an "unadjusted value".

Period of survey: Intermittently between September 12, 1975 to December 1975.

Total length of traverse: About 16 mi.

Notes concerning survey:

1. The survey was started at NGS benchmark R-182, using the above-indicated datum; and a traverse was taken eastward along the east-west road to the Roosevelt Hot Springs area.
2. Turning points were at about 300-ft intervals.
3. For measuring closure error, an 18-inch rebar was set in the ground at intervals of about 1/2 mi along each traverse; and the survey was closed back to the preceding rebar.

Monuments erected in Roosevelt Hot Springs area

The monuments erected by Bulloch Bros. Engineering, Inc. in the Roosevelt Hot Springs area at the Phillips Petroleum Company drill holes and other locations were generally concrete monuments rising about 8 inches above the surface of the ground, with a 2-inch brass cap on top. For four monuments only, a pipe was used, with a 2-inch brass cap on the top of each pipe. The elevation of the top of the 2-inch brass cap for each monument, as given by the Bulloch Bros. Engineering, Inc. survey, is given in table 2 in the column headed "Elev. of Mon. (ft.)".

"Pads" erected in Roosevelt Hot Springs area

During December 1975 and January 1976, the AAA Welding, Inc. (Mr. O'Dell Webb, President), Milford, Utah, under contract to the Phillips Petroleum Company, installed a concrete pier (also designated "pad") at a location within several feet of each of the above-described "monument" locations. The top of each concrete pier (or pad) was made about 12 inches in diameter, so that the tripod of a gravity meter could be set on it conveniently for an accurate reading. Each concrete pier was made by pouring concrete into a hole 3 ft deep and tapered, so that the bottom of the hole was approximately the width of a shovel (9 inches) and the top of the hole was about 12 inches in diameter (G. K. Crosby, 1977, oral communication). The top of each pier was made essentially level with the original surrounding ground surface. Three small holes were chipped in the top of each concrete pier with a chisel so that the legs of the gravimeter tripod would be in the same position for repeat gravity readings at each station.

The elevation of the top of each pier was obtained by using a sensitive carpenter's level and accurate scale to measure the difference in elevation between the top of the above-described monument (with a 2-inch brass cap) and the top of the pier (or pad). The measurements of the differences in elevation were made by O'Dell Webb and Craig Davies; and the brass discs were stamped by them with the designations E, G, I, etc. The differences in elevation, and the elevation of the pad (or pier) on which the gravity meter was placed, are both listed in table 2 in the columns headed "Elev. Dif. (ft.)" and (Elev. Pad (ft.)", respectively.

APPENDIX 2

Techniques Used in Precision Leveling Survey No. 2
(by W. B. Cook, 1977, U.S. Geological Survey)

Type of survey: First-order leveling

Date of survey: May 1977

Accuracy: The vertical control for first-order leveling by the U.S. Geological Survey is as follows (B. Lofgren, 1976, oral communication):

The error in leveling shall be less than:

$$4 \text{ mm} \times \sqrt{\text{distance}} \text{ (in km)}$$

For example, for a profile 9 km in length, the error in leveling would be less than:

$$4 \text{ mm} \times \sqrt{9} = 4 \times 3 \text{ mm} = 12 \text{ mm} = 1.2 \text{ cm}$$

Datum used: U.S. National Geodetic Survey (NGS) benchmark Q-182, (originally established in 1970) located on Union Pacific railroad tracks about 0.6 mi north of the point of intersection of lines AA' and CC' (Fig. 1).

Elevation Used: 4968.664 ft

Check line to NGS benchmark R-182

Starting at NGS benchmark Q-182, a tie was made in May 1977 by W. B. Cook to NGS benchmark R-182 (originally established in 1970), for which he gives the following results (W. B. Cook, 1977, p. 1):

CHECK LINE TO NGS BM "R-182-1970"

BM "R-182-1970"		Elevation: 4970.998 ft
R 182 by NGS (in 1970)		4970.974* ft
R 182 this run		4970.998 ft
Closure	=	-0.024 ft

*Note that this differs by 0.004 ft from the "unadjusted value" of 4970.978 ft for this benchmark R-182 given to N. L. Rhodes by the Denver Office of the USGS.

Lines AA' and BB' (Fig. 1)

Using the above-mentioned elevation datum for NGS benchmark Q-182 (originally established in 1970), W. B. Cook, in May 1977, erected about 30 benchmarks along lines AA' and BB' (Fig. 1) and determined their elevations, which have been published (W. B. Cook, 1977).

APPENDIX 3

Statistics

Statistics were computed by assuming each survey of the networks by any one instrument was affected by normally distributed random error. Repeated station readings were averaged and the variance for each station was computed. Then the assumption of normally distributed random error allowed calculation of a pooled variance according to the formula (Draper and Smith, 1966):

$$S_p^2 = \frac{\sum_{i=1}^{K} \sum_{u=1}^{n_i} (Y_{iu} - \overline{Y}_i)^2}{\sum_{i=1}^{K} n_i - K}$$

where S_p^2 is the pooled variance, Y_{iu} is the uth reading at the ith station, $\overline{Y}_i$ is the mean of the n_i readings at the ith station, and k is the number of stations in the survey. The square root of the pooled variance gives the standard deviation of the error for each survey (table 7).

Appendix 4 (See Fig. 1)

Supplemental List of Elevations

Station	Elevation (feet)
BM-A 1/	4957.697 (stamped on marker in the field)
C-332 2/ (Milford airport)	5029.629 (stamped on marker in the field)
K-182 3/	4893

1/ Benchmark located on Union Pacific railroad tracks about 1 1/2 mi north of point of intersection of lines AA' and CC' (Fig. 1); installed prior to 1958.

2/ Benchmark at Milford airport about 1/2 mi north of Milford, Utah; stamped C-332-1945".

3/ NGS benchmark (established in 1970) located along the Union Pacific railroad tracks about 6 1/2 mi north of point of intersection of lines AA' and CC' (Fig. 1). Elevation obtained from USGS preliminary 7 1/2-minute topographic quadrangle map.