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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

PRELIMINARY RESULTS OF ABSOLUTE AND HIGH-PRECISION GRAVITY MEASUREMENTS AT THE NEVADA TEST SITE AND VICINITY, NEVADA

By

M. A. Zumberge, R. N. Harris, H. W. Oliver, G. S. Sasagawa, and D. A. Ponce

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Menlo Park, California
1988

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ABSTRACT

Absolute gravity measurements were made at 4 sites in southern Nevada using the Institute of Geophysics and Planetary Physics absolute gravity free-fall apparatus. Three of the sites are located on the Nevada Test Site at Mercury, Yucca Pass, and in northern Jackass Flats. The fourth site is at Kyle Canyon ranger station near Charleston Park where observed gravity is 216.19 mGal lower than at Mercury. Although there is an uncertainty of about 0.02 mGal in the absolute measured values, their gravity differences are considered accurate to about 0.03 mGal. Therefore, the absolute measurements should provide local control for the calibration of gravity meters between Mercury and Kyle Canyon ranger station to about 1 to 2 parts in 10,000. The average gravity differences between Mercury and Kyle Canyon obtained using LaCoste and Romberg gravity meters is 216.13 mGal, 0.06 mGal lower, or 3 parts in 10,000 lower than using the absolute gravity meter. Because of the discrepancy between the comparison of the absolute and relative gravity meters, more absolute and relative gravity control in southern Nevada, as well as the Mt. Hamilton area where the LaCoste and Romberg instruments were calibrated, is needed.

Multiple gravity meter ties were also made between each of the four absolute stations to nearby base stations located on bedrock. These stations were established to help monitor possible real changes in gravity at the absolute sites that could result from seasonal variations in the depth to the water table or other local mass changes.

INTRODUCTION

Four absolute gravity stations have been established in support of the Nevada Nuclear Waste Storage Investigations (NNWSI) program (fig. 1). Three of the sites are located on the Nevada Test Site (NTS): at Mercury; at Control Point 2; and Test Cell C (appendix 1). The fourth site is at Kyle Canyon ranger station near Charleston Park. One purpose of these measurements is to provide absolute gravity control for the Charleston Peak calibration loop (Ponce and Oliver, 1981) which is being used to calibrate LaCoste and Romberg gravity meters in southern Nevada under the NNWSI program. Additionally these measurements will help provide an absolute datum for high precision relative gravity measurements established to help monitor temporal variations of gravity at Yucca Mountain and vicinity. To this end, base stations, located on bedrock, were established near each of the absolute gravity sites to help monitor possible changes in gravity at the absolute sites related to seasonal variations in depth to the water table or other mass changes.

The absolute gravity stations were measured with the Institute of Geophysics and Planetary Physics (IGPP) gravity meter which directly measures the gravitational acceleration by timing a freely falling mass with a laser interferometer. The relative gravity measurements were made with three LaCoste and Romberg gravimeters, G161, G614, and D-26. Complete descriptions of both measurements made with the absolute IGPP apparatus and the relative LaCoste and Romberg gravity meters are presented with a comparison between the absolute and relative observed gravity values.

ACKNOWLEDGMENTS

We appreciate the assistance of J. M. Glen, V. E. Langenheim, R. F. Sikora, and R. L. Morin for their assistance in making the relative gravity measurements.

ABSOLUTE GRAVITY MEASUREMENTS

Instrument Design

The IGPP, La Jolla, California, absolute gravity meter is identical in concept and similar in design to a prototype instrument constructed at the University of Colorado (fig. 2) (Zumberge and others, 1982). The acceleration due to the Earth's gravity is directly and absolutely determined by tracking a freely falling body using a laser interferometer.

The significant aspect of a measurement with this device is its absolute nature. The gravitational acceleration (g) is measured directly using the wavelength of a stabilized laser for a length standard and the frequency of an atomic clock for a time standard. Both atomic standards are accurate to about 1 part per billion, allowing in principle a measurement accurate to 1 microgal. In practice, other considerations typically limit the accuracy obtained to about 10 microgals. If great care is taken to avoid systematic errors, the measurement is drift free.

To facilitate the free fall of a test mass under the force of gravity alone, a vacuum chamber containing a small motor driven elevator is used. Residing within the elevator is the test mass, which is a cornercube retroreflector mounted in an aluminum body. The function of the elevator is to 1) raise the test mass to the top of the vacuum chamber, 2) accelerate downward to release the test mass and surround it during its free fall, 3) and finally gently stop the descent of the test mass. An optoelectronic subsystem determines the relative position of the test mass within the elevator and drives the motor to maintain a constant separation between the two. This allows the test mass to fall freely in the main vacuum chamber while being surrounded by (but not in contact with) the co-falling elevator chamber. This scheme attenuates non-gravitational forces on the test mass. The net velocity of the falling mass relative to residual air molecules inside the falling elevator is zero and no air drag will result from the imperfect vacuum. Furthermore, the falling elevator is made of conductive materials and shields the test mass from electrostatic forces.

A laser interferometer measures the position of the falling test mass with respect to a stationary reference frame, which is a retroreflector mounted on the inertial mass of a 1 Hertz seismometer. The seismometer is used to nullify vibrations in the instruments. Windows on the bottom ends of both the main vacuum chamber and the moving elevator permit laser light to reflect from the corner cube retroreflector on the test mass. The interferometer generates an electronic pulse for each half laser wavelength (about 316 nm) passed through during the test mass's descent. By accurately recording the arrival time of these pulses, a table of position versus time is acquired by a microcomputer. A quadratic least squares fit to these data yields the acceleration due to gravity.

Operational Procedures

In the configuration used for this work in 1984, the IGPP absolute gravity meter weighed 230 kilograms and required 700 watts of electrical power and a stable sheltered environment (fig. 3). This limits observations to the interiors of buildings with solid concrete foundations and electrical outlets. Two operators can assemble the gravity meter and begin acquiring data in an hour.

After selecting a suitable site, a dish of mercury is placed on the floor on the point above which gravity measurements will be made. The optics in the interferometer base are assembled and adjusted above the mercury pool, which acts as a horizontal mirror to produce a vertical beam. The atomic frequency standard and stabilized laser are turned on as soon as possible, to allow these devices to reach stable operating conditions. The dropping chamber is then assembled over the interferometer base and a seismograph mounted corner cube is set in place to complete the system.

Before measurements are taken, checks are made on the performance of the test mass elevator servo-system, data acquisition and time digitization are tested, and the laser is locked and the position signal adjusted to maximize the signal-to-noise ratio.

The measurements proceed under computer control. One hundred measurements of g are taken per set and then the mean, variance, residuals, data histogram and tidal corrections are calculated and displayed. If there is no evidence of an instrumental problem, another run is started. Periodic checks and adjustments to the instrument are made throughout the observation period. Typically, 1,000 to 1,200 measurements of g are acquired at each site.

Data Analysis

The computer samples the position signal during the drop (the test mass free falls for 200 milliseconds in approximately a 20 cm interval) at a rate sufficient to obtain 65 time versus position ordered data pairs. The device acquires 100 independent measurements of g, each derived from a fit to the 65 data pairs, in about 20 minutes.

Ignoring the gravity gradient, the position x of the falling test mass is given by

$$x = x_o + v_o t + gt^2/2,$$

where
x = position of falling mass,
x_o = initial position at time zero,
v_o = initial velocity,
t = time, and
g = acceleration of gravity.

The quadratic coefficient is half the local value of g and is estimated by least squares fitting a parabola to 60 of the 65 time-position data pairs. By ignoring the first 5 data pairs, transient perturbations of the test mass at the start of the drop are removed.

The residual plot is the differences between each observed position-time pair and the estimated parabolic curve averaged over 100 drops. If the noise in the experiment were symmetrically distributed about the theoretical curve, the residuals would sum to zero in the limit as an infinite number of measurements were made. Because systematic errors do not average out, the average residual plot is a measure of the systematic vibration caused by the measurement itself. For example, if measurements were taken above a basement, the floor would vibrate like a drumhead, excited by each drop. Residual plots are diagnostic of site quality and the quality of the data.

The other diagnostic is the reproducibility of the average value for g for each 100 drop set. For example, if laser alignment drifted from vertical, the residuals would not change but the dropset value of g would drop anomalously. At this point, the operator would check the vertical and other parts of the instrument and perhaps reject this set of data if the cause of the anomaly were found.

The final data analysis compiles all of the acceptable sets by computing a global mean and rejecting all points more than 3 standard deviations from the mean. The average variance of the sets is also computed.

Error Analysis

A large number of effects contribute to the total uncertainty in the result of any absolute gravity measurement. For the IGPP instrument, the sources are distributed into five categories. They are:

1) the fundamental uncertainty based on the instrument's design.
2) the possible error introduced by the photo-detector at a particular site.
3) the uncertainty in laser wavelength.
4) the uncertainty in the determination of the local free-air gravity gradient.
5) the statistical uncertainty based on the actual variance in the average value of g.

The various uncertainties are tabulated in this manner because they often vary from site to site, although, in the measurements described here only the last category was variable. The first category (instrument design) is the same at each site, and is calculated from the following list (a more in-depth discussion can be found in Zumberge and others, 1982):

differential pressure	2 μGal
differential temperature	2 "
magnetic forces	1 "
electrostatic forces	1 "
deviation from vertical	2 "
optical path length	3 "
rotation	1 "
translation	1 "
frequency standard	1 "

If sources of error are not correlated with one another (and in this case, there is no reason to suspect that they are), then they propagate as the sum of their squares (Bevington, equation 4.9, p. 60, 1969) that is, the total uncertainty γ_{Total} is calculated from

$$\gamma_{Total} = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 + \dots}$$

where σ_1 , σ_2 , etc., are each an uncertainty from a particular source. The root-summed-squared (RSS) result of the fundamental error sources listed above is about 5 μGal. (See table 5, general).

A perhaps overly pessimistic estimate for the uncertainty due to our photomultiplier (10 μGal) contributes heavily to the total uncertainty. It should be noted that improvements to the instrument have been made since these measurements were done. The photomultiplier has been replaced with an avalanche photo-diode and the laser's temperature dependence has been investigated, allowing a more accurate determination of its wavelength. These changes have reduced the uncertainty in current measurements significantly (Zumberge and others, 1986).

Raw absolute gravity data must also be corrected for several instrumental factors. The laser wavelength depends upon the tube and ambient temperature, as well as the age of the laser tube. Light has a finite velocity and thus the position inferred from the interferometer is actually the position of the dropped object some time in the past.

The absolute gravity meter measures g at a point 109 cm from the floor, and a LaCoste and Romberg model G gravity meter is used to measure the free-air gradient and thus get an estimate for g at the floor. The free-air gradients were measured with LaCoste and Romberg meter G-349 119.5 cm above the floor and on the floor at each station by making 3 successive measurements at each point. Thus, these data provide 3 closed loops at the 119.5 cm level, but don't take into account possible non-linearity in free-air gradients as one approaches the floor, a point of singularity. Thus, the floor-level values reported may have a higher uncertainty than the absolute values themselves, and contributes an additional uncertainty of 5 μGal (gradient in table 5).

Data

Between November 25 and December 1, 1984, the absolute gravity at four sites in southern Nevada were measured (fig. 1). Detailed site descriptions and photographs are in appendix 1. Table 1 summarizes the absolute gravity measurements giving the mean absolute gravity at 109 cm above the floor, the free-air gradient used to reduce the measurement to the floor, and the mean absolute gravity at the floor. The free air gradients are summarized in table 2. Figure 4 shows samples of the observed residuals at each site.

The three sites at the Nevada Test Site were stable (table 3 and fig. 4). The station at Mercury (MERCA) is on a solid concrete floor, but experiences noise due to heavy traffic on the adjacent Mercury Highway. Control Point 2 (CP2A) site is located in a heavy concrete bunker. Test Cell C (TCCA), the best site in terms of measurement variance, is on a heavy concrete floor and isolated from human activity.

Residuals were quite large at the Kyle Canyon Ranger Station. Frost may have cracked and weakened the foundation on which g-measurements were made. We found it necessary to move the absolute gravity meter several feet from its original site at CPEA to CPEAA. Furthermore, the low ambient temperature and large vertical temperature gradient may have affected both the laser wavelength and the vacuum pressure, producing errors larger than those estimated in table 5.

Another problem that we have recently begun examining, prompted by the large residuals seen at Kyle Canyon, is the effect of systematic ground vibration. As described earlier, the floors at the other three sites were solid, so we believe that our estimates for the total uncertainty at those sites are accurate. However, calculations of the size of systematic errors caused by vibrations as large as those seen at Kyle Canyon are an order of magnitude larger than any of the uncertainties listed in table 1. These numerical calculations consist of least-squares fitting synthetic gravity data which has been perturbed by a sinusoidal position variation with adjustable phase, amplitude, and frequency. We suspect that this simulation over-estimates the problem because we do not see set-to-set varaiations nearly as large as one might expect based on these computer models. Thus, we do not yet have a reliable recipe for the calculation of the total uncertainty at sites where large ground vibration is encountered. Until these investigations are complete, our estimated uncertainty for the Kyle Canyon gravity measurement must be viewed with skepticism.

Determining site quality by the nature of the residuals is still a subjective process made by experienced operators. Sites which show small amplitude residuals and lack low frequency components tend to have low drop-to-drop scatter. Figure 4 presents representative residuals from each of the four NTS and vicinity sites. The sites with the least drop-to-drop scatter (Test Cell C and Control Point 2) have the smallest variances and means.

We do not know if there is a correlation between these quantitative measures of the residuals and any possible systematic error introduced into the measurement because of these residual vibrations. At this point, the residual average and variance serve as a guide to site quality.

Table 1.--Summary of absolute gravity data

Station	Mean absolute gravity(109 cm) (mGal)	Standard deviation (μGal)	Free-air gradient (μGal)	Mean absolute gravity(floor) (mGal)	Standard Error (μGal)	Total uncertainty (μGal)
MERCA	979,518.520	4	3.25	979,518.874	5	15
CP2A	979,509.470	4	2.79	979,509.774	3	15
CPEAA	979,302.420	10	2.44	979,302.686	2	18
TCCA	979,509.664	2	3.15	979,510.007	2	15

Table 2. NTS Gravity Gradients found with G-349

Site	Gradient (μGal/cm)	Number of Loops	g at 109 cm (mGal)	g on floor (mGal)
MERCA	3.25	1	979,518.520	979,518.874
CP2A	2.79	2	979,509.470	979,509.774
CPEAA	2.44	2	979,302.420	979,302.686
TCCA	3.15	2	979,509.664	979,510.007

Table 3.--Residual means and variances of absolute gravity data

Site	Mean residual (nm)	Residual variance (nm)	Comments
MERCA	-0.569	0.947	Mercury, NTS
CP2A	-0.048	0.602	Control Point2, NTS
CPEA	0.672	13.9	Kyle Canyon Ranger Station, original site
CPEAA	-0.271	6.08	Kyle Canyon Ranger Station
TCCA	-0.010	0.888	Test Cell C, NTS

Table 4.--Summary of number of absolute measurement drops

Station	Total number of drops	Number of drops used to calculate means
MERC	1,000	900
CP2	700	600
CPEA[1]	500	---
CPEAA	1,000	500
TCCA	1,000	700

[1]Site abandoned, because of too much noise in the data

Table 5.--Sources of uncertainity for the absolute gravity measurements at each site in µGal

Site	General[1]	Detector[2]	Laser[3]	Gradient[4]	SD[5]	RSS[6]
MERCA	5	10	8	5	4	15
CP2A	5	10	8	5	4	15
TCCA	5	10	8	5	2	15
CPEAA	5	10	8	5	10	18

[1] General (fundamental) sources
[2] Detector
[3] Laser wavelength
[4] Extension to floor level using gravity gradient
[5] Standard deviation of the mean of measurement sets
[6] Root-summed-square of columns

RELATIVE GRAVITY MEASUREMENTS

In addition to the absolute measurements, high-precision gravity surveys were conducted for the purpose of comparing the differences between the four absolute gravity values with those determined with the best available LaCoste and Romberg gravity meters. LaCoste and Romberg gravity meters, D-26, G-161, and G-614 were chosen for the work based on their excellent previous performances, and multiple loop surveys were made at the same time as the absolute measurements in November, 1984, and repeated several times between then and June, 1986.

Instrument Design

The LaCoste and Romberg gravity meter measures differences in the acceleration of gravity between two locations. The responsive element, a mass at the end of a zero-length spring (fig. 5) is designed so that a small change in gravity produces a large displacement of the mass against the restoring force of the spring. A zero-length spring is one in which the tension of the spring is proportional to the actual length of the spring. The tension created by the displacement of the spring from its equilibrium when the beam is in the null position, is counterbalanced by the weight of the beam. With this arrangement the elongation of the spring caused by a change in gravity is proportional to the change in gravity and the deflection of the beam is symmetrical about the equilibrium position. For a small difference in gravity the displacement of the spring (Δs) is proportional to the change in gravity (Δg) according to Hooke's Law

$$\Delta g = k \Delta s,$$

where k is the spring's sensitivity. The spring's sensitivity is proportional to the square of its natural period, so that doubling the period will increase the sensitivity by a factor of four. LaCoste and Romberg meters use spring systems with a period of about 15 seconds. To further increase the sensitivity of the LaCoste and Romberg gravity meter an additional negative force, which acts in the same sense of gravity against the restoring spring, has been added to the system. This design accentuates the moment associated with the gravity change so that a small gravity change produces a large displacement of the beam, thereby increasing the meters sensitivity.

The reading accuracy of LaCoste and Romberg model D and G gravity meters with electonic readout is about 1 μGal and 2 μGal respectively, their ability to measure gravity differences greater than about 10 mGal is similar, yielding standard errors in the range of 10-15 μGal (one computed standard error) for a closed loop with one instrument, and 4-6 μGal for two closed loops with two instruments (H.W. Oliver and S.L. Robbins, written commun., 1975, 12 p.; Jachens, 1978; 1983). With increasing gravity differences, the uncertainty in the calibration of gravity meters becomes increasingly important and is considered to be about 1 part in 10,000 based on comparisons with Gulf quartz pendulums and limited absolute gravity measurements over the North American calibration range from Costa Rica to Alaska (Barnes and others, 1969; George Peter, written commun., 1985).

Operational Procedures

All gravity measurements were made along closed loops originating from the base station at Mercury (MERCA). Generally, each station was occupied twice during a day, with three gravimeters, and a base reading was made between each set of station occupations.

Survey procedures were designed to reduce or eliminate possible sources of error due to site relocation problems, and clamp hysteresis effects. To reduce site relocation problems which might introduce errors due to local terrain and magnetic field influences, the reading sites were monumented, described and marked, so that the precise location and reading orientation could be recovered. Clamp hysteresis effects were standardized by maintaining a fixed time of about five minutes between unclamping and reading the gravity meters.

Reduction of relative gravity measurements

Gravity meter readings were converted to mGal-equivalents using factory calibration factors. In addition to the factory calibration factors, values were modified based on repeated measurements made over the Mt. Hamilton (Barnes and others, 1969) and the Charleston Peak calibration loops (Ponce and Oliver, 1981). Additionally, short-wavelength periodic fluctuations (circular error) which arise from imperfections in the reading drive train were accounted for by running the gravity meters over the Palms to Pines calibration loop in southern California, a mountain loop which is specially designed to find possible fluctuations (J.D. Fett and R.C. Jachens, written commun., 1978). Measurements on the Charleston Peak and Mt. Hamilton calibration loops between 1984 and 1986 confirm that there was no significant change in the calibration of the meters between surveys. Earth tide corrections were applied to the measurements, calculated from the formulation of Longman (1959) with an assumed compliance factor of 1.16. The data were then examined for evidence of sudden changes in readings or "tares" and corrections were applied where necessary. Finally, the data from each day were analyzed by means of a least-squares procedure. The system unknowns for this procedure were the gravity differences between the field stations and the base, and the coefficients of a time-dependent "drift" polynomial. A first-order polynomial was assumed if the base station was occupied only twice per day and a second-order polynomial was assumed if the base station was occupied three or more times.

COMPARISON OF ABSOLUTE AND RELATIVE GRAVITY MEASUREMENTS

Comparisons were made between absolute and relative gravity measurements to check the calibration factors of the LaCoste and Romberg gravity meters (Table 6 and 7). The absolute measurement at MERCA was chosen as the datum level because the relative gravity measurements were measured on loops originating from MERCA. The difference in gravity was calculated between MERCA and each of the other stations for both the absolute and relative measurements. These differences were then compared to determine the agreement between the absolute and relative gravity measurements (table 7).

Station CPEAA is the most important for comparing relative and absolute gravity data because it has the greatest range in gravity from MERCA. The average gravity difference between Mercury (MERCA) and Kyle Canyon (CPEAA) obtained using LaCoste and Romberg gravity meters is 216.13 mGal, or 0.06 mGal lower than the 216.19 mGal value measured with the absolute meter (table 7). The 0.06 mGal difference or 3 parts in 10,000 is larger than the 1 part in

10,000 uncertainty that had been assumed for the Mount Charleston calibration loop (Ponce and Oliver, 1981), and other mountain gravity calibration loops in the western United States (Barnes and others, 1968).

DISCUSSION AND CONCLUSIONS

The work reported in this paper represents only the second time that any mountain calibration loops for gravity meters have been tested with direct absolute measurements, because the accuracies of absolute measurements have only recently begun to approach the difference measuring capabilities of gravity meters such as the LaCoste and Romberg instruments. The other loop tested is the Mount Hamilton loop in central California, where a preliminary discrepancy of about 1 part in 100,000 (.1 part in 10,000 was found), and some of this discrepancy seems to be in the uncertainty in reducing the absolute measurements to floor level (R.N. Harris and C.W. Roberts, written commun., 1987). One could avoid the floor-level reduction of absolute measurements by making the relative LaCoste and Romberg measurements at the same height as the absolute measurements of 109 cm, although there is some variation in this height for the several free-fall apparatus now in operation. (For example, the measuring height of the Italian apparatus is about or less than 100 cm). This procedure has the disadvantage of having to read the LaCoste and Romberg instrument at about waist level which is a precarious position for such an expensive and fragile instrument.

Another ramification in comparison studies might be to use the proposed LaCoste and Romberg measurements at the 109 cm level and tie it directly by multiple closed-loop measurements to the normal reading height of 12 cm above floor level for the LaCoste and Romberg instrument when it is resting on a standard base plate. Then comparisons at the 12 cm level at the bottom and top of the calibration loop could, perhaps, be more accurately made.

Part of the problem in the Mt. Charleston Loop comparisons may be simply the effect of reverberation caused by a crack in the concrete floor at Kyle Canyon Ranger Station, and we need to test this hypothesis by re-occupying and by making absolute measurements on other sites on Mt. Charleston. Also, tests with different absolute apparatus need to be made at some convenient, stable site, and such tests are being planned for the University of California at San Diego in December, 1987.

The excellent agreement among the relative and absolute measurements at three of the four sites (MERCA, CP2A, and TCCA) indicates good repeatability in the absolute measurements. It is an unfortunate coincidence that the site which provided dynamic range for the calibration loop happened to be the site with non-ideal operating conditions, thus limiting our confidence in the absolute result there. In any case, the results presented here represent the first base-level absolute gravity measurements at NTS essential for detecting possible future changes.

Table 6.--Summary of relative gravity measurements

Station	Relative observed gravity (mGal)	Standard deviation(mGal)	Standard error
MERCA	-----	-----	-----
CP2A	979,509.774	0.0174	0.0028
CPEAA	979,302.747	0.0175	0.0027
TCCA	979,510.000	0.0137	0.0023

Table 7.--Comparison of absolute gravity and relative gravity measurements

Station	Absolute Measurements		Relative Measurements		Differences between absolute & relative measurements (mGal)
	Observed gravity (mGal)	Differences from MERCA (mGal)	Observed gravity (mGal)	Differences from MERCA (mGal)	
MERCA	979,518.874	---	979,518.875	---	---
CP2A	979,509.774	9.100	979,509.782	9.092	0.008
CPEAA	979,302.686	216.188	979,302.747	216.127	0.061
TCCA	979,510.007	8.867	979,510.000	8.874	-0.007

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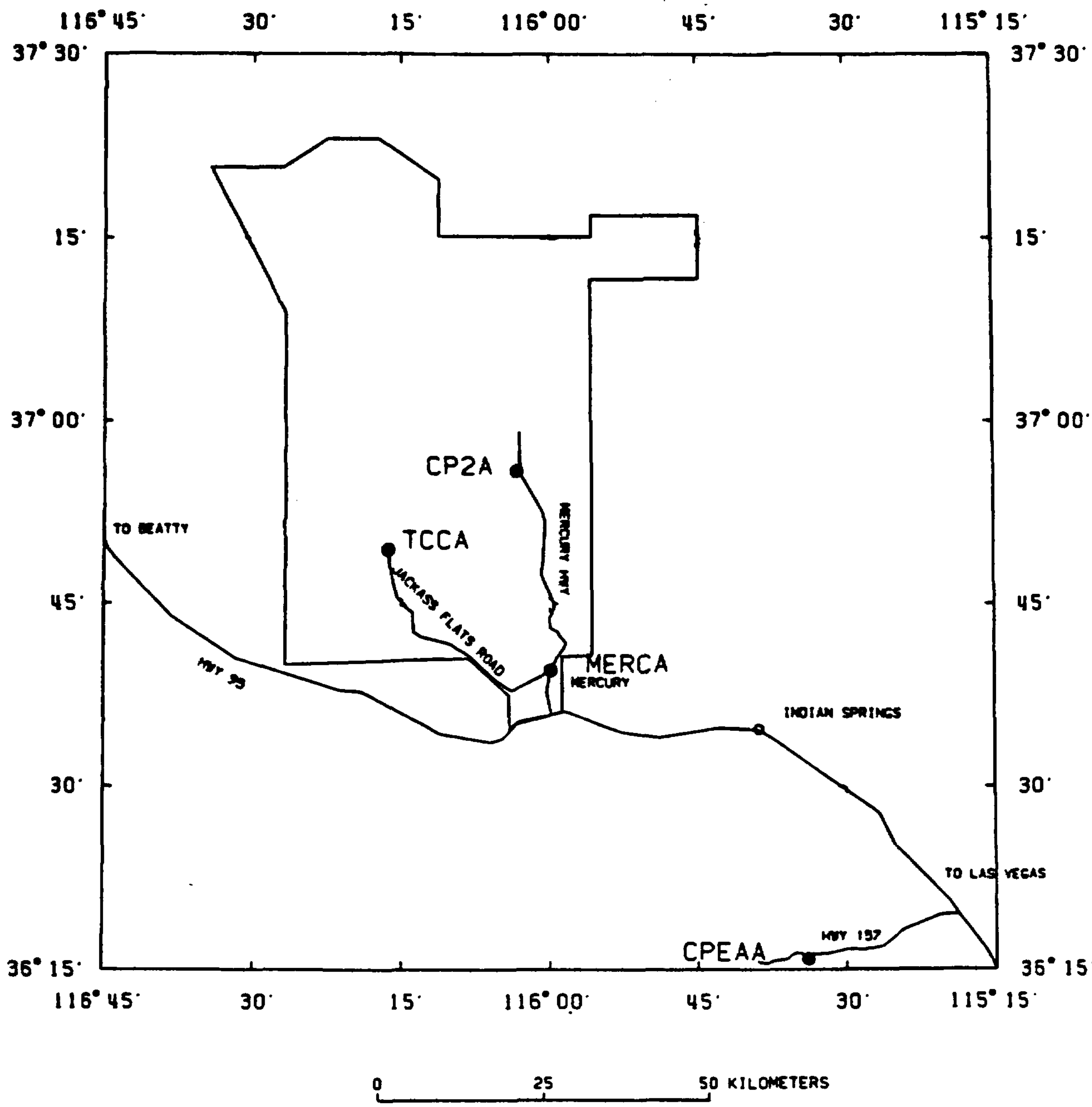


FIGURE. 1.–Location map of absolute gravity stations locations. •, absolute gravity station.

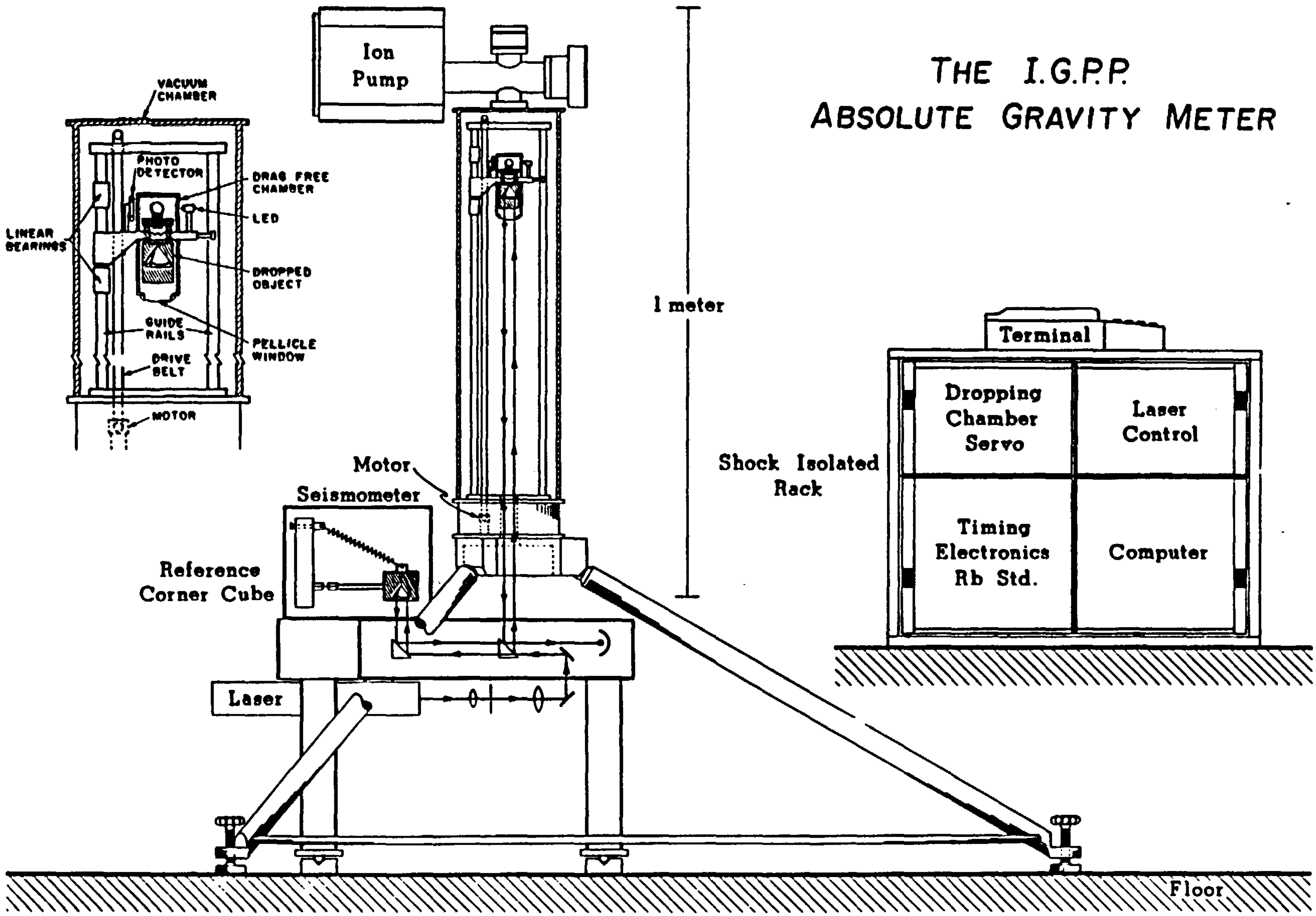


FIGURE. 2.–Schematic of IGPP absolute gravity meter.

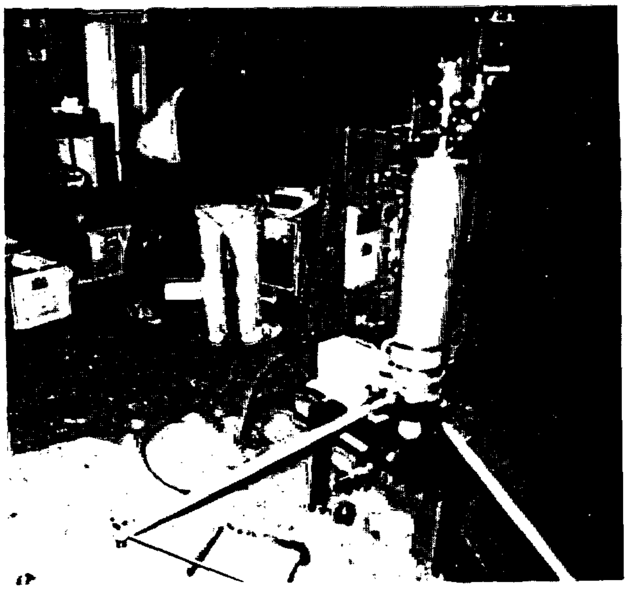


FIGURE. 3.–Photograph of absolute gravity meter in operation.

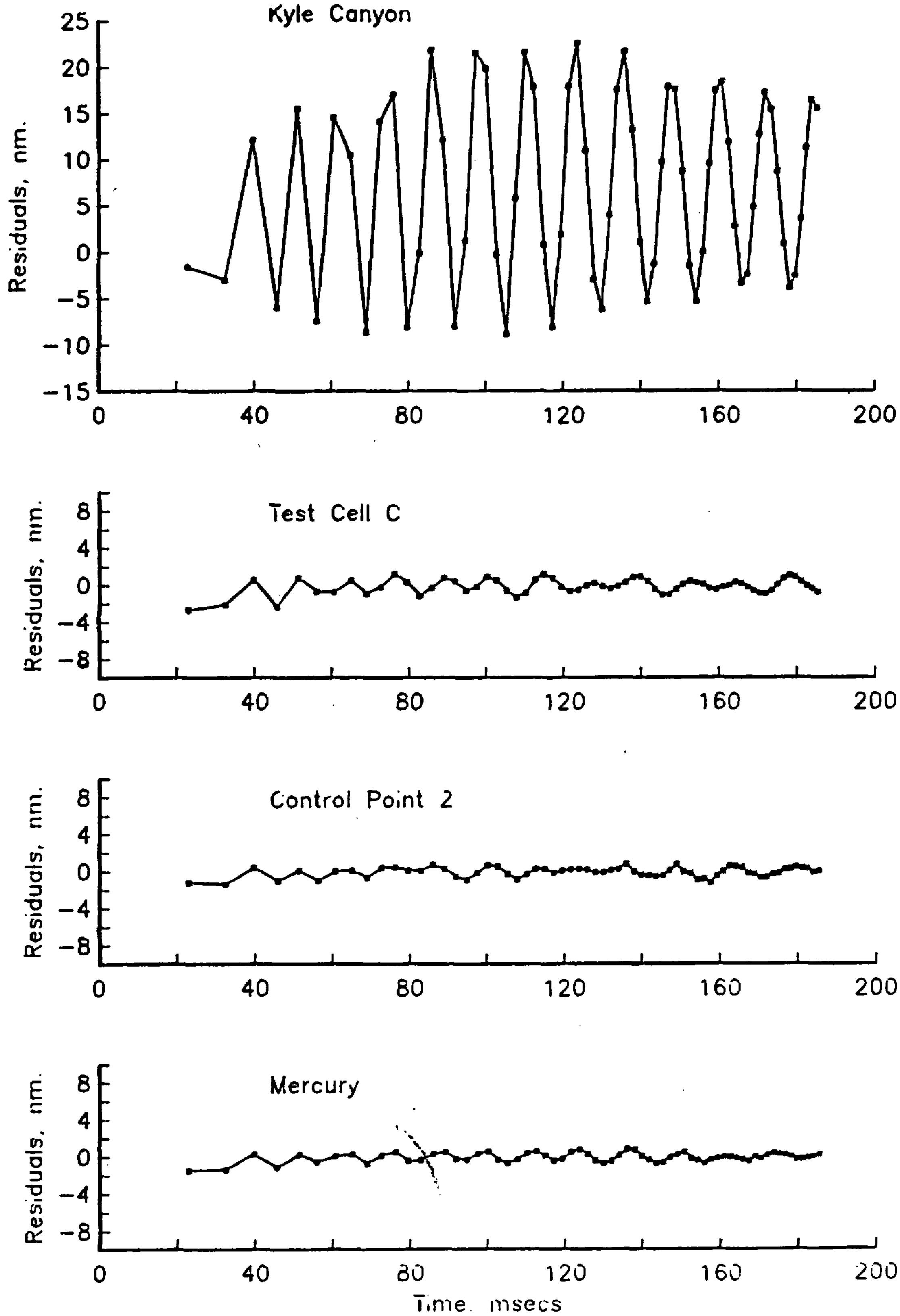
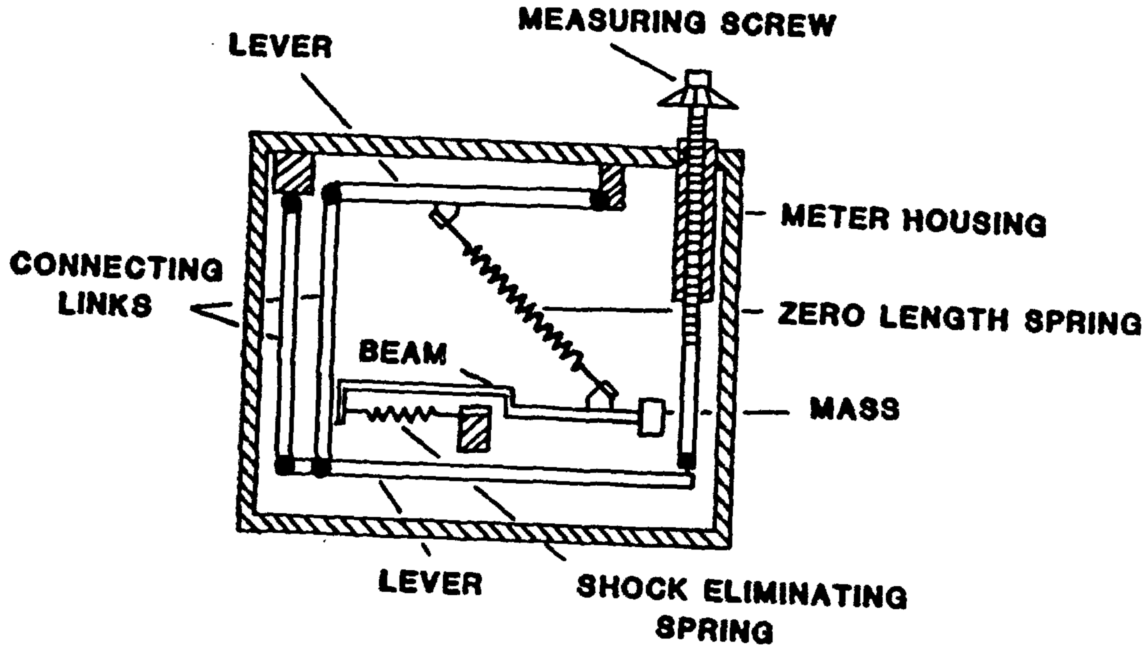


Figure. 4.–Residuals of absolute gravity stations.



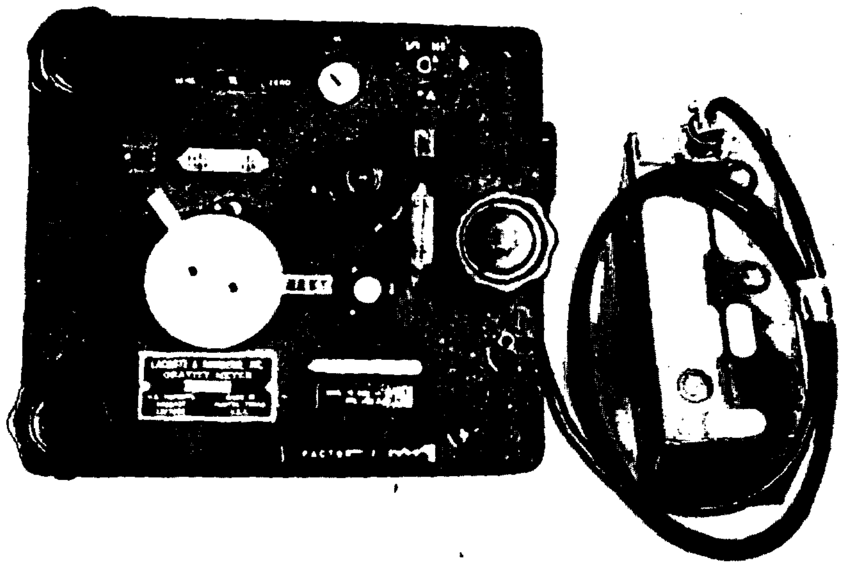


FIGURE. 5.–LaCoste and Romberg gravity meter.

Description of Gravity Base Station: *CP2A*

Name	State	Latitude deg min	Longitude deg min	Elevation	Absolute Gravity mGal
CP2A	Nevada	36 55.66	116 03.53	1,249.7 m (4,100 ft) est.	979,509.77 (109cm)

Absolute gravity station at Control Point 2, 32 km (20 mi) north of the USGS Core Library building in Mercury, Nev., along Mercury Highway, then 0.25 km (0.15 mi) along paved road that goes to guard station for CP1 area. Located in an office in the southeast corner of the basement of the Radiological Safe Building CP2. Enter the building via the basement loading ramp at east end, turn left (south) and go through door to office area. The station is marked with a standard USGS gravity base station disc stamped *CP2A 1984*. Align the gravity base plate legs in the star-drilled holes, read over the gravity disc with the meter facing north.

Free-air gradient 2.79 μGal/cm
Absolute gravity 109cm above floor 979,509.470 mGal
Absolute gravity at floor 979,509.774 mGal

Address and contact at measurement site:

Dick Roberts, Supervisor
Radiological Safe Building
Area 6, CP2, MS 235
Nevada Test Site, NV
702 295-3520, FTS 575-3520

Description of Gravity Base Station: *CP2B*

Name	State	Latitude deg min	Longitude deg min	Elevation	Observed Gravity mGal
CP2B	Nevada	36 55.66	116 03.53	1249 m (4100 ft) est.	979,510.399

High-precision gravity station CP2B is about 0.4 km (0.25 mi) south-southwest of CP2A near south edge of parking lot south of CP2A, 27 m (90 ft) beyond edge of parking lot pavement, near northeast trending powerline, in carbonate outcrop. Stamped *CP2B 1984*. Align the gravity base plate legs in the star-drilled holes, read over the gravity disc with the meter facing north.

Alternate: High-precision gravity station *CP2C* 6 m (20 ft) northeast of CP2B in same outcrop. Base is stamped *CP2C 1984*. Align the gravity base plate legs in the star-drilled holes, read over the gravity disc with the meter facing north. Observed gravity 979,510.356 mGal.

Description of Gravity Base Station: *CPEAA*

Name	State	Latitude deg min	Longitude deg min	Elevation	Absolute Gravity mGal
CPEAA	Nevada	36 15.80	115 36.65	2,170 m (7,120 ft) est.	979,302.420 (109cm)

Absolute gravity station at Kyle Canyon Ranger Station, about 30 km (18.6 mi) west of the junction of Nevada State Highway 157 and 95. The junction is about 25 km (16 mi) northwest of McCarren Internation Airport in Las Vegas, Nev., or about 80 km (50 mi) southeast of Mercury, Nev. Located in the center of an office in the Maintenance Building. The station is marked with a standard USGS gravity base station disc stamped *CPEAA 1984*. Align the gravity base plate legs in the star-drilled holes, read over the gravity disc with the meter facing east. See description of base *CPEAB* for picture of site.
Free-air gradient 2.44 μGal/cm
Absolute gravity at 109cm above floor 979,302.420 mGal
Absolute gravity at floor 979,302.686 mGal

Address and contact at measurement site:
Kyle Canyon Ranger Station
Star Route 38
Box 450
Las Vegas, NV 89124
702 382-4271

Description of Gravity Base Station: *CPEA*

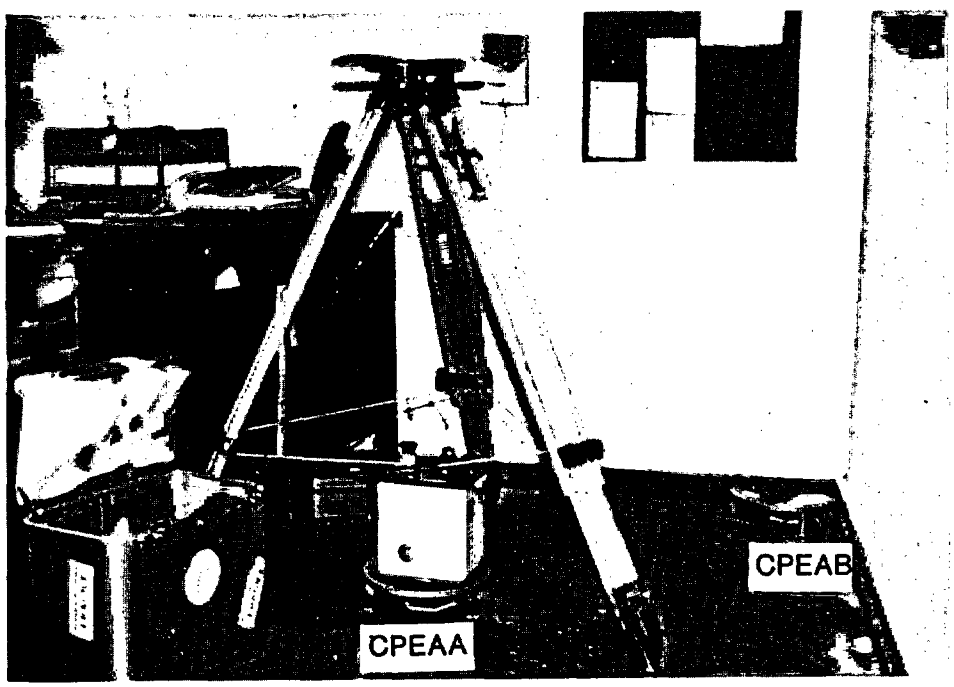
Name	State	Latitude deg min	Longitude deg min	Elevation	Absolute Gravity mGal
CPEA	Nevada	36 15.80	115 36.65	2,170 m (7,120 ft) est.	979,302.768 (109cm)

Absolute gravity station in maintenance building at Kyle Canyon Ranger Station. The base in located in the center of the building, marked with a standard USGS gravity disc stamped *CPEA 1984*. Align the gravity base plate legs in the star-drilled holes, read over the disc with the meter facing east. Note: the location of the absolute measurement was moved due to stability problems of the foundation and the site was abandoned.

Description of Gravity Base Station: *CPEAB*

Name	State	Latitude deg min	Longitude deg min	Elevation	Observed Gravity mGal
CPEAB	Nevada	36 15.80	115 36.65	2,170 m (7,120 ft) est.	979,302.742

High-precision gravity station 3 m (10 ft) southeast of CPEA, in the southeast corner of office, and 2 m (8 ft) east of entrance door. The base is marked with a disc stamped *CPEB 1984*. Align the gravity bse plate legs in the star-drilled holes, read over the gravity disc with the meter facing north.

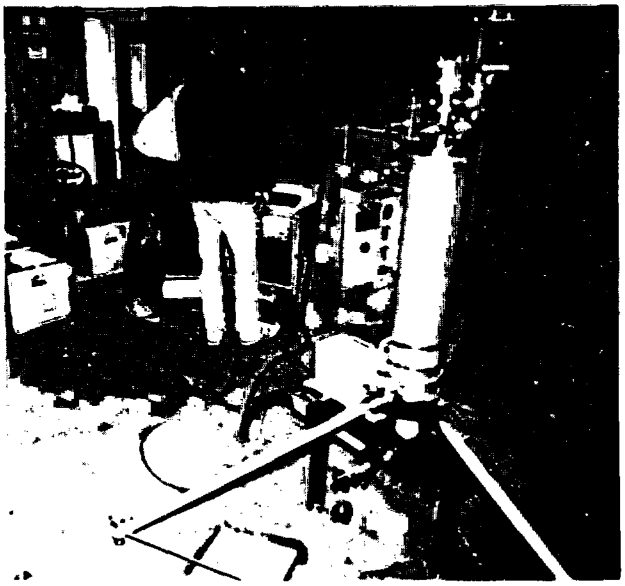


Description of Gravity Base Station: *MERCA*

Name	State	Latitude deg min	Longitude deg min	Elevation	Absolute Gravity mGal
MERCA	Nevada	36 39.35	115 59.75	1,152 m (3,780 ft) est.	979,518.520 (109cm)

Absolute gravity station at Mercury, Nev., about 112 km (70 mi) northwest of Las Vegas along U.S. Highway 95. Located in the southwest corner of the U.S. Geological Survey Core Library building, Nevada Test Site, in a rear storage room, near the geophysics workbench, about 6 m (20 ft) south-southeast of gravity station *MERC* (Ponce and Oliver, 1981, p.13). The station is marked with a standard USGS gravity base station disc stamped *MERCA 1984*. Align the gravity base plate legs in the star-drilled holes, read over the gravity disc with the meter facing north.
Free-air gradient 3.25μGal/cm
Absolute gravity at 109cm above floor 979,518.820 mGal
Absolute gravity at floor 979,518.874 mGal

Address and contact at measurement site:
Andy Benton, Secretary
U.S. Geological Survey
Box 327
Mercury, NV 89023
702 295-7016, FTS 575-7016



Description of Gravity Base Station: *MERC*

Name	State	Latitude deg min	Longitude deg min	Elevation	Observed Gravity mGal
MERC	Nevada	36 39.35	115 59.75	1,152 m (3,780 ft) est.	979,518.80

The base station is at Mercury, Nev., about 112 km (70 mi) northwest of Las Vegas along U.S. Highway 95. The station is in the southwest corner of the U.S. Geological Survey Core Library Building, in a rear storage room, by the geophysics workbench. Read the meter in the corner formed by the two gray cabinets in the northwest corner of the room with the meter facing the corner. Align the gravity base plate legs in the star-drilled holes.

Address and contact at measurment site:

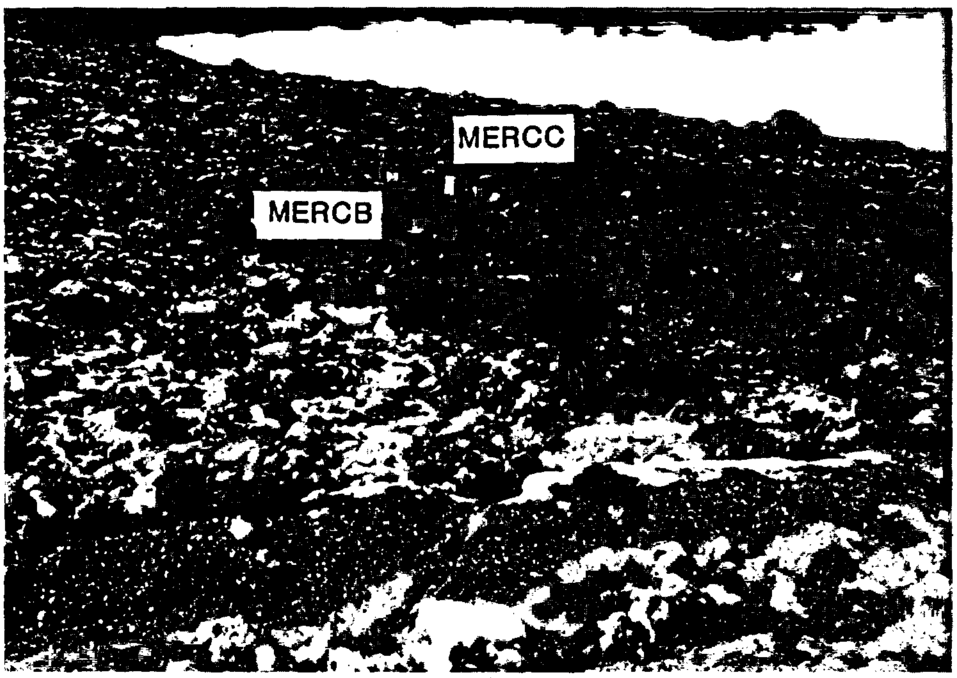
Andy Benton, Secretary
U.S. Geological Survey
Box 327
Mercury, NV 89023
702 295-7016, FTS 575-7016

Description of Gravity Base Station: *MERCB*

Name	State	Latitude deg min	Longitude deg min	Elevation	Observed Gravity mGal
MERCB	Nevada	36 41.39	115 58.40	1,216 m (3,990 ft) est.	979,509.82

High precision gravity station *MERCB* about 4.5 km (2.8 mi) north of USGS office in Mercury, Nev. along Mercury Highway, then about 0.1 km (0.05 mi) nortwest along abondoned road (once paved). About 30 m (100 ft) west of Mercury Highway, about 15 m (50 ft) west of abondoned road, and about 6 m (20 ft) higher than road. Atop a pink factured outcrop. Stamped *MERCB 1984*, read meter facing west.

Alternate: High precision gravity station *MERCC* 2 m (6 ft) north of *MERCB*, 0.3 m (1 ft) lower, and on the same rock outcrop. Stamped *MERCC*, read meter facing west. Observed gravity 979,509.89 mGal.



Description of Gravity Base Station: *TCCA*

Name	State	Latitude deg min	Longitude deg min	Elevation	Absolute Gravity mGal
TCCA	Nevada	36 49.50	116 16.64	1,158 m (3,800 ft) est.	979,509.01 (109cm)

Absolute gravity station at the Test Cell C administration building, Nevada Test Site, Nev. about 32 km (20 mi) from Mercury, Nev., along Jackass Flats Road, then about 0.12 km (0.08 mi) northwest along spur road to Test Cell. Located in the center of office no. 22 in the northeast corner of building. Test Cell C is the USGS Nuclear Hydrology office. The station is marked with a standard USGS gravity station disc stamped *TCCA 1984*. Align the gravity base plate legs in the star-drilled holes, read over the gravity disc with the meter facing north.
Free-air gradient 3.15μGal
Absolute gravity at 109cm above floor 979,509.664 mGal
Absolute gravity at floor 979,510.007 mGal

Address and contact at measurement site:
Chuck Warren, Representative
Test Cell C Administrative Building
Building 3229
Nevada Test Site, NV 89023
702 295-5973, FTS 575-5973

Description of Gravity Base Station: *TCCB*

Name	State	Latitude deg min	Longitude deg min	Elevation	Observed Gravity mGal
TCCB	Nevada	36 49.77	116 16.64	1,158 m (3,800 ft) est.	979,510.050

High-precision gravity station located at bottom of steps to south entrance of Test Cell C office building. Base is marked with a gravity disc stamped *TCCB 1984*. Align the gravity base plate legs in the star-drilled holes, read over the gravity disc with the meter facing north.

Description of Gravity Base Station: *TCCC*

Name	State	Latitude deg min	Longitude deg min	Elevation	Observed Gravity mGal
TCCC	Nevada	36 51.67	116 17.67	1,158 m (3,800 ft) est.	979,489.973

High-precision gravity station located 0.1 km (0.07 mi) south of Test Cell C, then 0.5 km (0.3 mi) west along dirt road, then about 4.3 km (2.7 mi) north along dirt road leading to security gate 25-8C, Calico Hills, and drill-hole UE25a-3. The station is about 20 m (66 ft) south of the security gate, 6 m (20 ft) east of dirt road, and in pink outcrops of volcanic tuff. The base is marked with a standard gravity disc stamped *TCCC 1984*. Align the gravity base plate legs in the star-drilled holes, read meter facing north. Location was chosen to avoid going through security gate.

Alternate: Station TCCD is about 15 m (50 ft) southeast of TCCC on bleached white volcanic tuff and about 23 m (75 ft) east of dirt road. Base is marked with a standard gravity disc stamped *TCCD 1984*. Align the gravity base plate legs in the star-drilled holes, read over the gravity disc with the meter facing north.