

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

PRECISION GRAVITY NETWORKS

AT LASSEN PEAK AND MOUNT SHASTA, CALIFORNIA

by

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## Abstract

Reoccupiable precision gravity networks for the purpose of monitoring volcanic activity were established in the vicinity of Lassen Peak and Mt. Shasta. Base-line measurements were made during the summer of 1981, nearly coincident in time with other base-line geodetic measurements. The gravity surveys yielded gravity values at network stations relative to local bases with typical uncertainties of 0.007 mGal (1 computed standard error).

## Introduction

Temporal gravity variations accompany at least some types of volcanic activity, and the measurement of gravity changes at points on or near a volcano can therefore be used as a relatively rapid and inexpensive means of monitoring the activity. Recent studies at a number of volcanoes (Jachens and Eaton, 1980; Dzurisin and others, 1980; Johnsen and others, 1980, Torge and Kannigieser, 1980; Jachens and others, 1981) have demonstrated that temporal gravity variations associated with volcanic activity reflect both surface deformation and subsurface magma movements. In those cases where substantial deformations could be independently verified there was often a strong correlation between gravity change and elevation change, with the gravity decreasing approximately 0.002 mGal for every centimeter of elevation increase.

In order to most effectively apply temporal gravity techniques to the study and monitoring of volcanic activity, initial gravity measurements must be made before the activity begins. With this in mind, reoccupiable gravity station networks were established during the summer of 1981 at the Cascade Range volcanoes Lassen Peak and Mount Shasta (fig. 1) as part of the U.S. Geological Survey's Volcano Hazards Assessment program. Both volcanoes have been active in historic time (Simkin and others, 1981) and probably will again

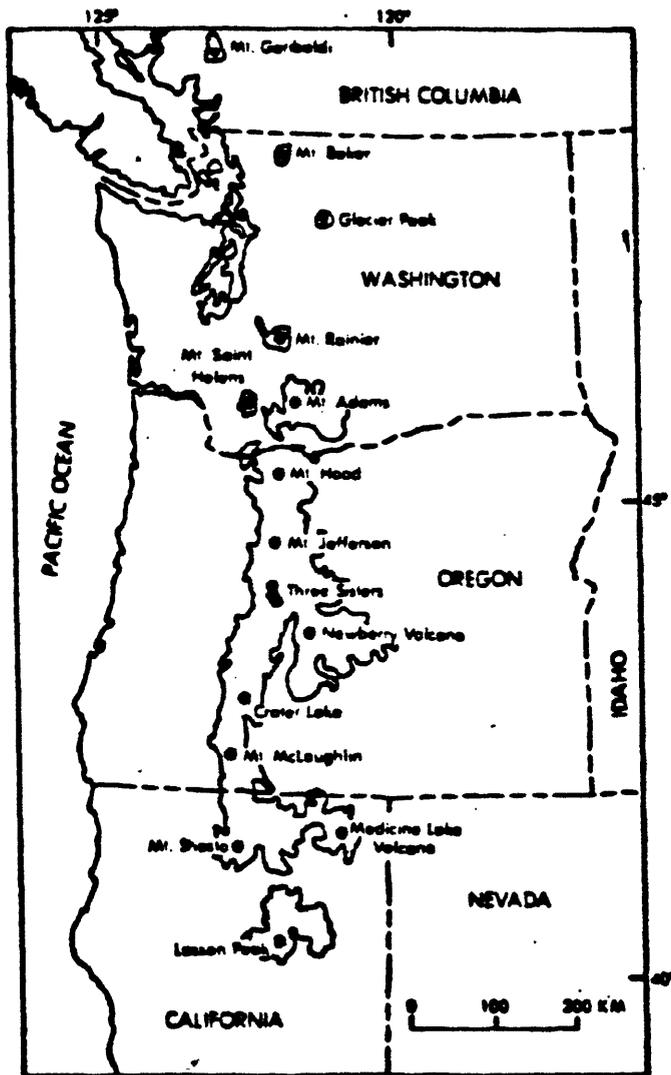


Figure 1. Index map showing locations of Lassen Peak and Mount Shasta.

be active in the future. Many of the gravity stations are located at or near points where other baseline geodetic measurements were made during 1981 (B. Chadwick, personal commun., 1982; Dzurisin and Johnson, 1982). In the event of future activity at either of these volcanoes, the 1981 geodetic measurements will provide a basis for monitoring and studying the activity.

#### Gravity Measurement Procedure and Reductions

Each gravity station contains two reading sites. The sites are marked and described such that the reading position of the gravimeter can be recovered to better than 3 cm horizontally and 1 cm vertically, and the gravimeter orientation can be recovered to within approximately 10°.

Relative gravity with respect to a local reference station was measured at each station using LaCoste and Romberg model G and D gravimeters equipped with electronic readout. The measurements were taken along closed circuits with reference station measurements typically repeated every 4-5 hours. Each station was measured during at least two circuits with a set of 2 or 3 gravimeters.

The gravimeter readings were converted to gravity units using the calibration tables provided by the manufacturer, modified according to the results of measurements taken over the U.S. Geological Survey's Mt. Hamilton calibration range (Barnes and others, 1969). The correction factors applied to the calibration tables of the gravimeters used in this study are given in table 1.

Table 1--Gravimeter calibration correction factors

<u>Gravimeter</u>	<u>Correction Factor</u>
D26	1.00100
G8	1.00061
G248	1.00047
G550	1.00055

Earth tide corrections were applied to all measurements according to the formulation of Longman (1959), with an assumed compliance factor of 1.160. The data were then analyzed by means of a least squares procedure with system unknowns that include the relative gravity between field stations and the local reference station and the coefficients of time dependent drift polynomials. Based on a study of the drift characteristics of LaCoste and Romberg gravimeters (Jachens, 1979), each day's run with each gravimeter was assumed to be represented by an independent drift polynomial. A first order polynomial was assumed if the reference station was measured only twice during a day and a second order polynomial was assumed for the data from days with three reference station measurements. The drift terms in the analyses include both actual gravimeter drift and inaccuracies in the applied tidal correction such as might arise from the influence of ocean tides.

Lassen Peak Network

The Lassen Peak precision gravity network (plate 1) consists of 12 stations, including five on Lassen Peak and its flanks and two atop Chaos Crags. The local reference station (LP001) is at U.S. Coast and Geodetic Survey benchmark F 196 (1934), located approximately 9 km northwest of the summit of Lassen Peak and approximately 1 km northwest of Manzanita Lake. Three stations (LPG01, LPG02, LPG04) are located at tilt sites where precision leveling surveys were conducted in 1981 (Dzurisin and Johnson, 1982), three

others (LPG03, LPG05, LPG06) are located at or near benchmarks of a network that was surveyed with an EDM (electronic distance measuring) instrument in 1981 (B. Chadwick, personal commun., 1982,) and two others (ML7, ML8) are part of the Mount Lassen Calibration Loop (Barnes and others, 1969).

The Lassen Peak network is tied directly by our measurements to the local reference station of the Mount Shasta network (see Appendix 2) and tied by previous measurements at ML7 and ML8 (Robbins and others, 1976) to base station "A" in Menlo Park, California (Robbins and others, 1974).

Detailed descriptions of the stations in the Lassen Peak network are given in Appendix 1 and gravity values at the reading sites relative to reference station LP001 are given in Appendix 2. Uncertainties associated with the relative gravity values (Appendix 2) average 0.007 mGal (1 computed standard error).

Computed gravity differences between the relative gravity values obtained in this survey and those obtained in any subsequent survey will have uncertainties defined by  $s.e._{1,2} = [(se_1)^2 + (se_2)^2]^{1/2}$  where  $se_{1,2}$  is the computed standard error of the gravity difference and  $se_1$  and  $se_2$  are the computed standard errors of the relative gravity values from the two surveys. If uncertainties similar to those in the present survey are obtained in subsequent surveys, then standard errors of about 0.010 mGal can be expected for the computed gravity differences at stations of the precision gravity network.

In addition to the precision gravity network shown in plate 1, gravity was measured at approximately 400 sites within 15 km of Lassen Peak. The measurements were made as part of a geophysical study of the volcanic field rather than for the purpose of future remeasurement. However, all measuring sites were located on 1:24,000 aerial photographs and described in notes taken

in the field; many sites are marked with P-K nails. We estimate that approximately 90 per cent of the reading sites could be recovered at this time, although the percentage will decrease with time as the area changes and the aerial photographs become outdated. Most of these sites were measured only once with a single gravimeter but a few were measured repeatedly and an analysis of these repeat measurements suggests that the relative gravity values at these stations have uncertainties of approximately 0.025 mGal (1 $\sigma$ ). Therefore, an extensive but somewhat less accurate set of gravity measurements exists and could be repeated in the event of renewed volcanic activity.

In terms of deformation monitoring, assuming a relation between gravity change and elevation change of -0.002 mGal/cm, the precision gravity network provides the capability of detecting elevation changes of approximately 10 cm at the 2 standard error level. Similarly, the more extensive network provides the capability of detecting elevation changes of approximately 35 cm (2 $\sigma$  level) over a wide area.

#### Mount Shasta Network

The Mount Shasta precision gravity network (plate 2) consists of six stations on the cone above the 2,200 m level. The local reference station (SPG01) is located in the parking lot of the Ski Bowl lodge on the south flank of the mountain. Five stations (SPG01, SPG02, SPG03, SPG04, SPG06) are located at tilt sites where precision leveling surveys were conducted in 1981 (Dzurisin and Johnson, 1982) and one (SPG05) is located at a benchmark of a network that was surveyed with an EDM instrument in 1981 (B. Chadwick, personal commun., 1982).

The Mount Shasta precision gravity network is tied directly to LP001 of the Lassen Peak network and, therefore, indirectly to base station "A" in Menlo Park, California.

Detailed descriptions of the stations in the Mount Shasta network are given in Appendix 3, and gravity values at the reading sites relative to the reference station SPG01 are given in Appendix 4. Uncertainties associated with the relative gravity values (Appendix 4) range from 0.005 to 0.007 mGal (1 computed standard error). Because these uncertainties are similar to those associated with the Lassen Peak network, the Mount Shasta network provides the same capability of detecting gravity changes and vertical deformation.

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## Appendix 1

The station descriptions given below assume that the reader has the Lassen Volcanic National Park and Vicinity, California (1957) 1:62,500 scale topographic map (or the Manzanita Lake (1956), Prospect Peak (1957), Lassen Peak (1956), and Mt. Harkness (1956), 1:62,500 scale topographic maps) and has been able to identify the general locations of the various stations using the geographic coordinates given for each. For stations at tilt sites, 3 benchmarks exist at each site. The southernmost benchmark is "x"; "y" and "z" are located progressively in a counter-clockwise direction. More detailed descriptions of these benchmarks are given by Dzurisin and Johnson (1982) and descriptions of the EDM network benchmarks are available from B. Chadwick of the U. S. Geological Survey Cascade Volcano Observatory, Vancouver, Washington.

LP001 (40° 32.53' N., 121° 34.61' W.)

On north side of abandoned road 1 km northwest of Manzanita Lake. Reading site is at high point of large boulder containing U.S. Coast and Geodetic Survey benchmark "F196 1934" and about 0.3 m higher than benchmark. (Benchmark has elevation 5737 on topographic map). Face summit of Lassen Peak to read.

LP001A

Reading site is over National Park Service benchmark "ML-27" 1978, located 24 m 164° from benchmark "F196". Face summit of Lassen Peak to read.

LPG01 (40° 30.17' N., 121° 30.03' W.)

Above Crescent Crater 2 km north of Lassen Peak, at tilt site B. Reading site is directly over benchmark "x". Base plate without level bubble should be used at this site. Face summit of Lassen Peak to read.

LPG01A

Reading site is directly over benchmark "z". Face summit of Lassen Peak to read.

LPG02 (40° 28.85' N., 121° 29.36' W.)

On east flank of Lassen Peak at tilt site C. Reading site is directly over benchmark "y". Base plate without level bubble should be used at this site. Face summit of Lassen Peak to read.

LPG02A

Reading site is on rock 0.6 m above and 1.0 m 340° from benchmark "z". Face summit of Lassen Peak to read.

LPG03 (40° 29.36' N., 121° 29.96' W.)

On east flank of Lassen Peak about 0.5 km east of summit. Reading site is 7.5 m 150° from EDM network benchmark "L IV", on rock outcrop approximately 0.3 m below benchmark. Rock contains a P-K nail in a crack approximately 0.25 m below base plate. Face summit of Lassen Peak to read.

LPG03A

Reading site is on rock outcrop 3 m 240° from benchmark "L IV" and approximately 1.2 m above benchmark. Standard gravity disk attached to rock. Face summit of Lassen Peak to read.

LPG04 (40° 28.75' N., 121° 31.00' W.)

On north flank of Eagle Peak, at tilt site A. Reading site is directly over benchmark "x". Face summit of Lassen Peak to read.

LPG04A

Reading site is directly over benchmark "y". Face summit of Lassen Peak to read.

LPG05 (40° 31.05' N., 121° 31.05' W.)

Near southern end of Chaos Crags, at helicopter landing site for EDM network benchmark "L III." Landing site is a flat, rectangular rock. Reading site is over standard gravity disk at southwest corner of landing site. Face summit of Lassen Peak to read.

LPG05A

Reading site is over P-K nail at southeast corner of landing site. Face summit of Lassen Peak to read.

LPG06 (40° 31.69' N., 121° 31.17' W.)

Near northern end of Chaos Crags, at helicopter landing site for EDM network benchmark "L VIII." Landing site is approximately 150 m 275° true from benchmark. Reading site is at northwest corner of landing site, on a rock bench approximately 1 m high, Site marked by a standard gravity disk. Face summit of Lassen Peak to read.

LPG06A

Reading site is directly over P-K nail in rock bench approximately 7.5 m south of LPG06. Face summit of Lassen Peak to read.

LP049 (40° 28.59' N, 121° 28.62' W.)

On Lassen Park road (Highway 89) at west end of Reading Peak. Reading site is over P-K nail in pavement at northeast edge of road, in turnout, 12 m 200° from tree at north edge of turnout. Face summit of Lassen Peak to read.

LP049A

Reading site is over P-K nail in west end of outcrop, 23 m west of and across the road from LP049. Site is 9 m southwest of centerline of road and approximately 1.5 m above road. Face summit of Lassen Peak to read.

LP138 (40° 28.48' N., 121° 30.26' W.)

In parking area for Lassen Peak trail. Reading site is over P-K nail in asphalt, 70 m 276° from westernmost of two trees located 30 m north of intersection of Lassen Park road (Highway 89) and northeast entrance road to parking area. Face summit of Lassen Peak to read.

LP138A

Reading site is over P-K nail in rock outcrop in unpaved area between Lassen Park road (Highway 89) and Lassen Peak parking area. Site is located 9 m northwest of centerline of Lassen Park Road (Highway 89), 14.5 m southwest of centerline of northeast entrance road into parking area, 17 m southeast of edge of pavement in parking area, and 0.6 m above parking area. Face summit of Lassen Peak to read.

LP144 (40° 26.86' N., 121° 31.91' W.)

On Lassen Park road (Highway 89) 200 m southeast of sharp turn at Sulphur Works. Reading site is over southernmost of two P-K nails in pavement at west edge of road, in center of paved turnout. Face summit of Lassen Peak to read.

LP144A

Reading site is over P-K nail in 1.2 m diameter rock projecting 0.3 m above ground, 4.6 m west of a 1.2 m diameter pine tree and 100 m south of the centerline of Lassen Park road (Highway 89) at turnout containing "LP144."

ML7 (40° 22.16' N., 121° 31.98' W.)

On Lassen Park road (Highway 89) about 300 m north of the intersection of Highways 36 and 89 near Morgan Summit. Reading site is on top of and at south end of the second white culvert north of the intersection. Gravity mark has been removed but cement from mark is visible. Culvert is 1.2 m east of east edge of road. Face road to read and do not use a base plate.

ML7A

Reading site is on top of and at north end of culvert containing "ML7", directly over P-K nail scar. (We did not succeed in driving a P-K nail into the concrete.) Face road to read and do not use a base plate.

ML8 (40° 26.32' N., 121° 31.94' W.)

At Lassen Chalet about 9 km north of intersection of Highways 36 and 89. Reading site is over standard gravity disk stamped "ML8" which is cemented onto a concrete platform on the north end of the Lassen Chalet, adjacent to a concrete stairway. The disk is approximately at ground level in a corner formed by a shallow right-angle turn in the structure. Face Lassen Chalet to read.

ML8A

Reading site is over P-K nail in platform 10 m northwest of "ML8", against the northeast wall of a covered walkway, northeast of the wall. Face wall to read.

Appendix 2.

All gravity values are in milligals and are relative to station LP001.

STATION	RELATIVE GRAVITY	STANDARD ERROR
LP00 1A	-0.136	0.003
LPG01	-210.192	0.006
LPG0 1A	-209.978	0.006
LPG02	-202.050	0.007
LPG02A	-202.206	0.006
LPG03	-312.440	0.008
LPG0 3A	-313.188	0.008
LPG04	-228.794	0.006
LPG0 4A	-228.690	0.006
LPG05	-202.136	0.006
LPG0 5A	-202.186	0.006
LPG06	-209.066	0.006
LPG0 6A	-208.942	0.006
LP049	-173.096	0.008
LP049A	-173.456	0.008
LP138	-197.390	0.008
LP138A	-197.541	0.008
LP144	-91.305	0.008
LP14 4A	-89.377	0.008
ML7	-12.063	0.008
ML7A	-12.077	0.008
ML8	-76.601	0.007
ML8A	-76.489	0.008
SPG0 1	-71.403	0.004
SPG0 1A	-71.642	0.005

Appendix 3.

The station descriptions given below assume that the reader has the Shasta, California (1954) 1:62,500 scale topographic map and has been able to identify the general locations of the various stations using the geographic coordinates given for each. For stations at tilt sites, 3 or 4 benchmarks exist at the sites. The southernmost benchmark is "x" and "y", "z", "w" are located progressively in a counter-clockwise direction. More detailed descriptions of the tilt site benchmarks are given by Dzurisin and Johnson (1982) and descriptions of the EDM network benchmarks are available from B. Chadwick at the U. S. Geological Survey Cascade Volcano Observatory, Vancouver, Washington.

SPG01 (41° 21.58' N., 122° 11.91' W.)

In parking lot of Ski Bowl Lodge on south flank of Mount Shasta, at tilt site Ski Bowl. Reading site is directly over benchmark "x". Face summit of Mount Shasta to read.

SPG01A

Reading site is directly over benchmark "z". Face summit of Mount Shasta to read.

SPG02 (41° 23.22' N., 122° 11.50' W.)

On Sargents Ridge, at tilt site Shasta South. Reading site is directly over benchmark "x". Face summit of Mount Shasta to read.

SPG02A

Reading site is over P-K nail in rock, 0.41 m 105° from benchmark "z". Face summit of Mount Shasta to read.

SPG03 (41° 24.78' N., 122° 13.00' W.)

In saddle between Mount Shasta and Shastina, at tilt site Shasta West. Reading site is over P-K nail in rock, 1.68 m 215° from benchmark "x". Face summit of Mount Shasta to read.

SPG03A

Reading site is over P-K nail in rock, 3.48 m 165° from benchmark "z". Face summit of Mount Shasta to read.

SPG04 (41° 25.84' N., 122° 11.86' W.)

On north flank of Mount Shasta, at tilt site Shasta North. Reading site is over benchmark "x". Face summit of Mount Shasta to read.

SPG04A

Reading site is over P-K nail in rock, 1.17 m 170° from benchmark "y". Northwest leg of gravimeter base plate is about on P-K nail. Face summit of Mount Shasta to read.

SPG05 (41° 24.08' N., 122° 11.98' W.)

At Red Banks, south of summit of Mount Shasta. Reading site is over EDM benchmark "81 14". Face summit of Mount Shasta to read.

SPG05A

Reading site is over P-K nail in lava 4 m 10° from benchmark "81.14". Face summit of Mount Shasta to read.

SPG06 (41° 24.70' N., 122° 8.92' W.)

On east flank of Mount Shasta, at tilt site Shasta East. Reading site is directly over benchmark "y". Face summit of Mount Shasta to read.

SPG06A

Reading site is directly over benchmark "z". Face summit of Mount Shasta to read.

Appendix 4.

All gravity values are in milligals and are relative to station SPG01.

STATION	RELATIVE GRAVITY	STANDARD ERROR
SPG0 1A	-0.234	0.005
SPG02	-240.534	0.006
SPG0 2A	-240.353	0.006
SPG03	-301.934	0.007
SPG0 3A	-302.792	0.007
SPG04	-214.044	0.006
SPG0 4A	-213.916	0.006
SPG05	-409.253	0.007
SPG0 5A	-409.429	0.007
SPG06	-90.206	0.006
SPG0 6A	-89.805	0.006