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Measurements of slope distances and vertical angles at Mount Baker and Mount Rainier, Washington, Mount Hood and Crater Lake, Oregon, and Mount Shasta and Lassen Peak, California, 1980-1984

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ABSTRACT

Personnel of the U.S. Geological Survey's Cascades Volcano Observatory established trilateration networks at Mount Baker, Mount Rainier, Mount Hood, Crater Lake, Mount Shasta, and Lassen Peak in 1980-1984. These networks are capable of detecting changes in slope distance of several centimeters or more. The networks were established to provide baseline information on potentially active volcanoes and were designed along guidelines found useful at Mount St. Helens. Periodic reoccupation of the networks is planned as a part of the overall monitoring program of Cascade volcanoes. Methodology, slope distance and vertical angle data, maps of the networks, and bench mark descriptions are presented in this report. Written benchmark descriptions are augmented by photographs, which we have found by experience to be very useful in relocating the marks. All repeat measurements at the six volcanoes are probably within measurement error.

INTRODUCTION

In response to renewed eruptive activity at Mount St. Helens in 1980, the Cascades Volcano Observatory (CVO) was established in Vancouver, Washington, with the support of the U.S. Geological Survey's Volcano Hazards Program. In addition to continued monitoring at Mount St. Helens, CVO scientists have initiated geodetic and geochemical monitoring at other potentially active volcanoes in the Cascade Range (fig. 1). Field work in 1980-84 included the acquisition of baseline geochemical and geodetic information at six Cascade volcanoes other than Mount St. Helens. Geochemical studies include temperature measurements and gas sampling of fumaroles at Mount Baker, Mount Hood, Mount Shasta, and Lassen Peak (T. J. Casadevall, oral commun., 1983). Geodetic studies consist of: 1) slope distance and vertical angle measurements at Mount Baker, Mount Rainier, Mount Hood, Crater Lake, Mount Shasta, and Lassen Peak; 2) tilt surveys at Mount Baker (Frank and others, 1975; Daniel Dzurisin, unpublished data), Mount Rainier (Dzurisin and others, 1983), Mount Shasta and Lassen Peak (Dzurisin and others, 1982), and Mount Hood (Daniel Dzurisin, unpublished data); and 3) precision gravity surveys at Mount Shasta and Lassen Peak (Jachens and others, 1983). Further work is planned at these and other Cascade volcanoes as funds permit. The geodetic studies supplement a program for continuous seismic monitoring of Cascade volcanoes funded by the U. S. Geological Survey in cooperation with the University of Washington. These investigations provide useful baseline data for evaluating future activity.

GEODETIC MONITORING OF VOLCANOES

Magma rising beneath a volcano forcefully displaces the surrounding rock, and the resulting deformation can be measured at the ground surface. Since about 1910, attempts have been made to measure this deformation in order to help understand magmatic processes and predict eruptions at active volcanoes (F. Omori, in K. Mogi, 1958). The vertical component of deformation has generally been determined by leveling techniques and by the less precise measurement of vertical angles. Early attempts to measure the horizontal component of deformation utilized relatively imprecise triangulation methods. In the mid-1960's, the development of electronic distance meters (EDM) spurred personnel of the U.S. Geological Survey's Hawaiian Volcano Observatory to initiate studies of horizontal

strain at Kilauea Volcano. These measurements have helped document repeated episodes of inflation and deflation of the shield volcano related to intrusions and eruptions (Kinoshita and others, 1974).

Few such detailed and precise monitoring efforts had been attempted on active stratovolcanoes or composite volcanoes before 1980 (a notable exception is the study of Usu volcano, Japan [Yokoyama and others, 1981]), when the reawakening of Mount St. Helens provided an ideal opportunity to test the utility of such measurements. In late April 1980, distance and angle measurements were initiated from instrument sites at the foot of the volcano to targets on its flanks. This monitoring documented the remarkable bulging of the north flank as magma intruded the volcano before the large landslide and explosion of May 18, 1980 (Lipman and others, 1981). The need to monitor all sides of a volcano was evidenced by the localized development of the bulge, which covered 3-4 km^2, extended nearly 2 km downslope from the summit area, and was mostly confined to a 60 degree radial sector of the cone. Points on the bulge moved tens of meters northward, whereas points just off the bulge and elsewhere on the cone were nearly immobile. After the May 18 events, geodetic monitoring of the volcano's flanks suggested slight horizontal expansion before other explosions in 1980 and slight contraction afterward (Swanson and others, 1981). Since 1980, distance measurements inside the crater of Mount St. Helens have been used to predict dome-building extrusions of dacite a few days to 3 weeks in advance (Swanson and others, 1983; Chadwick and others, 1983). The unprecedented success of horizontal strain monitoring at Mount St. Helens suggests that this technique can be used for surveillance of other composite volcanoes, such as those of the Cascade Range.

TRILATERATION NETWORKS AT CASCADE VOLCANOES

We describe in this report the trilateration networks installed and occupied in 1980 to 1984 at Mount Baker, Mount Rainier, Mount Hood, Crater Lake, Mount Shasta, and Lassen Peak (table 1), including installation procedures, benchmark locations, and baseline measurements. We intend the report to be a reference to facilitate future reoccupation of the networks and analysis of the data obtained, and also to be a guide to those interested in making similar measurements at other volcanoes.

Equipment and procedures

All benchmarks are 10 cm diameter die-cast brass monuments with 7 cm stems cemented into holes bored into bedrock or large boulders using a masonry (star) drill. In general, we tried to place benchmarks within each 60 degree sector of the volcano and at two different elevations within each sector. These goals were not often realized. Site selection was governed largely by the distribution of bedrock outcrops accessible by helicopter. Ease of ground access was not a strong factor in site selection, because helicopter support was considered logistically essential for adequate monitoring. A resurvey 1-2 yrs after the first survey was planned for each volcano to check the initial data and provide an estimate of expected errors. Subsequent reoccupations are scheduled every 3-5 years, unless increased seismicity, phreatic activity, or reports of increased snow melt or other visible changes are reported.

Slope distances were measured with an EDM (Hewlett-Packard 3808A) and vertical angles with a theodolite (Wild T-2, both old and new styles) from benchmarks generally at low elevations around each volcano to reflectors at benchmarks high on the cones. Vertical angles were measured primarily to establish station elevations and to make mark-to-mark distance reductions; they were not measured reciprocally (table 2). Temperature, pressure, and humidity corrections were applied to EDM data. Temperature was measured with a thermistor or thermometer generally about 2.5 m above ground at each benchmark. Pressure was measured with a pressure transducer at each reflector site and a transducer backed up by a precision aneroid barometer at the instrument site. In 1983 and 1984, humidity was read at the instrument site with a sling psychrometer; no end-point humidity measurements were made in 1981 and 1982, when a nominal correction of -0.5 ppm was assumed.

Measured distances several kilometers long commonly cross 1 km or more of elevation on the steep volcanoes; consequently atmospheric properties change significantly along the line path. Determining the atmospheric refractivity using end-point measurements of temperature, pressure, and humidity provides some correction for the EDM measurements, but temperature and humidity do not necessarily change linearly along such steep lines with large elevation differences.

We attempted to improve the precision of the slope-distance measurements by using a helicopter to take semi-continuous temperature and humidity readings along most line paths while distance measurements were being made. (This procedure was not followed at Crater Lake, where the lines are nearly horizontal and the noise of a helicopter would be particularly disturbing to tourists.) Temperatures and humidities were determined with a thermistor and hygrister mounted on the front of the left helicopter skid and recorded on a data logger inside the aircraft. The helicopter generally flew downslope at a nearly constant air speed and was guided by radio from the reflector end in order to stay within a few meters of the line path. Most lines were flown at an air speed of about 45 mph, but some were flown as slowly as 25 mph and others as rapidly as 60 mph.

Programs for CVO's VAX 11/750 computer (Endo and others, 1985), adapted from similar programs used in the U. S. Geological Survey's Tectonophysics Branch in Menlo Park, California, use the flight-line data to calculate an average refractive index for the entire line and correct the measured slope distances accordingly. Savage and Prescott (1973) and Bomford (1980) describe in detail the measurement techniques and related procedures. Slope distances for 1982-1984 were calculated using flightline atmospheric data (table 4). Most distance measurements in 1981 were accompanied by flightline readings, but equipment malfunctions led to so many obviously incorrect temperature measurements that we decided to discard all of the 1981 flightline data.

The manufacturer's stated precision for the EDM is $\pm$(5 mm+1 ppm) in the temperature range of interest. If two measurements of the same line differ by twice this value or less, the difference cannot be considered significant. This is an instrumental precision only, however, and does not take into account inaccuracies in measuring the atmospheric index of refraction. An overall precision of $\pm$3 ppm, including errors resulting from end-point temperature, pressure, and humidity measurements, was found for relatively flat lines measured with the same instrument model at Long Valley, California (R. P. Denlinger, personal commun., 1984). By assuming

no strain in our networks, we calculate an overall precision of ±3.9 ppm from the differences in 142 end-point line lengths given in table 3 (exclusive of the long lines at Crater Lake) (fig. 2). This value may be larger than that at Long Valley owing to the differences in terrain, to some strain or benchmark instability in our networks, or to problems in our method of temperature measurement. In addition, the figure was calculated using some data from Mount Shasta and Lassen Peak in 1984 that we believe are of poorer quality than normal owing to windy conditions. Lacking objective evidence of this, however, we use the figure of ±3.9 ppm as a guide for evaluating apparent changes.

A significant improvement in precision was apparently not obtained by flying the lines. We had expected a precision of perhaps about ±2 ppm (at Long Valley it is ±1.5 ppm), but instead we find a precision of about ± 3.4 ppm for the 72 measurements in table 4 under the assumption of no strain (fig. 3). This result is addressed in the discussion section.

Results

Table 3 gives slope distances computed on the basis of end-point temperature and pressure measurements and an assumed humidity correction of -0.5 ppm. Table 4 lists the slope distances calculated using flight-line data. All distances listed are mark-to-mark, corrected for instrument heights, and not reduced to sea level. Maps of the survey networks and descriptions and photographs of benchmark sites are in Appendices A-F.

Surveys at Mount Baker (table 3A) show no evidence of deformation between 1981 and 1983 (fig. 4). All repeat measurements agree within twice the assumed error of one end-point measurement (3.9 ppm), consistent with the lack of seismicity at the volcano during the same time. Measurement conditions were excellent during both surveys: light winds, clear air, and moderate day and night temperatures. Such conditions probably contribute much toward the relatively high quality of the surveys. In 1983, distances calculated using flightline data are longer (mean=+3.1 ppm, s.d.=1.1) than those using end-point data (tables 3A, 4A, and 5A). This difference could be explained by an average end-point temperature about 3°C lower than that obtained by the aircraft. Pressure and humidity have relatively little effect on the calculations, and all other variables--instrument height, uncorrected slope distance readings, station elevations, etc.--are the same for both sets of calculations.

At Mount Rainier, most repeat measurements agree within twice the expected error of a single measurement between 1982 and 1983 (tables 3B and 4B). Some lines could not be measured in 1983 owing to poor weather. As at Mount Baker, distances calculated from flightline data are generally longer than those calculated from end-point data, in 1982 by a mean of 2.3 ppm (s.d.=1.5) and in 1983 by a mean of 2.0 ppm (s.d.=1.8) (table 5B). These comparisons suggest that the average end-point temperatures were about 2°C lower than the flightline temperatures. Conditions were poor during measurements of several lines. Particularly strong, gusty winds (30 knots) badly vibrated both the EDM and reflector during measurement of line 2 in both years. Past experience at Mount St. Helens with a Rangemaster 3 has shown that such windy and gusty conditions shake the instrument and reflector out of plumb and often accompany air instability, both factors adversely affecting measurements. The windy conditions may account for the large apparent change in length of line 2, which is much

above the expected error and was excluded from the precision analysis for that reason (this is the only measurement excluded from any statistical treatment in this report). Other shots involving the end points (McClure Tilt and Camp Hazard) of line 2 are within expected error, so that both benchmarks are probably stable. In addition, the relative elevation of McClure Tilt mark was determined in both years by precise levelling and showed no undue change (Daniel Dzurisin, unpublished data). The apparent length change on line 29 (Iron Mountain to St. Andrews Rock) is beyond that of expected error for the end-point calculation and barely within expected error for the flightline calculation. Local site stability of St. Andrews Rock cannot be checked because it is not sighted from another station. The apparent change in flightline distance for line 8 is above expected error, but the end-point calculation is acceptable; the reason for this discrepancy is unknown. A longer history of measurements will be necessary before such changes can be evaluated adequately. The inconsistent changes on adjacent lines (fig. 5) argues against but cannot exclude the possibility of deformation of the cone.

At Mount Hood, several apparent changes between 1980 and 1983 are relatively large (table 3C; fig. 6), but little stock can be placed in them owing to the lack of adequate temperature and pressure equipment and the use of a different EDM (Rangemaster 3) in 1980, when a limited number of PK masonry nails were installed (the nails were left in place when benchmarks were emplaced in 1983). The apparent changes are small by comparison with those expected should the volcano begin to swell in response to magma intrusion at depth.

Apparent changes in line length at Mount Hood from 1983 to 1984 are within expected error for flightline calculations and, except for line 20, also for end-point calculations (tables 3D and 4C; fig. 7). Flightline data yield longer distances than end-point data; in 1983, the mean difference is 3.6 ppm (s.d.=1.5), and in 1984, 2.8 ppm (s.d.=0.9) (table 5C). This is consistent with end-point temperatures being about 3.5°C and 3°C lower respectively than flightline temperatures. Three of the four distances measured from Cathedral in 1984 (lines 17, 18, and 20) are longer by 4.5, 6.6, and 10.7 ppm than in 1983, but the fourth (line 19) is nearly the same length. Flightline data for these lines are not available owing to equipment malfunction. Perhaps the Cathedral benchmark is unstable or the setup was not properly centered, although neither of these possibilities by itself can account for the small change on line 19. Random error is possibly the best explanation for the apparent changes.

At Crater Lake, repeat measurements are well within expected precision limits (table 3E). The presence of the lake beneath virtually the entire length of each line may help stabilize air density. Moreover, the lines are nearly flat (table 2D) and are high enough above lake surface to be unaffected by scintillation and enhanced humidity. End-point measurements should suffice across the caldera under most conditions.

Most line lengths at Mount Shasta were similar in 1981 and 1982 (table 3F; fig. 8)). Most of the apparent changes were small extensions, generally within expected error. However, lines 12 and 13 show apparent changes greater than expected; no reason is evident. The apparent 1981-1982 extensions were cancelled or changed to contractions by measurements in 1984 (fig. 9), and the net apparent change on most lines between 1981 and 1984 is contraction (tables 3F and 4D). The small 1981-1982 extensions and somewhat larger 1982-1984 contractions probably reflect slightly

different atmospheric conditions. In 1982, the comparison between calculated line lengths using end-point and flightline data (table 5D) is closer (flightline data slightly longer, mean=0.9 ppm, s.d.=1.5) than in 1984 at Mount Shasta (mean=3.1 ppm, s.d.=1.3) and at other volcanoes in 1982-1984 (Mount Baker, Mount Rainier, Mount Hood, and Lassen Peak). This suggests that end-point temperatures were closer to average air temperatures in 1982 than normal. In 1984, conditions at Mount Shasta were very windy, and the overall quality of the survey was probably less than in other years. This may account for the large apparent changes on lines 9, 12, and 20 (end-point calculation only), although downslope movement of Shastina (line 9) and Wishbone (line 12) is also possible. On balance, the data probably should be considered as reflecting measurement errors rather than real strains, although we cannot eliminate the possibility of slight areal contraction around the mountain between 1981 and 1984.

The pattern of apparent changes at Lassen Peak is very similar to that at Mount Shasta. Generally small extensions within expected error were recorded between 1981 and 1982 (fig. 10) and larger contractions, shown both by end-point and flightline data, accrued between 1982 and 1984 (fig. 11), with a net overall contraction between 1981 and 1984 (tables 3G and 4E). Calculated distances based on flightline data (table 4E) are slightly longer than those based on end-point data in 1982 (mean=1.3 ppm, s.d.=0.9) and significantly longer in 1984 (mean=3.2, s.d.=2.1) (table 5E), a pattern similar to that at Mount Shasta. The 1984 survey was made during strong winds, just as at Mount Shasta, and the quality of the data is probably less than in previous years and likely accounts for large apparent changes on many of the lines beyond those expected from our estimates of overall precision. The 1982 weather at Lassen was favorable except for one day of strong winds ending with a thunderstorm. Mornings were cooler than during other surveys at Lassen, however, and this apparently caused the great disagreement (7 ppm) between flightline and end-point calculations for line 10, which was measured early in the morning when the ground was cold and the average end-point temperature was 9.4°C cooler than in 1982. We conclude that there is no strong evidence that deformation is occurring at Lassen Peak and that the spread in the line lengths probably reflects measurement error. We cannot, however, rule out the possibility of slight areal contraction between 1982 and 1984.

DISCUSSION AND SUMMARY

The distances calculated on the basis of flightline temperature and humidity measurements are of unexpectedly poor quality compared with what we expected; those calculated from end-point measurements alone are nearly equivalent. Why are the flight-line data so poor?

We have no good reason but can suggest several possibilities. Our temperature-measuring setup on the skid of the helicopter may need improvement, and we are investigating this now. To date, however, we have found nothing that leads us to believe that the thermistor is inferior. Perhaps the air speed of the helicopter is too slow to enable proper corrections for frictional effects of airspeed to be made to the raw thermister readings. Perhaps rotor wash effects the readings in a way unaccounted for. Possibly inherent but unrecognized errors exist when using a helicopter on short, generally steep lines that are absent when using an airplane on long, relatively flat lines. We will investigate

and test means to improve the quality of the flightline data, but it they cannot be improved, we will probably revert to making only end-point measurements of temperature and humidity.

The end-point results differ from the flightline results in a predictable manner, as described above for each volcano. Combining all 190 differences between flightline and end-point results yields a mean of 2.4 ppm (s.d.=1.7), with flightline calculations consistently longer than end-point calculations (fig. 12). This suggests that end-point temperatures are systematically about $2.4^{o}C \pm 1.7$ cooler than the effective flightline temperatures, regardless of time of day. This was surprising to us, for we had thought that the end-point temperatures would generally be warmer than the air temperatures or at least cooler only in the early morning hours. Of course, the flightline temperatures may be incorrect.

The distance measurements, although of less than desired quality, indicate no significant deformation of any of the monitored volcanoes. We cannot rule out the possibility of slight areal contraction at Mount Shasta and Lassen Peak between 1982 and 1984 but prefer an alternative interpretation that the data from 1984 are adversely affected by the windy conditions during the surveys.

The data presented in this report should define adequate baselines for detecting changes of a few centimeters but no less. We will attempt to improve the quality of these baselines, but already they are far superior to those existing at Mount St. Helens before 1980. We now have a way to recognize and interpret the early stage of deformation at the monitored volcanoes that may be precursory to future eruptions, although we must realize that typical winter and spring snow will make reoccupation of most of each network impossible.

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Table 1. Dates of installation and measurement of trilateration networks at Cascade volcanoes.

Network	Date installed	Dates measured	Lines flown?
Baker	Aug. 1981	Aug. 1981	yes*
		Aug. 1983	yes
Rainier	Sep. 1982	Sep. 1982	yes
		Sep. 1983	yes
Hood (PK nails)	Jul. 1980	Jul. 1980	no
		Jul. 1980	no
		Aug. 1983	no
Hood (BM's)	Aug. 1983	Aug. 1983	yes
		Aug. 1984	yes
Crater Lake	Jul. 1981	Jul. 1981	no
		Jul. 1982	no
		Aug. 1983	no
		Jul. 1984	no
Shasta	Jul. 1981	Jul. 1981	yes*
		Jul. 1982	yes
		Jul. 1984	yes
Lassen	Jul. 1981	Jul. 1981	yes*
		Jul. 1982	yes
		Jul. 1984	yes

*Flight-line data not used owing to unreliable temperature readings

Table 2. Mark-to-mark vertical angles

A. MOUNT BAKER

Line	Line No.	Vertical angle (deg., min., sec.) 1981	1983	avg.
Forest Divide(B14)-Crag View(B12)	1	79 55 49	79 55 56	79 55 52.5
Forest Divide(B14)-Talum(B6)	2	73 54 59	73 54 44	73 54 51.5
Forest Divide(B14)-Lava Divide(B17)	3		88 48 54	88 48 54
Lava Divide(B17)-Talum(B6)	4	83 00 14	83 00 07	83 00 10.5
Lava Divide(B17)-Boulder(B5)	5	79 07 06	79 07 01	79 07 3.5
Landes Cleaver(B13)-Boulder(B5)	6	84 04 41	84 04 53	84 04 47
Landes Cleaver(B13)-Cockscomb(B4)	7		75 42 43	75 42 43
Landes Cleaver(B13)-Hadley(B16)	8	86 39 05	86 38 54	86 38 59.5
Hadley(B16)-Cockscomb(B4)	9	80 05 50	80 05 50	80 05 50
Hadley(B16)-Roosevelt(B9)	10	83 59 15	83 59 08	83 59 11.5
Thunder(B11)-Hadley(B16)	11	89 18 13	89 18 08	89 18 10.5
Thunder(B11)-Cockscomb(B4)	12	83 01 59	83 01 47	83 01 53
Thunder(B11)-Roosevelt(B9)	13	84 15 34	84 15 31	84 15 32.5
Thunder(B11)-Colfax(B3)	14	75 29 07	75 29 04	75 29 5.5
Park Butte(B1)-Colfax(B3)	15	78 52 43	78 52 43	78 52 43
Park Butte(B1)-Deming(B2)	16	84 08 16	84 08 14	84 08 15
Park Butte(B1)-Sherman Crater(B7)	17	78 14 26	78 14 16	78 14 21
Park Butte(B1)-Crag View(B12)	18	85 32 33	85 32 34	85 32 33.5
Crag View(B12)-Sherman Crater(B7)	19		71 16 00	71 16 00

Table 2 (cont.)

B. MOUNT RAINIER

Line	Line No.	Vertical angle (deg., min., sec.) 1982	1983	avg.
Iron Mountain-McClure Tilt	1		87 42 24	87 42 24
McClure Tilt-Camp Hazard(R5)	2	73 34 17	73 33 53	73 34 05
McClure Tilt-Gibralter(R1)	3	70 11 37		70 11 37
McClure Tilt-Whitman(R2)	4	81 50 01		81 50 01
McClure Tilt-Cowlitz(R18)	5	89 03 45	89 03 50	89 03 47.5
Cowlitz(R18)-Gibralter(R1)	6	74 54 57		74 54 57
Cowlitz(R18)-Whitman(R2)	7	78 29 08		78 29 08
Goat Island(R10)-K Spire(R6)	8	85 07 21		85 07 21
Goat Island(R10)-Gibralter(R1)	9	77 31 27		77 31 27
Goat Island(R10)-Steamboat Prow(R3)	10	82 07 24		82 07 24
Burroughs(R4)-Goat Island(R10)	11	92 17 38		92 17 38
Burroughs(R4)-K Spire(R6)	12	88 37 59		88 37 59
Burroughs(R4)-Steamboat Prow(R3)	13	80 48 07		80 48 07
Burroughs(R4)-Curtis(R7)	14	85 35 21		85 35 21
Burroughs(R4)-Old Desolate(R11)	15	93 12 00		93 12 00
Old Desolate(R11)-Steamboat Prow(R3)	16	82 31 32		82 31 32
Old Desolate(R11)-Curtis(R7)	17	83 24 56		83 24 56
Old Desolate(R11)-Ptarmigan(R16)	18	80 09 41		80 09 41
Observation Rock(R12)-Ptarmigan(R16)	19	77 20 59	77 21 01	77 21 00
Observation Rock(R12)-Mowich(R8)	20	81 48 13	81 48 08	81 48 10.5
Sunset(R19)-Mowich(R8)	21	80 37 41		80 37 41
Sunset(R19)-Puyallup(R14)	22	80 41 49	80 41 48	80 41 48.5
Andrew-Sunset(R19)	23	89 49 03	89 48 48	89 48 55.5
Andrew-Puyallup(R14)	24	78 20 29	78 20 16	78 20 22.5
Andrew-Glacier Island(R15)	25	83 56 33	83 56 23	83 56 28
Andrew-Iron Mountain	26	91 41 29	88 20 31*	
Iron Mountain-Puyallup(R14)	27	82 07 08	82 07 01	82 07 4.5
Iron Mountain-Glacier Island(R15)	28	83 07 12	83 07 06	83 07 09
Iron Mountain-St. Andrews Rock(R13)	29	78 29 07	78 28 47	78 28 57
Iron Mountain-Camp Hazard(R5)	30	76 57 58		76 57 58

*Measured from Iron Mountain to Andrew

Table 2 (cont.)

C. MOUNT HOOD (Benchmarks)

Line	Line No.	Vertical angle (deg., min., sec.) 1983	1984	avg.
Timberline(005)-White(H17)	1	76 37 45	76 37 56	76 37 50.5
Timberline(005)-Mitchell(H14)	2	89 02 52	89 03 12	89 03 02
Mitchell(H14)-Crater Rock(H18)	3	74 24 04	74 24 06	74 24 05
Mitchell(H14)-White(H17)	4	75 30 41	75 30 58	75 30 49.5
Mitchell(H14)-Big Rock(H16)	5	80 14 11	80 14 21	80 14 16
Lambertson(H13)-White(H17)	6	79 14 42	79 14 49	79 14 45.5
Lambertson(H13)-Cooper(H7)	7	77 36 19	77 36 24	77 36 21.5
Meadow(H8)-Lambertson(H13)	8	87 17 56	87 18 10	87 18 03
Meadow(H8)-Cooper(H7)	9	77 47 20	77 47 36	77 47 28
Meadow(H8)-Langille(H4)	10	81 07 13	81 07 35	81 07 24
Cloud Cap(H12)-Cooper(H7)	11	76 47 37	76 47 45	76 47 41
Cloud Cap(H12)-Langille(H4)	12	77 11 28	77 11 39	77 11 33.5
Cloud Cap(H12)-Barrett(H6)	13	80 27 09	80 27 13	80 27 11
Sticks(H11)-Cloud Cap(H12)	14	87 48 45	87 48 55	87 48 50
Sticks(H11)-Barrett(H6)	15	81 56 12	81 56 12	81 56 12
Sticks(H11)-County Line(H3)	16	82 50 33	82 50 41	82 50 37
Cathedral(H9)-Sticks(H11)	17	92 49 42	92 49 39	92 49 40.5
Cathedral(H9)-Barrett(H6)	18	77 00 04	77 00 12	77 00 08
Cathedral(H9)-County Line(H3)	19	76 20 58	76 20 49	76 20 53.5
Cathedral(H9)-Sandy(H1)	20	80 33 44	80 33 54	80 33 49
Yokum(H10)-County Line(H3)	21	79 56 26	79 56 44	79 56 35
Yokum(H10)-Sandy(H1)	22	76 42 33	76 42 53	76 42 43
Yokum(H10)-Reid(H5)	23	84 14 41	84 15 10	84 14 55.5
Yokum(H10)-Mississippi(H15)	24	84 30 59	84 31 12	84 31 05.5
Yokum(H10)-Paradise(H2)	25	93 33 55	93 34 07	93 34 01
Paradise(H2)-Sandy(H1)	26	82 04 44	82 04 42	82 04 43
Paradise(H2)-Reid(H5)	27	82 14 27	82 14 56	82 14 41.5
Paradise(H2)-Crater Rock(H18)	28	72 34 25	72 34 28	82 14 26.5
Paradise(H2)-Mississippi(H15)	29	75 24 10	75 24 18	75 24 14
Timberline(005)-Crater Rock(H18)	30		73 14 14	73 14 14

D. Crater Lake

Line	Vertical angle (deg., min., sec.) 1981	1982	1984	avg.
Palisade Point(CL1)-BM 7076	89 28 34	89 28 44	89 28 29	89 28 35.7
Victor View(CL2)-VABM 8156 Ref. Mk. 2	88 26 15	88 25 56	88 25 56	88 26 02.3
Palisade Point(CL1)-Chute(CL3)		89 33 18	89 33 16	89 33 17

Table 2 (cont.)

E. MOUNT SHASTA

Line	Line No.	Vertical angle (deg., min., sec.) 1981	1982	avg.
Red Butte(81.1)-Red Banks(81.14)	1	72 41 42	72 41 57	72 41 49.5
Red Butte(81.1)-Sargent(81.2)	2	74 33 05	74 32 59	74 33 02
Green Butte(81.13)-Red Banks(81.14)	3	70 28 30	70 28 27	70 28 28.5
Green Butte(81.13)-Red Butte(81.1)	4	95 56 47	95 56 36	95 56 41.5
Helen(81.17)-Red Banks(81.14)	5	68 58 46	68 58 38	68 58 42
Helen(81.17)-Red Butte(81.1)	6		98 11 19	98 11 19
Helen(81.17)-Shastina(81.11)	7	78 45 41	78 45 45	78 45 43
Helen(81.17)-Avalanche Gulch(81.16)	8	109 33 31	109 33 35	109 33 33
Spur-Shastina(81.11)	9	65 05 10	65 05 20	65 05 15
Pilgrim Creek(81.3)-Sargent(81.2)	10		78 39 19	78 39 19
Pilgrim Creek(81.3)-Red Butte(81.1)	11	92 56 11	92 55 53	92 56 02
Pilgrim Creek(81.3)-Wishbone(81.4)	12	74 14 51	74 14 49	74 14 50
Pilgrim Creek(81.3)-Wintun(81.6)	13		75 49 47	75 49 47
Ash Creek(81.5)-Wishbone(81.4)	14		76 54 48	76 54 48
Ash Creek(81.5)-Wintun(81.6)	15	74 39 40	74 39 42	74 39 41
Ash Creek(81.5)-Hotlum(81.8)	16	74 40 54	74 41 04	74 40 59
Ash Creek(81.5)-Pilgrim Creek(81.3)	17	85 42 26	85 42 19	85 42 22.5
North Gate(81.7)-Hotlum(81.8)	18	78 12 05	78 11 49	78 11 57
North Gate(81.7)-Bolam(81.9)	19	75 39 34	75 39 40	75 39 37
Lava Ridge(81.10)-North Gate(81.7)	20	89 18 03	89 17 55	89 17 59
Lava Ridge(81.10)-Bolam(81.9)	21	73 40 58	73 40 53	73 40 55.5

F. LASSEN PEAK

Line	Line No.	Vertical angle (deg., min., sec.) 1981	1982	avg.
Emigrant-East Lassen(L.IV)	1	75 34 46	75 34 37	75 34 41.5
Emigrant-Crescent Crater(L.V)	2	77 56 03	77 55 52	77 55 57.5
Hot Rock-East Lassen(L.IV)	3	77 41 35	77 41 36	77 41 35.5
Hot Rock-Crescent Crater(L.V)	4	77 36 54	77 36 43	77 36 48.5
Jumbles(L.IX)-North Chaos(L.VIII)	5	75 35 38	75 35 47	75 35 42.5
South Chaos(L.III)-East Lassen(L.IV)	6	83 08 59	83 08 46	83 08 52.5
Loomis(L.II)-North Chaos(L.VIII)	7	90 55 04	90 55 25	90 55 14.5
Loomis(L.II)-South Chaos(L.III)	8	91 02 02	91 02 16	91 02 09
Loomis(L.II)-Brokeoff(L.VI)	9	87 55 38	87 55 25	87 55 31.5
Bumpass(L.XI)-Brokeoff(L.VI)	10	88 29 48	88 29 46	88 29 47
Reading(L.XII)-East Lassen(L.IV)	11	83 06 48	83 06 33	83 06 40.5
Reading(L.XII)-Bumpass(L.XI)	12	88 22 57	88 23 02	88 22 59.5
Bumpass(L.XI)-South Lassen(L.X)	13	82 44 05	82 44 05	82 44 05
Loomis(L.II)-South Lassen(L.X)	14	82 41 43	82 41 34	82 41 38.5
Loomis(L.II)-West Lassen(L.I)	15	82 50 28	82 49 53	82 50 10.5
South Chaos(L.III)-West Lassen(L.I)	16	82 15 11	82 15 11	82 15 11
Brokeoff(L.VI)-West Lassen(L.I)	17	88 35 07	88 34 59	88 35 03
Brokeoff(L.VI)-South Lassen(L.X)	18	88 07 19	83 07 27	83 07 23
Brokeoff(L.VI)-Pilot Pinnacle(L.VII)	19	92 07 00	92 07 04	92 07 02

Table 3. Mark-to-mark slope distances calculated using end-point temperatures and pressures and an assumed humidity correction of -0.5 ppm

A. MOUNT BAKER

Line	Line No.	Distance		Change	
		1981	1983	m	ppm
Forest Divide(B14)-Crag View(B12)	1	2283.407	2283.403	-.004	-1.8
Forest Divide(B14)-Talum(B6)	2	2240.844	2240.842	-.002	-0.9
Forest Divide(B14)-Lava Divide(B17)	3		4954.203		
Lava Divide(B17)-Talum(B6)	4	4235.688	4235.682	-.006	-1.4
Lava Divide(B17)-Boulder(B5)	5	3702.080	3702.075	-.005	-1.3
Landes Cleaver(B13)-Boulder(B5)	6	3104.315	3104.307	-.008	-2.6
Landes Cleaver(B13)-Cockscomb(B4)	7		2769.772		
Landes Cleaver(B13)-Hadley(B16)	8	2959.836	2959.826	-.010	-3.4
Hadley(B16)-Cockscomb(B4)	9	2963.909	2963.905	-.004	-1.4
Hadley(B16)-Roosevelt(B9)	10	3022.007	3022.010	+.003	+1.0
Thunder(B11)-Hadley(B16)	11	5440.950	5440.950	0	0
Thunder(B11)-Cockscomb(B4)	12	4754.880	4754.880	0	0
Thunder(B11)-Roosevelt(B9)	13	3842.380	3842.367	-.013	-3.4
Thunder(B11)-Colfax(B3)	14	2803.250	2803.253	+.003	+1.1
Park Butte(B1)-Colfax(B3)	15	6270.992	6270.990	-.002	-0.3
Park Butte(B1)-Deming(B2)	16	3772.244	3772.236	-.008	-2.1
Park Butte(B1)-Sherman Crater(B7)	17	6490.739	6490.733	-.006	-0.9
Park Butte(B1)-Crag View(B12)	18	4103.397	4103.389	-.008	-2.0
Crag View(B12)-Sherman Crater(B7)	19		3128.819		

Table 3 (cont.)

B. MOUNT RAINIER

Line	Line No.	Distance		Change	
		1982	1983	m	ppm
Iron Mountain-McClure Tilt	1	8246.109	8246.119	+.010	+1.2
McClure Tilt-Camp Hazard(R5)	2	4469.302*	4469.347**	+.045	+10.1
McClure Tilt-Gibralter(R1)	3	Not measured			
McClure Tilt-Whitman(R2)	4	4083.395	4083.395	0	0
McClure Tilt-Cowlitz(R18)	5	4375.589	4375.592	+.003	+0.7
Cowlitz(R18)-Gibralter(R1)	6	5915.211			
Cowlitz(R18)-Whitman(R2)	7	2545.002	2545.001	-.001	-0.4
Goat Island(R10)-K Spire(R6)	8	3529.130	3529.121	-.009	-2.6
Goat Island(R10)-Gibralter(R1)	9	7686.757			
Goat Island(R10)-Steamboat Prow(R3)	10	5544.477	5544.458	-.019	-3.4
Goat Island(R10)-Burroughs(R4)	11	4676.866	4676.865	-.001	-0.2
Burroughs(R4)-K Spire(R6)	12	4750.147	4750.149	+.002	+0.4
Burroughs(R4)-Steamboat Prow(R3)	13	3600.291	3600.290	-.001	-0.3
Burroughs(R4)-Curtis(R7)	14	3446.868	3446.867	-.001	-0.3
Burroughs(R4)-Old Desolate(R11)	15	3821.068			
Old Desolate(R11)-Steamboat Prow(R3)	16	6044.433			
Old Desolate(R11)-Curtis(R7)	17	4160.467			
Old Desolate(R11)-Ptarmigan(R16)	18	5911.613			
Observation Rock(R12)-Ptarmigan(R16)	19	3688.094	3688.083	-.011	-3.0
Observation Rock(R12)-Mowich(R8)	20	3123.991	3123.997	+.006	+1.9
Sunset(R19)-Mowich(R8)	21	4687.815	4687.818	+.003	+0.6
Sunset(R19)-Puyallup(R14)	22	3903.410	3903.387	-.023	-5.9
Andrew-Sunset(R19)	23	3479.380	3479.389	+.009	+2.6
Andrew-Puyallup(R14)	24	3183.045	3183.034	-.011	-3.5
Andrew-Glacier Island(R15)	25	2791.253	2791.259	+.006	+2.2
Andrew-Iron Mountain	26	4508.379	4508.376	-.003	-0.7
Iron Mountain-Puyallup(R14)	27	5642.938	5642.900	-.038	-6.7
Iron Mountain-Glacier Island(R15)	28	3556.887	3556.874	-.013	-3.7
Iron Mountain-St. Andrews Rock(R13)	29	7237.857	7237.787	-.070	-9.7
Iron Mountain-Camp Hazard(R5)	30	7078.989	7079.005	+.016	+2.3

*Very windy at McClure Tilt
**Very windy at Camp Hazard

Table 3 (cont.)

C. MOUNT HOOD (PK nails)

Line	7/17/80	Change		7/28/80	Change		Aug. 1983
		m	ppm		m	ppm	
Falls-White	3378.513	+.008	+2.4	3378.521	-.013	-3.8	3378.508
Falls-Big Rock	1859.917	+.010	+5.3	1859.927	-.001	-0.5	1859.926
4875-Barrett	6453.590	+.041	+6.4	6453.631	-.014	-2.2	6453.617
Paradise-Crater Rock	3996.747	+.001	+0.3	3996.748	-.028	-7.0	3996.720
Paradise-Miss. Head	1631.376	+.024	+14.7	1631.400	-.027	-16.6	1631.373
6227-Cooper	3939.949	+.007	+1.8	3939.956	-.032	-8.1	3939.924
6227-Langille Crags	4207.127	-.054	-12.9	4207.073			

D. MOUNT HOOD (Benchmarks)

Line	Line No.	Distance		Change	
		1983	1984	m	ppm
Timberline(005)-White(H17)	1	3394.182	3394.184	+.002	+0.6
Timberline(005)-Mitchell(H14)	2	2289.976	2289.978	+.002	+0.8
Mitchell(H14)-Crater Rock(H18)	3	4224.408	4224.407	-.001	-0.2
Mitchell(H14)-White(H17)	4	2984.671	2984.660	-.011	-3.7
Mitchell(H14)-Big Rock(H16)	5	1478.624	1478.625	+.001	+0.7
Lambertson(H13)-White(H17)	6	3400.717	3400.711	-.006	-1.8
Lambertson(H13)-Cooper(H7)	7	3297.684	3297.677	-.007	-2.1
Meadow(H8)-Lambertson(H13)	8	2603.374	2603.388	+.014	+5.3
Meadow(H8)-Cooper(H7)	9	3927.388	3927.403	+.015	+3.8
Meadow(H8)-Langille(H4)	10	4113.520	4113.533	+.013	+3.2
Cloud Cap(H12)-Cooper(H7)	11	4288.711	4288.720	+.009	+2.1
Cloud Cap(H12)-Langille(H4)	12	3538.492	3538.493	+.001	+0.3
Cloud Cap(H12)-Barrett(H6)	13	3884.436	3884.448	+.012	+3.1
Sticks(H11)-Cloud Cap(H12)	14	6865.168	6865.163	-.005	-0.7
Sticks(H11)-Barrett(H6)	15	6468.941	6468.949	+.008	+1.2
Sticks(H11)-County Line(H3)	16	7378.431	7378.429	-.002	-0.3
Cathedral(H9)-Sticks(H11)	17	5287.166	5287.190	+.024	+4.5
Cathedral(H9)-Barrett(H6)	18	2891.783	2891.802	+.019	+6.6
Cathedral(H9)-County Line(H3)	19	2810.366	2810.362	-.004	-1.4
Cathedral(H9)-Sandy(H1)	20	3168.458	3168.492	+.034	+10.7
Yokum(H10)-County Line(H3)	21	2302.251	2302.266	+.015	+6.5
Yokum(H10)-Sandy(H1)	22	1125.271	1125.270	-.001	-0.9
Yokum(H10)-Reid(H5)	23	1204.272	1204.273	+.001	+0.8
Yokum(H10)-Mississippi(H15)	24	2540.295	2540.286	-.009	-3.5
Yokum(H10)-Paradise(H2)	25	2726.375	2726.376	+.001	+0.4
Paradise(H2)-Sandy(H1)	26	3099.238	3099.237	-.001	-0.3
Paradise(H2)-Reid(H5)	27	2146.470	2146.468	-.002	-0.9
Paradise(H2)-Crater Rock(H18)	28	4039.697	4039.688	-.009	-2.2
Paradise(H2)-Mississippi(H15)	29	1635.422	1635.428	+.006	+3.7
Timberline(005)-Crater Rock(H18)	30		4071.298		

Table 3 (cont.)

E. CRATER LAKE

Line	Jul. 1981	Change m	Change ppm	Aug. 1982	Change m	Change ppm	Aug. 1983
Palisade Point(CL1)-BM 7076	8901.899	-.001	-0.1	8901.898	+.002	+0.2	8901.900
Palisade Point(CL1)-Chute(CL3)				9140.115	-.025	-2.7	9140.090
Victor View(CL2)-VABM 8156 Ref. Mark 2	9179.370	-.008	-0.9	9179.362	+.005	+0.5	9179.367

Line	Aug. 1983	Change m	Change ppm	Jul. 1984
Palisade Point(CL1)-BM 7076	8901.900	+.019	+2.1	8901.919
Palisade Point(CL1)-Chute(CL3)	9140.090	+.009	+1.0	9140.099
Victor View(CL2)-VABM 8156 Ref. Mark 2	9179.367	-.004	-0.4	9179.363

Table 3 (cont.)

F. MOUNT SHASTA

Line	Line No.	Distance		Change	
		1981	1982	m	ppm
Red Butte(81.1)-Red Banks(81.14)	1	4901.090	4901.104	+.014	+2.9
Red Butte(81.1)-Sargent(81.2)	2	3093.793	3093.794	+.001	+0.3
Green Butte(81.13)-Red Banks(81.14)	3	3620.085	3620.076	-.009	-2.5
Green Butte(81.13)-Red Butte(81.1)	4	2403.790	2403.797	+.007	+2.9
Helen(81.17)-Red Banks(81.14)	5	2325.330	2325.342	+.012	+5.2
Helen(81.17)-Red Butte(81.1)	6	4399.352	4399.370	+.018	+4.1
Helen(81.17)-Shastina(81.11)	7	2428.013	2428.020	+.007	+2.9
Helen(81.17)-Avalanche Gulch(81.16)	8	1894.739	1894.743	+.004	+2.1
Spur-Shastina(81.11)	9	2112.341	2112.350	+.009	+4.3
Pilgrim Creek(81.3)-Sargent(81.2)	10	3101.596	3101.588	-.008	-2.6
Pilgrim Creek(81.3)-Red Butte(81.1)	11	4207.009	4207.014	+.005	+1.2
Pilgrim Creek(81.3)-Wishbone(81.4)	12	1599.526	1599.513	-.013	-8.1
Pilgrim Creek(81.3)-Wintun(81.6)	13	2563.045	2563.064	+.019	+7.4
Ash Creek(81.5)-Wishbone(81.4)	14	2615.112	2615.111	-.001	-0.4
Ash Creek(81.5)-Wintun(81.6)	15	2969.477	2969.482	+.005	+1.7
Ash Creek(81.5)-Hotlum(81.8)	16	3508.328	3508.338	+.010	+2.9
Ash Creek(81.5)-Pilgrim Creek(81.3)	17	2106.460	2106.464	+.004	+1.9
North Gate(81.7)-Hotlum(81.8)	18	4227.518	4227.532	+.014	+3.3
North Gate(81.7)-Bolam(81.9)	19	4415.957	4415.968	+.011	+2.5
Lava Ridge(81.10)-North Gate(81.7)	20	5150.500	5150.525	+.025	+4.9
Lava Ridge(81.10)-Bolam(81.9)	21	4124.983	4125.004	+.021	+5.1

F. MOUNT SHASTA (cont.)

Line No.	Distance		Change		Net Change, 1981-1984	
	1982	1984	m	ppm	m	ppm
1	4901.104	4901.082	-.022	-4.5	-.008	-0.5
2	3093.794	3093.776	-.018	-5.8	-.017	-5.5
3	3620.076	3620.078	+.002	+0.5	-.007	-1.9
4	2403.797	2403.792	-.005	-2.1	+.002	+0.8
5	2325.342					
6	4399.370	4399.341	-.029	-6.6	-.011	-2.5
7	2428.020	2428.009	-.011	-4.5	-.004	-1.6
8	1894.743	1894.727	-.016	-8.5	-.012	-6.3
9	2112.350	2112.322	-.028	-13.3	-.019	-9.0
10	3101.588	3101.580	-.008	-2.6	-.016	-5.2
11	4207.014	4207.001	-.013	-3.1	-.008	-1.9
12	1599.513	1599.529	+.016	+10.0	+.003	+1.9
13	2563.064					
14	2615.111	2615.111	0	0	-.001	-0.4
15	2969.482	2969.455	-.027	-9.0	-.022	-7.4
16	3508.338					
17	2106.464	2106.464	0	0	+.004	+1.9
18	4227.532					
19	4415.968	4415.962	-.006	-1.4	+.005	+1.1
20	5150.525	5150.486	-.039	-7.6	-.009	-1.7
21	4125.004	4124.981	-.023	-5.6	-.002	-0.5

Table 3 (cont.)

G. LASSEN PEAK

Line	Line No.	Distance		Change	
		1981	1982	m	ppm
Emigrant-East Lassen(L.IV)	1	4116.350	4116.353	+.003	+0.7
Emigrant-Crescent Crater(L.V)	2	2873.493	2873.503	+.010	+3.5
Hot Rock-East Lassen(L.IV)	3	5242.579	5242.573	-.006	-1.1
Hot Rock-Crescent Crater(L.V)	4	3232.547	3232.544	-.003	-0.9
Jumbles(L.IX)-North Chaos(L.VIII)	5	2744.990	2744.997	+.007	+2.5
South Chaos(L.III)-East Lassen(L.IV)	6	3542.687	3542.679	-.008	-2.3
Loomis(L.II)-North Chaos(L.VIII)	7	4912.755	4912.748	-.007	-1.4
Loomis(L.II)-South Chaos(L.III)	8	3909.604	3909.611	+.007	+1.8
Loomis(L.II)-Brokeoff(L.VI)	9	4860.354	4860.359	+.005	+1.0
Bumpass(L.XI)-Brokeoff(L.VI)	10	5462.942	5462.956	+.014	+2.6
Reading(L.XII)-East Lassen(L.IV)	11	3348.236	3348.241	+.005	+1.5
Reading(L.XII)-Bumpass(L.XI)	12	2829.722	2829.728	+.006	+2.1
Bumpass(L.XI)-South Lassen(L.X)	13	2722.024	2722.013	-.011	-4.0
Loomis(L.II)-South Lassen(L.X)	14	2958.274	2958.286	+.012	+4.1
Loomis(L.II)-West Lassen(L.I)	15	2706.872	2706.870	-.002	-0.7
South Chaos(L.III)-West Lassen(L.I)	16	3020.714	3020.712	-.002	-0.7
Brokeoff(L.VI)-West Lassen(L.I)	17	6391.362	6391.367	+.005	+0.8
Brokeoff(L.VI)-South Lassen(L.X)	18	6002.396	6002.403	+.007	+1.2
Brokeoff(L.VI)-Pilot Pinnacle(L.VII)	19	3344.994	3344.999	+.005	+1.5

G. LASSEN PEAK (cont.)

Line No.	Distance		Change		Net Change, 1981-1984	
	1982	1984	m	ppm	m	ppm
1	4116.353	4116.327	-.026	-6.3	-.023	-5.6
2	2873.503	2873.487	-.016	-5.6	-.006	-2.1
3	5242.573	5242.553	-.020	-3.8	-.026	-5.0
4	3232.544	3232.527	-.017	-5.3	-.020	-6.2
5	2744.997	2744.998	+.001	+0.4	+.008	+2.9
6	3542.679	3542.652	-.027	-7.6	-.035	-9.9
7	4912.748					
8	3909.611	3909.602	-.009	-2.3	-.002	-0.5
9	4860.359	4860.338	-.021	-4.3	-.016	-3.3
10	5462.956	5462.912	-.044	-8.0	-.030	-5.5
11	3348.241	3348.220	-.021	-6.3	-.016	-4.8
12	2829.728	2829.725	-.003	-1.0	+.003	+1.1
13	2722.013	2721.991	-.022	-8.1	-.033	-12.1
14	2958.286	2958.267	-.019	-6.4	-.007	-2.4
15	2706.870	2706.856	-.014	-5.2	-.016	-5.9
16	3020.712	3020.709	-.003	-1.0	-.005	-1.7
17	6391.367	6391.352	-.015	-2.3	-.010	-1.6
18	6002.403	6002.381	-.022	-3.7	-.015	-2.5
19	3344.999	3344.990	-.009	-2.7	-.004	-1.2

Table 4. Mark-to-mark slope distances calculated using flight-path temperature and humidity and end-point pressure

A. MOUNT BAKER

Line	Line No.	Distance 1983
Forest Divide(B14)-Crag View(B12)	1	2283.411
Forest Divide(B14)-Talum(B6)	2	2240.848
Forest Divide(B14)-Lava Divide(B17)	3	4954.217
Lava Divide(B17)-Talum(B6)	4	4235.692
Lava Divide(B17)-Boulder(B5)	5	3702.088
Landes Cleaver(B13)-Boulder(B5)	6	3104.316
Landes Cleaver(B13)-Cockscomb(B4)	7	2769.781
Landes Cleaver(B13)-Hadley(B16)	8	2959.831
Hadley(B16)-Cockscomb(B4)	9	2963.909
Hadley(B16)-Roosevelt(B9)	10	3022.013
Thunder(B11)-Hadley(B16)	11	5440.966
Thunder(B11)-Cockscomb(B4)	12	4754.894
Thunder(B11)-Roosevelt(B9)	13	3842.378
Thunder(B11)-Colfax(B3)	14	2803.260
Park Butte(B1)-Colfax(B3)	15	6271.012
Park Butte(B1)-Deming(B2)	16	3772.257
Park Butte(B1)-Sherman Crater(B7)	17	6490.763
Park Butte(B1)-Crag View(B12)	18	4103.409
Crag View(B12)-Sherman Crater(B7)	19	3128.830

Table 4 (cont.)

B. MOUNT RAINIER

Line	Line No.	Distance		Change	
		1982	1983	m	ppm
Iron Mountain-McClure Tilt	1	8246.146	8246.149	+.003	+0.4
McClure Tilt-Camp Hazard(R5)	2	4469.319*	4469.363**	+.044	+9.8
McClure Tilt-Gibralter(R1)	3	Not measured			
McClure Tilt-Whitman(R2)	4	4083.408	4083.403	-.005	-1.2
McClure Tilt-Cowlitz(R18)	5	4375.606	4375.606	0	0
Cowlitz(R18)-Gibralter(R1)	6	5915.221			
Cowlitz(R18)-Whitman(R2)	7	2545.007	2545.004	-.003	-1.1
Goat Island(R10)-K Spire(R6)	8	3529.139	3529.112	-.027	-7.7
Goat Island(R10)-Gibralter(R1)	9	7686.764			
Goat Island(R10)-Steamboat Prow(R3)	10	5544.486	5544.473	-.013	-2.3
Goat Island(R10)-Burroughs(R4)	11	4676.877	4676.879	+.002	+0.4
Burroughs(R4)-K Spire(R6)	12	4750.163	4750.161	-.002	-0.4
Burroughs(R4)-Steamboat Prow(R3)	13	3600.299	3600.294	-.005	-1.4
Burroughs(R4)-Curtis(R7)	14	3446.880			
Burroughs(R4)-Old Desolate(R11)	15	3821.075			
Old Desolate(R11)-Steamboat Prow(R3)	16	6044.458			
Old Desolate(R11)-Curtis(R7)	17	4160.483			
Old Desolate(R11)-Ptarmigan(R16)	18	5911.635			
Observation Rock(R12)-Ptarmigan(R16)	19	3688.107	3688.084	-.023	-6.2
Observation Rock(R12)-Mowich(R8)	20	3124.005	3124.003	-.002	-0.6
Sunset(R19)-Mowich(R8)	21	4687.811	4687.817	+.006	+1.3
Sunset(R19)-Puyallup(R14)	22	3903.408	3903.390	-.018	-4.6
Andrew-Sunset(R19)	23	3479.389	3479.390	+.001	+0.3
Andrew-Puyallup(R14)	24	3183.044	3183.042	-.002	-0.6
Andrew-Glacier Island(R15)	25	2791.256	2791.259	+.003	+1.1
Andrew-Iron Mountain	26	4508.394	4508.392	-.002	-0.4
Iron Mountain-Puyallup(R14)	27	5642.937	5642.923	-.014	-2.5
Iron Mountain-Glacier Island(R15)	28	3556.891	3556.881	-.010	-2.8
Iron Mountain-St. Andrews Rock(R13)	29	7237.867	7237.821	-.046	-6.4
Iron Mountain-Camp Hazard(R5)	30	7079.010	7079.035	+.025	+3.5

*Very windy at McClure Tilt
**Very windy at Camp Hazard

Table 4 (cont.)

C. MOUNT HOOD (Benchmarks)

Line	Line No.	Distance		Change	
		1983	1984	m	ppm
Timberline(005)-White(H17)	1	3394.193	3394.192	-.001	-0.3
Timberline(005)-Mitchell(H14)	2	2289.981	2289.985	+.004	+1.7
Mitchell(H14)-Crater Rock(H18)	3		4224.425		
Mitchell(H14)-White(H17)	4	2984.681	2984.668	-.013	-4.4
Mitchell(H14)-Big Rock(H16)	5	1478.630	1478.629	-.001	-0.7
Lambertson(H13)-White(H17)	6	3400.730	3400.720	-.010	-2.9
Lambertson(H13)-Cooper(H7)	7	3297.693	3297.685	-.008	-2.4
Meadow(H8)-Lambertson(H13)	8	2603.382	2603.395	+.013	+5.0
Meadow(H8)-Cooper(H7)	9	3927.403	3927.410	+.007	+1.8
Meadow(H8)-Langille(H4)	10	4113.534	4113.542	+.008	+1.9
Cloud Cap(H12)-Cooper(H7)	11	4288.729	4288.729	0	0
Cloud Cap(H12)-Langille(H4)	12	3538.505	3538.503	-.002	-0.6
Cloud Cap(H12)-Barrett(H6)	13	3884.450	3884.454	+.004	+1.0
Sticks(H11)-Cloud Cap(H12)	14	6865.185	6865.183	-.002	-0.3
Sticks(H11)-Barrett(H6)	15	6468.952	6468.960	+.008	+1.2
Sticks(H11)-County Line(H3)	16	7378.448	7378.444	-.004	-0.5
Cathedral(H9)-Sticks(H11)	17	5287.198			
Cathedral(H9)-Barrett(H6)	18	2891.797			
Cathedral(H9)-County Line(H3)	19	2810.375			
Cathedral(H9)-Sandy(H1)	20				
Yokum(H10)-County Line(H3)	21	2302.261			
Yokum(H10)-Sandy(H1)	22	1125.280			
Yokum(H10)-Reid(H5)	23	1204.279			
Yokum(H10)-Mississippi(H15)	24	2540.300			
Yokum(H10)-Paradise(H2)	25	2726.381			
Paradise(H2)-Sandy(H1)	26	3099.246	3099.246	0	0
Paradise(H2)-Reid(H5)	27	2146.473	2146.476	+.003	+1.4
Paradise(H2)-Crater Rock(H18)	28	4039.718	4039.707	-.011	-2.7
Paradise(H2)-Mississippi(H15)	29		1635.433		
Timberline(005)-Crater Rock(H18)	30		4071.318		

Table 4 (cont.)

D. MOUNT SHASTA

Line	Line No.	Distance		Change	
		1982	1984	m	ppm
Red Butte(81.1)-Red Banks(81.14)	1	4901.118	4901.093	-.025	-5.1
Red Butte(81.1)-Sargent(81.2)	2	3093.804	3093.792	-.012	-3.9
Green Butte(81.13)-Red Banks(81.14)	3	3620.080	3620.082	+.002	+0.6
Green Butte(81.13)-Red Butte(81.1)	4	2403.796	2403.797	+.001	+0.4
Helen(81.17)-Red Banks(81.14)	5	2325.342			
Helen(81.17)-Red Butte(81.1)	6	4399.367	4399.362	-.005	-1.1
Helen(81.17)-Shastina(81.11)	7	2428.016	2428.017	+.001	+0.4
Helen(81.17)-Avalanche Gulch(81.16)	8	1894.745	1894.736	-.009	-4.7
Spur-Shastina(81.11)	9	2112.353	2112.328	-.025	-11.8
Pilgrim Creek(81.3)-Sargent(81.2)	10	3101.600	3101.590	-.010	-3.2
Pilgrim Creek(81.3)-Red Butte(81.1)	11	4207.026	4207.016	-.010	-2.4
Pilgrim Creek(81.3)-Wishbone(81.4)	12	1599.517	1599.535	+.018	+11.3
Pilgrim Creek(81.3)-Wintun(81.6)	13	2563.066			
Ash Creek(81.5)-Wishbone(81.4)	14	2615.112	2615.120	+.008	+3.1
Ash Creek(81.5)-Wintun(81.6)	15	2969.482	2969.464	-.018	-6.1
Ash Creek(81.5)-Hotlum(81.8)	16	3508.341			
Ash Creek(81.5)-Pilgrim Creek(81.3)	17	2106.465	2106.465	0	0
North Gate(81.7)-Hotlum(81.8)	18	4227.526			
North Gate(81.7)-Bolam(81.9)	19	4415.968	4415.973	+.005	+1.1
Lava Ridge(81.10)-North Gate(81.7)	20	5150.522	5150.508	-.014	-2.7
Lava Ridge(81.10)-Bolam(81.9)	21	4125.011	4124.989	-.022	-5.3

Table 4 (cont.)

E. LASSEN PEAK

Line	Line No.	Distance		Change	
		1982	1984	m	ppm
Emigrant-East Lassen(L.IV)	1	4116.357	4116.335	-.022	-5.3
Emigrant-Crescent Crater(L.V)	2	2873.505	2873.490	-.015	-5.2
Hot Rock-East Lassen(L.IV)	3	5242.582	5242.545	-.037	-7.1
Hot Rock-Crescent Crater(L.V)	4	3232.551	3232.530	-.021	-6.5
Jumbles(L.IX)-North Chaos(L.VIII)	5	2745.006	2745.001	-.005	-1.8
South Chaos(L.III)-East Lassen(L.IV)	6	3542.687	3542.661	-.026	-7.3
Loomis(L.II)-North Chaos(L.VIII)	7	4912.760			
Loomis(L.II)-South Chaos(L.III)	8	3909.619			
Loomis(L.II)-Brokeoff(L.VI)	9	4860.364			
Bumpass(L.XI)-Brokeoff(L.VI)	10	5462.956	5462.950	-.006	-1.1
Reading(L.XII)-East Lassen(L.IV)	11	3348.239	3348.229	-.010	-3.0
Reading(L.XII)-Bumpass(L.XI)	12	2829.732	2829.739	+.007	+2.5
Bumpass(L.XI)-South Lassen(L.X)	13	2722.018	2722.005	-.013	-4.8
Loomis(L.II)-South Lassen(L.X)	14	2958.290	2958.277	-.013	-4.4
Loomis(L.II)-West Lassen(L.I)	15	2706.874	2706.866	-.008	-3.0
South Chaos(L.III)-West Lassen(L.I)	16	3020.715	3020.721	+.006	+2.0
Brokeoff(L.VI)-West Lassen(L.I)	17	6391.373	6391.378	+.005	+0.8
Brokeoff(L.VI)-South Lassen(L.X)	18	6002.406	6002.412	+.006	+1.0
Brokeoff(L.VI)-Pilot Pinnacle(L.VII)	19	3345.002	3345.005	+.003	+0.9

Table 5. Differences in calculated distances using flightline and end-point meteorological measurements

A. MOUNT BAKER

Line No.	Flightline distance minus end-point distance 1983	
	Millimeters	Ppm
1	8	3.5
2	6	2.7
3	14	2.8
4	10	2.4
5	13	3.5
6	9	2.9
7	9	3.3
8	5	1.7
9	4	1.3
10	3	1.0
11	16	2.9
12	14	2.9
13	11	2.9
14	7	2.5
15	22	3.5
16	21	5.6
17	30	4.6
18	20	4.9
19	11	3.5
	mean=	3.1
	s.d.=	1.1

Table 5 (cont.)

B. MOUNT RAINIER

Line No.	Flightline distance minus end-point distance			
	1982		1983	
	Millimeters	Ppm	Millimeters	Ppm
1	37	4.5	30	3.6
2	17	3.8	16	3.6
4	13	3.1	8	2.0
5	17	3.9	14	3.2
6	10	1.7		
7	5	2.0	3	1.1
8	9	2.6	-9	-2.6
9	7	0.9		
10	9	1.6	15	2.7
11	11	2.4	14	3.0
12	16	3.4	12	2.5
13	8	2.2	4	1.1
14	12	3.5		
15	7	1.8		
16	25	4.1		
17	16	3.8		
18	22	3.7		
19	13	3.5	1	0.3
20	14	4.5	6	1.9
21	-4	-0.9	-1	-0.2
22	-2	-0.5	3	0.8
23	9	2.6	1	0.3
24	-1	-0.3	8	2.5
25	3	1.1	0	0
26	15	3.3	16	3.5
27	-1	-0.2	23	4.1
28	4	1.1	7	2.0
29	10	1.4	34	4.7
30	21	3.0	30	4.2
		mean=2.3		mean=2.0
		s.d.=1.5		s.d.=1.8

Table 5 (cont.)

C. MOUNT HOOD

Line No.	Flightline distance minus end-point distance			
	1983		1984	
	Millimeters	Ppm	Millimeters	Ppm
1	11	3.2	8	2.4
2	5	2.2	7	3.1
3			18	4.3
4	10	3.4	8	2.7
5	6	4.1	4	2.7
6	13	3.8	9	2.6
7	9	2.7	8	2.4
8	8	3.1	7	2.7
9	15	3.8	7	1.8
10	14	3.4	9	2.2
11	18	4.2	9	2.1
12	13	3.7	10	2.8
13	14	3.6	6	1.5
14	17	2.5	20	2.9
15	11	1.7	11	1.7
16	17	2.3	15	2.0
17	32	6.1		
18	14	4.8		
19	9	3.2		
21	10	4.3		
22	9	8.0		
23	7	5.8		
24	5	2.0		
25	6	2.2		
26	8	2.6	9	2.9
27	3	1.4	8	3.7
28	21	5.2	19	4.7
29			5	3.1
30			20	4.9
	mean=3.6		mean=2.8	
	s.d.=1.5		s.d.=0.9	

Table 5 (cont.)

D. MOUNT SHASTA

Line No.	Flightline distance minus end-point distance			
	1982		1984	
	Millimeters	Ppm	Millimeters	Ppm
1	14	2.9	11	2.2
2	10	3.2	16	5.2
3	4	1.1	4	1.1
4	-1	-0.4	5	2.1
5	0	0		
6	-3	-0.7	21	4.8
7	-4	-1.6	8	3.3
8	2	1.1	9	4.7
9	3	1.4	6	2.8
10	12	3.9	10	3.2
11	12	2.9	15	3.6
12	4	2.5	6	3.8
13	2	0.8		
14	1	0.4	9	3.4
15	0	0	9	3.0
16	3	0.9		
17	1	0.5	1	0.5
18	-6	-1.4		
19	0	0	11	2.5
20	-3	-0.6	22	4.3
21	7	1.7	8	1.9
		mean=0.9		mean=3.1
		s.d.=1.5		s.d.=1.3

Table 5 (cont.)

E. LASSEN PEAK

Line No.	Flightline distance minus end-point distance			
	1982		1984	
	Millimeters	Ppm	Millimeters	Ppm
1	4	1.0	8	1.9
2	2	0.7	3	1.0
3	9	1.7	-8	-1.5
4	7	2.2	3	0.9
5	9	3.3	3	1.1
6	8	2.3	9	2.5
7	12	2.4		
8	8	2.0		
9	5	1.0		
10	0	0	38	7.0
11	-2	-0.6	9	2.7
12	4	1.4	14	4.9
13	5	1.8	14	5.1
14	4	1.4	10	3.4
15	4	1.5	10	3.7
16	3	1.0	12	4.0
17	6	0.9	26	4.1
18	3	0.5	31	5.2
19	3	0.9	15	4.5
		mean=1.3		mean=3.2
		s.d.=0.9		s.d.=2.1

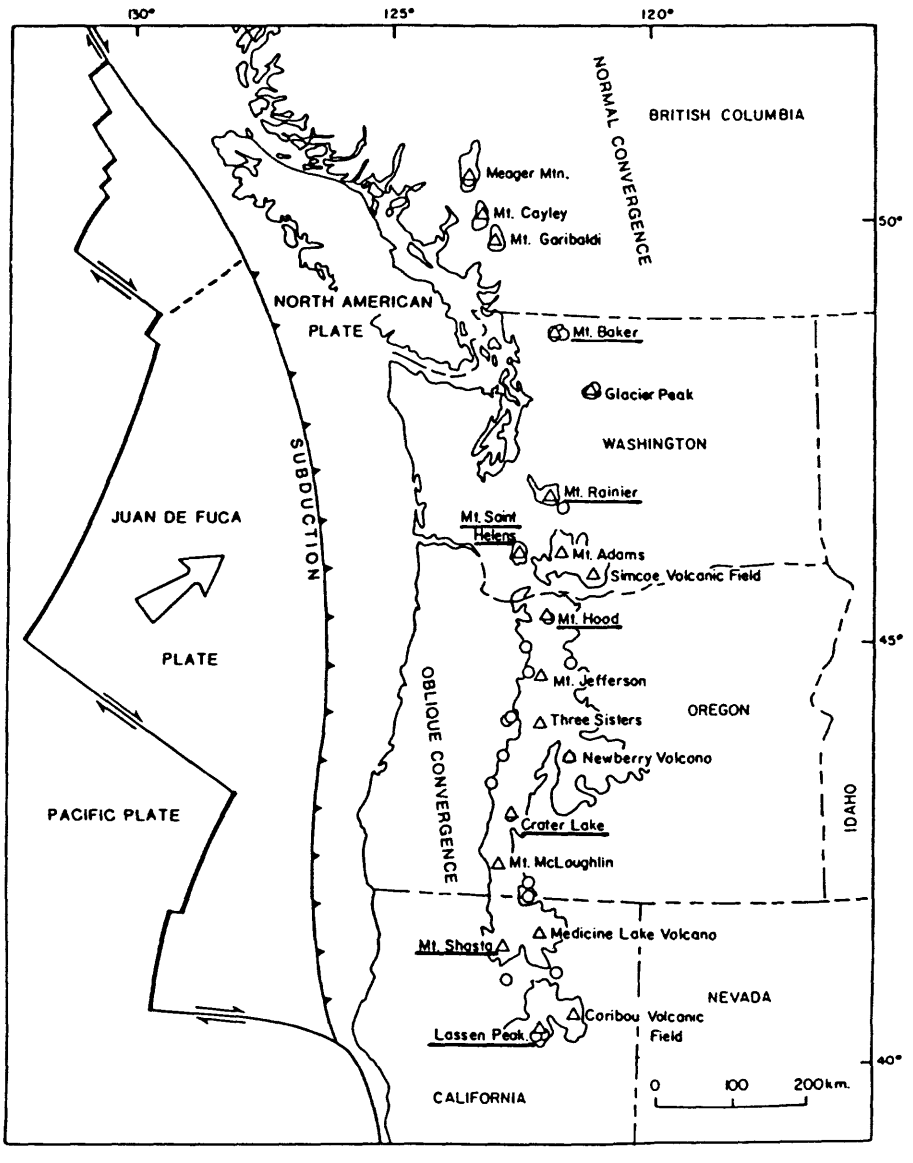

Figure 1. Index map of major Cascade volcanoes; areas of Quaternary volcanic rocks stippled. Underlined names indicate volcanoes with existing geodetic networks as of 1984. Figure courtesy of L.J.P. Muffler.

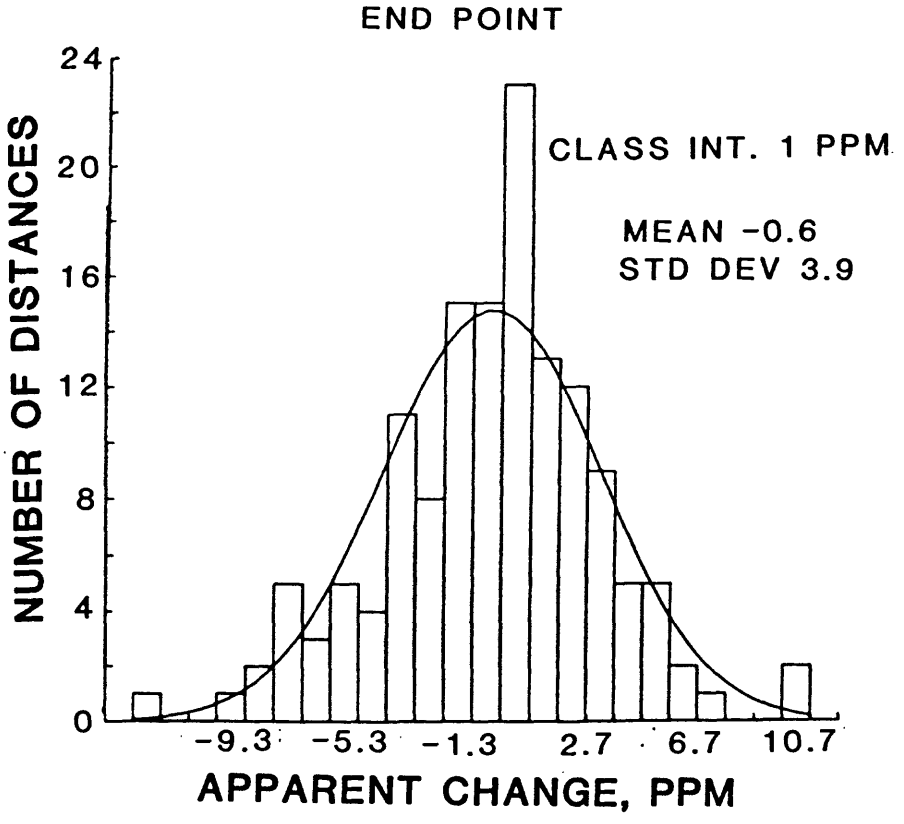

Figure 2. Histogram of apparent changes (in ppm) in 142 distances calculated from end-point measurements of temperature, pressure, and humidity at Mount Baker, Mount Rainier, Mount Hood, Mount Shasta, and Lassen Peak in 1981-1984. Smooth curve is normal in distribution with mean of -0.6 ppm and standard deviation of 3.9 ppm. Class int., class interval.

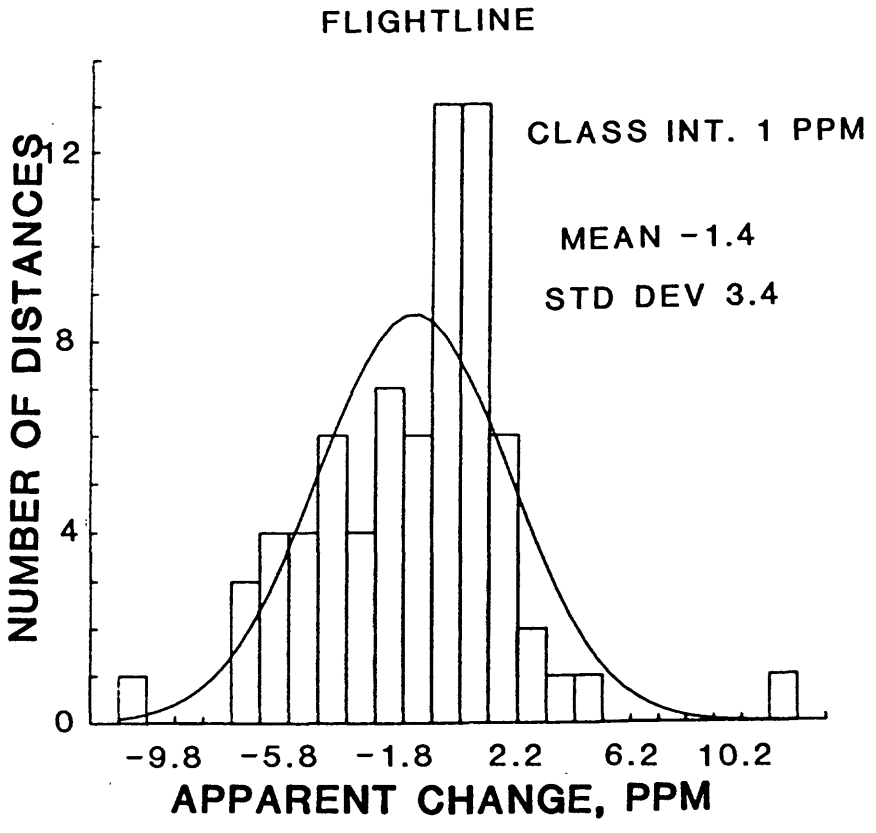

Figure 3. Histogram of apparent changes (in ppm) in 72 distances calculated from flightline measurements of temperature and humidity at Mount Baker, Mount Rainier, Mount Hood, Mount Shasta, and Lassen Peak in 1982-1984. Smooth curve is normal in distribution with mean of -1.4 ppm and standard deviation of 3.4 ppm. Reason for negative mean and skewness toward negative values not known, but we suspect poor distance measurements because of high wind at Mount Shasta and Lassen Peak in 1984 are biasing the distribution (see text). Class int., class interval.

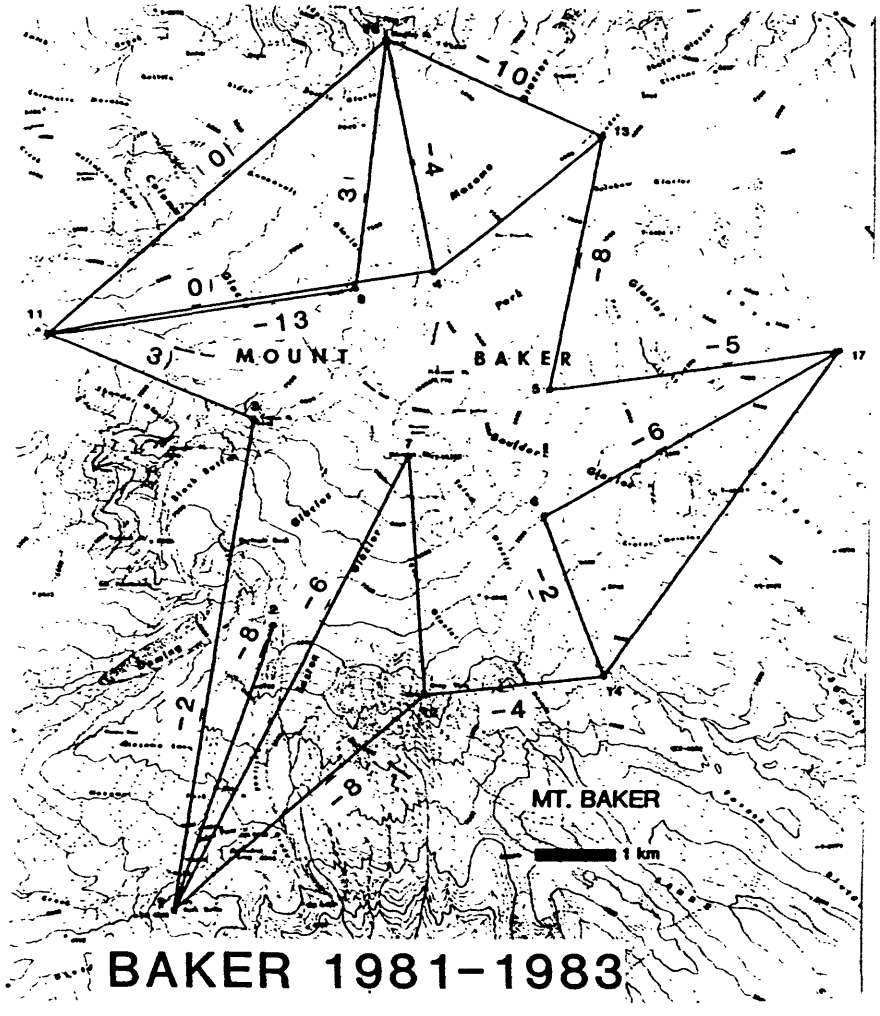

Figure 4. Map showing apparent changes in slope distance in millimeters at Mount Baker between 1981 and 1983, calculated with end-point data.

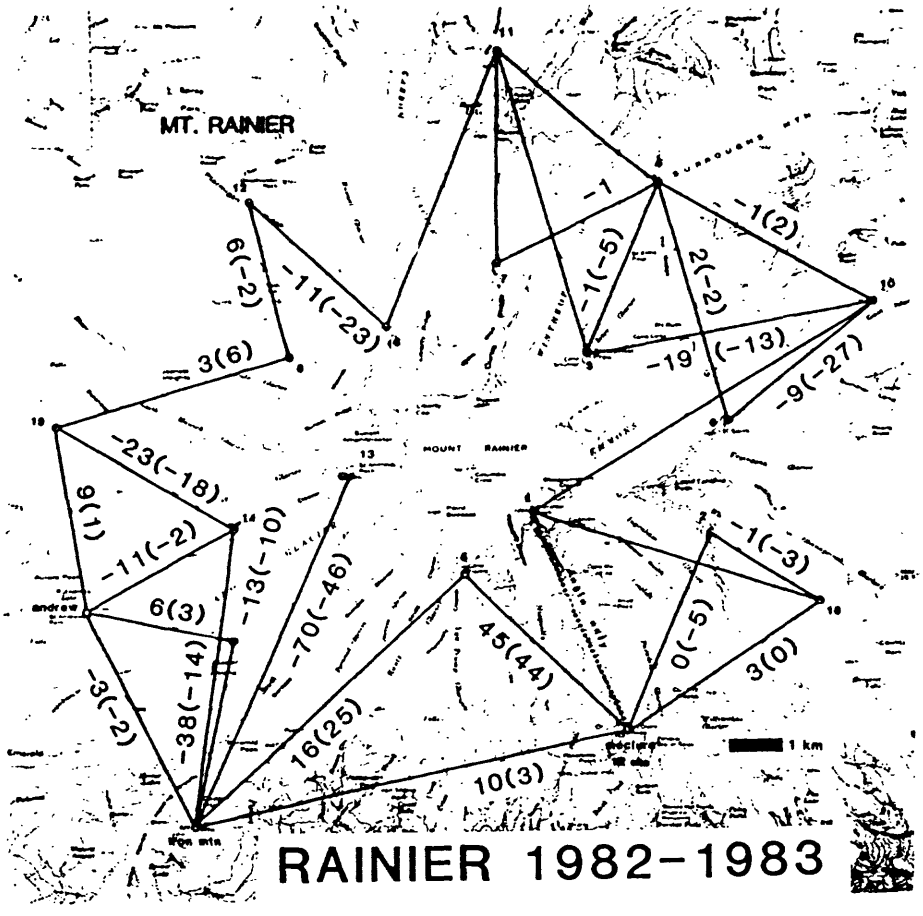

Figure 5. Map showing apparent changes in slope distance in millimeters at Mount Rainier between 1982 and 1983. Number outside parentheses, change based on end-point data. Number in parentheses, change based on flightline data.

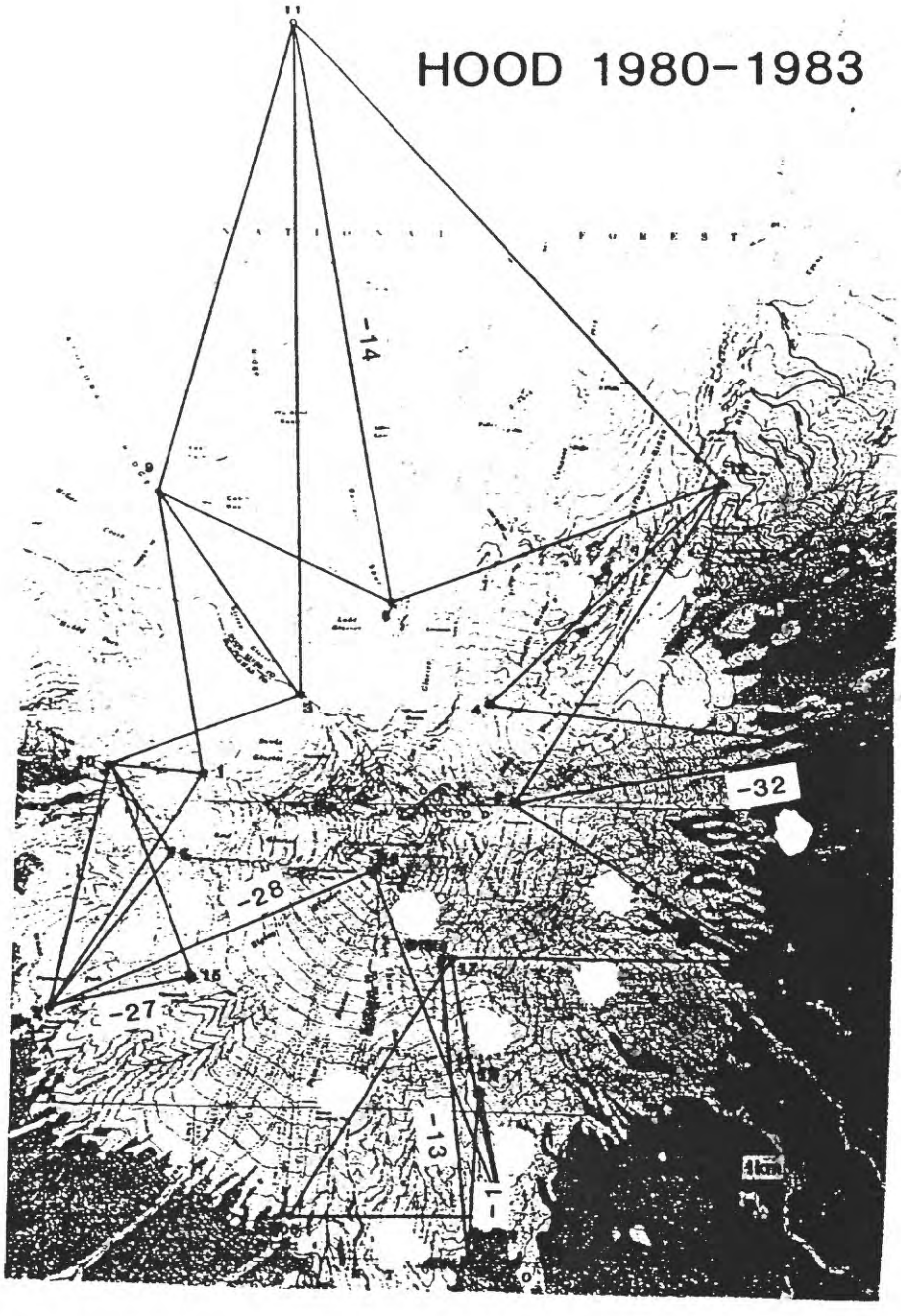

Figure 6. Map showing apparent changes in slope distance in millimeters at Mount Hood between 1980 and 1983, calculated with end-point data. Apparent changes are relatively large, but different EDM's were used in the two surveys and instruments for measuring temperature and pressure in 1980 were relatively crude.

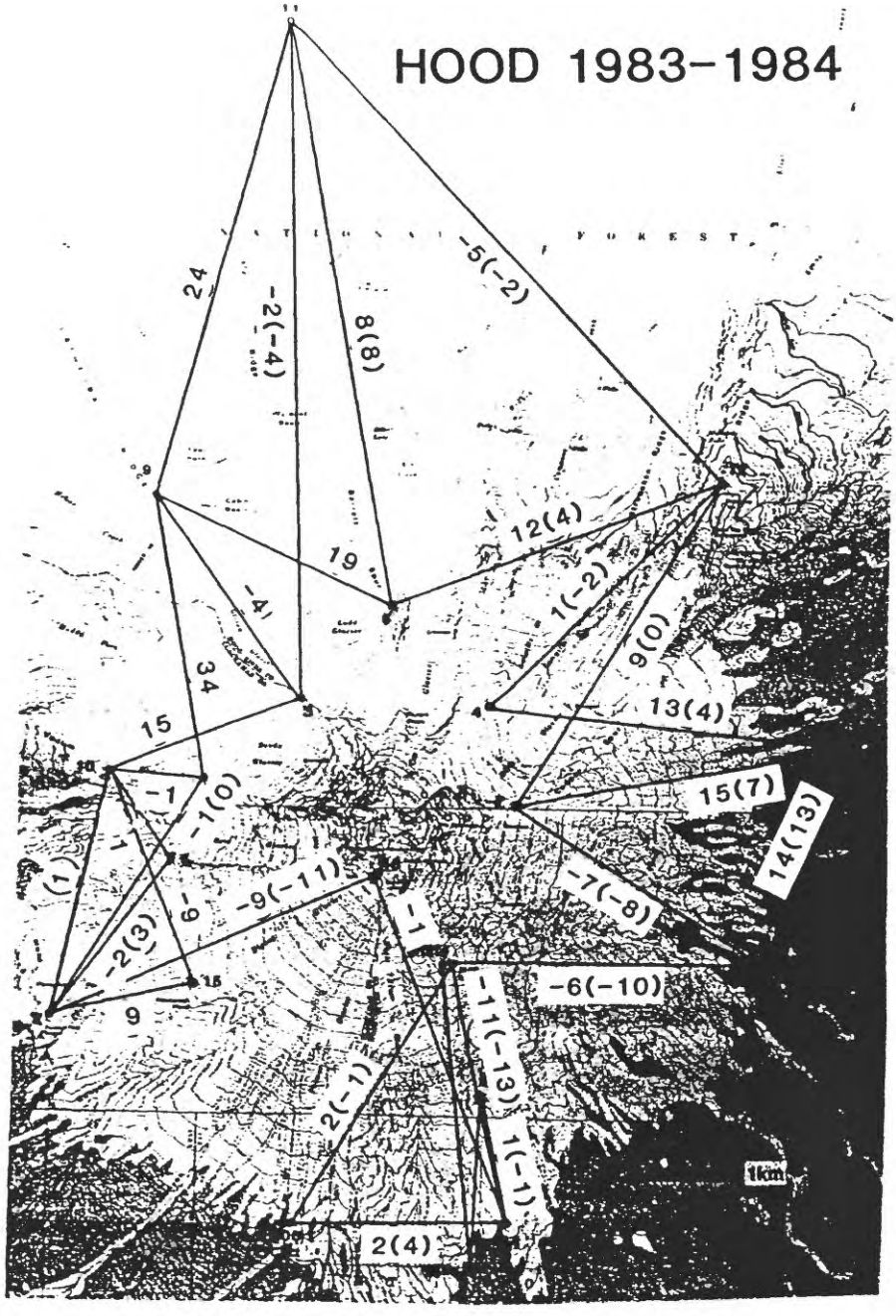

Figure 7. Map showing apparent changes in slope distance in millimeters at Mount Hood between 1983 and 1984. Number outside parentheses, change based on end-point data. Number in parentheses, change based on flightline data.

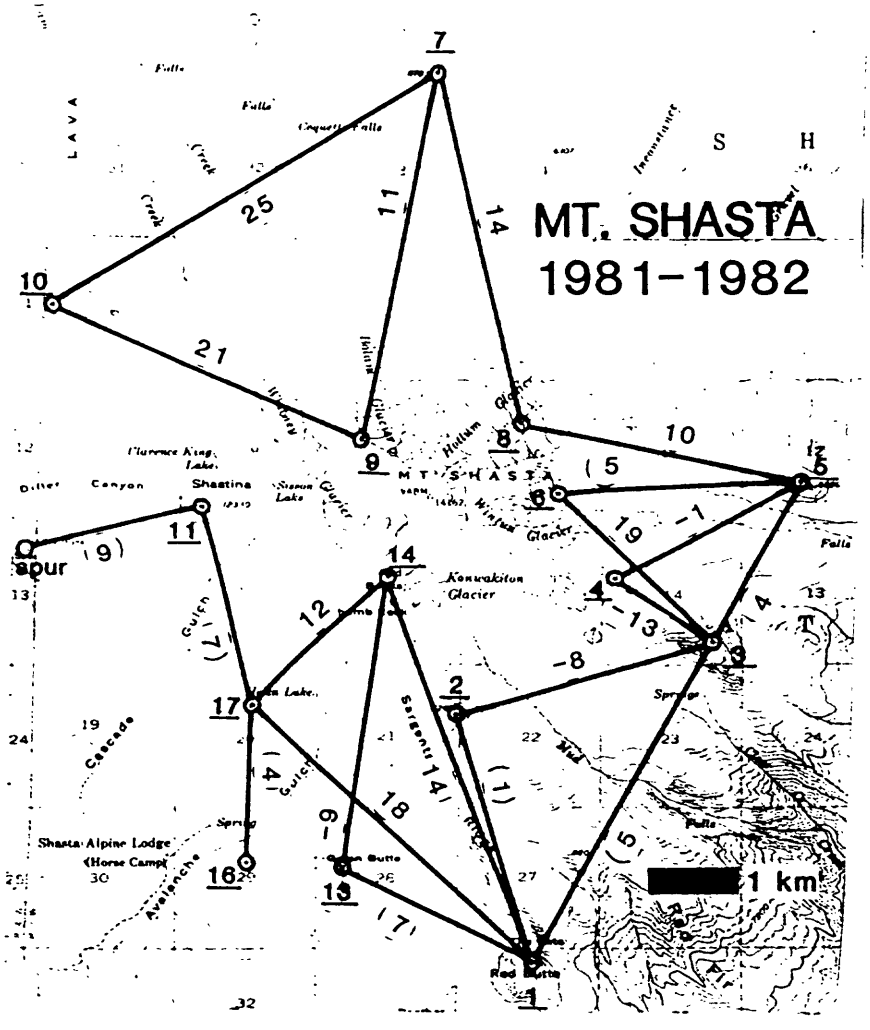

Figure 8. Map showing apparent changes in slope distance in millimeters at Mount Shasta between 1981 and 1982, calculated with end-point data. Underlined numbers, station designations

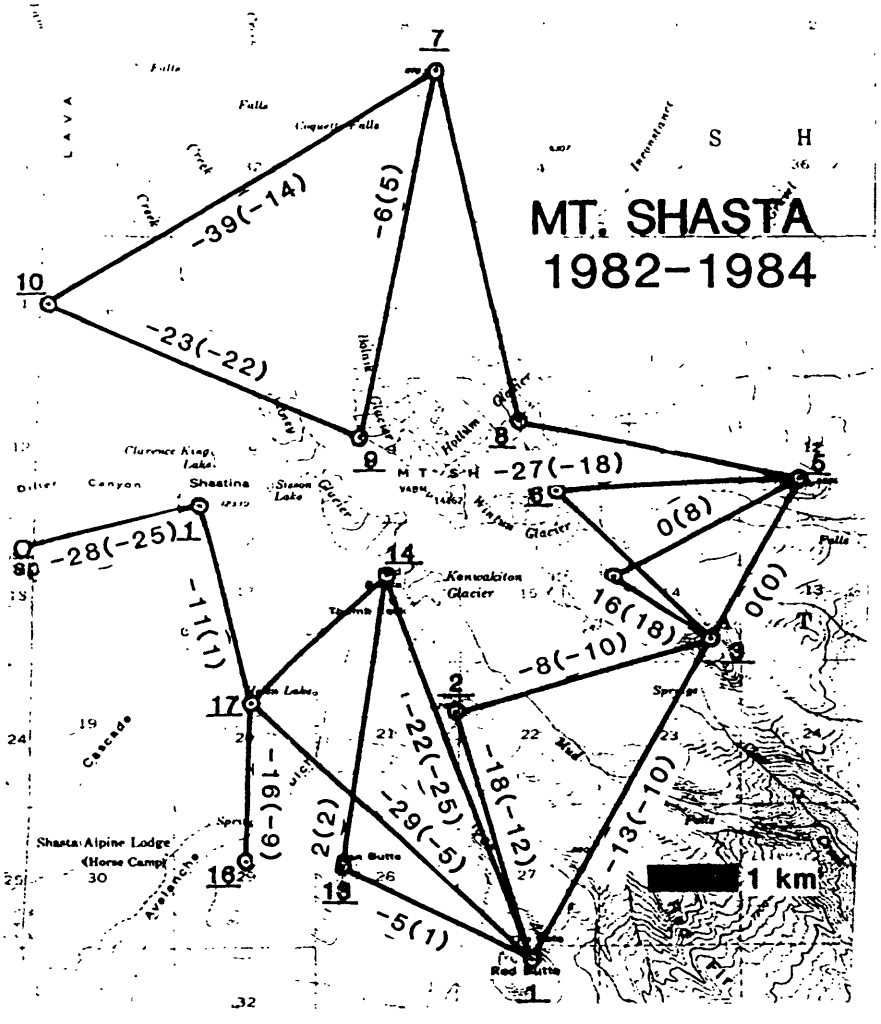

Figure 9. Map showing apparent changes in slope distance in millimeters at Mount Shasta between 1982 and 1984. Number outside parentheses, change based on end-point data. Number in parentheses, change based on flightline data. Underlined numbers, station designations.

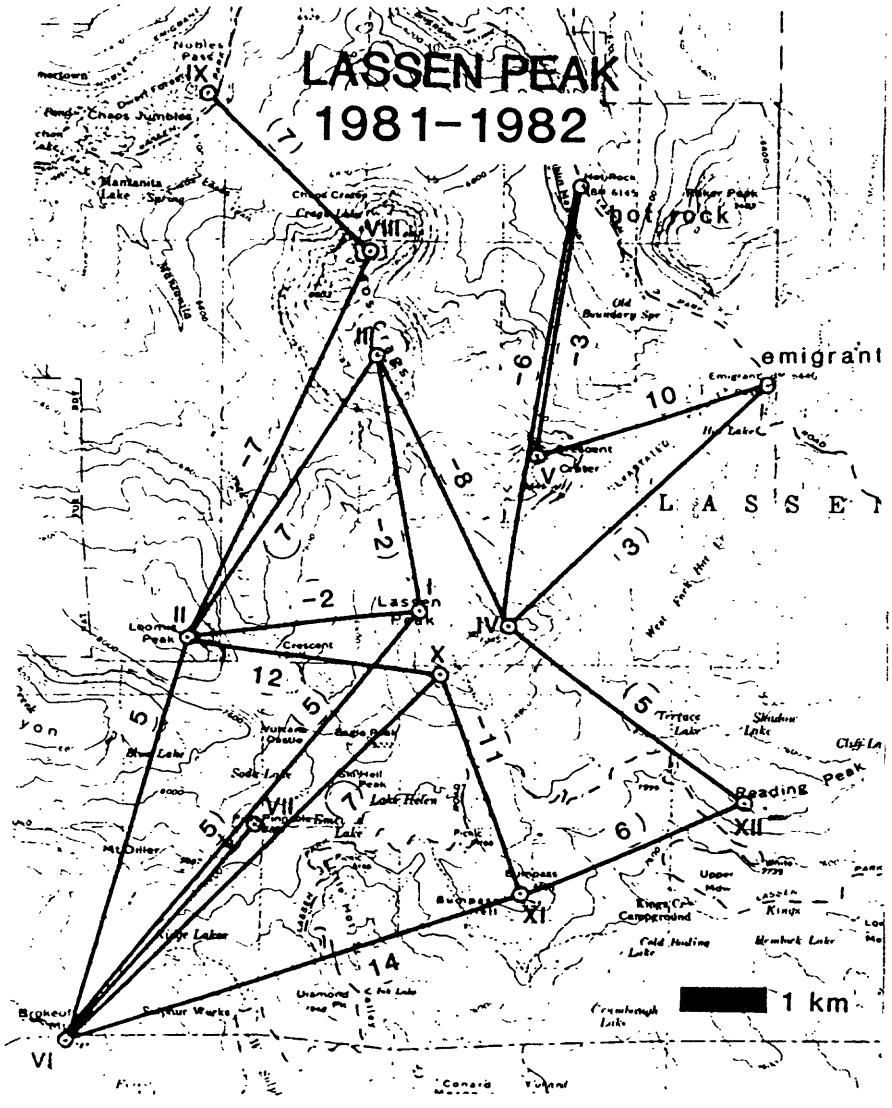

Figure 10. Map showing apparent changes in slope distance in millimeters at Lassen Peak between 1981 and 1982, calculated with end-point data.

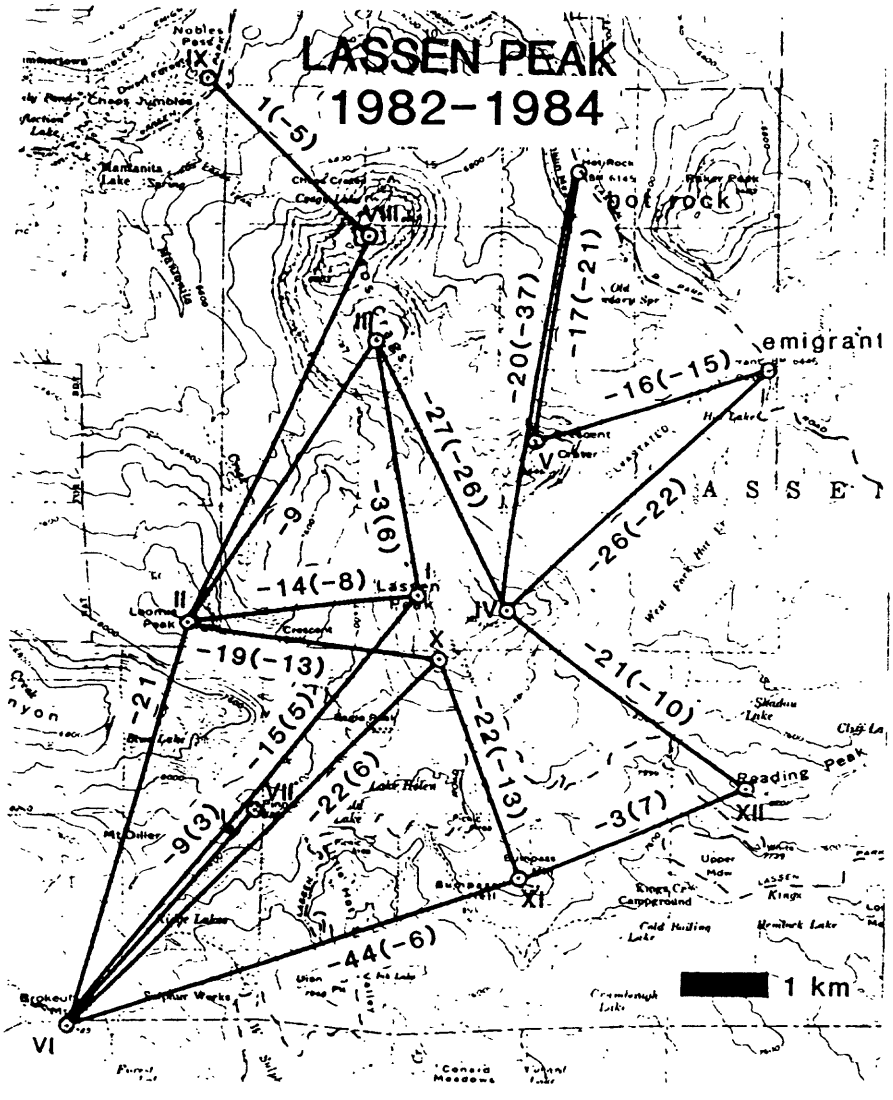

Figure 11. Map showing apparent changes in slope distance in millimeters at Mount Shasta between 1982 and 1984. Number outside parentheses, change based on end-point data. Number in parentheses, change based on flightline data.

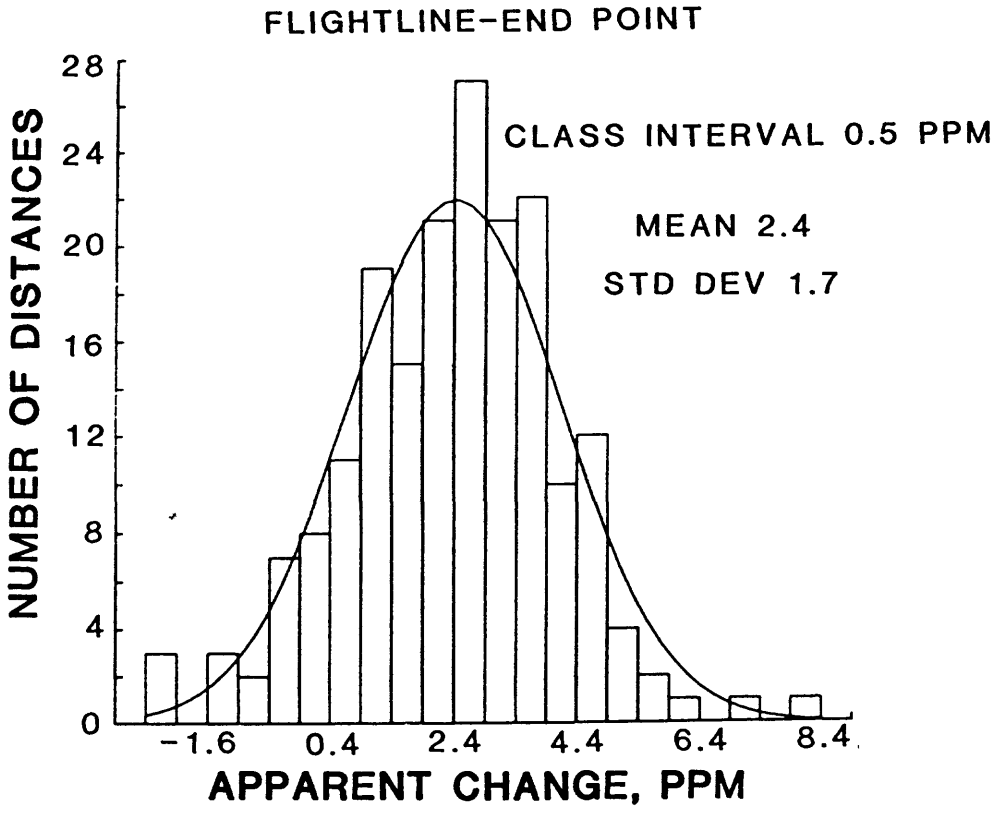

Figure 12. Histogram of differences in ppm between 190 distance-pairs calculated using flightline data and end-point data. Flightline calculations yield distances longer by a mean of 2.4 ppm (s.d.=1.7) than end-point calculations.

INTRODUCTION TO APPENDICES

The following appendices document benchmark (BM) locations at each volcano with maps, station descriptions, and photographs. The station descriptions assume that the reader has studied Figures A1, B1, C1, D1, E1, and F1, on which station locations and line numbers (circled) are indicated, and has access to appropriate topographic maps available from the U.S. Geological Survey:

Mount Baker: 1:24,000 USGS Interim Topographical Map of Mt. Baker (compiled by USGS Glaciology Project, Tacoma, Washington), or 1:62,500, Mt. Baker, Hamilton, and Mt. Shuksan, Wash., quadrangles;

Mount Rainier: 1;50,000, Mt. Rainier National Park, Wash.;

Mount Hood: 1:24,000, Mt. Hood North, Mt. Hood South, Oreg., quadrangles;

Crater Lake: 1:62,500, Crater Lake National Park and Vicinity, Oreg.;

Mount Shasta: 1:62,500, Shasta, Calif. quadrangle;

Lassen Peak: 1:62,500 Lassen Volcanic National Park and Vicinity, Calif.

Station elevations are given in feet to facilitate their use with topographic maps. Each network has one BM with a known or estimated elevation (the "reference elevation") from which the other station elevations were calculated using distance and vertical-angle measurements. Elevation closures for the Mount Baker, Mount Rainier, Mount Hood, and Lassen Peak networks are 5 ft, 3 ft, 4 ft, and 3 ft respectively. The Crater Lake and Mount Shasta networks do not close.

For each network, photographs are provided to assist in locating benchmarks precisely. A more complete set of photographs is on file at CVO. By coincidence, USGS Water Resources Division contracted 1:24,000 scale vertical aerial photography of Mount Shasta and Lassen Peak soon after our stations were installed in 1981. Photo targets were placed at all EDM and tilt stations prior to the flights and are discernible on the photographs. The contractor for the photography was Cartwright Aerial Surveys, Inc., Sacramento, CA. The relevant flight lines are 81167 and 81178. No such aerial photography showing locations of stations exists for the other monitored volcanoes.

A NOTE OF CAUTION: Be prepared when these surveys are attempted. Especially at Mounts Baker, Rainier, and Hood, an ice axe and crampons are minimal and mandatory safety equipment. Go equipped to walk or climb down the slopes if an emergency arises. No one should go to any of the high stations without at least some mountaineering experience. For Mount Rainier, each party member should have a copy of Becke's climbing guide.

APPENDIX A:
MOUNT BAKER

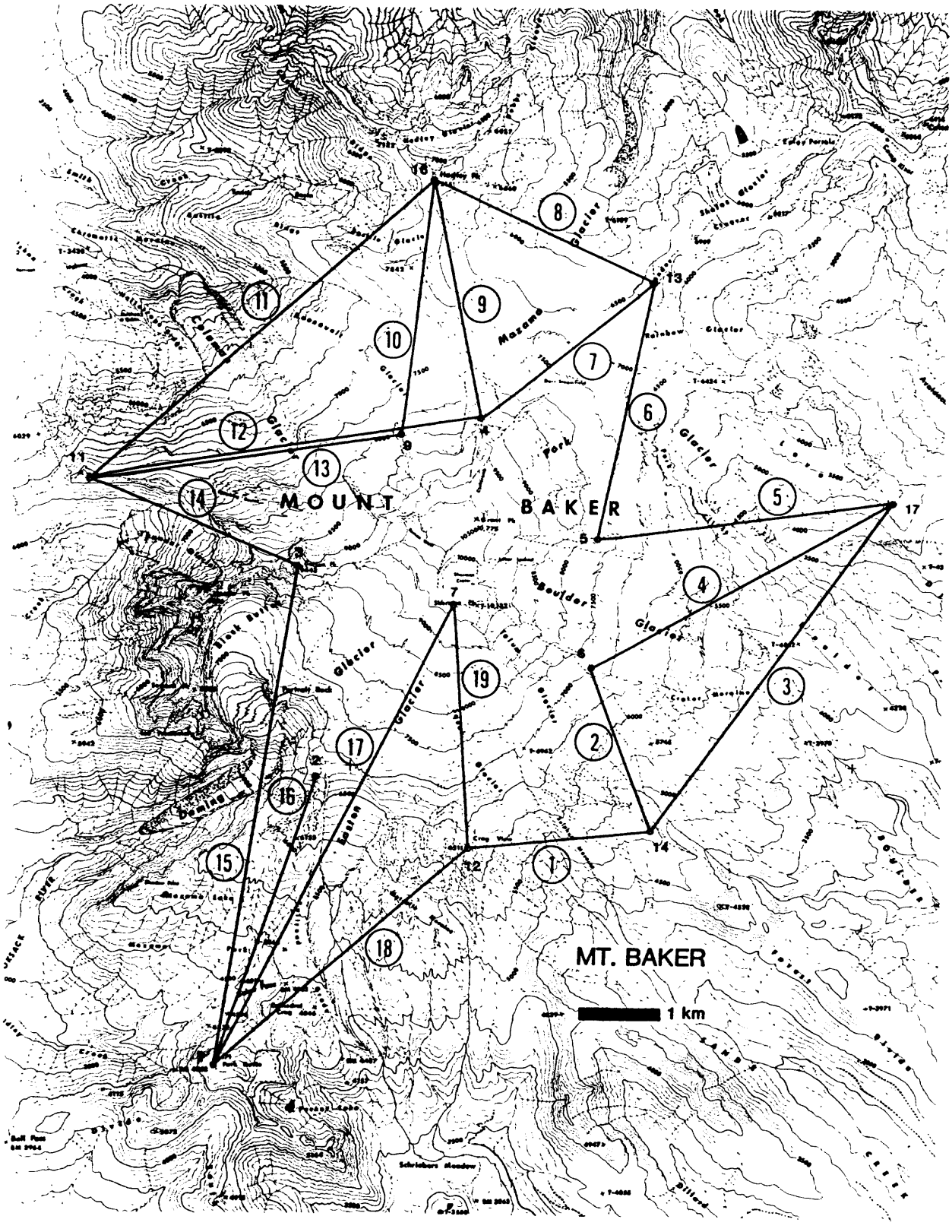

Figure A1. Map of trilateration network at Mount Baker, Washington.

B.1: "Park Butte" (5471'; reference elevation). BM is located on Park Butte near southeast end of rocky ridge on which lookout is built. Well maintained foot trail leads to site from Schriebers Meadow.

B.2: "Deming" (6738'). BM is east of curve in Deming Glacier and cemented in solid rock on relatively narrow part of ridge that broadens just to north. A 75 foot-high step, down to the south, occurs just downslope of BM. Small rock cairn marks site.

B.3: "Colfax" (9448'). BM is on summit of Colfax Peak (in Black Buttes area). Large snow bank just north of mark in 1981 and 1983.

B.4: "Cockscomb" (9041'). BM located about 100 feet north of very steep segment of narrow ridge crest at southwest head of Mazama Glacier. View to station 13 may be obscured by snow.

B.5: "Boulder" (7857'). BM is on northern spur of ridge south of Park Glacier, on ridge crest about 75 feet from where the spur leaves main ridge. Landing site is on snow at start of spur ridge.

B.6: "Talum" (7250'). Ridge between Talum and Boulder Glaciers forms prominent cliff facing south. At about 7300 feet, ridge steps up about 50 feet; a small natural window occurs just downslope. BM is about 150 feet downslope from step, on crest of ridge and just above small (5 by 10 feet in diameter) bench filled with white ash. Landing site is on snow north of step in ridge.

B.7: "Sherman Crater" (9820'). BM is cemented in rock at low point in saddle between Pooch Peak and Sherman Peak (both on the south rim of Sherman Crater). A piece of rebar is about 10 feet toward Sherman Peak from BM. View to station 12 may be obscured by snow.

B.9: "Roosevelt" (8408'). On west side of Roosevelt Glacier is a series of snow-free ridges. BM is on relatively flat upslope (south) end of northernmost ridge, in bedrock 1 ft above general ground surface, very near landing site.

B.11: "Thunder" (7144'). BM is northeast of Thunder Glacier, at east end of broad, flat, rocky area labeled 7128 on map, along start of narrow ridge leading toward summit, on top of low knob forming north side of narrow, 3 feet-deep "pass".

B.12: "Crag View" (6521'). BM is located upridge from tilt site A, about 100 feet downslope from high point of Crag View, along crestline of ridge where it changes from craggy to flat. Helicopter landing site is about 100 feet downslope from BM. Outcrop containing BM overhangs to west. Brunton compass lost here in 1983. Tilt site "A" (Frank and others, 1975) is about 400 feet lower on east side of same ridge.

B.13: "Landes Cleaver" (6809'). BM is at southwest end of Landes Cleaver, above and northeast of 600 by 600 foot-diameter flat area. BM is in center of 6 by 6 foot boulder located 12 feet west of north-trending ridge crest, about 120 feet north of end of ridge where ridge meets large flat area. Tilt site "B" (Frank and others, 1975) is about 500 feet west of BM.

B.14: "Forest Divide" (5212'). BM is on Forest Divide in small rock at east end of flat ridge crest. Looking from BM, a cluster of rocks and pine trees occurs toward the summit, and a clump of heather lies to the southwest. At southwest edge of this heather clump is large rock. Azimuth from this rock to Mount Shuksan is 55° and from rock to BM is 45°. Small bench occurs about 25 feet lower and 50 feet east of BM. Helicopter landing site is within few feet of BM, which was covered by snow in 1983 and had to be shoveled clear.

B.16: "Hadley" (7368'). BM is above first broad saddle south of Hadley Peak, in northernmost of two truck-sized rock outcrops south of high point on Hadley Peak. These outcrops are the lowest large outcrops on ridge, which becomes a smooth saddle further south. Outcrop with BM is flush with ridge and juts out westward to create 25 foot step. Landing site is east of saddle on snow.

B.17: "Lava Divide" (5562'). On Lava Divide (between Avalanche Gorge and Park Creek), east of Park Glacier, is a pair of high points downslope from glacier ice hanging on north side of Lava Divide and west of highest broad flat area on ridge. BM is on summit of southeast high point of the pair, at edge of cliff between the two high points. Landing site is in broad flat area at base of pair of high points. Steep short climb to mark.

Figure A2. EDM set-up at B1 with Park Butte lookout in background.

Figure A3. Aerial view looking north of B2.

Figure A4 Reflector set-up at B2.

Figure A5. Aerial view looking north of reflector set-up at B3.

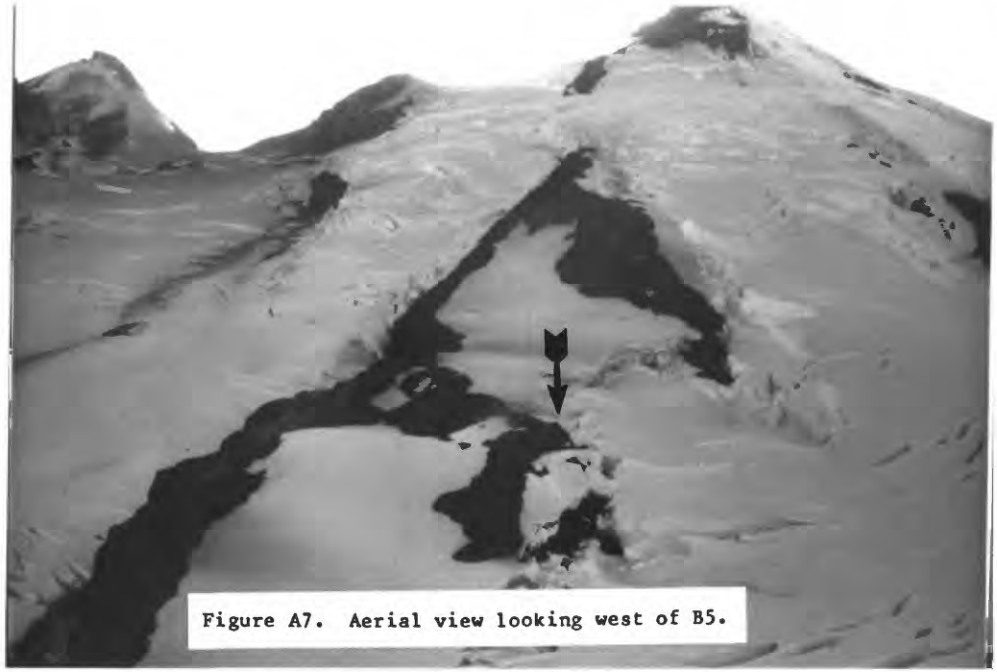

Figure A7. Aerial view looking west of B5.

Figure A6. Aerial view looking east of reflector set-up at B4.

Figure A9. Aerial view looking northwest of B6.

Figure A8. Aerial view looking south of B5.

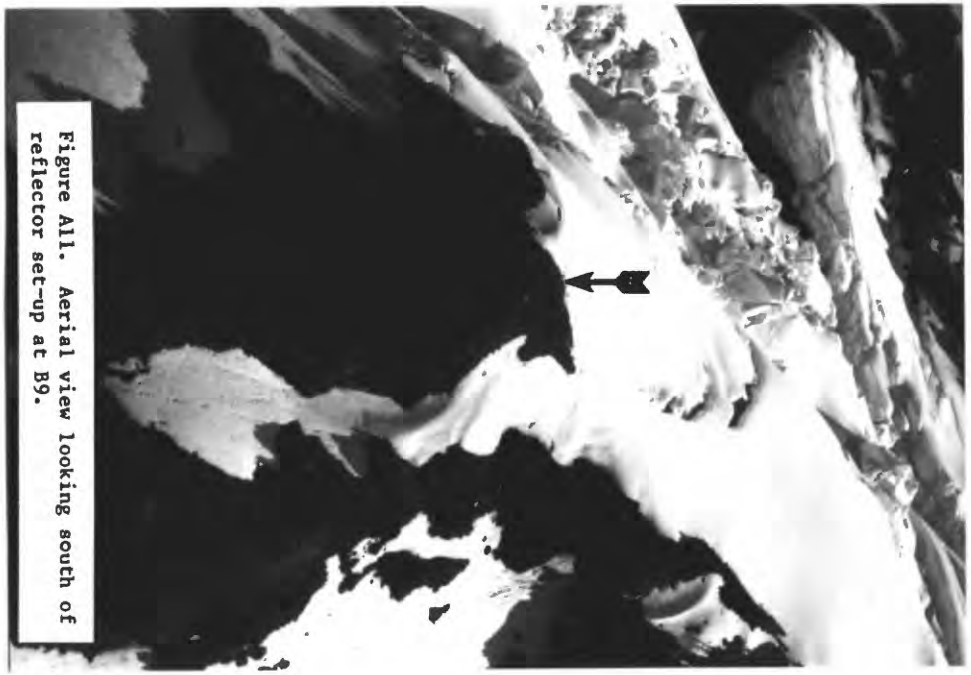

Figure A11. Aerial view looking south of reflector set-up at B9.

Figure A10. View looking west of reflector set-up at B7.

Figure A13. Aerial view looking northwest of reflector set-up at B12.

Figure A12. Aerial view looking north of EDM set-up at B11.

Figure A14. View from B1 of mirror flash from B12

Figure A16. Aerial view looking southwest of EDM set-up at B14.

Figure A15. Aerial view looking north of B13.

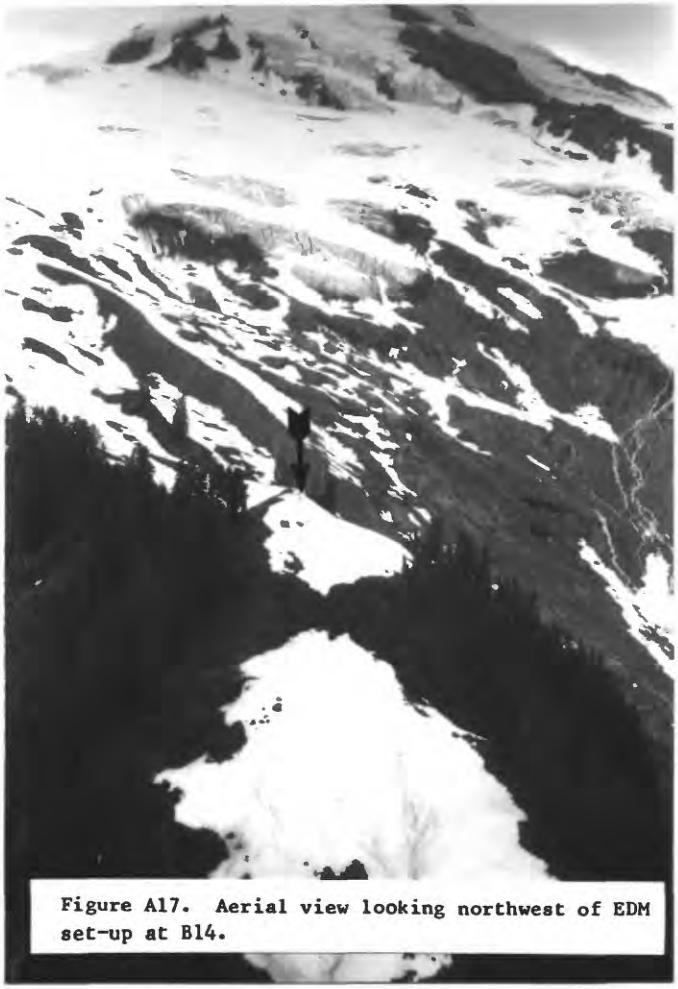

Figure A17. Aerial view looking northwest of EDM set-up at B14.

Figure A19. Aerial view looking north of B16.

Figure A18. EDM set-up at B14.

Figure A21. View from B6 of mirror flash from B17.

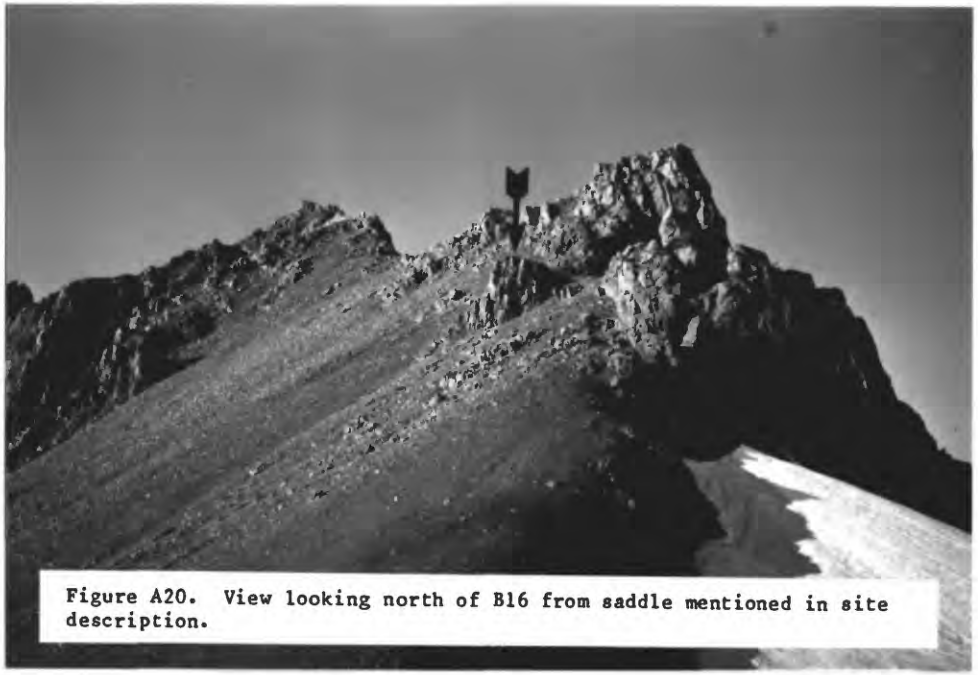

Figure A20. View looking north of B16 from saddle mentioned in site description.

APPENDIX B:
MOUNT RAINIER

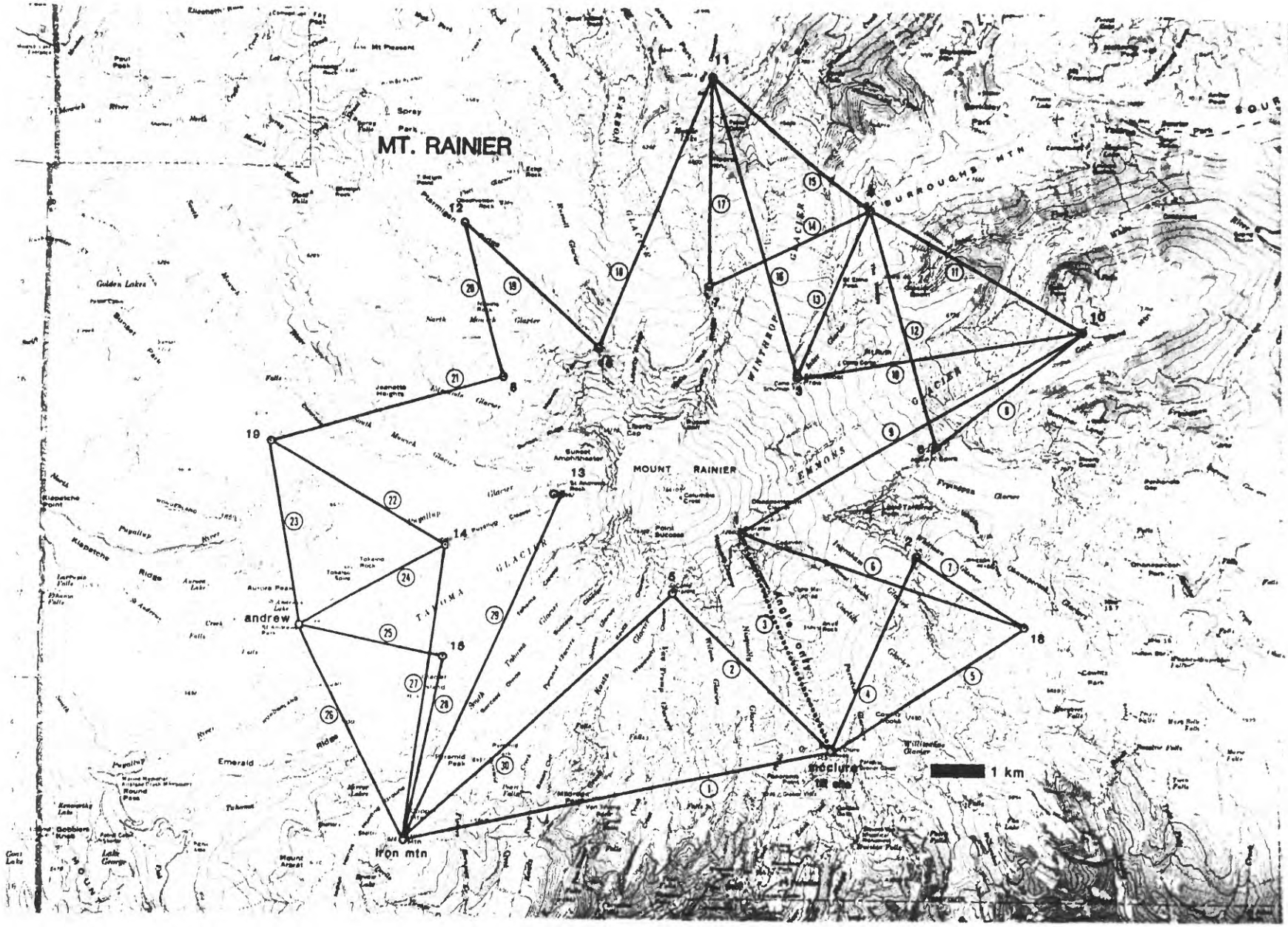

Figure B1. Map of trilateration network at Mount Rainier, Washington

R.1: "Gibralter" (12676'). BM is about 5 feet below highest point on Gibralter Rock. Landing site is in narrow saddle at highest point. Very difficult landing, not possible in moderate or strong wind.

R.2: "Whitman" (9286'). BM is southeast of Little Tahoma Peak on ridge just west of Whitman Glacier. Landing site is in prominant flat on ridge. Station is 30 feet south-southeast of highest point on this part of ridge, right at landing site. BM is in top of rock near large flat rock.

R.3: "Steamboat Prow" (9720'). BM is 3 feet below highest point on Steamboat Prow, on stable side of big rock.

R.4: "Burroughs" (7830'). BM is southwest of broad saddle between two high points, on broad rocky ridge northeast of westernmost high point, about 50 feet north of curve in ridge.

R.5: "Camp Hazard" (11531'). BM is below the small wishbone of summit glacier. Landing site is smooth flat area above rock cliffs just east of lower west arm of glacier, just downslope from rock about as large as a two-man tent whoses long axis is oriented upslope. BM is in rock just upslope from "tent rock". Nippled tilt BM "Y" (one of 3 in area) is within a few meters of BM. NOTE: In Dzurisin and others (1983), locations of nippled tilt BM's in this area are described, but site is mislocated on photograph in Figure 7. Figures B2 and B3 in this report show correct location.

R.6: "K-Spire" (8206'). Between K-Spire and next prominent knob downslope is saddle, which is landing site. From low point in saddle walk about 100 feet toward mountain on north side of the saddle, staying at same elevation. BM is in top of rock outcrop, part of small cliff about 60 feet northwest of saddle ridgeline.

R.7: "Curtis" (8702'). BM is at downslope end of very flat part of Curtis Ridge, in rock outcrop forming cliff on east side of ridge. Nippled tilt BM's nearby (Dzurisin and others, 1983).

R.8: "Mowich" (9265'). Below Mowich Face are three fin-shaped (tall and thin) outcrops of welded breccia elongate downslope. Just above fins is small ridge perpendicular to them that resembles miniature Steamboat Prow. Landing site is flat area on this ridge. BM is 100 feet north of high point on flat, in boulder 1 1/2 feet above ground level.

R.10: "Goat Island" (7220'). Goat Island Mountain is a discontinuous ridge just east of terminus of Emmons Glacier, with high points at either end. BM is on top of broad west peak, map elevation 7218 feet, on a 3 feet diameter rock.

R.11: "Old Desolate" (7133'). BM is on southwest-trending dogleg of Old Desolate ridge immediately north of Mystic Lake, at base of one of four high points comprising this section of ridge. From landing site on ridge crest just north of highest knob at about 7100 feet elevation (note rock cairn), walk up and south to base of next high point. Two prominent transverse ribs (5-10 feet high) must be crossed. BM is on ridge crest below this second high point.

R.12: "Observation Rock" (7802'). BM is southwest of Observation Rock on Ptarmigan Ridge, approximately 10 feet from south-facing cliff that descends to terminus of North Mowich Glacier. Two large depressions occur in this part of ridge (but only one is noticeable if there is much snow). BM is located on southwest edge of western depression.

R.13: "St. Andrews Rock" (11033'). BM is about 30 feet higher than, and east of, saddle between two peaks of St. Andrews Rock, in lowest small ledge above saddle. Only station visible from site is Iron Mountain.

R.14: "Puyallup" (8830'). On Puyallup Cleaver just downslope from map point 8966 is flat landing site. BM is 50 feet downslope from flat in one of first large boulders.

R.15: "Glacier Island" (7686'). BM is on flat surface about 15 feet west and 6 feet below highest point on Glacier Island.

R.16: "Ptarmigan" (10455'). BM is on Ptarmigan Ridge on first bench above (south of) broad saddle, about 75-100 feet higher in elevation than saddle and about 8 feet lower than high point on nearby bench. High cliff to east. Saddle is landing site.

R.18: "Cowlitz" (7819'). BM is on Whitman Crest Ridge south of Ohanapecosh Glaciers, on small knoll sloping gently eastward, about 5 feet from steep slope to west, and about 300 feet east of most prominent knoll on ridge. Cliff of nicely columnar andesite starts several meters east of BM.

R.19: "Sunset" (6756'). BM is on lower end of ridge south of South Mowich Glacier, southwest of terminus of glacier and southeast of map point 6718. Landing site is flat just downslope from hogback. BM is on south side of ridge, slightly west of landing site about 100 feet below ridge crest in rib of rock extending south from ridge. (NOTE: BM is not labelled as of 1984 but should be in near future).

McClure Tilt Site: (7380'). McClure Rock is prominent rock rib above Paradise at map elevation 7385 feet. Our station is <u>not</u> the old BM (installed in 1910) set on large boulder. Instead, tripod is centered over hole punched in apex of letter "A" of word "PARK" on "Z" nippled tilt BM, established September 1982 for dry tilt leveling (Dzurisin and others, 1983). "Z" BM is farthest north of 3 tilt BM's within 5 feet of 40 foot cliff to east.

Preexisting benchmarks used:

Iron Mountain: (6283'; reference elevation). BM is at northernmost end of summit of Iron Mountain, on rock outcrop above high cliff.

Andrew: (6718'). St. Andrews Park is at map point 6716 on lower end of Puyallup Cleaver, on broad, flat-topped, sparsely vegetated peak. BM is on low rock marked by rock cairn near west-northwest edge of summit, perhaps 50 feet from cliff.

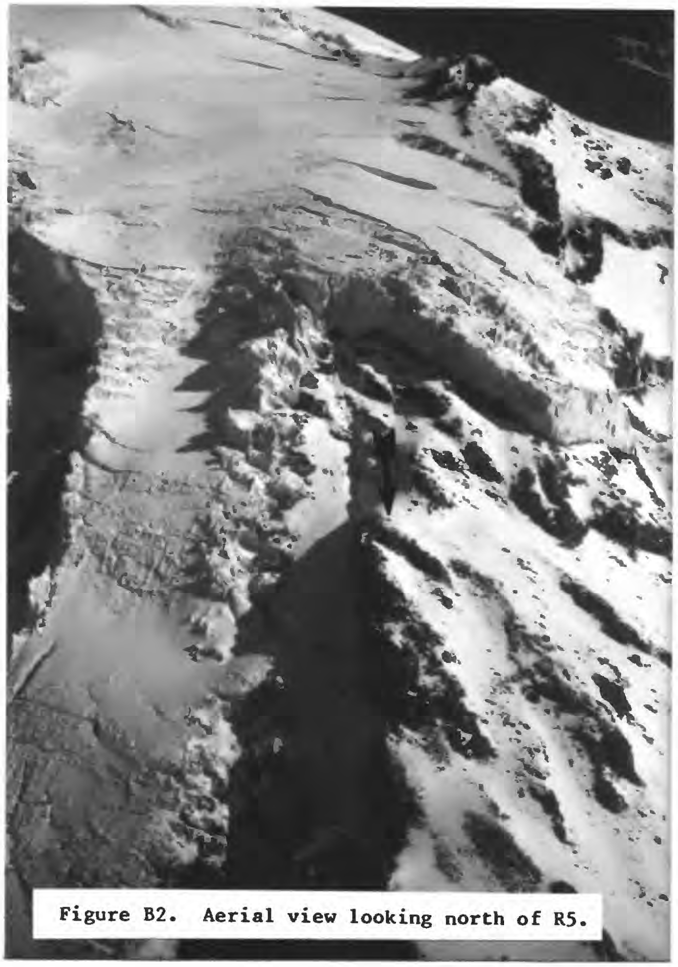

Figure B2. Aerial view looking north of R5.

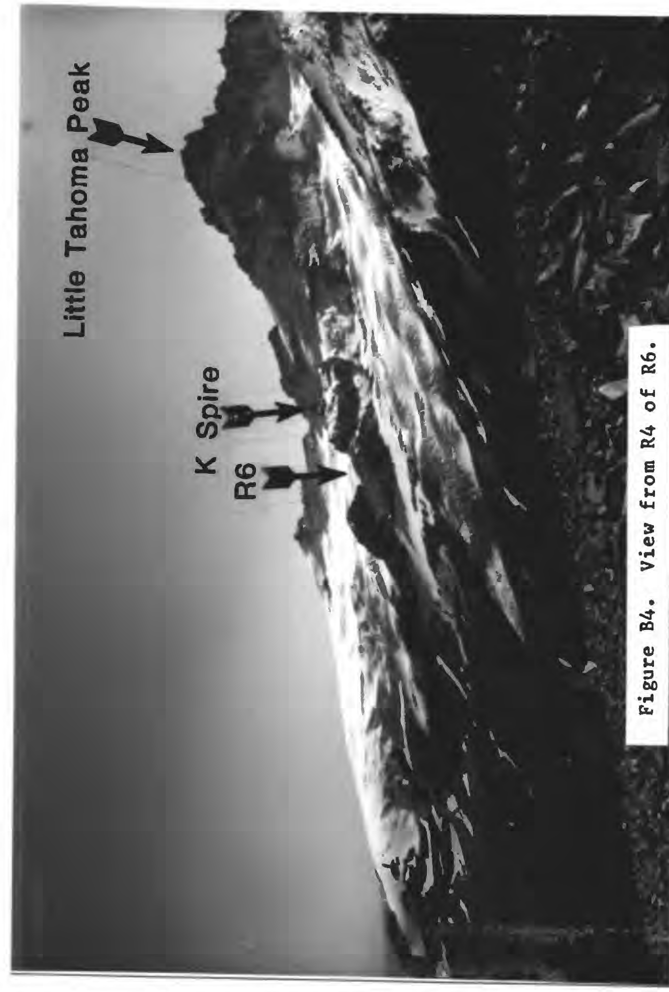

Figure B4. View from R4 of R6.

Figure B3. View looking north of reflector set-up at R5.

Figure B5. Aerial view looking north of R7.

Figure B6. View from R12 of mirror flashes from R8 and R16.

Figure B8. View from R7 of mirror flash from R11.

Figure B7. Aerial view looking northwest of reflector set-up at R8.

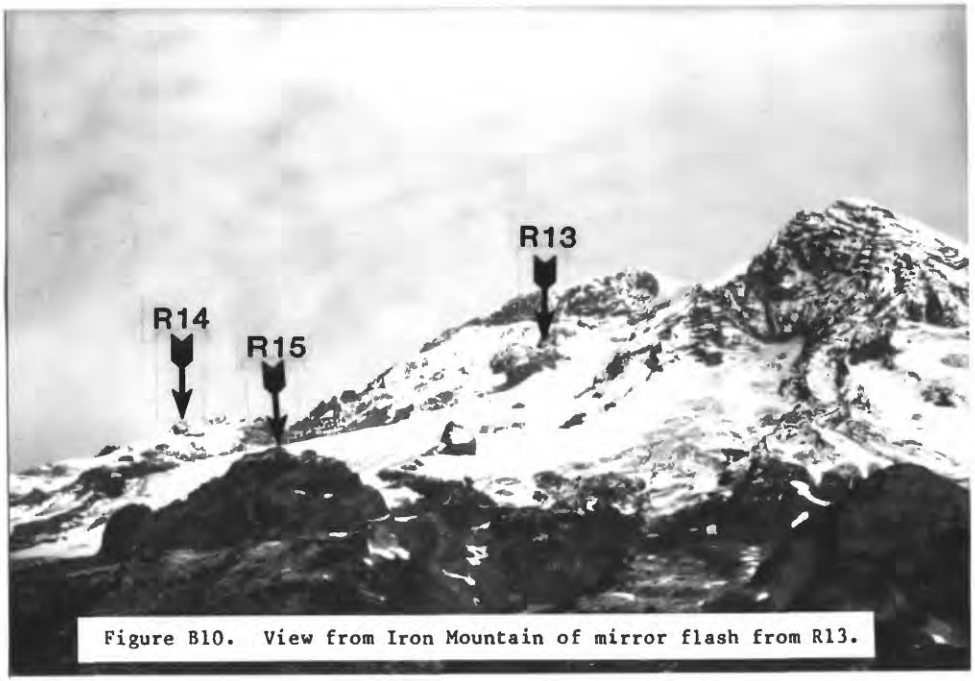

Figure B10. View from Iron Mountain of mirror flash from R13.

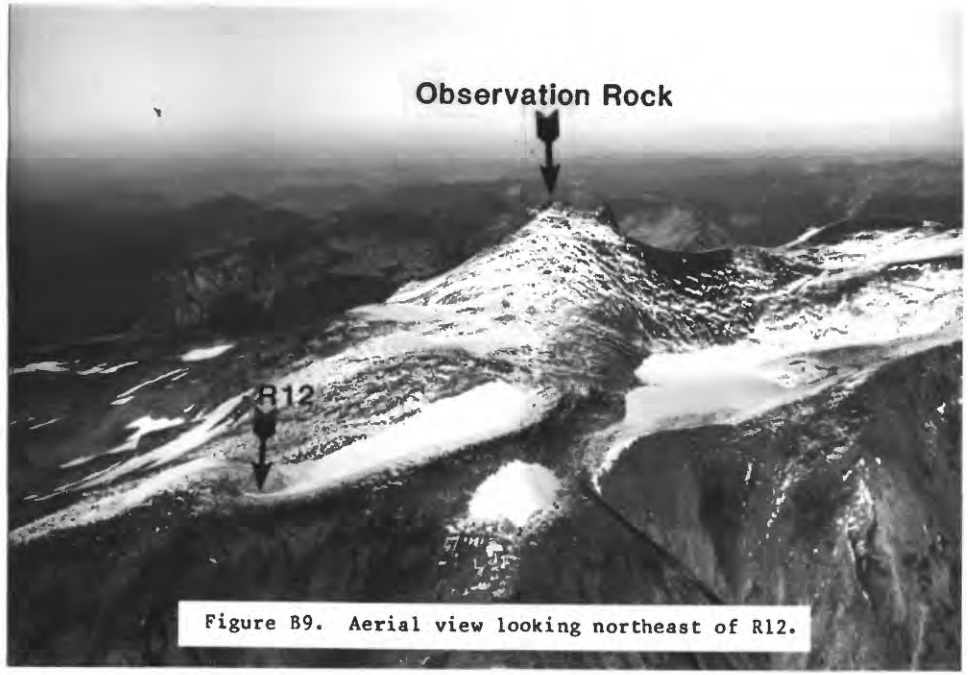

Figure B9. Aerial view looking northeast of R12.

Figure B12. View looking southeast of reflector set-up at R16.

Figure B11. Aerial view looking northeast of R14.

Figure B13. View looking northwest of EDM set-up at R18; locations of R1 and R2 indicated.

Figure B14. View from R14 of mirror flash from R19.

APPENDIX C:
MOUNT HOOD

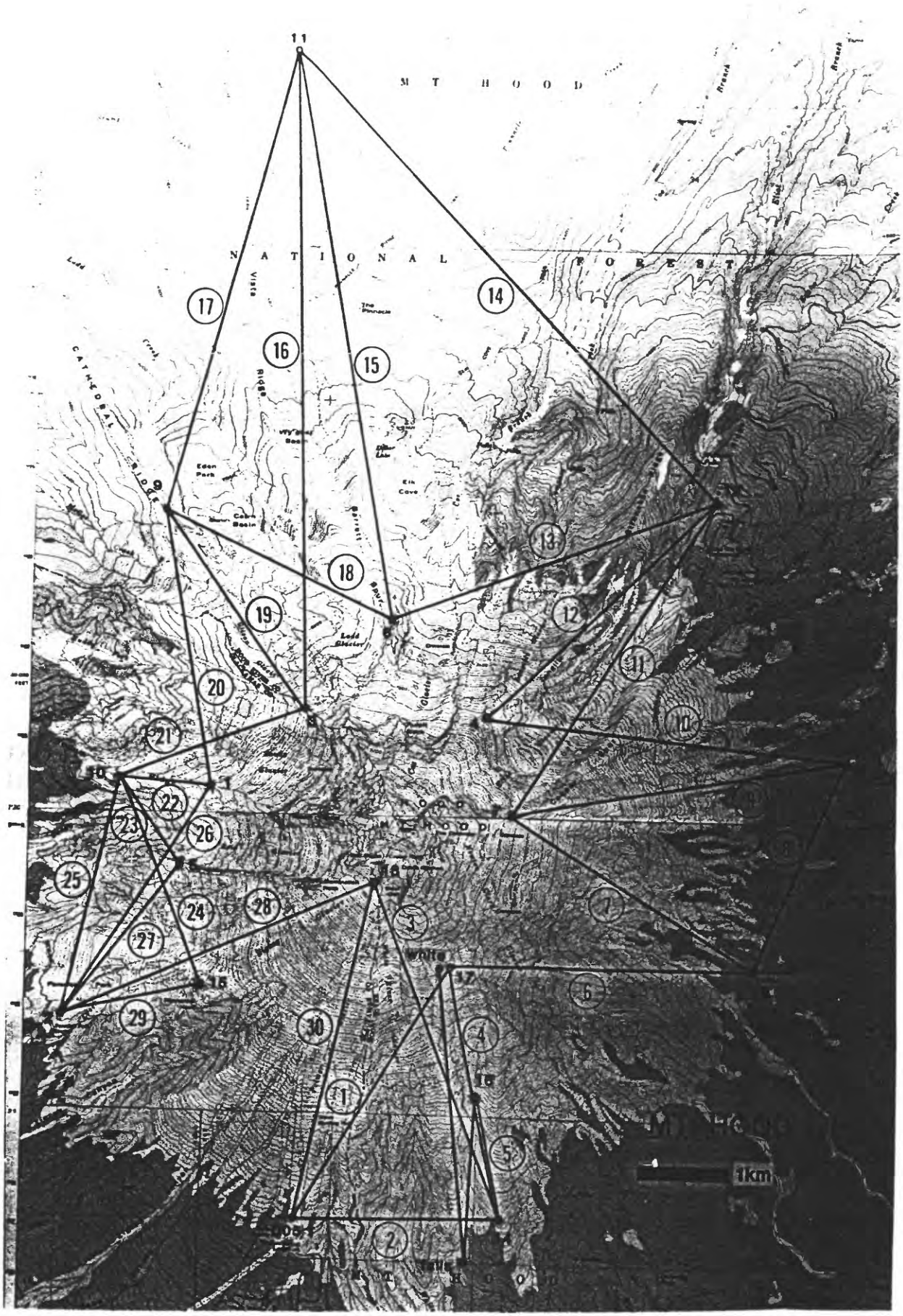

Figure C1. Map of trilateration network at Mount Hood, Oregon.

MOUNT HOOD

NOTE: A skeletal network of 7 EDM lines was installed and measured (using endpoint atmospheric data) at Mount Hood in July 1980 in response to a reported earthquake swarm. Instrument and reflector marks consisted of PK masonary nails hammered into bedrock. In August 1983, the PK lines were remeasured (using endpoint atmospheric data) and then replaced by a new network of benchmarks consisting of 29 lines. Benchmarks were installed near the old PK sites where possible. PK nail sites are "4875" (near H.11), "Barrett" (near H.6), "Langille" (should be near H.4, but PK nail could not be located in 1983), "Cooper" (near H.7), "Meadow" (near H.8; in 1980 known as "6227"), "Falls" (see location on the map), "White" (on the map; near H.17), "Big Rock" (near H.16), "Paradise" (near H.2), "Mississippi Head" (near H.15), and "Crater Rock Low" (near H.18). Benchmark "005", installed in 1972 near Timberline Lodge, was incorporated into the new network.

H.1: "Sandy" (7441'). BM is on Yokum Ridge about 150 feet west of tip of small peak labeled 7465 on map. BM is 2 feet below ridge crest on south side of crest. Many andesite plates form scree slope to south. Landing site is north of ridge, just upslope from peak 7465, on snow. Climb to saddle above landing site and traverse west below south side of peak to station.

H.2: "Paradise" (6037'). BM is in bare rock outcrop at Paradise Park. Standing at BM, two segments of Timberline trail can be seen where it dips down into north tributary of Lost Creek. Other rocks in Paradise Park offer no such view. Rock cairn exists about 40 feet south of BM. PK nail is about 3 feet east of BM.

H.3: "County Line" (7891'). BM is north of Sandy Glacier on ridge that forms Hood River-Clackamas county line. BM is at top of ridge within small closed contour at 7880 feet elevation (not labeled on map). Landing site is in snow just north of ridge. Traverse west a short distance before making easy ascent across rock ledges to station.

H.4: "Langille" (8312'). BM is 3 feet below top of knoll about 100 feet downridge from small saddle and about 100 feet upslope from prominent steep pitch. BM is cemented in rounded, red-weathered outcrop. PK nail was installed in 1980 upridge from this site (at approximately 8400 feet elevation) "in a rock near the top of a bare rock ridge," but could not be located in 1983.

H.5: "Reid" (6988'). On ridge downslope from Illumination Rock, landing site is only place along ridge that flattens out. BM is 50 feet downslope from this flat on ridgecrest in isolated rock about 3 feet above general ground surface.

H.6: "Barrett" (7854'). BM is on northern edge of northern high point on Barrett Spur. PK nail is a few feet from BM. Landing site is either near northern high point, or if conditions do not permit, south of southern high point.

H.7: "Cooper" (8955'). BM is near highest point on Cooper Spur where it emerges from snow, in scoriaceous lava flow a foot or so above general ground surface. Landing site is were ridge emerges from snow. PK nail is in same rock as BM.

H.8: "Meadow" (6233'). At map point 6227, downridge from "Cooper," is small dusty meadow on top of ridge. Half of meadow is flat. Most rocks are on north edge of this flat, on ridge crest. BM is in rock in north-south center of flat, at western edge of flat where first small pines grow. PK nail is in smaller rock in center of flat (both north-south and east-west) about 40 feet east of BM.

H.9: "Cathedral" (5730'). BM is on prominent outcrop 1/4 mile northwest of trail crossing Cathedral Ridge. Landing site is by pond on south side of ridge. From there, climb to ridge crest and then across boulders to BM.

H.10: "Yokum" (6595'). BM is in large flat rock on south side of first large prominent outcrop below timberline on Yokum Ridge. Landing site is on ridge crest about 100 feet toward mountain.

H.11: "Sticks" (4868'; reference elevation - BM is assumed to be 7 feet lower than map point 4875). BM is about 50 feet north of map point 4875, high point on hill. PK nail is in rock at high point.

H.12: "Cloud Cap" (5737'). BM is 20 feet east of large boulder in clearing with many dead trees about 1200 feet northwest of Cloud Cap Inn. Good landing site south of boulder.

H.13: "Lamberson" (6635'). BM is along crest of Lamberson Butte on third high point (the second highest of all) as one walks southward (away from mountain) from saddle. Landing site is in saddle, along trail.

H.14: "Mitchell" (6273'). BM is on rocky mound on ridge crest about 150 feet upslope from timberline on ridge crest (although only about 50 feet upslope where timberline wraps around west side of ridge). Mound is slightly west of center of ridge, with view of Timberline Lodge but not of Mt. Hood Meadows. BM is in buried boulder 20 feet south of top of mound. Several snags and small trees occur nearby.

H.15: "Mississippi" (7390'). BM is on highest point on Mississippi Head in solid rock at lip of west-facing cliff. PK nail is about 15 feet south. Good landing site nearby.

H.16: "Big Rock" (7096'). BM is in large rock outcrop about 50 feet below and west of crest of spur ridge. PK nail is at same site. Landing site is upslope near where spur ridge begins. High setup necessary.

H.17: "White" (8719'). PK nail is at very good landing site in low rock about 30-50 feet west of very large rock in large, rather flat area. BM is across small snow field east of PK nail, on ridge crest about 40-50 feet lower than PK nail. BM is at base of slightly steeper part of ridge and is cemented in a low rock about 15 feet toward mountain from relatively large gray rock. Top of Lamberson Butte as well as Timberline Lodge visible from BM.

H.18: "Crater Rock" (9990'). Landing site is on climbing route along ridge between Zigzag and White River Glaciers, where it emerges from snow. Climb up climbers' trail 100 feet or so, then traverse northwestward, crossing steep snow. Walk perhaps 400-500 feet. PK nail is near south edge of first snowfree scree slope east of Illumination Rock and below Crater Rock, on prominent outcrop, not scree slope. To get to BM, walk up this scree slope to point about 20-30 feet above and west of lowest outcrop of Crater Rock. From here, walk 30-50 ft east across snow to Crater Rock, where BM is on small flat at top of 20-30 foot south-facing cliff. Both PK nail and BM are directly below and just south of wide, deep notch in Crater Rock as seen from Paradise (H.2).

Falls: (approximately 5900'). PK nail is on west edge of ridge overlooking waterfall. No BM at this site.

Preexisting benchmark used:

005: "Timberline" (6150'). To get to BM, take main trail from Timberline Lodge up along west side of gully containing long snow finger (this is direct route down from ski fields in summer). Very large rock lies just west of this trail, opposite point where several clusters of small trees begin to occur on east side of gully. BM is cemented in low rock just upslope from the very large rock. In 1972, BM was about 100-125 feet upslope from lone pole with two pulleys attached.

Figure C3. Aerial view looking southwest of H2.

Figure C2. Aerial view looking northeast of H1 and H10.

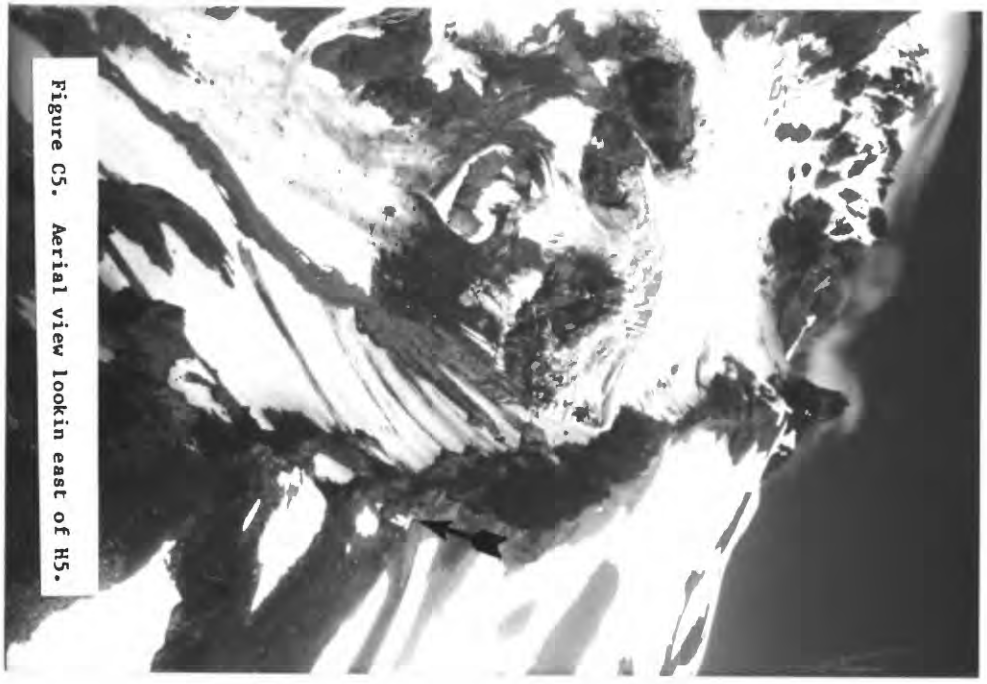

Figure C5. Aerial view lookin east of H5.

Figure C4. Aerial view looking southeast of H3.

Figure C6. View from H12 of H7 and mirror flashes from H4 and H6.

Figure C8. View looking west of H8.

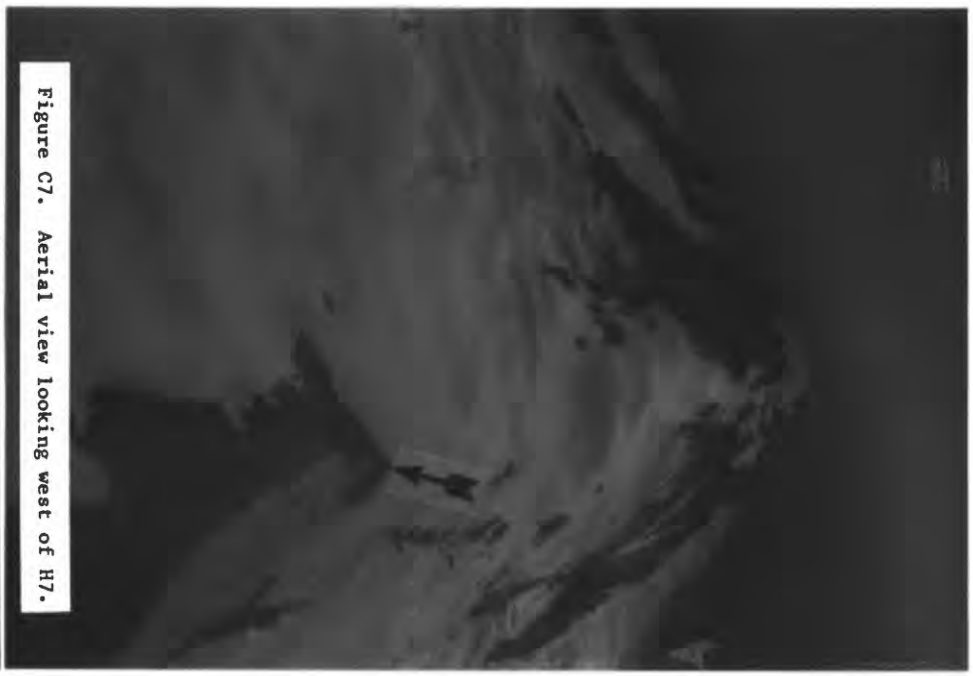

Figure C7. Aerial view looking west of H7.

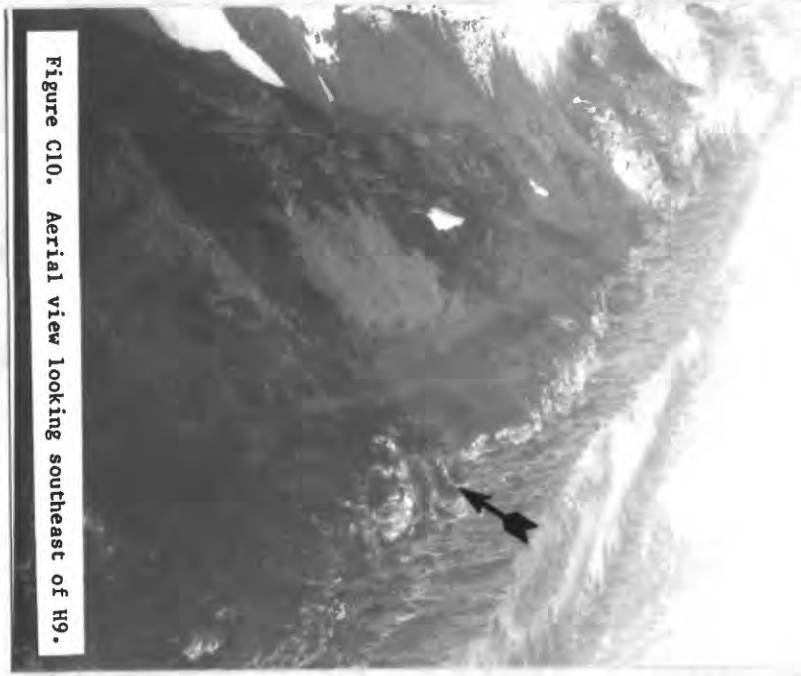

Figure C10. Aerial view looking southeast of H9.

Figure C9. View from H1 of mirror flash from H9.

Figure C12. View looking southeast of reflector set-up at H13.

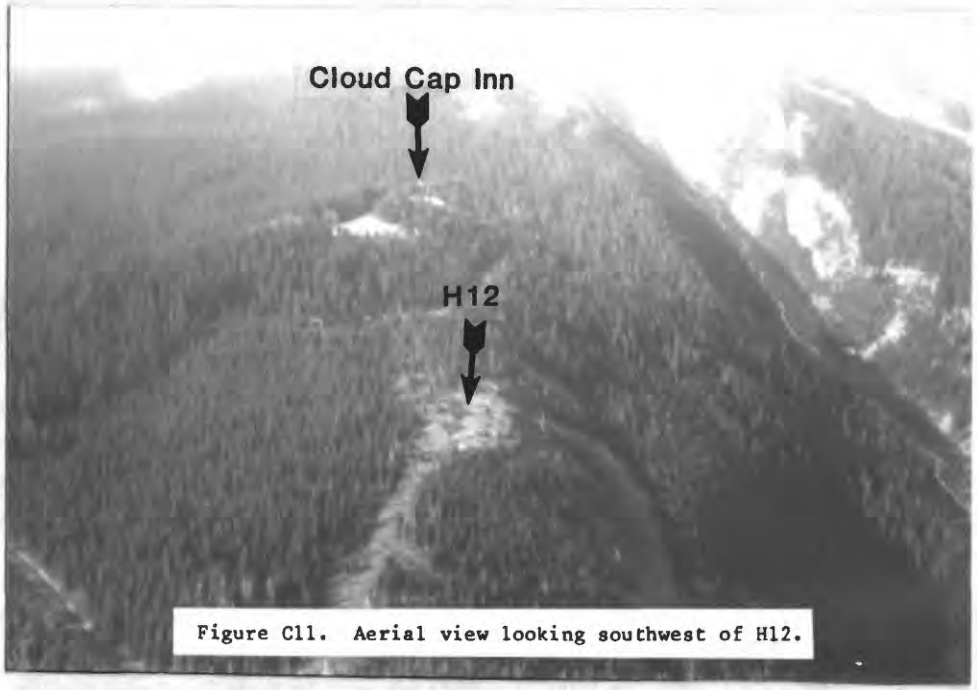

Figure C11. Aerial view looking southwest of H12.

Figure C14. Aerial view looking southwest of H14.

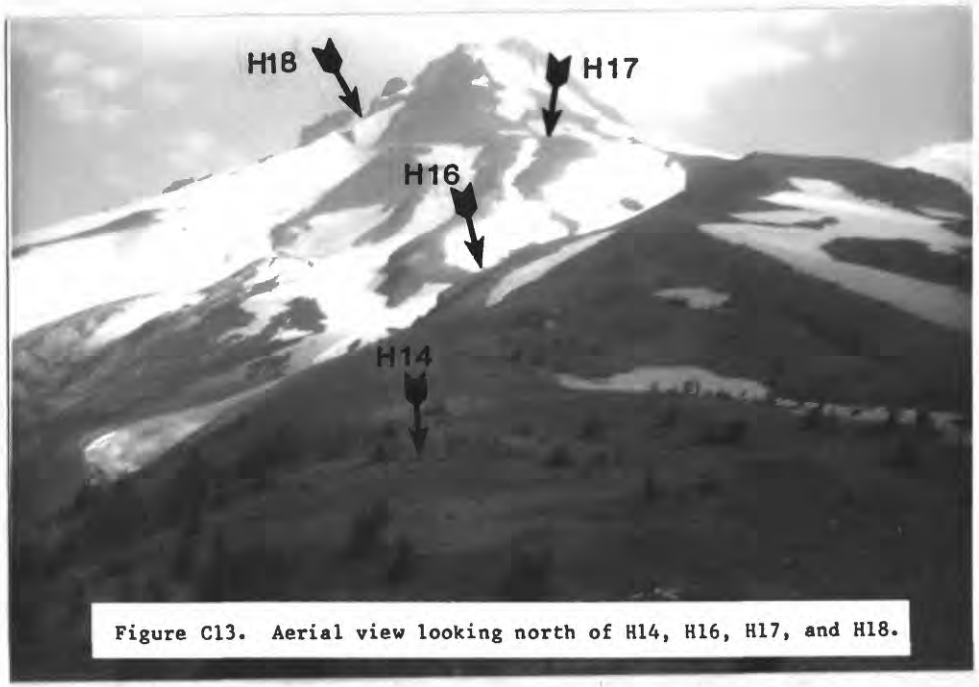

Figure C13. Aerial view looking north of H14, H16, H17, and H18.

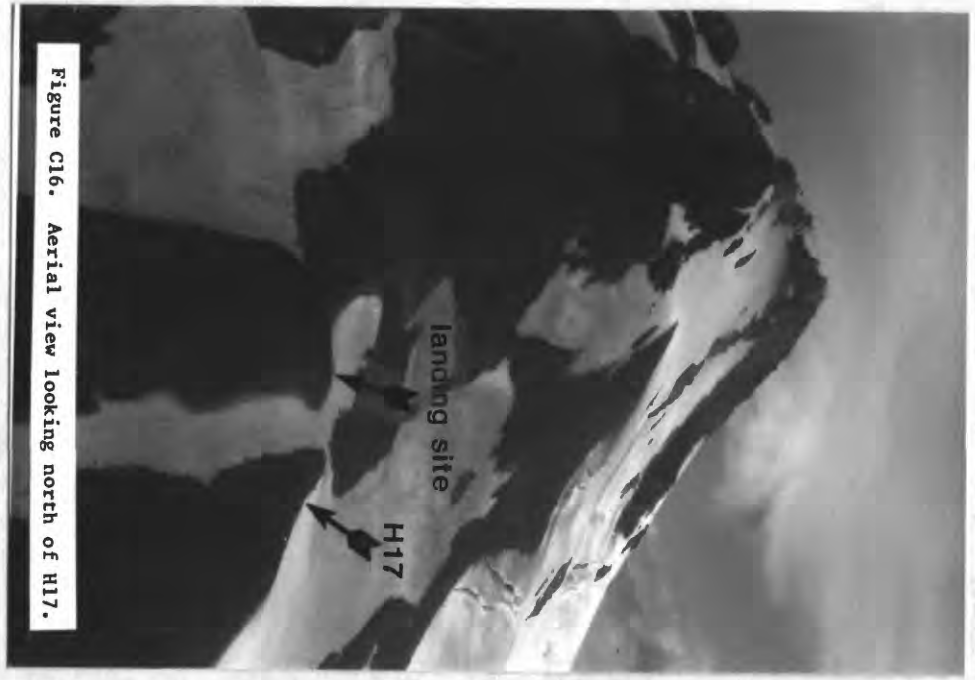

Figure C16. Aerial view looking north of H17.

Figure C15. Aerial view looking northeast of H16.

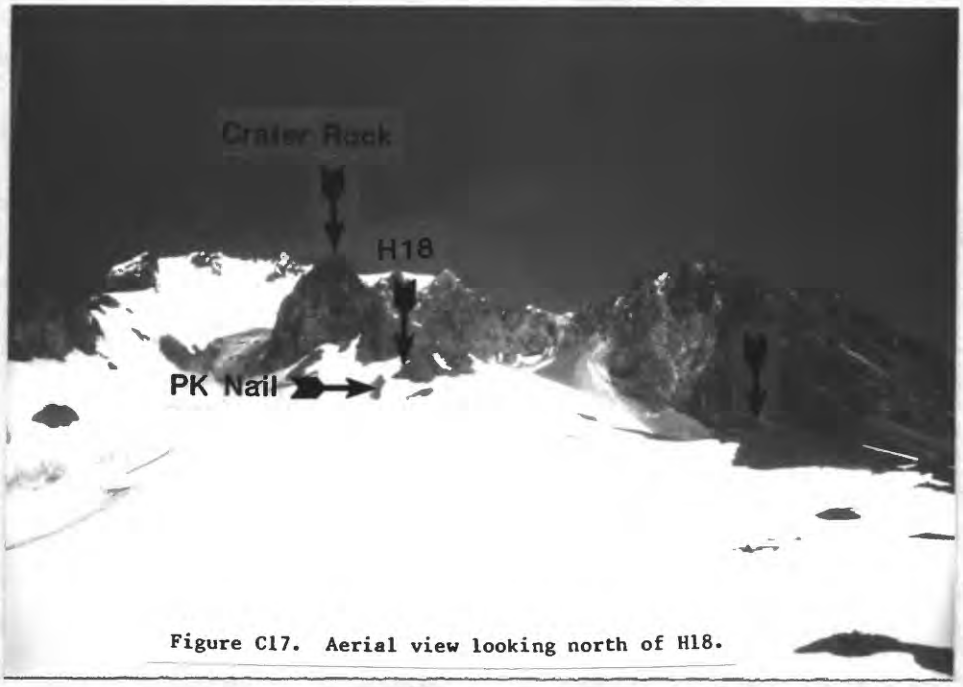

Figure C17. Aerial view looking north of H18.

Figure C18. Aerial view looking north of 005 and H18.

APPENDIX D:
CRATER LAKE

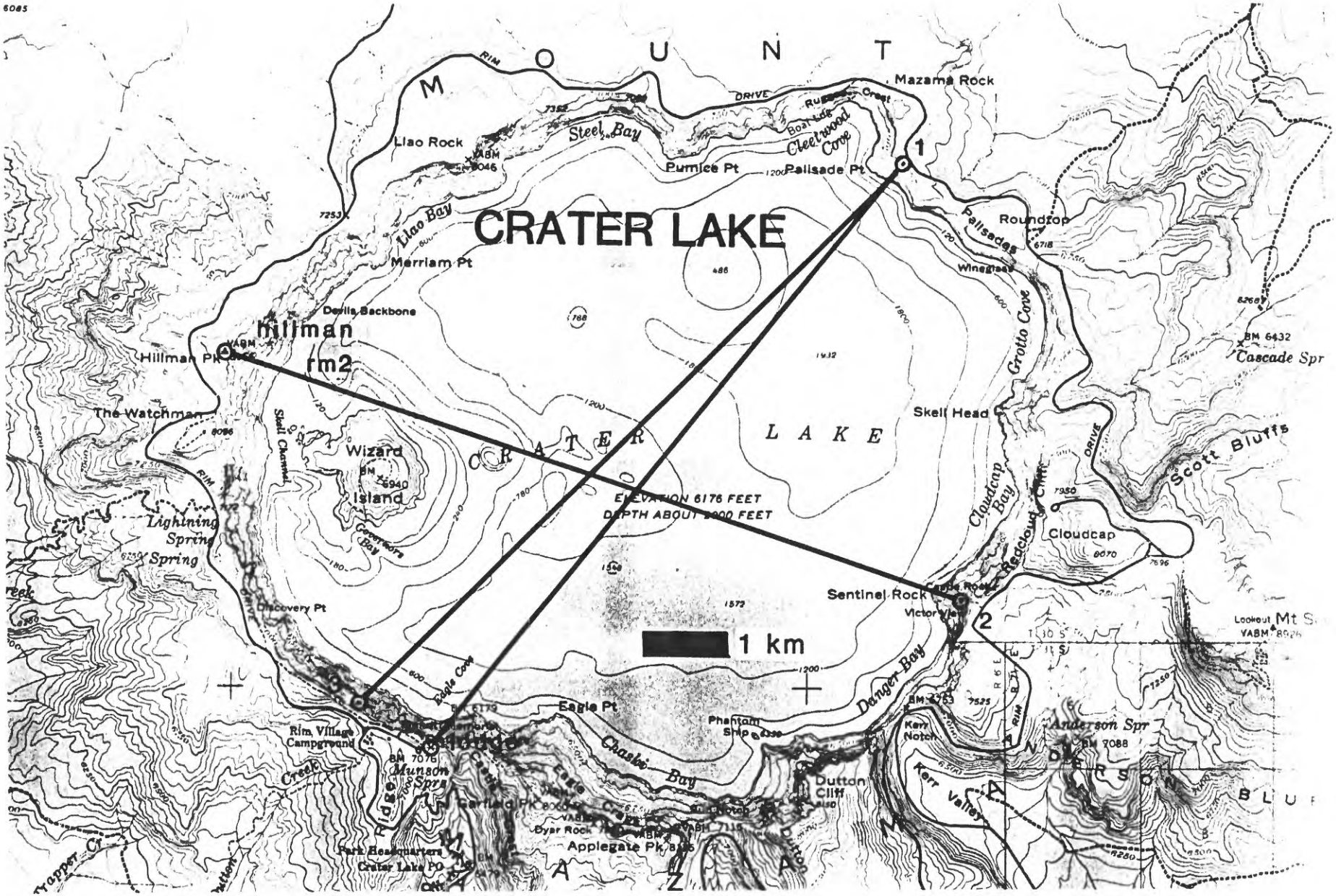

Figure D1. Map of EDM network at Crater Lake, Oregon.

CRATER LAKE

CL.1: "Palisade Point" (6821'). BM is due east of Palisade Point on flat surface of red Wineglass Tuff, about 85 feet toward lake from road at point where first view of lake appears from road (traveling south). Park along road.

CL.2: "Victor View" (7342'). BM is at end of trail at Victor View, about 3 feet below highest point at end of trail, below steep loose pitch.

CL.3: "Chute" (7586'). Drive west on Crater Rim Drive past Rim Village and continue about 0.1 mi to small turnout. From turnout walk back to east to first major chute extending down to lake. BM is on top of prominent lava-flow outcrop jutting into chute.

Preexisting benchmarks used:

BM 7076: "Lodge" (7076'; reference elevation). BM is located just east of Crater Lake Lodge in large rock along trail. NOTE: this BM is in a possibly unstable area.

VABM 8156 (reference mark 2): "Hillman Peak" (8150'; reference elevation-the reference mark is assumed to be 6' below BM at summit). Triangulation BM is on summit of Hillman Peak but was loose in 1981. We use reference mark 2, located about 10 feet south and about 6 feet below summit. Tripod centered over intersection of arrow on mark and cross hatch perpendicular to midpoint of arrow.

Figure D4. View looking north of CL3.

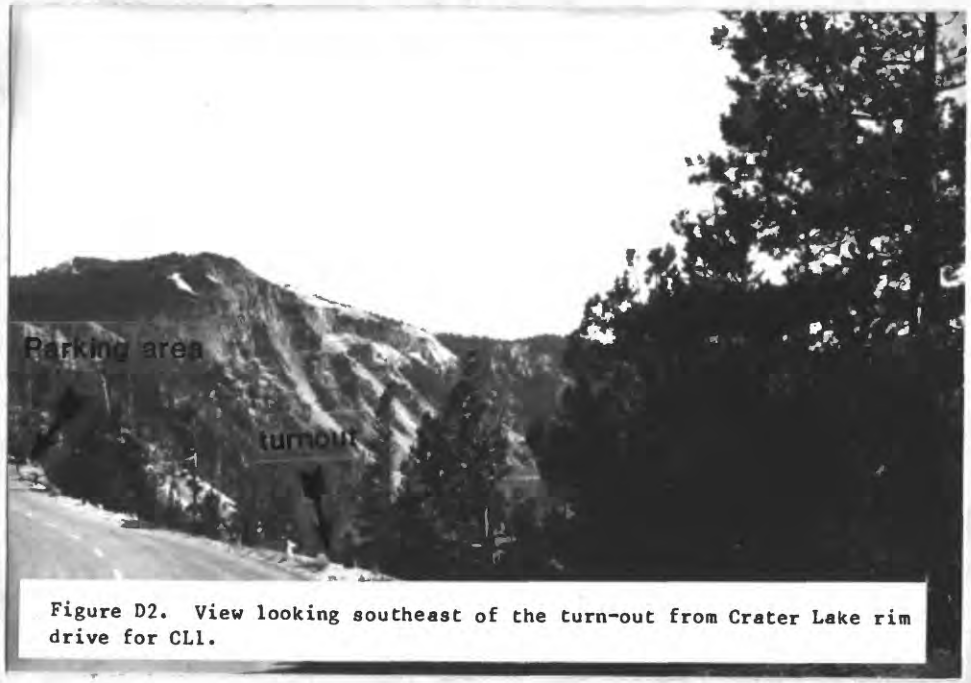

Figure D2. View looking southeast of the turn-out from Crater Lake rim drive for CL1.

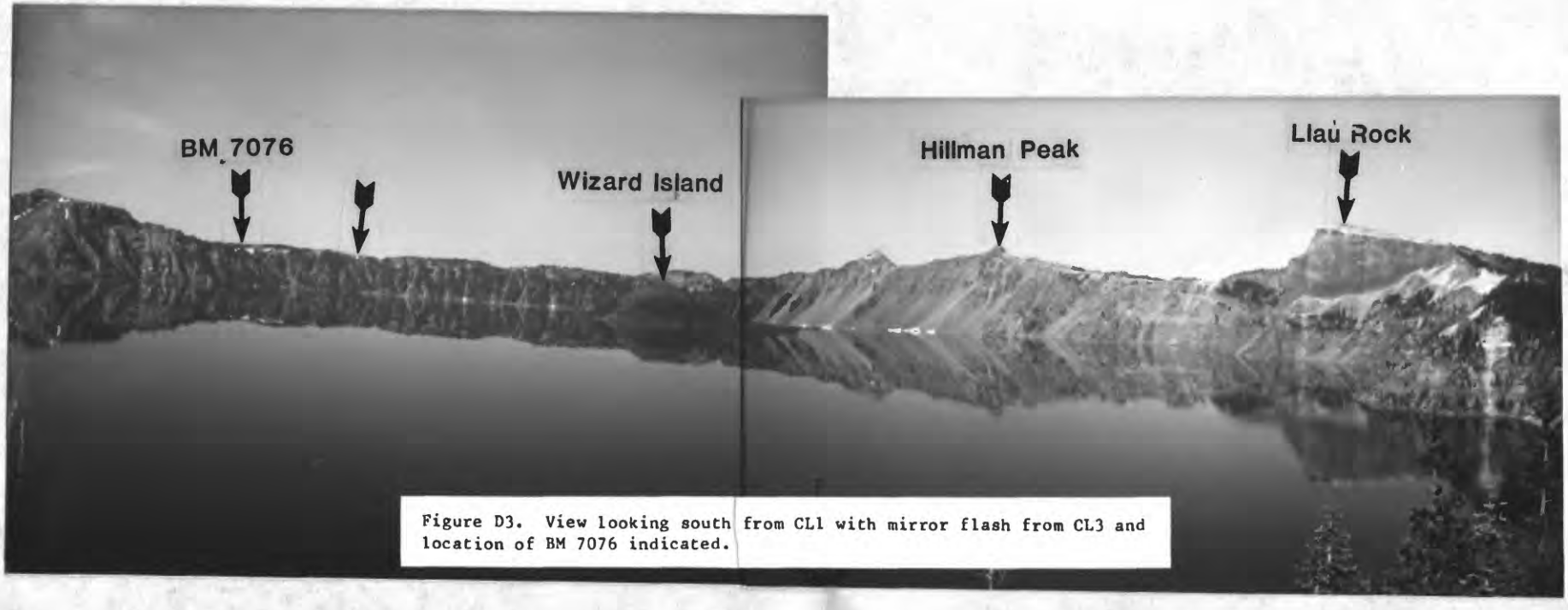

Figure D3. View looking south from CL1 with mirror flash from CL3 and location of BM 7076 indicated.

APPENDIX E:
MOUNT SHASTA

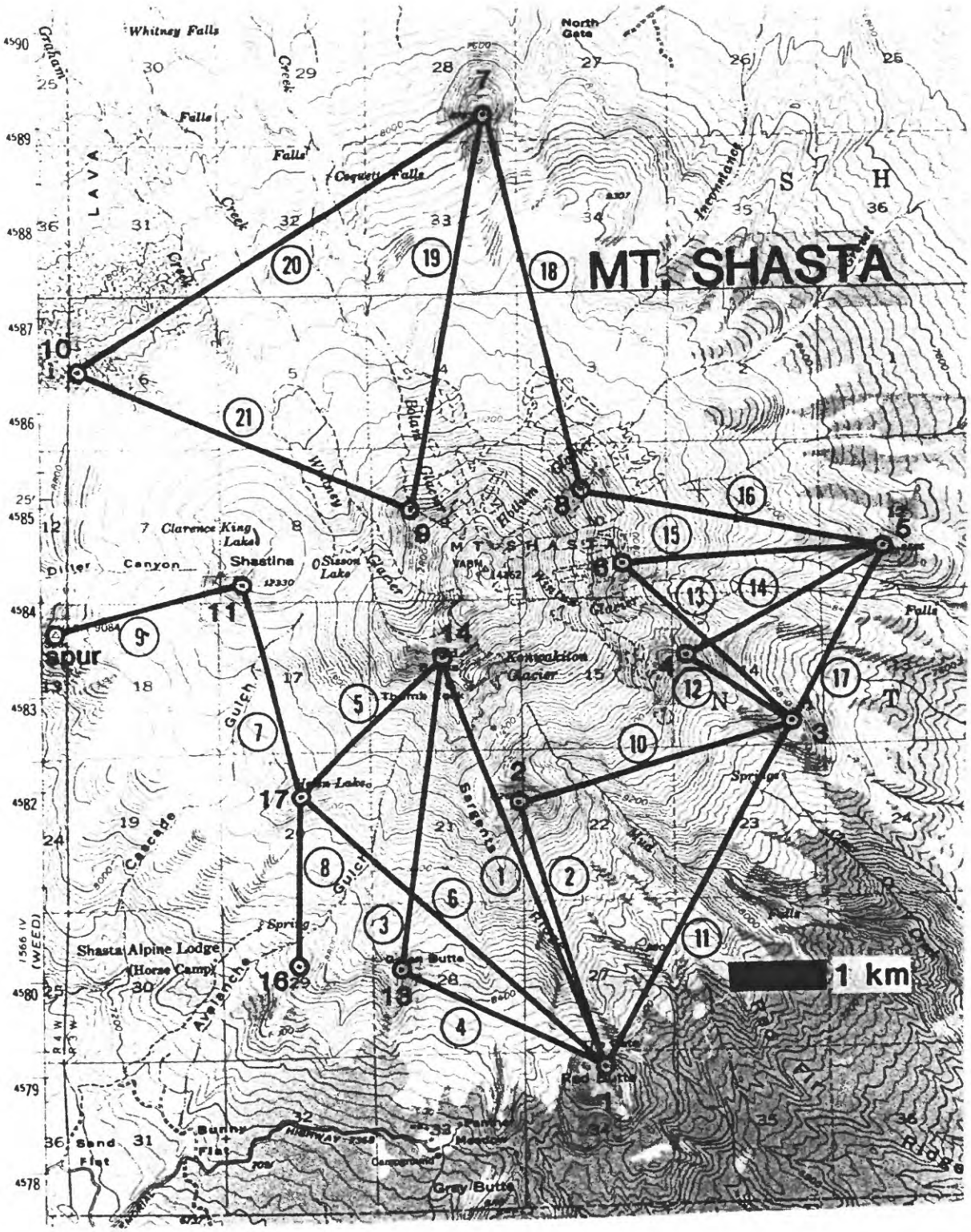

Figure E1. Map of trilateration network at Mount Shasta, California.

81.1: "Red Butte" (8398'). BM is cemented in solid rock on rocky, relatively flat ridge crest about 70 feet toward summit of Shasta from high point on Red Butte. Site is on northeast side of major gulley across Red Butte.

81.2: "Sargent" (11104'). Two large dome-shaped outcrops with a broad, flat saddle between them occur along radial line from Red Butte to Shasta's summit, on eastern side of Sargents Ridge below Thumb Rock. BM is on eastern dome-shaped outcrop, which has map elevation of 11267 feet. BM is on crest of south shoulder of "dome" forming eastern edge of saddle, at approximately same elevation as saddle. Azimuth from high point on western "dome" to BM is 45°. Landing site is in saddle.

81.3: "Pilgrim Creek" (9101). Blocky lava flow forms prominent ridge downslope from southernmost arm of Wintun Glacier. At about 9050 feet elevation on this flow is broad, flat, open area bordered by steep drop to northeast. BM is located on northeastern crest near this drop. Open, unvegetated area has two basins. BM is northeast of upper basin. Azimuth from Thumb Rock to BM is 105°.

81.4: "Wishbone" (10526'). BM is directly up ridge on which BM 81.3 is located, below wishbone of Wintun Glacier, along southwest crest of ridge on second major cluster of rock outcrops below wishbone. BM is at approximately same elevation as change in slope and first group of rock outcrops on northeast skyline of same ridge BM is on. BM is in large block several feet above general ground surface. Ridge crest broadens slightly downslope from BM. Part of Red Butte is just visible from BM. Landing site is upslope from BM.

81.5: "Ash Creek" (8583'). BM is on high ridge between Brewer and Ash Creeks, on next major rocky knob above (west of) map point 8566. BM is at top of knob near west end and is cemented in flat rock. A major drop-off occurs on east side of knob.

81.6: "Wintun" (11160'). BM is near east edge (cliff) of relatively flat area just north of Wintun Glacier. Larger, more prominent flat lies at lower elevation (about 10700 feet) to northeast. Azimuth from 81.3 to 81.6 is 323°. BM is in reddish rock.

81.7: "North Gate" (8784'). Due north of summit and southwest of North Gate is a double dome. The highest (northern) lobe is shown on map by elevation 8793. BM is located on ridge crest about 25 feet southeast of summit of dome.

81.8: "Hotlum" (11625'). BM is on lava flow, whose surface is littered with loose blocks, just southeast of Hotlum Glacier and northwest of large snow field. BM is about 50 feet southeast of cliff overlooking glacier, on low plateau more or less at downslope end of most of rocky litter. Station is in vesicular top of flow at ground level, just above large outcrop with 6 foot step-down perpendicular to ridge. Landing site is about 200 feet higher in elevation along same cleaver near where it emerges from snow.

81.9: "Bolam" (12376'). Between Bolam and Whitney Glaciers, at about same elevation as Shastina, is conspicuous flat area with numerous large bread-crusted blocks. BM is located toward north edge of this flat area, below and east of large blocks, in bedrock about 1 foot above general ground level.

81.10: "Lava Ridge" (8572'). BM is 2 mi northwest of high point on Shastina, on narrow ridge crest. BM is located about 100 feet upridge from point at which station 81.7 becomes visible and about 70 feet downslope from point at which summit of Black Butte comes into view. Deep ravine occurs on northeast side of ridge, and flat area lies to southwest.

81.11: "Shastina" (12003'). BM is on west end of ridge extending west from map point 12330 on Shastina, on narrow ridge crest 30-40 feet east of large rock rib. VABM 9084 ("Spur") is barely visible along south side of rib.

81.13: "Green Butte" (9214'). BM is on southeast summit of Green Butte.

81.14: "Red Banks" (13187'). BM is about 30 feet lower than top of Red Banks on third snow-free rib of rock (about 150 feet) north of main climbing route. From landing site (top of Red Banks on snow), walk toward Thumb Rock to get to BM, located between crest of Red Banks and overhang to southeast.

81.16: "Avalanche Gulch" (8369'). On southeast side of creek bed in Avalanche Gulch is flat area just east of treeline. BM is on first crest northeast of highest knoll with trees, near rock-littered slope of ridge to southeast. BM is about 70 feet in 70° azimuth from large reddish rock, which is prominent and stands about 5 feet high. In 1984, small rock cairn was about 20 feet north of BM.

81.17: "Helen" (10450'). Series of rugged, knife-edged crags occurs on ridge leading down from Red Banks, between Cascade Gulch and Avalanche Gulch west of Helen Lake. At about 10450 feet, ridge widens and flattens out. BM is located between two southeast-facing craggy outcrops, just below point where ridge changes from knife-edge to gently sloping, in bedrock southeast of crest of ridge.

Preexisting benchmark used:

Spur (VABM 9084) (9084'; reference elevation). BM is considerably below (west of) high point of ridge south of Diller Canyon on east-west-trending crest. Some old wooden beams lie on ground near BM.

Figure E3. Aerial view looking west of photo target at 81.1.

Figure E2. View from 81.2 of mirror flash from 81.1.

Figure E5. Aerial view looking northwest of photo target at 81.3.

Figure E4. Aerial view looking north of 81.2.

Figure E6. View from 81.3 of mirror flashes from 81.4 and 81.6.

Figure E8. Aerial view looking southwest of photo target at 81.6.

Figure E7. Aerial view looking northwest of 81.4.

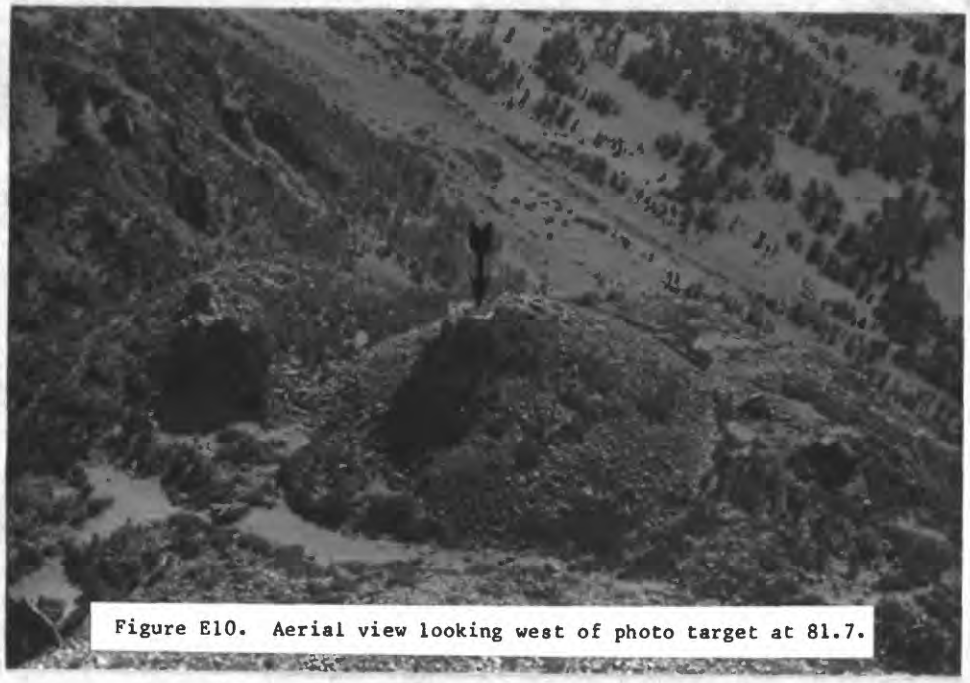

Figure E10. Aerial view looking west of photo target at 81.7.

Figure E9. Aerial view looking west of photo target at 81.5.

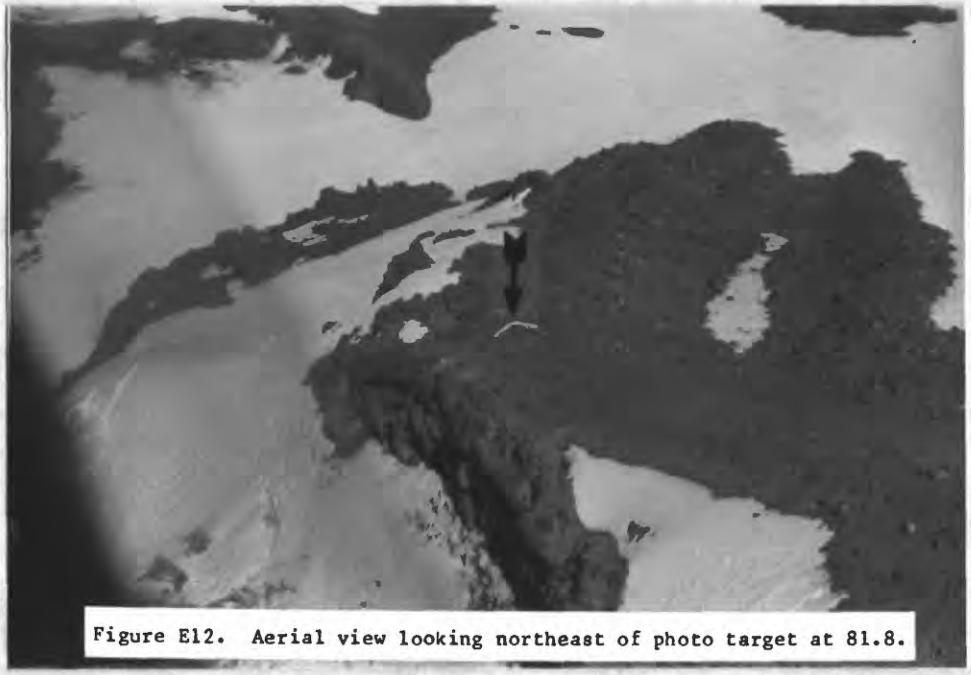

Figure E12. Aerial view looking northeast of photo target at 81.8.

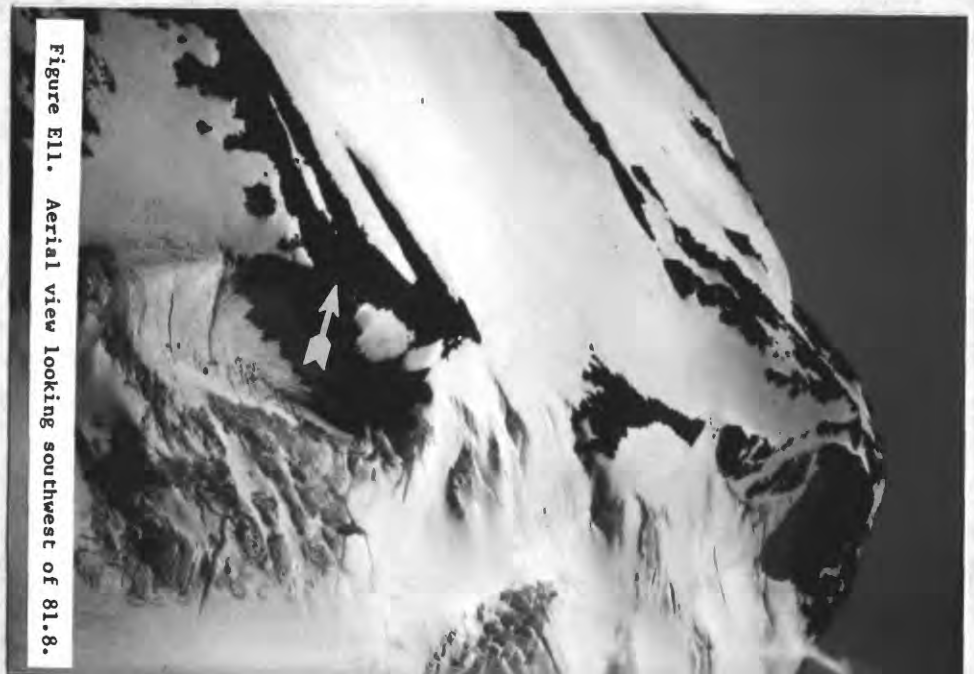

Figure E11. Aerial view looking southwest of 81.8.

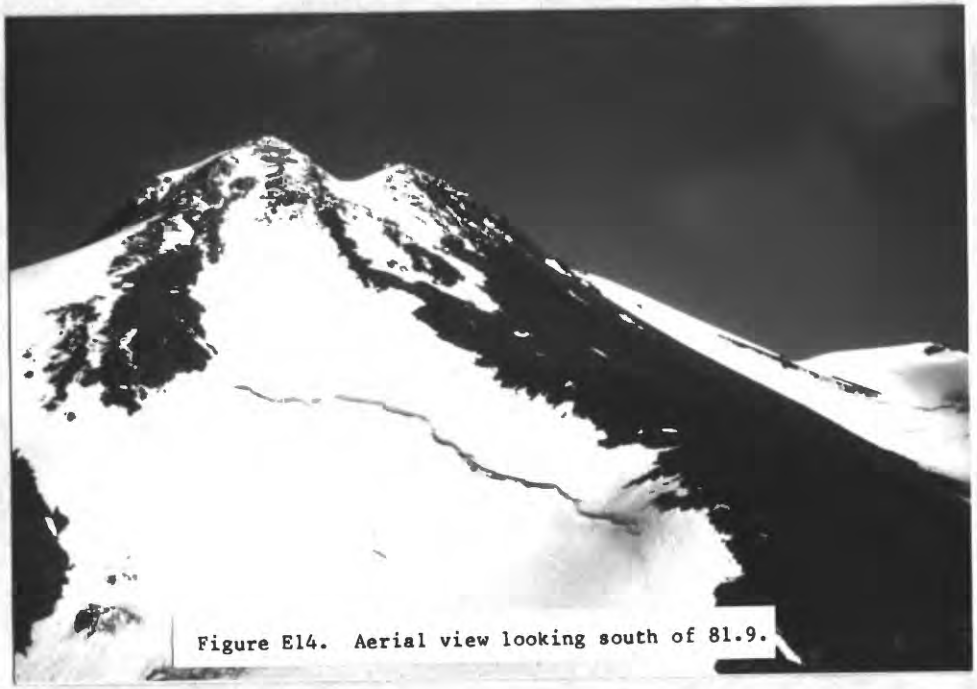

Figure E14. Aerial view looking south of 81.9.

Figure E13. View looking downslope of reflector set-up at 81.8.

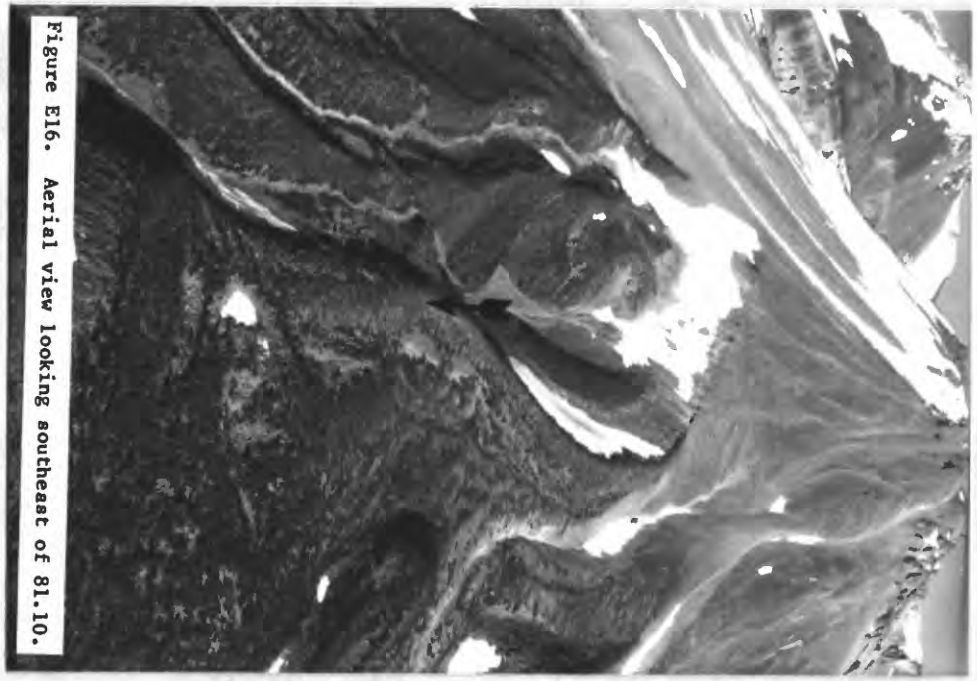

Figure E16. Aerial view looking southeast of 81.10.

Figure E15. Aerial view looking southwest of photo target at 81.9.

Figure E18. View from 81.9 of mirror flash from 81.10.

Figure E17. Aerial view looking southeast of photo target at 81.10.

Figure E20. Aerial view looking northeast of 81.14.

Figure E19. Aerial view looking east of photo target at 81.11.

Figure E22. View from 81.17 of mirror flash from 81.16.

Figure E21. View looking south of reflector set-up at 81.14.

Figure E24. Aerial view looking northwest of photo target at 81.17.

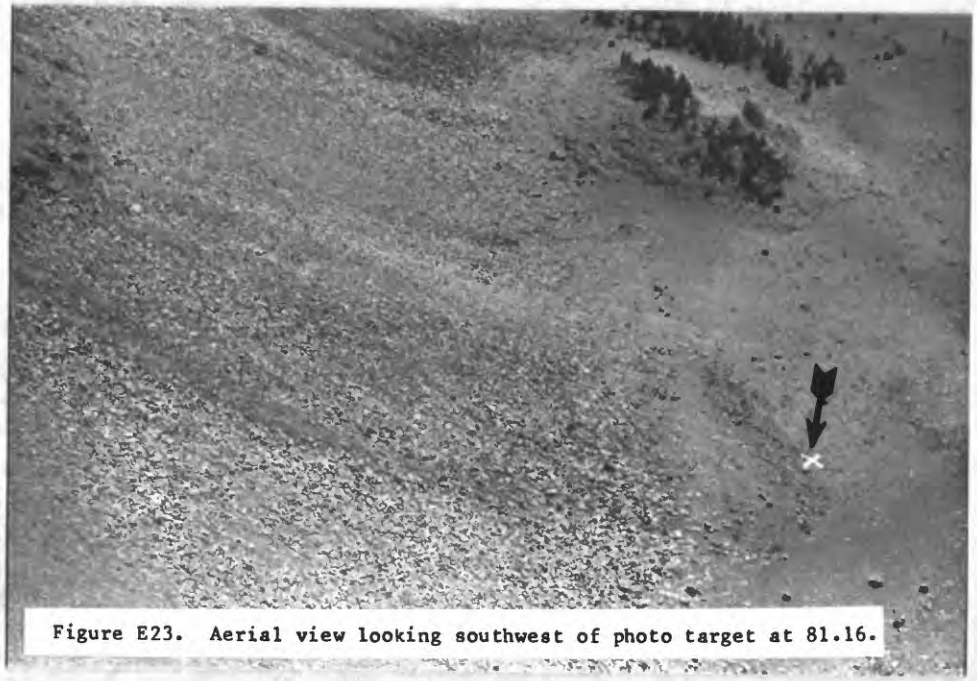

Figure E23. Aerial view looking southwest of photo target at 81.16.

Figure E25. Aerial view looking east of photo target at Spur.

APPENDIX F:
LASSEN PEAK

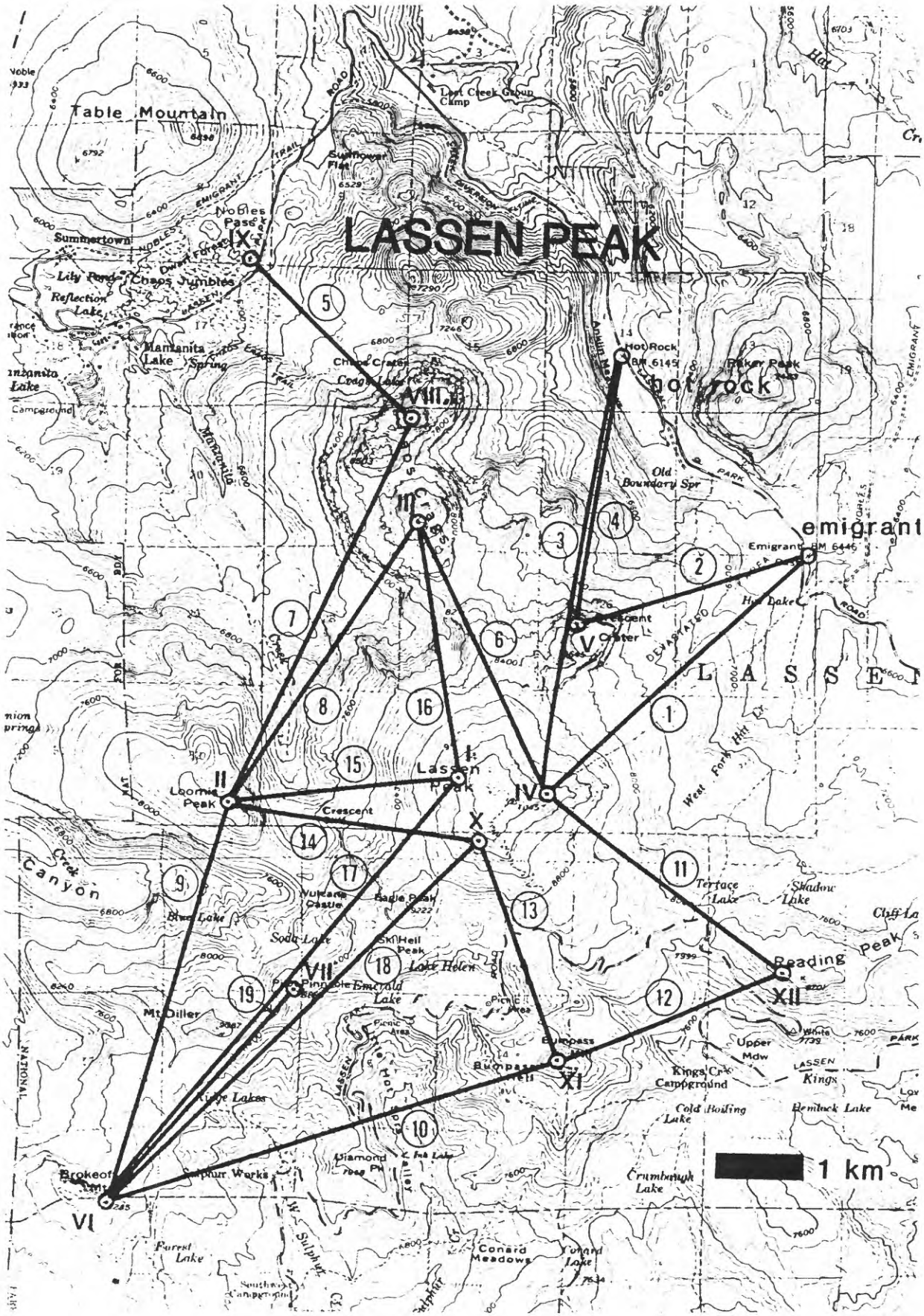

Figure F1. Map of trilateration network at Lassen Peak, California.

LASSEN PEAK

L.I: "West Lassen" (9761'). West of summit north of spillout of 1915 lava flow, and at about the same elevation as its snout, is group of rock outcrops forming ridge down slope of cone. BM is on highest of this group of rocks, 300 feet lower in elevation than large pinnacle located above same ridge. Azimuth from high point on Loomis Peak to BM is 85°. Landing site is about 100 feet higher and 500 feet north of BM.

L.II: "Loomis" (8653'). BM is on summit of Loomis Peak.

L.III: "South Chaos" (8424'). On southern lobe of Chaos Crags, highest points form vague horseshoe open to south. BM is on nearly horizontal slab about 20 feet across on northwest part of horseshoe, just north of westernmost high point of horseshoe. Landing site is north of BM on very square, flat slab.

L.IV: "East Lassen" (9812'). Prominent craggy ridge occurs on east side of peak. BM is on ridge crest next to small flat saddle just above very large pinnacle. BM is on first rock outcrop from Lassen summit on north side of ridge. Landing site is in small saddle just upslope.

L.V: "Crescent Crater" (8418'). BM is in boulder on high point of north end of Crescent Crater.

L.VI: "Brokeoff" (9235'). BM is on eastern summit of Brokeoff Mountain.

L.VII: "Pilot Pinnacle" (8831'). BM is on northwest base of Pilot Pinnacle on slanting surface, 40-50 feet north-northeast of and above brush. Brokeoff and most of Lassen are visible from BM.

L.VIII: "North Chaos" (8400'). Two high points occur on north lobe of Chaos Crags. BM is on top of smaller, eastern high point. Landing site can be on either high point, depending on winds.

L.IX: "Jumbles" (6158'). BM is on ridge in Chaos Jumbles about 150-200 feet north of highway and 60-70 feet west of east edge of "new" Chaos Jumbles ("old" Chaos Jumbles is to east). Station is 1.925 road miles east of entrance station.

L.X: "South Lassen" (9889'). BM is at top of highest outcrop on western of two rocky areas, about 600-750 feet west of summit trail. Landing site is saddle 20 feet higher than station. Prominent rocky ridge lies between summit trail and ridge with station. Only low part of trail visible from station, whereas high part of trail can be seen from next ridge to east.

L.XI: "Bumpass" (8759'). BM is on highest point on Bumpass Mountain.

L.XII: "Reading" (8496'). BM is west of summit of Reading Peak along ridge, just above low tree-covered saddle in bedrock. Small tree blocks view to Emigrant BM. Large cairn stands 10 feet west of BM.

Preexisting benchmarks used:

Hot Rock; Bm 6141 (6141'). BM is just off highway northeast of peak. NOTE: we did <u>not</u> use BM 6145 (on map) located in top of rock (about 5 feet above ground surface) about 15 feet north of "Hot Rock" boulder. Because of restricted views of Lassen Peak, we instead used another BM that is about 40 feet north of BM 6145 on same side of road. This BM is at ground level in concrete pad and has "US Dept. of Agriculture, Bureau of Public Roads" stamped on it. Clearing of lines of sight by bending tree limbs necessary.

Emigrant; Bm 6446 (6446'; reference elevation). BM is just off Lassen Park Road east-northeast of peak. Bending tree branches necessary.

Figure F3. Aerial view looking east of L.I.

Figure F2. View from L.II of mirror flash from L.I; L.X indicated.

Figure F5. View from L.II of mirror flash from L.III.

Figure F4. View from L.I of mirror flash from L.III.

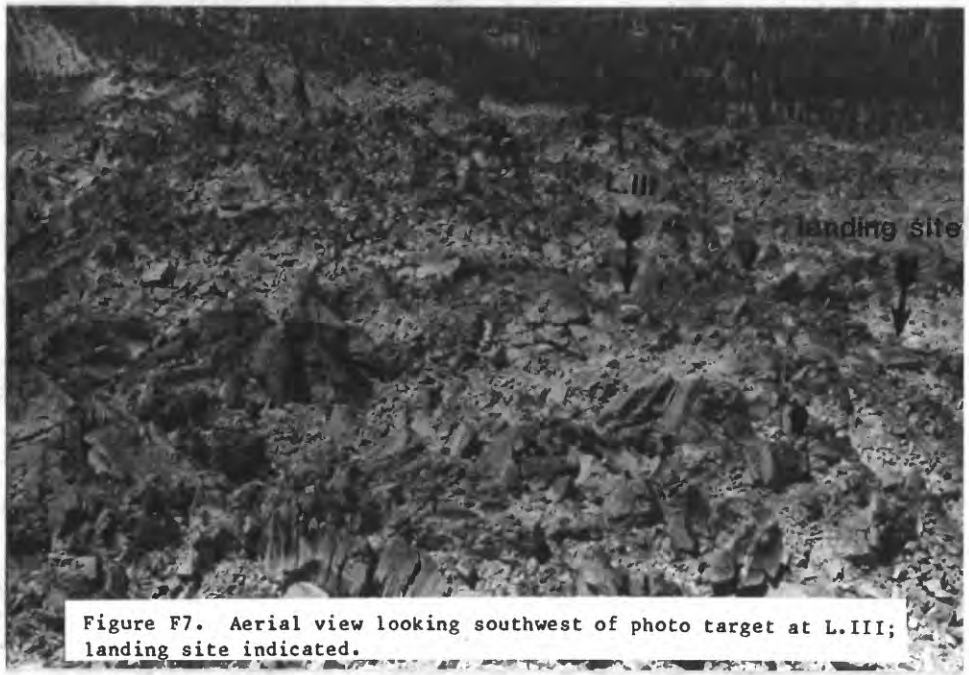

Figure F7. Aerial view looking southwest of photo target at L.III; landing site indicated.

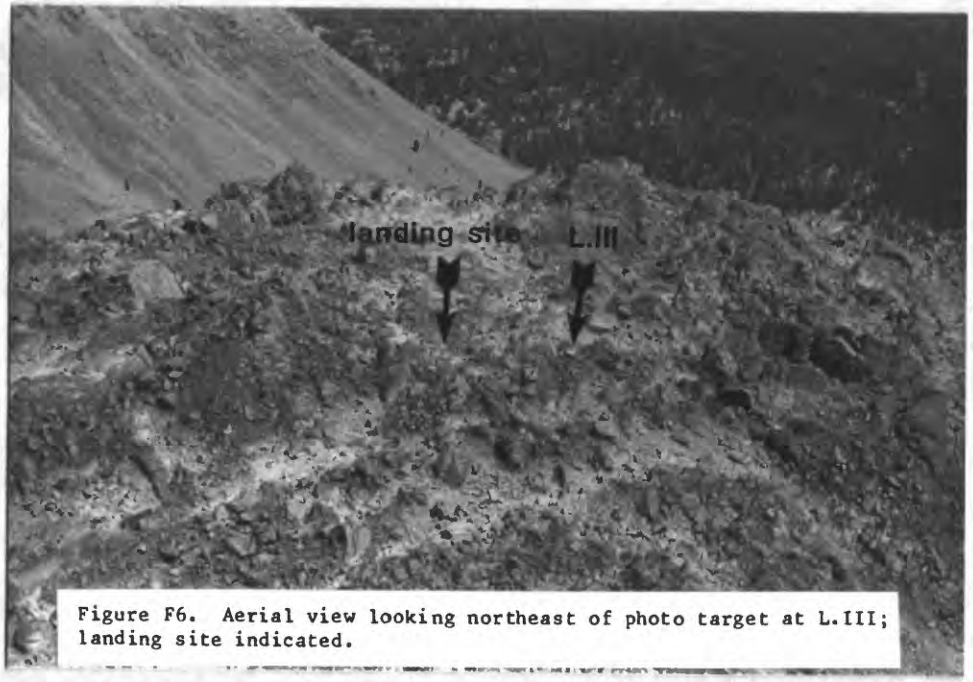

Figure F6. Aerial view looking northeast of photo target at L.III; landing site indicated.

Figure F9. Aerial view looking southeast of L.VII.

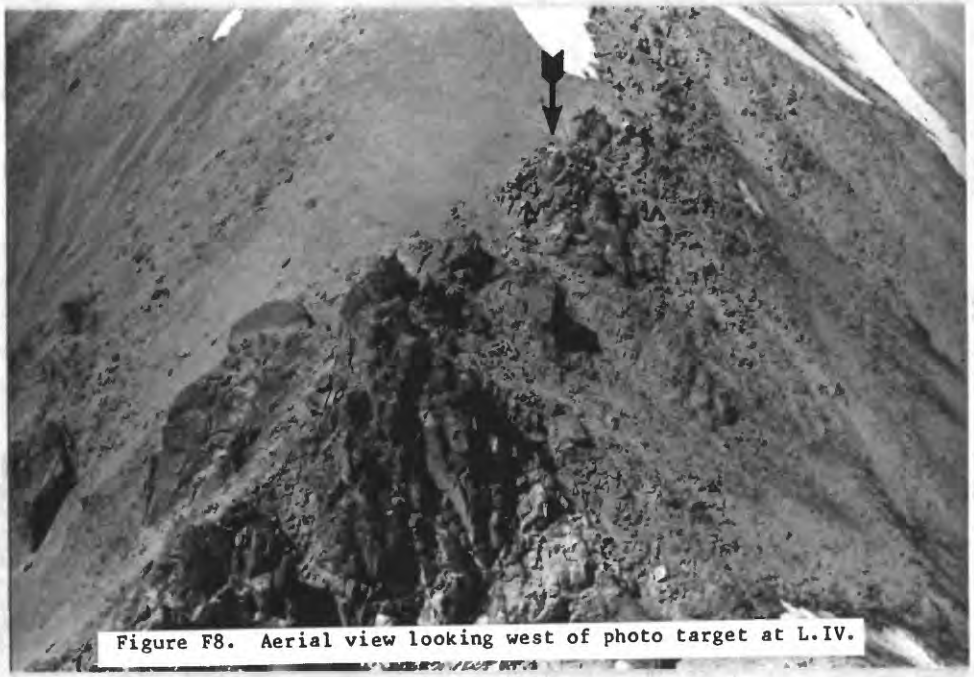

Figure F8. Aerial view looking west of photo target at L.IV.

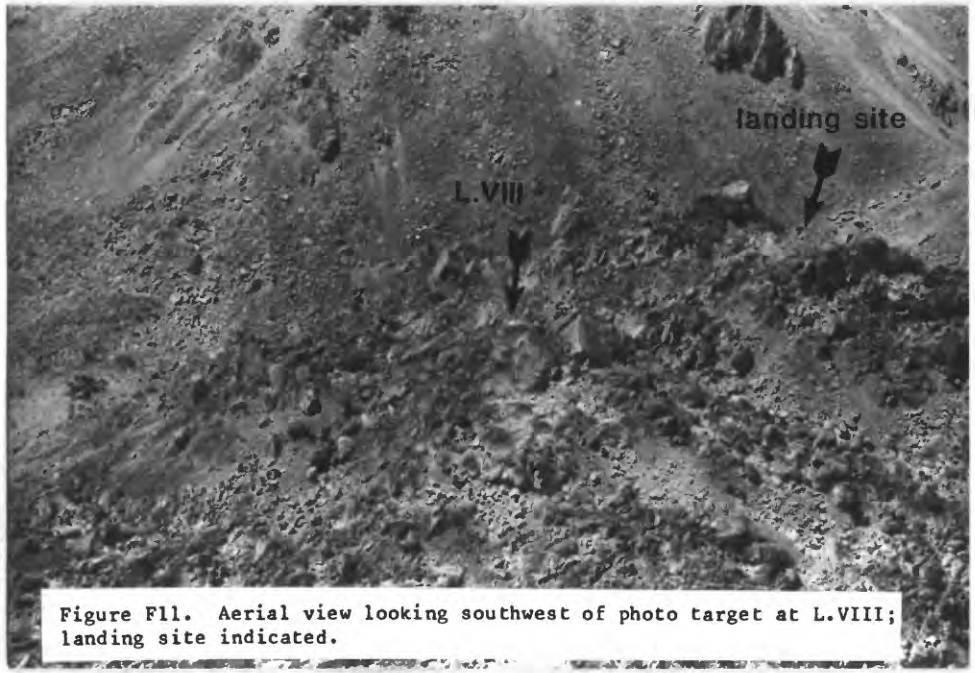

Figure F11. Aerial view looking southwest of photo target at L.VIII; landing site indicated.

Figure F10. Aerial view looking northwest of L.VIII.

Figure F12. View from L.VIII of mirror flash from L.IX and landing site.

Figure F14. View looking southeast of photo target at L.IX.

Figure F13. View from L.IX of mirror flash from L.VIII.

Figure F16. View from L.XI of mirror flash from L.XII.

Figure F15. Aerial view looking south of photo target at L.X.

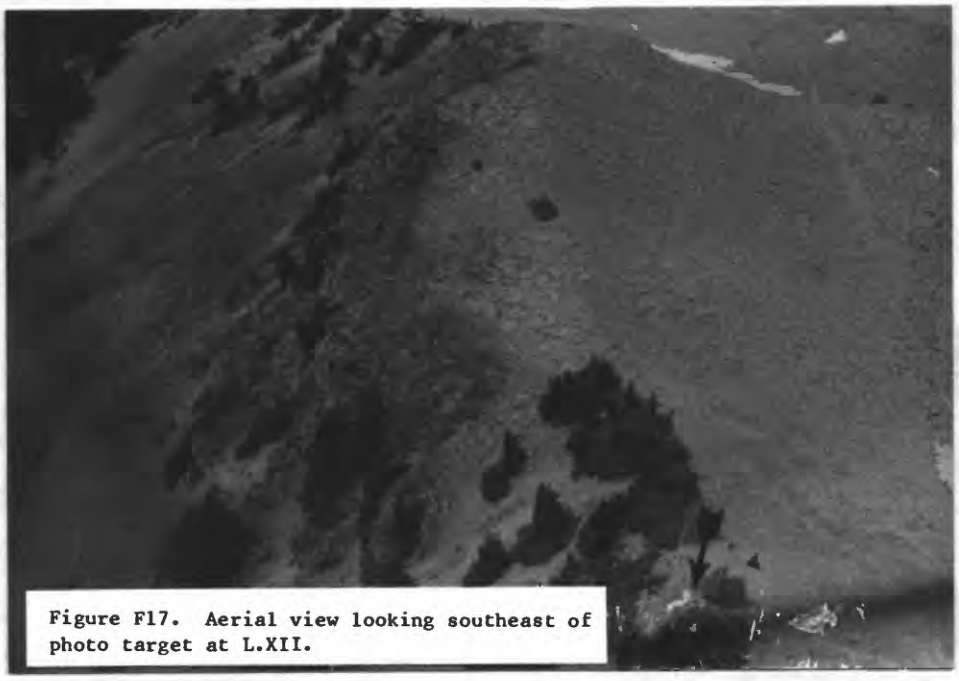

Figure F17. Aerial view looking southeast of photo target at L.XII.