TILT NETWORKS AT MOUNT SHASTA AND LASSEN PEAK, CALIFORNIA

Daniel Dzurisin, Daniel J. Johnson, Thomas L. Murray, and Barbara Myers
U.S. Geological Survey
Cascades Volcano Observatory
5400 MacArthur Blvd.
Vancouver, Washington 98661

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ABSTRACT

In response to recent eruptions at Mount St. Helens and with support from the USGS Volcanic Hazards Program, the Cascades Volcano Observatory (CVO) has initiated a program to monitor all potentially-active volcanoes of the Cascade Range. As part of that effort, we installed tilt networks and obtained baseline measurements at Mount Shasta and Lassen Peak, California during July 1981. At the same time, baseline electronic distance measurements (EDM) were made and fumarole surveys were conducted by other crews from CVO. Annual surveys are planned initially, with subsequent visits as conditions warrant. These geodetic and geochemical measurements supplement a program of continuous seismic monitoring of Cascade volcanoes by the USGS Office of Earthquake Studies in cooperation with local universities.

Other tilt networks were established at Mount Baker in 1975 and at Mount St. Helens in 1981. EDM networks were established at Mount Baker in 1975, Mount St. Helens in 1980, and Crater Lake in 1981. Additional tilt and/or EDM networks are planned for Mount Rainier, Mount Hood, Glacier Peak, Three Sisters, and Crater Lake as funds permit.

INTRODUCTION

With support from the USGS Volcanic Hazards Program, the David A. Johnston Cascades Volcano Observatory (CVO) has been established in Vancouver, Washington to monitor ongoing eruptive activity at nearby Mount St. Helens. In addition, CVO has initiated a program of geodetic and geochemical monitoring at other potentially-active volcanoes in the Cascade Range. Fieldwork during 1981 included acquisition of baseline geochemical and/or geodetic information at five Cascade volcanoes other than Mount St. Helens. Geochemical investigations included temperature measurements and gas sampling of fumaroles at Lassen Peak, Mount Shasta, Mount Hood, and Mount Baker (T. Casadevall, oral communication). Geodetic studies consisted of: 1) tilt surveys at Mount Shasta, Lassen Peak, and Mount Baker; 2) electronic distance measurements at Mount Shasta, Lassen Peak, Crater Lake, and Mount Baker (Swanson and Chadwick, 1982); and 3) precision gravity surveys at Mount Shasta and Lassen Peak (Jachens and others, 1982). Additional work is planned at other Cascade volcanoes as funds permit.

Our procedure for measuring ground tilt has been informally called "dry tilt", "telescopic spirit level tilt", "precision leveling", and "tilt leveling", none is which is completely satisfactory in our opinion. The term "dry-tilt" has an obscure derivation which deserves explanation. The technique was developed at the Hawaiian Volcano Observatory as a convenient alternative to long-base (40-50 m) water-tube tilt stations, which provided excellent precision but were cumbersome to measure. As an alternative to long sojourns on misty nights with flashlights, hoses, and a water tank, the new technique was joyously

dubbed "dry-tilt!" by observatory staff. "Telescopic spirit-level tilt" has also been used (Kinoshita, Swanson, and Jackson, 1974, pp. 91-94) to refer to the instrument originally used in making the measurements, but the term became outdated with the advent of self-leveling pendulum instruments. "Precision leveling" has been used informally, but is not sufficiently descriptive of the technique. We feel that none of the terms used to date is satisfactory, but we note that "dry-tilt" has achieved wide acceptance in the volcanological community. We have chosen to avoid this problem in nomenclature here by referring simply to "tilt stations" and "tilt networks", but we hope that a satisfactory term will soon be proposed for this widely-used technique.

This report describes the installation of tilt networks at Mount Shasta and Lassen Peak during July 1981, including station locations and baseline measurements. It is intended as a reference work to facilitate future re-occupations of the Shasta and Lassen networks, and also as a guide to those interested in making similar measurements at other volcanoes. The reader is referred to Yamashita (1981) for a detailed description of the "dry-tilt" technique and related procedures. Electronic distance measurement (EDM) networks installed at Mount Shasta, Lassen Peak and Crater Lake in July 1981, and at Mount Baker in August 1981, are described separately by Swanson and Chadwick (1982).

Selection of suitable tilt sites at Mount Shasta and Lassen Peak was complicated by relatively steep slopes and rugged topography. We assigned the highest priority to locating stations in bedrock (for stability), but also attempted to select sites which were: 1) suitable for triangular arrays (for closure and directional information), 2)

distinctive and therefore easy to re-locate, and 3) well-situated so as to maximize the simplicity and efficiency of the networks. Ease of access was not a strong factor in site selection, because helicopter support was considered essential for adequate monitoring of both volcanoes.

Although topographic constraints initially appeared severe, adequate sites were eventually identified for 1 quadrilateral and 4 triangular stations at Mount Shasta, and 3 triangular stations at Lassen Peak. Six of the eight stations are in bedrock, 1 is in large buried boulders, and 1 in tephra. Six are located on distinctive prominences which should be relatively easy to re-locate; another (Ski Bowl Lodge, Mount Shasta) lies along a paved road adjacent to an abandoned ski lodge. Only one (Lassen C) is difficult to reference to a specific cultural or topographic feature; its location was dictated by the layout of the Lassen Peak network. In our opinion, the existence of adequate sites makes periodic tilt monitoring a viable and useful tool at Mount Shasta and Lassen Peak, and probably at other Cascade volcanoes as well.

In a happy coincidence, USGS Water Resources Division flew 1:24000 scale aerial photography of Mount Shasta and Lassen Peak soon after our stations were installed. Photo-targets were placed at all tilt and EDM stations prior to the flights; examples of the photography are provided in our illustrations. The contractor for the photography was Cartwright Aerial Surveys, Inc., Sacramento, CA. The relevant flight lines are 81167 and 81178.

MOUNT SHASTA NETWORK

A network of 5 tilt stations was installed and measured at Mount Shasta with helicopter support during July 13-17, 1981 (Figure 1). Four of the benchmark arrays approximate 40-meter equilateral triangles; the fifth (Shasta North) is a quadrilateral dictated by local topography. At all but the Shasta West (Shastina) site, benchmarks were cemented into bedrock or large buried boulders as described by Yamashita (1981). A bedrock site was not feasible at Shastina, where benchmarks were epoxied to the tops of copper-weld rods "driven to refusal" (1.0-1.5 m) by a Cobra Model 148 gas-powered rock drill. In this case, the benchmark and upper 30 cm of copper-weld rod were isolated from the surrounding pyroclastic debris by a collar of 15.5 cm ID plastic pipe to minimize the effects of near-surface creep. This procedure is described in greater detail in Figure 8 and by Yamashita (1981).

By convention, the southernmost benchmark in each array is labelled X. Benchmarks Y, Z, and W (Shasta North only) are then assigned sequentially in a counterclockwise direction. All stations utilize 10 cm diameter die-cast brass benchmarks with 2 x 2 cm nipples for rod placement and 7 cm hollow stems for affixing to bedrock or copper-weld rods (see Figure 8e).

MOUNT SHASTA STATION DESCRIPTIONS

The following station descriptions assume that the reader has access to the Shasta Quadrangle 1:62500 scale topographic map and has identified general station locations from Figure 1 and the geographic coordinates provided for each. Figures 2-13 include additional information useful for more precise benchmark locations.

Ski Bowl Lodge (41° 21.58' N, 122° 11.91' W)

A triangular array of benchmarks straddles the upper paved parking lot east and immediately adjacent to abandoned Ski Bowl Lodge at roughly 7760 feet elevation, 5.5 kilometers S5°W of Mount Shasta summit (Figures 2-3). Benchmarks X and Y are cemented atop large buried boulders; benchmark Z is cemented in a concrete footing near the northeast corner of the lodge (Figure 4). The reading site is located at the center of the array and marked by a P-K masonry nail driven flush with the pavement.

Shasta South (41° 23.22' N, 122° 11.50' W)

This triangular array is situated on a flat prominence between two steep-sided knobs along Sargents Ridge, roughly 2.5 km S4°E of Mount Shasta summit (Figure 5). The northern knob is shown at 11,267 feet elevation on the Shasta Quadrangle map. Benchmarks are cemented into highly vesicular bedrock and marked with cairns. The largest cairn at the site marks a Glacier Survey Photo Station within the benchmark array. The reading site is a low setup near the center of the station, as marked by a small cairn.

Shasta West (41° 24.78' N, 122° 13.00' W)

This triangular array straddles an open flat atop an arcuate ridge at roughly 11,760 feet elevation on the east flank of Shastina (Figures 6-7). The station lies near the base of the main Shastina cone, roughly 1.9 km N77°W of Mount Shasta summit, and 0.35 km N22°W of Sisson Lake. The site is lighter in color than its immediate surroundings owing to minor alteration of surface materials. Benchmarks are surrounded by 16 cm white plastic pipes projecting 10-30 cm above the surface and covered with aluminum caps stamped "WATER" (Figure 8). Small cairns mark each benchmark and the reading site at the center of the array.

Shasta North (41° 25.84' N, 122° 11.86' W)

This quadrilateral array is located at roughly 10,600 feet elevation on a bedrock ridge between Bolam and and Hotlum glaciers, roughly 2.5 km N3°W of Mount Shasta summit (Figures 9-10). Bedrock at the site is reddish in outcrop; roughly 100 m upslope is a second flat area containing large dark-gray boulders. Cairns mark the center of the array and each of 4 benchmarks, arranged such that diagonals of the array are roughly radial and cross-radial to the summit. Setups are required along each leg of the array, and the W-Z leg requires an intermediate setup with a turning cup.

Shasta East (41° 24.70' N, 122° 8.92' W)

A triangular array is situated at roughly 8,920 feet elevation 3.8 km N86°E of Mount Shasta Summit, along a linear ridge with a series of high-standing knobs and intervening lowlands (Figures 11-12). The station occupies the second prominent knob from the top; the next lower

knob is marked by spot elevation 8566 on the Shasta Quadrangle map. Cairns mark the central reading site and each benchmark.

LASSEN PEAK NETWORK

Three tilt stations were installed and measured near Lassen Peak with helicopter support during July 18-20, 1981 (Figure 14). All are triangular arrays of nippled benchmarks cemented in bedrock as described earlier. Sites were chosen to monitor edifice-wide deformation of Lassen Peak; station Lassen B may also be sensitive in part to Chaos Crags.

LASSEN PEAK STATION DESCRIPTIONS

The following descriptions assume that the reader has access to the Lassen Volcanic National Park And Vicinity 1:62500 scale topographic map, and has determined the general location of each station from Figure 14 and the geographic co-ordinates provided for each. Additional site information is provided in Figures 15-19.

Lassen A (40° 28.75' N, 121° 31.00' W)

A triangular array is situated at roughly 8,880 feet elevation in highly-fractured and glacially-striated bedrock on the north flank of Eagle Peak, roughly 1.5 km S48°W of Lassen Peak summit (Figures 15-16). Benchmarks and the central reading site are marked with small cairns.

Lassen B (40° 30.17' N, 121° 30.03' W)

This triangular station sits atop a bedrock knob at roughly 8,520 feet elevation 1.6 km N9°E of Lassen Peak summit, and 0.3 km S73°W of the 8645 spot elevation shown for Crescent Crater on the Lassen Volcanic National Park And Vicinity map (Figures 15,17). The benchmark array straddles the top of the knob and is marked with small cairns, including the central reading site.

Lassen C (40° 28.85' N, 121° 29.36' W)

A triangular array is located at roughly 8,400 feet elevation on a lava flow 1.4 km S55°E of Lassen Peak summit and 1.9 km N86°W of the center of Shadow Lake. The station occupies a 50-meter open area which is largely free of vegetation, roughly 50 m from the southern wall of a large east-west trending canyon (Figures 15,18). It is marked with small cairns at each benchmark and the central reading site, and with a large T of dead branches. Benchmark Z is located on a large boulder slightly below ground level and is enclosed in a 16 cm white plastic pipe roughly 20 cm high, covered with an aluminum cap stamped "WATER".

EQUIPMENT AND PROCEDURES

The initial surveys were conducted with a Wild NA2 self-levelling level and GPM3 micrometer plate, together with Kern 3-meter rod #183124. Measurement procedures were as described by Yamashita (1981), except that the single rod was moved sequentially around the array until satisfactory closure was obtained. In most cases, the entire procedure was then repeated as a consistency check. Observed closures were often better than .005 cm and generally better than .010 cm. Important sources of reading error probably included wind, heat shimmer, rod setup errors, and physical changes in the rod, level, or tripod during the time required to close each circuit (30-45 minutes). Precision could likely be improved in future surveys if 2 or preferably 3 rods are used to reduce setup and measurement time.

STATION PARAMETERS AND EQUATIONS

Each tilt station can be characterized by two unique station equations which incorporate orientation and dimensional parameters into site-specific expressions for tilt change as a function of measured elevation changes (see Yamashita, 1981). Required input to the station equations includes the angle theta from due east to the XY leg of the array, angle phi from due east to the XZ leg, and the lengths of the XY and XZ legs of the array. A quadrilateral array such as Shasta North can be solved in a similar manner as two triangles with a common side. Input

parameters to the Mount Shasta and Lassen Peak station equations are illustrated in Figures 13 and 19; the equations themselves are listed in Tables 1 and 2.

BASELINE MEASUREMENTS

Baseline measurements and their estimated uncertainties (1 standard deviation) for each of the Mount Shasta and Lassen Peak tilt stations are listed in Tables 3 and 4, respectively. Each value in the table represents the average of 6-12 left/right reading pairs at each benchmark acquired during two circuits of each station, and includes a linear closure correction.

SUMMARY

Tilt networks were installed during July 1981 at Mount Shasta and Lassen Peak as part of a monitoring program which also includes electronic distance measurements, fumarolic gas sampling, and precision gravity measurements. Standard deviations of the baseline tilt measurements range from .003 to .014 cm, and average .007 cm. If comparable accuracy is achieved during future occupations of the stations, standard errors of about .010 cm can be expected for the calculated elevation changes between benchmark pairs. For a typical station, such an uncertainty corresponds to a ground tilt of roughly 5 microradians.

Experience in Hawaii and at Mount St. Helens suggests that 5 microradians is the useful detection limit for meaningful ground tilts with this technique, even though better precision may be indicated by the consistency of field measurements. Thus, the precision of baseline measurements at Mount Shasta and Lassen Peak is probably adequate to detect any meaningful grounds tilts in the next few years. Nevertheless, an attempt should be made to improve the precision of future surveys by using two or preferably three stadia rods rather than one, and by standardizing measurement techniques at more frequently occupied tilt sites such as those at Mount St. Helens.

In order to assess the stability of tilt sites at Mount Shasta and Lassen Peak, we suggest that the stations be re-occupied at least once annually during 1982 and 1983. If null results are obtained, the measurement interval might be lengthened when there are no independent indications of impending activity (e.g., anomalous seismicity, fuming, or snowmelt). Even in such quiet times, however, it would be prudent to re-occupy the tilt and EDM networks at least every third year.

ACKNOWLEDGMENTS

We salute the professionalism displayed by pilot Steve Wistrand of Trans-Western Helicopters (formerly Cascade Commercial Helicopters), who routinely made tight landing sites seem spacious. We also appreciate the cooperation and assistance of the U.S. Forest Service at Shasta-Trinity National Forest, and of the U.S. National Park Service at Lassen Volcanic National Park. Perspective drawings for this report are by B. Myers; T. Murray skillfully wielded the Cobra hammer and helped with station installations.

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TABLE 1
Mount Shasta Station Equations

Ski Bowl Lodge

$\tau(N) = 0.204\ \Delta(Y-X) - 0.104\ \Delta(X-Z)$
$\tau(E) = 0.261\ \Delta(Y-X) + 0.224\ \Delta(X-Z)$

Shasta South

$\tau(N) = 0.064\ \Delta(Y-X) - 0.239\ \Delta(X-Z)$
$\tau(E) = 0.302\ \Delta(Y-X) + 0.239\ \Delta(X-Z)$

Shasta West

$\tau(N) = -0.010\ \Delta(Y-X) - 0.253\ \Delta(X-Z)$
$\tau(E) = 0.292\ \Delta(Y-X) + 0.140\ \Delta(X-Z)$

Shasta North

$\tau(N) = 0.287\ \Delta(Y-X) - 0.083\ \Delta(X-W)$
$\tau(E) = 0.258\ \Delta(Y-X) + 0.216\ \Delta(X-W)$
(or) $\tau(N) = 0.212\ \Delta(Z-Y) - 0.313\ \Delta(Y-W)$
$\tau(E) = 0.303\ \Delta(Z-Y) + 0.055\ \Delta(Y-W)$

Shasta East

$\tau(N) = -0.055\ \Delta(Y-X) - 0.281\ \Delta(X-Z)$
$\tau(E) = 0.391\ \Delta(Y-X) + 0.156\ \Delta(X-Z)$

Note: Tilts are expressed in microradians, elevation changes in thousanths of a centimeter.

TABLE 2
Lassen Peak Station Equations

Lassen A

$$\tau(N) = -0.199\ \Delta(Y-X) - 0.352\ \Delta(X-Z)$$
$$\tau(E) = 0.359\ \Delta(Y-X) + 0.056\ \Delta(X-Z)$$

Lassen B

$$\tau(N) = 0.049\ \Delta(Y-X) - 0.208\ \Delta(X-Z)$$
$$\tau(E) = 0.312\ \Delta(Y-X) + 0.208\ \Delta(X-Z)$$

Lassen C

$$\tau(N) = 0.222\ \Delta(Y-X) - 0.065\ \Delta(X-Z)$$
$$\tau(E) = 0.284\ \Delta(Y-X) + 0.335\ \Delta(X-Z)$$

Note: Tilts are expressed in microradians, elevation changes in thousanths of a centimeter.

TABLE 3
Mount Shasta Baseline Measurements

STATION	Y-X	X-Z	Z-Y
Ski Bowl Lodge	-26.895±.007cm	+73.966±.006cm	-47.071±.007cm
Shasta South	4.973±.007	+170.297±.009	-175.270±.008
Shasta West	+73.963±.005	+105.234±.007	-179.197±.005
Shasta East	+103.066±.003	-95.994±.007	-7.072±.004
	Y-X	X-W	W-Y
Shasta North	+284.243±.010	-233.348±.009	-50.895±.014

(Triangle YZW not measured; turning cup required)

Stated uncertainties are ±1 standard deviation, calculated from 6-12 measurements of elevation difference between each benchmark pair.

TABLE 4
Lassen Peak Baseline Measurements

STATION	Y-X	X-Z	Z-Y
Lassen A	-81.456±.009cm	-52.367±.007cm	+133.823±.005cm
Lassen B	+102.716±.007	-203.961±.009	+101.245±.008
Lassen C	+10.613±.005	+50.829±.007	-61.442±.008

Stated uncertainties are ±1 standard deviation, calculated from 6-12 measurements of elevation difference between each benchmark pair.

FIGURE CAPTIONS

Figure 1. Network of 5 tilt stations installed at Mount Shasta in July 1981, shown on the Shasta Quadrangle 1:62500 scale topographic map.

Figure 2. Vertical air photo taken 24 July 1981, showing the locations of Ski Bowl (bottom left) and Shasta South (top) tilt stations. Ticks at the margins help to locate white arrows, which point to the tilt sites. The white "T" photo panel visible in the original photo at the head of the arrow at Shasta South is centered on benchmark Y, with its tail pointing to Z. North is at the top.

Figure 3. View northward to Shasta summit, showing the locations of Ski Bowl, Shasta West (Shastina), and Shasta South tilt sites.

Figure 4. View from the north-northeast of Ski Bowl tilt site, with inset and sketch showing benchmark locations. Scale and north arrow are approximate; see Figure 13 for additional station information.

Figure 5. Photo (a) and sketch (b) of Shasta South tilt site from northeast, with arrow pointing to the station between 2 prominent knobs along Sargent's Ridge. A closer view (c) looking north shows the northern knob with the tilt station in the foreground; benchmark locations are shown in the inset (d).

FIGURE CAPTIONS (CONTINUED)

Figure 6. Vertical air photo taken 23 July 1981, showing Shasta West tilt station on the eastern flank of Shastina. White arrow indicated by ticks along the margin points to a white T-shaped photo panel which is centered on benchmark X, and points to Z. North is at the top.

Figure 7. Photo and sketch looking west at tilt station Shasta West. Sisson Lake is off the lower left corner of the photo. Scale and north arrow are approximate.

Figure 8. Installation of benchmarks in fragmental debris at station Shasta West (Shastina). First, a small hole roughly 0.5 m deep is dug (a), then a copper-weld rod is driven into the bottom of the hole with a Cobra gasoline-driven rock drill (b). Subsequent 5-foot sections of copper-weld rod are joined with threaded couplings and crimped with a hydraulic crimper (c). When the rod has been driven to refusal, it is cut off at ground level and a benchmark is affixed to its top with metallic epoxy and the crimper (d). Finally, a plastic collar is placed around the rod and benchmark to isolate them from near-surface creep (e), and a metallic cover is placed over the plastic pipe (f).

FIGURE CAPTIONS (CONTINUED)

Figure 9. Vertical air photo taken 24 July 1981 showing the location of tilt station Shasta North between Bolam and Hotlum glaciers on the north flank of Mount Shasta. A T-shaped photo panel visible at the head of the white arrow is centered on benchmark X and points to Z. North is at the top.

Figure 10. Photo and sketch looking south at tilt station Shasta North, with benchmark locations indicated in the inset sketch. A large cairn is located near the midpoint of line WX. Scale and north arrow are approximate.

Figure 11. Vertical air photo taken on 23 July 1981, showing the location of tilt station Shasta East. A T-shaped photo target at the head of the white arrow is centered on benchmark Z, and points away from the center of the triangular array. North is at the top.

Figure 12. Photo and sketch looking southeast at tilt station Shasta East, with benchmark locations shown in the inset sketch. Scale and north arrow are approximate.

FIGURE CAPTIONS (CONTINUED)

Figure 13. Station parameters for Mount Shasta tilt sites. Shown are the lengths and true bearings of each leg of the array, and the lengths and bearings from the instrument site to each benchmark in the array. At Ski Bowl, the instrument site is marked with a P-K nail driven flush with the parking lot pavement. At the other stations, instrument sites are marked with small cairns. The angles theta (from east to XY) and phi (east to XZ) are required input to the station equations given in Table 1 (see Yamashita, 1981 for generalized equations)

Figure 14. Network of tilt stations at Lassen Peak installed in July 1981, shown on the Lassen Volcanic National Park And Vicinity 1:62500 scale topographic map.

Figure 15. Vertical air photo taken 27 July 1981, showing tilt stations at Lassen Peak marked with large white arrows pointing to small T-shaped photo panels visible in original photos. The lava flow of 1915 is visible as a dark patch with an associated snowfield in the summit crater, just below and left of the photo's center. North is at the top.

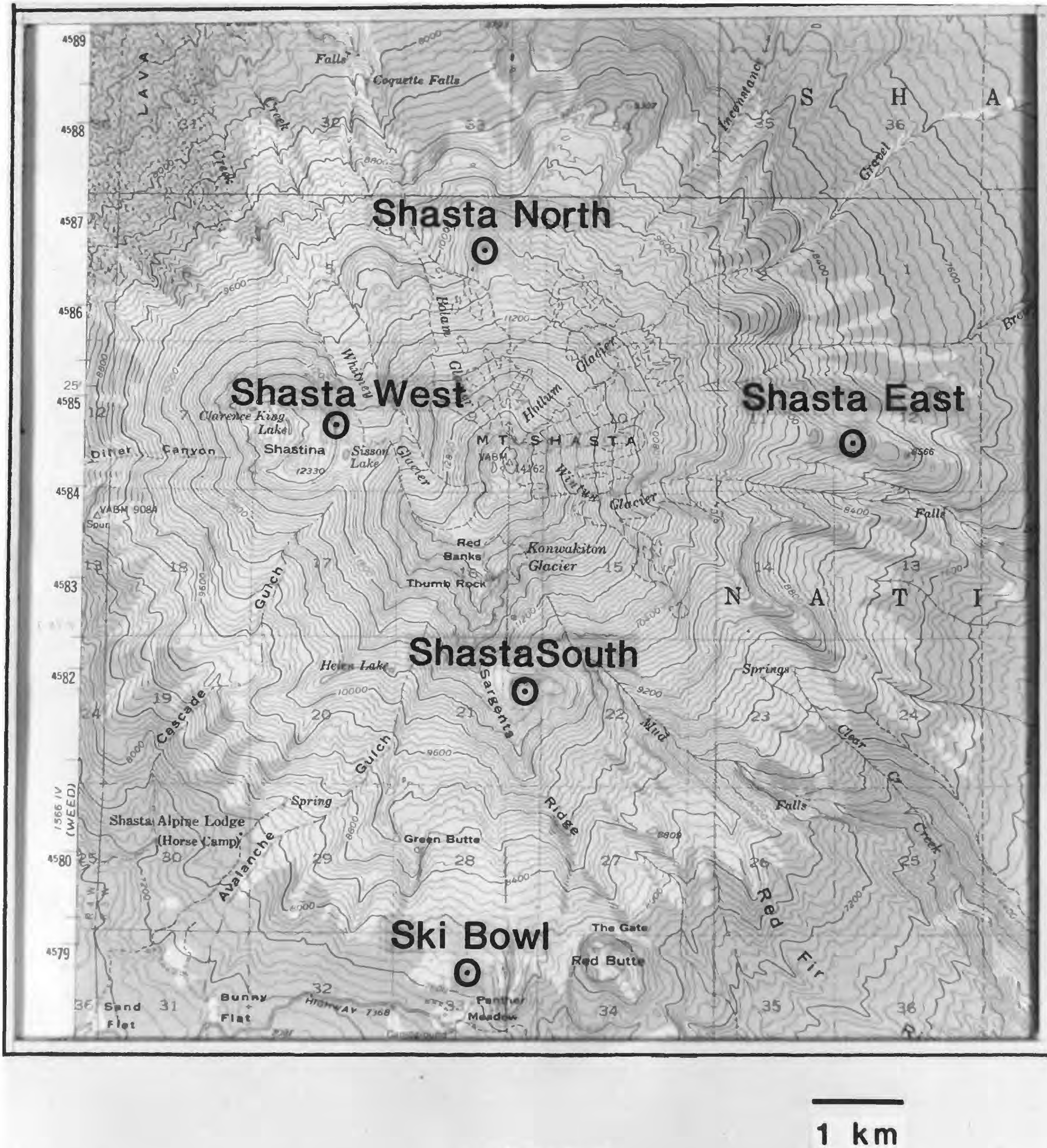
Figure 16. Photo and sketch looking east at tilt station Lassen A on Eagle Peak, with benchmark locations shown in the inset sketch. Scale and north arrow are approximate.

FIGURE CAPTIONS (CONTINUED)

Figure 17. Photo and sketch looking northeast at tilt station Lassen B near Crescent Crater. Benchmark locations are shown in the inset sketch; scale and north arrow are approximate.

Figure 18. Photo and sketch looking northeast at tilt station Lassen C. Note cliff which forms the southern wall of a large canyon in the foreground. Benchmark locations are shown in the inset sketch; scale and north arrow are approximate.

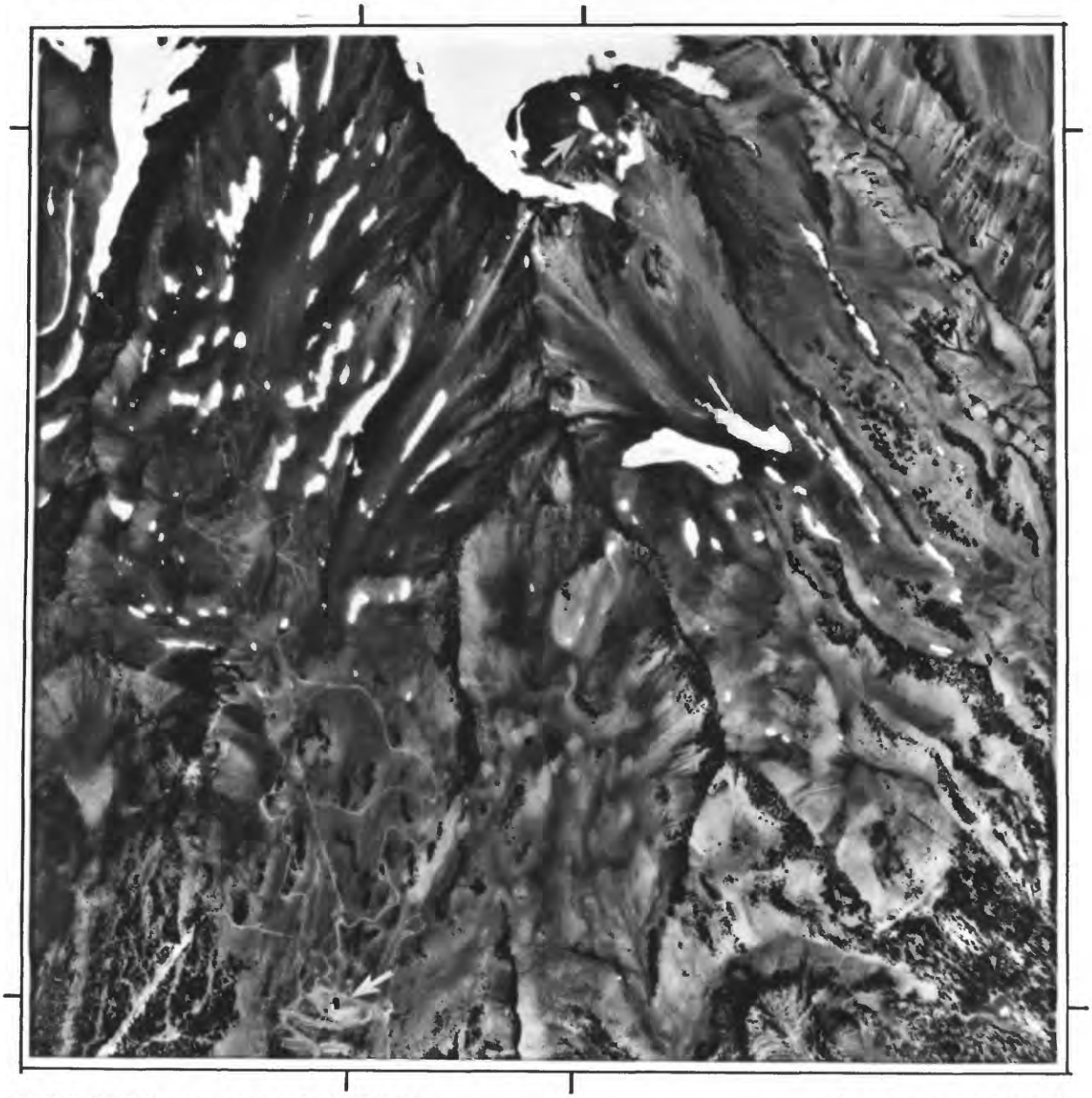
Figure 19. Station parameters for tilt sites established in July 1981 at Lassen Peak. Distances and bearings within each triangular array are from small cairns marking instrument sites. See Table 2 for the corresponding stations equations.



Shasta North
Shasta West
Shasta East
ShastaSouth
Ski Bowl
1 km

Figure 1

SKI BOWL and SHASTA SOUTH



USGS Photo 81167-269

Scale 1:24000

1 km

Figure 2

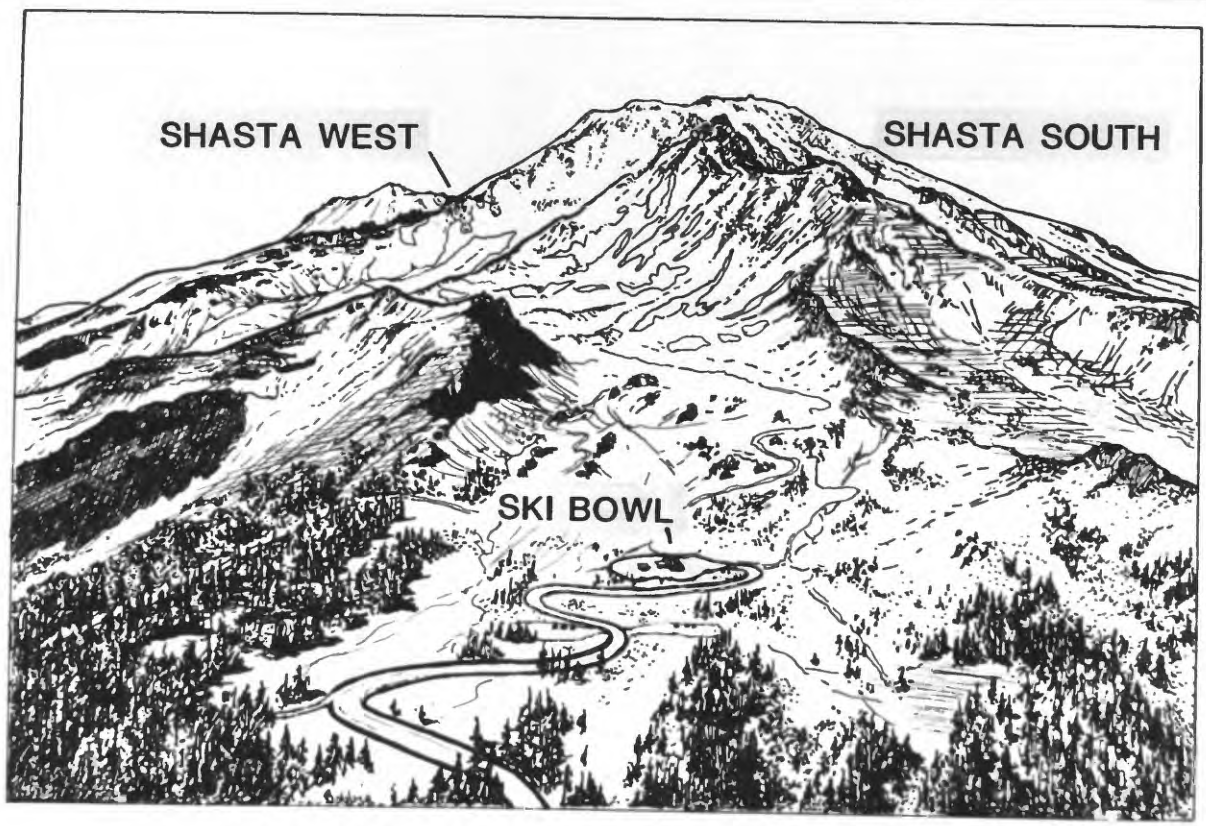
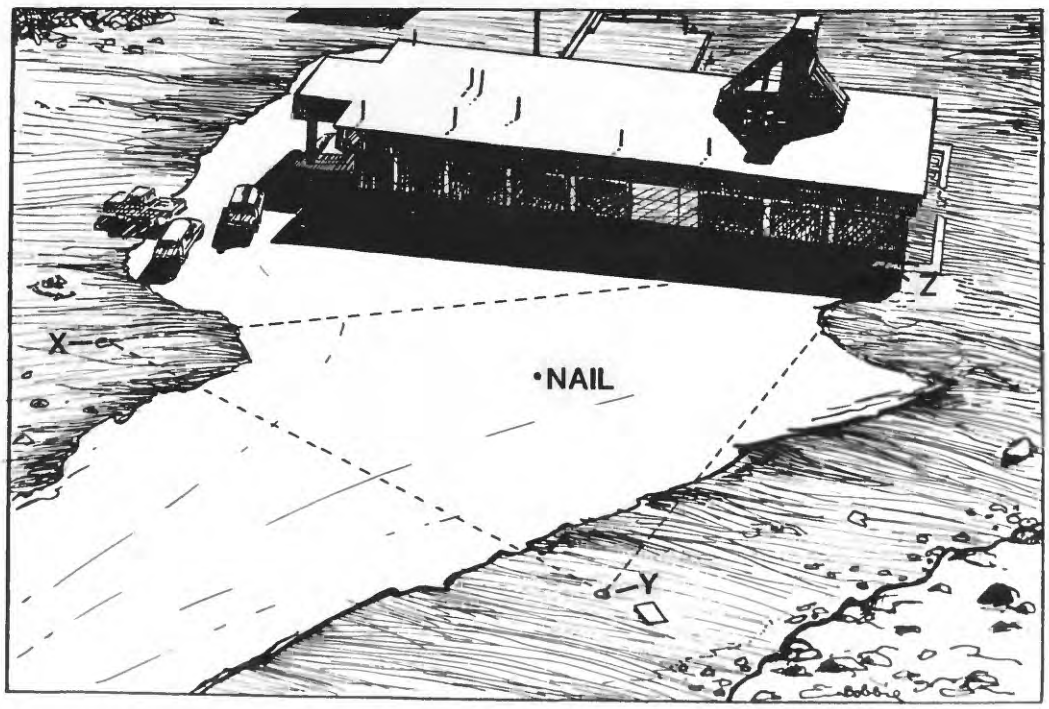


Figure 3

SKI BOWL LODGE



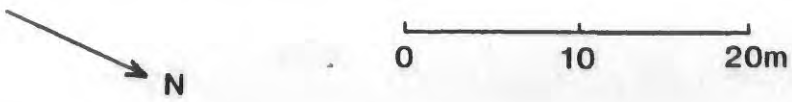
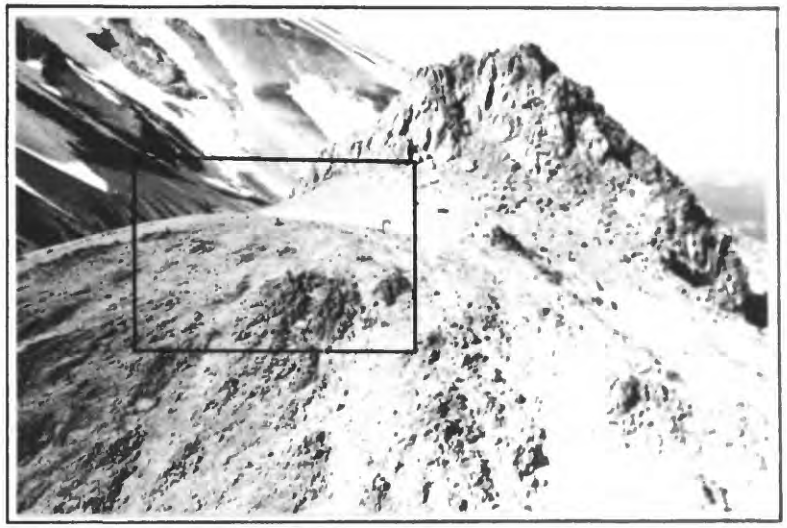


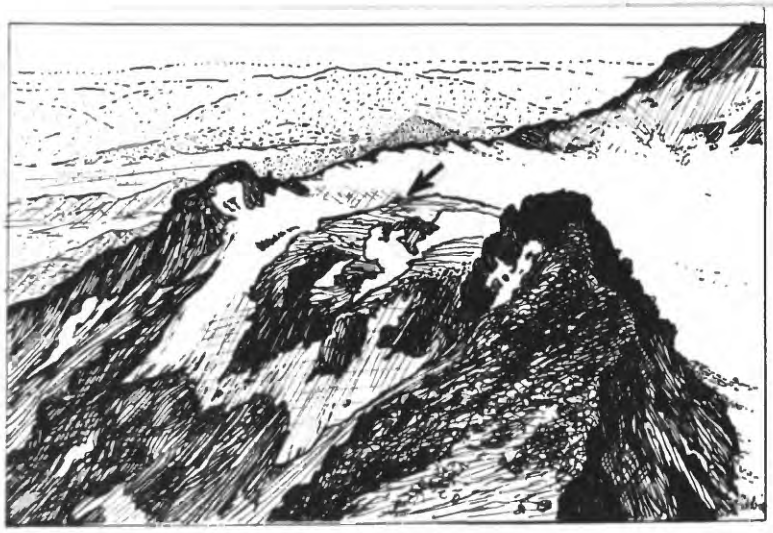
Figure 4

SHASTA SOUTH

a



c



b

d

N

0 10 20m

Figure 5

SHASTA WEST

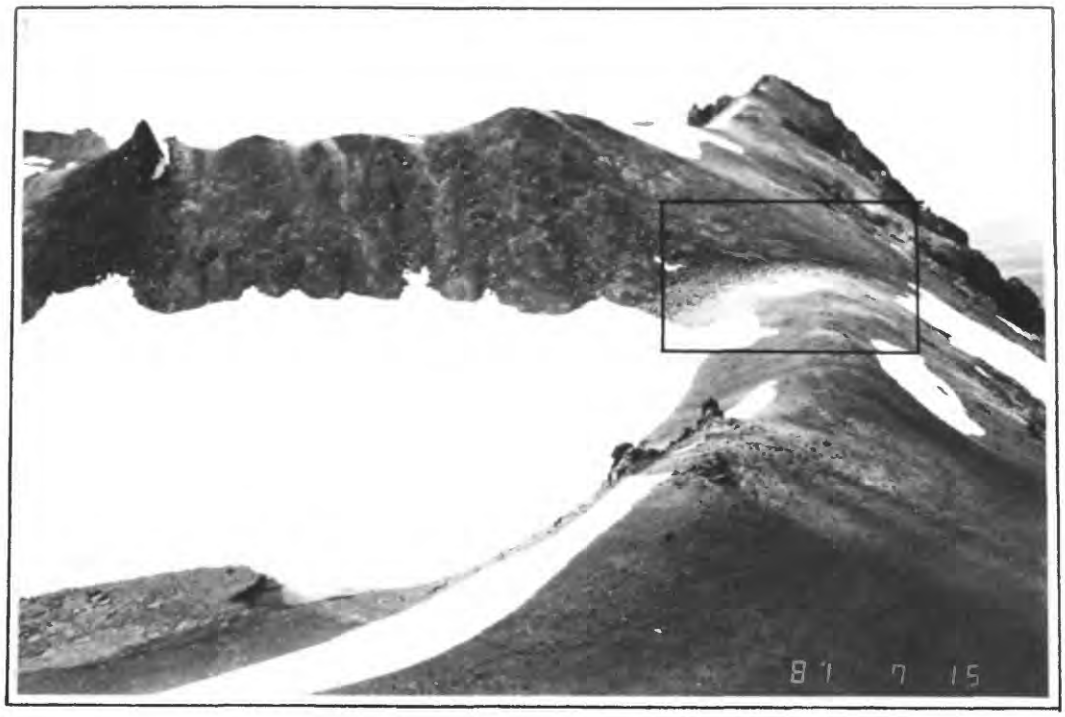
USGS Photo 81167-117

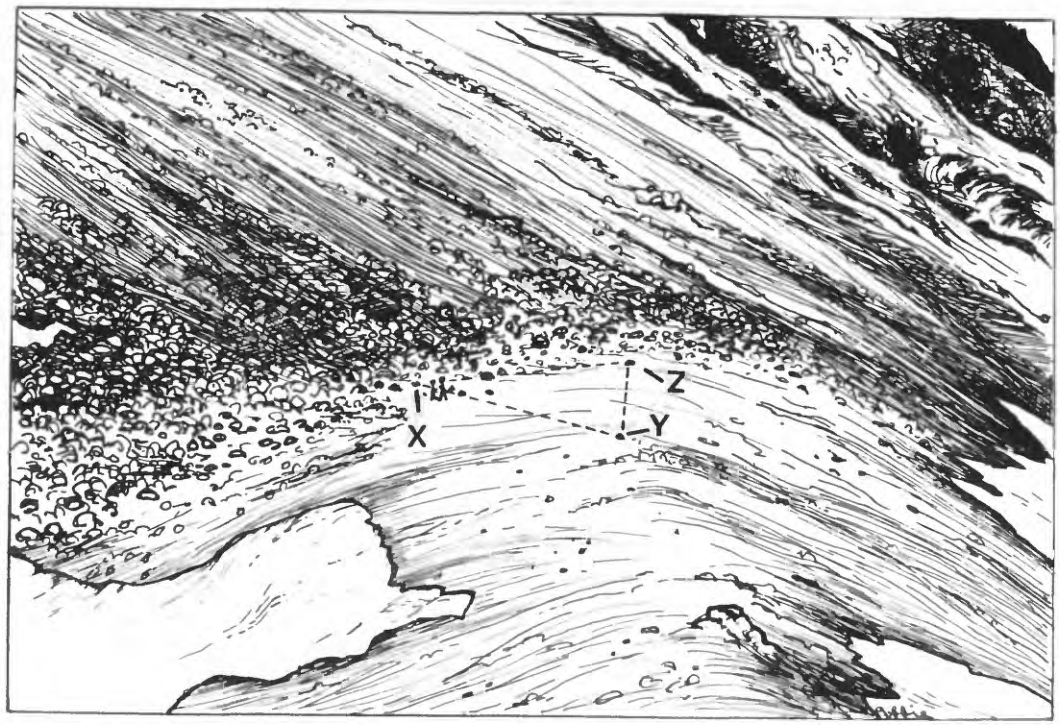
Scale 1:24000

1 km

Figure 6

SHASTA WEST





N

0 20 40m

Figure 7

Figure 8

SHASTA NORTH

USGS Photo 81167-274

Scale 1:24000

1 km

Figure 9

SHASTA NORTH

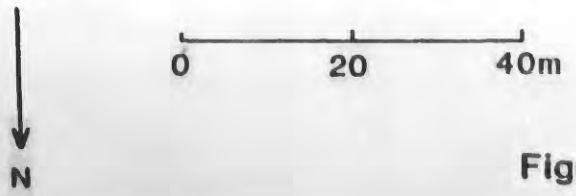


Figure 10

SHASTA EAST

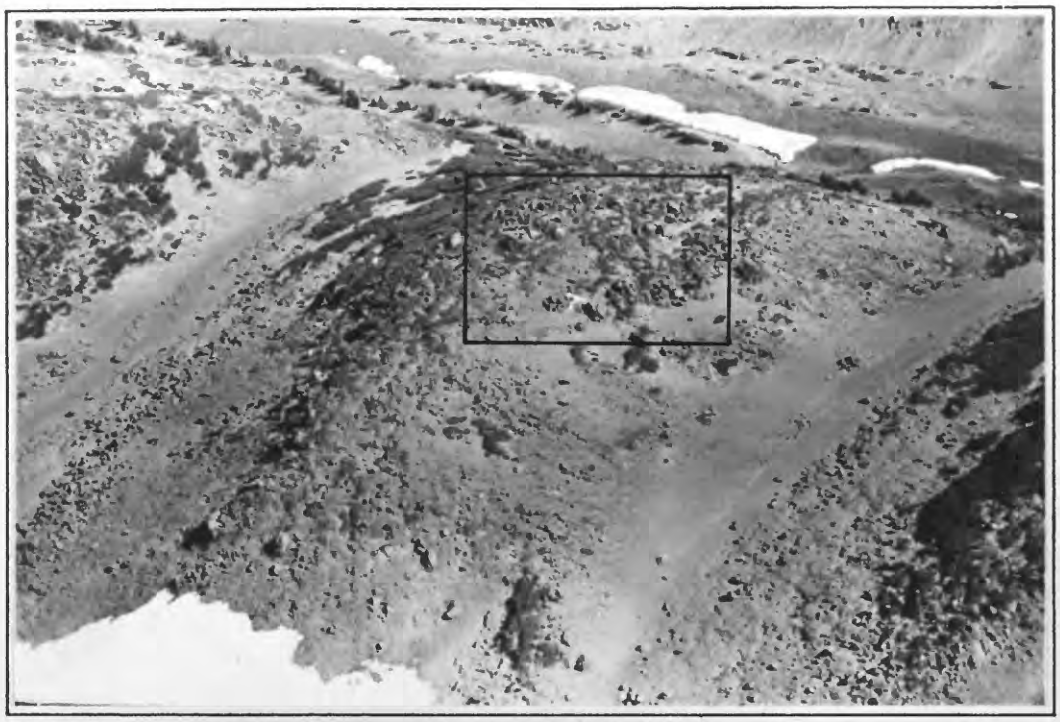
USGS Photo 81167-162

Scale 1:24000

1 km

Figure 11

SHASTA EAST



N

0 10 20m

Figure 12

STATION LAYOUTS

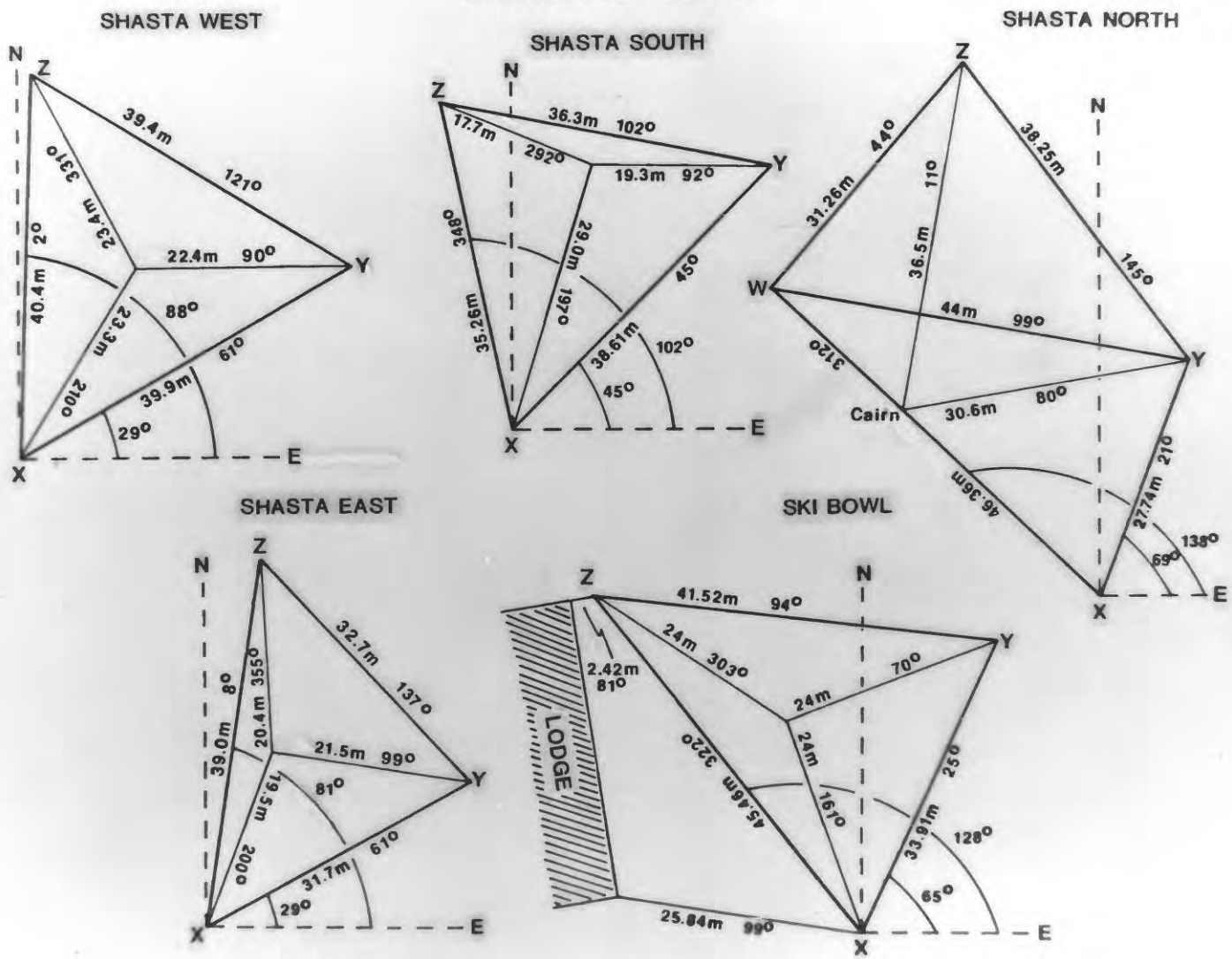
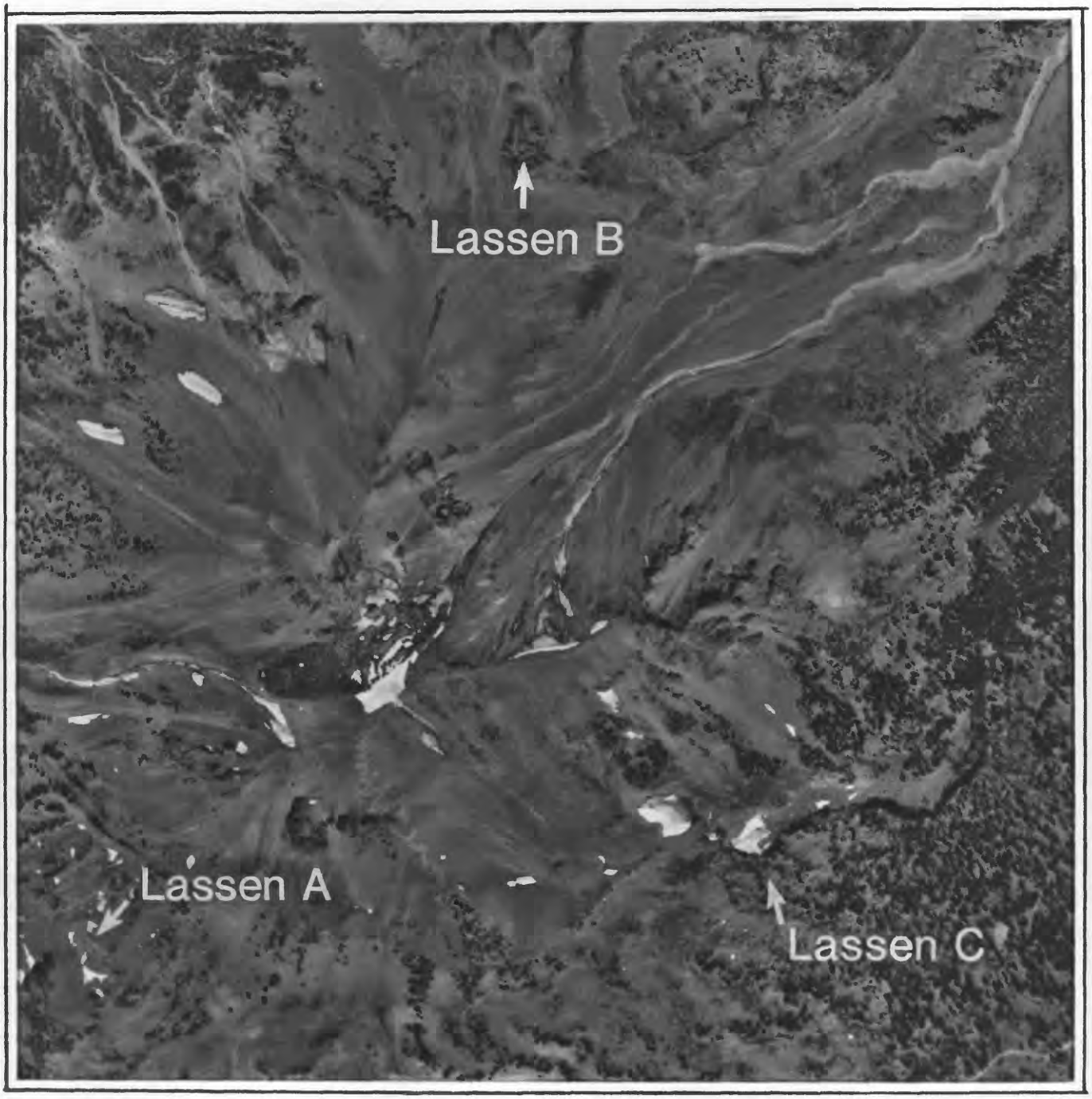


Figure 13


Lassen B
Lassen A
Lassen C
Lassen Peak
Chaos Crags
Crescent Crater
Old Boundary Spr
Emigrant Pass
Hat Lake
Loomis Peak
Crescent Cliff
Vulcans Castle
Blue Lake
Soda Lake
Ski Hell Peak
Lake Helen
Pilot Pinnacle
Emerald Lake
Mt Diller
Picnic Area
Bumpass
Bumpass Mtn
Terrace Lake
Upper Mdw
West Fork Hat C
DEVASTATED
AREA
PARK
ROAD
1 km

Figure 14

LASSEN PEAK STATIONS



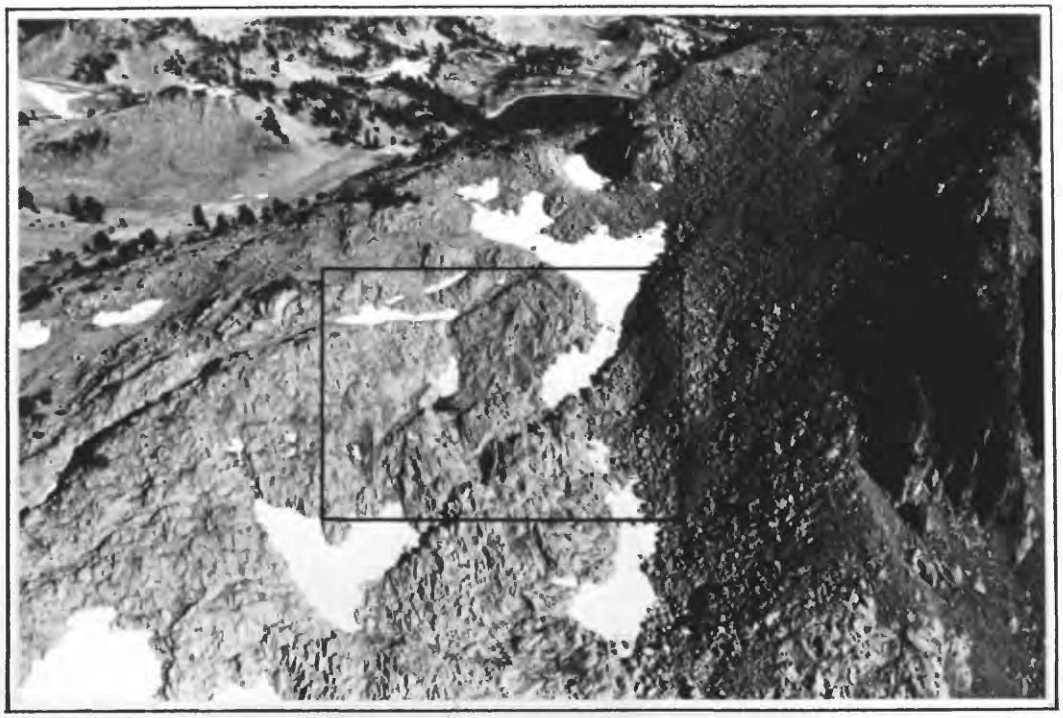
USGS Photo 81178-52

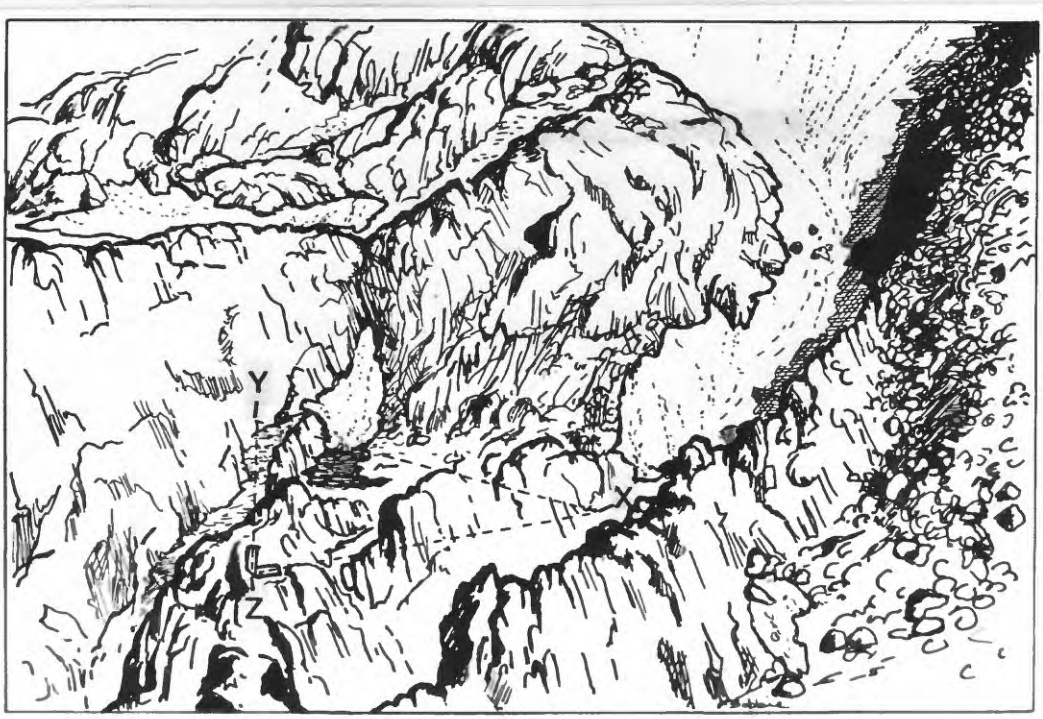
Scale 1:24000

1 km

Figure 15

LASSEN A



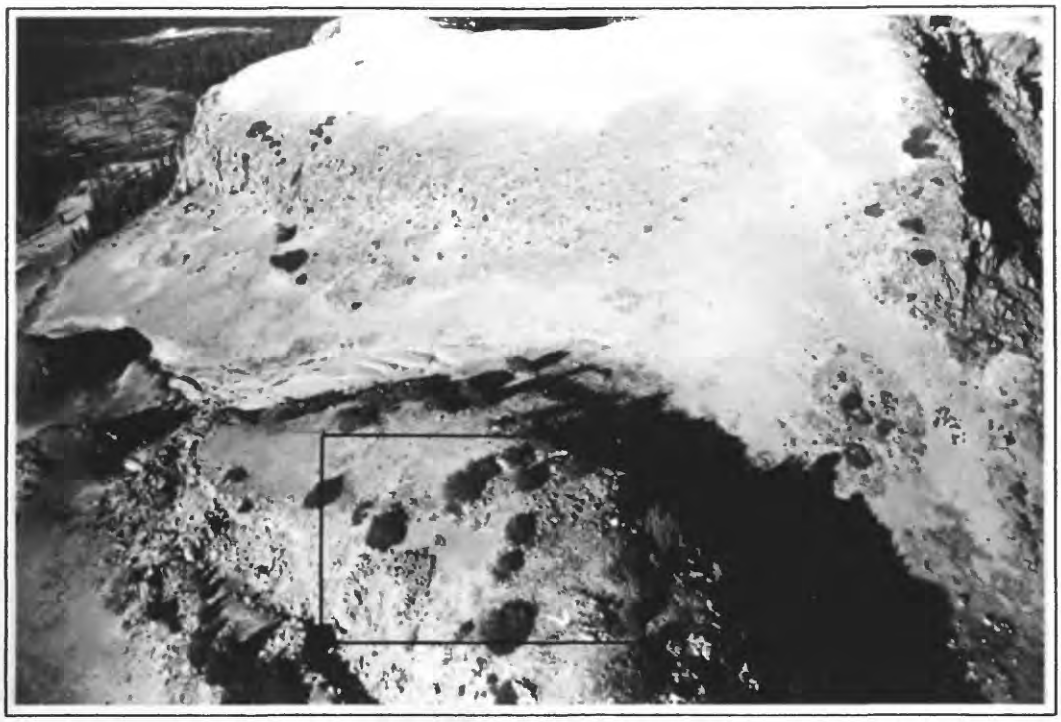


N ←

0 10 20m

Figure 16

LASSEN B

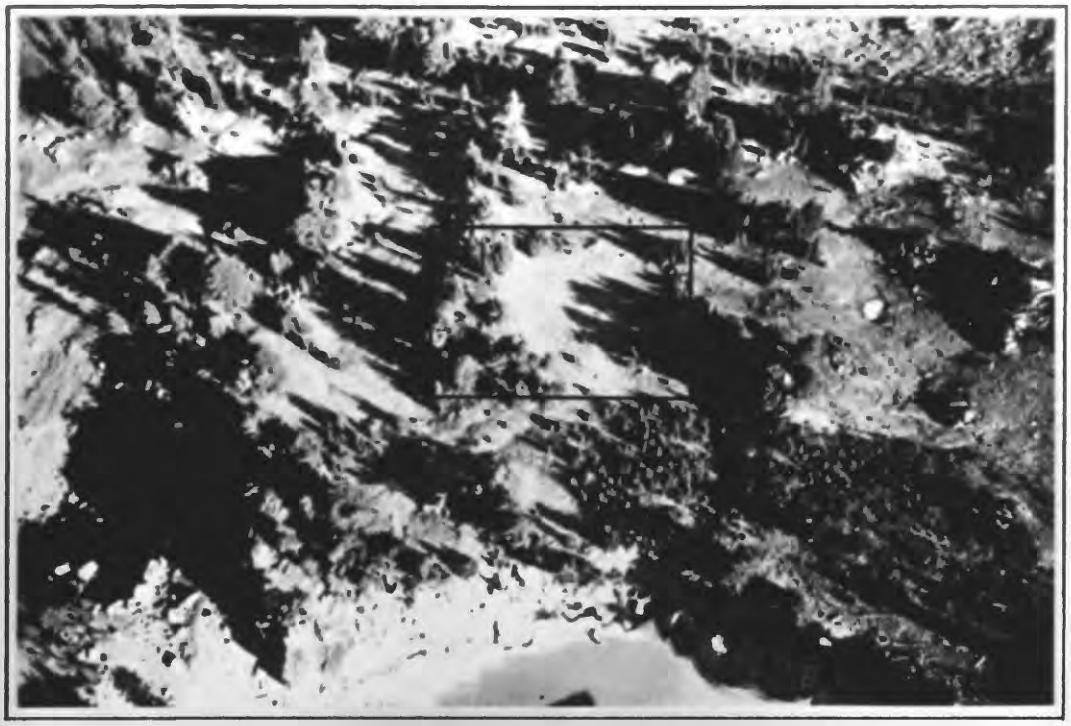


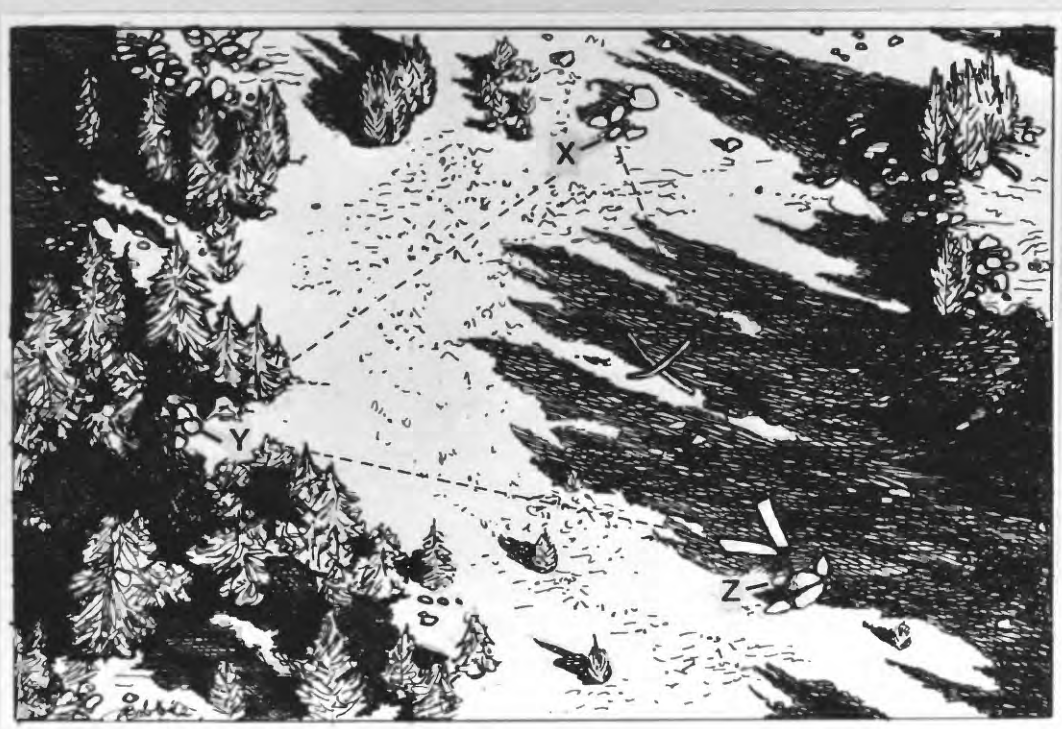
N

0 10 20m

Figure 17

LASSEN C





N

0 10 20m

Figure 18

STATION LAYOUTS

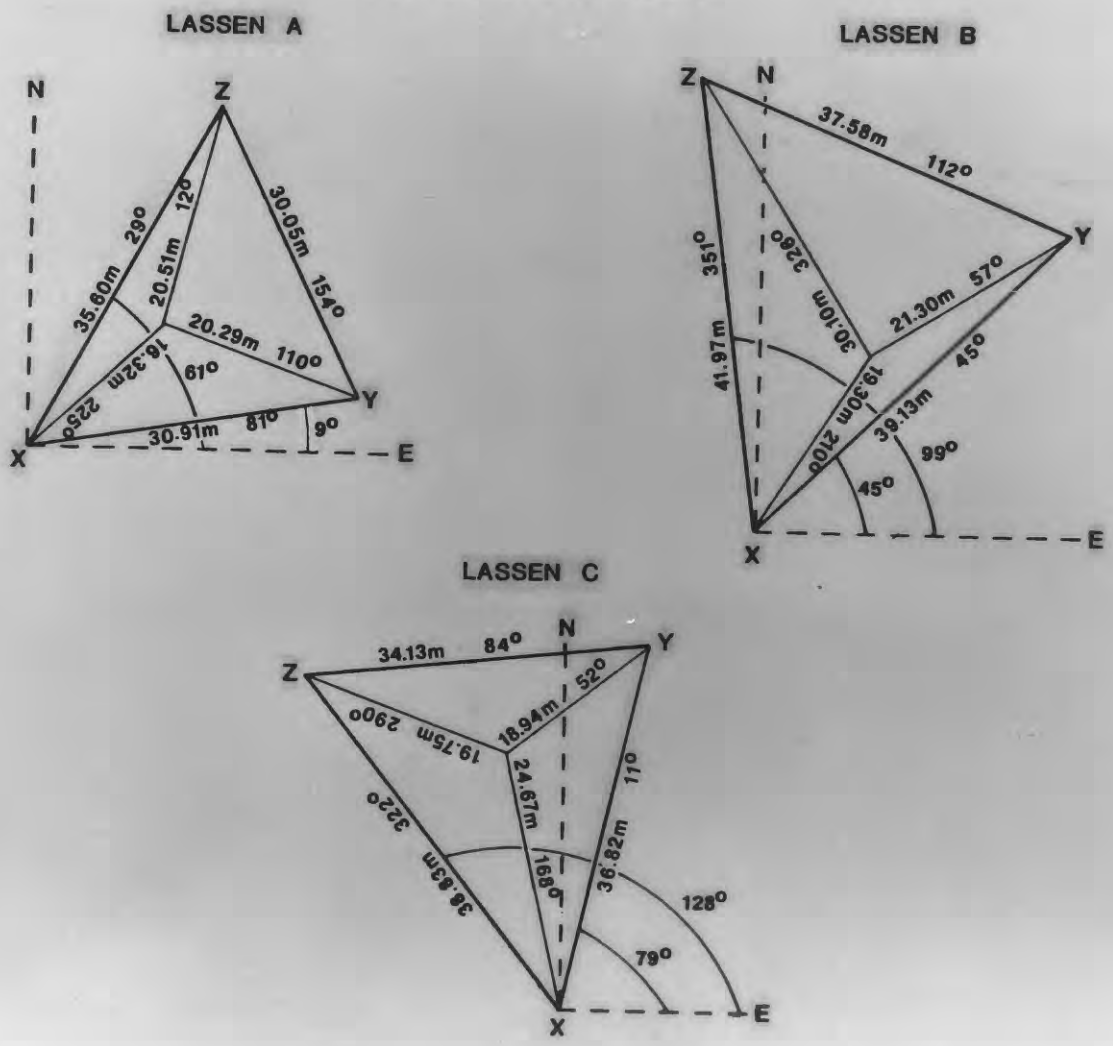


Figure 19

Figure 19