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BATHYMETRY OF CANNIKIN LAKE, AMCHITKA ISLAND, ALASKA, WITH AN EVALUATION OF COMPUTER-MAPPING TECHNIQUES

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ABBREVIATIONS AND CONVERSION FACTORS

Multiply English Units	By	To Obtain Metric Units
Miles (mi)	1.609	Kilometres (km)
Feet (ft)	0.3048	Metres (m)
	0.0003048	Kilometres (km)
Inches (in)	2.54	Centimetres (cm)
	25.4	Millimetres (mm)
Square miles (mi^2)	2.590	Square kilometres (km^2)
Acres	0.4047	Hectares (ha)
Acre-feet (acre-ft)	1233	Cubic metres (m^3)
Miles per hour (mi/h)	0.868	Knots (k)
Cubic feet per second (ft^3/s)	0.02832	Cubic metres per second (m^3/s)

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ABSTRACT

Defining the characteristics of Cannikin Lake was essential in determining the effect of a subsurface nuclear detonation on the hydrologic and biologic environment. A bathymetric map, the basic geometry of the lake, and the stage-area-volume relationship were derived from data produced by a sonic survey of the lake. At the lake's highest level, the maximum depth is 31 feet (9.45 metres), it has a volume of 325 acre-feet (401 x 10^3 cubic metres) and covers a surface area of 30 acres (12.1 hectares). A computer-mapping technique utilizing two different computer programs (WET and Calcomp GPCP) was used to evaluate the usefulness of the programs as mapping tools. The two bathymetric maps of the lake bottom produced by this method show a high degree of reliability when compared with the hand-drawn version.

INTRODUCTION

The Cannikin event was detonated at a depth of 5,875 ft (1.79 km) on Amchitka Island, Alaska (fig. 1), on November 6, 1971. It was the largest underground nuclear test that the United States has conducted.

Cannikin, with a yield of less than 5 megatons, was detonated in saturated volcanic rock. Milliseconds after the explosion the energy of the device was expended, creating a spherical cavity formed by heat and pressure. The surrounding medium was fractured several

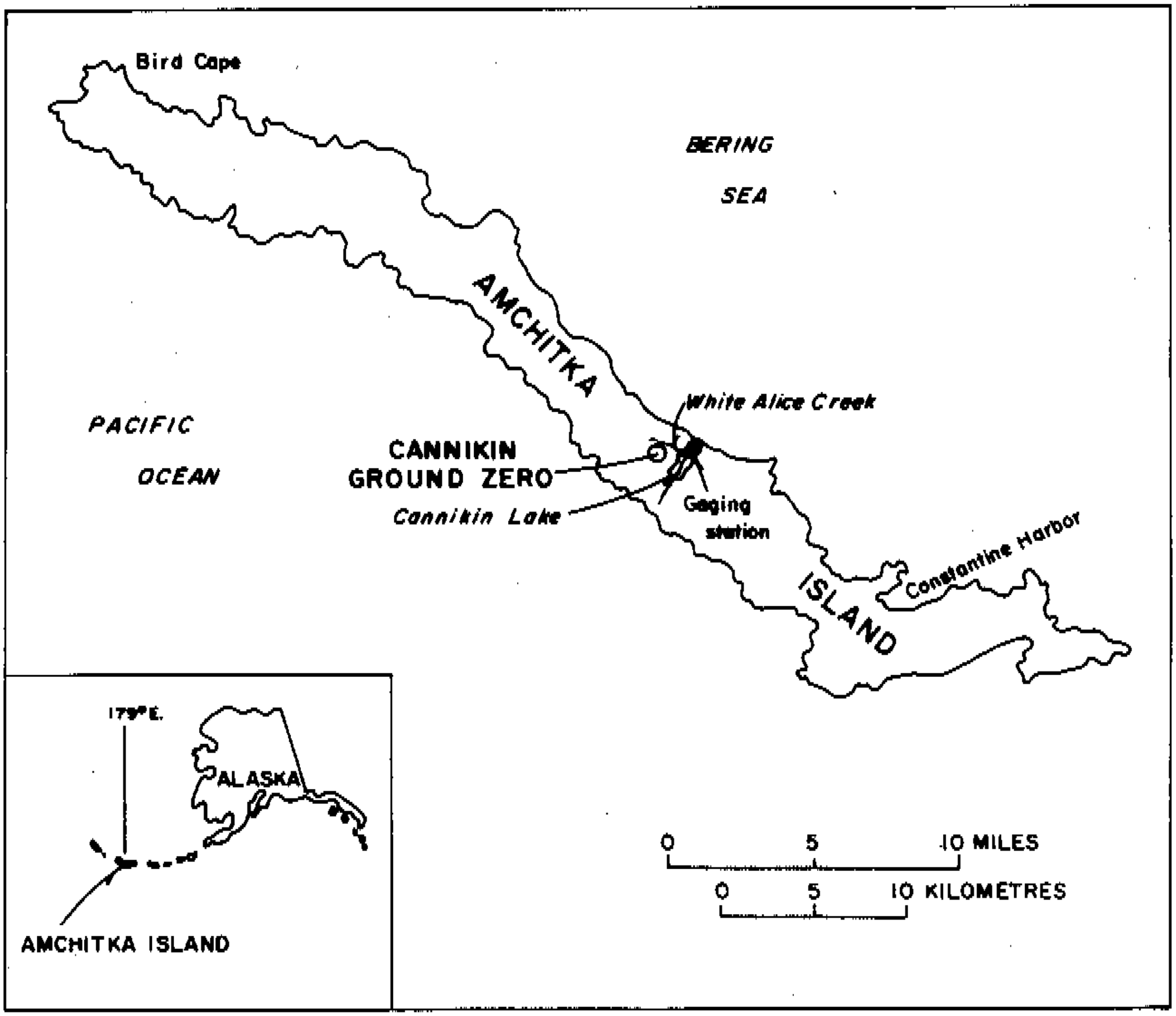


Figure 1--Index map of report area showing location of Cannikin Lake.

cavity-radii from the point of the explosion. At the land surface, the ground lifted and cracked from the force of the explosion (fig. 2). Thirty-eight hours after the explosion, temperatures and pressures in the underground cavity subsided sufficiently for the overlying rock to collapse into the cavity. The collapse initiated the growth of a rubble chimney that extended to the land surface, forming a collapse sink (ground surface depression) with associated fractures and faults.

The deepest part of the triangular collapse sink was offset about 1,500 ft (460 m) east of GZ (ground zero), the surface location of the emplacement hole. This topographic closure captured surface-water runoff from 84 percent of the surrounding drainage area (fig. 2). Stage recorders placed in the collapse sink in July 1972 showed that a lake began to form in August and began to spill into the lower reaches of White Alice Creek by December 1, 1972. This lake, commonly referred to as Cannikin Lake by the AEC (U.S. Atomic Energy Commission) and its contractors, was the first lake created by an underground nuclear explosion.

The USGS (U.S. Geological Survey), in cooperation with the AEC, has the responsibility to document and to interpret the geologic and hydrologic effects of nuclear explosions. An accurate description of collapse sinks is part of this responsibility.

The formation of a lake within the collapse sink is a unique geologic and hydrologic effect of an underground nuclear explosion. Cannikin Lake provides an opportunity to conduct bioenvironmental studies of a newly-formed aquatic habitat and to determine dilution patterns in the event of radioactive leakage. An accurate description of the lake bottom and

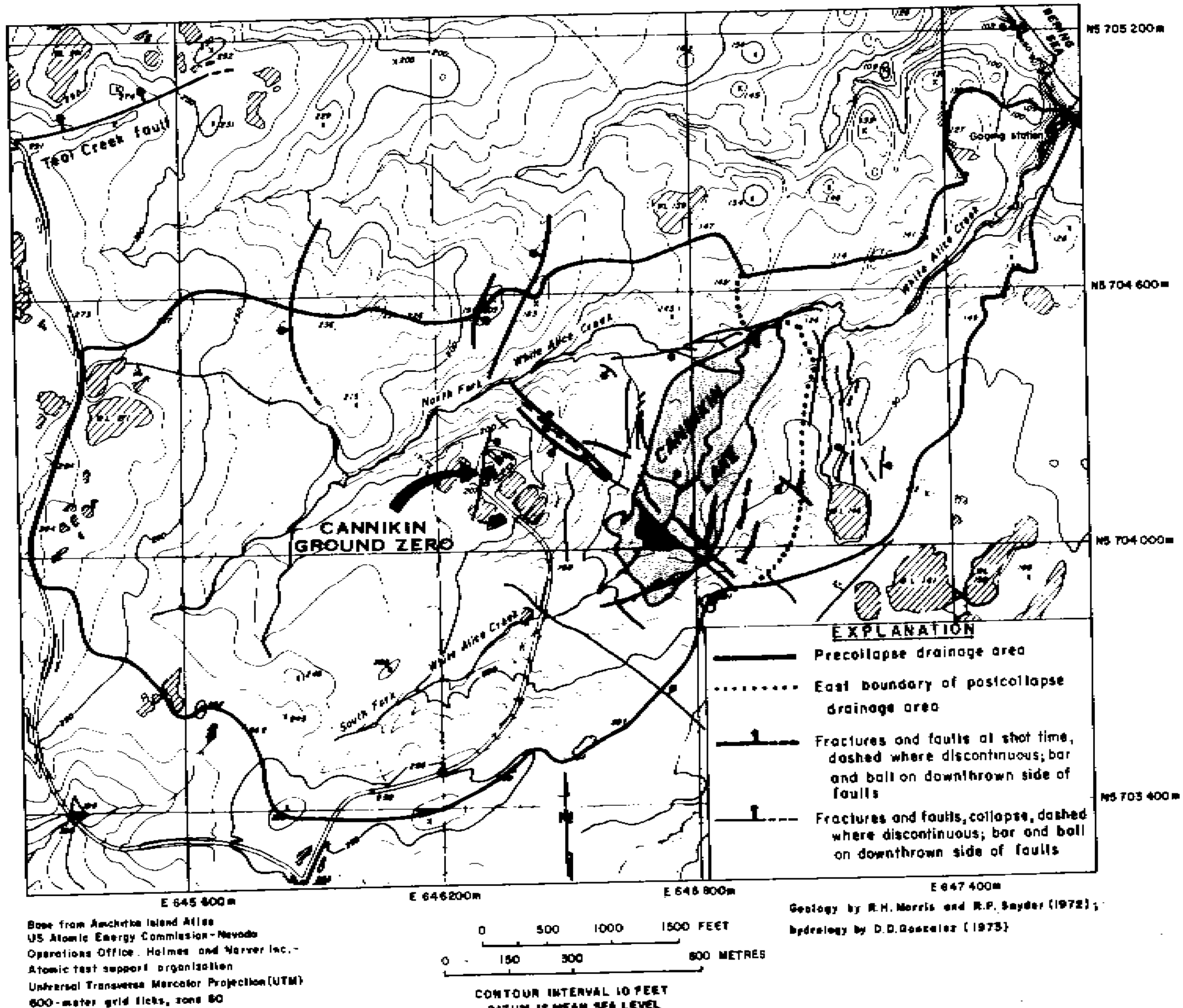


Figure 2.--Primary geologic and hydrologic effects resulting from the Cannikin event.

volume of the lake, based on bathymetry, was necessary to document and interpret the geological, hydrological, and bioenvironmental effects associated with the creation of Cannikin Lake.

The stage-volume relationship for Cannikin Lake was calculated using the computer program, WET. This program and another, Calcomp GPCP, were used to produce bathymetric maps from the same data. Because the manually-drawn bathymetric map includes details determined by photography and visual observation before the lake basin was submerged, comparison of the maps provides a test of the reliability of the computer programs in mapping irregularly spaced data.

Acknowledgments

The authors wish to express their gratitude to Owen Sammons of Holmes and Narver, Inc., Las Vegas, Nevada, for his assistance in making the survey of Cannikin Lake.

GEOLOGIC AND HYDROLOGIC SETTING

The area surrounding Cannikin ground zero ranges in altitude from 50 ft (15.2 m) to 280 ft (85.3 m); the average altitude is 160 ft (48.8 m). The land surface is covered with turf and underlying peat as much as 13 ft (4 m) thick. Bedrock consists predominately of volcanic rocks, most of which were deposited under the sea or on the flanks of volcanoes. The area drains northeastward toward the Bering Sea, where the shoreline is characterized by steep cliffs ranging from 40 to 60 ft (12.2 to 18.3 m) high.

The average annual precipitation is 30 to 35 in (762 to 889 mm) including an average snowfall of 70 in (1,778 mm). Wind velocities sometimes exceed 100 mi/h (87 k) in the winter, and average 20 to 25 mi/h (17 to 22 k) during the summer months. The drainage area surrounding GZ is 0.80 mi^2 (2.07 km^2) and is drained by White Alice Creek, which flows northeastward to the Bering Sea (fig. 2). Streamflow records collected near the mouth between August 1968 and November 1971 indicate that the mean average flow in White Alice Creek was approximately 2.80 ft^3/s (0.08 m^3/s). This flow, approximately 2,000 acre-ft (2,470 x 10^3 m^3) per year, is expected to be the approximate annual drainage into Cannikin Lake after equilibrium is established.

EFFECTS OF CANNIKIN

At the time of the detonation numerous fractures and faults were created; one major northwesterly fault occurred perpendicular to the south fork of White Alice Creek. The upthrown block of this fault immediately prevented normal runoff and water began to collect on the downthrown side of the fault, forming a pond (hatched area within Cannikin Lake on figure 2). Cavity collapse occurred 38 hours after the detonation, and resulted in a triangular ground-surface depression. Pertinent features of the collapse were major faults that trend east-northeast, north, and west-northwest (fig. 2). Only the major faults and those significant to the formation of Cannikin Lake are shown on figure 2. For a more detailed discussion of the structural geology refer to Morris and Snyder, 1972. Recent surveys by the U.S. Geological Survey and by Holmes and Narver, Inc. indicate that the maximum subsidence is about 60 ft (18.3 m).

Following the detonation and collapse, the drainage area surrounding GZ (fig. 2) was severely altered by upheaval, compressional forces, and major faulting (Gonzalez and Wollitz, 1972). Eighty-four percent of the original drainage area was temporarily transformed into a closed basin, the lowermost part of which contains Cannikin Lake. This basin, the area west of the dotted line within the drainage boundary on figure 2, comprises 425 acres (172 ha) of which 30 acres (12.1 ha) was covered by the lake at its highest known elevation. Water in the lake is mainly surface-water runoff from the upper reaches of White Alice Creek and seepage from the shallow water table.

The spillway of Cannikin Lake is formed by an east-northeast-trending fault where it intersects the north fork of White Alice Creek (fig. 2). This fault, which occurred at the time of collapse, had a vertical displacement of 10 ft (3.05 m) and a right-lateral horizontal displacement of 2 ft (0.61 m). At the highest known level of 116 ft (35.4 m) above msl, the lake covered 30 acres (12.1 ha) and stored 325 acre-ft (401×10^3 m^3) of water. The lake began to spill into the main reach of White Alice Creek 78 days after puddles began to store water in the low areas of the depression, indicating saturation of the underlying materials in the rubble chimney. The elevation of the spillway is estimated at 114 ft (34.7 m) above msl, while the lowest elevation in the lake determined by sounding is about 85 ft (25.9 m) above msl. The lake is about 2,150 ft (655 m) long, has an average width of 650 ft (198 m), and has 1.3 mi (2.09 km) of shoreline.

BATHYMETRY

The bathymetric map of Cannikin Lake is based on a sonic and land survey made in May 1973. Horizontal control consisted of a closed survey made around the lake. Control points were aligned at traverse stations using a transit positioned on a temporary benchmark. Right angles were turned with a compass and distances were measured with a surveying chain. The survey was adjusted one-half degree for closure between two permanent benchmarks.

Boat traverses with a sonic sounder were made across the width and length of the lake. Traverses were controlled and positions were determined by line of sight using lath at a traverse station as a control point. Weather conditions during the survey were exceptionally good. Ten traverses were made the width of the lake and four traverses the length of the lake.

Vertical control (edge of water), established by differential levels from post-detonation ground-zero control, was determined to be 114.8 ft (35.0 m) above msl at the time of the survey.

Vertical soundings from the sonic sounder were recorded on a continuous strip-chart recorder; the soundings are accurate to the nearest tenth of a foot. The number of data points selected along each traverse were based on change in relief on the lake bottom. From these traverses, 760 data points were used for analysis.

The manually-drawn bathymetric map (fig. 3) was based on data from the sonic survey and knowledge of the basin before it filled with water. The contour interval is 2 ft (0.61 m). Most of the steep slopes shown by close spacing of the contours indicate faulting.

Stage-area-volume relationships were calculated from the basic data, and the water-surface areas for different lake levels were measured using standard planimetric techniques. The manually-drawn map as well as the computer versions were used to obtain these relationships. The two sets of results are similar; they are shown on figure 3.

COMPUTER-MAPPING TECHNIQUES

The traverse data obtained from the bathymetric survey of Cannikin Lake gave the authors an opportunity to test the applicability of current computer-mapping techniques for traverse-type data. Bathymetric maps were produced using two different computer programs (WET and Calcomp GPCP) and were compared with a manually-drawn bathymetric map. In addition to the bathymetric maps, part of the WET computer program was used to produce an oblique three-dimensional projection of the lake basin, and to calculate the volume of water in the lake at given water levels.

There are three distinct steps in computerized map production:

1. Data Preparation. Establish an x-y coordinate system whose orientation and scale are compatible with the size and shape of the lake. The x and y coordinate of the data point and the measured lake-bottom elevation at that point are coded and then key-punched on computer cards.

2. Data Conversion. The data from step 1 are used as input into a computer program which calculates lake-bottom altitudes for an array of regularly-spaced points covering the entire area of the lake.

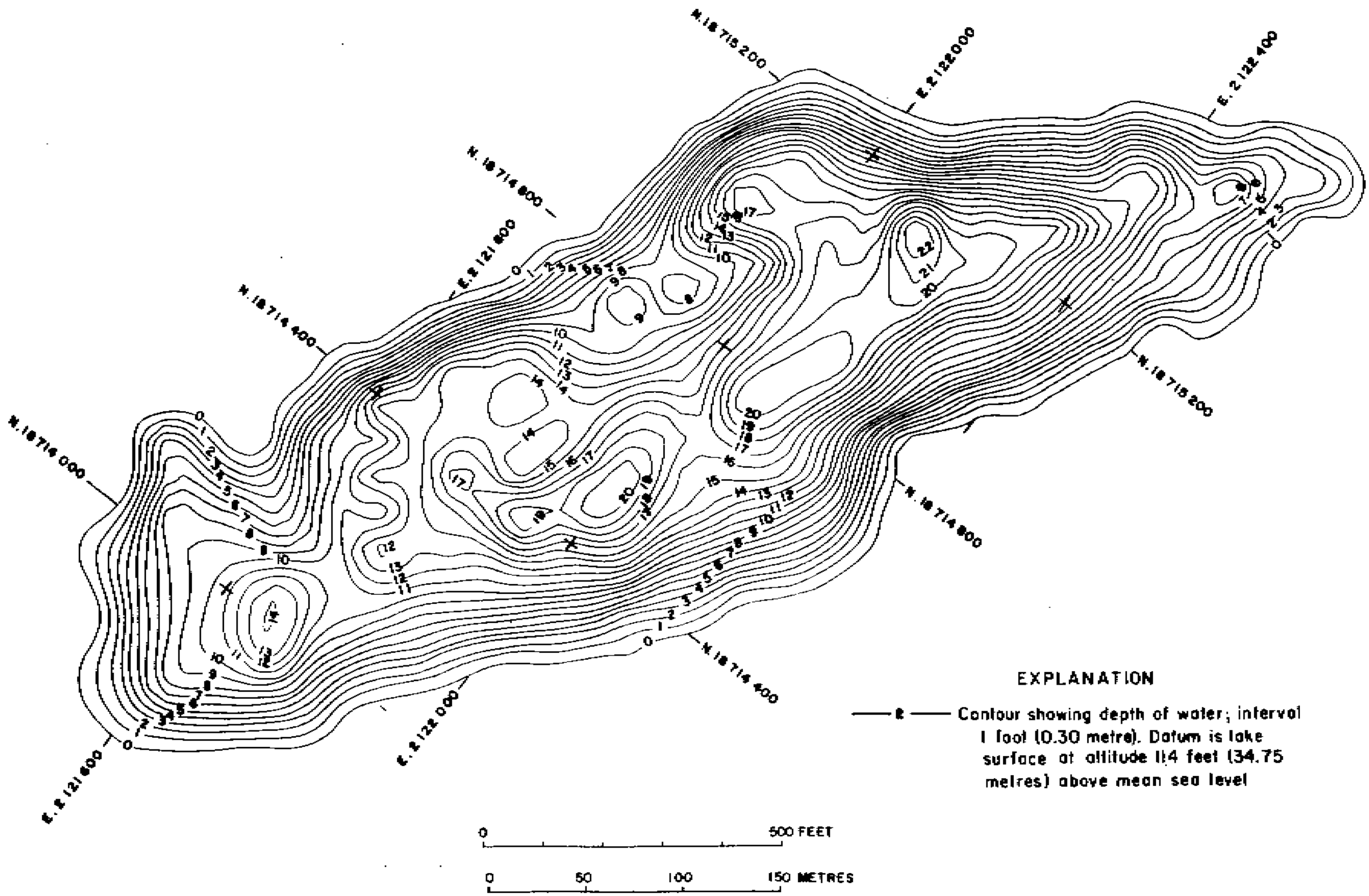
3. Manipulation of Converted Data. This array of x-y coordinates and calculated lake-bottom altitudes is used as input to one or both of the computer programs. Each of the computer programs is used to produce planimetric maps of the lake-bottom altitudes. Appropriate parts of the

WET computer program are selected to produce oblique three-dimensional projections, and to calculate the volume of water in the lake at given water levels.

The parameters used in steps 2 and 3 that influence the quality of contour and oblique projections and volumetric calculations are grid size, map scale, contour interval, and the x, y, and z coordinates of observation points used in the production of oblique projections. The values of these parameters are based on the type of basic data being investigated (clustered, sparse, linear, etc.), the change in the calculated lake-bottom altitude values, specific control required, and directions and areas of interest.

The WET (Wahl-Evenden-Van Trump) program was written and(or) modified by R. R. Wahl, G. I. Evenden, and George Van Trump, Jr. of the U.S. Geological Survey. The program is designed to calculate surface values at grid intersections of a regularly-spaced grid using surface values at irregularly-spaced points as input. The interpretative portion of this program employs a locally-weighted, least-squares surface-fitting technique. This program is designed to allow the user the option of using the output tape to produce a bathymetric map (fig. 4) or an oblique projection of the surface. The part of the program used to obtain the oblique projections is based on work by Wright (1973) and was modified for use on the IBM 360-65.

The Calcomp GPCP (Calcomp, 1971) program is available for users of the U.S. Geological Survey IBM 360-65 computer system. This program also calculates surface values at grid intersections of a regularly-spaced grid using surface values at irregularly-spaced points as input. The interpretative part differs from the WET program and consists of two operations. The



Universal Transverse Mercator Projection (UTM)
400-foot grid ticks, zone 60

Figure 4--Computer-drawn bathymetric map of Cannikin Lake, using WET program, May 1973.

first operation determines the gradient or tangent-plane at each data point using a specified number of neighboring points. This plane must pass through the z value of the datum point in question and the angles this plane makes with vectors to the specified neighboring points are minimized. The second operation uses the gradients at a specified number of data points and a weighting function to determine the surface values at the grid intersections of a regularly-spaced grid. The number of neighboring points used in each operation (neighborhood) and the size of the grid are specified by the user. The map made using the Calcomp GPCP program is shown on figure 5.

COMPARISON OF COMPUTER-MAPPING TECHNIQUES

The same basic data were used in production of all bathymetric maps except that subjective control was used in the manually-drawn map based on terrain knowledge obtained before and after the lake started to fill with water. For this reason the manually-drawn version is probably more realistic and was selected as the basis of comparison. In general, the computer-produced maps showed a definite similarity to the manually-drawn map.

The degree of similarity between the computer maps and the manually-drawn map was directly related to the selection of grid size and neighborhood. Varying the grid size and neighborhood during trial runs of the WET and Calcomp GPCP programs showed the following:

1. Features would not appear unless the grid size was approximately one-half (or less) of the minimum diameter of the feature;

2. Small grid sizes tend to break up and localize long linear features; and

3. Large neighborhoods should be used with traverse-type data, as is done in this report.

The water-level datum used for both computer programs is 114.8 ft (35.0 m) above msl, while that of the manually-drawn version is rounded to 115 ft (35.0 m) above msl. The computer-drawn maps were plotted at 1-ft (0.30-m) intervals; therefore, the highest altitude contour shown on the computer maps is 114 ft (34.75 m). This contour line was used as the shoreline datum for both computer-produced maps. This difference in shoreline datum results in a slightly larger surface area on the manually-drawn map and makes the depths 1 ft (0.30 m) greater.

The map produced by the WET program (fig. 4), when compared with the manually-drawn map, matches the outline of the lakeshore very closely (fig. 3); however, the match between contours of the two maps is less exact. The low areas are in about the correct perspective but the mounds are nearly all omitted.

The Calcomp GPCP product (fig. 5) is a very close approximation of the hand-drawn version. Differences in shoreline configuration may be a result of several factors.

1. A difference in shoreline datum;
2. A smoothing property inherent in both computer programs; and
3. An inadequate shoreline control where there is a rapid change in relief.

At the southwest end of the lake, only local details are omitted--that is, two mounds and a shallow depression; however, the main features are apparent. These are the outline of the pond formed by the northwest-trending fault and its outlet. Water depths are consistent with figure 3.

The middle part of the lake also lacks some of the local details but the main features are present. The Calcomp GPCP program has not completely isolated the actual mounds and depressions but has characterized them as knolls or fingers. Isolation of these mounds could probably be effected by slightly decreasing the grid size. The deeper parts of the lake conform well to the manually-drawn version.

The northeast part of the lake shows the poorest correlation, because of the omission of a depression and a weak impression of the uppermost mound. In this region, where there is rapid change in altitude, the poor correlation may be due to inadequate shoreline control. This tends to centralize the deeper areas rather than offset them as in the manually-drawn map.

As a whole, the comparison is good and gives a good representation of the main features shown in the manually-drawn map. Some of the local features omitted on the map produced using the Calcomp GPCP program could be brought out by decreasing the grid size; however, too small a grid size will tend to break up the long linear features shown which correlate well with the same features on the manually-drawn map.

The map produced using the Calcomp GPCP program compared more favorably with the manually-drawn map than did the map produced using the WET program. The map produced using the Calcomp GPCP program permitted recognition of smaller features without breaking up the long linear features when using the same grid size for both programs.

COMPUTER CALCULATION OF CUMULATIVE VOLUME

A plot tape produced using the WET program contained an array of values giving the x and y coordinates and the calculated elevation of the lake bottom at regularly-spaced distances over an area covering the entire lake. This array was used to calculate the volume of water in the lake for any desired water elevation using the following procedure:

Plot the array of x and y coordinates covering the lake. The distance between two adjacent points with the same y coordinate is Δx. The distance between two adjacent points with the same x coordinate is Δy. In the WET program, Δx and Δy were equal, thus the distance between parallel x or y coordinates is equal and is called Δd.

As stated previously, a calculated altitude of the lake bottom is associated with each point (x and y coordinate). Assume that this altitude is constant for a square of area $(\Delta d)^2$ in which the point (x,y coordinate) is located at the center of the square. The volume of the lake can be calculated by subtracting the calculated altitude of the lake bottom at each applicable point from the given water-level altitude, multiplying this difference by $(\Delta d)^2$, and summing this result for all applicable points. An applicable point would be one for which the calculated altitude of the lake bottom was lower than the given water-level altitude.

The array from the WET program plot tape was read in as input to part of the WET computer program which scanned the calculated altitude values of the lake bottom and noted and stored each different altitude value. These altitude values were then sorted in ascending order and used as given water-level altitudes to calculate the volume of the lake using the method described above. These water-level altitudes versus volumetric results are shown as the stage-volume relationship for Cannikin Lake in figure 3.

OBLIQUE PROJECTIONS

The result of using the oblique-projection option in the WET program is shown in figure 6 and is typical of the type of representations produced. The oblique projections of the lake bottom are viewed downstream toward the intersection of the northeast-trending fault and White Alice Creek. Variations in perspective may be obtained by varying the x-y-z viewing coordinates. A pictorial view may be obtained and it is possible to produce views of the lake bottom as would be seen from above or below shoreline datum by using various shading techniques as those shown on figure 7. These figures are often helpful in visualizing features displayed on the computer-produced planimetric contour maps. A change in the viewing position allows one to view certain pertinent features along a favorable line of sight.

SUMMARY

The detonation of the Cannikin nuclear explosion and subsequent collapse in the area has created Amchitka's most outstanding lake. The manually-drawn bathymetric map (fig. 3), based on data from a sonic survey made of the lake, is the standard of comparison for two additional bathymetric maps produced from two computer-mapping programs using the same data. These are the WET program and the Calcomp GPCP program. The comparisons show that the Calcomp program, with proper selection of neighborhood and grid size, can produce a map that compares very well with the hand-drawn standard.

The WET program gives a close approximation of the standard basis and is a fair representation. Many of the local effects are omitted and the features are generalized.

A table summarizing the characteristics of Cannikin Lake is presented on figure 3.

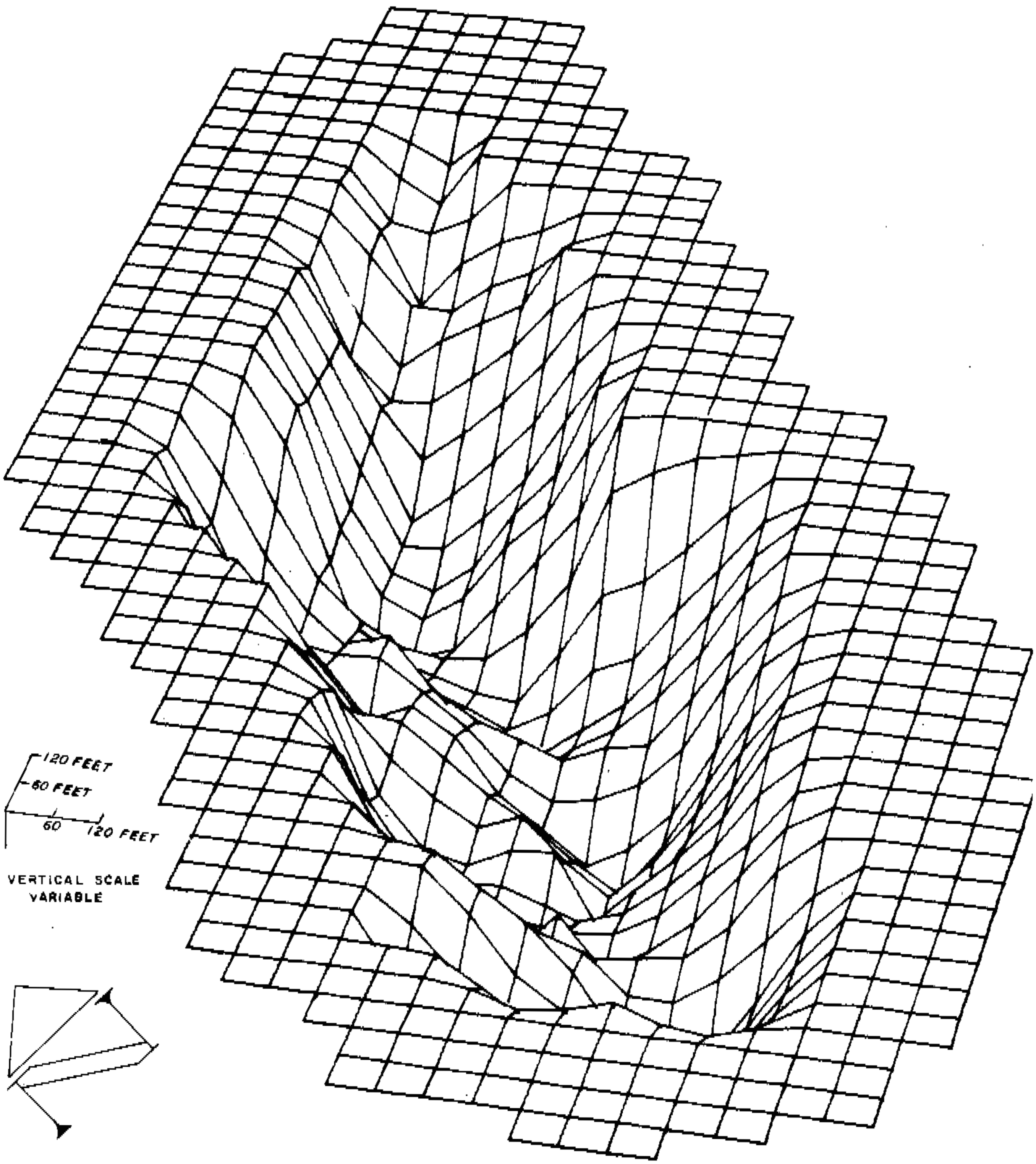


Figure 6-- Oblique projection, Cannikin Lake, produced using WET program.

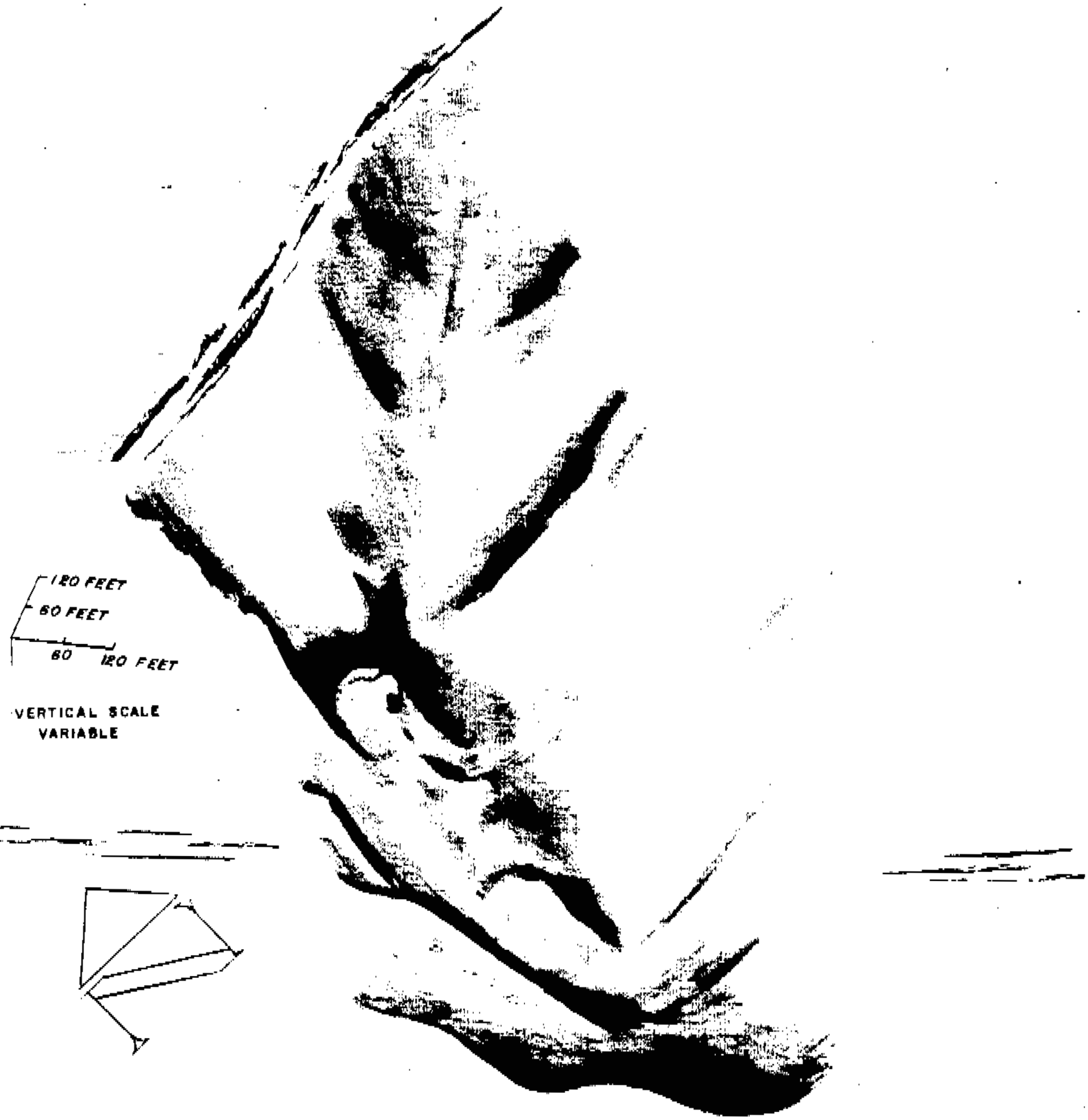


Figure 7.--Oblique projections, with shaded relief, Cannikin Lake, based on projection produced using WET program.

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