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Operation

JANGLE

NEVADA PROVING GROUNDS
OCTOBER-NOVEMBER 1951

Project 1(8)a

GEOLOGIC, HYDROLOGIC, AND THERMAL FEATURES OF THE SITES

ARMED FORCES SPECIAL WEAPONS PROJECT
WASHINGTON, D.C.

[redacted]

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Cy #210 A

December 15, 1952

ERRATUM FOR JANGLE PROJECT 1(8)a (WT-343)

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Operations WINDSTORM and JANGLE

Project 1(8)a

GEOLOGIC, HYDROLOGIC, AND THERMAL FEATURES OF THE SITES

By Arthur M. Piper

May 1952

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[redacted]

United States Geological Survey
Portland, Oregon

[redacted]

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[redacted]

PROJECT 1(8)a

ACKNOWLEDGMENTS

Personnel attached to Project 1(8)a were as follows:

Beauregard Perkins, Jr., Program Director (in Operation WINDSTORM and early stages of Operation JANGLE)

Capt. Woodrow Wilson, Assistant Program Director and successor to Mr. Perkins (in late pre-test stages of Operation JANGLE)

Arthur M. Piper, Project Officer and head of Geological Survey party

Geological Survey:

H. A. Powers) in Operation	Joe L. Poole) in Operation
J. E. Sceva) WINDSTORM	R. F. Brown) JANGLE

United Geophysical Company (in Operation JANGLE):

Allen Rugg, party chief

O. W. Schoenberg	K. L. Crocker
O. G. Erich, Jr.	R. B. Sargent
Q. F. Feaster	W. T. Elia
W. A. Fillmore	H. B. Jaques
P. R. Konow	E. J. Ness, Jr.
S. J. Goldenstein	G. W. Brown, Jr.
P. E. Stuteville	G. W. Brown, Sr.

Enlisted men (in Operation JANGLE):

Sgt. Don E. Hibbard	Sgt. Mike S. Johnson

[redacted]

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[redacted]

PROJECT 1(8)a

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PROJECT 1(8)a

ILLUSTRATIONS

TABLES

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PROJECT 1(8)a

ABSTRACT

Geologic features are described for the two sites involved: an initial site for Operation WINDSTORM (suspended), on Amchitka Island of the Aleutian Chain; and the final site for Operation JANGLE, in Yucca Valley near Las Vegas, Nevada. At least partly on geologic grounds, the initial site was found unsuitable.

The Nevada site affords a body of valley fill which is largely incoherent and sufficiently extensive and thick to accommodate tests of the effects of 1-KT bombs detonated 17 feet below land surface (to center of gravity) and at the land surface, respectively. Within the area available, the valley fill was not sufficiently extensive also to accommodate a third detonation at 60 feet below land surface.

The valley fill is not homogeneous in texture. Locally it includes some tongues of clean coarse sand or fine gravel, but for the most part it is unassorted. Near the valley margins the fill commonly contains cobble- or boulder-size rock fragments, but even this coarse facies has a matrix of fine particles. Away from the valley margins, texture becomes progressively finer from north to south.

In the immediate test area, from land surface to a few tens of feet in depth, the greater part of the valley fill is relatively fine grained, with about from 30 to 90 per cent (by volume) composed of particles passing a 14-mesh screen—that is, less than 1.2 mm. (0.046 inch) in size. At vertical intervals of a few feet, this fine material encloses streaks and discontinuous pebbly and cobbly beds, in which the largest particles commonly are as much as 3 inches in greatest dimension and a fairly large percentage exceed 0.5 inch. Particles are angular or slightly rounded; all are derived from the siliceous, limestone, and volcanic formations which form the highlands adjacent to the alluvial plain. Layers of caliche are fairly numerous in the fill but are discontinuous and random in depth.

West of the underground and surface test sites and roughly a mile away, one fault cuts the valley fill and throws materials of unlike elastic properties against one another. No other faults in the alluvium have been recognized.

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PROJECT 1(8)a

Seismic-wave velocities in the incoherent and moderately cemented valley fill were determined by the United Geophysical Co., Inc., to be about from 2,000 to 3,000 feet per second near land surface and to increase to about 5,000 feet per second at a depth of 500 feet. In layers of compact caliche the wave velocities are greater, possibly as much as 10,000 feet per second. A considerable part of the bedrock is volcanic tuff in which velocities may be little, if any, greater than in parts of the valley fill.

Density of the valley fill in the immediate test area was found to average 1.46 among 7 samples less than 2 feet below land surface, and 1.65 among 14 samples at greater depth. Density of caliche layers is greater--2.02 among 9 samples.

Prior to the tests, earth temperatures were measured daily for 15 weeks at six points along and in prolongation of the blast line, by means of "thermistors" (resistance thermometers) buried 3, 5, 10, 20, and 30 feet below land surface. Temperatures ranged between 73.0 and 50.4° F. at 3 feet in depth, 70.0 and 57.0° F. at 5 feet, 66.0 and 62.4° F. at 10 feet, and 61.5 to 60.1° F. at 20 feet. At 30 feet below land surface the temperature was sensibly constant at any one place but varied from 61.0 to 60.1° F. within the test area. Earth temperatures on the test dates were projected so that suitable preliminary adjustments could be made in certain instruments installed under other programs.

Potential target areas of a penetrating atomic missile would differ from the Nevada Test Site in the character of their earth materials. Most such areas would be substantially more humid, or cooler, or both. In these geologic and related aspects, the effects of Operation JANGLE can not be scaled up readily to a full-size missile and an actual target. Scaling factors should be evaluated according to features of specific targets, as necessary.

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PROJECT 1(8)a

OBJECTIVES

Specific objectives of Project 1(8)a were to:

1. Determine whether the test areas met the topographic, geologic, and hydrologic requirements specified, as follows:

a. Topographic specification was that the land surface should not slope more than 2° (3.5 per cent) along the blast line, and should not deviate more than 10 feet above or below a uniform slope; and should be "flat" for 800 feet on either side of the blast line, with no abrupt increase in slope beyond that distance.

b. Geologic specification for Operation WINDSTORM was a body of incoherent alluvium at least 250 feet thick over an area at least 1 mile wide and from 3 to 7 miles long. For Operation JANGLE, the requisite minimum thickness of alluvium was increased to 500 feet, and horizontal extent was specified at about 3 miles square. Within these space limits, the alluvium was to be reasonably homogeneous and to be free from faults or other substantial physical discontinuities.

c. Hydrologic specification was that the water table should be at least 200 feet below land surface.

2. Evaluate seismic characteristics of the alluvium to a depth of 500 feet throughout the test area, and measure field density of the alluvial materials at representative places. This information is needed chiefly by Program One, for interpreting arrival time of ground shock waves induced by the test detonations.

3. Measure earth and air temperatures at key points along the blast line, as a basis for projecting earth temperature at the time of the tests. This information was also needed by Program One.

4. Supply for other projects, pre-test earth samples for radiochemical analysis representing natural conditions.

5. Discriminate and evaluate geologic aspects of the effects produced by the detonations.

Incidental to these specific objectives, a reconnaissance geologic map of the Nevada site was prepared, as general background for this report.

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PROJECT 1(8)a

If the water table in the test area was not excessively deep, it had been contemplated to install instruments for measuring the amplitude and rate of propagation of pressure and displacement waves that inferentially would be generated in the ground-water body by the underground detonation. The purpose was to ascertain whether such waves might effectively increase the damage to structures by a penetrating atomic weapon. Owing to the great depth to the water table at the Nevada site, estimated to be in the order of 1,500 feet, such instrumentation and investigation proved infeasible.

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PART I

OPERATION WINDSTORM[1]

CHAPTER 1

GEOLOGY OF AMCHITKA

1.1 SCOPE AND ADEQUACY OF THE WORK

Initially the mission of the geologic party was to outline certain areas whose main characteristic was to be a minimum thickness of 150 feet of incoherent detrital material in which seismic velocities would be essentially uniform. Three possible areas--designated "A", "B", and "C", respectively--had been selected for initial investigation.

Preliminary study of the surface geology and one drilled hole in each, indicated that in both the B and C areas the mantle of incoherent detritus was discontinuous and probably nowhere as much as 15 feet thick.

In the A area, outcrops of underlying rock are few. However, a few trenches cut with a bulldozer and several shallow drilled holes showed that the mantle of incoherent detritus averaged between 5 and 10 feet thick and probably did not exceed 25 feet, but was more extensive and more nearly continuous than in the B and C areas.

Even in the absence of any body of incoherent material of the thickness initially specified, two areas designated "U" and "S" were indicated for detailed geologic investigation. The geologists pointed out that a concurrent, detailed seismic investigation would be necessary to provide basic data required by Operation WINDSTORM. The geologic mapping was proceeding but seismic work had not been started when the operation was suspended.

In part to explore geologic features, 22 test holes were drilled by Mobile Construction Batalion 3 using Failing rotary drill rigs, and another 12 holes by Lynch Bros., a contractor, using diamond coring equipment. Logs of the holes constitute Tables A.1 and A.2 (see Appendix A). This test drilling was monitored by the geologists. Interpretation of the findings by rotary drilling involved the following four steps:

1/ This description of geologic and hydrologic features of Amchitka prepared by H. A. Powers and J. E. Sceva.

[redacted]

1. The geologic formations expected to be encountered in each area to be drilled were examined at all adjacent surface outcrops, especially in the sea cliffs.

2. Drilling time per foot of hole was logged.

3. Samples of drill cuttings were taken whenever a significant change in drilling speed indicated a change in nature of the rocks.

4. Data from the drilling-time log and the samples of cuttings were evaluated in terms of the geologic formations exposed in the vicinity, and the probable stratigraphy in each hole thus deduced.

The geologic study progressed to the point where the following general descriptions of rock formations, and the general areas of their occurrence as shown on Plate 1 are dependable. Details of actual boundaries between rock formations, and detailed location and description of the many faults are not dependable, and would require a tremendous amount of trenching and core drilling to make them so.

1.2 CHARACTER OF THE VOLCANIC BEDROCKS

The "basement" or oldest rock on Amchitka is exposed in a few isolated knobs and sea cliffs in the central part of the island between 179°00' and 179°15' E. longitude, and forms the greater part of the mountainous areas farther west. It is composed of marine-bedded, fine-grained volcanic tuff and agglomerate which have been completely recrystallized so thoroughly that they now have all the physical properties of a fine-grained, dense extrusive rock. This formation was faulted and deeply eroded before the next younger formation was deposited.

Rocks of this oldest formation showed longitudinal wave velocities of 12,000 feet or more per second in seismic tests made at "Charlie 1" hole in the summer of 1950.

The rocks which form most of the island east of 179° E. longitude include marine-bedded volcanic products interbedded and mixed with greywacke sandstone and conglomerate derived from the erosion of an adjacent basaltic terrain which has not yet been located. The volcanic members of this series include a few lava flows (some with pillow structure and some with a great thickness of glassy scoria and breccia), agglomerates of large angular blocks and sparse tuffaceous matrix, fine agglomerates with a few small blocks in abundant tuffaceous matrix, and a few thin layers of fine tuff. The greywacke members include massive conglomerate composed of boulders from 6 inches to several feet in diameter with sparse sandy matrix, massive fine conglomerate composed

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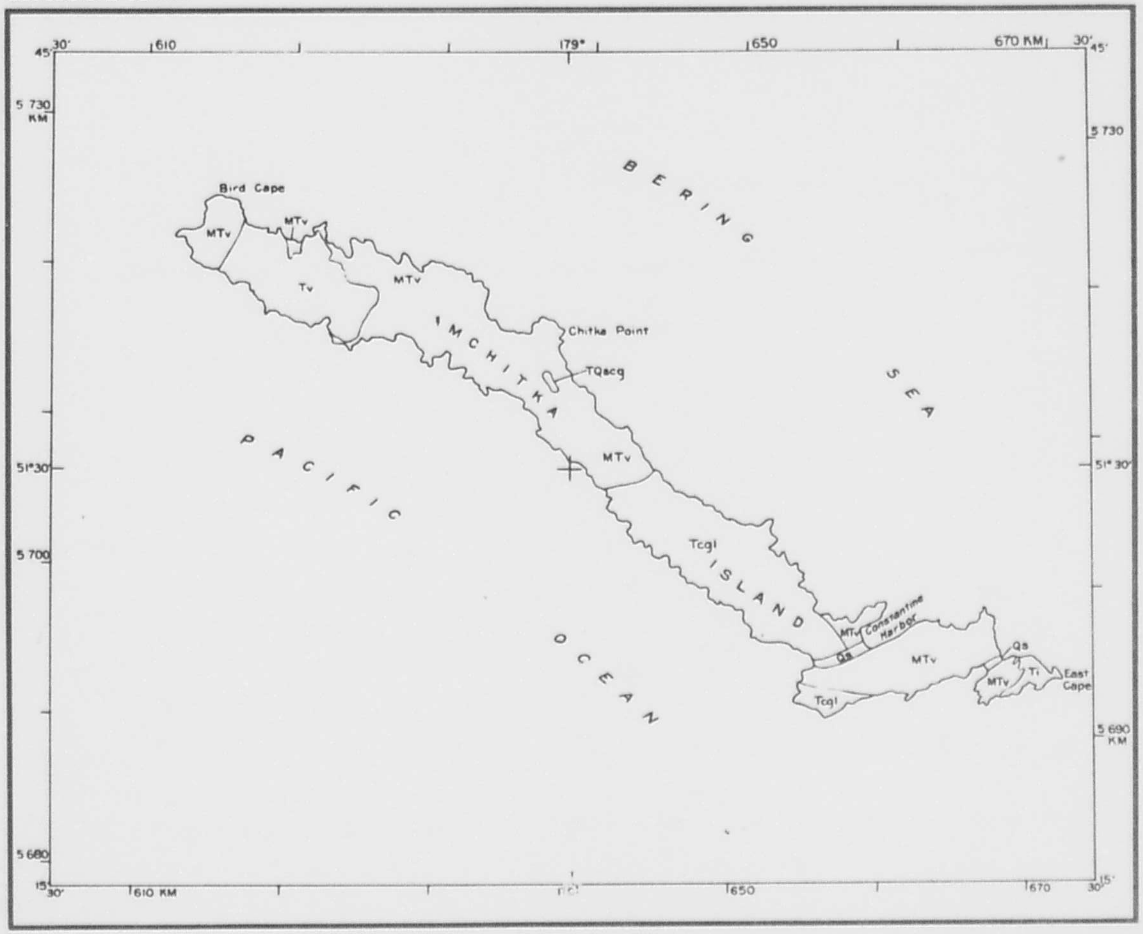
PROJECT 1(8)a

GEOLOGICAL SURVEY

PLATE 1



SKETCH GEOLOGIC MAP OF AMCHITKA ISLAND

10-kilometer grid, transverse Mercator projection, zone 60. Base from map by Geological Survey

Reconnaissance geology by H. A. Powers and J. E. Sceva, in 1951

EXPLANATION

Qs

Sand, pebble gravel, and silt; stratified

TQscg

Sandstone and conglomerate, marine-bedded and coarse-grained; interbedded with volcanic agglomerate

Ti

Hornblende diorite, coarse-grained

Tv

Hornblende porphyry, in dikes and extrusive layers

Tcgl

Conglomerate and sandstone, massive and interbedded with agglomerate, tuff, and a few lava flows; marine-bedded in large part

MTv

Tuff and agglomerate, fine-grained and initially marine-bedded; thoroughly recrystallized into a very dense rock

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of pebbles in an abundant matrix of coarse to fine sand, and bedded sandstone and siltstone. The mixed members most frequently are volcanic tuff or agglomerate containing many rounded or partly rounded pebbles and cobbles.

For the most part these rocks are well indurated but are not recrystallized. They have been faulted and eroded. Like the "basement" rocks, they have been extensively mineralized by pyrite along a system of east-trending faults.

The lava members of this series probably transmit longitudinal waves at velocities greater than 10,000 feet per second, whereas the conglomerate and tuff members probably yielded the velocities ranging between 5,000 and 10,000 feet per second which were measured during the seismic reconnaissance in 1950.

A series of volcanic rocks characterized by numerous phenocrysts of plagioclase feldspar and hornblende is found on top of the two formations just described. On the west end of the island this hornblende porphyry forms subaerial lava flows lying on an erosion surface. At many places throughout the island it forms dikes which generally follow the system of east-trending faults. In the central ridge, just south of Chitka Point and above the 400-foot contour, marine-bedded coarse sandstone and conglomerate are interbedded with coarse blocky volcanic hornblende porphyry. This formation is only slightly indurated and is uniquely characterized by relatively smooth land forms. It showed seismic velocities as low as 3,500 feet per second in the 1950 reconnaissance.

Dikes cut the several formations, some of feldspar-rich basalt and some of a coarse-grained hornblende diorite. The diorite also forms a sill and an irregular-shaped intrusive mass on the east end of the island.

1.3 FAULTS

All formations are offset and moderately tilted by many faults, mostly exposed in the rock benches bared at low tides. Some fault-controlled depressions are recognizable on aerial photos, and a few of the stream valleys are apparently fault controlled. Tracing the full pattern of faults would have required much more time than was available for the work here reported (also, it would require extensive trenching through the tundra and detrital mantle).

CHAPTER 2

HYDROLOGY

2.1 GROUND-WATER FEATURES

Except for faults and joint cracks, the unweathered rocks have very low permeability to ground water. Nearly the entire mass of the island is saturated, as shown by the fact that water rose to 5 feet below land surface (295 feet above sea level) inside 315 feet of 3-inch casing in a well drilled to a depth of 428 feet. The absence of springs at sea level shows that there is little movement of water through the rock.

Only the thin surficial mantle of tundra, detritus, and frost-split bedrock contains mobile ground water, and even in these materials movement is slow. The tundra, whose thickness ranges from a few inches to about 7 feet, has very high porosity and contains much water when unfrozen but its permeability is extremely low. The underlying layer of detritus and frost-split rock varies greatly in thickness but probably averages not more than 10 feet; its permeability is low or moderate.

In these materials, and with recharge of the ground water being derived wholly from local precipitation, the water table is not more than 6 feet, and probably averages about 2 feet below land surface over much of the island. Hence, the configuration of the water table is essentially the same as that of the land surface. Most of the numerous ponds and lakes on the island, especially on its central part, occur at water-table level. Commonly two lakes only a short distance apart differ considerably in water level: another evidence that ground-water movement is slow locally and that the quantity moving any great distance (as into the central part of the island from the highlands to the west) is inappreciable.

Under these conditions, drainage of the island is virtually all to the ponds and lakes and thence to the ocean by small surface streams. At most places any excavation more than a few feet deep will encounter ground water, but inflow ordinarily is so slow that a small-capacity pump will suffice to keep the excavation water-free. No extensive area of tundra could be drained by ditches nor, in general, could the ponds be drained by wells drilled through their beds: the earth materials beneath are much too impermeable.

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PART II

OPERATION JANGLE

CHAPTER 1

INSTRUMENTATION AND SCOPE OF OPERATIONS

1.1 GEOLOGIC RECONNAISSANCE AND TEST DRILLING

At the Nevada Test Site--in Yucca Valley, about 85 air-line miles northwest of Las Vegas--only general features of the geologic setting were determined by reconnaissance mapping (see Pl. 2), carried on incidentally to other activities. The physical character, texture, and stratification of the valley fill (in which the tests were made) were evaluated largely through continual monitoring of the test holes drilled during the pre-construction stage, also of excavations opened in connection with construction (see Table A.3). Samples of drill cuttings and other samples cut from the walls of excavations have been examined visually, and sieved in the field to ascertain approximate distribution of particle sizes (see Table A.4). Field density of the alluvium has been measured at opportune places (see Table A.5). Representative samples have been preserved for such later examination in the laboratory as may prove desirable.

Prior to construction and concurrently with the geophysical exploration, four test holes were drilled by a cable-tool rig. Three of these were approximately 500 feet deep; the fourth, 177 feet deep. The driller's logs, with some interpretation by the geologist-monitor, constitute Table A.6. Excepting the first hole, drilling procedure was so controlled that cuttings were reasonably representative of the materials penetrated. Samples of un-washed cuttings have been preserved from each of the other three holes, generally at 10-foot depth intervals. Each such sample is about 500 cc. in volume.

[redacted]

1.2 GEOPHYSICAL EXPLORATION

Seismic characteristics of the valley fill were evaluated chiefly by refraction traverses, supplemented by vertical or "up-hole" velocity measurements and by short refraction spreads at each of the four churn-drill holes. This work was done by the United Geophysical Co., Inc., under contract with the Navy; results were reported prior to the construction stage of the Operation[2/].

In the refraction traverses, paired geophones were spaced at 100-foot intervals along 1,100-foot cable "spreads." The two geophones of each pair were connected in series. Signals from the geophones were fed into an amplifying circuit and thence into recording galvanometers. Shot points generally were at both ends of each spread, also in prolongation of and at distances of 1,100 and 2,200 feet from each end of a spread. The extent and position of the traverse lines are shown on Plate 2. In the vertical-velocity measurements, shot points were at successive depths in the several churn-drill holes, with geophones set at 15-foot intervals in line across the holes.

1.3 EARTH AND AIR TEMPERATURES

Beginning 15-18 August 1951, earth temperatures were observed daily by thermistors (resistance thermometers) buried at depths of 10, 20, and 30 feet below land surface at five points along and in prolongation of the blast line. At a sixth point on this line, another set of thermistors was buried at depths of 3, 5, and 10 feet. The observations measure resistance of the thermistor cells by means of a battery-energized Wheatstone bridge. Resistance is translated into temperature according to prior calibrations of the several thermistor cells.

Air temperatures were recorded by two thermographs installed 9 and 30 August 1951, in shelters near the underground- and surface-shot zero points, respectively. Instruments and shelters were of the type which is standard in the U. S. Weather Bureau.

This placement of instruments anticipated that earth temperature fluctuates very little at depths greater than about 10 feet, that the fluctuations at less depth correlate with fluctuations of air temperature (with a moderate time lag), and so that earth temperatures could be projected for the times of the test detonations.

2/ Seismic Refraction Survey for Navy contract NOY 26616, Nye County, Nevada: United Geophysical Co., Inc., typewritten report, 17 pp., tables, 16 velocity graphs, 2 maps, July 27, 1951. Published under Project 1(8)a-1 in the series of final reports on Operation JANGLE.

1.4 EARTH SAMPLES

The initial schedule of samples to be taken from the valley fill for radiochemical analysis was as follows:

Project 2.5a (U. S. Naval Radiological Defense Laboratory).- From a core-drilled hole at zero point for the underground test, samples at land surface and at 10-foot intervals to a depth of 100 feet. Each sample in 25 cc. volume.

Project 2.5a, continued (Army Chemical Center).- From the 17-foot-deep excavation at zero point for the underground test, samples at land surface and at depths of 5, 10, and 15 feet. Each sample in 100 cc. volume.

Project 2.6c (National Institute of Health).- Three series, as follows: (1) From core-drilled holes at the respective zero points for the underground and surface tests, samples at depths of 10, 20, 40, 60, 80, and 100 feet. (2) At each of the two zero points, also at radial distances of 200 and 400 feet along two lines at right-angles to one another, samples at the depth of 3 inches. (3) At the four points 200 feet radially from each of the two zero points, samples also at the depth of 4 feet. All these samples in 500 cc. volume each.

Under revisions of schedule made in the field prior to the tests, only the samples for Project 2.5a (Army Chemical Center) and the 3-inch and 4-foot samples for Project 2.6c were taken by the geologic party and shipped to the requesting laboratories.

CHAPTER 2

GEOLOGY OF NEVADA TEST SITE

2.1 GENERAL FEATURES

In briefest terms, Yucca Valley (Pl. 2) is an undrained basin in deformed bedrocks, with its lowest part filled by detritus washed from the marginal slopes. Its detrital fill is the material which forms and underlies its central plain, and in or on which the detonations of Operation JANGLE were made. The bedrocks are those forming the hills and ridges which enclose that plain; the same bedrocks underlie the detrital fill continuously.

The bedrocks and their detrital products are of diverse character. Hence the fill, composed of the transported detritus, varies considerably in its character from one place to another.

2.2 BEDROCKS OF THE VALLEY MARGIN

2.2.1 Succession and character

In general upward succession--that is, from oldest to youngest--the bedrocks of the valley margin, as discriminated in the geologic reconnaissance, are (1) a siliceous series which includes argillite, sandstone, quartzite, shale, and conglomerate; (2) both thin-bedded and thick-bedded limestone, which in part contains much chert and which is interbedded with quartzite locally; (3) a single body of intrusive granite or grandiorite; and (4) a volcanic series which is composed largely of tuff but which includes intercalated and capping layers of lava rock (rhyolite or dacite and possibly basalt). The siliceous series and the limestone are each several thousand feet thick; the volcanic series, at least 1,500 feet thick. Unconformities separate the several series one from another.

In the western part of the valley, these rocks were mapped previously at small scale in a reconnaissance by Ball3/. The extreme southwest part of the valley and the vicinity of the inactive small mine in the northern end of the valley (at coordinates N. 905, E. 6804/)

3/ Ball, S. H., A geologic reconnaissance in southwestern Nevada and eastern California: U. S. Geol. Survey Bull. 308, 218 pp., 1907.
4/ This report uses local engineering coordinates, in thousands of feet.

are covered by unpublished mapping nct available during the field term of Project 1(8)a. Plate 2, which covers all the valley and its margins, delineates the siliceous series and the limestone, the intrusive granite, and the volcanic series.

The rocks of the siliceous series are most extensive in the northwest quadrant of the valley margin. Detritus from their quartzite and conglomerate members is angular, commonly of cobble or small-boulder size, and relatively free from small particles. Rock streams of such detritus are common. Hence the adjacent valley fill commonly is coarser and its particles more angular than average. In contrast, detritus from the argillite and shale members commonly is of pebble- or cobble-size and is flaky.

Limestone is most extensive in the southwest quadrant and the east-central part of the valley margin. A prominent mass is immediately east of the surface-shot zero. Its detritus commonly is slightly rounded and from pebble to large-boulder size. Adjacent valley fill generally is coarse and poorly assorted. At some places its detritus and adjacent fill are dense fanglomerate, thoroughly cemented by calcium carbonate.

The granite or granodiorite forms one area of rough triangular outline, about 1½ miles on a side, along the north margin of the valley. The small mine just cited is on its north-central edge. The granite is coarse-grained to porphyritic; its detritus commonly is granular and largely from grit to coarse sand in size.

Rocks of the volcanic series form at least two-thirds of the east margin of the valley. Along much of the west margin they commonly overlie the sedimentary rocks of the siliceous series or the limestone, and occur largely above the level of the valley plain. Everywhere, they are highly diverse in physical character.

The tuff, the predominant component in the volcanic series, is in part massive or very thickly bedded and in part thin-bedded to finely stratified. Some is minutely cellular (inflated); the extreme of this facies probably has a density little, if any, greater than one. On the other hand, the bedded and stratified facies are non-cellular and have densities estimated to be about two. Locally, some of the tuff is compact and glassy (welded).

Excepting the compact, glassy facies, the tuff does not resist the weather. It yields copious detritus whose particles are largely in the size range between coarse sand and silt, and are easily transported by either wind or water. It has been the source of by far the greater part of the smaller grade sizes in the detrital fill, throughout the valley.

The intercalated layers of lava rock occur largely in about the upper third of the volcanic series. A few of these, and the layer which caps the series, are cliff-formers that extend for miles and commonly are from a few tens to as much as 250 feet thick. Others are thinner and tongue-like. Locally, the lowest exposed part of the volcanic series appears to include still other lava rocks. All these cliff forming rocks yield coarse detritus containing blocks as much as 10 feet in greatest dimension (owing to failure of weak underlying tuff). However, blocks so large are not readily transported and ordinarily do not occur in the valley fill except locally at its very margin.

Associated with the volcanic series are several dikes and plugs which cut both volcanics and limestone, largely in the northeast quadrant of the area. These are too small in extent to be discriminated on Plate 2. Their detrital products are inconsequential as a source of the valley fill.

2.2.2 Structure

Geologic structure, as disclosed in the bedrocks of the valley margin, is pertinent to interpretation of results in Operation JANGLE for reasons which include the following: (1) Faults, whose pattern is indicated by Plate 2, cut the several bedrock series into numerous distinct slices and blocks; consequently, the areal distribution of those series in the valley margin is somewhat random. (2) The same general pattern of faults and the same random distribution of the bedrock series doubtless extends beneath the valley fill, in and on which the test detonations were made. (3) The several bedrock types differ widely in elastic properties, so that large anomalies may be expected in the velocities of seismic waves propagated by the detonations.

As has been stated, Yucca Valley is a basin of structural origin. The dominant mechanisms have been step faulting and diverse tilting of bedrock slices which trend about from N. 35° W. to N. 20° E., with downthrow commonly (but not universally) to the east. Faults transverse to, and tears branching from this general trend are common. Folds, certain of them somewhat intricate and sharp, occur locally in the larger slices and blocks of the siliceous series and the limestone. Extensive gentle warps occur in the volcanic series.

Plate 2 suggests the fault pattern, but does not pretend to show all components of that pattern. In particular, faults probably define a considerable part of the valley-plain margin but are concealed by valley fill. Such is implied by numerous segments of that margin which trend parallel to the traces of known or probable faults.

Master faults pass through Yucca Pass at the south end of the valley (coordinates N. 795, E. 680), and at the east face of Oak Spring Butte at the north end of the valley (coordinates N. 910, E. 684). Along both these faults, volcanics are downthrown to the east against limestone to the west, with displacements in the order of 1,500 feet. Along other faults shown on Plate 2, downthrow ranges from a few tens to several hundred feet, at least. However, the present reconnaissance did not establish stratigraphic succession and thicknesses in detail, so that the amounts of downthrow at each of the several faults can not be evaluated at this time.

Evidently the general structural pattern of Yucca Valley was established before the rocks of the volcanic series were deposited. Then, after the epoch of volcanism, many of the faults were rejuvenated and both downthrow and tilt commonly were increased. Such is made evident by the fact that very commonly, although not universally, volcanic rocks in a particular bedrock block dip in about the same direction as, but in an amount moderately less than underlying limestone or rocks of the siliceous series. One major fault definitely, and others probably, has been active recently. This is made evident by one fault, to be described, which cuts the detrital fill in the northern part of the valley.

Owing to the deformation briefly described above, and subsequent erosion, rocks of the volcanic series cover somewhat more than half the valley-margin area shown on Plate 2. Beneath the cover of valley fill, in the central part of the basin, the volcanic series may be even more extensive in proportion to limestone and to rocks of the siliceous series. This inference follows because accumulating detrital fill halts the erosion of underlying bedrock areas, of course. Thus, beneath the cover of fill any slices or blocks of the volcanic series have been subjected to stripping by erosion for a shorter time than in the present valley-margin area.

2.2.3 Seismic properties

Elastic, or seismic, properties of the several bedrock types can be deduced only in general terms. In the quartzite and conglomerate of the siliceous series, in much of the limestone, and in the granite the longitudinal velocity of seismic waves would be relatively high, probably considerably more than 10,000 feet per second. Excepting the granite, substantial elastic anisotropy is to be expected. In the argillite and shale, longitudinal velocities probably are somewhat less. In contrast, the rocks of the volcanic series doubtless are extremely diverse in elastic properties. At one extreme, longitudinal wave velocities in the lava-rock layers (rhyolite or dacite, and probably basalt), and possibly in the most compact of the welded tuff, probably are moderate: in the general order of 10,000 feet per second. At the other extreme, in the cellular, highly inflated tuff, longitudinal velocity doubtless is much less and probably little, if any, greater than in much of the valley fill. Thus, any large mass of the volcanics is exceedingly non-homogeneous in elastic properties.

The bedrocks having these general elastic properties and being cut by faults along which members of very unlike elasticity may be thrown against one another, the seismic waves propagated in them by the detonations of Operation JANGLE may be expected to have very different velocities in different directions and at different distances. Abrupt discontinuities in elastic properties would be numerous. Consequently, the interpretation of seismic phenomena well may be obscured by large anomalies.

2.3 VALLEY FILL

2.3.1 Origin and physical character

As has been stated, the fill which forms and underlies the extensive central plain of the Yucca Valley is constituted of detritus transported from the surrounding bedrock areas (see Pl. 2). The chief agent of transportation has been intermittent runoff of rain-water or, during winter, of snow-melt. The pattern of transport has been along the several "washes" which transect the bedrock areas, down the alluvial fans which radiate from those washes, and then generally southward along the axis of the valley toward its lowest point in the playa just northeast of Yucca Pass.

In the washes and on the higher parts of the alluvial fans the land-surface gradients are and have been relatively steep--several hundred feet to the mile. Hence, detritus of all grade sizes, from silt to small boulders, is transported readily even under intermittent runoff. However, little assortment according to grade sizes takes place. Lower on the fans and along the axis of the valley, gradients flatten progressively to about 10 feet to the mile and runoff is attenuated. Thus, the grade size of particles which can be transported diminishes progressively and only the finest particles are mobile in the central part of the valley.

As has been described, the several bedrock types yield detritus of different textures--on the one hand moderately coarse and fines-free from the quartzite and conglomerate, on the other hand predominantly very fine from the massive unwelded tuff.

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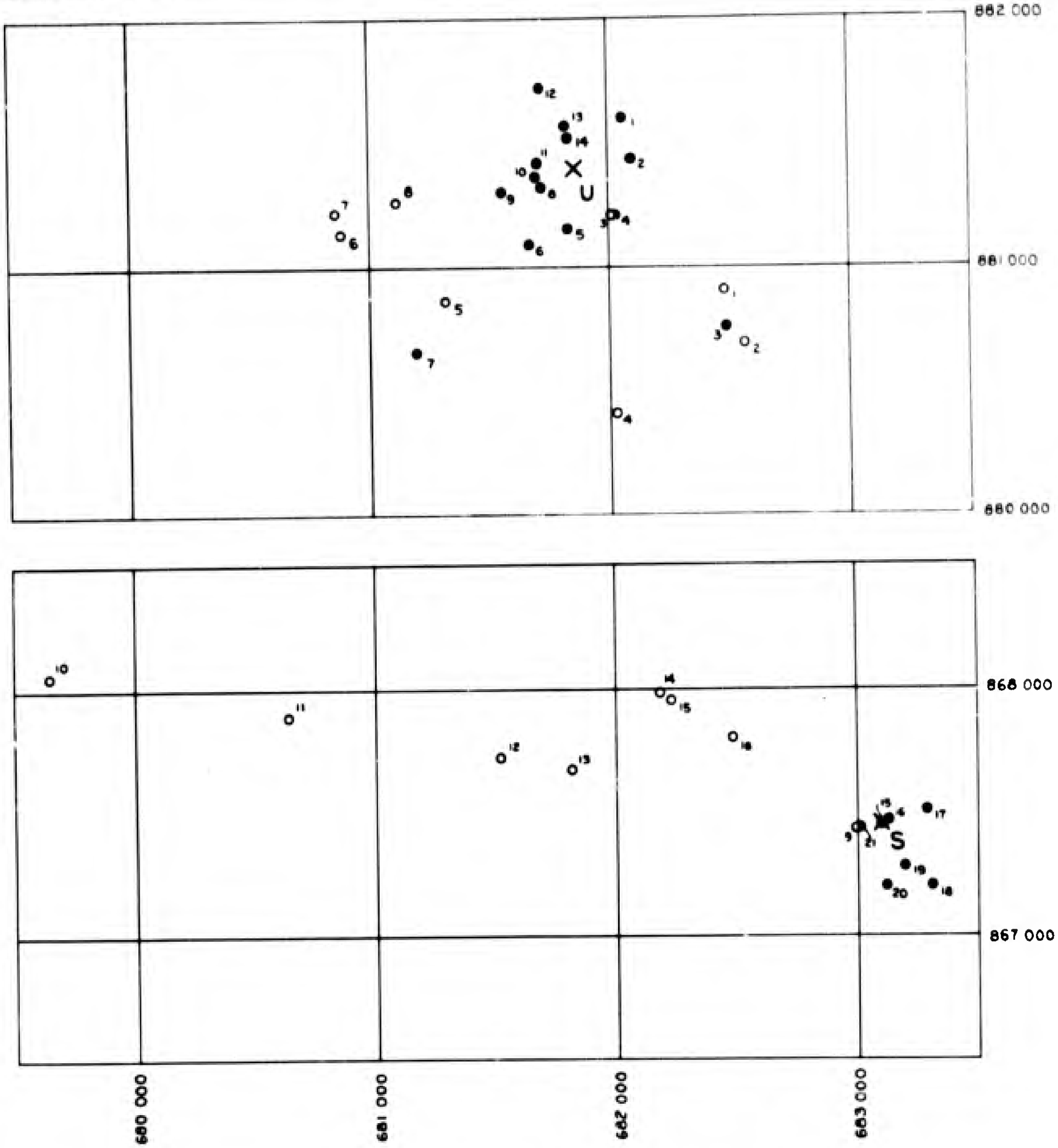
PROJECT 1(8)a

GEOLOGICAL SURVEY

PLATE 3



Locations of sections described in Table A.3 and of densities given in Table A.5. Scale, 1:4,800; coordinates in feet. $\circ_5$, section measured; $\bullet_7$, density determined. (Numbers refer to items in Tables 3 and 5.)

[redacted]

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In general, therefore, the valley fill is an assemblage of interfingering thin sheets and interlacing tongues of transported detritus whose texture varies greatly from place to place. By far the greater part is unassorted in particle size. Near the valley-plain margin commonly it is cobbly or bouldery but even there, if volcanic tuff is adjacent, is composed largely of fine particles. In the central part of the valley it is largely of sand- and silt-size particles; on the playa at the south end of the valley, of silt- and probably clay-size particles.

Tables A.3 and A.4 show stratigraphic and textural characteristics of the valley fill in the vicinities of the underground and surface zero points, at radial distances up to 11,000 feet and depths below land surface as great as 33½ feet. Plates 2 and 3 show the locations of the trenches and excavations to which the data of these two tables apply.

The textural data in Table A.4 are of considerable interest. Specifically, among 60 values, the so-called 50-per cent grain size ranges from 0.009 to 0.39 inch; the average is 0.082 inch and the median is 0.026 inch. The corresponding range in dimension of largest particle is from 1 to 12 inches. The percentage of particles passing a 100-mesh sieve (size of opening 0.0058 inch or 0.15 mm.) ranged from 3 to 31 and averaged 13; median percentage was 11. These variations in size of particle appear to be random in geographic position and in depth below land surface, within the area spanned by the data.

Table A.5 gives field densities, including contained moisture, on 21 samples of incoherent valley fill, at radial distances as great as 1,000 feet from the underground zero point and 325 feet from the surface zero point, and depths below land surface ranging from 0.5 foot to 16 feet. Locations are shown on Plate 3. Values of density range from 1.30 to 1.81; the average is 1.46 for seven values at depths from 0.5 foot to 2 feet, and 1.65 for those at greater depth. Otherwise, the variation appears to be random in geographic position and in depth. The somewhat less density for the topmost two feet is reasonable, because the materials at and just below land surface have been winnowed by the wind.

The physical characteristics described in the preceding two paragraphs apply only to the topmost 5 to 35 feet of the valley fill near the two zero points. The only corresponding information for other parts of the valley and for greater depths is that in the driller's logs for the four deep test holes drilled during the exploratory stage of the operation (see Table A.6). Excepting Well 2, to which reference is made later, these disclose neither substantial changes in texture nor widespread stratigraphic zoning to the depth penetrated, 500 feet.

[redacted]

At numerous places the valley fill encloses stringers, lenses, and sheets of "caliche," the compact and coherent material formed by deposition of carbonates in the interstices of the valley fill. Only general information on the extent and number of caliche layers can be given. Thus, as disclosed by trenches and excavations: (1) The greatest known horizontal reach of a single layer is 900 feet; the greatest thickness 2 feet. (2) More commonly the caliche occurs as stringers or lenses from a fraction of an inch to several inches thick and a few feet or tens of feet long, dispersed irregularly through zones as much as 5 feet thick. (3) Individual layers and zones both are discontinuous horizontally and random in vertical spacing. (4) Near the underground zero point, within a radial distance of about 1,000 feet, excavations and test holes encountered no caliche in the topmost 14 to 20 feet of the valley fill. (5) With this exception, caliche constitutes about 20 per cent of the total stratigraphic thickness spanned by the sections of Table A.3 (which reach from 4½ to 33½ feet below land surface). This percentage well may be too large for the whole body of valley fill. (6) The density of the caliche is about 25 percent greater than that of the incoherent valley fill; for nine samples taken from 15 to 25 feet below land surface, the average is 2.02 (see Table A.3).

Monitor's data from the four deep test holes suggest that vertical spacing of caliche zones increases with depth below land surface. However, the method of drilling was not competent to define the thickness and spacing of individual caliche layers, although such information may be required for full interpretation of test results under other programs and projects.

The seismic exploration by the United Geophysical Co., Inc., disclosed several high-velocity zones and areas in the valley fill. The high-velocity material probably is caliche (see Section 2.3.4). Such zones are about from 60 to 70 feet below land surface in Test Hole 1 near surface zero, at about 20 feet and possibly below 465 feet in Test Hole 3, and 20 to 40 and 50 to 60 feet in Test Hole 4 near underground zero. A general area of abnormally high velocity at shallow depth was found to extend from surface zero northward half way to underground zero.

More specific information on the distribution of caliche can be obtained only through further field exploration. For this, if contemplated, the optimum method probably would be to run detailed electric-resistivity logs in a series of mud-filled test holes arranged in one or more profiles across the area of interest, to whatever depth is required. A representative few of the holes would need to be drilled and sampled with extreme care for an independent determination of thickness and spacing of any caliche layers or zones penetrated. Resistivity characteristics determined in these few holes then would afford a basis for discriminating caliche in the remaining holes.

[redacted]

Although this is suggested as the optimum procedure, it should be borne in mind that neither a large number of test holes nor any other feasible method of exploration will disclose the distribution of caliche in all details.

In certain alcoves along the valley-plain margin, bouldery and cobbly facies of the valley fill are thoroughly cemented, chiefly by calcium carbonate, into dense fanglomerate. This material is known to occur only where, by inference, the fill is only a mantle over shallow bedrock, and where limestone crops out close at hand. In the banks of certain washes it forms ledges as much as 10 feet thick. Its principal known occurrences are shown on Plate 2 by letter symbol. Most extensive of these is in the north-central part of the valley, west and northwest of underground zero. There, discontinuous outcrops over several square miles disclose fanglomerate as much as 25 feet thick, with its base not exposed. The included stones are angular, commonly from 3 to 12 inches in greatest dimension, and chiefly of quartzite or conglomerate. This is the material into which Test Hole 2 was drilled (Table A.6).

2.3.2 Thickness

Only general limiting facts are known as to the thickness of the fill in Yucca Valley. Over numerous reentrants of the valley plain into the bedrock areas, the fill is only a veneer on a rock-cut bench or pediment. Here it is extensively no more than a few feet or tens of feet thick; locally, as in the beds of washes, it has been removed in "windows" which expose the underlying bedrock. Certain of these areas are identified on Plate 2 by letter symbol. Beneath the greater part of the valley plain, however, the fill is hundreds of feet thick, although doubtless thickness varies substantially and abruptly from place to place owing to irregular contour of the underlying bedrock. None of the four test holes near the two zero points, three of them 500 feet deep, penetrated the fill. According to the seismic survey by United Geophysical Co., Inc.,[5] the fill: (1) along the line from surface zero northward to underground zero is about from 800 to more than 1,000 feet thick, (2) thins eastward to a feather edge at the margin of the valley plain, (3) farther north thins abruptly to about 600 feet over the crest of a buried bedrock "high" about at coordinates N. 884, E. 686, but (4) elsewhere in the area of the survey is generally more than 800 feet thick. Some of these determinations of thickness may be somewhat in error owing to the probable difficulty of discriminating valley fill from volcanic tuff by seismic methods (see Section 2.3.4).

5/ Op. cit., isopach map.

Finally, one of several wells drilled by the Atomic Energy Commission in a search for water, went to a depth of some 1,500 feet near the south end of the valley, west of Yucca Playa. An unconfirmed report from the driller's log suggests that this well may have reached bedrock (volcanic tuff), but was in valley fill for more than 1,000 feet.

2.3.3 Structure

One known fault cuts the body of fill in the north part of Yucca Valley. Its trace, shown on Plate 2, is an east-facing scarp which trends generally southward and passes 1.1 miles and 0.9 mile west of the underground and surface zero points, respectively. Opposite underground zero this scarp is about 50 feet high and, at the land surface, brings generally incoherent fill on the east against compact fanglomerate on the west. Some two miles to the north, where it crosses an extensive pediment, the scarp is roughly 100 feet high; there the fill to the east probably is several hundred feet thick but to the west is no more than a pediment veneer, by inference only a few tens of feet thick, with bedrock beneath. Southward from underground zero, the scarp diminishes in height and dies out in the valley plain about three miles beyond surface zero.

The height of this scarp is inferred to be a minimum measure of eastward downthrow along the fault late in the epoch of valley filling. To the east the valley plain appears to be aggrading; to the west, erosion has only recently breached the scarp and begun to degrade. Probably, however, this visible displacement represents only the latest of recurring movements along an active fault which extends down into bedrock, where the aggregate displacement is much greater.

This fault doubtless creates a substantial discontinuity in elastic and other physical properties of earth materials through which the seismic waves produced by the JANGLE detonations would pass. Anomalies are to be expected between effects measured to the east and to the west, respectively. Conceivably other such discontinuities exist in the body of valley fill but, if so, their expression at the land surface is obscure and was not recognized during the reconnaissance mapping of Project 1(8)a.

2.3.4 Seismic properties

Project 1(8)a did not include measurements of seismic properties of the valley fill. These properties are herein evaluated only relatively, from the previously cited report by the United Geophysical Co., Inc., and from the general character of the materials.

Data in the cited report, recomputed by the writer, indicate the following vertical velocities:

TABLE 2.1

Vertical or "Up-hole" Wave Velocities in Valley Fill, at the Four Test Holes

Depth-zone (feet)	Feet per second		
	Mean	Minimum	Maximum
0- 15	2,690	1,430	3,030
15- 40	3,050	1,630	3,380
40-100	3,240	1,960	12,500
100-150	4,000	2,750	5,820
150-300	4,300	3,790	5,560
300-350	4,710	4,170	8,060
350-460	5,220	3,590	8,060
460-500	. . .	4,500	13,350

In the preceding table the mean values are for zones between the successive depths at which there is an appreciable "break" in velocity in one or more of the four wells. The minimum and maximum values are of apparent velocities for the individual depth segments measured by the United Geophysical Co., Inc.,—generally 10-foot segments to a depth of 100 feet, 25-foot segments from 100 to 200 feet, and 25- to 50-foot segments below 200 feet. These may be substantially in error because instrumental errors ar not fully compensating in the time-interval value that enters each computation. However, they are valid in indicating a fairly wide range of vertical velocities from place to place in the valley fill.

The cited report includes plottings showing horizontal (refraction) wave velocities in the vicinities of the four test holes. These were determined with 165-foot geophone spreads centered across each of the holes, and with shot points ordinarily 12.5, 177.5, and 342.5 from either end of each spread. Values so determined would be derived only from the higher-velocity layers of the valley fill; intervening low-velocity layers would not be evaluated. The values reported are from 2,820 to 2,900 feet per second near Test Hole 1, 2,480 to 5,200 feet per second near Test Hole 2 (on the fanglomerate-covered pediment west of underground zero, 2,860 feet per second near Test Hole 3, and 3,940 feet per second near Test Hole 4. Excepting the determinations at Test Hole 2, these values of horizontal velocity fall in the lower part of the range of vertical velocities just given.

The copy of the report by the United Geophysical Co., Inc., which is available to the writer, is not accompanied by travel-time curves for the long traverse lines shown on Plate 2. It notes, however, that the measured horizontal or refraction velocities vary considerably from place to place in the area, vary randomly at some places, and for most parts of the area vary abruptly at different depths below land surface. It concludes, appropriately, that much of this variation probably is due to varying degrees of cementation in the valley fill, with the highest velocities applying to caliche layers (the most thoroughly cemented of the valley-fill materials). Greater-than-average velocity at shallow depth is noted in the vicinity of Test Hole 2 (which is in the bouldery and thoroughly cemented fanglomerate previously described). "Several layers of caliche or other cemented material in the upper 100 feet" of the valley fill are noted as occurring along traverse line G between stations 288+50 and 357+25—that is, from surface zero about half way to underground zero (see preceding Section 2.3.1).

In the wholly incoherent and the slightly or moderately cemented materials of the valley fill, longitudinal wave velocities, in either the horizontal or vertical direction, may be expected to fall about within the range of mean and minimum vertical velocities given in the preceding table—that is, less than about 5,000 feet per second. Higher velocities would characterize the thoroughly cemented materials such as well defined layers of caliche and much of the fanglomerate.

Even in the incoherent parts of the fill, seemingly random and continual variation in velocity would correspond to the wide variation in textures of the component materials. High-velocity layers would be discontinuous horizontally and random in depth, largely corresponding to the distribution of caliche layers and zones. Other factors being the same, velocity would be expected to increase somewhat with depth below land surface, because porosity would diminish owing to compaction under the load of overlying material. Further, the ratio of longitudinal to transverse wave velocities may vary considerably with depth6/.

Under these conditions, considerable range is to be expected in the apparent travel time of elastic waves propagated by the detonations of Operation JANGLE. The diverse elastic properties of valley-fill materials in which the several detecting instruments were placed would be a principal contributing factor.

6/ Heiland, C. A., Geophysical exploration, p. 474, New York, Prentice-Hall, 1940.

[redacted]

Wave velocity in the least coherent and compact of the bedrocks—that is, in much of the tuff—probably is little if any greater than the higher of the velocities in the valley fill. Hence, elastic phenomena measured in and near the feather edge of the valley fill (near the margin of the valley plain) will be complex and difficult to interpret at many places.

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CHAPTER 3

HYDROLOGIC FEATURES

3.1 MOISTURE CONTENT OF THE VALLEY FILL

Yucca Valley is arid. It has sparse precipitation, which occurs as occasional intense showers or thunderstorms in summer and as snow at the higher altitudes in winter. It has no perennial streams and only a few perennial springs of small magnitude. Its water table is deep, in the order of 1,200 to 1,500 feet below the playa at the southern end of the valley and probably at least 1,500 feet beneath the valley plain in the area of Operation JANGLE. Thus, that operation involves earth materials which are nominally "dry" (but not completely desiccated in the technical sense). Certain relevant details are expanded in the following three paragraphs.

The principal three springs—Tippipah Spring, roughly at the mid-point of the west margin of the valley at coordinates N. 835, E. 635; Whiterock Spring, in the alcove at the northwest corner of the valley at coordinates N. 895, E. 655; and Oak Spring, near the north end of the valley about at coordinates N. 910, E. 675—issue at or near the contact between volcanic tuff and underlying rocks of the siliceous or limestone series. In 1951, each flowed only a gallon or two in a minute. These are contact springs, fed by slow percolation in the tuff, along the top of the less permeable rocks beneath. They do not indicate that the bedrocks of the valley margins are saturated to a general level above the valley plain.

As has been stated, in the valley fill the regional water table is some 1,500 feet below land surface in the test area. To some such depth, therefore, the fill is not saturated. To a depth of a few feet below land surface, evaporation and transpiration by desert vegetation doubtless reduce moisture about to the hygroscopic coefficient each summer—that is, to one or two per cent water (by weight). The resulting deficiency in soil moisture would be sufficiently great that over most of the valley plain there would be virtually no deep infiltration of rain water. This condition probably holds even in the relatively sandy fill of the test area. At depths of more than a few feet below land surface, therefore, the moisture content of the valley fill in the test area probably is about at specific retention—say not more than about 10 per cent (by weight), to judge from the general texture of the component materials.

Such being its hydrologic characteristics, the valley fill of the Nevada Test Site would have appreciably less density and probably lower seismic-wave velocities and amplitudes than the same assemblage of earth materials in a more humid area. This bears directly on the manner in which the energy released by the test detonations was expended (see Section 5.2).

[redacted]

[redacted]

CHAPTER 4

EARTH AND AIR TEMPERATURES

4.1 SCOPE OF THE TEMPERATURE RECORDS

Plate 4 shows the fluctuations of earth and air temperatures in the test area during the 15 weeks preceding and the week following the underground test as measured at the six thermistor and two thermograph stations (see Section 1.3). The six thermistor stations were located as follows:

TABLE 4.1

Location of Thermistor Stations

Thermistor	Depths (feet)	Coordinates		Location
		N.	E.	
169	10, 20, 30	887.8	681.1	6,400 feet N.6°W. from underground zero.
164	do.	880.8	681.8	550 feet S.5°W. from underground zero.
163	3, 5, 10	874.4	682.7	250 feet S.60°W. from zero point of the pre-test high-explosive detonations.
167	10, 20, 30	873.5	681.9	1,100 feet S.30°W. from zero point of the pre-test high-explosive detonations.
166	do.	867.0	682.8	550 feet S.25°W. from surface zero.
168	do.	860.5	683.6	2,300 feet S.60°E. from Camp 1.

On air temperature, Plate 4 shows a smoothed graph of daily medians. These are index, rather than absolute, values. They were derived from the two thermograph records as follows: (1) On each thermograph chart averages were interpolated for the six hours of mid-day peak temperature and for the six hours of night-time low temperature. (2) The value mid-way between average high and average low temperature was taken as the median of the day for each thermograph. (3) The two median temperatures, which from day to day differed by as much as 4° F., then were averaged to determine a daily median value for the area, as plotted on Plate 4. On most days, if not all, variation in temperature was such that this simplified procedure approximated the true daily mean with sufficient accuracy for the purpose.

[redacted]

The early part of the thermistor records does not indicate true earth temperature, because settings were made by boring holes about 18 inches in diameter and then back-filling with the excavated material which had been warmed by the sun. Thus, substantial amounts of heat had to dissipate by radiation before all the back-fill was in thermal equilibrium with surrounding material. The terms of unreliable record are about 15 days for the thermistors set at 30 feet depth, 10 days for those at 20 feet, and shorter intervals for those at 10, 5, and 3 feet.

4.2 EARTH-TEMPERATURE CHARACTERISTICS

The following generalizations are warranted from earth temperatures observed after thermal equilibrium had been reached:

1. At 30 feet in depth, earth temperature ranged only about 0.2° F. (0.1° C.); this range is little, if any, greater than over-all tolerance of the instruments and procedure. As a preliminary conclusion, earth temperature at 30 feet in depth may be taken as sensibly constant at any one place in the area (and approximately equal to yearly mean air temperature at that place). For the northernmost and southernmost of the thermistor stations, this constant temperature was 61.0° F. (16.1° C.). For the intervening three stations it was somewhat lower—specifically, from 60.1 to 60.3° F. (15.6-15.7° C.). The difference is not explainable at this time.

2. At depths substantially greater than 30 feet, earth temperature may be assumed to be essentially invariable but to increase slowly with depth.

3. At 20 feet in depth, earth temperature was slightly less than at 30 feet during the early part of the record, surpassed the 30-foot temperature beginning 8 August to 6 October, and continued to rise thereafter. For the three stations in the reach from underground zero to surface zero, the observed range was from 60.1 to 61.5° F. (15.6-16.4° C.). This fluctuation doubtless is in dynamic response to that of air temperature, with a lag exceeding two and a half months. For the northernmost and southernmost stations the 20-foot temperature showed the same amount of range during the period of observation, but was consistently higher by 1.1° F. (0.6° C.).

4. At 10 feet in depth and at all six stations, earth temperature was from 1.4 to 4.9° F. (0.8-2.7° C.) greater than at 20 feet during the period of observation. It was from 62.4 to

64.9° F. (16.9-18.3° C.) on 25 August, peaked at 63.7 to 66.0° F. (17.6-18.9° C.) on 8 to 17 October, and then diminished until at the end of the period it was 62.4 to 64.6° F. (16.9-18.1° C.). It was least near underground zero and increased both northward and southward. The observed range during the period, from 1.3 to 2.5° F. (0.7-1.4° C.) at the several stations, again represents dynamic response to the range in air temperature, with the peak earth temperature lagging roughly a month after the peak air temperature on 16 September. Presumably yearly mean earth temperature would approximate yearly mean air temperature. If so, the yearly minimum earth temperature at 10 feet in depth will be considerably less than any yet observed.

5. At the one 5-foot-depth station, earth temperature was 69.4° F. on 1 September, rose to an observed peak of 70.0° F. on 26 September (10 days after peak air temperature), and then diminished to 57.0° F. on 3 December. Corresponding values in degrees Centigrade are 20.8, 21.1, and 13.9, respectively. At the companion 3-foot-depth station, earth temperature was 71.6° F. on 26 August, peaked at 73.0° F. on 22 September (6 days after peak air temperature), and diminished to 50.4° F. on 3 December (22.0, 22.8, and 10.2° C., respectively). Thus, observed earth temperatures at the 5-foot and 3-foot depths surpassed the range at greater depths, to a considerable degree. As would be expected, the greatest fluctuation was found at the least depth—a range of 22.7° F. (12.6° C.) was observed at the 3-foot station. Over the year, it is expected that both the 5-foot and the 3-foot earth temperatures would fall substantially lower and might rise somewhat higher than any values yet observed.

From the data shown on Plate 4, earth temperatures on the two test days of Operation JANGLE were projected about a week in advance, with the error probably not exceeding 0.5° F.

Reference has been made to the lag between peak air temperature and peak earth temperatures, from six days at 3 feet in depth to more than two and a half months at 20 feet in depth. From this it should not be assumed that earth temperature is a simple first-order function of air temperature some constant number of days earlier. The principles of heat transfer between air and earth are much more complex, and for Yucca Valley can not be resolved from the data now at hand. However, the thermistor stations were not removed prior to the JANGLE detonations. All were reoccupied within the week following the surface test and four of the six within the week following the underground test. It is hoped that all can be continued through the greater part of a year, so that the relation of earth temperatures to air temperature can be analyzed rigorously at some future time.

CHAPTER 5

GEOLOGIC AND RELATED ASPECTS OF WEAPON EFFECTS

5.1 OPERATION JANGLE

As observed visually and inferred by the writer, principal stages in the underground test were somewhat as follows:

1. With detonation, a conical mass of the valley fill sheared off and was ejected from the locus of the crater in several massive plumes of debris. Apex angle of the cone is estimated at 90°; its depth below land surface, at two or three times that of the detonating charge.

2. By the intense convection as the fireball expanded, a considerable additional volume of valley fill was excavated from the crater and the component particles were carried radially outward and upward in a cylindrical column perhaps 1,500 feet in diameter. Presumably this column was hollow.

3. The finest particles formed into a rudely hemispherical dust canopy which was somewhat less than a mile in diameter and height, and which dissipated ultimately by conveyance downwind.

4. Concurrently with formation of the dust canopy, valley-fill particles of intermediate and coarser sizes cascaded back to earth in a cylindrical curtain within the peripheral part of the central column. At least a considerable part of this cascade was beyond the crater rim.

5. Beginning at the curtain cascade, a "base surge" of fine particles developed to a height of several hundred feet and progressed outward to a diameter of say 3,000 feet before it was attenuated greatly.

These inferences from visual observation have not been verified and scaled against the official photographs. Neither have they been amplified on the ground by the writer to determine dimensions and contour of the crater and its lip, size and distribution of any ejected rock missiles, or volume, distribution, and particle sizes of the immediate fall-out. Such amplifying facts would be prerequisite to even a rough estimate of the amount of energy expended in dislodging and transporting valley fill. Such an estimate is not a responsibility of Project 1(8)a.

The surface test was not observed by the writer. By inference, Stage 1 as just described would not have taken place and the subsequent stages would have been of diminished intensity, in various degrees.

5.2 POTENTIAL TARGET AREAS OF A PENETRATING ATOMIC MISSILE

Target areas of a penetrating atomic missile presumably would be principal municipalities and industrial centers, which commonly are on alluvial plains along major streams, on river-mouth deltas, or on coastal terraces. Incoherent alluvial, deltaic, or terrace deposits in such target areas commonly would differ substantially in textural and elastic characteristics from the valley fill of the Nevada Test Site. Most such areas would be substantially more humid, or cooler, or both. These differences are amplified in the following paragraphs.

In the incoherent materials of potential target areas, particles are likely to be much more uniform in size than in the valley fill of the test area. From one target area to another, materials might range from silt to pebble- or cobble-gravel, but commonly any one area would not contain a wide range of particle sizes, each in abundance. Also, particles are likely to be derived largely from rocks of greater specific gravity than the volcanic tuff which has contributed so much of the fines in the valley fill of the Nevada Test Site. Among target areas, therefore, the materials might be either fine- or coarse-textured but in general would be somewhat more porous and of substantially higher specific gravity. In general, also, probably they would not contain as many or as extensive cemented zones.

Assuming other factors to be the same, a penetrating atomic missile probably would expend substantially different proportions of its energy in displacing diverse target-area earth materials. In coarse-textured materials the crater should be relatively small and the expenditure of energy disproportionately large, and vice versa. The displacement of earth materials in the JANGLE underground test probably would be in scale only for the finer of target-area materials, and that only approximately.

Most potential target areas would be quite unlike the test area in their hydrologic features, which would bear directly on probable effectiveness of the penetrating missile. Numerous target areas would be adjacent to rivers or other water bodies; the missile might be placed to penetrate the river bed. Even at a distance from surface-water bodies, the earth materials of most target areas would contain more moisture and the ground-water table would be much closer to land surface, commonly so close that the missile might reach it.

In the moist soil of a humid-region target, thermal energy from a detonating missile would convert water to steam, possibly with some increase in destructiveness near the point of impact. This effect would be greatly accentuated if detonation were in the saturated materials of a stream bed or below the water table.

With detonation close above the water table, or below it, displacement and pressure waves presumably would be generated in the ground-water body. These might well aggravate the destructiveness of the missile by imposing widely and rapidly fluctuating hydraulic pressures on the foundations of structures previously subjected to earth shock and air blast. It has been noted that a test of these effects was precluded in Operation JANGLE by the very deep water table in the test area.

Greater soil-water content and a relatively shallow water table being a probable rule rather than an exception among potential target areas, elastic properties of the earth materials should be substantially different from those in the test area. On the average, wave velocities should be greater in material of any particular texture. In the zone of saturation below the water table, wave amplitudes or intensities well might increase substantially. Especially in saturated materials of fine grain, such as certain delta deposits, destruction by the missile might be aggravated considerably near the point of impact.

Certain potential target areas would be in a climate sufficiently cool that in winter frozen ground would create transient high-velocity zones. Under this condition, damage to utilities and to structures with shallow foundations might reach considerably farther from the point of detonation.

Geologic and related factors discussed in this section seem to warrant further analysis in any future consideration of specific, rather than potential, target areas. However, scaling from the results of Operation JANGLE to a full-size missile, a specific target, and a definite strategic objective goes considerably beyond the writer's qualifications and the data available to him.

APPENDIX A—TABLES

PROJECT 1(8)a

Table A.1

Logs of Test Holes Drilled by Mobile Construction Battalion 3 on Amchitka Island1/

C'51-1.- Coordinates: N. 5,704.84, E. 644.952/; land surface 295 feet above sea level. Six-inch casing to bottom. Drilled Feb. 18-20, 1951.

Material	Thickness (feet)	Depth (feet)
Tundra	1½	1½
Windblown silt and humus	1	2½
Volcanic conglomerate, few boulder-size inclusions; fractured	15½	18
Volcanic conglomerate, fine-grained, a few boulder-size inclusions	35	53
Volcanic tuff, bedded	11	64
Volcanic conglomerate, coarse-grained, mostly boulder-size particles	29	93

U'51-1.- Coordinates: N. 5,705.33, E. 644.84; zero point on blast line; land surface 295 feet above sea level. Drilling bit stuck in hole; no casing. Drilled April 6-7, 1951.

Material	Thickness (feet)	Depth (feet)
Tundra	1	1
Windblown silt and swamp humus	2	3
Volcanic conglomerate, shattered	3	6
Volcanic conglomerate, sound, many boulder-size inclusions	50	56
Volcanic conglomerate, few boulder-size inclusions, matrix coarse-sand and pebble sizes	46	102

1/ In geographic sequence, proceeding northwestward; logs in following Table A.2 arranged likewise.

2/ Coordinates, in kilometers, refer to military grid, universal transverse Mercator projection, zone 60, as shown in general on Plate 1 and in detail on U. S. Coast and Geodetic Survey topographic manuscript, surveys 5595, 5596, 5597, and 5599.

Table A.1 (Cont.)

Logs of Test Holes Drilled by Mobile Construction Battalion 3 on Amchitka Island

U'51-7.- Station 0+00 along blast line, right 7 feet; land surface 295 feet above sea level. Temporary casing set at 51 feet in cement plug and plug drilled through to 52 feet to determine ground-water head; casing then pulled. Drilled April 24-25, 1951.

Material	Thickness (feet)	Depth (feet)
Tundra	1	1
Windblown silt	1	2
Volcanic conglomerate, shattered	7	9
Volcanic conglomerate, sound, many boulder-size inclusions	43	52

U'51-8.- Station 0+05 along blast line, right 5 feet; land surface 295 feet above sea level. Temporary 6-inch casing set in cement plug at 20 feet to determine ground-water head, then pulled. Drilled April 25-26, 1951.

Material	Thickness (feet)	Depth (feet)
Tundra	1	1
Windblown silt	1	2
Volcanic conglomerate, shattered	6	8
Volcanic conglomerate, many boulder-size inclusions	13	21

U'51-11.- Station 0+06 along blast line, left 3 feet; land surface 295 feet above sea level. No casing. Drilled April 30-May 1, 1951.

Material	Thickness (feet)	Depth (feet)
Tundra	1	1
Windblown silt and swamp humus	3	4
Volcanic conglomerate, shattered and weathered	9	13
Volcanic conglomerate, many boulder-size inclusions	40	53

Table A.1 (Cont.)

Logs of Test Holes Drilled by Mobile Construction Battalion 3 on Amchitka Island

U'51-6.- Station 0+80 along blast line, left 175 feet; land surface 300 feet above sea level. Hole stopped and pattern of instrument holes changed because presence of dike would vitiate contemplated tests. Drilled April 24, 1951.

Material	Thickness (feet)	Depth (feet)
Tundra	½	½
Dike rock (basalt), shattered	½	1
Dike rock, sound and massive	4	5

U'51-5.- Station 0+80 along blast line, left 200 feet; land surface 300 feet above sea level. Six-inch casing. Drilled April 24, 1951.

Material	Thickness (feet)	Depth (feet)
Tundra	1	1
Windblown silt	1	2
Volcanic conglomerate, shattered	3	5
Volcanic conglomerate, fine-textured, few boulder-size inclusions	20	25
Dike rock (basalt), not penetrated	6	31

U'51-9.- Station 0+80 along blast line, left 225 feet; land surface 300 feet above sea level. Six-inch casing. Drilled April 28, 1951.

Material	Thickness (feet)	Depth (feet)
Tundra	1	1
Windblown silt	1	2
Volcanic conglomerate, shattered	2	4
Volcanic conglomerate, boulder-size inclusions	27	31

Table A.1 (Cont.)

Logs of Test Holes Drilled by Mobile Construction Battalion 3 on Amchitka Island

U'51-3.- Station 0+85 along blast line, left 325 feet; land surface 300 feet above sea level. Tools lost in hole and not recovered. Drilled April 16-17, 1951.

Material	Thickness (feet)	Depth (feet)
Tundra	1	1
Windblown silt	1	2
Volcanic conglomerate, shattered	3	5
Volcanic conglomerate, few boulder-size inclusions	38	43

U'51-4.- Station 1+05 along blast line, left 200 feet; land surface 300 feet above sea level. Six-inch casing. Drilled April 23, 1951.

Material	Thickness (feet)	Depth (feet)
Tundra	1	1
Windblown silt	1	2
Volcanic conglomerate, shattered	3	5
Boulder-size inclusion, massive	2	7
Volcanic conglomerate, fine-textured, few boulder-size inclusions	21	28
Dike rock (basalt), not penetrated	3	31

U'51-10.- Station 1+05 along blast line, left 225 feet; land surface 300 feet above sea level. Six-inch casing. Drilled April 29, 1951.

Material	Thickness (feet)	Depth (feet)
Tundra	1	1
Windblown silt and humus	1	2
Volcanic conglomerate, shattered	1	3
Volcanic conglomerate, sound	28	31

PROJECT 1(8)a

Table A.1 (Cont.)

Logs of Test Holes Drilled by Mobile Construction Battalion 3 on Amchitka Island

U'51-13.- Station 1+05 along blast line, left 350 feet; land surface 300 feet above sea level. Hole stopped when project abandoned. Drilled May 7-10, 1951.

Material	Thickness (feet)	Depth (feet)
Tundra	1	1
Windblown silt	1	2
Volcanic conglomerate, shattered	3	5
Volcanic conglomerate, many boulder-size inclusions	23	28
Volcanic conglomerate, fine-textured, few boulder-size inclusions	24	52
Volcanic conglomerate, many large boulder-size inclusions	36½	88½

U'51-12.- Station 1+30 along blast line, left 225 feet; land surface 300 feet above sea level. Six-inch casing to 95 feet. Drilled May 3-6, 1951.

Material	Thickness (feet)	Depth (feet)
Tundra	1	1
Windblown silt	1	2
Volcanic conglomerate, many boulder-size inclusions	9	11
Volcanic conglomerate, fine-textured, no boulder-size inclusions	5	16
Volcanic conglomerate, many boulder-size inclusions	60	76
Dike rock (basalt), not penetrated	25	101

PROJECT 1(8)a

Table A.1 (Cont.)

Logs of Test Holes Drilled by Mobile Construction Battalion 3 on Amchitka Island

U'51-2.- Station 6+49 on blast line; coordinates: N. 5,705.46, E. 644.69; land surface 290 feet above sea level. Six-inch casing seated at 37½ feet; remainder of hole drilled with 5-3/4-inch bit; 3-inch pipe hung in hole to depth 315 feet to determine deep ground-water head. Drilled April 9-14, 1951.

Material	Thickness (feet)	Depth (feet)
Tundra	1	1
Windblown silt	½	1½
Volcanic conglomerate, shattered	1½	3
Volcanic conglomerate, a few boulder-size inclusions	37	40
Volcanic tuff and grit	26	66
Volcanic conglomerate, large boulder-size inclusions	35	101
Volcanic tuff and grit	104	205
Volcanic conglomerate, fine-grained, cobble-size inclusions	93	298
Volcanic conglomerate, large boulder-size inclusions	18	316
Volcanic conglomerate, cobble-size inclusions	7	323
Volcanic tuff and grit	64	387
Volcanic conglomerate, small boulder-size inclusions	41	428

B'51-1.- Coordinates: N. 5,707.66, E. 642.20; land surface 325 feet above sea level. Not cased; 9-7/8-inch bit. Drilled February 22, 1951.

Material	Thickness (feet)	Depth (feet)
Tundra	½	½
Windblown silt and humus	1½	2
Volcanic agglomerate, coarse blocks, fractured	3	5
Volcanic agglomerate, blocky, very little matrix (augite porphyry)	26	31

PROJECT 1(8)a

Table A.1 (Cont.)

Logs of Test Holes Drilled by Mobile Construction Battalion 3 on Amchitka Island

B'51-2.- Coordinates: N. 5710.22, E. 639.98; land surface 360 feet above sea level. Not cased. Drilled Feb. 26, 1951.

Material	Thickness (feet)	Depth (feet)
Volcanic agglomerate, blocky, fractured . . .	6	6
Volcanic agglomerate with very little matrix, coarse-textured, sound (feldspar-hornblende porphyry)	18	24

A'51-1.- Coordinates: N. 5,712.45, E. 637.65; land surface 435 feet above sea level. No casing. Drilled Feb. 27 to March 7, 1951.

Material	Thickness (feet)	Depth (feet)
Conglomerate, large boulder-size inclusions	12	12

GS'51-2.- Coordinates: N. 5,712.80, E. 637.65; land surface 460 feet above sea level. Bit lost in hole at 43 feet and not recovered. Drilled March 14-16, 1951.

Material	Thickness (feet)	Depth (feet)
Conglomerate, partly weathered, loose	8	8
Conglomerate, many cobble-size inclusions, sound and compact (all of feldspar-hornblende porphyry)	35	43

A'51-2.- Coordinates: N. 5,713.00, E. 636.94; land surface 450 feet above sea level. Not cased. Drilled March 3-8, 1951.

Material	Thickness (feet)	Depth (feet)
Conglomerate, large boulder-size inclusions	17	17
Single boulder or thin lava flow	5	22
Volcanic tuff, bedded (feldspar-hornblende porphyry)	9	31

Table A.1 (Cont.)

Logs of Test Holes Drilled by Mobile Construction Battalion 3 on Amchitka Island

Holes A'51-3 and A'51-4, respectively 14½ and 8 feet deep, and 25 and 50 feet from hole A'51-2, wholly in topmost material described above.

GS'51-1.- Coordinates: N. 5,714.27, E. 636.11; land surface 640 feet above sea level. No casing. Drilled March 14-16, 1951.

Material	Thickness (feet)	Depth (feet)
Recrystallized tuff, shattered	9	9
Recrystallized tuff, faulted and mineralized with pyrite	54	63

PROJECT 1(8)a

Table A.2

Logs of Test Holes Core-drilled by Lynch Bros.
on Amchitka Island

Material	Thickness (feet)	Depth (feet)
Core 2.- Coordinates: N. 5,693.53, E. 660.66; land surface 200 feet above sea level. Started on bare rock. Drilled April 12-18, 1951.		
Lava rock (feldspar porphyry)	113	113
Volcanic tuff, glassy, fine-textured	94	207
Core 1.- Coordinates: N. 5,693.53, E. 660.55; land surface 200 feet above sea level. Started on bare rock. Drilled April 12-18, 1951.		
Volcanic agglomerate, glassy	105	105
Lava rock (feldspar porphyry) with glass . . .	97	202
Volcanic tuff, fine-grained and glassy	4	206
Core 7.- Coordinates: N. 5,693.79, E. 661.32; land surface 240 feet above sea level. Drilled April 28-May 4, 1951.		
Runway fill (no core)	12½	12½
Volcanic agglomerate, glassy	321	333½
Core 9.- Coordinates: N. 5,693.83, E. 660.58; land surface 208 feet above sea level. Drilled May 5-6, 1951.		
(Casing washed down, no core)	11	11
Dike rock (hornblende gabbro)	26	37
Volcanic tuff, silicified	3	40
Dike rock (hornblende gabbro)	8	48
Volcanic agglomerate, green	64	112

Table A.2 (Cont.)

Logs of Test Holes Core-drilled by Lynch Bros. on Amchitka Island

Core 11.- Coordinates: N. 5,693.83, E. 660.49; land surface 204 feet above sea level. Drilled May 7-9, 1951.

Material	Thickness (feet)	Depth (feet)
(Casing washed down, no core)	5	5
Lava rock (feldspar porphyry)	30	35
Tuff, fine-grained, black and glassy	62	97
Volcanic agglomerate, green, decomposed . . .	21	118

Core 10.- Coordinates: N. 5,693.85, E. 660.04; land surface 195 feet above sea level. Drilled May 5-8, 1951.

Material	Thickness (feet)	Depth (feet)
(Casing washed down, no core)	21½	21½
Lava rock (feldspar porphyry)	45½	67
Volcanic agglomerate, green	66	133

Core 12.- Coordinates: N. 5,693.82, E. 659.82; land surface 193 feet above sea level. Drilled May 9-10, 1951.

Material	Thickness (feet)	Depth (feet)
(Casing washed down, no core)	5	5
Volcanic agglomerate, fine-grained, glassy . .	119	124

Core 5.- Coordinates: N. 5,693.94, E. 663.01; land surface 135 feet above sea level. Drilled April 23-28, 1951.

Material	Thickness (feet)	Depth (feet)
(Casing washed down, no core)	8	8
Volcanic agglomerate, green	50	58
Volcanic tuff, bedded	7	65
Fault gouge (chlorite and some zeolites) . . .	10	75
Volcanic tuff and grit, bedded	45	120
Dike rock (hornblende porphyry)	29	149
Volcanic tuff, bedded	25	174
Volcanic agglomerate, green	27	201

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PROJECT 1(8)a

Table A.2 (Cont.)

Logs of Test Holes Core-drilled by Lynch Bros.
on Amchitka Island

Core 8.- Coordinates: N. 5,693.98, E. 660.76; land surface 225 feet above sea level. Drilled April 28–May 5, 1951.

Material	Thickness (ft.)	Thickness (in.)	Depth (ft.)	Depth (in.)
(Casing washed through runway fill, no core)	15		15	
Volcanic agglomerate, glassy	299		304	

Core 4.- Coordinates: N. 5,694.04, E. 663.04; land surface 151 feet above sea level. Drilled April 18-23, 1951.

Material	Thickness (ft.)	Thickness (in.)	Depth (ft.)	Depth (in.)
(Casing washed down, no core)	10	4	10	4
Volcanic tuff, bedded	12	8	23	0
Volcanic agglomerate, green	29		52	
Dike rock (?) (feldspar porphyry) . . .	1		53	
Volcanic agglomerate, green, slightly altered	22		75	
Dike rock (?), (feldspar porphyry) . . .	1		76	
Volcanic agglomerate, green	3		79	
Dike rock (?) (feldspar porphyry), shattered	11		90	
Volcanic agglomerate, green	88		178	
Dike rock (?) (feldspar porphyry) . . .	22		200	

Core 3.- Coordinates: N. 5,694.12, E. 662.92; land surface 153 feet above sea level. Drilled April 18-22, 1951.

Material	Thickness (ft.)	Thickness (in.)	Depth (ft.)	Depth (in.)
Surficial detritus (casing washed down, no core)	7		7	
Volcanic tuff, bedded	11		18	
Volcanic agglomerate, green	73		91	
Dike rock (?) (feldspar porphyry) . . .	16		107	
Volcanic agglomerate, green	97		204	

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Table A.2 (Cont.)

Logs of Test Holes Core-drilled by Lynch Bros.
on Amchitka Island

Core 6.- Coordinates: N. 5,694.26, E. 662.14; land surface 152 feet above sea level. Drilled April 24-27, 1951.

Material	Thickness (feet)	Depth (feet)
(Casing washed down, no core)	19	19
Volcanic agglomerate, green	92	111
Dike rock (hornblende-gabbro porphyry)	23	134
Volcanic agglomerate, green	35	169
Volcanic tuff, bedded, fine-grained	2	171
Volcanic agglomerate, green	20	191

PROJECT 1(8)a

Table A.3

Representative Sections of the Valley Fill

[Measured in pits and trenches, whose locations are shown on Plate 3. All sections are top-side up and begin at land surface]

Section 1.- In pit, 800 feet S. 52° E. from underground zero. Coordinates: N. 880.90, E. 682.48*. No caliche exposed.

	Feet
Successive layers of silty sand with enclosed grit, pebbles, and cobbles (of volcanics and quartzite, and a few of limestone). Topmost part nearly all silt	7½
Sand and silt, with a few pebble lenses 6 inches thick. Massive and fairly homogeneous	3
Largely grit and pebbles to 1-inch diameter (of volcanics and quartzite). Pebbles coated with calcium carbonate. Vaguely stratified	1½
Total	12

Section 2.- In pit, 1,000 feet S. 45° E. from underground zero. Coordinates: N. 880.68, E. 682.56. No caliche exposed.

	Feet
Silt and sand enclosing scattered pebbles (of volcanics and quartzite). Fairly massive and homogeneous	1½
Successive 1- to 6-inch layers of silt, sand, and pebbles with 6- to 8-inch cobbles (of rhyolite, tuff, quartzite, and limestone). Stratified at some places. Particles subangular to slightly rounded. Truncates underlying bed somewhat	3
Silt and fine sand with a few streaks of cobbles. Fairly massive and homogeneous	3
Largely grit and ½-inch-pebble gravel, with some cobbles to 3-inch diameter (of volcanics and some tuff)	1½
Total	9

*In thousands of feet.

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PROJECT 1(3)a

Table A.3 (Cont.)

Representative Sections of the Valley Fill

Section 3.- In pit, 250 feet S. 40° E. from underground zero. Coordinates: N. 881.20, E. 682.02.

	Feet
Largely silt and fine sand, with scattered ½-inch pebbles (of tuff and rhyolite)	2
Largely silt and finer grades of sand, enclosing 1- and 2-inch cobbles (of tuff, rhyolite, and quartzite)	2
Unassorted silt, sand, pebbles, and cobbles to 3-inches diameter (of tuff, rhyolite, limestone, and quartzite); rudely stratified and cross-bedded. A scour-and-fill deposit; truncates two beds next beneath	16-11
Largely silt and finer grades of sand, stratified. Includes several pebbly layers about 2 inches thick . .	0-2½
Caliche, white to light buff, compact	0-1
Largely sand and silt, with scattered pebbles and cobbles (of volcanics, limestone, and quartzite). Upper 5 feet traversed by vertical stringers of caliche; spotty calcium-carbonate cementation throughout. Minor truncation of bed below	11
Interfingered lenses of pebbles and cobbles to 4 inches diameter, with sandy matrix; some "pockets" of clean pebble- or cobble-gravel. (Pebbles largely of tuff and rhyolite, sub-angular to slightly rounded; cobbles largely of limestone, rhyolite, and quartzite.) Discontinuous stringers of caliche a few inches thick; calcium-carbonate cementation throughout	4
Total	33½

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PROJECT 1(8)a

Table A.3 (Cont.)

Representative Sections of the Valley Fill

Section 4.- In pit, 1,000 feet S. 10° E. from underground zero. Coordinates: N. 880.40, E. 682.03. No caliche exposed.

	Feet
Silt and sand enclosing rock fragments from ½-inch to 8-inches in size (of volcanics, quartzite, and limestone). Heterogeneous and very poorly stratified. Fragments make up about half the bed, by volume	3
Grit to ½-inch pebbles (of volcanics and limestone), with several layers of silt up to 2 inches thick. Well stratified	2½
Almost wholly silt and finer grades of sand, with one 6-inch-thick lens of pebbles (of volcanics and limestone). Massive	4
Total	9½

Section 5.- In the southerly one of two large pits, 750 feet S. 45° W. from underground zero. Coordinates: N. 880.86, E. 681.32.

About 90 percent silt, with 3- to 6-inch-thick lenses of pebbles and 2-inch cobbles. Fairly homogeneous	6
Silt to 4-inch cobbles (of volcanics and limestone), in cross-bedded and interfingering lenticular layers from a few inches to a foot thick. Heterogeneous in texture. A scour-and-fill deposit. Truncates two beds next below	14-11
Caliche, light buff, compact. Silty at top. Lower part includes 2-inch cobbles (of limestone and volcanics)	0-2
Caliche, light buff to cream, containing rock fragments up to ¼-inch size. Compact in considerable part	0-1
Total	20

PROJECT 1(8)a

Table A.3 (Cont.)

Representative Sections of the Valley Fill

Section 6.- In pit, 1,000 feet S. 75° W. from underground zero. Coordinates: N. 881.13, E. 680.89.

	Feet
Largely silt enclosing scattered pebbles and a few thin lenses of cobbles	5
Pebble gravel (largely of tuff), largest particles 1-inch size. Well stratified	$2\frac{1}{2}$
Silt, sand, pebbles, and cobbles in interfingering lenses and cross-bedded layers, each from 1 to 6 inches thick. Heterogeneous. A scour-and-fill deposit. At some places truncates underlying two beds	$4\frac{1}{2}$-$3\frac{1}{2}$
Cobbles, 1- to 6-inch size (largely of rhyolite)	0-$\frac{1}{2}$
Silt and fine sand, with a few $\frac{1}{2}$-inch pebbles enclosed. Well cemented with calcium carbonate	0-$\frac{1}{2}$
Silt and fine sand. Cemented. Discontinuous 1/8-inch streaks of hard caliche	2
Caliche, light buff, enclosing $\frac{1}{4}$- to 1-inch pebbles. Compact in considerable part	1
Total	15

Section 7.- In trench, 1,000 feet S. 80° W. from underground zero. Coordinates: N. 881.22, E. 680.87. No caliche exposed.

Unstratified silt and sand containing numerous sub-angular to slightly rounded pebbles (largely of tuff and other volcanics, some of quartzite)	$1\frac{1}{2}$
Clay, silt, and the finer grades of sand, with few included rock fragments. Grain size increases downward. Massive and homogeneous for about 500 feet along the trench	$1\frac{1}{2}$
Grit to $\frac{1}{2}$-inch-pebble gravel, with a few larger included fragments (largely of tuff and other volcanics, but some of quartzite and limestone). Distinctly stratified and homogeneous for several hundred feet	3
Total	6

PROJECT 1(8)a

Table A.3 (Cont.)

Representative Sections of the Valley Fill

Section 8.- In trench, 750 feet S. 80° W. from underground zero. Coordinates: N. 881.26, E. 681.12. No caliche exposed.

	Feet
Silt and the finer grades of sand with scattered grit, pebbles, and cobbles to 6-inch size. Most common size among large particles is 1-inch. Pebbles and cobbles largely sub-angular (and of volcanics and quartzite). Fairly massive and homogeneous for several hundred feet along trench	5
Coarse sand and grit up to ¼-inch size (largely of volcanics, a few of quartzite). Distinctly stratified and homogeneous for about 500 feet along the trench	2½
Total	7½

Section 9.- In trench, 105 feet S. 80° W. from surface zero. Coordinates: N. 867.43, E. 683.00.

About 80 percent pebbles (of limestone and tuff), with matrix of sand and silt. Pebbles slightly rounded to sub-angular. Poorly consolidated	2
Caliche, light buff, in thin streaks forming matrix among pebbles (of limestone and volcanics). Bed extends about 850 feet westward along trench	1½
Successive layers of silt, sand, and scattered pebbles (of limestone and tuff, coated with calcium carbonate). Fairly hard owing to calcium-carbonate cement. Stringers of caliche up to 2 feet long and 1 inch thick scattered throughout	5
Total	8½

Table A.3 (Cont.)

Representative Sections of the Valley Fill

Section 10.- In trench, 3,500 feet N. 80° W. from surface zero. Coordinates: N. 868.06, E. 679.65. The two beds of this section are distinct for about 1,000 feet eastward.

	Feet
About 85 percent silt and fine sand (and clay ?); remainder is included pebbles (of limestone and tuff). No caliche	2
About 60 percent clay (?), silt, and sand; remainder is included pebbles. Massive and poorly consolidated	3
Total	5

Section 11.- In trench, 2,500 feet N. 80° W. from surface zero. Coordinates: N. 867.89, E. 680.64.

Largely sub-angular to somewhat rounded cobbles with some pebbles (largely of limestone and volcanics, a few of quartzite). Not consolidated	1
About 80 percent caliche, in discontinuous stringers through sand and silt	1
About 70 percent pebbles, with matrix of silt and fine sand (and clay ?). Massive, cemented in spots, contains a few caliche stringers	2½
Total	4½

Section 12.- In trench, 1,600 feet N. 80° W. from surface zero. Coordinates: N. 867.73, E. 681.52. The three beds of this section retain their identity for 700 feet to the northwest.

Soil, sandy to silty	1½
Caliche, light buff, dense. Varies from a single massive layer to a succession of discontinuous stringers, each a few inches thick, interspersed with pebble- and cobble-gravel	2
Pebble-and-cobble gravel (of limestone and tuff), with very little sand. Few caliche stringers, but generally not cemented	2
Total	5½

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PROJECT 1(8)a

Table A.3 (Cont.)

Representative Sections of the Valley Fill

Section 13.- In trench, 1,300 feet N. 80° W. from surface zero. Coordinates: N. 867.68, E. 681.82. The three beds of this section extend eastward about 1,000 feet, the caliche stringers in lowest bed becoming more numerous and extensive.

	Feet
Soil, silty to sandy, with a few stringers of caliche . . .	$1\frac{1}{2}$
Caliche, as stringers permeating most parts of a bed of fine sand and silt	1
Cobbles, pebbles, sand, and silt in interfingering lenses. Heterogeneous: well cemented in part, a few stringers of caliche. Coarse particles poorly rounded to sub-angular (largely of tuff and limestone	$6\frac{1}{2}$
Total	9

Section 14.- In trench, 1,060 feet N. 60° W. from surface zero. Coordinates: N. 867.98, E. 682.18. Textures of materials differ substantially from those of section 15, only 60 feet away.

Largely silt and sand, with included pebbles about 20 per cent by volume. Poorly consolidated. Within 150 feet, fingers northwestward into cobble- and pebble-gravel	$3\frac{1}{2}$
Largely clay (?) and silt, with little coarser material. Slightly cemented at some places	1
Total	$4\frac{1}{2}$

Section 15.- In trench, 1,000 feet N. 60° W. from surface zero. Coordinates: N. 867.95, E. 682.23.

Silt, with some sand and pebbles	2
Caliche, light buff, compact. Thickness variable but averages	$\frac{1}{2}$
Largely sand, some silt and a few included pebbles and cobbles. Fairly well cemented. A few discontinuous caliche stringers near bottom	3
Total	$5\frac{1}{2}$

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Table A.3 (Cont.)

Representative Sections of the Valley Fill

Section 16.- In trench, 700 feet N. 60° W. from surface zero. Coordinates: N. 867.80, E. 682.49. The three beds of this section retain their identity and vary little in thickness or texture for at least 500 feet along the trench.

	Feet
Silt and sand, with about 25 percent included pebbles (of limestone and tuff). Massive	2
Caliche, light buff, compact. Extends about 900 feet along trench	1
Silt and sand, with some included pebbles and a few cobbles (of tuff and limestone)	2
Total	5

Table A.4

General Texture of Valley Fill

/From sieve analyses made in the field on vertical-channel samples from pit faces and on cuttings from certain bored holes. Locations of pits shown on Plate 2/

No. of pit	Location		Coordinates (thousands of feet)		Depth1/ (feet)	Approximate grain size			
						50-per cent size2/		Included large particles	
	Course from zero point	Distance (feet)	N.	E.		in.	mm.	Average (inches)	Largest (inches)
Pits and bored holes near underground zero									
	N.	85	881.48	681.85	0-4	0.011	0.28	...	...
					4-12	.094	2.4	...	...
					12-20	.032	.82	...	...
					20-30	.028	.72	...	...
128	N.35°E.	11,000	890.40	688.16	0-6	.22	5.7	1/2	2
124	do.	8,000	887.94	686.44	0-5.8	.067	1.7	3/8	1
121	do.	6,000	886.30	685.30	0-6	.087	2.2	1/2	1½
115	do.	4,000	884.67	684.15	0-8.5	.071	1.8	3/8	4
109	do.	3,000	883.85	683.58	0-8.5	.071	1.8	3/8	1½
103	do.	2,000	883.03	683.00	0-8.5	.063	1.6	1/2	1¼

1/ Samples are composites spanning the depth ranges indicated.
2/ Grain size such that half the material is finer and half is coarser.

128. Fanglomerate, with included pebbles and cobbles (which are largely of volcanics and quartzite, but a few are limestone).

124. Pebble gravel and sand with some calcium-carbonate cement (about 80 per cent from volcanics, and 20 per cent from limestone).

121. Upper half is pebble gravel and sand with grains coated by calcium carbonate; lower half is compact pebble-sand fanglomerate or "caliche". (Coarse grains from volcanics and quartzite.)

115. Cobbles to sand with grains coated by calcium carbonate; no caliche. (Coarse grains from volcanics and quartzite.)

109. Pebble gravel and sand (about 80 per cent from volcanics and quartzite and 20 per cent from limestone.)

103. Pebble gravel and sand (largely from volcanics, some grains from limestone and quartzite).

[redacted]

Table A.4 (Cont.)

General Texture of Valley Fill

No. of pit	Location		Coordinates		Depth (feet)	50-per cent size		Included large particles	
	Course from zero point	Distance (feet)	N.	E.		in.	mm.	Average (inches)	Largest (inches)
Pits and holes near underground zero.- Cont.									
126	N.75°E.	9,000	883.72	690.55	0-8.5	0.15	3.8	3/8	6
122	do.	6,000	882.94	687.65	0-5.7	.18	4.5	1/2	8
116	do.	4,000	882.42	685.72	0-8	.13	3.4	...	4
110	do.	3,000	882.17	684.75	0-8	.094	2.4	1/2	3
104	do.	2,000	881.91	683.78	0-8	.19	4.7	1/2	4
	E.	85	881.39	691.94	0-4	.020	0.52	...	...
					4-12	.037	.95	...	...
					12-20	.087	2.2	...	...
					20-30	.036	.92	...	...
105	S.30°E.	2,000	879.66	682.85	0-8.5	.13	3.2	3/8	3

126. Sand and pebble gravel with included cobbles (largely from volcanics and quartzite). One 6-inch layer of caliche about 4 feet below land surface.

122. Sand and pebbles with included cobbles making up about 15 per cent of the whole (largely from volcanics, about 20 per cent from quartzite). About 80 per cent of the material is cemented by calcium carbonate.

116. Similar to material in pit 122, above.

110. Upper half is unconsolidated sand and pebbles with included cobbles (largely from volcanics, some quartzite and limestone); grains coated by calcium carbonate. Lower half is compact sandy caliche containing a few pebbles.

104. Similar to material in pit 110, above.

105. Sand and pebbles with some cobbles (largely from limestone, some from volcanics). Lower 2.5 feet cemented by calcium carbonate.

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Table A.4 (Cont.)

General Texture of Valley Fill

No. of pit	Location		Coordinates		Depth (feet)	50-per cent size		Included large particles	
	Course from zero point	Distance (feet)	N.	E.		in.	mm.	Average (inches)	Largest (inches)
Pits and holes near underground zero.- Cont.									
	S.	85	381.30	681.85	0-4	0.016	0.40	...	...
					4-12	.017	.42	...	...
					12-20	.022	.55	...	...
					20-30	.033	.83	...	...
3.16A	S.52°W.	750	880.93	681.26	0-2	.011	.27	3/8	½
					2-5	.22	5.5	...	...
					5.0- 7.8	.019	.48	3/8	1
					7.8-10.8	.25	6.4	1/2	1½
106	S.60°W.	2,000	880.39	680.12	0-8	.021	.53	3/8	6
	W.	85	881.39	681.77	0-4	.012	.30	...	...
					4-12	.031	.78	...	...
					12-20	.033	.85	...	...
					20-30	.038	.97	...	...
119	N.45°W.	6,000	885.63	677.61	0-6	.009	.24	3/8	2½

3.16-A. Sand and pebble gravel with some cobbles (from volcanics and limestone in about equal portions). Unconsolidated in upper 2 feet; discontinuous calcium-carbonate cement from 2 to 7.8 feet.

106. Upper 3 feet largely silt. Lower 8 feet is sand and pebble gravel with some cobbles (largely from volcanics, some from quartzite and limestone.) Partly cemented.

119. Sand, grit, and pebble gravel with a few included cobbles (predominantly from volcanics). Many grains coated with calcium carbonate.

[redacted]

Table A.4 (Cont.)

General Texture of Valley Fill

No. of pit	Location: Course from zero point	Location: Distance (feet)	Coordinates: N.	Coordinates: E.	Depth (feet)	50-per cent size: in.	50-per cent size: mm.	Included large particles: Average (inches)	Included large particles: Largest (inches)
		Pits and holes near underground zero.- Cont.							
113	N.45°W.	4,000	884.22	679.03	0-8	0.029	0.74	1/2	2
107	do.	3,000	883.51	679.73	0-8	.011	.29	3/8	1½
		Pits and bored holes near surface zero							
	N.	85	867.54	683.10	0-4	.11	2.9	...	...
					4-12	.025	.64	...	...
					12-20	.036	.91	...	...
					20-30	.020	.52	...	...
23	N.10°E.	8,000	875.33	683.39	0-6	.39	10	1/2	4
20	do.	6,000	873.36	684.14	0-6	.20	5.1	...	3
14	do.	4,000	871.39	683.79	0-8	.14	3.5	1/2	1
8	do.	3,000	870.41	683.62	0-7	.28	7.1	1/2	2½
2	do.	2,000	869.42	683.45	0-7	.079	2.0	3/8	1½

113. Upper 4 feet is largely silt and sand; lower 4 feet is silt, sand and pebble gravel (nearly all from volcanics). Calcium-carbonate coating on grains but no caliche layers.

107. Upper 6 feet is largely silt and sand; lower 2 feet cemented with calcium carbonate (predominantly from volcanics).

23. Largely caliche with inclusions (of limestone) commonly of pebble or cobble size, and very little of sand size.

20. Similar to No. 23, above. Upper 1 foot is leached and largely sand.

14. Largely caliche, sandy, with pebble-size inclusions (about 40 per cent from limestone).

8. Similar to No. 14, above. (About half of inclusions are from limestone.)

2. Similar to No. 14, above. (Inclusions largely of limestone but include some of volcanic rock.)

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Table A.4 (Cont.)

General Texture of Valley Fill

No. of pit	Location		Coordinates		Depth (feet)	50-per cent size		Included large particles	
	Course from zero point	Distance (feet)	N.	E.		in.	mm.	Average (inches)	Largest (inches)
		Pits and bored holes near surface zero.— Cont.							
22	N.90°E.	6,000	867.45	689.10	0–6	0.36	9.1	1	12
10	do.	3,000	867.45	686.10	0–8.5	.19	4.7	3/4	4
	E.	85	867.45	683.18	0–4	.026	.66	...	...
					4–12	.027	.69	...	...
					12–20	.051	1.3	...	...
					20–30	.029	.73	...	...
17	S.15°E.	6,000	861.66	684.65	0–8	.12	3.0	1/2	10
	S.	85	867.37	683.10	0–4	.038	.97	...	...
					4–12	.029	.74	...	...
					12–20	.036	.91	...	...
					20–30	.036	.97	...	...
	W.	85	867.45	683.02	0–4	.011	.29	...	...
					4–12	.033	.85	...	...
					12–20	.030	.76	...	...
					20–30	.036	.91	...	...

22. Coarse sand and pebble gravel with included cobbles and boulders (largely from volcanics). One layer of compact caliche from 3 to 4 feet; otherwise, material is incoherent.

10. Largely pebble gravel with included cobbles (of limestone). Upper 3 feet incoherent. Lower 5½ feet discontinuously cemented by calcium carbonate. Two layers of compact caliche 3 and 6 feet, respectively, below land surface.

17. Upper 5 feet is largely pebble- and cobble-size gravel with included boulders (commonly of siliceous limestone, but some of volcanic rocks). Lower 3 feet is largely caliche with pebble-size inclusions.

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PROJECT 1(8)a

Table A.5

Field Density of Valley Fill

No. on Plate 3	Course from zero point	Distance (feet)	Coordinates 1/ N.	Coordinates 1/ E.	Depth 2/ (feet)	Density 3/
	Determinations near underground zero					
1	N.45°E.	295	881.60	682.06	0.5	1.30
2	N.80°E.	250	881.43	682.10	9.0	1.76
3	S.45°E.	900	880.75	682.49	9.9	1.69
4	S.42°E.	260	881.20	682.03	13.9	1.71
5	S. 5°W.	240	881.15	681.83	.5	1.70
6	S.31°W.	355	881.09	681.67	10.0	1.50
7	S.42°W.	1,000	880.65	681.20	15.8	1.76
8	S.62°W.	150	881.32	681.72	10.0	1.56
9	S.73°W.	310	881.30	681.56	4.0	1.48
10	S.79°W.	155	881.36	681.70	7.0	1.63
11	N.80°W.	150	881.42	681.70	2.0	1.59
12	N.20°W.	360	881.72	681.72	.5	1.45
13	N. 8°W.	175	881.56	681.83	9.5	1.76
14	do.	125	881.51	681.84	6.0	1.42
			Maximum			1.76
			Average			1.594
			Minimum			1.30

1/ In thousands of feet.
2/ To mid-point of sample, which was from 0.5 to 1.0 foot long.
3/ Under field conditions, including retained moisture.

PROJECT 1(8)a

Table A.5 (Cont.)

Field Density of Valley Fill

No.	Course	Distance	N.	E.	Depth	Density
	Determinations near surface zero					
15	...	(a)	867.45	683.10	16.0	1.69
16	N.70°E.	30	867.46	683.13	4.0	1.81
17	N.74°E.	200	867.51	683.29	.5	1.45
18	S.40°E.	325	867.20	683.31	2.2	1.79
19	S.30°E.	195	867.28	683.19	.5	1.37
20	S. 5°E.	250	867.20	683.12	.5	1.50
21	S.84°W.	85	867.43	683.02	10.0	1.54
			Maximum			1.81
			Average			1.593
			Minimum			1.37
	Determinations on caliche layers					
22 b/	...	...	874.42	682.48	15-25	2.00
23 c/	...	...	867.45	683.10	15	2.05

a/ Pit at zero point.
b/ Six hand specimens from "HE" crater, at point "A"; value of density is the average.
c/ Three hand specimens from pit at surface zero; value of density is the average.

PROJECT 1(8)a

Table A.6

Driller's Logs of Exploratory Wells

[Drilled May 28 to July 27, 1951, by S. R. McKinney & Son of Las Vegas, Nevada. Locations shown on Plate 2. Geologist's identification of predominant rock types and other interpretations given in parentheses]

Material	Thickness (feet)	Depth (feet)
Well 1.- Coordinates: N. 867.56, E. 683.02; about 135 feet northwest of surface zero. Casing pulled after the seismic survey.		
Sand and gravel, silty, lightly cemented . . .	22	22
Sand and gravel, lightly cemented	253	275
Boulders (limestone)	3	278
Gravel, lightly cemented	22	300
Sand and gravel, lightly cemented	35	335
Sand, silty, lightly cemented	5	340
Sand, loose	25	365
Boulders	4	369
Sand	1	370
Gravel, cemented, medium hard	35	405
Gravel, cemented	44	449
Sand, cemented	53	502
Well 2.- Coordinates: N. 876.59, E. 673.39; about 13,300 feet northwest of surface zero. Casing pulled after the seismic survey. (At least upper part of hole is in bouldery fanglomerate.)		
"Surface"	2	2
Gravel and boulders, cemented	16	18
Gravel, cemented	97	115
Gravel and boulders, cemented	22	137
Boulders, cemented	40	177

Table A.6 (Cont.)

Driller's Logs of Exploratory Wells

Well 3.- Coordinates: N. 882.35, E. 683.52; about 1,900 feet east-northeast of underground zero. Casing pulled after the seismic survey.

Material	Thickness (feet)	Depth (feet)
Sand and gravel (limestone)	20	20
Sand and gravel, lightly cemented (coarse zones at 35 and 55 feet; limestone to about 60 feet, rhyolite and tuff below) . .	65	85
Gravel, lightly cemented (rhyolite and tuff to about 200 feet, tuff from 200 to 325 feet, and limestone from 325 to 345 feet)	271	356
Sand and gravel, cemented (rhyolite and tuff about to 400 feet, tuff below)	89	445
Sand and gravel, cemented, soft (tuff)	57	502

Well 4.- Coordinates: N. 881.38, E. 681.75; about 90 feet nearly west from underground zero. Eight-inch casing left in hole about from 200 to 382 feet below land surface.

Material	Thickness (feet)	Depth (feet)
Sand and gravel (limestone; coarse zone at bottom)	76	76
Gravel, cemented (tuff)	52	128
Boulders (rhyolite ?)	2	130
Sand and gravel (tuff)	5	135
Gravel, cemented (tuff)	25	160
Sand and gravel (tuff)	15	175
Sand and gravel, cemented (coarse zone at top; limestone)	35	210
Sand and gravel (tuff)	30	240
Gravel, cemented (coarse zone at 365 feet; largely limestone but considerable tuff at 275 and below 380 feet)	175	415
Sand and gravel, cemented (limestone and tuff)	50	465
Sand, cemented (tuff and limestone)	35	500

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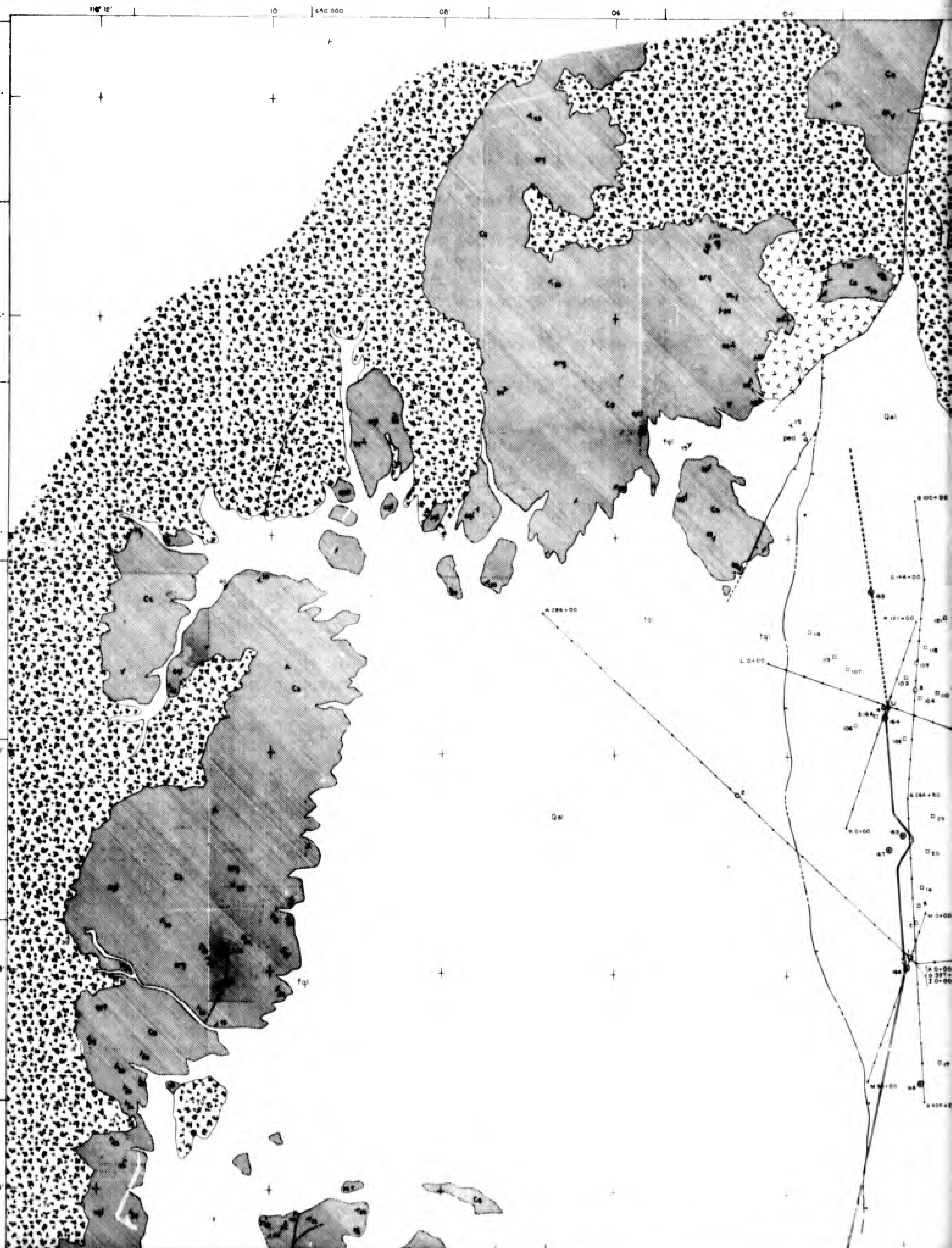

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EXPL

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not shown)

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Sedimen
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locally interstra
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not established

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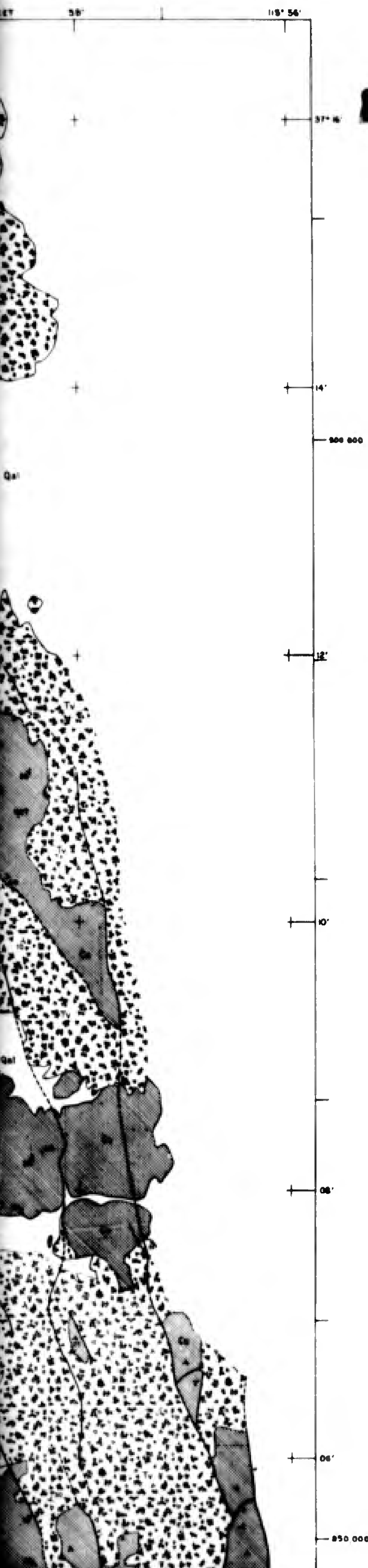
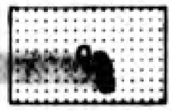
PLATE 2



EXPLANATION

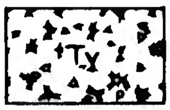


Playa deposits

(whitish silt and clay)

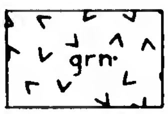
Valley fill

(In central part of valley: chiefly sand, silt, pebble- or cobble-gravel, and some clay (?); commonly unassorted but some tongues and lenses of fairly clean grit and gravel; stringers and lenses of caliche. Along valley margins: extremely heterogeneous, including boulder-size rock fragments and some rock streams; commonly a veneer on rock pediments (ped)*; at some places a coarse, dense fanglomerate* (fgl) *with carbonate matrix)*



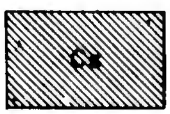
Volcanic rocks, of Tertiary age

(largely tuff with intercalated and capping layers of rhyolite or dacite (and basalt ?); tuff in part massive and thick-bedded, in part thin-bedded, and at some places compact and glassy (welded); associated dikes and plugs not shown)



Granite or granodiorite

(coarse-grained to porphyritic)

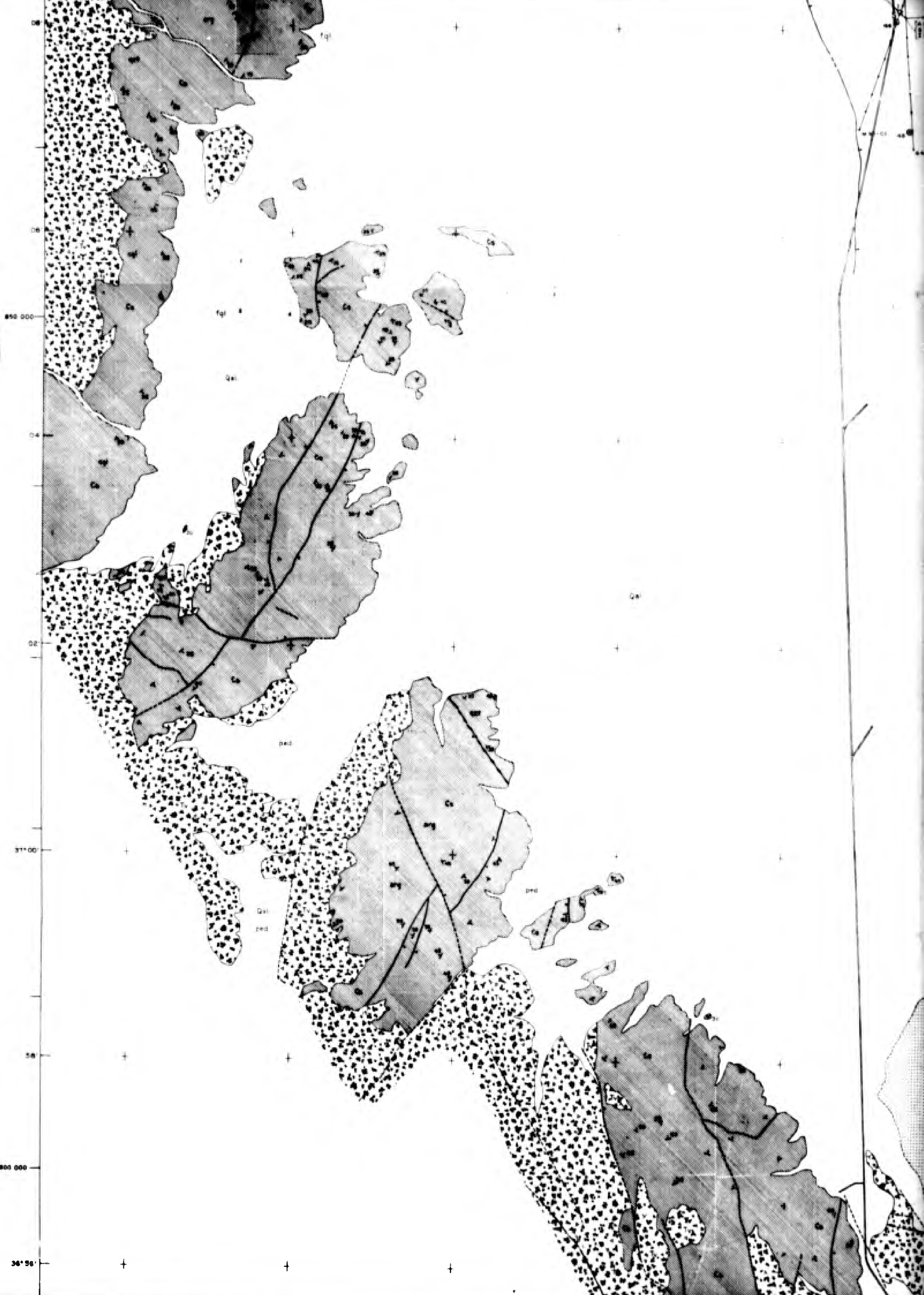


Sedimentary rocks, of Carboniferous (and pre-Carboniferous ?) age

(principally dense limestone, pearl- to dark-gray, generally thick- but in part thin-bedded with shale partings, some cherty beds; underlain by and locally interstratified with quartzite (qzt) *conglomerate* (cgl)*, shale* (sh)*, and argillite* (arg)*; stratigraphic succession not established in detail)*

Dip of strata

(numerals indicate amount of dip,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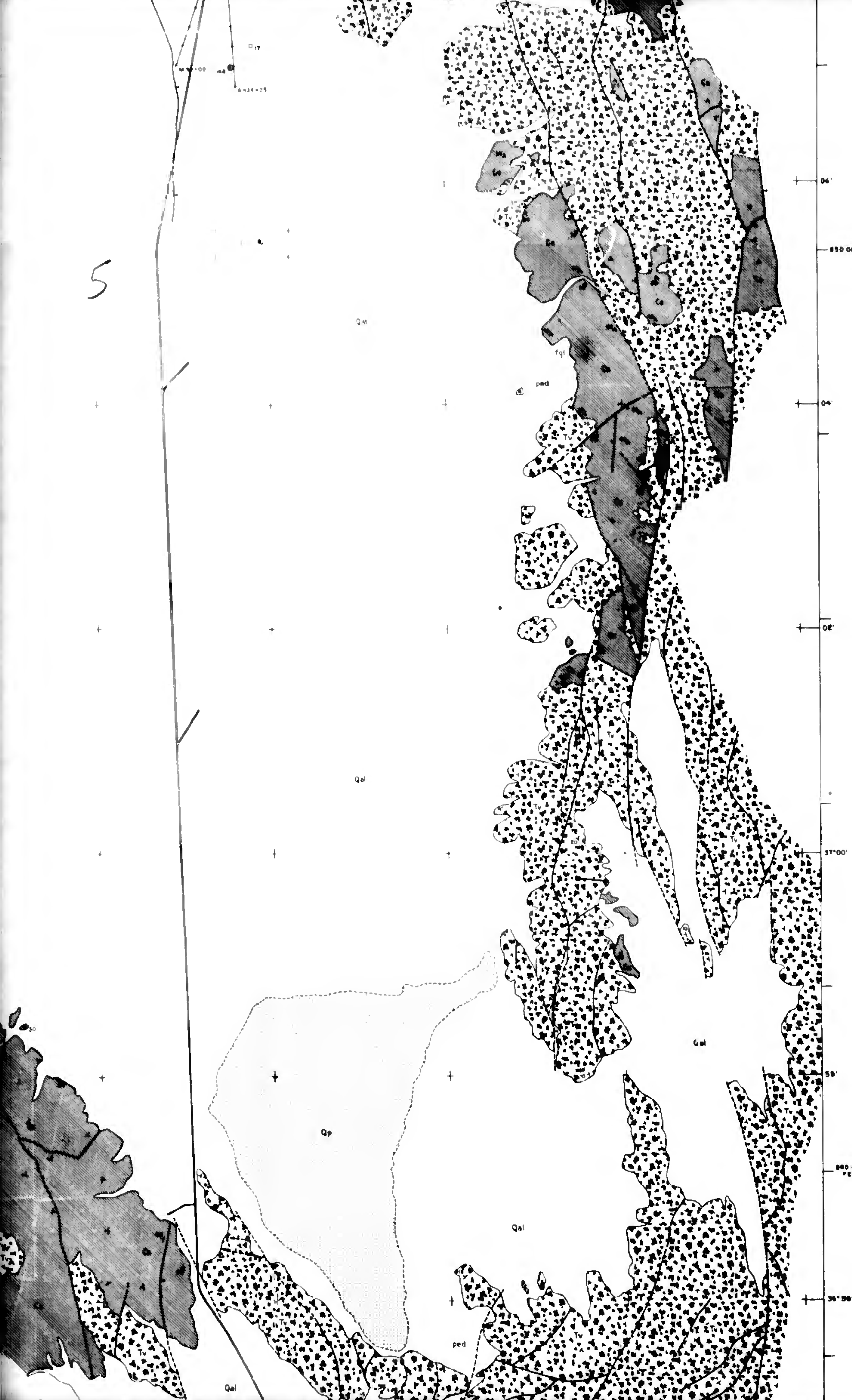

pre-Carbonifero

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to dark-gray, generall
part thin-bedded with
some cherty beds; und
locally interstratified
conglomerate (cgl), sha
argillite (arg); stratig
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Dip of str
(numerals indicate a
in degrees, where

Trace and downth
(solid line indicates a
fault; dashed line, a c
thetical fault; faults w
probably determine val
at many places)

×
Reference

Pit

Well

Thermistor
(numbers refer to
in text and

Seismic-refra
and shot p
(after United Geoph
identifies line and num
station distances)

to dark-gray, generally thick- but in part thin-bedded with shale partings, some cherty beds; underlain by and locally interstratified with quartzite (qzt) *conglomerate* (cgl), *shale* (sh), *and argillite* (arg); *stratigraphic succession not established in detail)*

6

25

Dip of strata
(numerals indicate amount of dip, in degrees, where measured)

Trace and downthrow of fault
(solid line indicates a known or probable fault; dashed line, a concealed or hypothetical fault; faults which are not shown probably determine valley-plain margins at many places)

×
Reference point

128
Pit

3
Well

169
Thermistor station
(numbers refer to descriptions in text and tables)

G 100+00
Seismic-refraction line and shot points
(after United Geophysical Co.; letter identifies line and numerals indicate station distances)

Base from uncontrolled photo mosaic by 5th Reconnaissance Technical Squadron, Strategic Air Command, with local adjustments by A M Piper, U S Geological Survey

RECONNAISSANCE GEOLOGIC MAP OF YUCCA
SHOWING LOCATION OF EXPLORATORY WORKS

Seismic-ref
and sho
*(after United Ge
identifies line and
station distances)*

EOLOGIC MAP OF YUCCA VALLEY
ION OF EXPLORATORY WORKS

2 3 4 5 MILES
10,000 20,000 30,000 FEET
1 2 3 4 5 KILOMETERS

Geology by R. F. Brown, D. E. Hibbard,
M. S. Johnson, A. M. Piper, and
J. L. Poole in 1951

[redacted]

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Geology by R. F. Brown, D. E. Hibbard,
M. S. Johnson, A. M. Piper, and
J. L. Poole in 1951

169

Thermistor station
(numbers refer to descriptions in text and tables)

G 100+00

Seismic-refraction line and shot points
(after United Geophysical Co.; letter identifies line and numerals indicate station distances)

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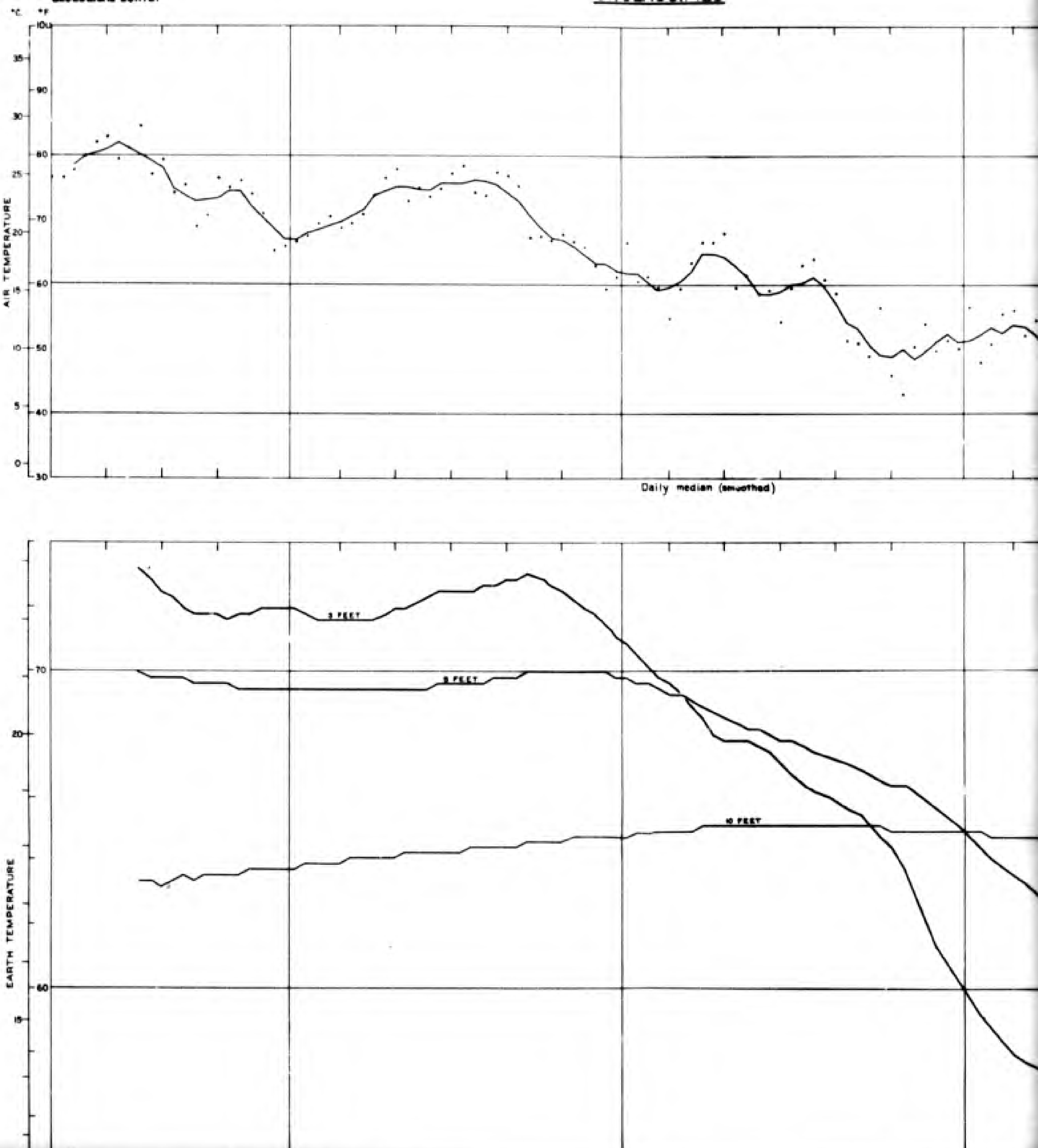

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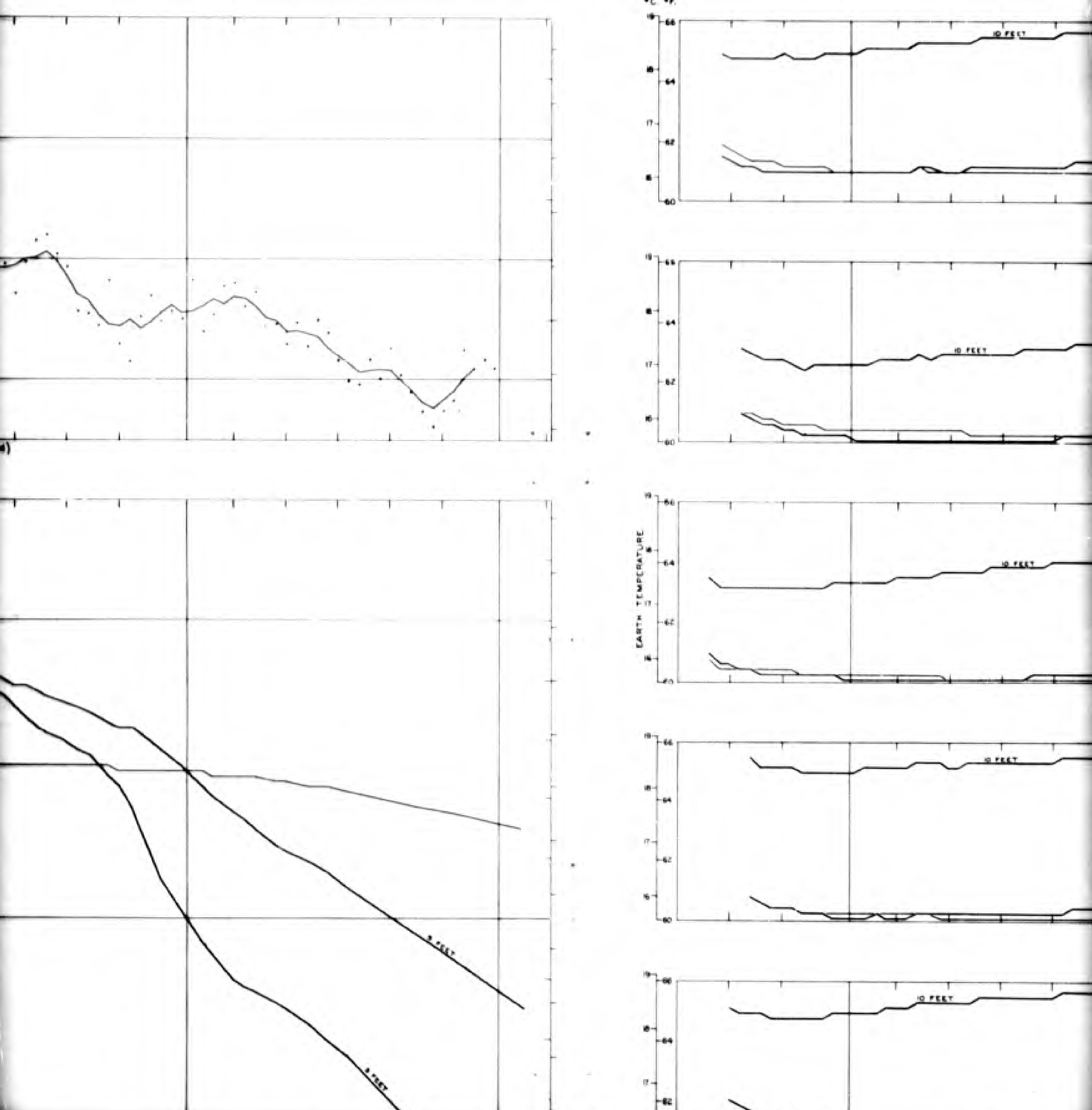

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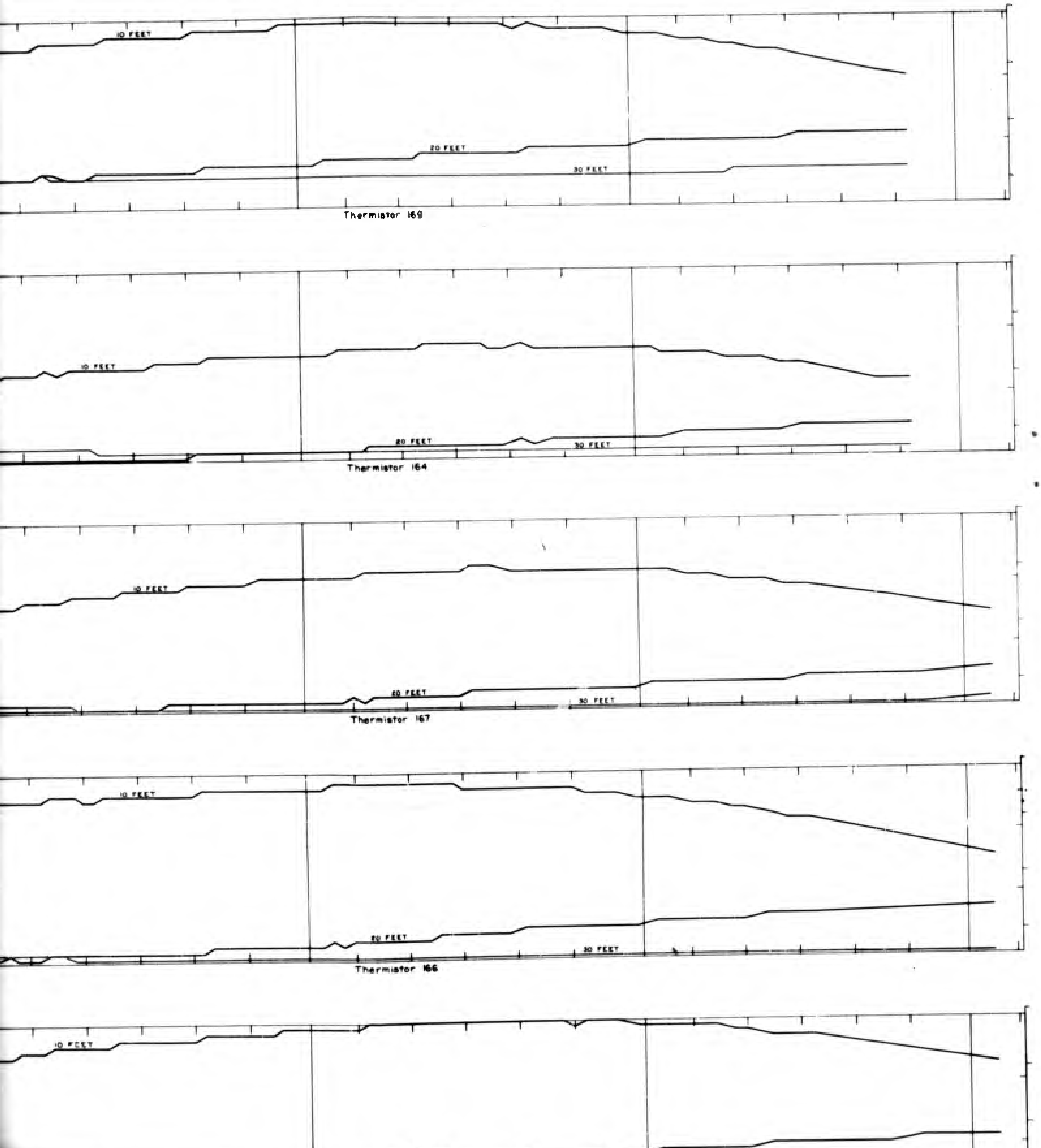
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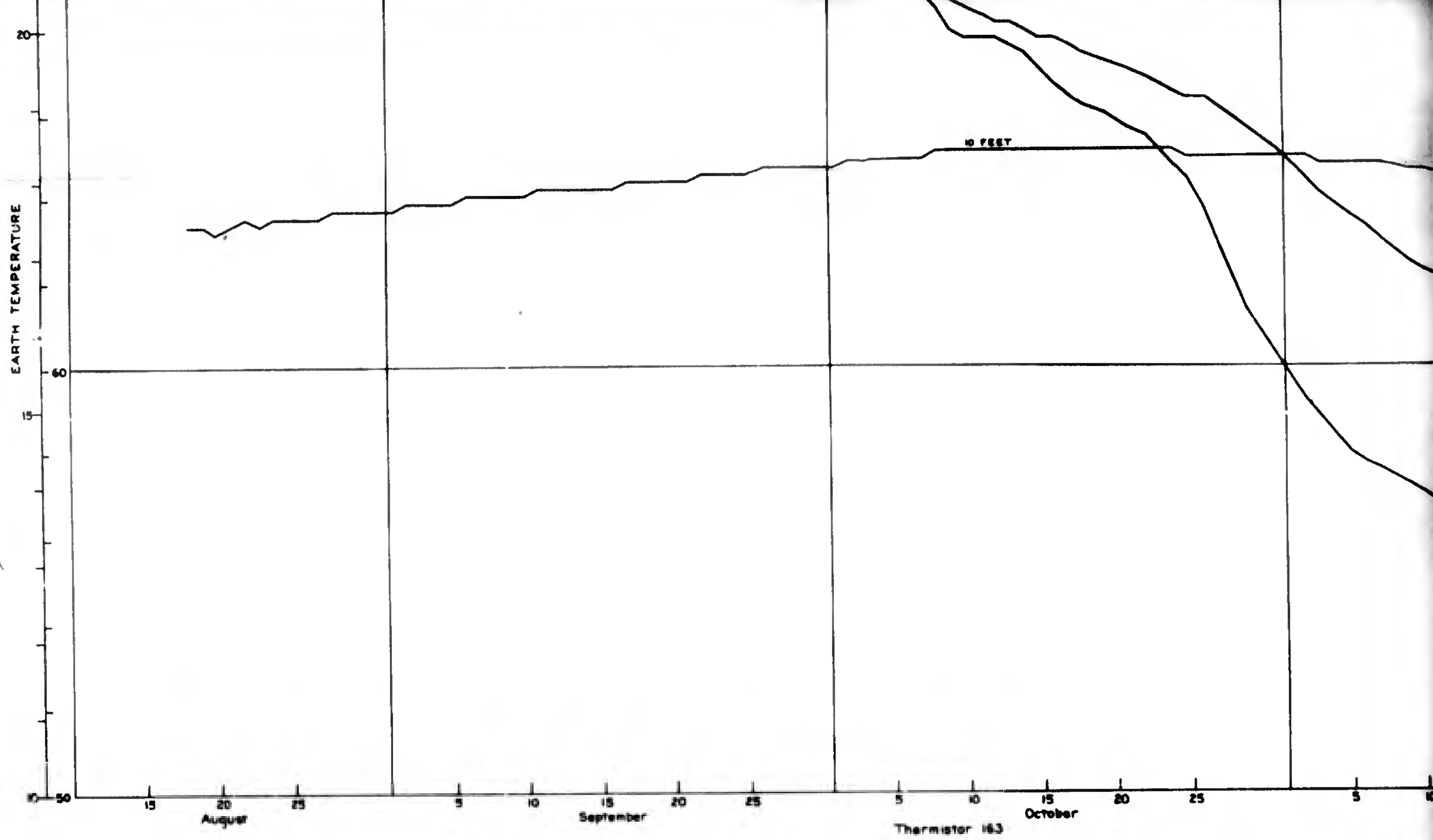

EARTH TEMPERATURE
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20
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October
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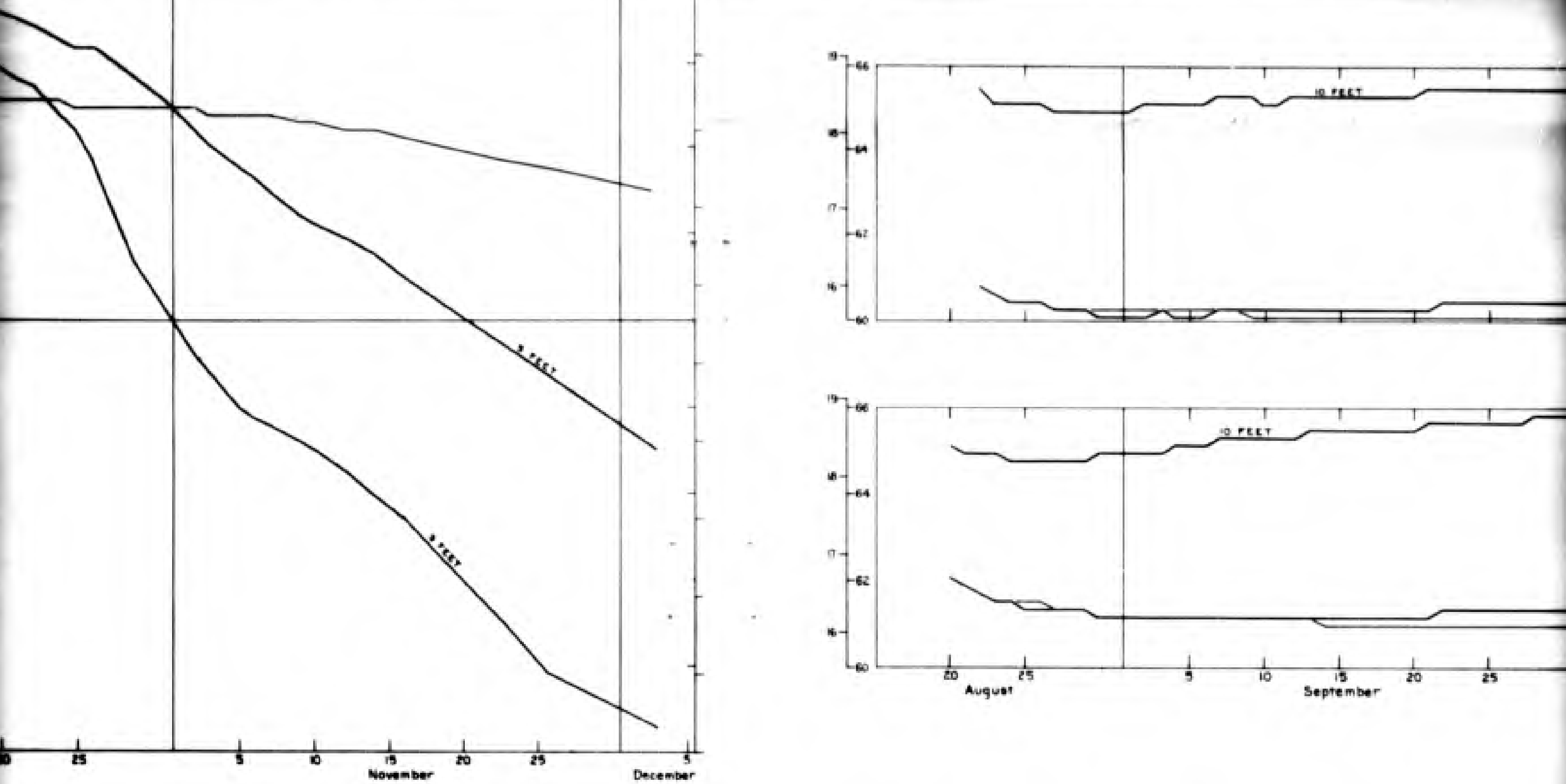
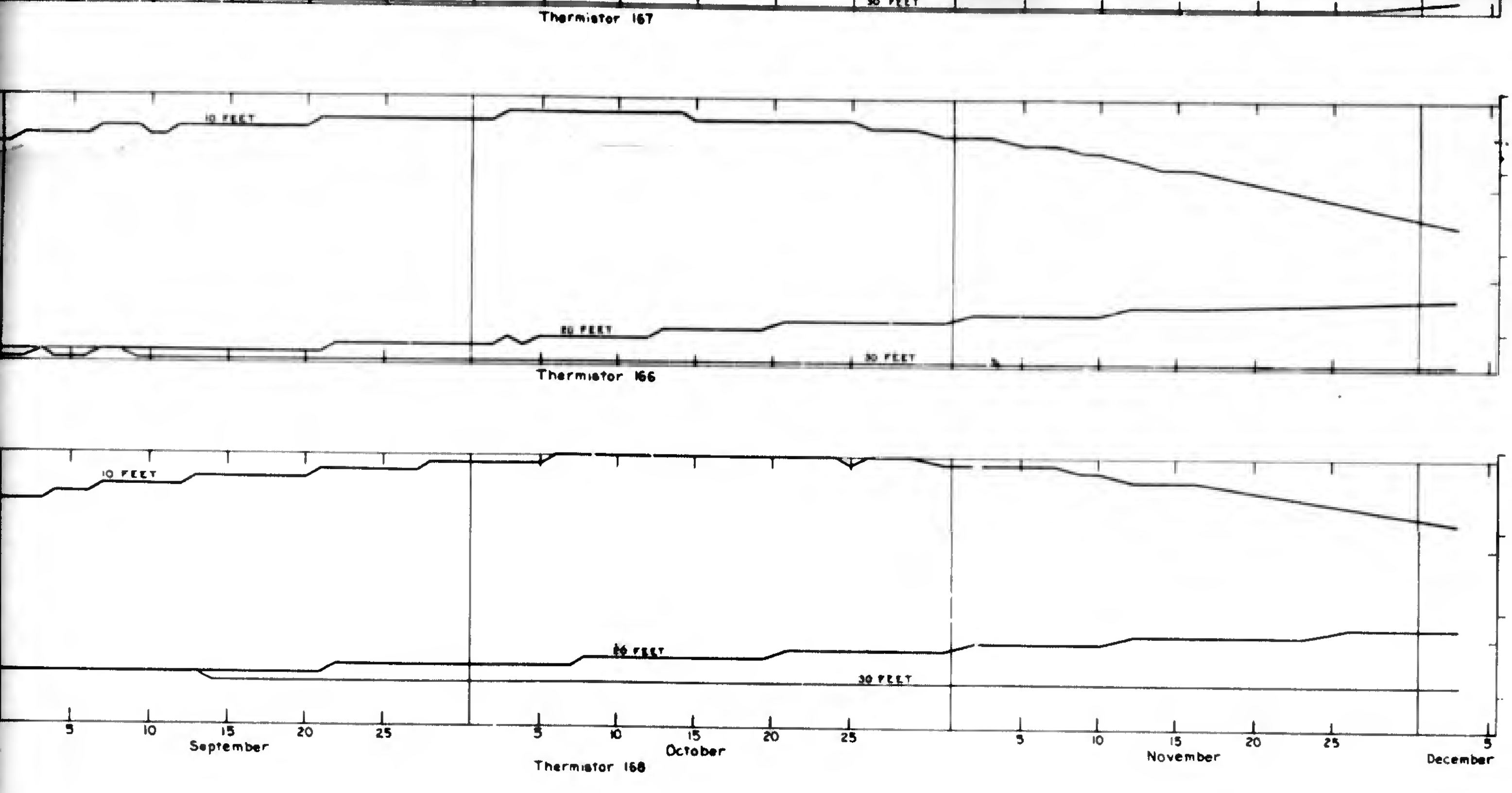
10
Thermistor 163

AIR



AIR AND EARTH TEMPERATURES, 10 AUGUST TO 3 DECEMBER 1951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December
Thermistor 168

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