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UNITED STATES
DEPARTMENT OF THE INTERIOR
Geological Survey
Ground Water Branch
503 Federal Building
Salt Lake City 1, Utah
August 24, 1954

Col. Donald D. Bode', Commanding Officer
Dugway Proving Ground
Tooele, Utah

Dear Col. Bode':

Transmitted herewith are two copies of a typewritten report (marked Copy No. 3 and Copy No. 4, respectively) entitled "Geologic reconnaissance of the eastern part of Dugway Proving Ground and adjacent areas, Tooele County, Utah, with reference to ground water" by Lorenzo C. Demars and others "With a section on geophysics" by Coyd B. Yost, Jr. This report contains the results of the geologic and geophysical investigations of the eastern part of Dugway Proving Ground and adjacent areas, that were made in 1953 by the Ground Water Branch of the U. S. Geological Survey in response to a request from the Chemical Corps, U. S. Army. The report is subject to revision because it has not been reviewed and approved in Washington.

This report has been submitted to our Washington office with a request for review and for approval for release to the open file. Duplication of the report cannot be undertaken until the report has been reviewed and approved in Washington.

Very truly yours,

/s/Herbert A. Waite
Herbert A. Waite
District Geologist

cc: Chief, Ground Water Branch
L. C. Halpenny
Coyd B. Yost, Jr.
Lorenzo C. Demars

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C O P Y

Copy No. 3 on file in Post Engineer Office.
Copy No. 4 on file in Mail and Records.

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GEOLOGIC RECONNAISSANCE OF THE EASTERN PART OF DUGWAY PROVING GROUND AND ADJACENT AREAS, TOOELE COUNTY, UTAH, WITH REFERENCE TO GROUND WATER

By Lorenzo C. Dunn and others

WITH A SECTION ON GEOPHYSICS

By Coyd B. Yost, Jr.

Prepared in cooperation with
The United States Army Chemical Corps

GROUND WATER BRANCH
U. S. Geological Survey
Salt Lake City, Utah

July 1954.

FOREWORD

Before the text and illustrations comprising the present report had been put in final form, the author, Mr. Demars, was transferred to the Geologic Division. Final preparation of the report, therefore, fell to other members of the staff of the Utah Ground Water District, who were less familiar with the Dugway region. The inevitable result was an inability to provide certain points of detailed information that would have been desirable. The principal features of the geology and the conclusions regarding the occurrence of ground water were described by Mr. Demars prior to his transfer. It is believed that the information desired by the Army Chemical Corps has been presented in this report.

Herbert A. Waite
District Geologist

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GEOLOGIC RECONNAISSANCE OF THE EASTERN PART OF DUGWAY PROVING GROUND, AND ADJACENT AREAS, TOOELE COUNTY, UTAH, WITH REFERENCE TO GROUND WATER

By Lorenzo C. Demars and others

ABSTRACT

The Dugway Proving Ground is an Army Chemical Corps testing center located in the desert of western Utah about 75 miles airline southwest of Salt Lake City. The reservation includes parts of Dugway Valley, the Great Salt Lake Desert, Skull Valley, and several mountainous areas. The Proving Ground comprises an area about 700 square miles. The area mapped is bordered on the east by the Stansbury, Onaqui, and Sheep Rock Mountains, and on the west by Dugway Valley which opens to the northwest into the Great Salt Lake Desert. Prominent features of the landscape include sand dunes and shorelines which mark still-stands of various stages of Lake Bonneville.

Sedimentary rocks exposed include a thick (24,000 ft.) section of Paleozoic strata ranging in age from Cambrian to Pennsylvanian. Igneous rocks include granitic stocks and other intrusive masses of probable Upper Cretaceous age. Lavas occupy part of the area and were extruded at various times from late Mesozoic to Recent (?). These rocks are generally too low in permeability to serve as ground-water reservoirs, although in places some of the limestones and volcanic rocks may be sufficiently permeable to accept recharge and conduct it to lower-lying gravels. The aquifers, or permeable deposits of sand and gravel in the valley fill, contain

nearly all of the recoverable ground water of the area. Where these beds of gravel and sand underlie lake clays in the lower parts of the valley, the water in them is commonly confined under artesian pressure which may be sufficient to cause wells to flow.

Granite is the most widespread intrusive igneous rock found in the area. Extrusive rocks consist of a series of rhyolites and andesites of early Tertiary (?) age, and locally of basalt thought to have been formed during the last stage of volcanic activity in the area.

Folding in the area was associated with the Laramide orogeny, hence is believed to be late Cretaceous and early Tertiary in age. Faulting is of two types: tear faults of Laramide age, and Basin-Range faults of middle and late Cenozoic age. Basin-Range faults are of several types north-trending normal block faults, en echelon faults, and step or distributive faults.

The use of resistivity equipment in geophysical investigations at Dugway Proving Ground proved successful in determining the depth of alluvial fill in Skull Valley. In the center of the valley southeast of Easy Area, the alluvium is more than 1,500 feet deep. Southwest of Fox Area, the fill is more than 500 feet deep.

Precipitation is the ultimate source of all ground water in the Dugway area. Hence its distribution is of great importance. Water may reach the aquifers from the mountains either as underflow down dry canyons or as ephemeral stream flow in the canyons, but in both ways the water is recharged into the permeable part of the valley fill within relatively short distances outward from the mouths of the canyons. Another source of ground water is recharge from precipitation that falls directly upon permeable parts of the valley fill. The chemical quality of ground water in the Dugway reservation is poor, but is adequate for domestic purposes. Water for industrial use requires treatment,

Prior to 1942 when the Proving Ground was established, few wells had been drilled in the region and little was known of the geology of the area with respect to the occurrence of ground water. Drilling of wells by the Army has yielded some information. The present investigation has capitalized insofar as possible on those data, and has supplemented them with geologic mapping and with geophysical probes. In light of present information, it appears that additional supplies of water of chemical quality that will meet minimum Public Health Service standards can be obtained by drilling additional wells. Because of rapid lateral variations in compositions and texture of the valley alluvium, a program of test drilling, prior to location of production-well sites, is suggested.

INTRODUCTION

Purpose and scope of the investigation

Net decline in water levels of wells in the Dugway Proving Ground, Chemical Corps, U. S. Army, Tooele County, Utah, during the period 1951-53 and the likelihood of increasing demands for water during 1954 resulted in a request from the Chemical Corps that the U. S. Geological Survey make an investigation of ground-water resources of the area. Recommendations for a four-part program were accordingly prepared, and transmitted to the Commanding Officer, Dugway Proving Grounds, July 16, 1953. The recommendations were accepted in principal and parts 1 and 2 of the program activated. The results obtained from parts 1 and 2 of the program are described in the present report. The entire program proposed is in brief as follows:

1. (a) Analysis of existing records of wells.
   (b) Geologic mapping.
   (c) Determination of chemical quality of ground waters in the area.

2. Geophysical probing (electrical resistivity method) to delimit hardrock boundaries at depth and to forecast nature of valley fills.

3. Drilling of test wells at sites considered most favorable on the basis of information obtained from phases 1 and 2.

4. (a) Extension of ground-water studies into adjacent areas.
   (b) Drilling of supply wells.

Previous investigations

The most important publication concerning the geology of the Dugway area is that of Gilbert (1890) on the Pleistocene history of the region that was once covered by Lake Bonneville. No detailed studies have been made of the stratigraphy of the Dugway vicinity, however, Gilluly (1932) described the pre-Bonneville stratigraphy of the Stockton and Fairfield Quadrangles. These two quadrangles are situated in the southern part of the Oquirrh Mountains about 35 miles east of the Dugway area. A report entitled "Ground water in the Dugway Proving Ground, Tooele County, Utah" was transmitted to the Commanding Officer in 1951 (Fix, 1951). This report was classified as confidential at the time it was completed, and has not been released to the open file. In March, 1953, a preliminary report on the ground-water resources of Dugway Proving Ground was prepared by Shaw (1953). Other references consulted are referred to throughout the text.

Acknowledgments

The investigation was made under the general direction of A. N. Sayre, Chief, Ground Water Branch, and under the direct supervision of H. A. Waite,

District Geologist. Ben E. Lofgren and W. Baird Nelson assisted the writer in solution of various field problems. R. G. Butler and J. H. Feth provided much assistance in preparation of the illustrations and the text respectively. H. E. Thomas was generous with advice and suggestions throughout the study. The Arizona district, Ground Water Branch, U. S. Geological Survey, cooperated in making available the geophysical equipment and a geophysicist.

GEOGRAPHY

Location and general features

Dugway Proving Ground is situated in the desert of western Utah about 75 miles airline southwest of Salt Lake City (fig. 1). The reservation includes parts of Dugway Valley, the Great Salt Lake Desert, Skull Valley, and several mountainous areas. The Proving Ground comprises an area of about 700 square miles. A north-south paved road connects U. S. Highway 40 and the main entrance to Dugway Proving Ground. A second paved road extends northeastward from the entrance and continues over Johnson Pass, to Tooele. The reservation is traversed by a north-east-southwest paved road that connects Easy, Fox, and Dog areas. A secondary road extends southeast from the main entrance of Dugway Proving Ground and connects with a road to Lookout Pass which continues eastward and connects with State Highway 36 at Vernon.

The landscape of Dugway Proving Ground is characterized by the presence of former shorelines of Pleistocene Lake Bonneville that have been carved on the flanks of the surrounding mountains. Sand-dune areas are prominent in the reservation.

The site now occupied by Dugway Proving Ground was selected by the Army largely because of the isolation and very slight use made of the area prior to World War II. The dearth of water is clearly indicated by the sparse desert vegetation, the extensive salt and alkali flats, and the absence of perennial streams. On rare occasions rainstorms of unusual magnitude result in ephemeral stream flow. Several small springs are known in the reservation; three of them issue along the north flank of Granite Peak, and two are situated on the west flank of the Cedar Range.

Topography

The area mapped is located in the Great Basin subdivision of the Basin and Range physiographic province. It is composed of isolated and dissected block mountains that are separated by aggraded desert plains. The area is bordered on the east by a north-trending chain of mountains. From north to south along this roughly linear uplift, are the Stansbury, Onaqui, and Sheep Rock Mountains. Johnson's Pass divides the Stansbury and Onaqui Mountains, and Lookout Pass separates the Onaqui Mountains from the Sheep Rock Mountains.

Dugway Valley is a broad low area ranging from about 4,275 to more than 5,000 feet above sea level and is largely enclosed by mountains. A number of small hills protruding from the valley fill separate the drainage into two parts. The valley opens northwestward into the Great Salt Lake Desert, whose flat floor extends to the middle of the reservation. A broad channel, of an ancient river bed, was referred to by Gilbert (1890, pp. 181-184) as the "Old River Bed". It is about 45 miles long, and connects the heart of the Sevier Desert with the edge of the Great Salt Lake Desert. The "Old River Bed" was cut through a low pass between the Simpson and McDowell Mountains and drainage was from southeast to northwest. The channel was opened at a time, during the final desiccation of Lake Bonneville, when the level of the water in the main body fell below the low point of the pass. The remnant of Lake Bonneville that occupied a part of the Sevier Desert drained northwestward through the "Old River Bed" into the main body of the vanishing lake in what is now Great Salt Lake Desert. The continuance of desiccation finally lowered Sevier Lake below the level of outflow and dried the river bed. Much of the entire area studied was formerly covered by the waters of Lake Bonneville, and the shorelines of the lake are now prominent features of the landscape. Easy Area lies at the west edge of Skull Valley, separated from Dugway Valley by low mountains.

The mountains in the reservation are generally quite low, and some are partly buried by the accumulation of rock detritus on their flanks. Some, however, are relatively high, notably Granite Peak which is about 9,800 feet above sea level or 5,400 feet above the valley floor.

Climate

The climate is arid, the precipitation averaging about 8 inches. The rainfall is somewhat greater on the highest mountains. The precipitation is fairly well distributed throughout the year. Records of precipitation are available from 15 cooperative U. S. Weather Bureau stations located in Tooele County, and from one U. S. Army station located in Dog Area in the Proving Ground. No records of streamflow or runoff are available. In Skull Valley the highest precipitation, about 11.30 inches, is recorded at Iosepa. The mean annual precipitation in Dugway Valley is 8.63 inches, and in Skull Valley 8.97 inches. The highest precipitation in Dugway Valley occurs in the Government Creek watershed where the mean annual total is 12.88 inches. Winds and dust storms are characteristic of the area, and erosion occurs on even minor slopes with only moderately heavy rainfall.

Development

Prior to the establishment of the military base in 1942, the land was used as a range for sheep and cattle. When the Proving Ground was established, it was obvious that the water supply would have to be derived from wells. The lack of human activity in the area in the past then became a detriment. Because there had been very little prospecting for water, little was known of the geologic conditions that determine the availability of water underground, and no topographic or geologic maps of the area were available. It became necessary, therefore, to depend heavily on published geologic reports of nearby regions and to supplement this with information obtained from field reconnaissance, and the few existing well logs.

A stock well was drilled in what is now Dog Area in March 1935 by the U. S. Grazing Service. Use of the area as a Proving Ground began early in the second World War. In 1942 a few wells were drilled. Dog Area at the time housed the main garrison and administrative offices. Two wells drilled in 1942 in that area, provided an adequate supply of water for domestic and industrial purposes. Other wells were drilled in several parts of the reservation to provide water for specific projects. Some were adequate for their purposes, some were inadequate, and some yielded water too highly mineralized for the intended uses. The drilling of these wells provided valuable information concerning the ground-water reservoirs upon which the Proving Ground depends. The average daily water consumption at Dugway Proving Ground during the period from 1942-1953 inclusive is shown in the following table.

Table 1. Average daily use of water at Dugway Proving Ground during the period 1942-1953 inclusive. 1/

Year	Average daily water consumption, in gallons
1942	11,000
1943	40,000
1944	130,000
1945	177,000
1946	-----
1947	-----
1948	-----
1949	-----
1950	125,000
1951	485,000
1952	600,000
1953	900,000

1/ Based on water-consumption records furnished by the Post Engineer, Dugway Proving Ground.

No record is available for the period from 1946-49. Production during this period was small because of a reduction in activity at the Proving Ground after the end of World War II. In 1950 Dugway Proving Ground was reactivated, and in May of that year the construction of Easy Area began. The main garrison and administrative offices are now housed in Easy Area. The water supply for Easy and Fox areas is obtained from 2 wells drilled in Easy Area in 1950. An unused stock well drilled in September 1942 and situated about 1,200 feet from the present supply wells, has been equipped with a recording gage for the purpose of obtaining a continuous record of changes in water level.

Four hundred homes were built in 1950 in connection with the construction of the Wherry Housing Unit. Many acres of lawn and rye-grass were planted for the purpose of anchoring the unprotected soil cover as well as for beautification of the grounds. Prior to 1950 there had been no appreciable lowering of the water level as a result of pumping from the two supply wells. Since then, however, the possibility of a future water shortage has become evident. During the summer of 1953 the monthly water consumption in the Easy-Fox areas amounted to more than 30,000,000 gallons. The water usage during some individual days amounted to as much as 2,000,000 gallons. All of this water has been obtained from the present 2 supply wells.

An experimental farm situated immediately south of Fox Area is being used to study the types of vegetation that will grow most advantageously in the Dugway Area. The most successful types of grasses, plants, and trees are then planted in the various areas for beautification and as a protective covering for the soil.

GEOLOGY

Stratigraphy

General relations

The Paleozoic stratigraphy of the Dugway area is transitional between that of the Tintic Mining District (Lovering, 1949, pp. 5-9) and that of the Stockton-Fairfield area described by Gilluly (1932). The stratigraphic column of Gilluly (1932, p. 7) has been used in this report because the Stockton-Fairfield area is the nearest area to Dugway that has been covered by a comprehensive geologic investigation, and because the lithology of the formations in the Dugway area conform more closely to those described by Gilluly. To the southeast, in the vicinity of Erickson's Pass on the west flank of the Sheep Rock Mountains, some of the formations recognized by Lovering were found. Just a few miles to the north, these formations are not found, but rather the strata are like those described by Gilluly.

Sedimentary rocks of late Paleozoic age, and of Mesozoic and Tertiary ages have not been surely identified in the Dugway area. A small occurrence of redbeds, partly metamorphosed, that might possibly be of Mesozoic age, is, however, reported. Pleistocene to Recent sediments, largely unconsolidated, constitute the strata most important relative to the occurrence of ground water. The stratigraphy of the Dugway area is summarized in Table 2.

Sedimentary rocks

Paleozoic formations.-- The areal distribution of the Paleozoic formations is shown on Plate 1. The oldest rocks cropping out are quartzite and quartzite conglomerate of Lower Cambrian age. Other Cambrian strata include the Ophir formation, Hartmann limestone, Bowman limestone, and Lynch dolomite. The Devonian Jefferson (?) dolomite, and the Madison limestone, Deseret limestone, Humbug formation, and Great Blue limestone all of Mississippian age, were also recognized. Some rocks perhaps equivalent to the Mississippian - Pennsylvanian Manning Canyon shale, and the Pennsylvanian Oquirrh formation were also found. Although these Paleozoic formations mentioned above were recognized, only the Tintic quartzite was separately mapped. The remainder of the Paleozoic section was mapped as Paleozoic, undifferentiated limestone, and dolomite, with some shale and interbedded quartzite.

Mesozoic (?) strata. -- Ives, (1951, p. 785) reported a series of red beds in the Dugway vicinity that were slightly metamorphosed in places, and tentatively assigned them to the Mesozoic Era (?). He mentioned the presence of ammonite and Inoceramus fragments in the formation. An outcrop of limited extent and of possible Mesozoic age was found by the present writer in a small canyon on the southwest flank of Davis Mountain. No fossils were found that would help to date the strata, and it is only the resemblance in the lithology of this area to known rocks of Mesozoic formations that suggests the Mesozoic (?) age. The occurrence consists of reddish-pink argillite and yellowish-brown, weakly cemented, pebble conglomerate.

Unconsolidated sediments

Pre-Bonneville alluvium. -- The intermontane valleys of the Dugway region have long been the site of accumulation of rock detritus carried down from the mountains by running water. The total thickness of these deposits can only be estimated, as wells in the area have not been drilled to bedrock and the configuration of the bedrock floors of the valleys is unknown. Geophysical probes, discussed in a later section of this report, indicate that in places bedrock occurs variously from 500 to 1,500 feet below land surface. The distinction in such areas, between pre-Bonneville alluvium and sediments deposited when the lake covered the valleys, is not clear. It is probable, however, that from 250 to 1,000 feet of pre-Bonneville sediments underlie parts of the Dugway area.

The pre-Bonneville alluvium is known in outcrop only along the flanks of the mountains where, off some canyons, alluvial fans occur that have been marked by Lake Bonneville shorelines and thus indicate their pre-Bonneville age. Where exposed, the fans are comprised of coarse rock detritus liberally mixed with all grades of alluvial material. Parts of the fans have undoubtedly been deposited by streams debouching from the canyons during flash floods. Some of the fan material may have been deposited as mudflows. In any event, near the mountains, the fan deposits are somewhat heterogeneous and of locally high, locally low permeability. Some lime cementation has taken place, further reducing permeability. It is assumed that valleyward, the coarse, poorly sorted fans grade into well-sorted, alternating beds of gravel, sand, silt, and clay, the finer-grained fractions most often occurring near the valley axes. Deposition by ephemeral streams, mostly in time of flood, must have resulted, however in deposition in and adjacent to meandering, braiding channels. It is therefore most likely that the pre-Bonneville deposits that underlie the intermontane valleys at some depth, are laterally discontinuous. What modifications of the hypothetical picture of deposition sketched above are required by factors of differing Pleistocene climates during stages of deposition of the alluvium, can only be surmised. Experience in other valleys of the southwest suggests, however, that the general pattern is much like that indicated above.

Lakebeds deposited in pre-Bonneville -- and as yet essentially unknown -- stages during which large bodies of water may have occupied the Bonneville basin, may occur intercalated with the alluvium. The presence of relatively thick clay layers reported in drillers' logs of wells in various parts of the Bonneville basin, separated by gravels and sands from overlying Bonneville sediments, suggests that there may have been pre-Bonneville lakes during Pleistocene time.

Lake Bonneville group. -- Deposits of Lake Bonneville, the Pleistocene lake whose history was unraveled by G. K. Gilbert (1890), and whose shorelines and sediments are known from extensive exposures, have recently (Hunt, Varnes, and Thomas, 1953) been described from northern Utah Valley. In that area, Hunt (in, Hunt, Varnes, and Thomas, 1953, pp. 17-24) recognized and named 3 new formations. In order of age, the oldest cited first, these formations were designated the Alpine, Bonneville, and Provo formations.

In the Dugway area, it was found convenient to group the Alpine and Bonneville formations together, and map as a unit those deposits lying lower than the Bonneville shoreline, and higher than the Provo shoreline. In general, these strata include beds of the Alpine and the Bonneville formations. Near the mountains, especially where spits and bars were formed, the Alpine-Bonneville deposits are coarse, well-sorted, and highly permeable. They receive surface runoff after storms and direct precipitation, and are important in recharging deeper-lying aquifers. In other respects, they lie too high above the valley floor to enter the ground-water picture.

Deposits exposed at the surface, and lying at elevations lower than the Provo shoreline are indicated on the geologic map (pl. 1) as Provo-and-younger. It is recognized that in many places, these deposits are little more than a veneer over the surface of beds in the Alpine formation. Locally, the Alpine formation may crop out, although it was not recognized in the lower-lying areas in the present investigation.

In many places along the Provo shoreline, the Provo formation consists in large part of gravels and coarse sands. These are commonly permeable, although locally they may be lime cemented into an essentially impermeable conglomerate. An example of this type of occurrence is found north of Easy Area, where a Provo-level spit consisting mostly of well-rounded andesite and rhyolite cobbles and pebbles has been thoroughly impregnated and cemented together by tufa. In other areas, the calcareous tufa forms sheets and layers on the Provo surface, sometimes overhanging the edge of the Provo terrace like a meringue.

Post-Provo sands, silts, and clays overlie deposits of Alpine and Provo lake stages in the central parts of the valleys. Some of this material was deposited during geologically Recent time by waning stages of Lake Bonneville, and other deposits were formed by outwash of finer materials brought down in Recent flood runoff from the mountains. The distinction between Recent deposits and those of the Lake Bonneville group was not attempted during the mapping of the Dugway area.

Areas shown on the geologic map (pl. 1) as occupied by Provo-and-younger deposits are locally homogeneous, but considered areally, heterogeneous in the extreme. Textures range from coarse, clean gravels in many areas along the Provo shoreline to laminated clays in the valley troughs. As a result, it is impossible to give an overall characterization of these deposits in terms of their relation to the occurrence of ground water. In some areas, they are favorable for conducting water underground, and thus add to the volume of water recharged annually. In many other places, they constitute layers of very low permeability that act as confining layers in artesian systems.

In sheltered embayments at the Provo level, there are a few areas occupied by beds of banded, tuffaceous clay, white to yellowish-green in color. The larger of these occurrences are shown on the geologic map (pl. 1) notably between Davis and Little Davis Mountains, and on the north and south sides of Bowl Ridge. Apparently there was volcanic activity in the vicinity when the lake stood at the Provo level; volcanic ash fell into the lake, and was rafted by prevailing winds to sheltered coves where it was subsequently deposited on the lake floor, and over the centuries, altered to clay by weathering.

Recent deposits.-- Other than the geologically Recent sediments mentioned in the section immediately preceding, Recent deposits in the Dugway area are limited. Of the total sedimentation that took place in the valleys during Quaternary time, only a small part was accomplished during the Recent epoch. The agents active in Recent erosion are streams coming out of the canyons, and, in some places, sheet floods that have extended beyond the older and larger fans. Alluvium is being deposited in present stream channels and is slowly accumulating on the gentle slopes below the mouths of canyons. In some areas there is a high percentage of salts associated with the Recent alluvium. These salts have been concentrated by prevailing winds or by evaporation in areas of poor drainage where the water table is near or at the surface. Much of the Recent alluvium is well sorted, and in most areas rapid penetration of precipitation is possible. Part of the water reaches the aquifer as recharge, and some of the water probably penetrates no farther than a perched water table. Occurrences of perched water are, however, local and exist only in areas where the Recent alluvium has accumulated above an impermeable stratum.

Dunes. -- The largest areas of sand dunes in the Proving Ground are found on the north side of Granite Peak and Little Granite Mountain (pl. 1). Smaller dune areas are found in the low parts of the valleys and in sheltered reentrants. In every case, the accumulation of dune sand has been in areas which are sheltered to some extent from the winds. This has permitted the accumulation of dune materials. Thomas (1946, p.132) in speaking of the origin of dunes in Tooele Valley, said that wind action had caused a modification of the valley floor, and wherever the surface material was loose, of convenient size, and not held down by vegetation or water, wind erosion occurred and dunes were formed. This has also been the origin of the dunes in the Dugway area. Dunes representing at least two periods of accumulation are found in the area mapped. Some dune areas are at the present time inactive, being held in place by a lush growth of vegetation. Many of the other dunes are yet active, and continual movement of the dunes prevents the growth of vegetation. Besides the massive dune areas, longitudinal and barchan dunes are present in the Dugway Proving Ground. All of the dunes are composed of fine-grained quartz sand, unweathered feldspar, limestone, salts, and a few shell fragments. The presence of organic matter gives the dunes a dirty appearance.

Igneous Rocks

Intrusive rocks

Granite. -- The basement rock in much of the Dugway area is probably granite. Faulting has been responsible for bringing these intrusive rocks to the surface in some areas. The largest occurrence of intrusive rocks in the area of the present report is Granite Peak which is situated near the west margin of the Proving Ground. Butler (1920, p. 460) identified the rock as a light gray granite. Just south and west of Fox Area is Little Granite Mountain which is within the area shown on Plate 1. Other small granitic outcrops are found about 3 miles north of Easy Area in the Cedar Range.

Olivine gabbro. -- According to the driller's record of well 18 in Easy Area (fig. 2) "solid olivine gabbro" was found at a depth of 340 feet and penetrated for 5 feet. So far as is known this is the only reference to the presence of olivine gabbro in the area, and has not been confirmed.

Extrusive rocks

Rhyolite and andesite. -- Volcanic activity was widespread in north-central Utah during the Tertiary period, and continued sporadically until near the close of the Pleistocene epoch. According to Gilbert (1890, pp. 319-339), large scale eruptions in this area began in Tertiary time and continued until mid-Wisconsin time with appreciable quantities of volcanic ash being deposited in later Tertiary (Pliocene?) time. The larger areas of lava found in the Dugway region are on the west flank of the Cedar Mountains. According to Ives (1951, p. 785), the earlier eruptive rocks are for the most part rhyolite and the later flows basalt. This agrees with the findings of the writer who recignized both rhyolite and more basic eruptive rocks, tentatively identified as andesite.

Two volcanic necks occur just north of the area mapped. One is within the Proving Ground, east of Wig Mountain, and the other is in the Cedar Range about 6 miles north of Easy Area.

Basalt. -- Basalt erupted locally as the last stage of volcanic activity in the area. The amount of basalt found is very small. The

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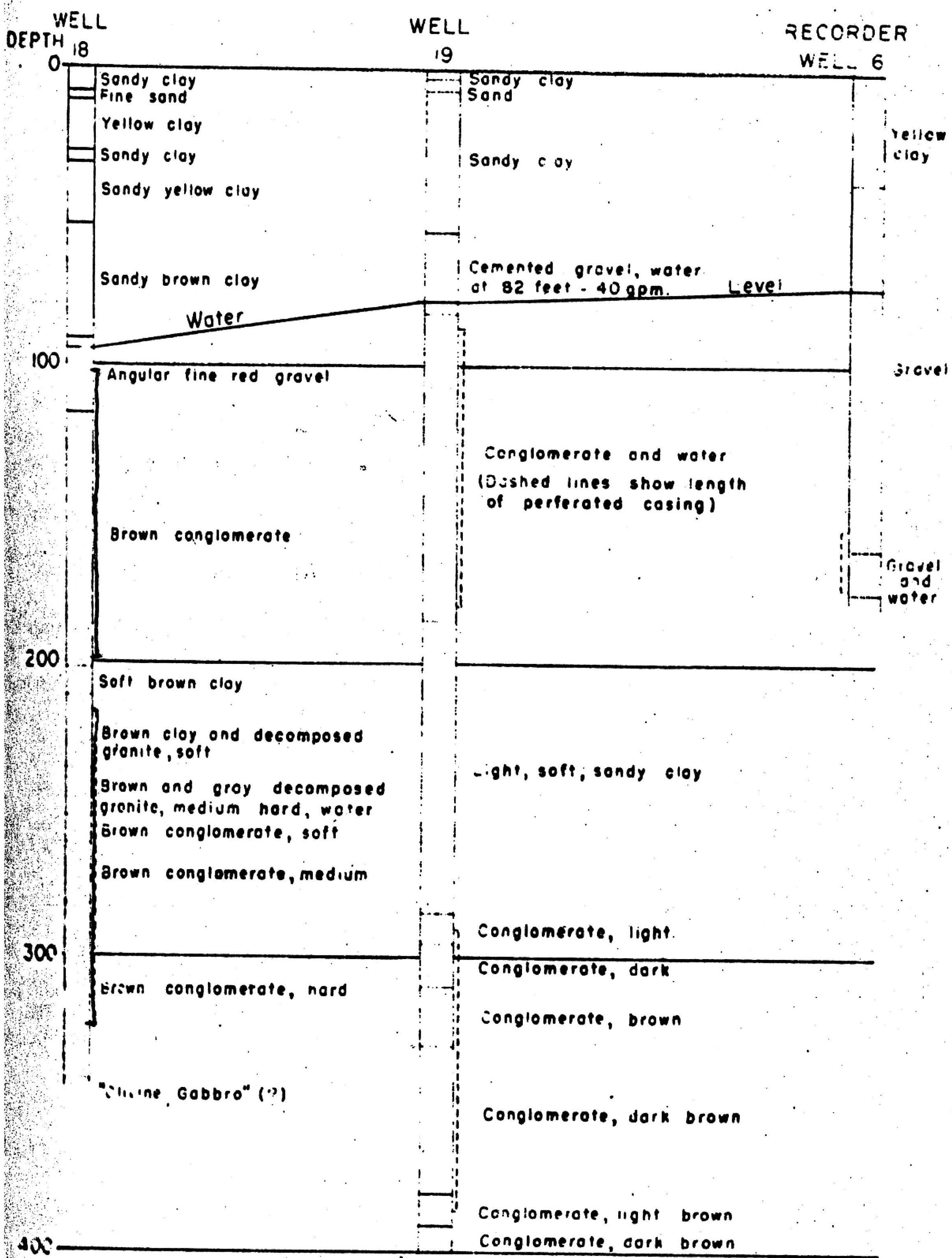

Figure 2- Logs of the three wells in Easy Area. Data from records in Post Engineer's Office, Dugway Proving Ground.

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rock occurs mostly as scattered patches of float. About 6 miles to the north, outside the area mapped, basalt flows were found on the east flank of the Cedar Range. In the Dugway area, some basalt is found just east of Little Davis Mountain, and in a very scattered pattern in the Government Wash Area. The basalt is vesicular and generally dark brown to black in color. The generalized stratigraphic section of the Dugway Area is given in Table 2.

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Table 2. Generalized stratigraphic section of the Dugway Area, Tooele County, Utah.

Geologic age: System	Geologic age: Series	Geologic age: Group	Formation and Symbol on Plate 1	Thick-ness (feet)	General Character	Water-bearing Properties
QUATERNARY	Recent	Post Provo deposits	Dunes (Qd)	30	Aeolian deposits, dominantly silt along borders of Great Salt Lake Desert coarser and more sandy on higher parts of the valley floor.	Highly permeable sand and less permeable silt, in deposits so thin as to be of little value as a source of water.
	Pleistocene	Lake Bonneville group	Provo fm. and younger sediments (Qp)	?	Gravel, sand and silt found below the Provo shore line.	Moderate to weak permeability
			Bentonitic clays (Qc)	?	Volcanic ash deposited in re-entrants at the Provo level of Lake Bonneville, and converted to Bentonitic Clays.	Generally low permeability. Too thin to be significant. May inhibit recharge locally.
			Alpine & Bonneville fms. (Qab)	?	Sand, silt, and clay cropping out between Provo and Bonneville shore lines. Subsurface occurence only partly known.	Constitute principal source of ground water in valley. Fine materials have low permeability and form the confining layers that give rise to artesian conditions.
			including Alpine and Bonneville gravels (Qabg)		Gravel, sand, and cobbles of ancient shore features (spits) along edges of valleys.	Very high permeability, underlie some of principal recharge areas.

Table 2 - Cont'd

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Geologic age			Formation and Symbol on Plate 1	Thick-ness (feet)	General Character	Water-bearing Properties
System	Series	Group				
TERTIARY and QUATERNARY	Pliocene - Pleistocene	Pre-Bonneville deposits	Fanglomerate (QTf)	?	Alluvial fan material. Exposed from Bonneville level to flanks of mountains. Boulders, cobbles, gravel, sand and silt. Includes stream wash, mud flows and some talus.	Moderate to low permeability. Important in recharge where crossed by ephemeral streams.
	Paleocene - Recent		Basalt (QTb)	?	Occurs mostly as float in the area. Vesicular, black to dark brown in color. Small outcrop west of Little Davis Mountains.	Considered of no consequence in relation to occurrence of ground water.
TERTIARY	Early Tertiary		Andesite and Rhyolite (Tra)	?	There have been many flows, of different textures, compositions, and varying colors confined to the northwest part of the mapped area.	Fractures probably form the only permeable zones. The texture of some rocks may permit infiltration of water.
CRETACEOUS to TERTIARY	Upper Cretaceous to Early Tertiary		Granitic rocks (Mg)	?	Medium to coarse-grained granite comprising most of Little Granite Mountain.	Low permeability except along fractures. Probably unrelated to occurrence of ground-water in Dugway area.

Table 2 - Cont'd

Unpublished records
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Geologic age: System	Geologic age: Series	Geologic age: Group	Formation and Symbol on Plate 1	Thickness (feet)	General Character	Water-bearing Properties
CAMBRIAN - CARBONIFEROUS	Cambrian - Carboniferous		Undifferentiated Paleozoic rocks (Pu)	24,000+	Thick series of marine sediments, chiefly limestone, some dolomite, quartzite and shale; detail by Gilluly.	Cavernous limestones form the chief permeable zone; give rise to a few springs in the mountains where exposed; may be important in recharging valley deposits.
CAMBRIAN	Lower Cambrian		Tintic quartzite (ϵt)	300+	Thick-bedded, cross bedded white quartzite weathering to rusty surface; shaly toward top and grades into overlying Ophir formation.	Bedding planes and fractures form the only permeable zones.

Geologic Structures

Folds

According to Thomas (1946, p. 147), the main part of the Stansbury Range is formed by a single great fold having a north-south axis, with several small subsidiary folds at the north end of the range. The Cedar Range is very similar in origin to the Stansbury. The Paleozoic strata have been involved in the folding, but the Tertiary strata have not. From information available in the region, the date of the folding is post-Pennsylvanian and pre-Tertiary. Some of the folding may be associated with the early part of the Laramide Revolution, and thus would be late Cretaceous in age. Some minor folds found in the area are the result of the bending associated with tear faults.

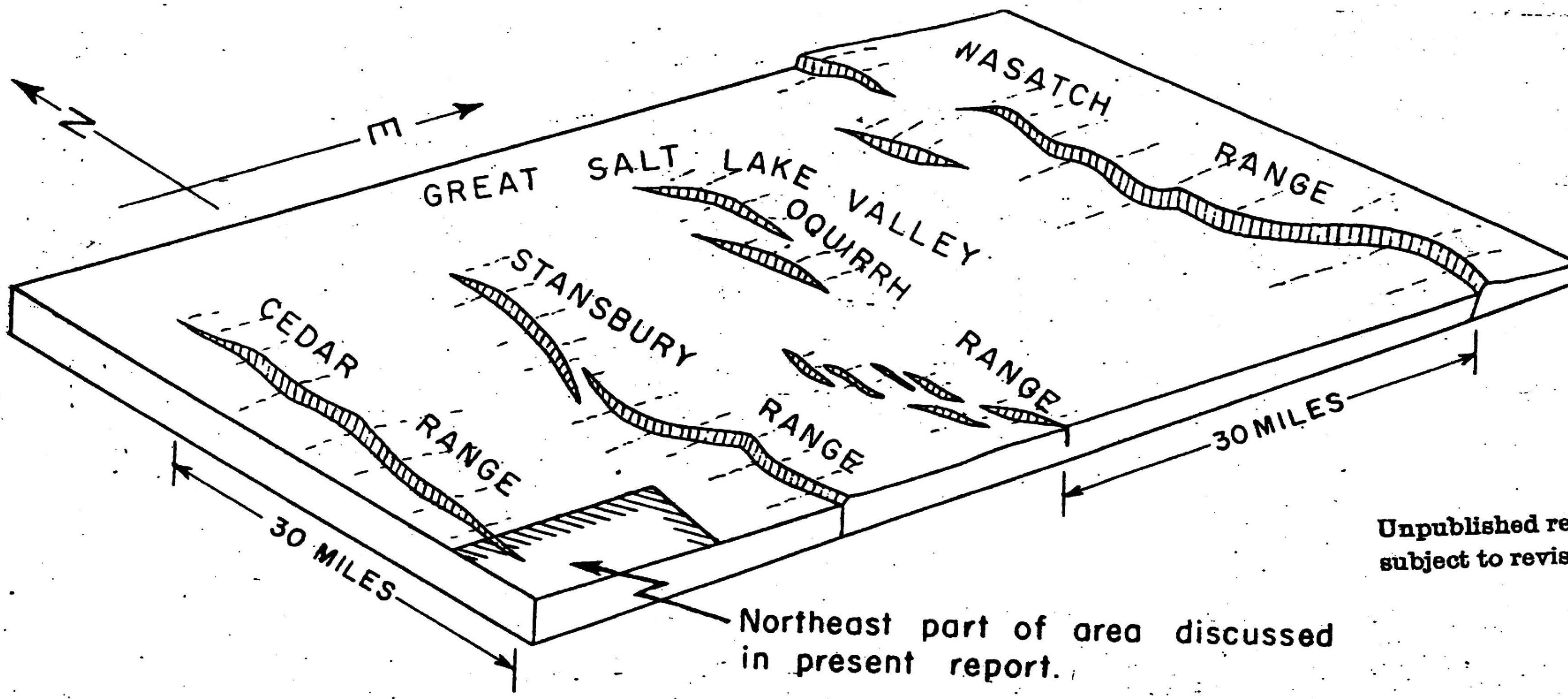
Inasmuch as folding in the Dugway area seems to be restricted to the mountain blocks, no effort was made to unravel the pattern. It appears to have no direct relation to the occurrence of ground water in the materials underlying the present valleys.

Faults

Earlier faulting. -- The term Laramide Orogeny is applied to the great compressional disturbances that occurred in very late Cretaceous, Paleocene, and Eocene time (Eardley, 1951, p. 284). So far as is known, movements in the Oligocene, if they occurred, were gentle, and in places were superposed discordantly on the more intense movements of the Paleocene and Eocene. Some of the most characteristic structures associated with the Laramide revolution are tear faults, folds, and thrust faults. A tear fault of major proportions trends N. 75° W. from the vicinity of Lookout Pass (pl. 1). The fault passes along the north side of Little Davis Mountain where the zone of fracture and brecciation is about 85 feet wide. The fault then continues northwestward on the south side of Bowl Ridge. It is believed that movement along this fault resulted in elevating Bowl Ridge into its present position.

Basin-Range faulting. -- The area discussed in this report is situated near the eastern margin of the Basin and Range province, and its approximate structural setting is shown schematically in figure 3. According to Eardley (1951, p. 474), "The Basin and Range system is one generally of north-south-trending basins and ranges, with the majority of the ranges probably blocked out by high-angle faults." The intervening plains are composed of subaerial deposits of waste materials derived from the mountains. These deposits are often very thick and are generally unconsolidated or weakly cemented. The area includes parts of two major structural units or crustal blocks, the Stansbury and Cedar Ranges fault blocks. Several smaller blocks, bounded by faults, are by-products of the rotation which brought into place the larger mountains. The Stansbury and Cedar Ranges comprise the raised western portions of these blocks, and the depressed eastern part of the Cedar Mountain block, with its alluvial cover, forms Skull Valley. Displacement of sediments along one of these faults could have an important bearing on the occurrence of ground water in the area.

Several directions of fault trends are found in the Dugway area. The block faults trend north, whereas the en echelon faults and step-or distributive faults trend east or northwest. En echelon faulting is prominent in the low, southeast-trending hills southeast of Easy Area.



Block diagram illustrating the nature of deformation of the earth's crust in the late Tertiary and early Pleistocene block faulting of the Wasatch-Great Basin region, Utah. The diagram is approximately to scale with the maximum throw of the faults from 500 to 5,000 feet, and the tilted blocks between faults 15 to 30 miles wide. The ranges owe their present topographic form to a combination of relief inherited from earlier Tertiary folding and to the block faulting.

Figure 3- Block diagram of Basin-Range structure showing part of mapped area.
After Eardley (1951, p.480, fig.281)

On the west flank of the Stansbury Mountains, off the limits of the area presently discussed, a Basin-Range type fault was traced from the air for about 15 miles. It is found at a higher elevation on the mountain than the Bonneville level of the Lake. Although not so clearly evident, it is probable that comparable faults are present along the west sides of Cedar Mountains and other Basin Ranges in the Dugway region.

Age of faulting. -- Not all of Basin-Range faults are of the same age. According to Eardley (1951, p. 479), in a single range, the maximum movement along an individual fault may have been much earlier or later than that on a neighboring fault. Thomas (1951, p. 147) says that the Basin-Range faulting is clearly later than the folding in the region, because the folds are transected by the faults. He interprets the faulting as being subsequent to the Laramide Orogeny. The presence of fresh fault scarps, indicates that the Basin-Range type faulting has continued in some places practically to the present day. Eardley (1951, p. 481-482) dates the age of block-faulting as being middle and late Cenozoic.

Geology in Relation to Occurrence of Ground Water

A series of steeply-dipping, fault-block mountains are found in the Dugway area. Among these fault blocks are structural basins which are closely related to each other. The processes of highland erosion and lowland deposition have been important in filling the basins with sediments, and the important ground-water reservoirs are situated in these alluvial basins.

An important feature in the geologic history of the area, both with respect to the mode of occurrence of ground water and to the topography, was the inundation of parts of the area by Pleistocene Lake Bonneville, whose highest shoreline was about 5,150 feet above sea level, and one of whose decimated remnants now constitutes Great Salt Lake. The clays and silts dropped on the bed of the lake at some distance from shore; underlie all of the lower parts of the Dugway area, and in some welllogs are reported to be more than 100 feet thick.

The permeable deposits of sand and gravel in the valley fill contain the recoverable ground water of the area, but little is known of their character, thickness, or lateral extent. Test drilling and the drilling of water wells in the future will contribute to a better understanding of subsurface relationships. Where these deposits of gravel and sand underlie impermeable lake clays in the lower parts of the valley, the water in the aquifers may be confined under artesian pressure.

The aquifers of Dugway Valley are closely related because they are in a single hydrologic basin. The aquifers of the Easy Area are in the Skull Valley hydrologic basin, and have no direct connection with those in Dugway Valley. Dog Area, in Dugway Valley, is about 500 feet lower in elevation than is that part of Skull Valley which is within the Easy Area. It is unlikely, however, that there is any movement of ground water from Easy Area to the Dog Area, as the two hydrologic basins apparently are completely seperated by a low, partly buried ridge of rock that intervenes.

The aquifers that underlie Easy Area are considered to be coextensive with the aquifers that underlie the homestead areas in the main part of Skull Valley, northeast of Dugway Proving Ground. Some water is believed to be moving northeastward from the Easy Area, but the amount is probably not great. Detailed discussion of these relations will be found in a later section on ground water in the Easy and Fox Areas.

WATER RESOURCES

Surface Water

As runoff in the area described in the present report occurs only sporadically following storms of more than usual intensity, and as records that might be pertinent have not been kept, the surface-water resources cannot be discussed or evaluated. There are no perennial streams in the area.

Runoff following heavy, usually local, rains is the source of most of the water recharged to aquifers. This feature is discussed in the following section.

Ground Water

Source

Precipitation is the ultimate source of all ground water in the Dugway area, hence the amount and distribution of rainfall is of great importance. The amount of precipitation that falls generally increases with increasing altitude, hence the mountains of the area are significant as sources of recharge to the aquifers in the valley fill. Water may reach the aquifers from the mountains as underflow down dry canyons, as the result of infiltration from the surface of coarse alluvial fans, or as ephemeral stream flow in the canyons. In each instance, the water enters the permeable parts of the valley fill within relatively short distances outward from the base of the mountains and from the mouths of the canyons.

Another source of recharge is precipitation that falls directly upon permeable areas of valley fill. Where the land surface consists of coarse alluvial deposits or the shore deposits of Lake Bonneville, there is likely to be an excellent opportunity for infiltration and deep penetration of water from rain or melting snow. The sand dunes at lower elevations are characteristically highly permeable, but where they rest upon lake clays or other fine-grained deposits, recharge to the deeper water-bearing beds is impeded significantly. Under the latter circumstances, the ground-water reservoir is recharged principally by lateral movement of water from areas where the clays are not present to impede downward penetration.

Movement

Ground water in Dugway Valley probably moves from the highlands toward the axes of the several forks of the valley and thence northward toward the Great Salt Lake Desert in the same general pattern followed by surface drainage. Ground water in Skull Valley similarly moves from the mountains inward toward the axis of the valley and thence northward to Great Salt Lake. In Skull Valley, existing wells are too few in number to provide data for a water-table contour map, or even to determine directly the general nature of ground-water movement in thevalley as a whole. The course of ground-water movement may be deflected locally by buried ridges of bedrock or by faults capable of serving as ground-water dams.

The only information on the position of the water table in the Easy Area and its immediate vicinity is based on a comparison of the water-surface altitudes in three wells in which depth-to-water level measurements have been made. Approximatelgnd-surface altitudes have been determined at these wells and their locations have been shown on plate 1. The available water-level information for five wells, including the three wells referred to above, is as follows:

Water-level information in five wells in the Easy Area and its immediate vicinity

Well No:	Altitude of land surface (feet)	Depth to water (feet)	Altitude of water-surface (feet)
Supply well No. 18, Easy Area	4,880±	-80	4,800±
(C-6-7)19ccd-1	--	-20	--
19ddd-1	4,765±	-25	4,740±
29acd-1	--	-41	--
(C-8-7)30dcd-1	5,170±	-292	4,878±

It will be noted from the above tabulation that the water level in Well (C-8-7)30dcd-1 is about 78 feet higher than that in Supply Well 18 in Easy Area which is about 10 miles to the northwest. Also, the water level in Well (C-8-7)30dcd-1 is about 138 feet higher than that in Well (C-6-7)19ddd-1, situated about 14 miles to the north in Skull Valley. Thus there is an indication of a general north or northwest slope of the water table, although there may be ground-water divides or troughs between the wells.

Recharge

During the time when Lake Bonneville covered the Dugway area, ground-water reservoirs were completely filled. Since then, until man intervened, inflow approximately equalled outflow each year, thus maintaining a balance. Equilibrium conditions prevailed more or less until the time when wells were drilled. Pumping from wells has had some effect locally on the amount of natural ground-water discharge.

Most of the recharge for the Easy and Fox Areas is derived from precipitation on the Onaqui and Sheep Rock Ranges to the east and southeast. It is believed that the amount of recharge that occurs in both Dugway and Skull Valleys is quite limited. Available water-level records cover too short a period to define long-term water-level trends in the area.

The possibility of artificial recharge of the underground reservoir taking place in the Easy Area must be considered as spreading of large quantities of water on the land surface continues. Of the total quantity of water that is pumped in the area, only a portion is lost to the atmosphere through evaporation and transpiration. The rest of the water, representing probably more than three quarters of the total water pumped from the two supply wells, soaks into the ground. This occurs not only over the extensive areas of irrigated lawn and rye grass, but also along the several ditches used for sewage disposal. Little or no effect of this recharge has been noted; however, over a period of years this infiltration will represent a major source of ground-water recharge. As the infiltration from the sewage disposal system occurs well within the reach of the pumping supply wells, the possibility of serious contamination of the ground-water reservoir must be given consideration.

Discharge

Natural Discharge. -- Discharge from the ground-water reservoir occurs, first, as natural discharge represented by the evapotranspirational losses, spring flow and ground-water movement out of the area, and second, as artificial discharge represented by the pumping of the several water wells. As the water table occurs at considerable depth below the surface of the land throughout most of the area studied, evapotranspirational losses are believed to be small.

Ground-water discharge from springs is estimated to range from 100-200 gallons per minute. This is largely concentrated in a group of springs at Orr's Range northeast of Easy Area (pl. 1). Here a series of springs emerge along a line trending about east-northeast. Because of the alignment and the abundance of spring-deposited travertine, it is suggested that the springs rise along a shallowly buried fault zone in a probable limestone source-rock. Most of this discharge occurs in two cirque-like springs about 400 feet apart. The westerly of the two discharges about 50 gpm. with a surface temperature of 61°F., the other about 75 gpm. at 59°F.

Springs of lesser discharge occur on the west flank of the Onaqui Range southeast of the Hatch Ranch (pl. 1) and on the western slopes of the Cedar Mountains. Within the reservation three other springs occur on the north flank of Granite Peak (fig. 1). Simpson Springs on the west slope of Simpson Mountains beyond the limits of the mapped area (fig. 1) is noteworthy as it has been a landmark throughout the period of pioneer settlement of the region. The discharge, however, is small.

As noted above, the water table in the Easy Area, and also in the broad valley east of Easy Area and stretching north to Orr's Ranch, is relatively flat. This suggests that little ground-water movement is taking place. As the ultimate subsurface run-off from the area moves northward along Skull Valley toward Great Salt Lake, it is believed that some loss is incurred in this direction. Because of the low hydraulic gradient that occurs, however, and the relatively low transmissibility of the saturated sediments, it is believed that the quantity of water thus lost from the area is not great.

<u>Artificial Discharge.</u> -- The two supply wells in the Easy Area are responsible for most of the artificial discharge within the area of this study. As noted in figure 4, the combined discharge from these two wells during 1953 varied from more than 1 million to more than 9½ million gallons of water pumped per week. During July of this year, the month of maximum pumping, 34.3 million gallons were used, bringing the average monthly use for the year 1953 to 16.9 million gallons. The close parallel between the graph of pumpage of the two supply wells (fig. 4) and the water levels in the observation well located 1700 feet from the center of this pumping, show the effect that the continued pumping is having on water levels in the Easy Area.

It has been estimated 1/ that during 1954 an increase of from 20 to 30 percent in water use can be anticipated. Thus, monthly peaks over 40 million gallons during the dry summer months and an annual withdrawal of 290 million gallons, is contemplated for 1954. The six months of record for 1954, shown on figure 4, suggest the water-level trend to be expected for the remainder of the year. It is interesting to note that this anticipated use is equal to about 1/80 of the total quantity of water used by Salt Lake City during 1953, which municipality had an average per capita demand of 249 gallons per day during 1953. 2/

Within the area of this study, at least 10 water wells have been drilled in addition to the two supply wells. Of these, only 3 are known to have pumped water during 1953 and one other began pumping in 1954. From these 4 wells an estimated total pumpage of considerably less than 1 million gallons will take place during 1954, thus, for practical purposes the discharge of the two supply wells may be considered as comprising the total pumpage from the ground-water reservoir.

Ground Water in the Easy Area

General Conditions

The Easy Area installation is situated at the southeast end of the Cedar Mountains in a re-entrant cove that is formed in part by a bedrock ridge projecting southeastward from the mountains into Skull Valley, and in part by a gravel spit constructed by Lake Bonneville, at the end of this bedrock ridge. The mountains in this area consist of low, maturely

1/ Oral Communication, Post Engineer, Dugway Proving Ground.

2/ Oral Communication, City Water Engineer, Salt Lake City, Utah.

eroded foothills that protrude from the edge of the older valley fill, and the flanking deposits of Lake Bonneville. To the east of this cove lies the broad bottomland of Skull Valley which extends more than 40 miles northward to Great Salt Lake. To the southwest are low granitic foothills that probably are related structurally to the Davis mountains further south, and form the divide between Skull Valley and Dugway Valley at this place.

The direction of movement of surface water in the Easy Area is southeastward for some distance, thence eastward toward the axis of the valley. The initial southeastward direction is produced by the ridge of bedrock and gravel that forms the cove in which the Easy Area installation is situated.

It appears that the bedrock of the same ridge that determines the course of surface-water movement may continue southeastward at shallow depth. If so, the bedrock must act as a ground-water dam that deflects the course of ground water southeastward for some distance before the low point in the surface of the bedrock is reached. From that low point, however, movement must be directly eastward toward the axis ? of Skull Valley. Such a pattern would approximate that of the movement of surface water in the area.

Uncertainty is introduced, however, by the fact that the elevation of the surface of the supposed ground-water dam is not known. If it is near the land surface everywhere in the distance of about one mile from the point where bedrock disappears under the gravel spit and reappears above the valley fill again to the southeast, ground water may be considered to be ponded underground in a zone that includes the

Easy Area installation, and movement over the low point of the dam would be near the surface. If, however, the dam should be cut by one or more ancient canyons or water-gaps, then ground water could move directly eastward in one or more narrow zones delimited by the existence of such canyons.

On the other hand, if the surface of the supposed bedrock dam should be a considerable distance below the land surface, then the deposits left by Lake Bonneville would merely conceal alluvial debris which spread out eastward into the valley in pre-Lake Bonneville time and which would conduct water eastward beneath the deposits of Lake Bonneville. Under these conditions, ground water would be moving eastward under much of the area.

Characteristics of Wells

The drillers' logs (fig. 2) of 3 existing wells in Easy Area are inconclusive with respect to depth to bedrock. Rock was reported at depths of 340 and 400 feet or more in Easy Wells Nos. 18 and 19, but was not found in the stock well that is 175 feet deep. The accuracy of the determinations, however, has not been demonstrated. The clays and sandy clays deposited by Lake Bonneville are reported as about 82, 46, and 35 feet thick respectively. Surface elevations at all 3 wells are nearly the same. The differences in thickness of clays in the wells appear to reflect inequalities resulting from differences in the environment of deposition that in turn were related to the shoreline of the lake and the resulting effects of waves and currents upon the nearby mountains that stood near or above the surface of the lake. The difference may, however, reflect in part diverging interpretations by the several drillers.

Water occurs in these three wells at depths averaging about 80 feet below the land surface. The water table seems to have very little gradient, and its flatness in this area is another indication of the possible presence of the ground-water dam suggested above.

Several measurements in the stock well in 1946 and 1951 suggest that during that period of time the water level remained fairly constant. Since 1951 the water level has steadily declined (see fig. 4). The record from the recording gage maintained on the stock well since April 1951 shows daily and weekly fluctuations of a few hundredths of a foot in the water level, with a gradual decline in the general water level.

In a pumping test conducted on Well No. 18 in January 1951 with sustained discharge of 1,000 gallons per minute, the measured drawdown was less than 0.5 foot without observable effect on the water levels in Well No. 19 or in the stock well, each of which is about 1,500 feet distant.

In a similar test, Well No. 19 was pumped for several hours at a rate of 1,000 gallons per minute. A maximum drawdown of 13 feet was observed. The greater drawdown in this well is believed to represent chiefly a difference in permeability of the aquifer resulting from differences in character of the water-bearing materials in the two localities, although the manner in which a well is constructed and developed, the type and size of perforations in the casing, and other factors may have a marked effect upon the drawdown. It is believed that the drawdown in this well may lessen somewhat as pumping continues. The drillers' logs (fig. 2) do not provide any clear explanation of the observed differences in drawdown during pumping.

Prospective yield of wells

The data from the pumping tests mentioned above were adequate only for a rough estimate of prospective sustained yield from the two supply wells in Easy Area. The absence of any observed effect upon the water level in the stock well during these tests suggested that the quantity of the water in the aquifer in the Easy Area was large in comparison with the quantity of water pumped during the test. A continuous recording gage operated on the stock well beginning August 9, 1951 indicates a progressive downward trend inwater levels. Despite this condition it is believed that pumping may be continued for some years to come. Decreasing water levels are a natural consequence of the development of an area.

An estimate of the prospective long-term yield that could be derived from the supply wells might be obtained by conducting a detailed pumping test on each of the wells. The period of the pumping tests should be sufficiently long to allow for the collection of the necessary factual data on the discharge, drawdown, and subsequent recovery in the pumped well and of similar water-level information in other existing wells in the immediate area. Records of water-level fluctuations in the stock well should also be maintained as long as the supply wells are used; these records will show whether there is a continual depletion of the storage in the Easy Area, or whether recharge to the area will be sufficient to balance the pumpage.

Chemical Quality

The chemical analyses of 18 samples of water from wells on the Dugway reservation (table 3) indicate that the ground water is quite mineralized. However, with the exception of the water from 4 wells, the general ground-water quality in the area does meet the minimum requirements for use as a public supply. For industrial use, the water may require treatment because of the high content of silica, bicarbonate, and total hardness.

The samples from wells 10 (Granite Peak), 3 (Cantonment Area), 16 and 17 (Baker Area) show a total dissolved solids content well in excess

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Table 3 - Chemical analyses of ground water from representative sources in Dugway Proving Ground, Tooele County, Utah.
Analyses by Quality Water Branch, U. S. Geological Survey

Source of sample		Date sampled	Depth (feet)	Temperature (°F)	Specific conductance (Micromhos at 25°C)	Chemical analyses, parts per million														Percent sodium	pH
Well No.[1]	Area					Dissolved solids (sum)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Hardness (calculated as $CaCO_3$) Total	Hardness Noncarbonate		
1	Cantonment Area	12/4/45	317	73	1750	989	50	0.01	43	21	283		255	95	300	0.3	5.8	--	194	0	76	7.5
3	Cantonment Area	12/4/45	330	73	1790	1040	46	.01	29	16	334		266	90	300	.5	1.5	--	138	0	84	7.6
3	Cantonment Area	11/3/53	330	56	1800	1040	47	.07	18	11	348	13	272	91	375	.6	6.2	--	90	0	--	7.9
4	Toxic Gas Yard	11/4/53	170	55	1150	669	34	.07	18	16	191	30	230	21	242	.7	0.2	--	111	0	--	8.6
5	Toxic Gas Yard	12/4/45	335	73	1070	601	47	.01	49	29	122		223	50	190	.3	3.7	--	242	59	52	7.8
5	Toxic Gas Yard	11/4/53	335	54	1070	616	48	.07	49	30	121	7.6	226	51	194	.3	4.0	--	246	62	--	8.0
10	Granite Peak Area	3/28/50	153	--	2990	1670	20	.13	72	26	514	13	242	142	760	3.2	1.7	0.08	286	88	79	7.2
16	Baker Area	7/31/51	284	--	3610	2050	56	.05	34	22	594	30	151	83	1050	.5	1.3	--	175	52	88	8.4
16	Baker Area	11/3/53	284	68	3500	1930	66	.05	37	24	620	35	168	91	970	.5	.3	--	191	54	--	7.9
17	Baker Area	7/27/51	1003	--	4880	2790	58	.25	36	23	774	41	173	63	1500	.3	1.8	--	134	42	90	8.4
18	Easy Area	7/31/51	345	--	1290	775	53	.06	70	18	162	12	212	132	215	.3	8.5	--	248	75	57	7.8
18	Easy Area	6/2/53	345	--	1340	840	50	.06	81	23	167	12	208	172	220	.3	18	.19	296	126	54	7.6
18	Easy Area	1/25/51	345	56	1250	764	50	.18	73	19	157	8.4	224	123	222	.2	5.3	.05	260	24	56	7.6
18	Easy Area	1/26/51	345	--	1310	808	53	.07	75	20	160	13	219	154	216	.2	8.5	.05	272	93	55	7.8
19	Easy Area	3/23/51	400	--	1480	--	--	--	--	--	--	--	207	249	225	--	--	--	345	176	--	7.5
19	Easy Area	10/15/52	400	--	1610	1030	48	.07	110	32	130	11	207	299	230	.2	19	--	406	236	48	7.5
19	Easy Area	11/4/53	400	54	1030	617	45	.05	57	19	129	7.1	194	51	213	.5	3.0	--	220	61	--	7.6
Spring	Stagecoach Canyon	3/28/50	--	--	1560	871	20	.05	85	22	202	10	222	72	348	2.0	0.6	.08	302	120	58	7.5

1/ Well numbers as listed correspond with the well numbers used by the Post Engineer in his mimeographed list of logs of "Dugway Proving Ground Water Wells" dated August 25, 1951

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of 1,000 p.p.m., the limit recommended by U. S. Public Health Service standards for culinary water. Two samples from well No. 3 (Cantonment Area) and one sample from well No. 19 (Easy Area) have borderline concentrations of slightly more than 1,000 p.p.m. total dissolved solids. Several of the waters sampled exceed the limit of 250 p.p.m. chloride recommended by U. S. Public Health Service standards, and two samples from well No. 19 (Ea Area) show concentrations for sulfate at and above the limit of 250 p.p.m. recommended. Relative to fluoride, it appears that only the water in the Granite Peak area are somewhat above recommended limits in concentration. Only one sample, from well No. 19 (Easy Area), showed a slightly high nitrate content indicating possible local contamination.

No definite correlation is immediately apparent between depth of wells and water quality. Well No. 17, 1,003 ft., (Baker Area) the only deep well sampled, has the highest mineralized water of all samples examined. Generally, the distribution in mineralization of the water appears to be more a matter of location than of depth of the aquifer below land surface.

Table 4 shows the changes in water quality that occurred in well No. 18 during a 24-hour pumping test. As indicated by values of specific conductance, the principal quality change occurred during the first 3 hours of pumping, after which the concentration of total dissolved solids remained constant, The sulfate ion showed the greatest increase, followed by bicarbonate, nitrate, and silica. A net decrease of 7 p.p.m. of chloride was noted during the test.

These comparisons relative to pumping time and quality suggest the possibility that well No. 18 may draw water from at least 2 aquifers of slightly different chemical characteristics. The changes involved, however, appear to be relatively minor, and there is no indication that water of

Table 4. Chemical analyses of ground water from Well No. 18, Easy Area, during a 24-hour pumping test, showing changes in water quality. Depth 345 ft. January 25-26, 1951. Analyses by Quality Water Branch, U. S. Geological Survey.

Sample No.	Lapse of time after pumping begun	Specific conductance (Micromhos at 25°C)	Chemical analysis, parts per million: Total dissolved solids	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Hardness (calculated as $CaCO_3$): Total	Hardness: Noncarbonate	Percent sodium	pH
6012-A	4 min.	1230	--	--	--	--	--	--	--	212	--	222	--	--	--	--	--	--	--
6012-B	30 min.	1250	768	50	0.18	73	19	157	8.4	214	128	222	0.2	5.3	0.05	260	84	56	7.6
6012-C	1 hr.23 min.	1280	--	--	--	--	--	--	--	216	--	221	--	--	--	--	--	--	--
6012-D	2 hr.31 min.	1290	--	--	--	--	--	--	--	218	--	218	--	--	--	--	--	--	--
6012-E	2 hr.51 min.	1300	813	52	.06	76	20	165	12	218	155	217	.2	8.2	.05	272	93	56	7.7
6012-F	6 hr.51 min.	1310	--	--	--	--	--	--	--	220	--	217	--	--	--	--	--	--	--
6012-G	16 hr.46 min.	1310	--	--	--	--	--	--	--	220	--	216	--	--	--	--	--	--	--
6012-H	18 hr.51 min.	1310	808	53	.07	76	20	160	13	218	154	216	.2	8.5	.05	272	93	55	7.8
6012-I	22 hr.21 min.	1310	--	--	--	--	--	--	--	218	--	215	--	--	--	--	--	--	--

Unpublished records
subject to revision

appreciably better quality could be obtained by analyzing the depth ranges of each aquifer and selectively sealing off those of poorer quality.

In general, the table of analyses (table 3) indicates that ground waters obtained in the Dugway region are marginal with respect to chemical quality. Some, however, including sources now utilized most extensively at the Dugway installation can be used without treatment for culinary purposes.

Water-level Fluctuations

Water-level fluctuations are caused by several factors which include pumping of wells, recharge, evapotranspiration, atmospheric pressure, earthquakes and earth tides.

Barometric Fluctuations

The water level in the stock well which is equipped with a recording gage fluctuates through a range of more than 0.1 foot in direct response to changes in atmospheric pressure, and has a barometric efficiency of about 30 percent. The barometric effect indicates that water in the aquifer is confined under artesian pressure. A slight artesian pressure is also indicated by the well driller's record, which shows that the water level rose about 5 feet above the top of the stratum in which it was first encountered.

Fluctuations related to discharge from wells.

Discharge by means of pumping from wells has a striking effect on water-level fluctuations. The depth to water fluctuates with the amount and rate of withdrawal of water. When the wells are turned off, or the pumping rate is decreased, the water surface rises even though the rise may be very slight. The periods of greatest water usage show the greatest declines in water levels as is shown on the hydrograph, figure 4. Spring and summer are the seasons of greatest pumping, and during these months there is an increase in the depth to water. During the fall and winter months the water level remains relatively stationery, or rises slightly. These generalities are illustrated for the years 1953-54 (fig. 4). The gradual, steady, net decline from 1951 to early 1953 requires another explanation for which data are not presently available.

Fluctuations related to recharge

In the Dugway region, it is believed that mean annual recharge is presently exceeded by mean annual discharge. From Sept. 12, 1953 to Feb. 2, 1954, as a result of decreased usage of water, the water level in the stock well equipped with a recording gage rose .79 of a foot. This is the only time since the recording gage was installed that there has been a rise in the water level recorded over a period of several months. Inasmuch as no estimate can presently be made of mean annual recharge, it is impossible to determine a rate at which water can be withdrawn without causing long-term declines in the water table.

GEOPHYSICS

By

Coyd B. Yost, Jr.

Introduction

The alluvial basins in the Dugway area contain the aquifers most readily available for development of a water supply for the Dugway Proving Ground. The "Easy Area" (pl. 2) is at the northern end of an alluvium-filled trough less than 5 miles in width and about 10 miles in length. The "Fox Area" is in a smaller basin a mile or so west of Easy Area. As a part of the overall investigation of the geology and ground-water resources in the vicinity of Dugway Proving Ground, data were needed regarding the areal extent and thickness of the alluvium in these basins. Data also were needed as to the thickness of the alluvium in the gaps in the hardrock boundary of the basin.

Surface geologic mapping provided data concerning the areal extent of the alluvium but, because of the scarcity of wells in the area and the resulting inadequacy of well-log data, it was necessary to apply geophysical methods to approximate the configuration and depth of the bedrock floor. An electrical resistivity survey was made during the period September 22 - October 22, 1953, using instruments and personnel detailed to the Dugway investigation from the Arizona district of the Ground Water Branch. Thirty-six probes were made, four in the Fox Area, one in Skull Valley, approximately 4 miles northeast of Easy Area, and the remainder in the Easy Area basin.

The data collected, the interpretations that were made, and the conclusions that were drawn from the geophysical phase of the investigation are discussed in this chapter of the report. The interpretation of resistivity data provides only an approximation of geologic conditions, and in some cases several different interpretations are theoretically possible for a given anomaly. The final solution of the problem depends upon information collected by drilling test wells at selected sites. Nevertheless, the method is of value in providing reconnaissance data. The cost of obtaining similar data by a drilling program would be many times greater.

For the benefit of those who may find it desirable to make a reinterpretation when pertinent data from other sources become available, this report contains statements concerning the theory and general application of the electrical resistivity method.

The work in the Dugway Proving Ground was done by the author and R. H. Fischer of the Arizona district, assisted by military personnel assigned from the Dugway Proving Ground. The work was under the direct supervision of H. A. White, district geologist, Salt Lake City, and the general supervision of A. N. Sayre, Chief, Ground Water Branch, L. C. Halpenny, district engineer, Tucson, Ariz., and H. N. Wolcott, of the Phoenix office, supplied ideas and reviewed the report. L. C. Dumars and B. E. Lofgren furnished geologic and hydrologic information presented elsewhere in this report and, together with R. G. Butler, gave part-time assistance in the field work.

Gratitude is expressed to the Commanding Officer at Dugway Proving Ground and to members of his staff, particularly to Major G. D. Fery, Post Engineer, for their friendly cooperation and for providing labor, supplies, and quarters.

Theory and method of making and interpreting electrical resistivity probes

Theory

The theory of the electrical resistivity method of geophysical prospecting is discussed by several authors (Jakosky, 1950, pp. 469-480; Heiland, 1946, pp. 707-744; Stommell, H. E, in Leroy, 1950, pp. 1110-1117). In brief, if a measured electrical current is introduced into the earth between two points, the effect of subsurface geologic bodies upon the flow of current can be determined by measuring the potential distribution about one or both of the points. The resistance of the earth materials to passage of a current can be evaluated in terms of geology if the electrical resistivity of the various rock types is known. In practice, steel stakes are driven into the earth at measured distances to introduce the current and to enable measurement of potential, the depth of probing being a function of the distance between stakes. The effects of stray earth currents and stake-to-earth potentials are minimized by introducing commutated direct current.

A probe involves obtaining the current and potential measurements corresponding to each of a series of stake positions, the distance between stakes being progressively greater for each succeeding determination in the series. The equation used to determine earth resistivity is $\rho = Ca\frac{V}{I}$

in which ρ = apparent earth resistivity in ohm centimeters (ohm - cm)

C = a constant
a = stake separation, in feet
V = potential in millivolts
I = current in milliamperes

The constant C includes factors for converting stake separation, in feet, to the metric system, and an instrument constant. If the data for each determination of ρ are plotted on logarithmic paper against stake separation a, a curve results which is sometimes interpretable in terms of layers of differing resistivity. If the differences among the resistivity layers can be correlated with differences in geologic character of the underlying rocks at the probe site, application of the electrical resistivity method will provide a means of approximating the subsurface geology of an area.

The correlation of resistivity and subsurface geology in any area must be based upon specific data obtained either by means of resistivity tests at well sites or upon formation outcrops or both. Probes made at such sites usually enable a correlation of resistivity anomalies and known subsurface geologic conditions.

Field methods

The equipment used consists of a resistivity instrument which is essentially a potentiometer and milliammeter, a commutator, a series of dry-cell batteries to provide direct current, copper-clad steel stakes, several miles of wire on reels, hand tools, test instruments, and a winch-equipped 4-wheel drive truck.

The plan followed in conducting the field work was to start in the areas where the geologic and electrical resistivity relations of the rocks could be established, and to proceed outward to areas where the subsurface geology was unknown. Therefore, the first probes were made near the Easy Area wells and also near bedrock outcrops in the vicinity.

The initial probes provided data relative to the resistivity characteristics of alluvium, volcanics, and limestone, the rock units that are most common in the area. Other rock types such as granite and quartzite are limited in occurrence in the region and were not tested. Following the preliminary work, probes were made southward at intervals on a line near the axis of the basin. These probes provided an approximate profile of the bedrock floor of the basin. Additional probes were made, both east and west of the line where the basin was wider. It was necessary in selecting probe sites to avoid pipe lines, power lines, steel fences, rough topography or other features that could cause undesirable electrical disturbances.

Making a probe. -- A crew of four is essential in making a probe: an instrument man, a computer, and two stake men. A fifth man is desirable to maintain liaison between the instrument man and the stake men.

The stake configuration used in this survey was a modification of the double-equidistant electrode method (Heiland, 1946, p. 710). In this method four stakes are required; current is introduced through two stakes and the resulting potential difference is measured between the other two stakes.

Figure 5 shows the modified configuration used in this survey. Three of the stakes were spaced at equal distances along a straight line. For the first resistivity determination in a series, the distance a between stakes was 10 feet. Succeeding readings were made for increased stake separations in steps to as much as 1,500 feet. The instrument was set up at the center stake which was not moved during the entire probe. The fourth stake, called the "infinite stake," was set at a distance from the instrument representing infinity. This distance is usually approximately 2 miles for probes having a maximum stake separation of 1,500 feet. The infinite stake also was not moved, and sometimes the same stake position was used for several probes. In determining the resistivity value for a given stake separation a, two sets of current-potential readings are made

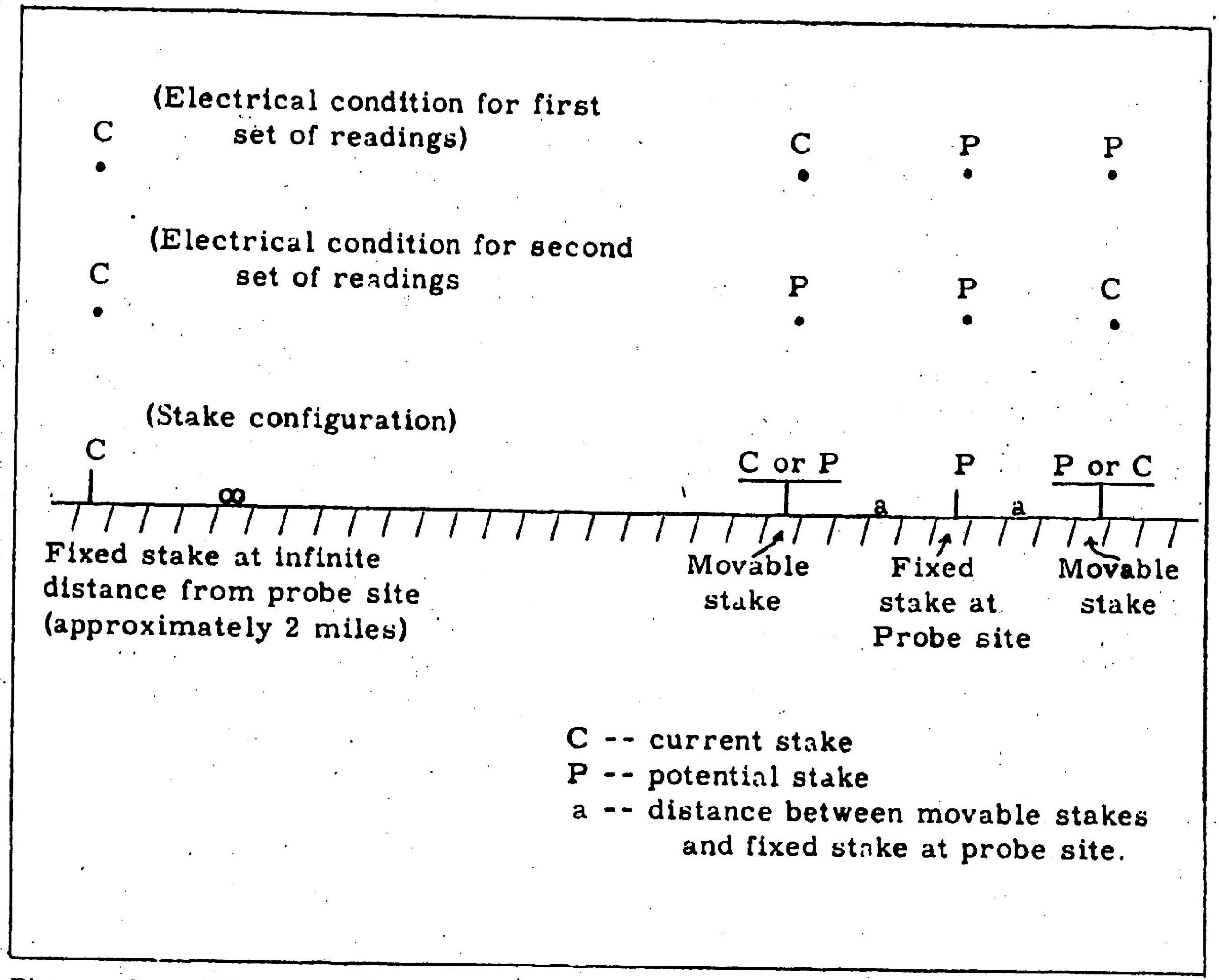


Figure 5. --Diagram showing stake configuration and corresponding electrical condition.

Following the readings for one stake separation distance, the two movable stakes are reset at a greater distance from the instrument, and the two sets of measurements are taken again. These steps are repeated until the desired maximum stake separation is reached. For the Dugway survey this distance was usually 1,500 feet.

Plotting and computing data. -- In the discussion of "Theory" it has been mentioned that the equation used to compute the apparent resistivity is $\rho = Ca\frac{V}{I}$, and that the values for ρ and a are plotted on logarithmic paper. The equation is sufficiently simple that each determination of ρ during a probe can be recorded, computed, plotted on the graph, and checked by inspection while the stakes are being moved outward for the next set of readings. A graph of one of the probes made during the survey is shown in figure 6. Three resistivity values are plotted; two, ρ_1 and ρ_2 respectively, being calculated from the two sets of readings, and the third (total) being the sum of the calculated values. The "total" curve is usually more indicative of conditions immediately below the probe site, whereas the other two curves are more likely to indicate lateral geologic changes.

Interpretation

Interpretation of a resistivity curve in terms of geology is a two-step process. First, it is necessary to interpret the curve in terms of resistivity layers and depths. The second phase of the interpretation is the identification of specific geologic conditions related to the resistivity layers.

Interpretation in terms of resistivity layers. -- A limited number of theoretically determined two- and three-layer overlay curves (Tagg, 1934;

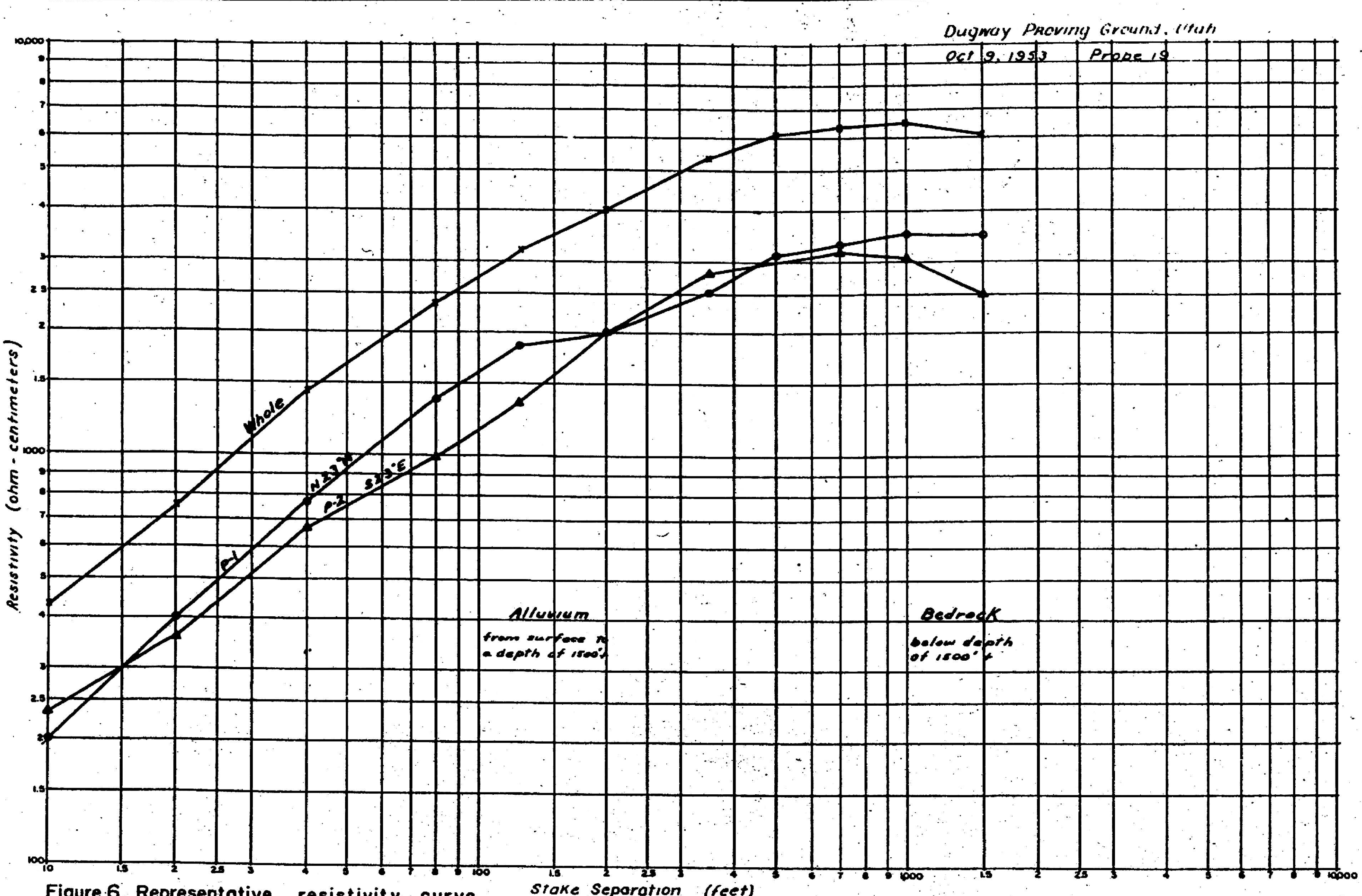


Figure 6. Representative resistivity curve.

Wetzel and McMurray, 1937) are available for use in finding the resistivities and depths of subsurface layers. These curves were computed for extensive horizontal layers of electrically isotropic material. A limited number of curves were determined for certain resistivity and thickness combinations, arbitrarily chosen from within the infinitely wide range of possible combinations. The theoretically calculated curves for these representative two- and three-layer conditions are very useful because there are many natural conditions which result in field curves approximately the theoretical curves. However, until practical methods are available for calculating curves for more than three layers of irregular shape and resistivity it will be necessary to apply empirical methods to supplement the use of the theoretical curves.

Because of the limitations of the interpretation process, field curves obtained in some areas are not interpretable. In contrast, curves from other areas may be readily interpreted and for some purposes may yield data approaching the usability of test-hole data. Obviously, resistivity surveying should be applied only to areas where satisfactory results can be anticipated.

Interpretation of resistivity data in terms of geology. -- After determining the resistivities and thicknesses of the resistivity layers, the next step is to identify the geologic condition responsible for the measured electrical qualities. Some general relations between geology and resistivity have been mentioned. The initial work, consisting of control and orientation-probing, generally indicates the quality of the resistitity-geology correlation that may be expected in the area. On the basis of a satisfactory correlation found in the preliminary probing, and confidence that this correlation obtains in the balance of the area, the survey is extended away from the control sites.

A satisfactory correlation, in which geologic conditions are interpretable, does not necessarily require an exactly constant relation between resistivity and geology, but can range within certain limits. Seldom do the boundaries of the resistivity and the geologic layers coincide exactly. However, for most ground-water development purposes, a knowledge of the exact depth is not required. For example, in an area where the maximum depth of wells is 600 feet, it is relatively unimportant whether the bedrock is at a depth of 1,000 feet or 1,100 feet. The measured resistivities associated with geologic formations may also vary within limits from one probe site to the next without changing the quality of the final interpretation. Such changes may be caused by facies changes or instrumentation. Radical changes of the curves from one probe site to another, however, provide cause for suspecting radical changes of geology. In this case it is usually necessary to resort to a knowledge of the local geology to explain the anomaly satisfactorily.

Results of the survey

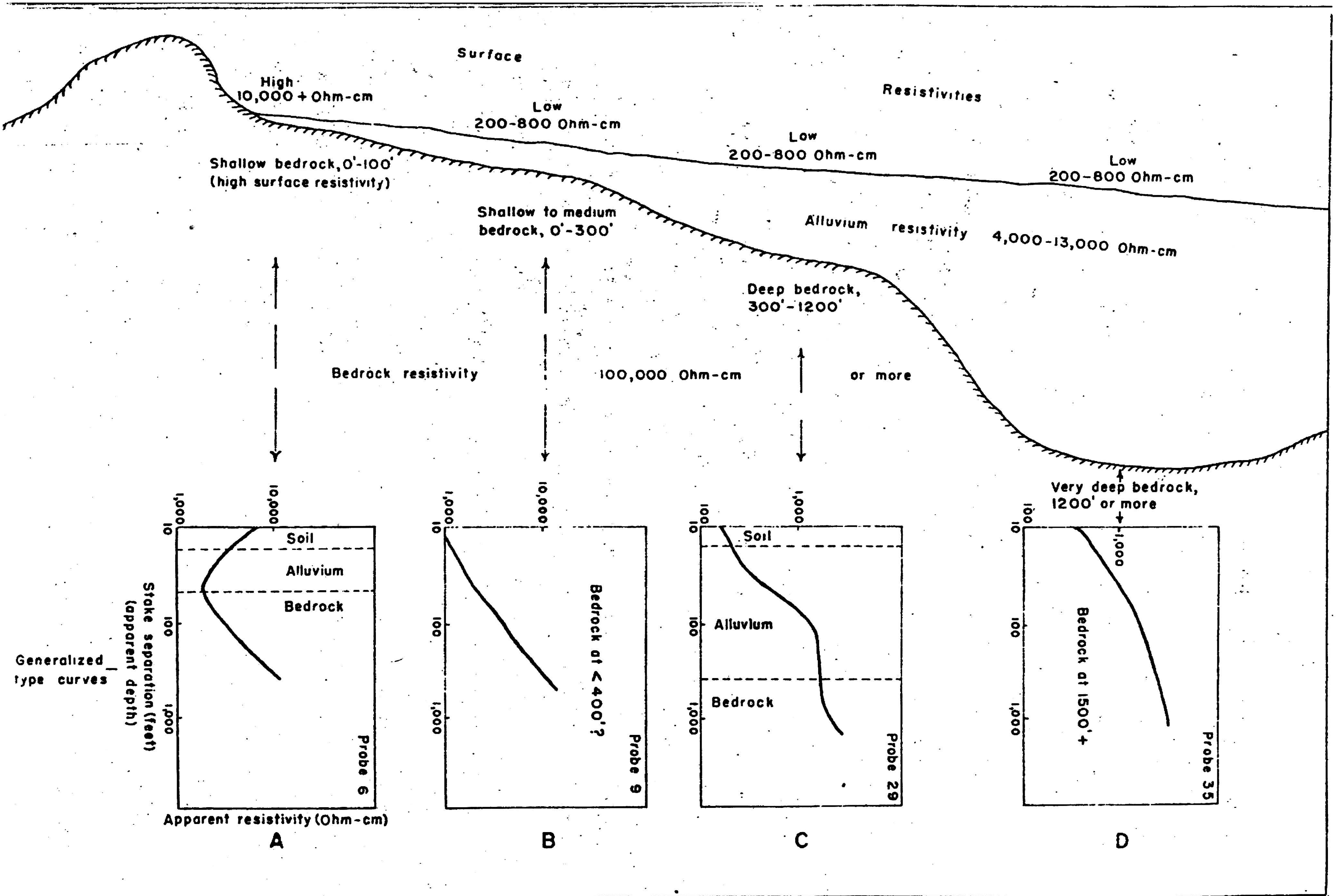
Characteristic resistivity curves obtained in the Dugway area

In the Dugway area the usual low alluvium resistivity-high bedrock resistivity contrast is present, but the surface resistivity in most of the basin is very low, typically less than 500 ohm-cm. This low surface resistivity is responsible for several curve types obtained in the shallow bedrock area, which are sometimes difficult to interpret. Possibly this low value is related to salt contained in the Lake Bonneville deposits covering the area.

In contrast to the low surface resistivities noted in most of the basin, the surface resistivity in the very shallow bedrock areas near the boundary of the basin is relatively high (7,000 ohm-cm at the site of probe 7). The higher resistivity of the surface material in these areas is probably related to their position on slopes near the outcrops, where coarser material has been deposited and salts have been leached. These conditions cause the curves to start at a higher resistivity, continue to level or perhaps drop, due to the influence of the alluvium, then rise sharply, owing to the effects of the shallow bedrock. Such a curve is shown in figure 7-A. The steep upward trend of the curve is typical of the slope caused by the bedrock. If the probe were extended to greater depths the curve would eventually level off asymptotically at the resistivity value of the bedrock. Curves of this type are common in other parts of the basin and range physiographic province.

Where the depth to bedrock is not more than approximately 300 feet, and the resistivity of the surface soil is low (fig. 7-B), the initial upward trend of the resistivity curve is caused by underlying alluvium of moderately high resistivity. In some instances bedrock beneath the alluvium begins to exert an influence before the curve can level off asymptotically, and the upward trend continues toward the bedrock resistivity value. In these instances it is impossible to determine closely the point on the curve where bedrock effects supercede those of the alluvium.

Where bedrock is at depths between 300 and 1,200 feet, the curve starts low, at the resistivity of the surface material, rises and begins to level at the asymptotic resistivity value of the alluvium, then rises again owing to the influence of the highly resistive bedrock (fig. 7-C). A curve of this type is difficult to interpret unless it has completely levelled asymptotically before rising again.



…ure 7.- Electrical resistivity type curves related to bedrock depths along hypothetical cross section.

In the areas of thick alluvium where bedrock is at depths greater than 1,500 feet (fig. 7-D) the typical curve starts at a low resistivity (200 to 800 ohm-cm) representing the value of the surface soil. The curve then rises rapidly and levels off asymptotically at the resistivity value of the alluvium (5,000 to 8,000 ohm-cm.) This is a two-layer curve, representing a thin surface layer of low resistivity underlain by a massive layer of alluvium, and the curve is readily interpretable.

The deep bedrock curve is modified in some cases by the effects of a deep third layer having a lower resistivity which causes the curve to take a downward trend near the end. Massive clay or saline water could be responsible for the lower resistivity layer at depth.

Nearly all the curves obtained during this survey were of one of the general types described above or composites of these types.

Results applicable to the ground-water problem

This survey provides data on the size of the alluvium-filled basin and the resistivity of the alluvium. The data should be of practical use in locating well sites, indicating quality of water, and in evaluating the over-all ground-water supply of the Easy Area basin. Permeability information obtained from future drilling and pumping tests may show the relation between permeability and resistivity. Probes in the Fox Area basin indicate several places where bedrock is deep. A single probe in Skull Valley indicates thick valley fill. The results of the survey are further discussed under the headings of "Basin size and shape" and "Resistivities related to ground water" and are shown on the accompanying map (pl. 2).

<u>Basin size and shape</u>. -- The primary purpose of the survey was to show the size and shape of the Easy Area as well as the size of the alluvium-filled openings between the discontinuous hills and mountains

that border the basin. This information, in conjunction with sufficient hydrologic data, would indicate among other things the amount of ground water within the basin and might supply additional information concerning the movement of ground water into or out of the basin through the gaps in the hard rock boundary.

Depths to bedrock interpreted from the resistivity probes are numerically shown on the map at each of the probe sites. The 1,500-foot maximum stake separation used for most of the probes is usually sufficient for obtaining fairly definite depth data within the 600 to 1,000-foot depth range. The resistivity curves approach or exceed their interpretable limits in the 1,000 to 1,500-foot range; so that within these limits the interpreted depth to bedrock is stated as the "minimum depth plus," for example, "1,200'+" at probe site 24. In an effort to incorporate a safety factor in the data, interpretations were conservatively made and it is unlikely that bedrock will be encountered at the probe sites during drilling within the stated depth limits.

Bedrock depth is also indicated on the map by iso-depth lines. The position of these lines is based on interpreted depths at probe sites, location of nearby outcrops, and assumptions concerning bedrock slopes. Because adequate depth control is lacking except at probe sites or outcrops, the contours are intended to indicate generalized conditions only. These data are necessarily less conservative than the numerical depth values shown at the probe sites. However, no data were extrapolated for more than a half-mile from probe sites. For instance, the 500-foot iso-depth line is not extended into the southeastern part of the Easy Area basin because no probes were made there.

Easy Area basin. The survey indicates that the deepest and broadest part of the basin is about 5 miles southeast of the Easy Area installation. Some of the probes in this deep area show no indication of bedrock within the 1,500-foot depth limits, and there is at least 9 square miles within the 1,000-foot iso-depth line.

Southward from the deepest part, the basin narrows to a width of less than two miles and has a depth exceeding 1,200 feet. Although probing was not continued south of probe 28, there is no indication that a deep opening does not connect the Easy Area basin with the Government Wash basin farther south. Northwest from the deepest part, toward Easy Area, the basin becomes narrower and shallower, the average depth to bedrock being about 500 feet.

Horizontally the basin is limited in extent by hardrock outcrops and shallow subsurface hardrock connections across the gaps between some of the outcrops. There is a possibility of ground-water movement into or out of the basin through gaps where the bedrock may be below the water table. The boundary line is discontinuous at these openings. Water in the Easy Area wells is at a depth of about 80 feet and in the well at the southern end of the basin at 192 feet. The direction of ground-water movement through any of these gaps would depend upon the slope of the water table.

A series of limestone and volcanic hills lies between Easy Area basin and Skull Valley. The study of a detailed map and aerial photos, and a brief geologic field reconnaissance indicated that only 5 of the gaps between the hills in this series might permit movement of ground water into or out of the basin. These five gaps were studied in more detail and one was eliminated on the basis of the presence of scattered small outcrops. Geophysical measurements indicated that the gap at the site of probe 11 was closed, and that two of the gaps, containing probe sites 12 and 13, and probe sites 5 and 10 might be open. The size of the fifth gap, north of probe 1, was not determined because of the lack of pertinent geologic evidence, and because the irregular topography, and the presence of grounded steel fences made probing impractical. The resistivity observations indicate that the gap in the vicinity of probe sites 5 and 10 is about ½ mile wide and about 300 feet deep and that the gap farther south at probe sites 12 and 13 is about 300 feet deep and about 0.5 mile wide.

On the southeast side of the basin, directly east of probe 20, are two related gaps having a total width of about 1 mile. Although no probes were made here, it seems probable, because of the width of the gaps, and the lack of geologic evidence to the contrary, that the depth to gedrock is several hundred feet.

he opening at the extreme south end of the basin is 2 miles wide, and the depth to bedrock is 1,200 feet or more at the probe sites. At the well, approximately 0.5 mile southwest of probe site 28, water is at a depth of 192 feet. The combined geophysical-hydrological data indicate that there is 1,000 feet or more of saturated alluvium in this pass that connects the Easy Area basin with the Government Wash basin to the south.

The pass between the Davis and Little Davis Mountains, southwest of probe site 27, is about 0.8 mile wide, but bedrock here is probably too shallow to permit any large movement of ground water. Resistivity probes could not be made in the pass because of terrain irregularities, but several inconspicuous outcrops were found near the center of the gap. The basin boundary line is shown here as a dashed line with a (?) mark.

There is a topographic divide between Easy and Fox Areas, along a line extending from the Little Davis Mountains northwdst to the Cedar Mountains. Geologic investigation indicated that the surface divide was a reflection of a shallow hardrock divide, Probe 33 was made along this line and confirmed the presence of the suspected hardrock barrier, On the basis of the combined geologic-geophysical evidence the gap is considered closed to appreciable ground-water flow and is shown as such by a heavy line having two small breaks.

Fox Area. Fox Area, about a mile west of Easy Area, is on the northeast side of a small basin which is separated topographically from Easy Area by a low ridge of limestone and lake-shore deposits. This ridge probably acts as a barrier to interbasin ground-water flow.

As there is no history of drilling in the area, four probes were made in the basin to determine the depth to which wells might be drilled before encountering bedrock. At three of the probe sites the investigation indicated that bedrock lies at depths of more than 500 feet. The fourth probe is inconclusive. Probes 31 and 32, nearest the built up area, show the most faverable bedrock depth condition; at these two sites the depths appear to be in excess of 800 and 900 feet respedtively. At the site of probe 29, the depth to bedrock is probably at least 600 feet.

Skull Valley. Probe 35 was made in Skull Valley, approximately 4.5 miles east of Easy Area, to determine the thickness of valley fill. The resistivity curve obtained at this site showed no bedrock influence, within the 1,500-foot depth limit of the probe.

Resistivities related to ground water. -- Interpretation of the geophysical data indicates the resistivity as well as the depth of subsurface layers. Primarily this survey was concerned with the determination of depth to bedrock.

However, alluvium resistivities which might be considered a by-product, are in many cases valuable as indicators of ground-water conditions. The resistivities of the alluvium are shown on plate 2 by columnar logs. These represent the resistivities from the surface either to bedrock or to the effective depths of the probes. Some of the columnar logs also show the resistivities of the bedrock.

Alluvium resistivity has more hydrologic significance than bedrock resistivity. In some localities where the various bedrock types have known and measurable resistivities, it is possible to differentiate areas underlain by the several rock types. However, in the Dugway area, bedrock resistivities were typically in excess of 100,000 ohm-cm, and as differentiation of rock types within this high range is usually difficult and as the information was not pertinent, it was not attempted during this survey.

Resistivities shown for the alluvium should be considered as an average within the depth limits shown. Within these resistivity depth zones there are certainly individual layers of greater and less resistivity than that interpreted for the whole zone, and accordingly the hydrologic quality implied by the average resistivity value should be considered as a composite quality resulting from the presence of numerous layers having hydrologic characteristics varying within a certain range. Near-surface or thick resistivity layers can be individually identified better than deeper or thinner ones.

Alluvium resistivity in the Basin and Range province is commonly related to the clay content, the amount of cementation, and the salinity of the contained water. Clay and saline water have a low resistivity; that of cemented alluvium usually is relatively high. In an area where no well-log data are available for geologic control, a low resistivity might indicate either clay or saline water or both; characteristics unfavorable for the development of large quantities of good-quality water. A high resistivity indicates water of low salinity and suggests the relative absence of clay. However, cementation which would adversely effect permeability may or may not be present.

Easy Area basin. Measurements obtained during the survey show that in most of the Easy Area basin the saturated alluvium below the water table has a fairly high resistivity. Alluvial resistivities discussed in this report, unless otherwise stated, refer to those of the saturated valley fill below the water table. The average resistivity for this material is approximately 6,000 ohm-cm. The lowest value was 1,000 ohm-cm, measured at probe site 17 and the highest was 13,000 at site 22.

There is apparently some pattern to the areal resistivity distribution within the Easy Area basin, although the geologic reasons for the distribution are not all apparent at the present time.

The alluvium in the narrow, tongue-like northwestern part of the basin has a medium-high average resistivity of about 6,000 ohm-cm. This elongated area is separated from the wide central part of the basin by a northeast-trending zone having a low average resistivity of about 2,000 ohm-cm. Within this zone there is also a rapid southeastward increase in the depth to bedrock between probes 16 and 17.

Resistivities of the alluvium in the major portion of the basin, southeast of the low resistivity zone, are higher than any others measured during the survey. Resistivities in this large area ranged from 6,000 ohm-cm at probe 18 to 13,000 at probe 22, and averaged about 9,000 ohm-cm over the whole area.

Some indication of the quality of ground water in the Easy Area basin is furnished by the relatively high resistivities of the alluvium in that area. As saline water is not highly resistive, it is concluded that the ground water must have a relatively low salt content.

The relatively high resistivities of the alluvium in parts of the Easy Area basin idicate that there is not much clay present. This condition alone would suggest a relatively high permeability, but the factor of cementation also must be considered. The proximity of mountains to the deeper part of the basin, where alluvium resistivities are highest, should be conducive to the deposition of coarse-grained sediments, but the degree of post-depositional cementation is not known at present. Final interpretation of the alluvium resistivity values in terms of permeability must await additional geologic control such as might be available from drilling logs.

Artesian conditions such as might result from the confinement of a gravel aquifer by clay are sometimes identifiable by resistivity measurements if the formations are sufficiently massive or shallow. The possibility of identification is provided by the contrasting resistivities of the formations. However, the curves obtained during this survey did not exhibit such identifiable anomalies.

Fox Area basin. The limited geophysical work in Fox Area shows an average alluvium resistivity of about 2,000 ohm-cm which is much lower than the average of approximately 6,000 in the Easy Area basin. This lower value may be due either to more saline water or to a larger proportion of clay and a correspondingly lower permeability.

Skull Valley. The single probe in Skull Valley shows an average alluvium resistivity of about 4,500 ohm-cm. This value is slightly lower than the average for the Easy Area basin.

The foregoing data on the resistivity of the alluvium give some indication of the quality of the ground water. They also suggest a variety of permeability conditions, information that may be of value in solving hydrologic problems when more supporting data become available.

SUMMARY AND CONCLUSIONS

The geologic and geophysical reconnaissance of the Dugway Proving Ground and adjacent areas has yielded information concerning the principal features of the geology of the region as it relates to the occurrence of ground water, the probable minimum thicknesses of valley fill in most of the areas of present major interest, the source and directions of movement of ground water in some parts of the region, the characteristics of the aquifers underlying Easy Area, the relation of declining water levels in the wells in Easy Area to increased pumping, and the pattern of chemical quality of ground waters in the region.

Conclusions that appear to be warranted in the present state of knowledge include the following:

1. The prevailing aridity of the climate precludes the possibility of large-scale recharge in years of normal precipitation.

2. Recharge to subsurface aquifers occurs principally as runoff from the mountains, passes across, and sinks into, coarse, permeable lakebed deposits (shore facies) of the Lake Bonneville group. Direct recharge from precipitation over the lakebeds occurs but is volumetrically less important.

3. Aquifers are lenticular, discontinuous, but interconnected. In consequence, although general areas (horizontal) and zones (vertical) can be indicated as relatively favorable or unfavorable for the development of wells, only test drilling can demonstrate the presence or absence of an aquifer or aquifers capable of yielding water in large quantity at any selected well-site.

4. Locally at least, layers of low permeability in the valley fill confine ground water under hydrostatic pressure and give rise to artesian conditions.

5. Individual wells may prove to be capable of delivering 500-1,000 gallons per minute over periods of several months at least, without damaging drawdowns resulting. Ultimately, however, existing wells, at least, must be shut down while water levels in the aquifers recover. Rates of recovery will depend largely on rates of recharge. These, in turn, will depend in greatest measure, upon precipitation. A cycle of wet years will alleviate certain problems, a cycle of years of subnormal precipitation will aggravate the problems.

6. Chemical analysis of waters from the region indicate high mineralization in Baker and Granite Peak areas and moderately high mineralization at all other sources sampled. Water from wells now used for culinary supply is acceptable within minimum standards of the U. S. Public Health Service. If the quality should deteriorate with additional use, the water may become inacceptable in certain constituents, especially chloride, sulfate, and perhaps nitrate.

7. Geophysical probing has given a general idea of the configuration of bedrock (or an equally resistive basement) in the principal valley areas being considered for development. The probes indicate that not less than than 500 feet, and in some places not less than 1,500 feet, of valley fill underlie land surface. The geophysical study also tends to confirm

the existence of a barrier ridge which hydrologically separates the Easy Area and the area to the south from the extension of Skull Valley farther east (see geophysical map, pl. 2).

8. The Easy Area basin, as shown on plate 2 is large, indicating a correspondingly large storage capacity. In the deeper parts, bedrock lies at depths greater than 1,500 feet and within the basin there is an area of approximately 9 square miles where wells probably can be drilled to depths of 1,000 feet or more. Throughout most of the basin, including much of the area within the military reservation, wells can be drilled in alluvium to depths of at least 500 feet. In Fox Area, bedrock is at some places more than 800 feet deep, and at the probe site in Skull Valley, alluvium extends to a depth of more than 1,500 feet.

9. The relatively high resistivity of the alluvium indicates that the ground water in most of Easy Area basin is of low salinity. Highly saline water has a low resistivity.

10. The indication of permeability is indefinite because the high alluvium resistivities common in the area can correspond either to a lack of clay or to the presence of cementation. These conditions can be responsible for either high or low permeability respectively. Lithologic data obtained by future drilling may provide sufficient information to permit the use of the resistivity data to predict permeability in most of the surveyed area.

11. Wells at the north and south end of the area surveyed have water at respective depths of about 80 and 192 feet, and since it is believed that the water-table slopes uniformly between these wells, it is considered probable that the thickness of the saturated alluvium is 1,300 feet or more.

12. Several openings in the bedrock boundary of the basin are indicated

to be sufficiently deep to permit ground-water movement through them. Whether the movement is into or out of the basin depends on the water-table gradient. The position and size of the openings as well as the water-table gradient influences the direction and magnitude of ground-water flow within the basin.

13. The deeper parts of the basin are outside the military reservation. All the reservation land southeast of Easy Area lies within a narrow northwestward extension from the main part of the basin, and much of it is underlain by bedrock at depths of about 500 feet. In planning the development of ground-water resources, care should be taken to avoid locating wells near the bedrock borders of the basin. Pumping from wells so located is liable eventually to cause abnormal drawdown.

14. Probing indicates that wells in Fox Area can be drilled to depths of as much as 800 feet in alluvium, but the resistivities are lower than in Easy Area, suggesting either the presence of more clay or of more saline water.

15. The geophysical results will become more useful as more geologic and hydrologic information is made available by drilling operations. An attempt should be made to correlate the resistivity indications with future data pertaining to bedrock depth, lithologic changes, permeability of aquifer, and quality of water. It is probable that some adjustments of the ideas presented here will be possible when additional control is supplied.

16. Geologic conditions in other parts of the Proving Ground will be different from those in the vicinity of Easy Area and in some respects may be less favorable for the application of electrical resistivity methods because of possible adverse conditions of salinity and sedimentation.

17. Many more data will be needed before the water-producing potentialities of the region can be assessed in any detail.

18. A cautious, comprehensive program of drilling test wells, and subsequently testing their performances, of assessing the chemical quality of all waters developed during drilling of wells, and of continuing and expending observation of fluctuations of the water table, should provide data that will permit maximum development of ground-water resources in the Dugway Region.

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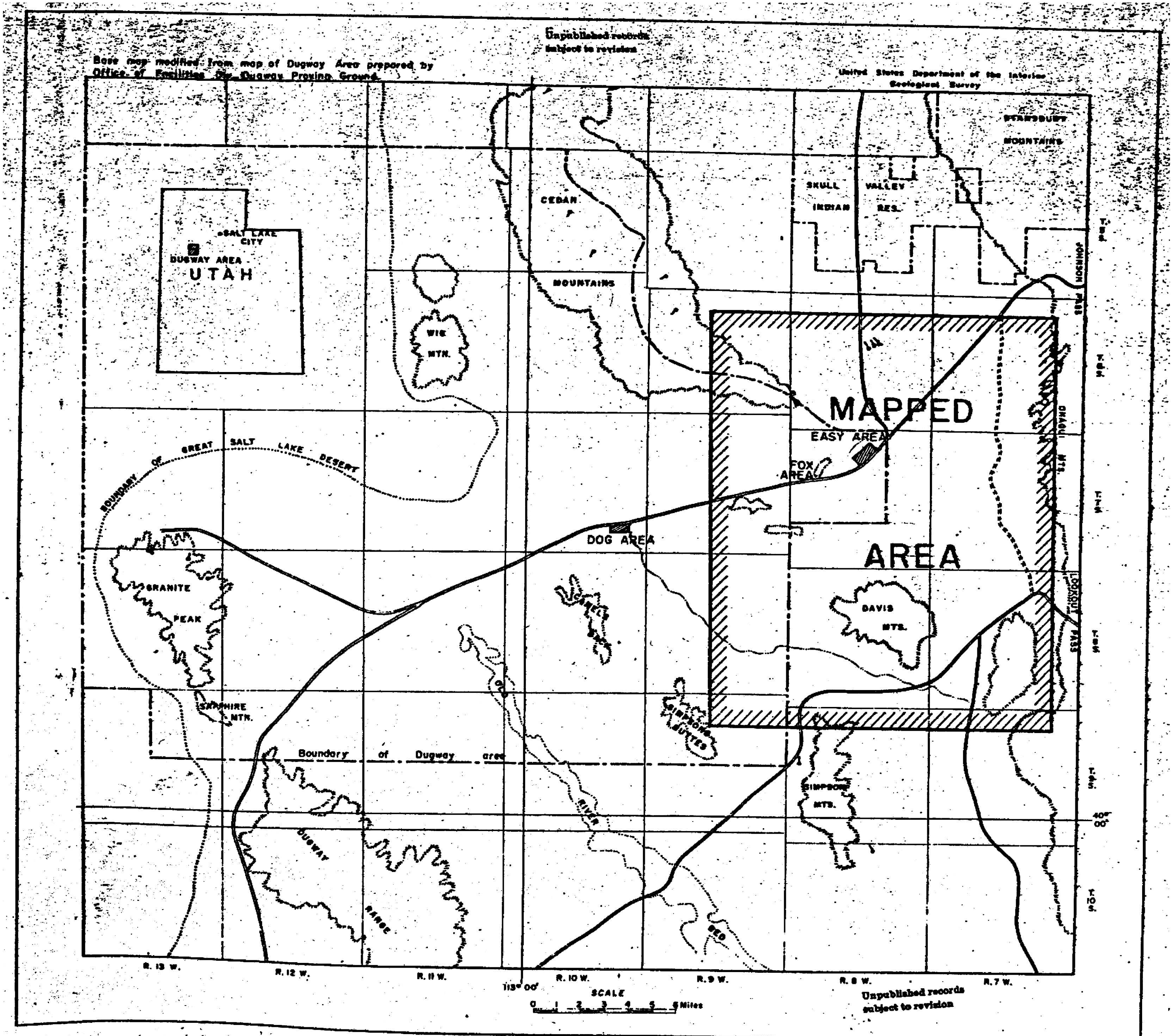
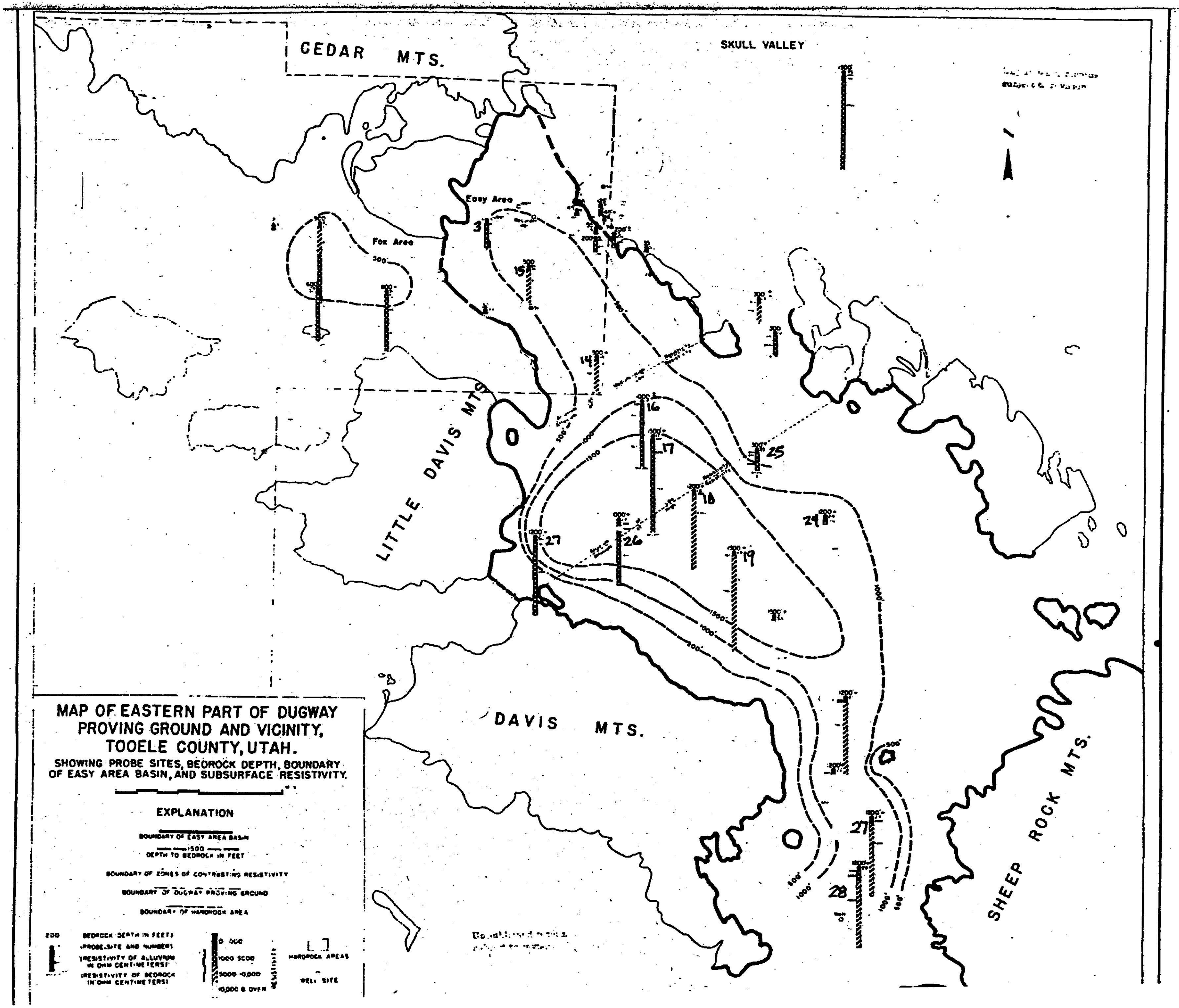


Unpublished records subject to revision
Base map modified from map of Dugway Area prepared by Office of Facilities Div. Dugway Proving Ground.
United States Department of the Interior Geological Survey
STANSBURY MOUNTAINS
SKULL VALLEY INDIAN RES.
CEDAR MOUNTAINS
SALT LAKE CITY
DUGWAY AREA
UTAH
WIG MTN.
JOHNSON PASS
MAPPED AREA
EASY AREA
FOX AREA
DOG AREA
DUGWAY MTS.
BOUNDARY OF GREAT SALT LAKE DESERT
GRANITE PEAK
SAPPHIRE MTN.
DAVIS MTS.
LOOKOUT PASS
SIMPSON BUTTES
Boundary of Dugway area
SIMPSON MTS.
DUGWAY RANGE
RIVER BED
40° 00'
R. 13 W.
R. 12 W.
R. 11 W.
113° 00'
R. 10 W.
R. 9 W.
R. 8 W.
R. 7 W.
SCALE
0 1 2 3 4 5 6 Miles
Unpublished records subject to revision



MAP OF EASTERN PART OF DUGWAY PROVING GROUND AND VICINITY, TOOELE COUNTY, UTAH.
SHOWING PROBE SITES, BEDROCK DEPTH, BOUNDARY OF EASY AREA BASIN, AND SUBSURFACE RESISTIVITY.
EXPLANATION
BOUNDARY OF EASY AREA BASIN
1500
DEPTH TO BEDROCK IN FEET
BOUNDARY OF ZONES OF CONTRASTING RESISTIVITY
BOUNDARY OF DUGWAY PROVING GROUND
BOUNDARY OF HARDROCK AREA
200
(BEDROCK DEPTH IN FEET)
(PROBE SITE AND NUMBER)
(RESISTIVITY OF ALLUVIUM IN OHM CENTIMETERS)
(RESISTIVITY OF BEDROCK IN OHM CENTIMETERS)
1000 5000
5000-10,000
10,000 & OVER
RESISTIVITY
HARDROCK AREAS
WELL SITE
CEDAR MTS.
SKULL VALLEY
Easy Area
Fox Area
LITTLE DAVIS MTS.
DAVIS MTS.
SHEEP ROCK MTS.
3
15
14
16
17
18
19
24
25
26
27
28