STATE OF NEVADA

DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES

Carson City, Nevada

WATER RESOURCES BULLETIN NO. 25

GEOPHYSICAL STUDIES IN NEVADA RELATING TO HYDROGEOLOGY

I. SEISMIC-REFRACTION AND EARTH-RESISTIVITY INVESTIGATION OF HYDROGEOLOGIC PROBLEMS IN THE HUMBOLDT RIVER BASIN, NEVADA

By

William W. Dudley, Jr., and Lyle D. McGinnis

(Reprint of D.R.I. Technical Report No. 1, in cooperation with the Nevada Department of Conservation and Natural Resources)

II. SEISMIC STUDIES OF THREE AREAS IN NORTHERN NEVADA

By

Lyle D. McGinnis and William W. Dudley, Jr.

(In cooperation with the Nevada Department of Conservation and Natural Resources)

III. EXTENSION OF THE EAST RANGE FAULT BY GRAVITY EXPLORATION

By

Keros Cartwright, J. N. Swinderman, and J. I. Gimlett

(In cooperation with the Mackay School of Mines and State Department of Conservation and Natural Resources)

(D.R.I.—Technical Report No. 2)

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FOREWORD

This report, the second in the Technical Reports series of the Desert Research Institute, includes three papers which report the results of geophysical studies in Nevada.

One of these papers (Part I of this report) was published in 1962 but is now out of print and is still in demand. For this reason and in order to present all of our geophysical work under one cover, we reprint it here.

The second paper in this report describes the concluding operations in geophysical studies by the Desert Research Institute under the Underground Water Act (Chapter 166, 1961 Nevada Statutes) to determine the value of geophysical methods in hydrologic studies in Nevada.

The third paper describes a study by personnel of the Mackay School of Mines which was accomplished in cooperation with the Nevada Department of Conservation and Natural Resources as a part of the Humboldt River Research Project. This paper is included here because the work is so closely related to the geophysical work supported by the Institute and the Department of Conservation and Natural Resources.

We believe that these studies clearly indicate the value of geophysical exploration methods in ground water and related fields in Nevada. It is obvious that each method or a combination of methods furnish valuable knowledge, especially in reconnaissance studies. They will not alone yield as much detailed or as accurate information as test drilling. However, they furnish data that can result in reduction of test drilling as well as allow considerable extrapolation and extension of knowledge gained by test drilling.

Another objective of our study was to develop adequate information to advise the Department of Conservation and Natural Resources as to whether a geophysical service should be set up within the Department for hydrologic exploration. Our studies have conclusively shown that:

1. Geophysical equipment and personnel are expensive in relation to the value of data usually acquired in hydrologic exploration.
2. The data acquired do not usually yield conclusive results.
3. A geophysical expert is needed to reduce and interpret the field data.
4. As is pointed out in the preceding paragraph, geophysical methods primarily allow closer definition of areas of required test drilling thus reducing the number of test holes needed and allows extension of test hole data into areas not test drilled.

We believe that the probable volume of geophysical exploration needed for the next decade or so by the department does not justify acquisition of equipment and personnel. Rather we would recommend that such exploration be contracted, preferably with the geophysical team in the Nevada State Bureau of Mines or with outside organizations.

We wish to express the gratitude of the Desert Research Institute staff and the authors of this paper for the wholehearted cooperation and advice furnished by Mr. Hugh A. Shamberger, Mr. George Hardman, and others on the staff of the Nevada State Department of Conservation and Natural Resources. Without this assistance, the generous loans of equipment from the Illinois State Geological Survey, and the support of the University of Illinois and the Mackay School of Mines of the University of Nevada this project could not have been completed as rapidly and successfully as was the case.

In addition to those mentioned in the foreword to Part I, valuable assistance in the field was given by Mr. Noel Usemack of the University of Illinois and Mr. Fred Constant of Princeton University.

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January 1, 1964

ABSTRACTS

SEISMIC-REFRACTION AND EARTH-RESISTIVITY INVESTIGATION OF HYDROGEOLOGIC PROBLEMS IN HUMBOLDT RIVER BASIN, NEVADA

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ABSTRACT

Experiments with seismic refraction and electrical resistivity instruments were conducted in the vicinity of Winnemucca, an area in which the detailed geology is well known, to determine the value of these geophysical methods in ground-water studies.

The seismic refraction method can be used to predict depth to bedrock and thickness of valley fill with considerable accuracy. Determination of the lithology and hydrologic characteristics of earth materials is less certain.

The earth resistivity method is not as useful as seismic refraction but it may aid in interpreting lithology if used with sufficient control.

Conjunctive use of the two methods does not produce as much useable information as test-well drilling but can result in material reduction of the number and depth of test wells necessary for acquiring needed information.

*Report is based upon a thesis submitted in partial fulfillment of the requirements for the M.S. degree at the University of Illinois.

SEISMIC STUDIES OF THREE AREAS IN NORTHERN NEVADA

by

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ABSTRACT

This report presents the results of 18 experimental seismic refraction and reflection stations in Northern Nevada during July of 1962. An attempt was made to evaluate the reflection technique in deep, sediment-filled valleys using shallow shot holes and various arrays of multiple shot patterns. It was found that reliable reflections could not be obtained with consistency although in some locations fair to weak reflections could be utilized when bedrock depths were known through refraction results. The refraction method proved useful, as previously illustrated by the authors (1962), in accurately defining the depth to the water table and the attitude and depth of the bedrock surface.

On the basis of refraction results the northward extension of the East Range border fault, southwest of Winnemucca, suggested by Cartwright et al. (1962), has been confirmed, and a relief of 1,200 feet on the bedrock surface is indicated by reflection shooting.

A stream channel, which once drained Granite Basin in northwestern Pershing County and which is now filled with a thick sequence of unconsolidated sediments, was located by use of a refraction profile. The channel may unite hydrologically Granite Basin with Black Rock Desert to the east.

A depth to bedrock of 720 feet was determined in the center of Reese River Valley about 14 miles south of Battle Mountain by both refraction and reflection techniques. Time-distance curves of refraction stations shot across topographic scarps on the east side of the valley give evidence of a flat high-velocity layer at a depth of 200 feet.

EXTENSION OF THE EAST RANGE FAULT BY GRAVITY EXPLORATION

by

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ABSTRACT

A gravity survey was undertaken to explore the possibility of a bedrock high in the Rose Creek constriction of Humboldt River. The presence of the high is shown by the gravity data which indicate that it is bounded on the west by an extension of the East Range Fault. A refraction seismic survey and a drill hole verify the gravity results. The depth to the lowest point in the high is estimated to be 230 feet below the present level of the river.

DESERT RESEARCH INSTITUTE
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SEISMIC-REFRACTION AND EARTH-RESISTIVITY INVESTIGATION OF HYDROGEOLOGIC PROBLEMS IN HUMBOLDT RIVER BASIN, NEVADA

By

WILLIAM W. DUDLEY, Jr., and LYLE D. McGINNIS

PART I OF TECHNICAL REPORT NO. 2
(REPRINT OF TECHNICAL REPORT NO. 1)

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FOREWORD

This report is the first in an anticipated series, entitled "Technical Reports of the Desert Research Institute," which will promptly make public the results of certain scientific studies conducted by the staff of the institute. The work reported upon herein was made possible by funds appropriated by the 1961 Nevada State Legislature (Chapter 166, 1961 Nevada Statutes) to be used for research on underground water problems in the State. Under this statute the Director of the State Department of Conservation and Natural Resources "shall make such funds available to the Desert Research Institute for such research studies as are mutually agreed upon."

Vast areas in the State are underlain by alluvial fill of unknown depth, much of which may be highly permeable and may contain large supplies of useable ground water. Only a few poorly spaced wells penetrate these sediments and, since the logs and pumping records of these wells are our chief source of knowledge, we know very little about the ground-water supplies and the geological framework. A method to assist us in location of wells and evaluation of ground-water supplies where adequate well data are lacking is sorely needed. In order to determine the usefulness of geophysical methods for this purpose members of the staff of the Desert Research Institute suggested conducting experiments with seismic-refraction and electrical-resistivity instruments in a well-known area where much geologic control was available.

Extensive test-well drilling by the U.S. Geological Survey and detailed geologic mapping by the University of Illinois geologists had just been completed in the Winnemucca area as a part of the Humboldt River Research Project. Thus an area ideally suited for testing the geophysical methods was readily available.

Early in the summer of 1961 arrangements were made to rent equipment belonging to the Illinois State Geological Survey, to hire a geophysicist from the survey's staff to supervise the work, and to arrange for the University of Illinois graduate students with some experience in geophysics to operate the equipment. Operations in the field were carried on from June 20 to September 8 and compilation, interpretation and report writing were completed in January 1962.

The results of the study given in this report show that the seismic-refraction method can be used to predict depth to bedrock and, therefore, thickness of the valley fill, with considerable accuracy but that identification of the lithology of the bedrock and the valley-fill materials is less sure. Neither can the seismic-refraction method be used to clearly determine hydrologic characteristics of the geologic materials.

The earth-resistivity method is not as useful as seismic refraction but it may aid in interpreting lithology if used with sufficient control. Conjunctive use of the two methods cannot produce as much valuable information as test-well drilling but it can result in reduction of the amount of test drilling necessary for acquiring needed information. Thus reconnaissance exploration with these methods early in an investigation aids greatly in defining areas where test drilling is most needed and reduces the overall number of test holes needed.

I should like to express here the gratitude of the Desert Research Institute staff and the authors of this paper for the wholehearted cooperation, valuable advice, and support furnished by Mr. Hugh A. Shamberger, Mr. George Hardman, and many others on the staff of the Nevada State Department of Conservation and Natural Resources. Without this assistance, the generous loans from the Illinois State Geological Survey, and the support of the University of Illinois and the Nevada Bureau of Mines, this project could not have been completed so rapidly and successfully.

Thanks are due many persons who aided in the field work and the preparation of this report.

Mr. Paul C. Heigold, University of Illinois, ably managed the field investigation during the authors' absence. Valuable field assistance was given by Mr. Adel A. R. Zohdy, of the University of California at Berkeley. Mr. Eugene Zeizel, Florida State University, and Mr. Lee B. Maxey, University of Montana, skillfully completed the many routine tasks associated with seismic and resistivity measurements.

Mr. John W. Hawley and Mr. William E. Wilson, both of the University of Illinois, described the geologic framework within which the field program was planned and gave freely of their time to criticize the various stages of the manuscript.

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April 1, 1962

INTRODUCTION

During the summer of 1961 reconnaissance shallow seismic-refraction and earth-resistivity studies were conducted in the Winnemucca Unit of the Humboldt River Basin in Northwestern Nevada to determine the value of these methods in hydrogeologic investigations in the Basin and Range Province. The combined use of the seismic and resistivity methods might be expected to provide the following information necessary to hydrogeologic studies: The shape of the bedrock valley; the lithology of the valley-fill sediments; and the depth to the water table.

Geologic maps of parts of the area have been published by Compton (1960), Ferguson, Muller, and Roberts (1951 and 1952), and by Willden (1961). In addition geologic studies conducted by personnel of the Humboldt River Project were available. The work and comments of J. W. Hawley, Keros Cartwright, and W. E. Wilson were of particular value.

In the Winnemucca Unit the Humboldt River Valley has been carved in sedimentary, metamorphic and igneous rocks of Paleozoic and Mesozoic age; in Tertiary lavas and partly consolidated sediments; and in Quaternary lavas and unconsolidated sediments. Lower and upper Paleozoic units include quartzite, slate, limestone, chert, and volcanic rocks. Triassic formations in the area are of similar lithology but are less metamorphosed than the Paleozoic rocks, except where they are altered by Jurassic (?) intrusive bodies. Rhyolitic lava and associated tuff dominate the Tertiary sequence, but sand and gravel, probably of fluviatile origin, also occur near Winnemucca. Quaternary-Tertiary (?) basalt flows are exposed and are present beneath younger sediments in some areas. Pleistocene Lake Lahontan clays and sands; later flood-plain gravel, sand, and clay; and alluvial fans bordering the mountain ranges are intricately related in the Winnemucca Unit.

Folding and thrust faulting in Paleozoic and post-Triassic time involved the rocks older than the Jurassic (?) intrusives. Beginning in Tertiary time, these and younger rocks were block-faulted to form the mountain ranges which control the present topography. Fault scarps on Quaternary gravels along the western border of the Sonoma Range show that this normal faulting is still active. Some dissected, high gravel terraces (Quaternary ?) south of Winnemucca may be erosion remnants or may be part of an uplifted fault block. Hydrothermal deposits and active hot springs are common in the area and are nearly always associated with faults at or near the range fronts.

The mountains are undergoing erosion by streams tributary to the sluggish Humboldt River, and their debris fills the basins separating the ranges.

Previous geophysical studies conducted by the Humboldt River Project personnel include gravity and magnetic surveys (Wilson, 1960; Keros Cartwright, personal communication), which are best suited to regional interpretations of the Paleozoic and Mesozoic rocks and of the configuration of the pre-Tertiary bedrock surface.

Field Procedure and Equipment

Several areas within the Winnemucca Unit were chosen for detailed study. These areas, located on Figure 1, are: the Preble narrows; the hot springs at Golconda; the confluence of the Humboldt and Little Humboldt rivers near Kern Ranch; the Winnemucca city well; Thomas Creek; and the McNinch and Hillyer ranches. The surficial geology of each area was reviewed before measurements and interpretations were made. After the interpretations were completed, the records of water wells, shallow test borings made by the U.S. Geological Survey, and the logs of three cored wells drilled in the summer of 1961 were studied to determine the accuracy of the interpretations. The results of these comparisons are presented in a series of maps, profiles and columnar sections (Figures 2 through 9).

Seismic measurements were made with a Century 12-channel portable refraction seismograph, and earth-resistivity measurements with a Gish-Rooney instrument modified to read apparent resistivity directly in ohm-meters. Both instruments are owned by the Illinois State Geological Survey, Urbana, Illinois. DuPont Nitramon-S explosives and electric blasting caps provided the energy for the seismic studies.

In addition to the refraction spreads, a seismic fan array and a lateral surface-velocity profile were utilized. The maximum depth investigated at the refraction stations was approximately 625 feet.

Both the depth profile (expanding electrode separation) and the lateral profile (constant electrode separation) were used in the resistivity studies. The maximum electrode separation used was 200 feet.

INTERPRETATION OF MEASUREMENTS

General

Investigations elsewhere have shown that the seismic-refraction method is effective in determining the configuration of a bedrock surface overlain by complex unconsolidated materials. Possible sources of error must be kept in mind, however. For example, Soske (1959) has shown that failure to receive primary arrivals of refracted waves from an intermediate-velocity layer, such as saturated sediments between an unsaturated layer and bedrock, may cause inaccuracies in determining bedrock depth. In addition, where low-velocity layers are contained within material of higher velocity, the computed depth to bedrock will be greater than the actual depth (McGinnis and Kempton, 1961).

Although earth resistivity has been used with only limited success in bedrock studies (Meidav, 1960; Norris and Spicer, 1958), it has proven more useful than the seismic method in determining the nature of unconsolidated materials similar to the valley-fill sediments of the Humboldt River Basin (Buhle, 1953 and 1957; Foster and Buhle, 1951; Meidav, 1960).

Consistent accuracy in predicting the depth to shallow water tables has not been achieved by the use of either method. Inability to predict correctly the depth to water by earth resistivity may be attributed to the presence of perched zones of saturation, variations in the amount of solids dissolved in the water, and rapid lateral and vertical changes in the porosity and permeability of the sediments. Because these variations are so common, resistivity solutions identifying shallow interfaces must be supplemented with considerable well control.

The two methods have been combined to produce interpretations corresponding closely with known situations in terrains with characteristics similar to the complex valley-fill material encountered in this study. McGinnis and Kempton (1961) have applied integrated seismic and resistivity investigations successfully in glacial deposits in Illinois. Earth resistivity has been used to supplement previous seismic studies of bedrock overlain by unconsolidated sediments in the Atlantic Coastal Plain (Dudley, 1960).

Seismic Method

Standard mathematical solutions described by Dix (1952), Jakosky (1950), and Nettleton (1940), were applied to the seismic time-distance curves to compute depths at refraction stations. Lateral variations in the velocity of near-surface materials were determined by inspection of the time interval between geophones at various geophone locations.

Resistivity Method

Theoretical and empirical methods were applied to the curves plotting apparent resistivity against electrode separation. Tagg's (1934) method and the rapid curve-matching method published by Mooney and Wetzel (1956) were used on those curves which required only minor smoothing. Empirical approximations described by Moore (1945) and Meidav (1960) were attempted for most of the stations. Use of these empirical methods requires the assumption that the effective depth of penetration of the electrical current is equal to the electrode separation. Theoretically, this effective depth is a variable, usually ranging from one-half to four-fifths of the electrode separation (Jakosky, 1950). Empirical solutions have been used with success in areas of less complex stratigraphy than the Humboldt Basin, but they are not applicable to situations involving several layers, as indicated by results obtained in this study. Resistivity curves shown in this paper are simply field curves with apparent resistivity plotted against electrode separation.

ANALYSIS OF DATA

Preble Narrows

Near Preble the valley of the Humboldt River is constricted to a width of only one-fourth to one-half of a mile. The Preble formation (Cambrian slate) contacts flood-plain deposits and small alluvial fans along the valley walls. According to the recollections of others (J. W. Hawley, personal communication), investigations for bridge pilings along Nevada Highway 18 indicate that the bedrock is shallow. Seismic solutions have given depths ranging from 30 to 60 feet to a

bedrock having a seismic velocity of 13,000 to 15,000 feet per second. This range agrees with the velocity of the slate as determined at an outcrop near Preble. One and one-half miles east of Preble a 12,000 feet-per-second layer at a depth of 80 feet may be the Preble formation. Two and one-half miles southwest of Preble a 9,600 feet-per-second layer occurs at a depth of 120 feet and dips about 4 degrees toward Preble. The identity of this layer is unknown, but its velocity is probably too low to be that of the Preble slate or the Osgood Mountain quartzite, which crops out in nearby mountains. This low velocity may represent less well-consolidated Tertiary sediments.

Figure 2 is a profile across the Humboldt Valley at Preble. The generalized geologic cross section is a composite picture of the Preble narrows, based not only on the data at Profile A-A′ but also on the records of nearby seismic stations. Readings at Station S-33 indicate that the Preble slate occurs at a depth of 34 feet, while a nearby well drilled to a depth of 38 feet did not encounter bedrock. Drilling was difficult at the bottom of the hole, however, suggesting that bedrock may have been penetrated (J. W. Hawley, personal communication). Failure to receive primary arrivals from the water table, which is about 10 feet beneath the surface at this station, would cause the computed depth to be too shallow, as described by Soske (1959). This effect may account for the difference of 4 feet between the well record and the seismic prediction at this site. Resistivity curves along Profile A-A′ indicate higher resistivities in the slate than in the flood-plain deposits.

Kern Ranch—Little Humboldt

The confluence of Humboldt and Little Humboldt rivers was the site of intensive investigation. Paradise Valley is constricted at its mouth by basalt flows apparently dipping gently beneath younger valley sediments at the northern boundary of the Humboldt River Valley. Two miles south of Kern ranch, along the extension of Profile B-B′, basalt crops out over a small area. Seismic Station S-16, 3½ miles south of Kern ranch along U.S. Highway 40 (Figure 1), does not yield a basalt velocity within a depth of about 400 feet, although it is only 90 feet higher than the small basalt outcrop. Apparently the basalt does not extend to the south, and the outcrop may indicate the southernmost extension of a depression existing at the time of deposition. The occurrence of basalt to the north of Humboldt River beneath the valley-fill sediments has been confirmed by magnetic measurements (Wilson, 1960) and by well records.

Geophysical profiles were run across each valley in an attempt to define more precisely the extent of the basalt. Figures 3 and 4 show seismic-refraction, earth-resistivity and well data along Profiles B-B′ and C-C′, respectively.

At Station S-8 a 12,500 feet-per-second layer was identified at a depth of 325 feet. This finding agrees with the driller's log of the nearby Kern well, which notes "dense brown rock" at a depth of 304 feet overlain by continuous sand and gravel. Two thousand feet north of the Kern well, Station S-12 indicates the same rock at 335 feet. Station S-14, 600 feet farther north, shows that basalt occurs at a depth of 47 feet. A nearby cored well, drilled in July 1961, to confirm the seismic interpretation, encountered basalt at a depth of 46.8 feet. Wilson's (1960) magnetic study indicates that the basalt north of the river does not extend as far south as the Kern well. Overlying bedrock near the center of Profile B-B′ (south of the river), materials with a seismic velocity of about 8,500 feet per second were encountered. The lithology of this layer is unknown, but it may represent partly consolidated sediments (Tertiary?). If this were true, then the brown rock logged at 304 feet in the Kern well would be Tertiary or older in age. The shallow basalt in the cored well and at Station S-14 does not appear to be overlain by this material of intermediate velocity. Apparent resistivities plotted on Figure 3 indicate that fine sediments of lower resistivity underlie the northern portion of Profile B-B′, while coarse material of high resistivity occurs beneath the present Humboldt channel.

Seismic data along Profile C-C′ (Figure 4) support the inference that the basalt dips beneath the flood-plain sediments at the mouth of Little Humboldt River. Two seismic stations, S-4 and S-5, also show that the intermediate-velocity material occurs about 40 feet below the top of the basalt in the center of the valley. Slightly higher resistivities in the valley center suggest more permeable sediments.

The basalt of Profile C-C′ correlates with the shallow basalt in the northern part of Profile B-B′ both by position and by velocity (10,200 to 11,700 feet per second), while the deeper layer has a higher velocity (12,500 to 13,500 feet per second). The two layers may be different rock units, or the discrepancy in velocities might arise from different degrees of weathering of the same material.

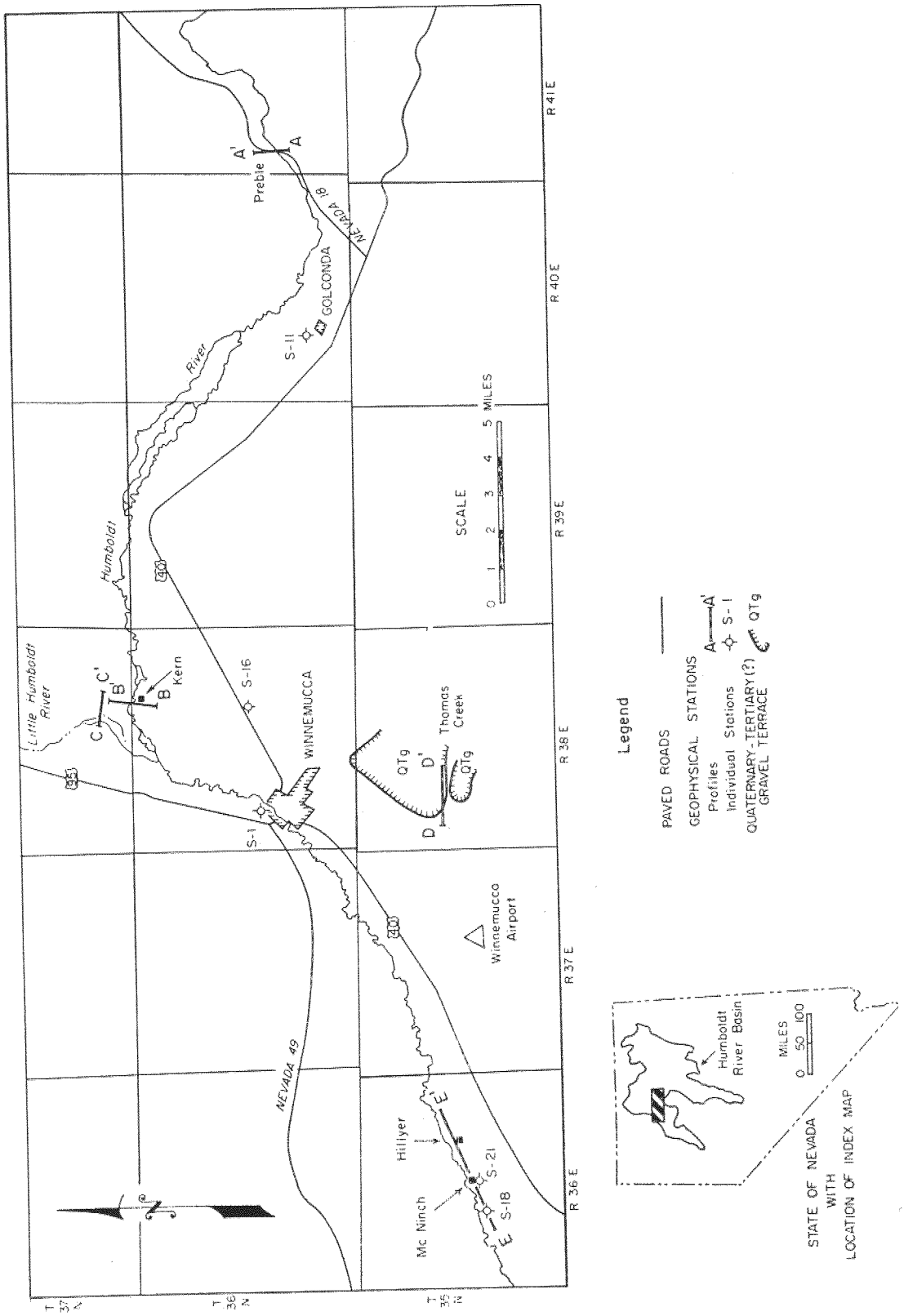


Figure 1. Index Map of Winnemucca Section, Humboldt River Basin, Nevada.

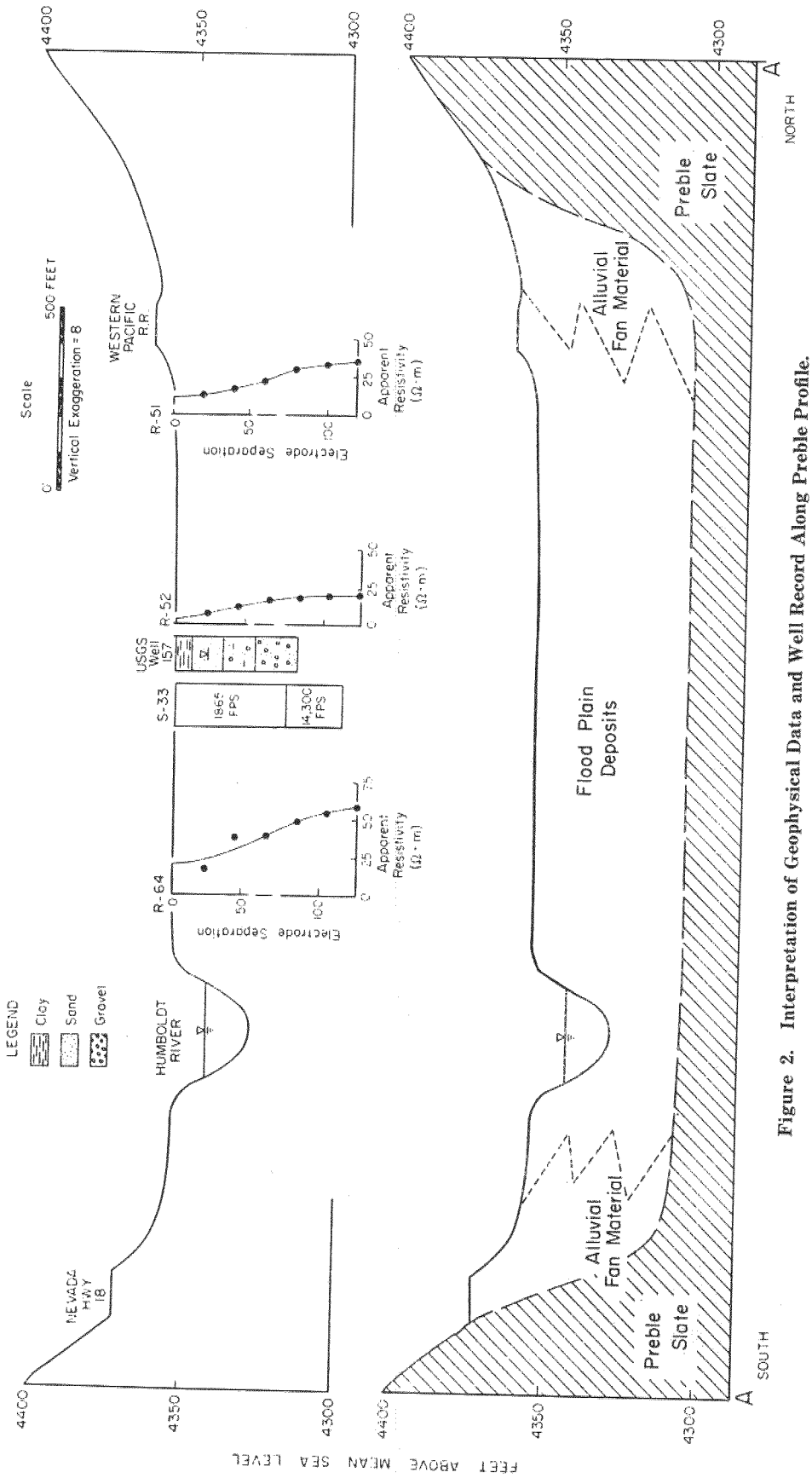


Figure 2. Interpretation of Geophysical Data and Well Record Along Preble Profile.

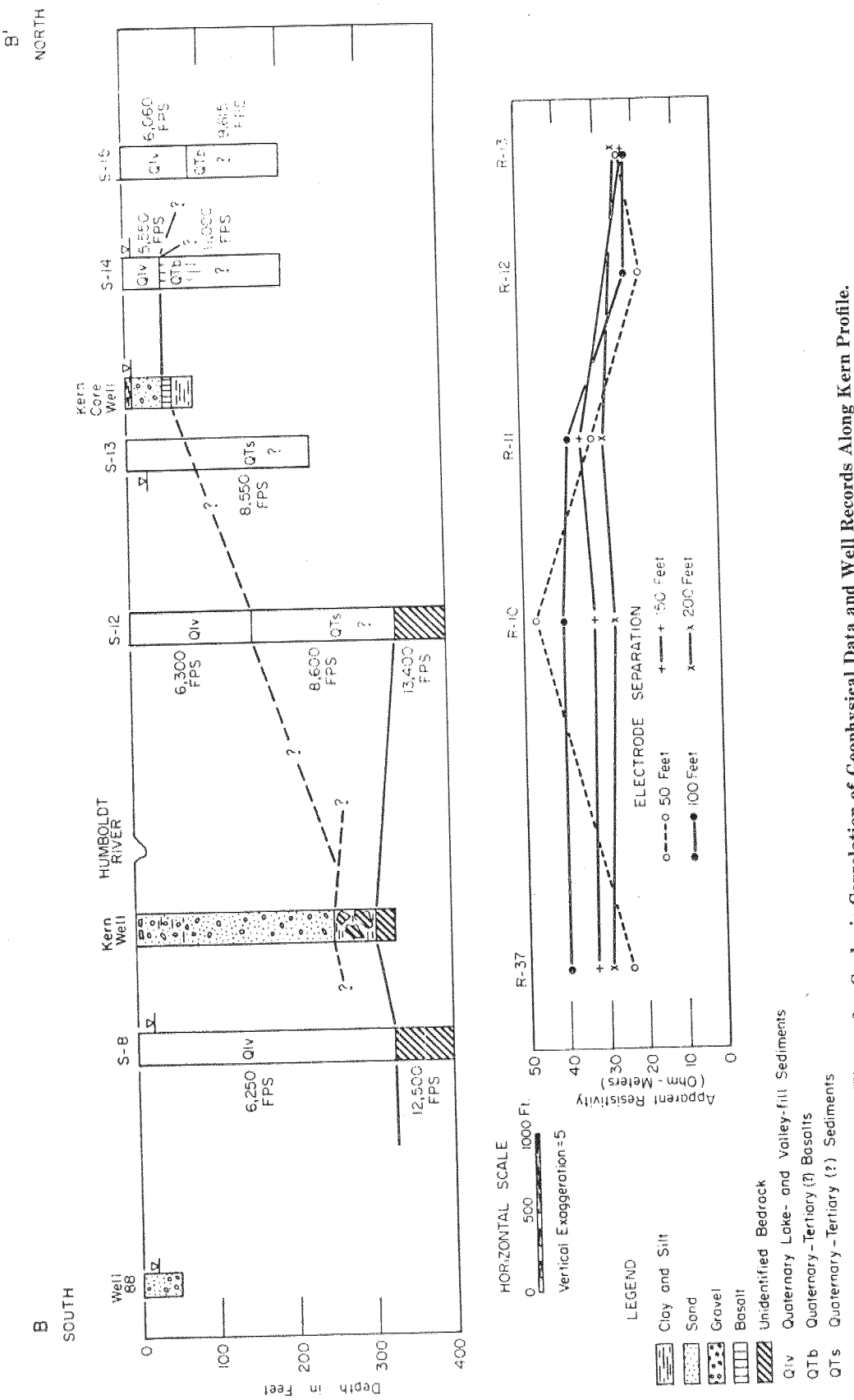


Figure 3. Geologic Correlation of Geophysical Data and Well Records Along Kern Profile.

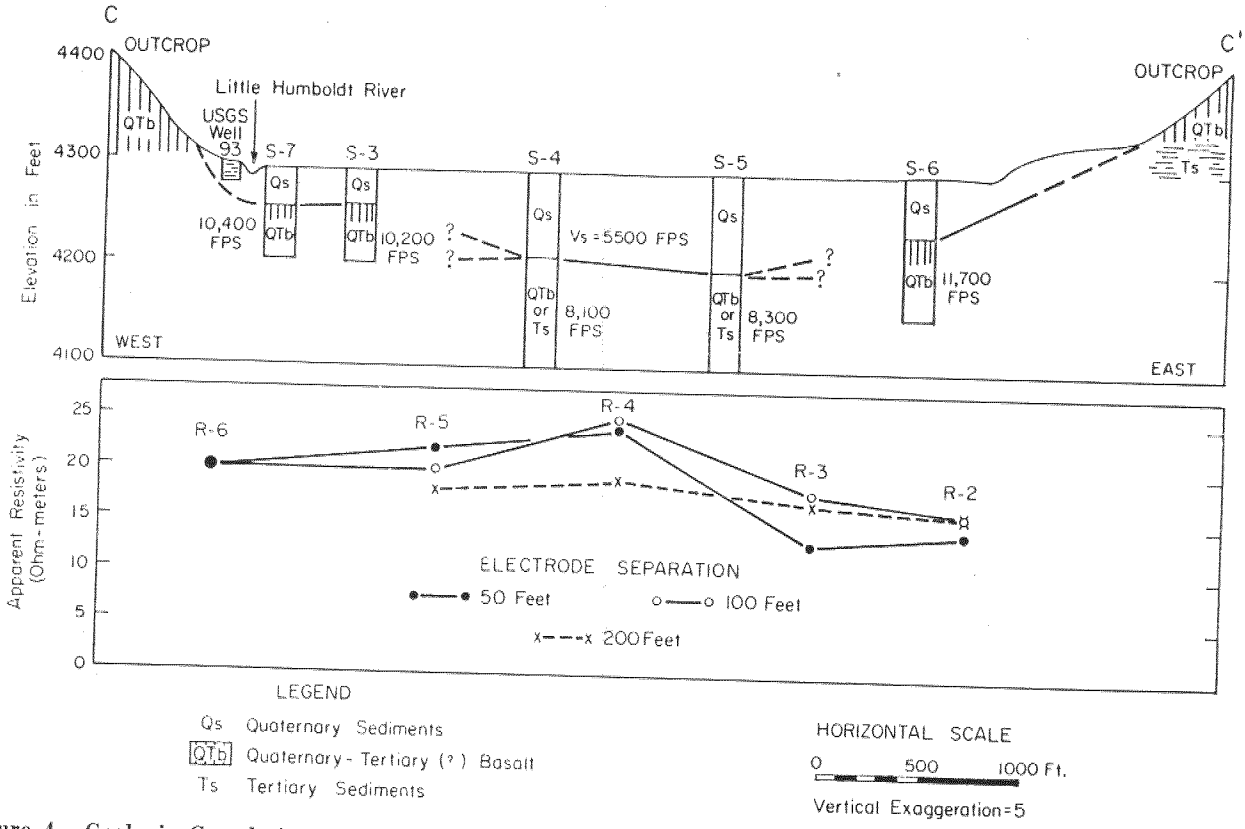


Figure 4. Geologic Correlation of Geophysical Data, Well Record, and Outcrops Along Little Humboldt Profile.

Winnemucca City Well

The first seismic and resistivity stations of the 1961 series were located on the Humboldt River flood-plain near the city well at the northern edge of Winnemucca (Figure 1). "Fissured lava" was logged in this well at a depth of 500 feet. Values obtained at Station S-1 indicate bedrock (basalt?), with a velocity of 16,500 feet per second, at a depth of 625 feet and overlain by materials with a velocity of 7,140 feet per second (Figure 5). The shape of the earth-resistivity curve suggests highly resistive gravels at least 100 feet thick, underlain by less resistive material, possibly sand. A cemented-gravel unit noted in the well record might yield the velocity of 7,140 feet per second, masking materials with lower velocities beneath. The 25 percent error in the determination of the depth to bedrock might be explained in this way.

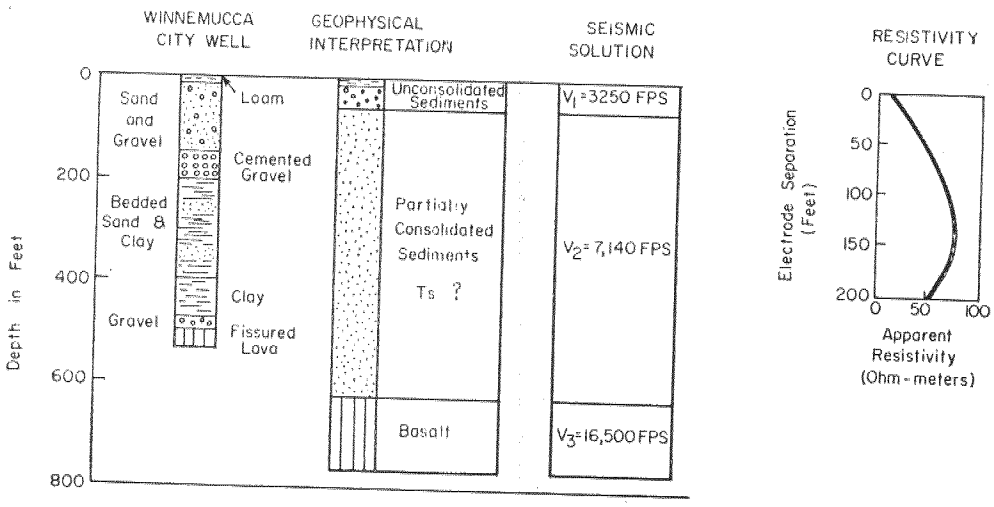


Figure 5. Comparison of Winnemucca City Well Record and Interpretation of Nearby Geophysical Data.

Because Station S-21 is 1,400 feet from the well, an equally logical explanation is the possibility of an uneven surface on the top of the basalt.

Thomas Creek

Standing above the Thomas Creek alluvial fan south of Winnemucca is a dissected terrace of coarse gravel and boulders. Since the cause of the present high elevation of these Quaternary (?) gravels is in question, Profile D-D′ was run in an attempt to determine whether bedrock faulting is involved under the scarp at the contact of the terrace with the Thomas fan. Figure 6 presents these seismic-refraction and earth-resistivity data. Because no control wells were available in this area, the resistivity curves are not solved but are presented for comparative purposes only.

A seismic layer of about 9,000 feet per second is 350 feet lower in elevation beneath the Thomas fan than it is 1¼ miles to the east, beneath the gravel terrace. It appears to be essentially flat-lying in each case. Postulating a fault on the basis of this evidence is not justified, however, because of the sparseness of the data and because identification of sediment and rock types cannot be made without control. Also, a gradient on the rock surface of 300 to 350 feet per mile is not unreasonable to expect in this geomorphic setting. Faulting is not ruled out, however, and extremely detailed seismic investigation might provide an answer to the question. Such a study would be rendered very difficult by the inaccessibility of the rugged terrain.

McNinch and Hillyer Ranches

Between the McNinch and Hillyer ranches, 11 miles downstream from Winnemucca, the Humboldt River Valley is constricted by Triassic metamorphic rocks and Quaternary-Tertiary (?) basalt. A bedrock high beneath the floodplain is suggested by earlier gravity data (Wilson, 1960), which indicates that the high is bounded on the west by the extension of a fault bordering the East Range (Keros Cartwright, personal communication). Station S-21 was placed along the axis of the gravity high, 500 feet south of the McNinch ranch house. Identification of the lithology was made by comparing the earth-resistivity results, obtained by the Mooney-Wetzel (1956) curve-matching method, with the seismic solution. A cored well drilled in September 1961, verified the geophysical solution without important differences (Figure 7).

Seismic stations ¾ mile, 1½ miles and 2 miles east of Station S-21 support the interpretation of the gravity data (Figure 8). Bedrock dips gently away from the axis of the gravity high, reaching a depth of 120 feet two miles upstream. Conflicting interpretations of adjacent stations in this area show that some complexities are superimposed on this general picture. Magnetic data by Wilson (1960) indicate that the basalt bordering the valley on the north (Figure 8) continues southward beneath or within the valley-fill sediments. This interpretation is supported by the bedrock velocities at Stations S-23 and S-24, which agree closely with the basalt velocities obtained near Kern ranch. Further test drilling in this area would be useful in outlining this constriction.

One mile downstream from Station S-21, Station S-17 (2,400 feet long) shows only valley-fill material with a seismic velocity of 5,900 feet per second extending to a depth of at least 600 feet (Figure 8). This is the minimum possible depth at which a layer with a velocity of 10,000 feet

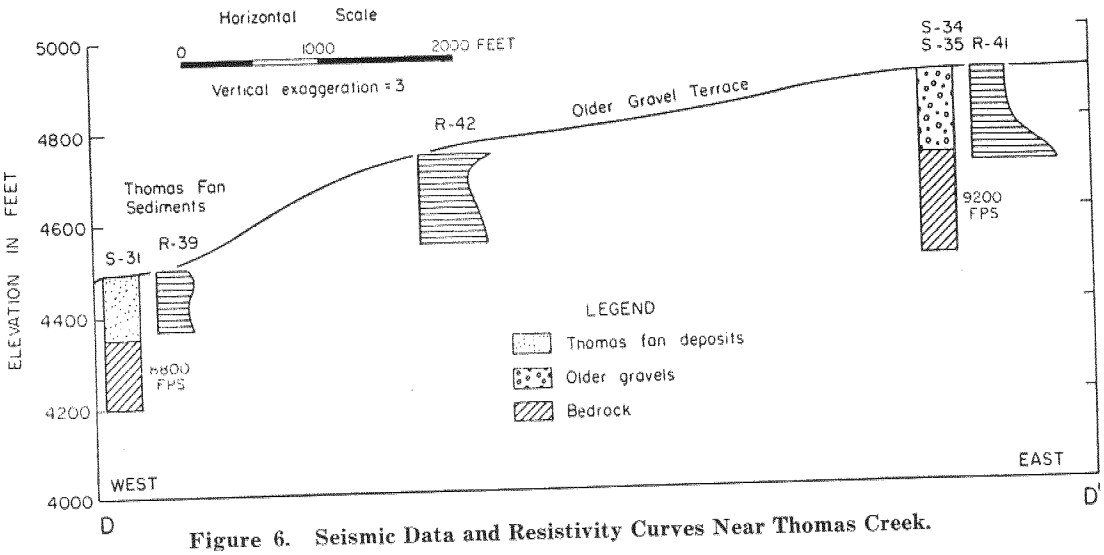


Figure 6. Seismic Data and Resistivity Curves Near Thomas Creek.

per second could occur without showing on the time-distance curve.

The extension of the fault zone bordering the East Range passes between Stations S-17 and S-21 and close to a small outcrop of dense, siliceous rock near the McNinch windmill. This outcrop was intensively studied during this investigation (Figure 9). Various seismic arrays (collectively, Station S-18) and a lateral resistivity profile were run adjacent to the outcrop. Together with well records these data doubled the known areal extent of the siliceous mass and established that it is limited to the approximate outline shown in Figure 9. The restricted distribution of the material and its association with a fault zone, as suggested by gravity data and seismic measurements, point strongly to a hydrothermal origin for the rock. The U.S. Geological Survey has received samples of this material and of known siliceous spring sinter and is observing the temperature and quality of the water in nearby wells. No report on the results of this sampling is available at present.

Golconda Hot Springs

The time-distance plot of Station S-11, near the hydrothermal springs northwest of Golconda, shows a set of short straight-line segments, each controlled by three or more points and offset from adjacent segments (Figure 10). Such effects are characteristic of both faulting and lateral variations in the velocity of a near-surface layer. The latter interpretation is probably correct in this case for two reasons. First, the offsets occur within the points representing arrivals from the shallow intermediate-velocity zone but not within those representing bedrock, as shown on Figure 10. Secondly, the presence of the hot springs, though it may indicate a fault, also suggests that a vertical zone of sediments cemented by hydrothermal material is enclosed in sediments of lower velocity, similar to those at the McNinch windmill. A seismic spread should record a higher surface velocity on the geophones located over the hydrothermal zone than on those underlain by normal sediments. Such appears to be the case at this location.

Measurements at Station S-11 reveal that bedrock with a velocity of 12,000 feet per second dips 10 degrees west, reaching a depth of 250 feet beneath the west shot. Another station, placed perpendicular to S-11 at this point, does not exhibit the segmented character shown in Figure 10, and a horizontal 9,700 feet-per-second layer at a depth of 160 feet does not correlate well with the interpretation at Station S-11. The difference between the results of the right-angle spreads may indicate that faulting is involved in the origin of the hydrothermal springs, but a more conclusive statement cannot be made without further study.

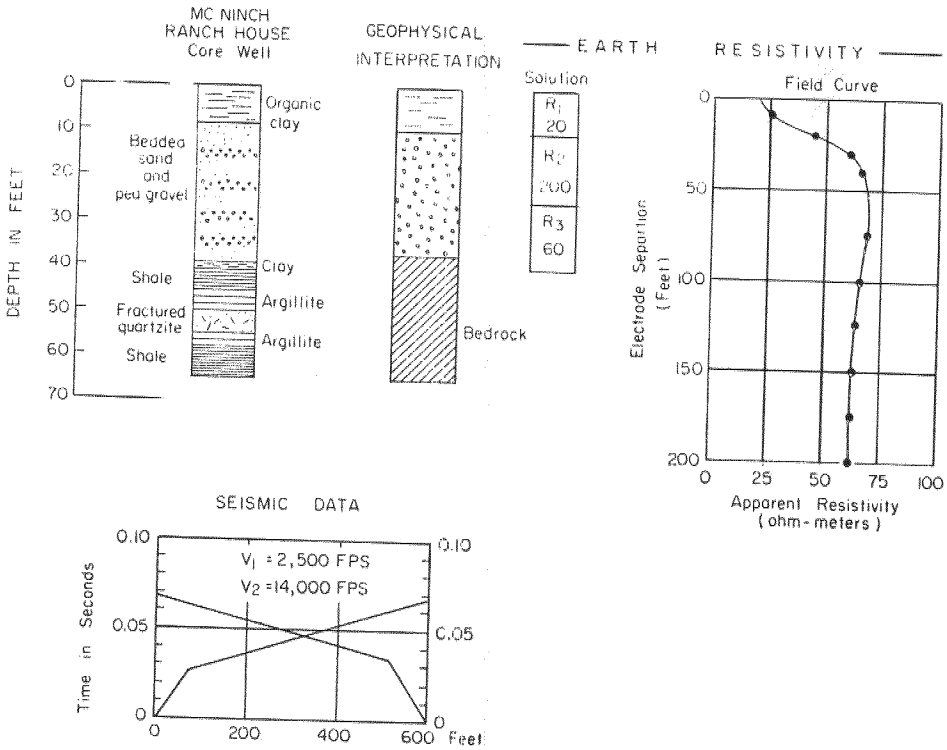
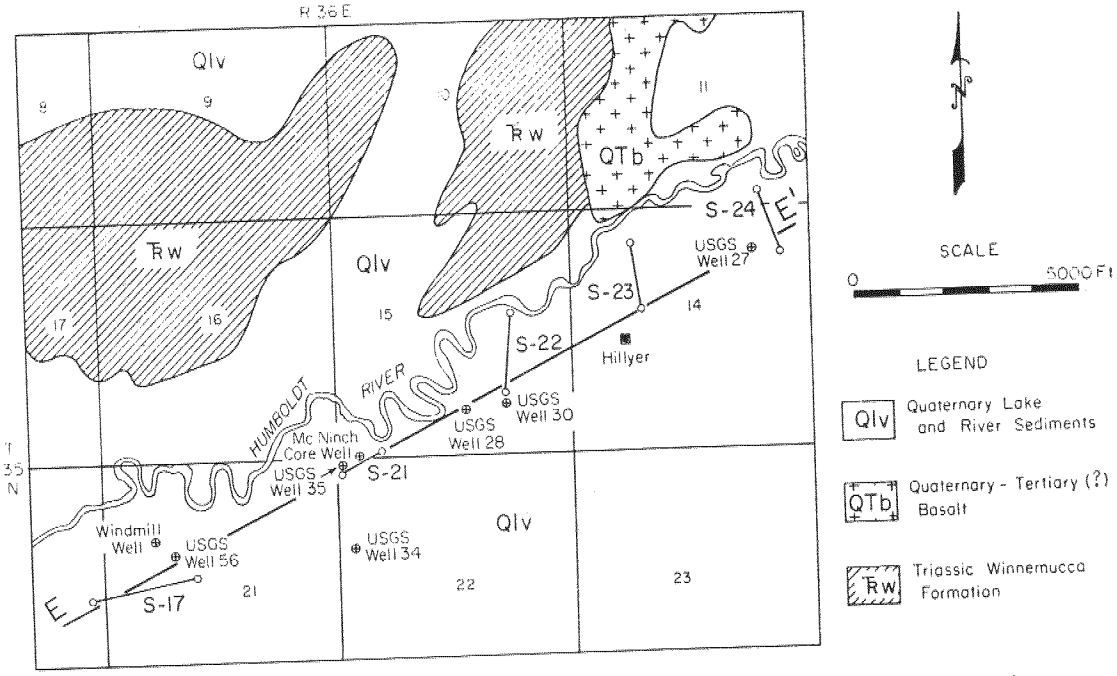


Figure 7. Comparison of Cored-Well Record and Interpretation of Geophysical Data at McNinch Ranch.



GEOLOGY OF MC NINCH - HILLYER AREA AND LOCATION OF PROFILE E-E'

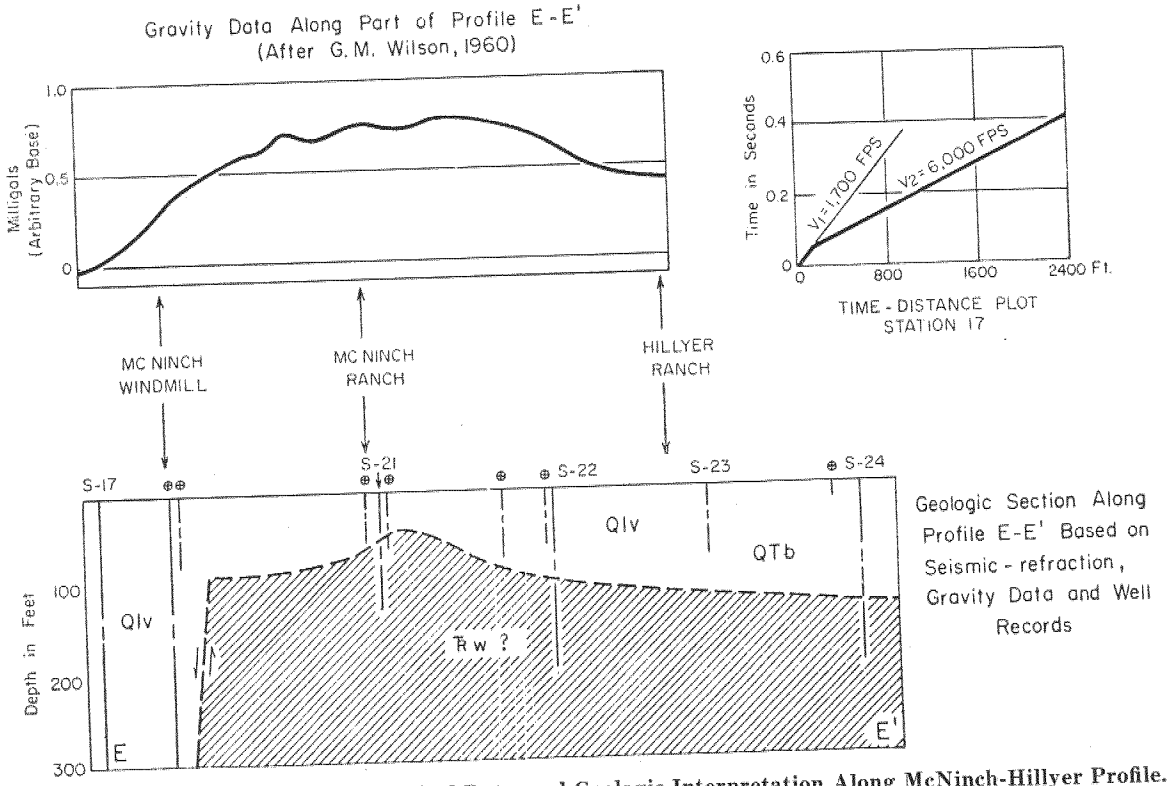


Figure 8. Surficial Geology, Geophysical Data, and Geologic Interpretation Along McNinch-Hillyer Profile.

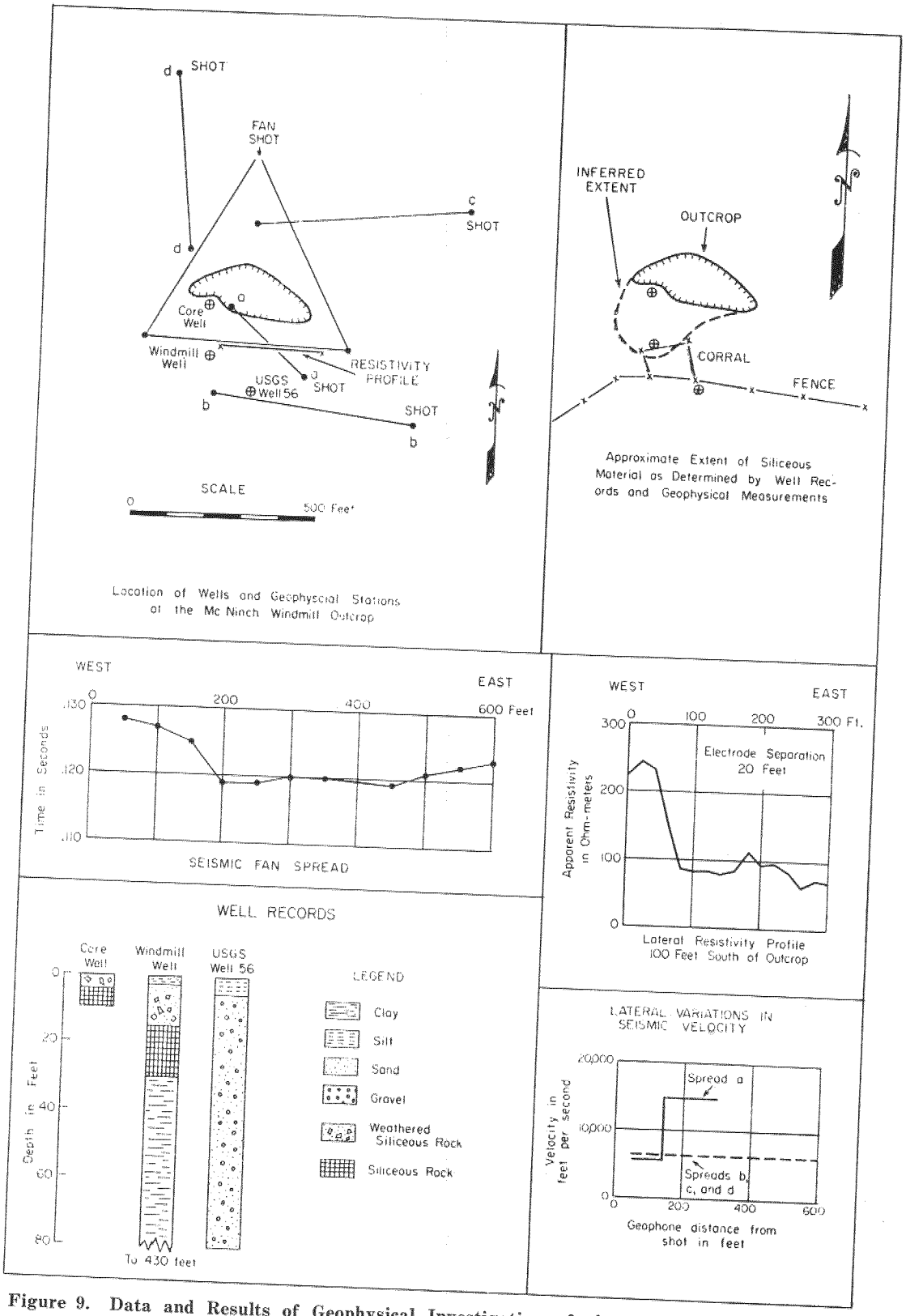


Figure 9. Data and Results of Geophysical Investigation of the Siliceous Outcrop Near McNinch Windmill.

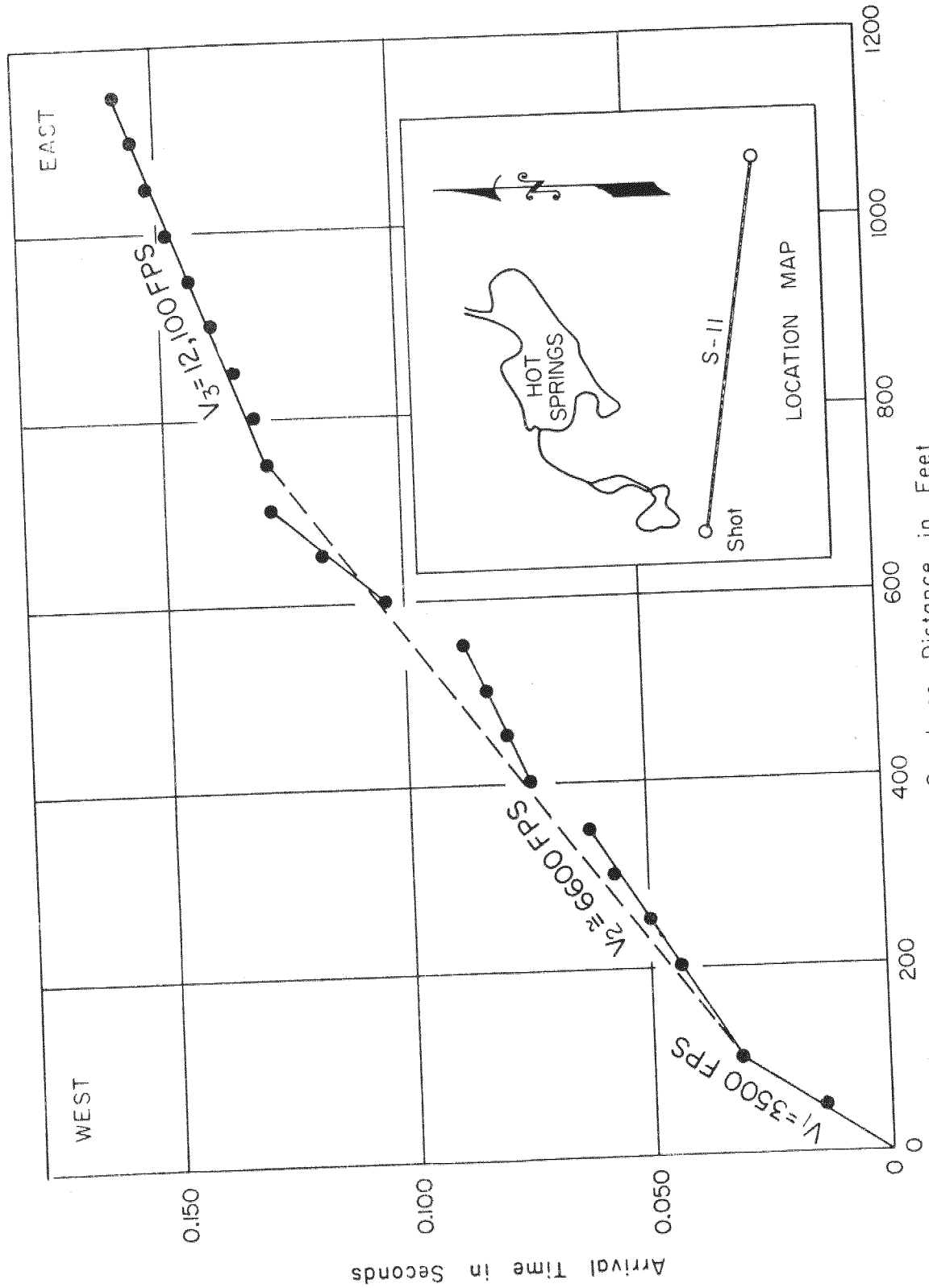


Figure 10. Segmented Time-Distance Curve at the Hot Springs Near Golconda.

CONCLUSIONS

Seismic-refraction methods have been shown to be very successful in predicting depth to bedrock. Comparing seismic predictions with the records of nearby wells yields a maximum error of 25 percent in one case (Winnemucca City well) and errors within 10 percent in all other cases (Kern profile, McNinch ranch). Identification of the lithology of the bedrock is less sure. Besides the refraction spread, other seismic arrays, such as those used to outline the siliceous outcrop at the McNinch windmill, may be useful in special cases. Where water-table arrivals were obtained, they were accurate (Kern ranch) or, where control data were lacking, of reasonable magnitude. Results at a few stations did not reveal the saturated sediments (Preble narrows).

Earth-resistivity has not proved to be as useful as the seismic method, particularly in predicting depths, but it aids in interpreting lithology if used with sufficient control. The most valuable technique in areas such the the Humboldt River Basin is probably the use of the lateral resistivity profile combined with the seismic method (Little Humboldt, McNinch windmill).

Conjunctive use of earth-resistivity and seismic investigations cannot replace bore-hole studies, even in the most favorable of areas, but it can reduce the amount of test drilling necessary for acquiring needed information. Neither the value of resistivity nor the velocity with which a layer transmits seismic waves can be used to identify clearly the exact lithology and hydrologic characteristics of the unit. In many cases, however, only occasional test holes are needed to provide a framework of control for geophysical interpretations, and reconnaissance geophysics early in an investigation aids greatly in defining areas where test drilling is most needed.

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DESERT RESEARCH INSTITUTE
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SEISMIC STUDIES OF THREE AREAS IN NORTHERN NEVADA

By

LYLE D. McGINNIS and WILLIAM W. DUDLEY, JR.

PART II OF TECHNICAL REPORT NO. 2

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INTRODUCTION

This report presents the results of 18 experimental seismic refraction and reflection stations in Northern Nevada during July of 1962 (Figure 1). Because of the sparsity of the data broad geologic interpretations cannot be made, but a few specific questions have been answered and one new problem is suggested.

The reliability of the refraction method in shallow bedrock studies in Northern Nevada has been illustrated previously (Dudley and McGinnis, 1962). An attempt was made to evaluate the reflection technique in deep, sediment-filled valleys using shallow shot holes and various arrays of multiple shot patterns. Only fair to weak reflections were obtained.

Equipment utilized in the survey was on loan from the Illinois State Geological Survey. The seismograph is a 12-channel reflection-refraction instrument which was originally built by Seismograph Service Corporation and later modified by members of the Illinois State Geological Survey for use in shallow exploration. Both 12- and 30-cycle geophones were used, the lower frequency phones being utilized for long refraction measurements and the higher frequency for reflection and short refraction studies.

Multiple-geophone strings were not available for the reflection attempts but they should be used in future work in the state, especially where only shallow shot holes are available and surface-wave energy is great.

The Illinois State Geological Survey generously loaned the seismic equipment without which this survey could not have been completed. Mr. William Sinclair of the United States Geological Survey, Carson City office, gave freely of his time to acquaint the writers with the Granite Basin area. Development of the authors' thoughts concerning

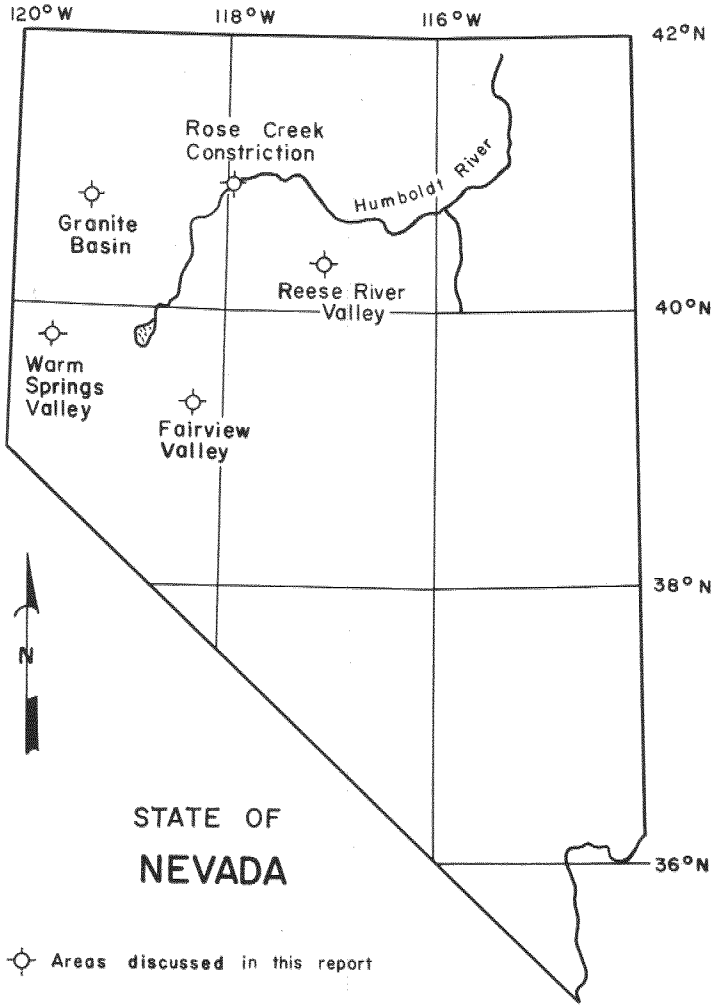

Figure 1. Areas discussed in this report.

the Rose Creek constriction was greatly influenced by the work and comments of Mr. Keros Cartwright, but responsibility for the interpretation given herein must be borne by the authors. The interest and long hours of work given by field assistants Noel Uzemack and Fred Constant were deeply appreciated.

ROSE CREEK CONSTRICTION

About 12 miles southwest of Winnemucca, near Rose Creek, the Humboldt River Valley is constricted by the East Range on the south and by low hills of Triassic metamorphic rocks and Quaternary basalts on the north (Figure 2). A major fault zone borders the Triassic rocks of the East Range on the west. It has been suggested by Cartwright et al. (1962) on the basis of gravity measurements that this fault zone crosses the Humboldt River Valley at the Rose Creek constriction forming the west boundary of a major bedrock high. Furthermore, Cartwright et al. identified a mineralized fault zone at a small outcrop of Triassic rocks on the north side of the Humboldt Valley.

An outcrop of siliceous "spring sinter" at a stock well on the Humboldt River flood plain is believed to be associated with this fault zone. This was an area of intensive study by the authors in a previous report (Dudley and McGinnis, 1962), in which a bedrock scarp with a minimum height of 600 feet passing approximately beneath the outcrop was postulated on the basis of seismic evidence.

A seismic profile completed during the present study was made across the predicted fault zone to define further its location and to determine the amount of bedrock relief. The results of this profile are shown in Figure 3. Delayed arrival times at the last two geophones on the west end of RL-1 are indicative of increasing bedrock depth and RL-2, directly to the west shows no bedrock arrival whatsoever. At the west end of station RL-2 a good reflection was received at about 0.4 seconds which would place bedrock at a depth of approximately 1,240 feet. Cartwright et al. (1962) have calculated a depth to bedrock of about 3,880 feet about 4 miles southwest of this station based on a gravity survey. At station RL-3, on the east side of this major scarp, bedrock refraction arrivals were again obtained on 1,300 foot spreads. The low velocity (7,900 feet per second) and an apparent bedrock offset of almost 100 feet may indicate further minor faulting and fracturing of the bedrock.

The major fault line defined by the data in this report and in the authors' earlier study (1962) may be extended to the northwest to the edge of the outcrop of Triassic rocks as also defined by Cartwright et al. Apparently the northeastward trend of the East Range border fault dies out, as Cartwright (personal communication) has been unable to find direct field evidence of its presence on the north side of the valley. It seems likely that the topographic low along this line north of the river, partially filled with Pleistocene Lake Lahontan sediments, is related to a zone of crushing contemporaneous with the faulting but that the major offsetting occurs along two fault zones intersecting at a high angle. This relationship is shown diagrammatically in Figure 4.

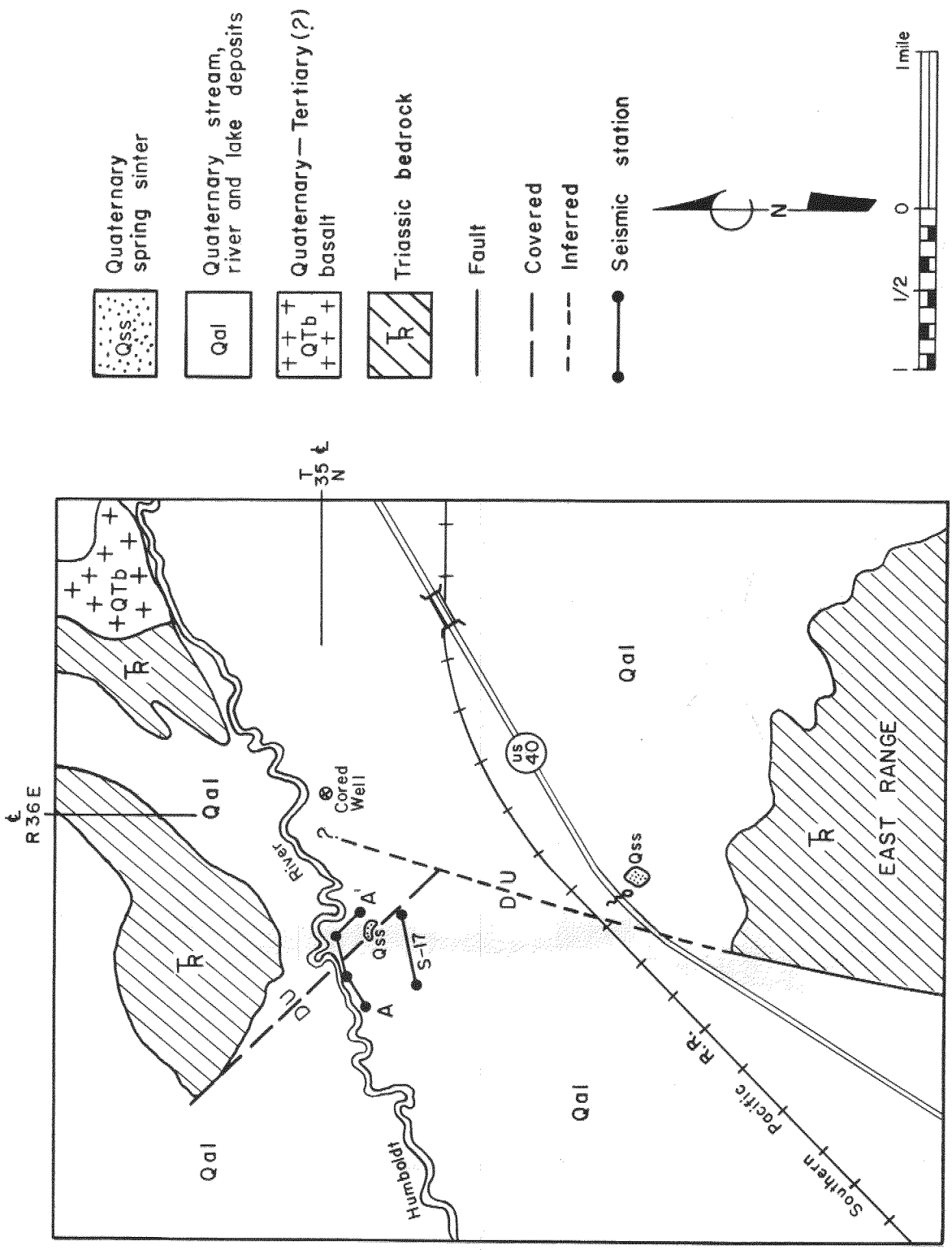

Figure 2. Geologic and location map of the Rose Creek constriction.

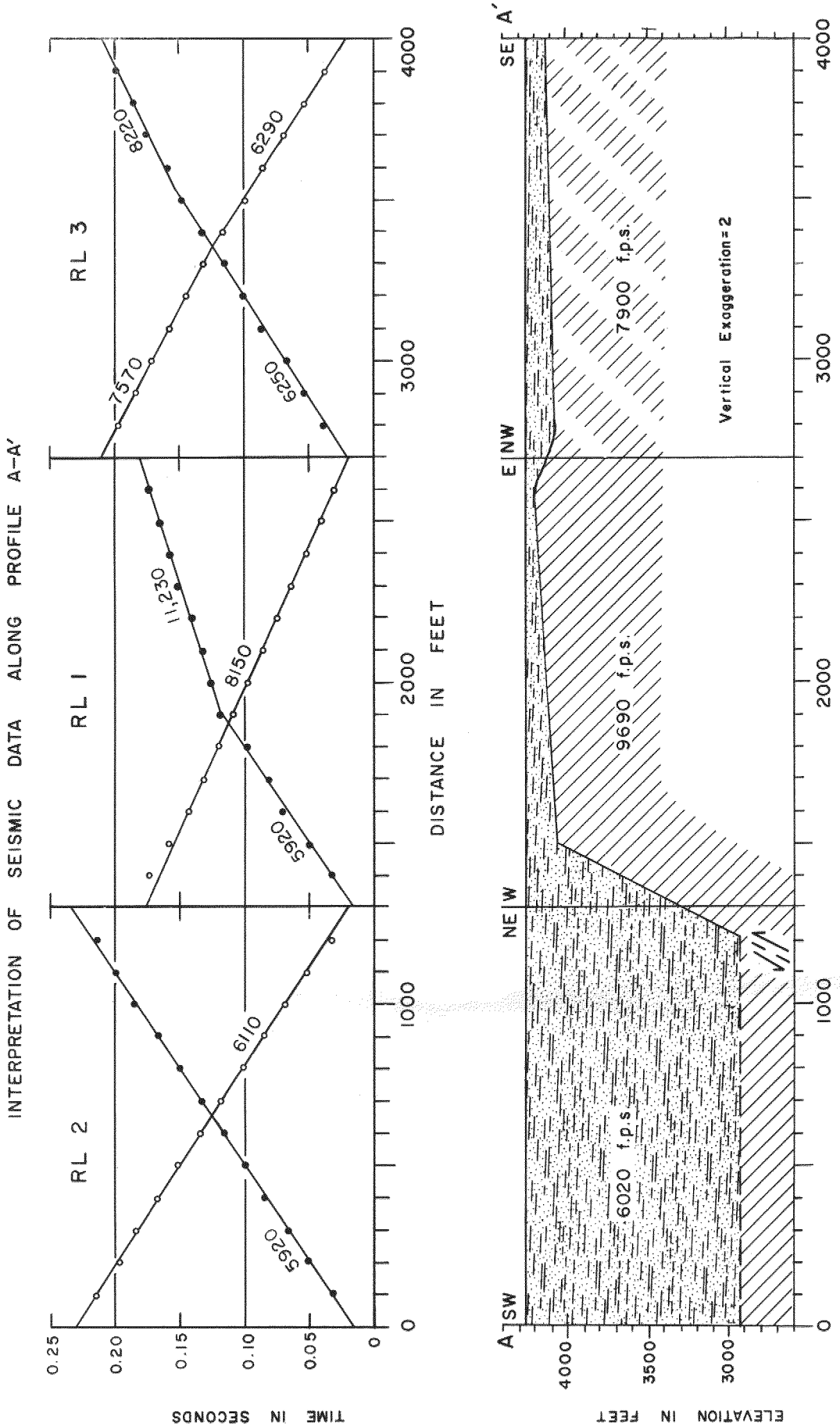

Figure 3. Interpretation of seismic data along profile A-A prime (see Fig. 2 for plan) in the Rose Creek constriction.

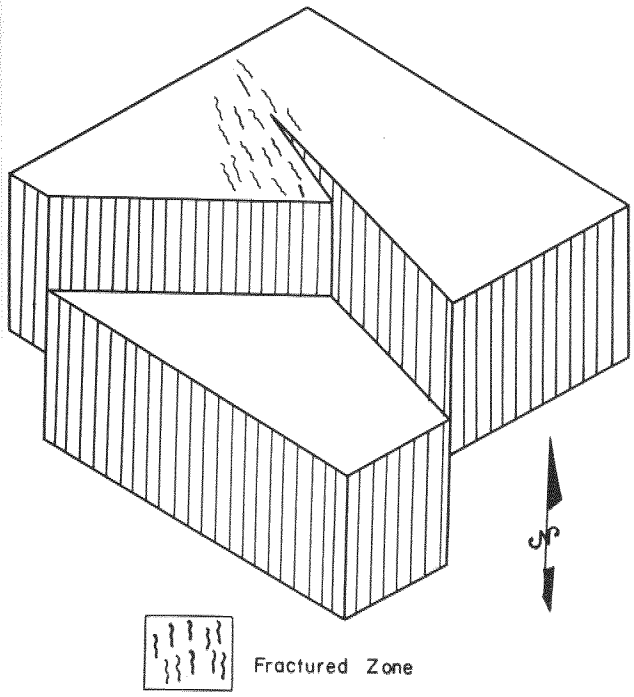

Figure 4. Probable displacement of the idealized bedrock surface in the Rose Creek constriction.

GRANITE BASIN

Granite Basin is a small, topographically closed basin lying near the southwest corner of the Black Rock Desert and about 10 miles north of Gerlach (Figure 5). Hot springs emerge in the southern portion, forming mineral ponds and bogs, and a small playa, Hualapi Flat, occurs in the southeastern part of the basin.

Jurassic and later intrusives comprise the Granite Range, which borders the basin on the west and northwest. To the northeast is the Calico Range, composed of Tertiary continental sediments, lava flows and tuff. The southern and eastern margins are formed by Quaternary (?) basalts, but these are breached by a low saddle on the east. Alluvial deposits and sand dunes fill this saddle and obscure the extent of the basalts. This is the only place along the periphery of the basin across which significant ground-water flow might take place, but if hydrologic isolation could be demonstrated, the area would be excellent for a pilot study of a small, hydrologically closed basin.

A seismic profile consisting of six 1,300-foot refraction stations was made between two basalt outcrops flanking the topographic low. The configuration of bedrock as determined from the refraction spreads and outcrops is shown in Figure 6. The volcanic outcrops appear to be truncated quite sharply a few thousand feet from where they dip beneath the unconsolidated deposits. They are about 75 to 80 feet thick at their terminal points and are immediately underlain by what appears to be weathered bedrock. Another sharp break occurs in the bedrock profile toward the center of the cross section. Here, bedrock reaches its deepest point and is covered by approximately 175 feet of sediment. The bedrock low has a fairly flat surface as indicated by reversed-spread velocities and straight-line segments of the time-distance plots. Examination of the entire profile leads one to believe that the basalt flows at one time were continuous across the profile, but were cut through at a later date by a river flowing out of the enclosed basin. The stream cut its way through the basalt then partially into bedrock resulting in the formation of the bedrock terraces. As a result of the slow filling of the basin with sediment, a thick mantle of unconsolidated material now obscures the relief.

It is interesting to note the progressive decrease in alluvial velocity from the southeast side of the

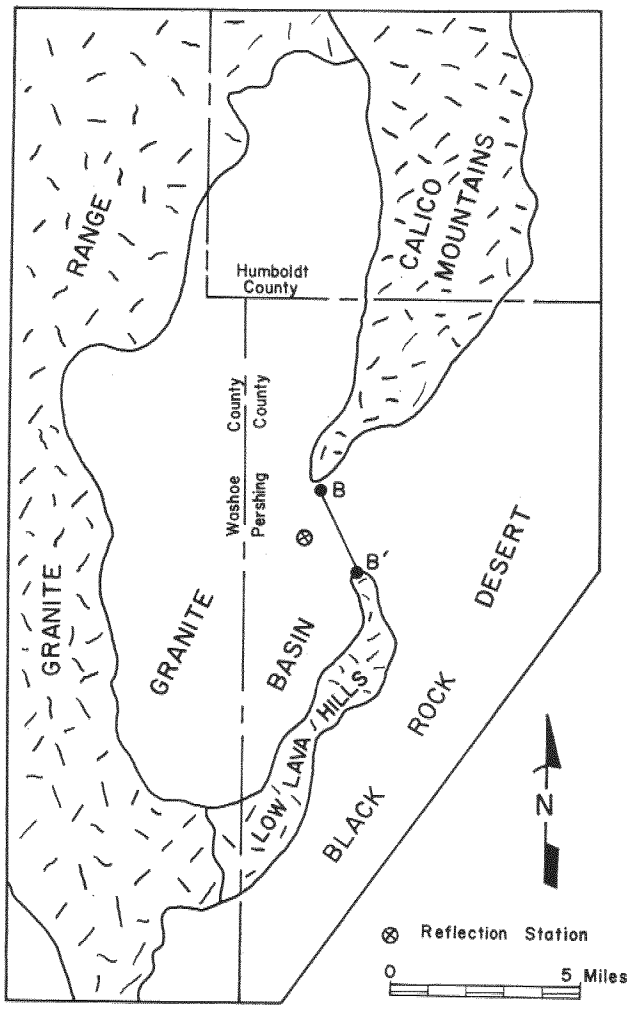

Figure 5. Geologic map and seismic spreads in Granite Basin.

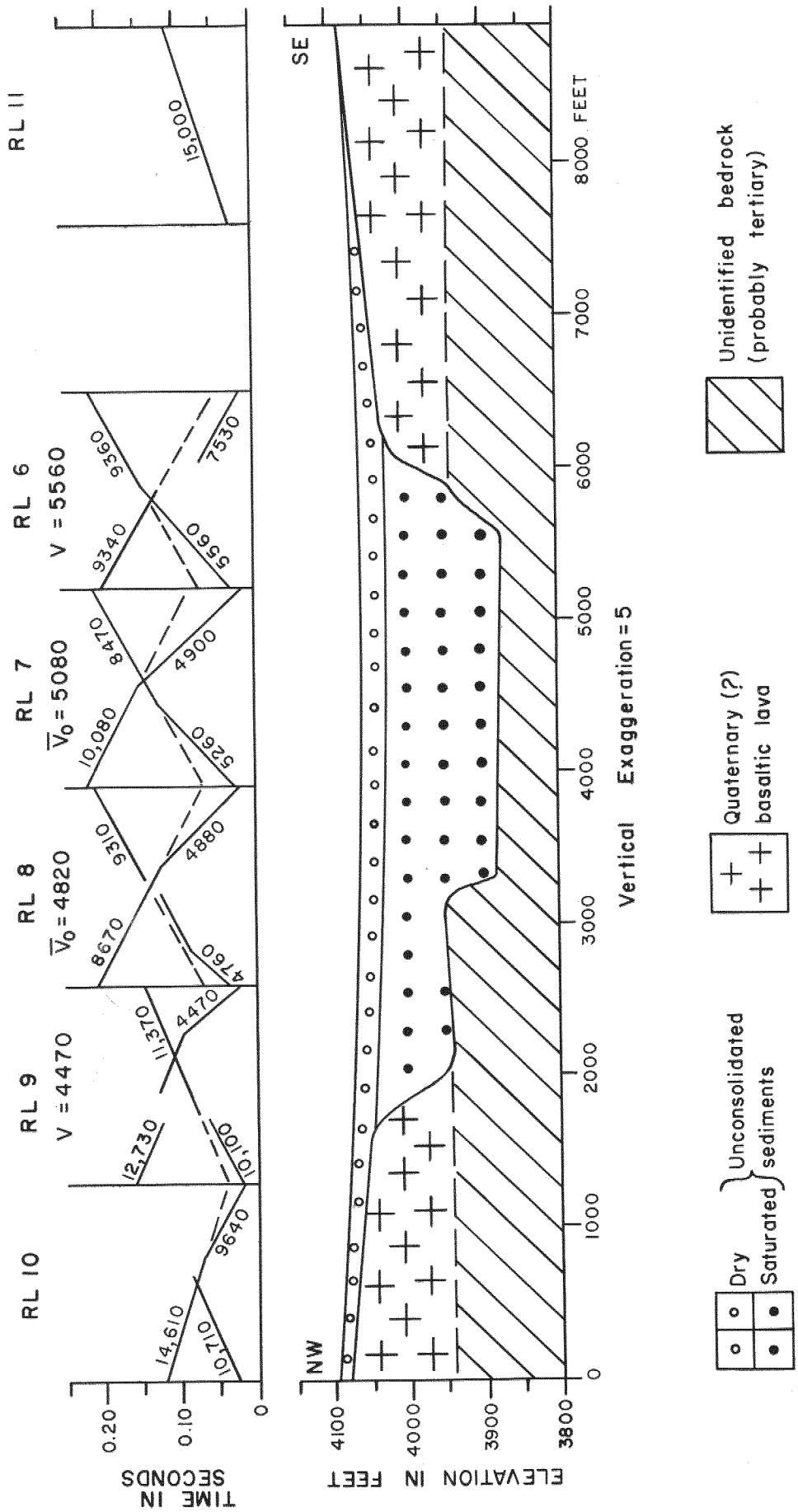

Figure 6. Interpretation of Profile B-B prime, Granite Basin.

profile to the northwest. The higher velocities to the southeast suggest greater rigidity and compaction of sediments with compaction decreasing to the northwest. Sedimentary conditions which would give rise to variations in the degree of compaction and thus to lateral velocity variations have not been examined by the authors.

A 1,200-foot refraction spread about 50 to 100 feet lower in elevation than the profile and placed near the edge of the playa lake failed to reach bedrock. Assuming a bedrock velocity the same as that in the long profile the minimum bedrock depth would be around 310 feet or bedrock elevation would be about 3,700 feet. This is well below the 3,870 foot elevation of the valley flat in the profile crossing the topographic constriction. Thus a closed bedrock basin is definitely assured. Hydrologically, however, the basin has an outlet since water table is at a depth of about 20 feet according to the refraction profiles. Reflection shots were also made at the location near the playa and a fairly good arrival was observed at .280 seconds which would give a thickness of 755 feet to the unconsolidated material and would result in a bedrock elevation of about 3,250 feet. If this reflection is a valid bedrock return there would be over 600 feet of relief from the basin floor to the bedrock constriction.

REESE RIVER VALLEY

The Reese River is part of the Humboldt River drainage system, flowing north to meet the Humboldt River near Battle Mountain. Although Reese River Valley is quite wide (10 miles), it is fault-controlled, and the actual river course is only a small part of its total width.

In the area of this study, 14 miles south of Battle Mountain, the Shoshone Mountain front, composed primarily of Tertiary rocks, form the eastern margin of the structural valley, and debris shed from this range forms an alluvial apron about five miles wide. A series of short *en echelon* scarps parallel to and a mile west of the range front occur in the alluvium. The topographic offset associated with these scarps, which face the valley, ranges from a few feet to about 25 feet. Fan-head trenches are well developed on the higher east sides and deep washes are cut through the scarps.

According to terminology used by Bredehoeft (1963), who has done extensive studies of these fans, the material above the scarps is the "Older Alluvium" and that below, the "Younger Alluvium." These terms have been used by various authors to distinguish between the higher fans, which presently are being dissected, and the lower, depositional fans. As Bredehoeft points out, this distinction is artificial and somewhat arbitrary because in many cases the two result from the continuous development of a complex fan system. In other cases the boundary between them is a fault or fault-line scarp. Both in the field and on air photos the offsets along the east side of Reese River Valley appear to be fault scarps. Figure 7 includes a sketch map prepared from these air photos.

The objectives of the Reese River Valley study were twofold. First of all the valley is easily accessible and provided the proper conditions for the comparison of reflection and refraction data. Secondly, the scarps mentioned above were also accessible to the instrument trucks and it was therefore decided to measure the relief on a possible bedrock scarp which might give rise to the topographic scarp.

A long east-west refraction spread of 4,700 feet was completed near the middle of Reese River Valley (Figures 8 and 10). A depth of 720 feet to bedrock was determined. Reflection results substantiate this depth, although the quality of the reflections was not good. Reflection spreads were shot at the end of the refraction spread and at the center. The alluvial material showed a rather constant velocity from a water-table depth of about 20

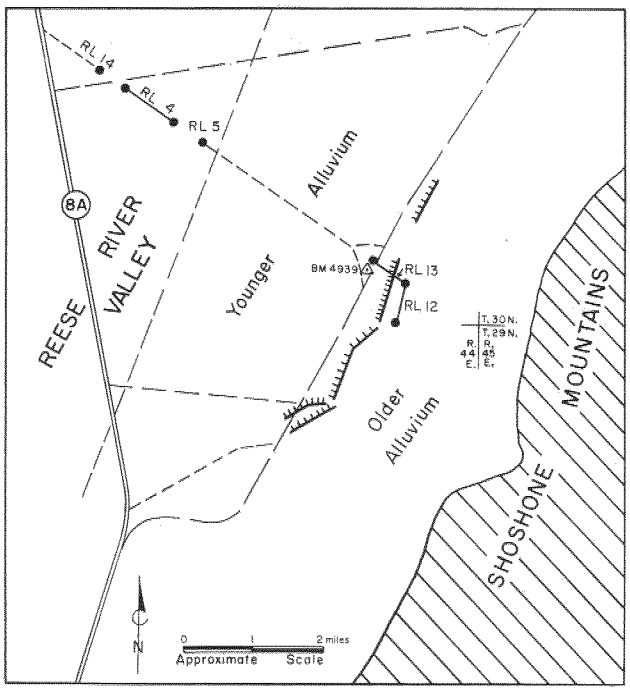

Figure 7. Location of seismic stations and en echelon scarps in Reese River Valley.

feet to bedrock, with an average velocity of 5,850 feet per second. A slight increase of velocity with depth was noted on the west end of the spread, however.

Two 1,300-foot reversed refraction spreads were shot near the scarps on the east side of the valley and in line with the long refraction and reflection stations (Figure 9). One of the spreads was shot directly across a scarp, the other about 300 feet east of the scarp and parallel to it. The two spreads had a common shot point in the northeast corner of the array (see Figure 7). As mentioned above a bedrock scarp was expected to be evidenced on the travel time curves; however, after careful examination of the records only the surficial topographic relief appears to be involved in any divergence from flat, unbroken planes. The high-velocity layer at depths of about 200 feet is extremely flat and nearly horizontal, having a velocity of about 8,140 feet per second. If the scarps are fault scarps or fault-line scarps they should be reflected by bedrock faulting and therefore this flat, horizontal layer must be something other than bedrock. The attitude of the high-velocity surface could be explained if it were caused by the water table, however, the velocity (8,140 ft./sec.) is too high for saturated fan material. For comparison, the saturated alluvial material out in the valley is 5,850 feet per second and the dry fan velocity, as observed on the time distance curves, ranges from 2,390 to 3,160 feet per second. A saturated fan velocity should therefore not exceed 6,000 feet per second. It should be noted, however, that the elevation of the high-velocity surface is about 100 feet above that of Reese River and by its position may well be indicative of the water table.

Conclusions as to the origin of the high-velocity surface cannot be made on the basis of one reversed refraction spread. It is possible however to enumerate several alternatives which are:

1. The surface represents the water table and a faulted surface exists below the water table.
2. The surface represents primarily a strike-slip faulted bedrock, producing a surficial scarp on an uneven topography but none on a smooth bedrock surface.
3. Bedrock is not faulted and the surficial scarp has been produced by erosional agents.
4. The bedrock surface is faulted, but the throw is too small to be detected on the records.

This last proposal is a possibility, but any throw of 25 feet or greater would have been detected, since it would have caused the arrival times on the east end of the 8,420 ft./sec. segment of RL-13 to be brought nearer to the straight line (see Figure 9). A better understanding of the causes for the high-velocity layer beneath the apron must await further investigations.

Fairview and Warm Springs Valleys

Two other areas were selected for rather cursory studies, both with negative results as far as reflections were concerned, but positive results with refractions. Reflection and refraction spreads were shot in Fairview Valley 30 miles southeast of Fallon. Reflections were not obtained, but a water table depth of 185 feet was determined using refraction spreads, which roughly approximates the 220 feet as stated by Zones a few years earlier (1957). Another refraction profile in Warm Springs Valley near Pyramid Lake was used to obtain a bedrock depth of 290 feet. Reflections were not obtained in a deeper part of this valley, perhaps because of too shallow a depth to bedrock.

CONCLUSIONS

Reflection and refraction studies of these three areas are illustrative of how seismic exploration can give quantitative answers from which geologic and hydrogeologic implications can be made. A bedrock high and fault line in the Rose Creek area have been extensively explored. The high indicates a real barrier to ground-water movement down valley. To the east (upstream) of the fault only a few hundred feet at the most of alluvium and lake deposits occur while to the west more than one thousand feet of these materials are present.

Results of the refraction profile across the topographic low on the east side of Granite Basin eliminate the hypothesis of a closed hydrologic basin. It is shown quite conclusively that an alluvial filled bedrock valley cuts through basaltic lava flows, hydrologically uniting the basin with the Black Rock desert.

In an attempt to compare reflection results with depths as determined from long refractions, a series of shots were made in Reese Valley. Reflection shots at the center and ends of a long refraction spread recorded weak reflections having times of the right magnitude to correlate with the depth determined from the refraction spread.

Refraction spreads were shot near scarps on alluvial fans in Reese Valley in an attempt to measure the throw of a presumed bedrock scarp. One of the most intriguing aspects of this study was the detection of a smooth, almost horizontal,

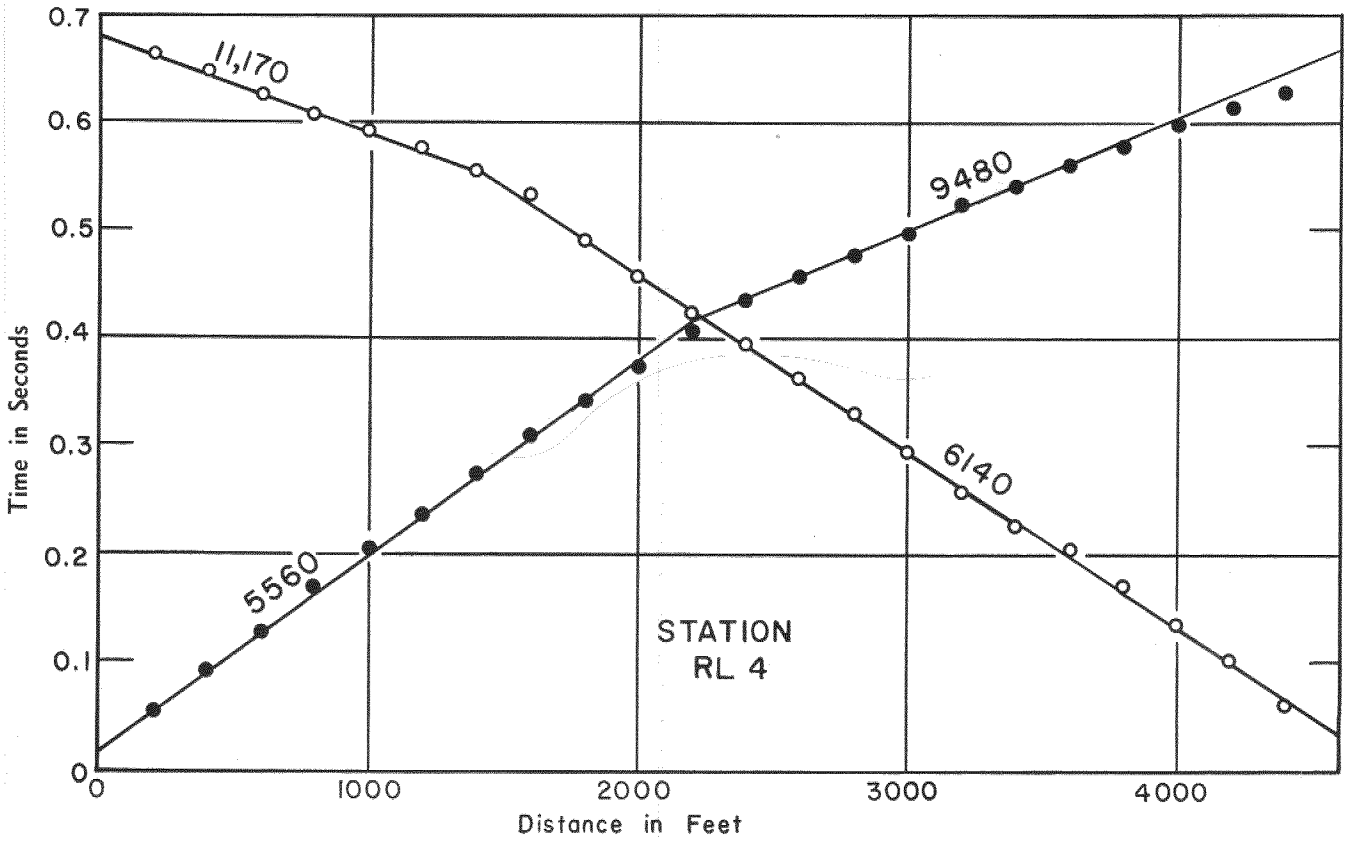

Figure 8. Travel-time curve of long refraction (RL-4) in Reese River Valley.

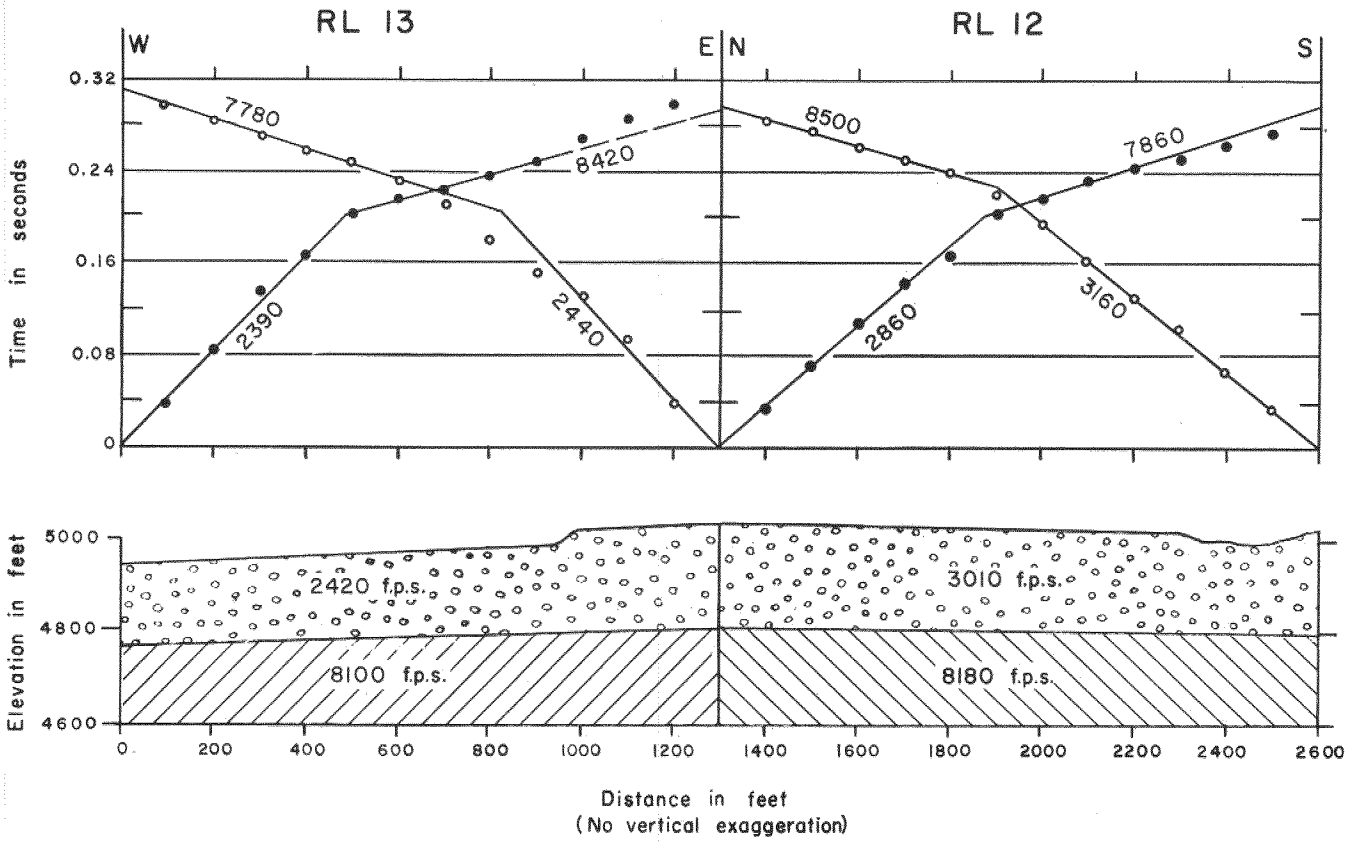

Figure 9. Interpretation of seismic data near scarps in Reese River Valley.

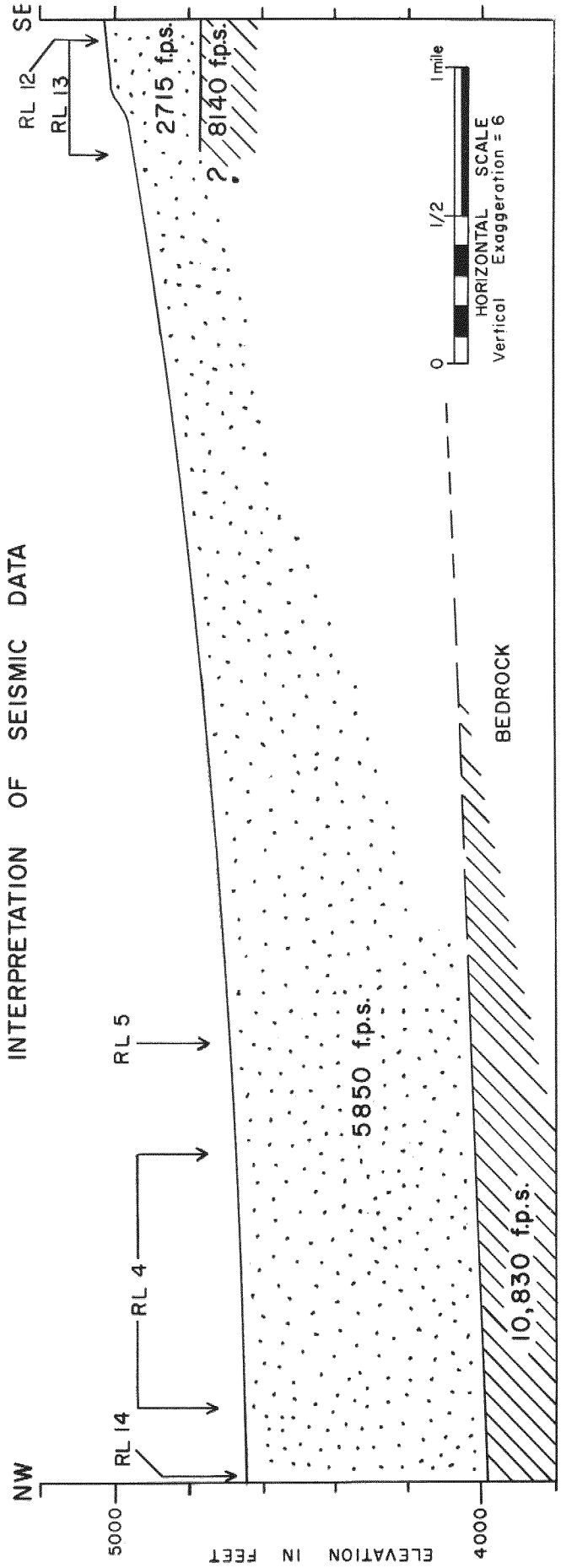

Figure 10. Interpretation of seismic data in Reese River Valley.

high velocity surface about 200 feet beneath the fan scarps. A number of explanations may be suggested for this surface, among which are: (1) it is an extraordinarily high velocity water table; and (2) it is the bedrock surface but the scarp on this surface is in the same order of magnitude or smaller than the alluvial scarp and is therefore undetectable at this depth. The authors prefer the first hypothesis, but reasons for this preference are perhaps more intuitive than scientific at this point.

In summary, it may be stated that seismic refraction measurements are generally consistent with true geologic situations, whereas reflection measurements are more prone to misinterpretation due to the scarcity of some form of geologic control. Reflection techniques as described in this paper have been about 50 percent successful. Bedrock reflections might have been greatly enhanced by the use of multiple geophones per trace and they would certainly have aided if deeper shot holes could have been drilled. However, the added requirement of deeper shot holes would have doubled the cost of the program and for this reason continued experimental work utilizing shallow shot holes is urged.

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DESERT RESEARCH INSTITUTE
UNIVERSITY OF NEVADA

in cooperation with

MACKAY SCHOOL OF MINES AND STATE DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES

EXTENSION OF THE EAST RANGE FAULT BY GRAVITY EXPLORATION

By

KEROS CARTWRIGHT, J. N. SWINDERMAN, and J. I. GIMLETT

PART III OF TECHNICAL REPORT NO. 2

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INTRODUCTION

Geophysical studies were initiated in 1959 in the Humboldt River Basin near Winnemucca, as part of the Humboldt River Research Project sponsored by the Nevada Department of Conservation and Natural Resources. The geophysical portion of the project, carried out in conjunction with hydrologic studies, was begun by G. M. Wilson in 1959, and continued in subsequent years by the writers. In part the data in this report have been taken from Wilson's report (1960).

In the early phases of the project it was noted that the low-water flow of Humboldt River increased in the area of the lower Hillyer and lower McNinch ranches (Figure 1) approximately 10 miles southwest of Winnemucca; this area is herein called the Rose Creek constriction of Humboldt River. The increase in flow occurred in spite of the fact that there are no surface tributaries along this stretch of the river. To explain this it was proposed that part of the gain of the river might be due to a buried bedrock high acting as a partial barrier to the down-gradient movement of ground water. In addition it was necessary to calculate the depth of alluvial fill so that the ground-water underflow out of the study area could be determined with some precision for the water budget. A gravity survey was made to study the depth and configuration of the bedrock in the Rose Creek constriction. This report is primarily concerned with the results of the gravity survey.

Several salient features of the bedrock configuration, as revealed by the gravity survey, were checked by seismic refraction surveys. Also, one test hole was drilled to bedrock; this hole was located on a gravity high.

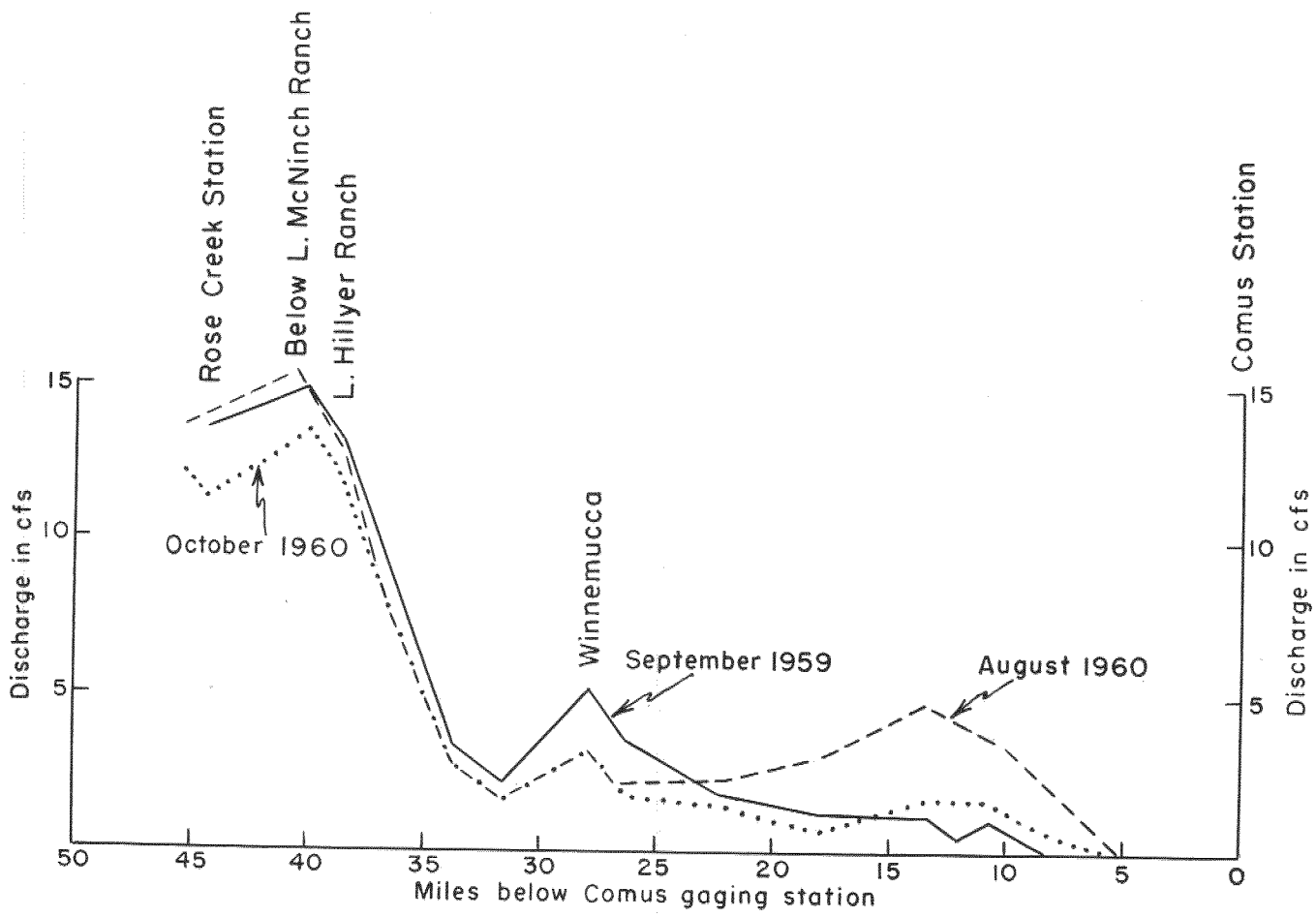

Figure 1. Hydrograph of flow in Humboldt River between Comus and Rose Creek Gaging Stations.

SURFACE GEOLOGY

The consolidated rocks of the area are described in detail by Ferguson, Muller, and Roberts (1951) and Willden (1961). The following interpretations have been largely drawn from these sources. Since the geology of the adjacent ranges is not within the scope of this paper, only a general summary is presented.

The ranges within the study area, the East Range and the Krum Hills, consist of a great thickness of Triassic rocks which were intruded by late Jurassic or Cretaceous plutonic rocks. The Ranges are of the block-faulted type typical of the Basin and Range physiographic Province. The pre-plutonic rocks were strongly deformed by folding and thrusting. Tertiary and Quaternary subaerial and lacustrine deposits and volcanic rocks are present along the flanks of the ranges. One basalt flow forms a louderback on the north side of Humboldt River.

Three Basin and Range type faults are present in the immediate area, the first only partially mapped by the writers is north of the river, the second bounds the north side of the East Range, and the third bounds the west side of the East Range. This paper deals with the extension of the latter, the so called East Range Fault, under the lacustrine and fluviatile deposits of late Quaternary and Recent age. This fault, as mapped by Ferguson, et al. (1951), from surface evidence is shown on the geologic map (Figure 2); the East Range Fault extends along the western flank of the East Range northward to about Sec. 33, T. 35 N., R. 36 E. Gravity data suggest that the fault extends further northward beneath the alluvium of Quaternary and Recent age to the vicinity of the section line between Secs. 21 and 28, T. 35 N., R. 36 E., where it may be cut off by a cross fault.

GRAVITY SURVEY

All gravimetric observations were made with a Worden "Educator" gravity meter with a scale constant of 0.4657 milligals per division. From previous work with this meter it is felt that the probable error of observation, including the drift-removal process, is somewhat less than 0.20 milligal. All elevations were obtained by differential leveling. Horizontal positions were obtained using a variety of methods, including: traversing (both with chain and odometer), map and photo identifying well sites and ends of traverses, and using a Nevada Highway Department traverse. The gravity map (Figure 3) shows the simple Bouguer anomaly data contoured. For the Bouguer density 2.67g/cc was used. Errors in assumed density would lead to very small errors in the anomaly because of the small elevation range encountered in the area. No terrain corrections were made. If they had been included in the anomaly their effect would have been to increase the anomaly up to 1.5 milligals near the ranges, less (0.5 mgal.) in the flood plain.

The isogal map (Figure 3) shows a marked positive anomaly along the section line between Secs. 16 and 15, 21 and 22, and 28 and 27, which probably is produced by a northward trending buried bedrock high across the constriction. The low point or saddle is near the corner of Secs. 21, 22, 27, and 28. The anomaly drops off steeply to the west (23 mgal. in 3.5 mi.) and slightly to the east (4.5 mgal. in 2.0 mi.). The steep gradient on the west side of the high strongly suggests a normal fault as shown on the geologic map (Figure 2). It is obvious that this fault corresponds closely enough in location and strike with that of the East Range Fault, which was mapped on surface evidence, to be a continuation of that same fault.

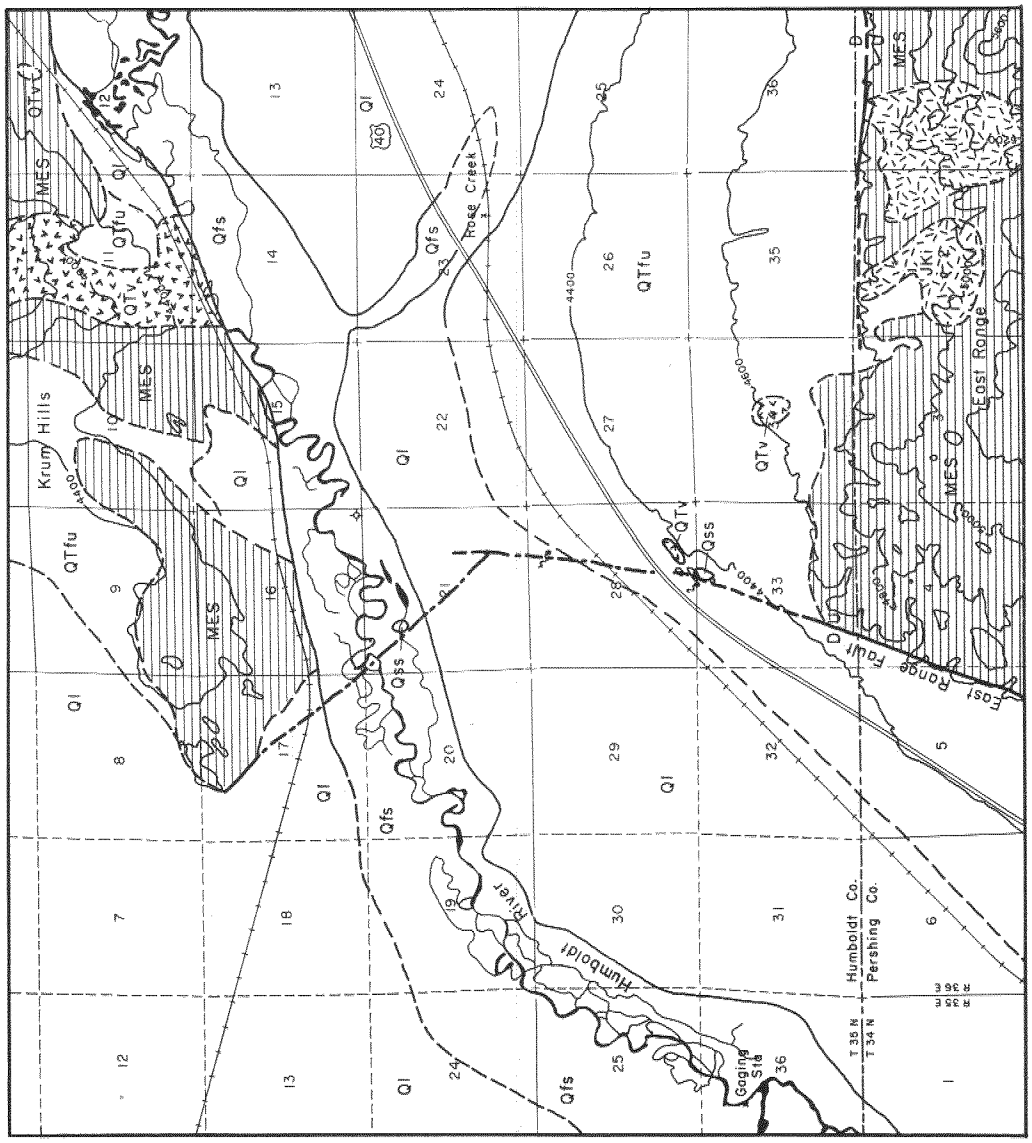

Figure 2. Geologic map of the Rose Creek constriction of Humboldt River.

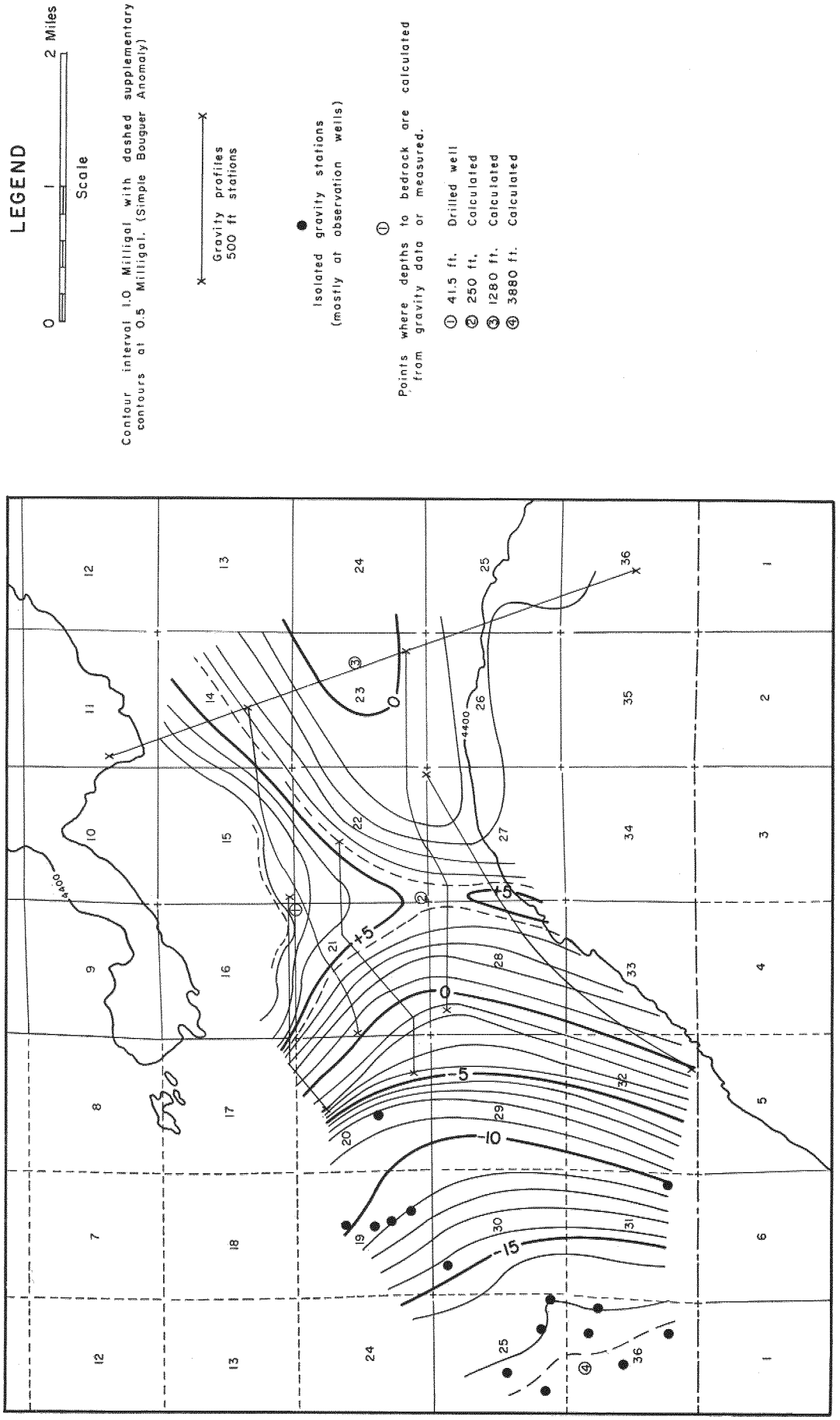

Figure 3. Gravity map of the Rose Creek constriction of the Humboldt River.

REFRACTION SURVEY

A seismic refraction profile at the southeast corner of Sec. 21, T. 35 N., R. 36 E., i.e., at site number (1) of Figure 4, verified the presence of the bedrock high (W. W. Dudley, Jr., personal communication). At this spot the depth to a high-speed (13,000 ft./sec.) horizon was only 29 feet. A well drilled at this location penetrated the unconsolidated valley fill and bottomed in slates at 41.5 ft. The difference between the two depths is probably caused by undulations in the bedrock-valley fill interface.

A very interesting seismic profile was run, some 80 ft. south of and parallel to the aforementioned one, with a Dynametric Seismic Timer. Consistent returns were obtained at 10-foot stations out to 300 ft. with this "Flintstone" unit. The data are plotted in Figure 4. This figure shows the classic refraction profile across a buried step. The difference between the depths as computed at each end of the profile, 18 ft. on the west and 11 ft. on the east, is the same as the 7 ft. obtained using the step in time discontinuity. This 7-foot escarpment, downthrown on the west, could be attributed to something prosaic, like a buried river bank. It would be more aesthetically pleasing, however, to attribute it to relatively recent movement along the extension of the East Range Fault. It is on strike and the displacement is in the proper direction.

The seismic method also proved useful in another area. The outcrop in the northwest corner of Sec. 21, marked Qss, was originally thought to be bedrock, though it does not lie on the gravity high, but rather on the west flank. A refraction survey, here, revealed that this outcrop, which does show a high velocity, has no "roots" and seems to be lying on the surface (L. D. McGinnis, personal communication). Based on this and petrographic evidence this rock has tentatively been identified as siliceous spring sinter.

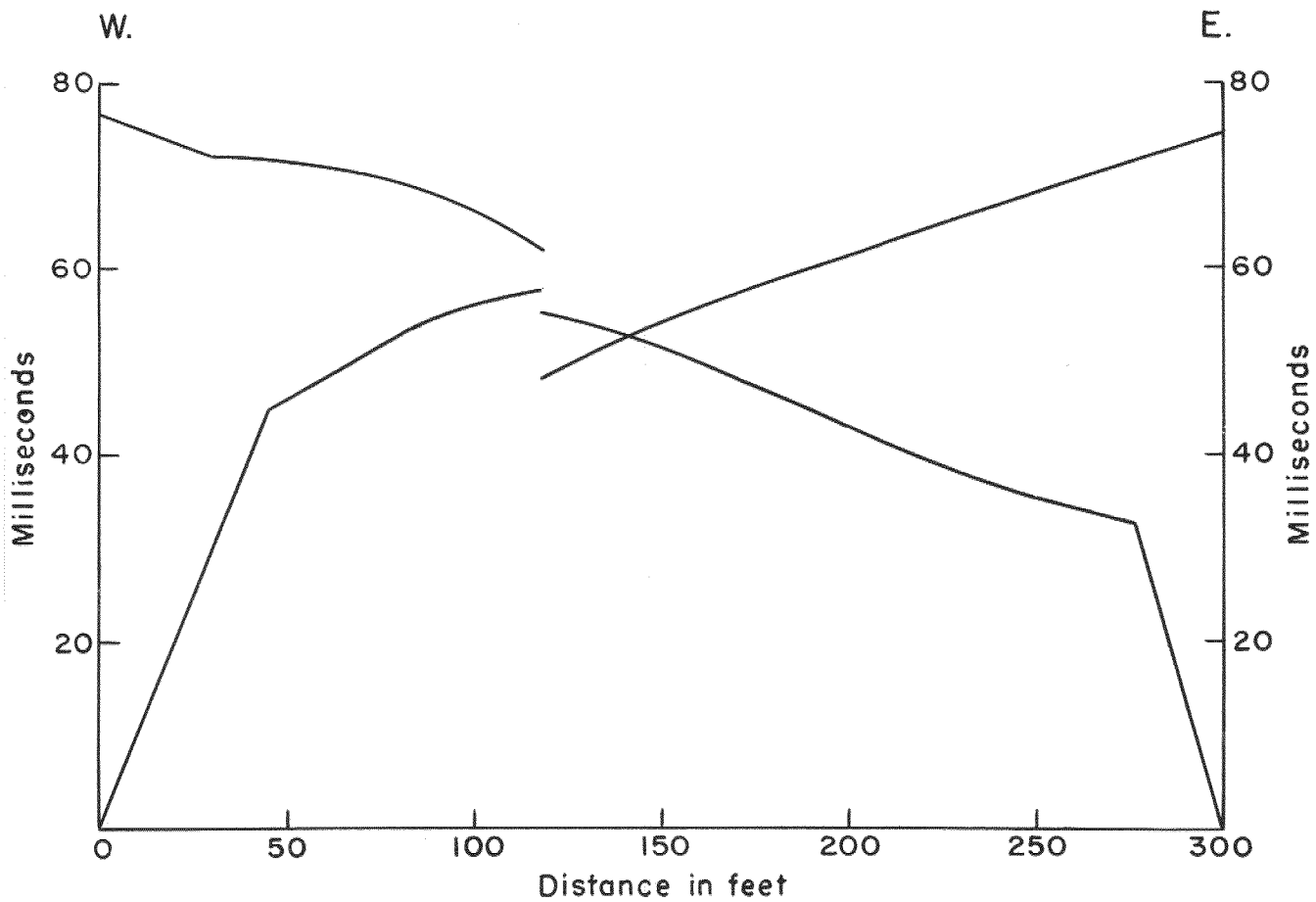

Figure 4. Seismic refraction profile near the Rose Creek constriction.

DEPTH DETERMINATIONS

Depth determinations from gravity data are difficult without regional control. Calculations were made using the infinite slab approximation, and using a graticule along a profile at right angles to the high through the saddle. A density contrast of —0.55g/cc was used. This value is in good agreement with others used in the Great Basin for the contrast between bedrock and the valley fill. Depths-to-bedrock at the four locations shown on the isogal map (Figure 3) are as follows:

1. 41.5 ft. (Lower McNinch Ranch—drilled well).
2. 250 ft. (low of saddle in the gravity high).
3. 1,280 ft. (low on the east side of the anomaly).
4. 3,880 ft. (low at Rose Creek Gaging Station).

In all cases ground surface is the elevation datum.

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