TID-17224

GEOLOGICAL, GEOPHYSICAL, AND HYDROLOGICAL INVESTIGATIONS OF THE SAND SPRINGS RANGE, FAIRVIEW VALLEY, AND FOURMILE FLAT CHURCHILL COUNTY, NEVADA

FOR

SHOAL EVENT

PROJECT SHADE, VELA UNIFORM PROGRAM

ATOMIC ENERGY COMMISSION

BY

NEVADA BUREAU OF MINES
NEVADA MINING ANALYTICAL LABORATORY
DESERT RESEARCH INSTITUTE

UNIVERSITY OF NEVADA

RENO, NEVADA

1962

UNIVERSITY OF NEVADA

RENO, NEVADA

OFFICE OF THE PRESIDENT

September 4, 1962

Mr. James E. Reeves
Manager of Nevada Operations
United States Atomic Energy Commission
Las Vegas, Nevada

Dear Mr. Reeves:

It gives me pleasure to transmit our University of Nevada report, "Geological, Geophysical, and Hydrological Investigations of the Sand Springs Range, Fairview Valley, and Fourmile Flat, Churchill County, Nevada", for the proposed Shoal Event. We trust you will find the results of our investigations adequate for your needs.

This report represents the cooperative effort of three University organizations, the Nevada Bureau of Mines, the Nevada Mining Analytical Laboratory, and the Desert Research Institute.

We look forward to continuing cooperation between the Atomic Energy Commission and the University of Nevada.

Kind personal regards.

Cordially yours,

C. J. Armstrong

Charles J. Armstrong
President

CJA:bb

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SUMMARY AND CONCLUSIONS

To help evaluate the Sand Springs Range as a site for the Atomic Energy Commission's proposed 5 kiloton underground nuclear Shoal Event, the University of Nevada with the aid of subcontractors and Atomic Energy Commission support groups (Holmes and Narver, Inc., and Reynolds Electrical and Engineering Co., Inc.), has completed an exploration program begun late in November, 1961. Elements of this program included bulldozer work, engineering control, aerial photography, preparation of photomosaics and topographic maps, geological mapping at three different scales, mineralogical studies, age determinations, diamond drilling of two test holes in granite, a gravity survey, an aero-magnetic survey, a refraction survey, certain physical tests on the core, study of the hydrology of the Range and the surrounding alluvium, drilling and study of four hydrological test holes in the alluvium, and study of hydrological conditions of the two holes in granite.

The northerly-elongated Sand Springs Range is cored by a medium- to coarse-grained, locally porphyritic, Cretaceous granitic body (granite-granodiorite), almost batholithic in size. On the north this intrusive is flanked by metamorphic rocks of probable Mesozoic and older age, and by Quaternary-Tertiary volcanic rocks. Metamorphic rocks in intrusive contact with the granite on the southwest are in turn lapped by Quaternary-Tertiary volcanics and alluvium. Fairview Valley lies on the east; geological and geophysical evidence indicates this is a complexly down-faulted block. The west-central part of the intrusive locally is overlapped by basalt flows which protrude eastward from the Cocoon Mountains. On the northwest is Fourmile Flat, which geological and geophysical evidence suggests to be a pediment floored mostly by granite and locally by metamorphic rock, and on which alluvial veneer gradually thickens westward.

The granite mass is broken by steeply dipping faults that strike predominantly N. 50°-60° W. and N. 30° E., and by joints, the best developed of which also strike N. 50°-60° W. and dip steeply. Closely spaced fracture cleavage planes that trend N. 30° E. and dip steeply, are prominent throughout the Range.

Aplite-pegmatite dikes are abundant in an elongate zone on the northwest side of the granite. This zone curves southeast through the west central part of the Range and intersects the granite-metamorphic rock contact to the south. These relatively narrow dikes are generally chaotic in strike and dip in the central part of the zone, but commonly are oriented by the northwest joint set on the fringes of the zone. This is especially true of the Ground-Zero area. A mass of intrusive breccia that somewhat resembles aplite, but which probably is more closely related to younger rhyolite dikes, occurs on the northeast side of the Range.

The northwest-trending faults and joints in the north half of the Range often are occupied by swarms of steeply dipping andesite and rhyolite dikes that rarely exceed 50 feet in width. The faults, particularly where the rhyolite dikes predominate, commonly have wide bleached and iron-stained bands. To the south, dikes are much less abundant and have northeast, east, and northwest orientations.

The gravity survey, designed to investigate the flanks of the Sand Springs Range and neighboring valleys, shows an expected gravity high over the mountains and lows over the valleys. The westward displacement of the high is attributed to metamorphics which could extend northwest under the alluvium of Fourmile Flat and possibly through the position of hydrological test hole H-3. The eastern side of the Range is bounded by a series of northwest- and northeast-trending faults of large displacement. A gravity nose extending into Fairview Valley south of Lucky Boy Canyon, marked also by a small aeromagnetic high, is interpreted as being produced by a shallow buried horst capped by metamorphics. No faults of large offset are evident from gravity data on the northwest side; there appears instead to be a rather featureless bedrock surface that dips westward at a low angle.

Using a quantitative approach based on an assumed density contrast of 0.5 g/cc, depth to "bedrock" in Fairview Valley is calculated at 5,800 feet; this is in good agreement with the depth obtained from aeromagnetic data. The depression apparently is a combination of step-faulting and down-warping. The western side of the Range may be bounded by a normal fault with a displacement of about 2,000 feet—part topographic and part stratigraphic. A section of metamorphic rocks is interpreted to extend from outcrops on the northwest end of the Range southward through test hole H-3. This either could be a xenolith in granite, or could represent the western contact of the main intrusive. The fill in Fourmile Flat appears to be 1,000 to 1,300 feet thick and apparently does not include thick basalt flows. If metamorphic rocks are present, thickness of the fill actually may exceed 2,000 feet, more in keeping with a thickness of 2,500 feet calculated from aeromagnetic data.

The aeromagnetic data help in the interpretation of gravity data as noted. Most of the major rock units described above can be identified by a characteristic grain on the aeromagnetic map. The limits of the surface exposures of the granite can easily be seen. The northern contact of the granite with the metamorphics is marked for its entire length by a prominent magnetic low which probably is due to the geometric effect as well as to contact effects, hydrothermal alteration, etc. On the south the granite pattern abuts the large magnetic high over the metamorphics. It is impossible to determine magnetometrically the extent of the granite north and south of its surface exposures because of the masking effect of overlying rocks. The presence of faults in Fairview Valley, away from the Range front, is based in part on small magnetic anomalies.

Refraction work was designed to augment gravity and aeromagnetic data. Crude seismic tests on granite in the Ground-Zero area produced low velocities, attributed to weathering and relatively open fracture cleavage. The first refraction profile confirms the thinness of alluvium in Fourmile Flat, and the velocities obtained suggest either weathered granite or metamorphics under unconsolidated alluvium. The second profile indicates a high velocity medium near test hole H-3 at a depth of 196 feet and dipping gently west; this medium is interpreted as 114 feet of metamorphic rock overlying granite, an interpretation which conforms well with gravity and aeromagnetic results. The third profile in Fairview Valley suggests compacted fill, the position of the water table, and depths to granite in excess of 2,000 feet for the line covered.

Water occurs at the surface in a few places and at varying depths underground throughout the area. In nearly all instances ground water is found shallower in the valleys and deeper in the mountains, although a few seeps and springs in the Sand Springs and Stillwater Ranges and on Fairview-Slate Mountain attest to the presence of some shallow, probably small, bodies of perched or otherwise trapped water. Evidence from drilling in the Sand Springs Range granite is essentially inconclusive regarding the water-bearing characteristics of these rocks, although it has been established that some water does occur in the granite. The consolidated rocks act as geohydrologic barriers and neither store nor transmit appreciable quantities of water—appreciable, at least, in relation to any probable contamination hazard that might result from the Shoal experiment. Therefore, emphasis in hydrogeologic study has been placed on the valley fill, because these sediments do contain and transmit appreciable quantities of water and form the reservoirs from which water supplies are withdrawn.

Near the Sand Springs Range the fill of Fairview Valley, and the valley of Fourmile and Eightmile Flats, consists of alluvial fan or apron sediments which farther down the alluvial slopes are cut by lake terraces and are overlain by lacustrine sand and silt. The alluvial and lacustrine deposits are cut by stream channels filled, in most instances, with varying but small thicknesses of stream alluvium. Thus, the upper parts of the alluvial slopes and lake terraces are composed of relatively permeable sediments, while the valley fill is composed of both interbedded coarser materials which form aquifiers below a depth of about 300 feet, and finer materials that form aquicludes. Playa deposits in the central low parts of the valleys contain a much higher proportion of fine materials, primarily fine silt with a little clay.

In Fairview Valley, ground water occurs at depths varying from over 300 feet, high on the alluvial slope, to about 225 feet near the valley center. Hydraulic gradients of the piezometric surface are low, on the order of 3 feet per mile, and the water moves with an apparent velocity of between 0.03 and 0.07 foot per day. It is doubtful that average velocities exceed 25 feet per year. Pumping tests indicate a range of the coefficient of transmissibility from about 5,000 to 17,000 gallons per day per foot, and a range of the coefficient of storage from about 2×10^{-4} to 3.5×10^{-4}.

In Fourmile Flat, ground water occurs at depths ranging from over 300 feet, high on the alluvial slopes, to a few feet or less in the valley bottom. Here the playa area is a "point sink" with water moving toward the playa from all directions to be discharged eventually by evapotranspiration. The piezometric surface is nearly flat, that is, gradients from all directions toward the point of discharge are extremely low, ranging from about 1.46 feet per mile to essentially horizontal. Estimates of velocity range from 0.02 feet per day to 0.04 feet per day, or on the order of 16 feet per year. The estimated coefficient of transmissibility of the granite, which acts as an aquifier high on the flank of the Range, is less than 200 gallons a day per foot. The coefficient of transmissibility of the alluvial materials near the east margin of the playa is about 76,000 gallons a day per foot.

Chemical data verify the conclusions regarding the gradients mentioned above. They also indicate that little if any recharge to the alluvial fill occurs on the west side of the Range. Preliminary study of distribution coefficients of materials determined in other areas such as the Nevada Test Site and Hanford, indicates that both the granite in the Sand Springs Range and the alluvial fill in adjoining valleys, would rapidly fix the radionuclides resulting from the proposed test shot. It is presently deemed safe to say that under ordinary conditions of underground movement of water at the estimated gradients in the Range, the radionuclides will not travel beyond the Range front.

If these estimates and this conclusion are in error and radionuclides should be carried by ground water into the alluvial fill, they will be fixed within a short distance of the Range front. This conclusion is substantiated by the following:

1. The gradients in the valley fill are very low, and the more or less uniform permeability of any section of the alluvial fill precludes anomalously rapid movement. Velocities calculated from the known gradients and permeabilities are low, on the order of three feet per mile in Fairview Valley and 1.46 feet per mile per year in Fourmile Flat.
2. The distribution coefficient of the alluvium is certainly higher than that of the granite, for the alluvium is the weathered product of the granite composed of discrete particles with much more exposed surface area.

The conclusions given above are based on the assumption that the shot will be wholly contained.

The granite within 1,000 feet of Ground-Zero, though jointed, cleaved, and faulted, is relatively unaltered and free of dikes. Faults recognized at surface also were identified in NX diamond drill hole ECH-A (N. 60° W., −45°, 1,898 feet). The upper portion of 6-inch diamond drill hole ECH-D (vertical, 2,017 feet) penetrated jointed and cleaved, relatively fresh granite, but at 1,440 feet a fault zone was encountered that extends to 1,675 feet. This zone is about 75 feet wide, dips about 70°, and probably is the downward extension either of a northeast fault zone exposed west of ECH-D, or an east-west fault zone north of ECH-D (exposed by additional trenching in August), or a combination of both. Nothing logged in either of the two holes suggests that either a flat thrust or a dike swarm is present at the proposed shot depth.

Thermal conductivity, elasticity, and permeability tests, and petrographic examination of core selected from 512, 994, 1,422, and 2,004 feet in ECH-D indicate, except for the fault zone, that the granite has essentially the same characteristics throughout the hole. Results from the tests are comparable with those reported in the literature for similar material. Results of the logs run in August by Schlumberger Well Surveying Corp. show excellent correlation with the lithologic logs.

Recovery tests and other observations made during the drilling of ECH-D indicate that some water occurs in the granite below a depth of about 1,086 feet. Little more can be said of the total hydrological characteristics of the Ground-Zero site.

If the preferred shot depth continues to be 1,500 feet, some constructional difficulties should be anticipated in the fault zone between 1,440 feet and 1,500 feet. These difficulties will be aggravated by water from 1,086 feet down to the emplacement point. If the depth is raised to 1,200 feet or less, only local and minor trouble will be caused by joint and fracture cleavage planes. At a depth of 1,200 feet the shot apparently will be about 114 feet under a normal or perched water table.

Although the immediate vicinity of Ground-Zero is one of the least fractured and altered parts of the Sand Springs Range, there are no extensive blocks of granite in which shock waves could travel without encountering fault surfaces. The pattern and density of faults and joints around the shot point, and the increasing number of dikes of various types away from that point may complicate the arrangement of seismographic stations. It is not believed that conditions could be improved much by moving the emplacement hole some distance from ECH-D; if such a move is desired, at least two additional small diameter holes should be drilled to establish ground characteristics of the new shot point.

With some reservation because of our limited knowledge of all requirements for the experiment, we conclude from exploration results and consideration of those safety factors related to geology, that the Sand Springs Range is suitable for the Shoal Event. The site may be somewhat more complicated by joints, cleavage, faults, dikes, and water than was realized when it was selected for more detailed study, but the exploration results should not be surprising for an area so active seismically. "Others" must decide whether or not the complications really detract from the acceptability of the site.

INTRODUCTION

Purpose and Scope of Investigation

The proposed Shoal Event is a part of Project Shade of the Vela-Uniform program sponsored jointly by the Department of Defense and the Atomic Energy Commission. Its purpose is to improve our knowledge of the characteristics of seismic waves generated by man-made explosions, especially as related to the detection and identification of underground nuclear explosions.

Prior to the test reasonable assurance must be given that rock conditions are satisfactory for the evaluation of test results; that no shock damage will result to surface structures, wells, or mine openings; and that no short or long term safety or health hazards will be generated by the explosion. This report contains the results of the geological, geophysical, and hydrological investigations that contributed to the evaluation of these conditions.

In preparing this report the writers have drawn freely from all information on the Shoal site readily available to them. Reports consulted are listed under References. The folio of maps accompanying this report and showing results of the University's investigation should be useful in subsequent planning.

Site Requirements

As a result of reconnaissance surveys of possible sites outside of California for the Shoal Event, a committee consisting of representatives of the U. S. Atomic Energy Commission, the U. S. Geological Survey, and the engineering firm of Holmes & Narver, Inc. determined that the Sand Springs Range, Churchill County, Nevada (see Figure 1) came nearest to meeting the following requirements:

1. Geologic medium to be tuff or granite in an area of simple geologic structure.
2. Relief to vary not more than 1,000 feet within a two-mile radius from Ground-Zero.
3. Emplacement depth to be 1,500 feet if in granite, or 1,350 feet if in tuff.
4. Site to be in a currently active seismic area with recent history of strong shallow-focus earthquakes.
5. Several granite outcrops to be located within a radius of 1,500 feet from the center of the site. Location of shot within chosen seismic area and depth of overburden are not of critical importance.
6. Technical operations to include a central working area around Ground-Zero, extending outward for a radial distance of ½ mile. Additional areas outside of the central areas to be available for strong motion studies.
7. Strong motion measurements and intermediate range measurements to be similar to those programmed for Lollipop. Approximately 40 temporary seismographic stations to be used in linear and azimuthal patterns at distances ranging from 200 to 4,000 kilometers.
8. Two half-acre areas, separated by a distance of ¼ mile, to be available for each off-site seismographic station. Bedrock outcrops to be available in one area of each pair, for use as seismographic vaults. The other area to provide for a recording shelter, generator, and vehicle storage.
9. The site to be in an area of low population and several miles removed from man-made structures.

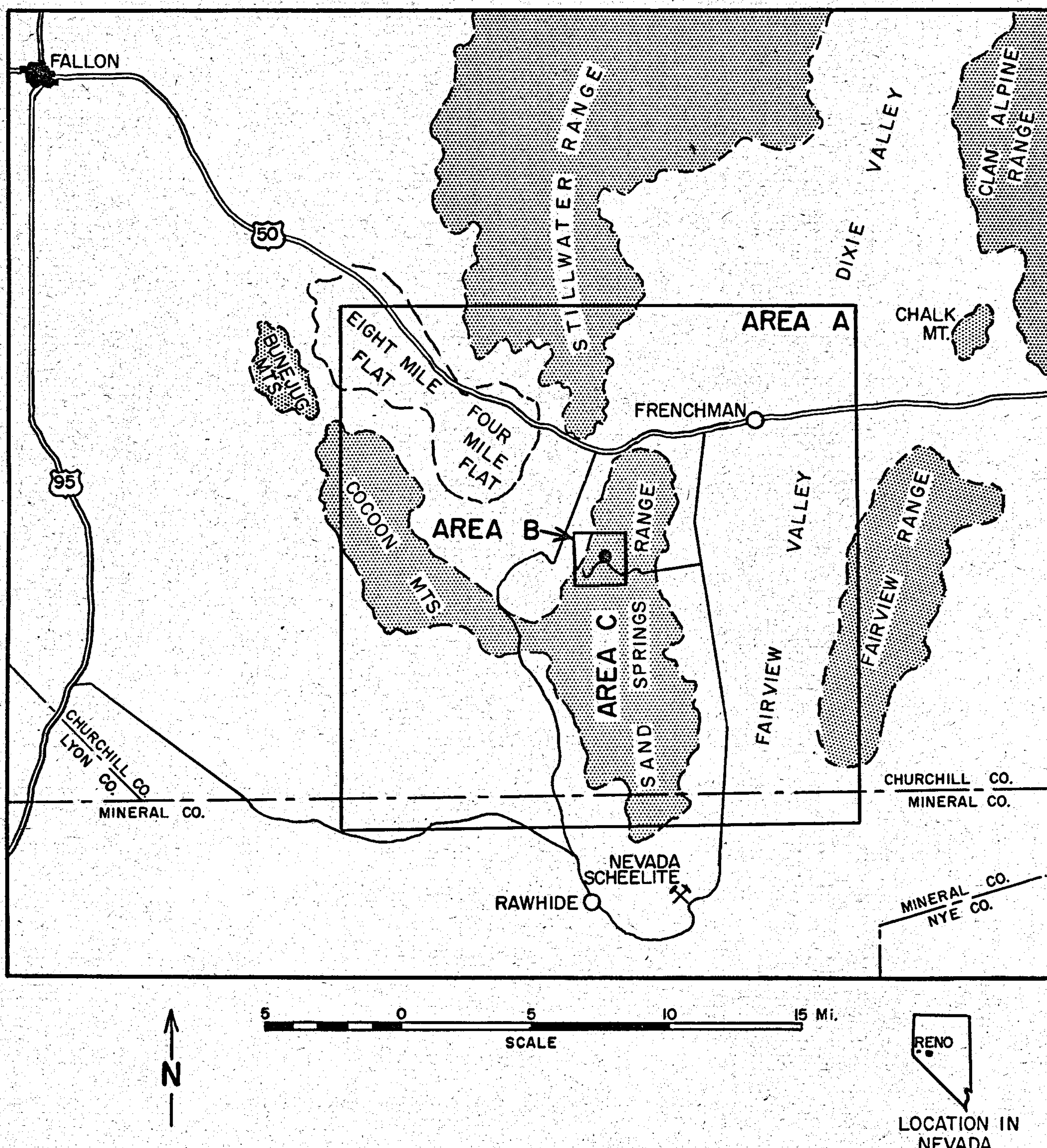
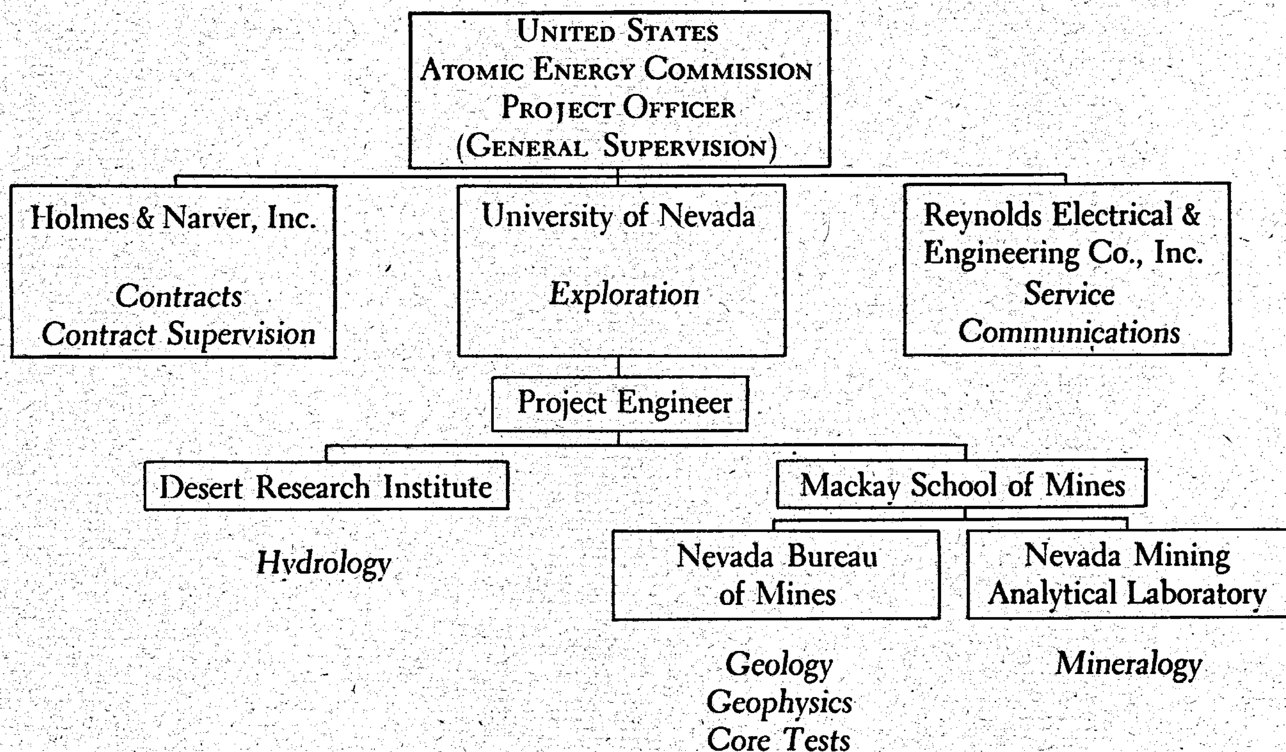


Figure 1. Index map to proposed Shoal site—Sand Springs Range, Nevada

Project Organization

In July 1961 preliminary discussions between representatives of the Atomic Energy Commission and the Mackay School of Mines, University of Nevada, led to a request from Mr. James E. Reeves, currently manager of Nevada Operations, U. S. Atomic Energy Commission, that the Mackay School of Mines submit a proposal covering the geological exploration phase of work involved in determining the suitability of the Sand Springs site. A preliminary proposal made in August 1961 was followed in November 1961 by a modified final one, accepted by the Atomic Energy Commission. This included geological, geophysical, and hydrological studies to be conducted by Mackay School of Mines and Desert Research Institute personnel over an estimated period of 37 weeks and involving an expenditure slightly in excess of $188,500. The program was activated on November 16, 1961.

The general organizational arrangement of participating agencies and University groups cooperating during the exploration phase of the Shoal Event was as follows:



The University of Nevada's exploration program was conducted with the endorsement and support of Dr. Charles J. Armstrong, University President, Dr. Vernon E. Scheid, Dean of the Mackay School of Mines and Director of the Nevada Bureau of Mines and Nevada Mining Analytical Laboratory, and Professor Wendell A. Mordy, Director of the Desert Research Institute.

The work was under the supervision of Dr. Stanley E. Jerome, Associate Director of the Nevada Bureau of Mines and Nevada Mining Analytical Laboratory. Dr. George B. Maxey and associates of the Desert Research Institute (DRI) were responsible for hydrologic aspects of the program. Nevada Bureau of Mines (NBM) and Nevada Mining Analytical Laboratory (NMAL) personnel handled all other phases of the work in accordance with their fields of specialization.

Acknowledgments

Members of the University staff connected with the Shoal project wish to express their appreciation to personnel of the Atomic Energy Commission, Holmes & Narver, Inc., and Reynolds Electrical and Engineering Co., Inc., for the cooperative and congenial atmosphere in which the exploration work was conducted.

METHODS OF INVESTIGATION

Access to Site

To expedite the exploration and subsequent work in the vicinity of the test site, 24 miles of roadway either were newly built or were improved from existing roads. A new road approximately 8 miles long was bulldozed south from U. S. Highway 50 along the west side of the range to a junction with an old, infrequently used road connecting Highway 50 with Rawhide. (See Figure 1.) This latter road was then improved by grader for an additional 11 miles southward to its junction with the Rawhide-Schurz road.

A five-mile road also was built on the east side of the range to serve as an access to the tentative Ground-Zero site and the microwave radio relay station on a peak to the west. This road proceeds westward from a point on the county road serving the Nevada Scheelite mine, and for the last three miles follows one of the few canyons in the central part of the Range that does not contain formidable road-building obstacles.

Road work and subsequent bulldozer trenches were laid out by R. Horton (NBM) assisted by J. Schilling (NBM). The jobs were let to a Fallon contractor by Holmes & Narver, Inc. who supervised his activities.

Aerial Photographs and Base Maps

In November 1961 the only available topographic map covering the region selected for Shoal exploration was the Army Map Service 1:250,000 scale Reno sheet, based on 1:60,000 aerial photography. Since this material obviously was inadequate for detailed planning and mapping purposes, specifications were completed by J. Gimlett (NBM) for aerial photography and topographic map coverage. A contract under his supervision was let to Mark Hurd Aerial Surveys, Inc., 5760 Dawson Ave., Goleta, California. A 400-square-mile block (Area A), centered on tentative Ground-Zero, was covered by 1:31,680 photography. For topographic mapping purposes photographs also were taken of two other areas within this block, Area B at 1:12,000 and Area C at 1:52,000. (See Figure 1.) Items based on this photography which can be ordered directly from Mark Hurd include:

1. 112 contact prints at about 1:31,680 of Area A; 25 contact prints at about 1:12,000 covering the proposed site, Area B; and 15 contact prints at about 1:52,000 of the Sand Springs Range, Area C. Enlargements of all of the above also can be ordered.
2. Photo-index maps to the above photography. See Plate 1 in map folio accompanying this report.
3. Semicontrolled photomosaic of Area A at about 1:31,680. Plate 2 in folio. A reduction of this to about 1:62,500 also is available.
4. Semicontrolled photomosaic of Area B at about 1:6,000. Plate 3 in folio.
5. Topographic map of Sand Springs Range at 1:31,680. Contour interval 40 feet. Used as a base map for presenting reconnaissance geology. Plate 4 in folio.
6. Topographic map of Area B, four-square-mile block centered on tentative Ground-Zero, at 1:6,000. Contour interval 5 feet. Used as a base map for presenting detailed geology. Plate 5 in folio.
7. A portion of the 1:6,000 topographic map has been enlarged to 1:2,400 and used in Plate 6 of the folio to show structural details of the granite in the vicinity of tentative Ground-Zero.

To prepare the topographic maps from photography, Mark Hurd Aerial Surveys, Inc. used U. S. Coast and Geodetic Survey coordinates and elevations supplemented by stations triangulated and levelled by Sprout Engineers, Inc., operating under contract to Holmes & Narver, Inc. and supervised by R. Horton and J. Gimlett. Prior to photography, all control points were panelled by Sprout Engineers, Inc., aided in part by helicopters from the Naval Auxiliary Air Station at Fallon.

Surveying, panelling, and flying for photography were hampered by unusually heavy snow storms. The season in which the job was initiated was not conducive to high-quality results from aerial photography. While some of the photographs and photomosaics are rather striking because of long, black shadows on north-facing slopes, such shadows made portions of some photographs almost useless in areas of extreme relief for both topographic and geologic mapping.

Geology

Geological reconnaissance of about 55 square miles in the Sand Springs Range was conducted as weather permitted between the end of January and the first of May by NBM personnel, L. Beal. S. Jerome, I. Lutsey, R. Olson, and I. Schilling. (Those with names underlined here, and subsequently, devoted the most continuous effort to completing a particular phase of work. If the burden was equal, underlines are omitted.) Snow storms interrupted mapping on several occasions. The 1:31,680 aerial photographs, supplemented in part by enlargements to 1:12,000, were used as mapping bases. Results were compiled on Mark Hurd's 1:31,680 topographic map and are presented in the folio as Plate 4.

Detailed mapping of Area B was completed in March by Messrs. Beal, Jerome, and Schilling. Photo-enlargements at 1:6,000 were used as bases, and the results compiled to Mark Hurd's 1:6,000 topographic sheet. See Plate 5 in the folio.

It was evident that outcrops in the vicinity of Ground-Zero were too scattered to permit reasonable appraisal of rock conditions in advance of deep exploratory drilling. Bulldozer trenches supplemented by short diamond drill holes were proposed. After access was gained to Area B, R. Horton laid out roughly north-south and east-west trench lines; these were stripped by grader and bulldozer (see Figure 2 and Plate 6). In the hope of eliminating many short diamond drill holes, alternate north-south trenches and all east-west trenches subsequently were ripped by heavy bulldozers. Owing to closely spaced fracture cleavage planes in the granite, ripping proved to be so effective a method for disclosing structure and rock types that the projected drilling of short diamond drill holes was eliminated.

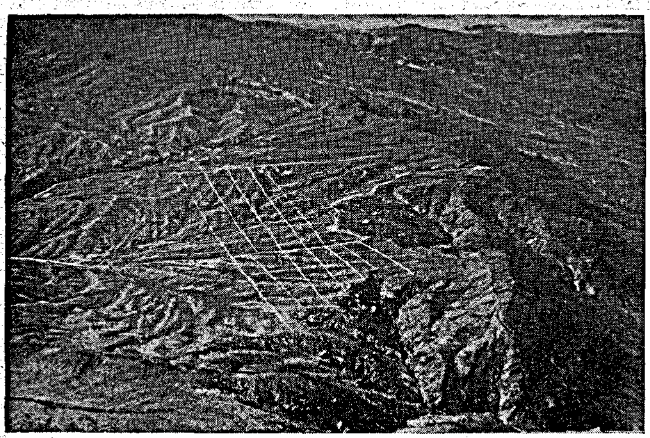


Figure 2. Ground-Zero area showing trench pattern and diamond drill hole sites. (looking southwest)

Trenches totaled about 12 miles. Using a rough layout map prepared by Sprout Engineers, most of the trenches were mapped at 1:2,400 scale; this work was supplemented by a number of mapping traverses in adjacent areas, totaling 6,400 feet, which contributed substantially to the study. Results presented on Plate 6 in the folio were obtained by Messrs. Beal, Horton, Jerome, Lutsey, Olson, and Schilling. Early completion of this work in December and January permitted the initiation of exploratory diamond drilling and saved the job from undue weather delays. Subsequently, in August 1962 one and three-quarter miles of additional trenching and ripping were done to help clarify fault details in the vicinity of Ground-Zero. Mapping was completed by L. Agenbroad and S. Jerome.

Ground observations were supplemented by two flights over the area in June, when a number of oblique aerial photographs were taken. Fifty-eight thin sections were prepared by J. Murphy (NBM), and examined and described in detail by A. von Volborth (NMAL). Results have been condensed and are incorporated in the geology section of this report. Four age determinations were made by Geochron Laboratories on material prepared by J. Murphy.

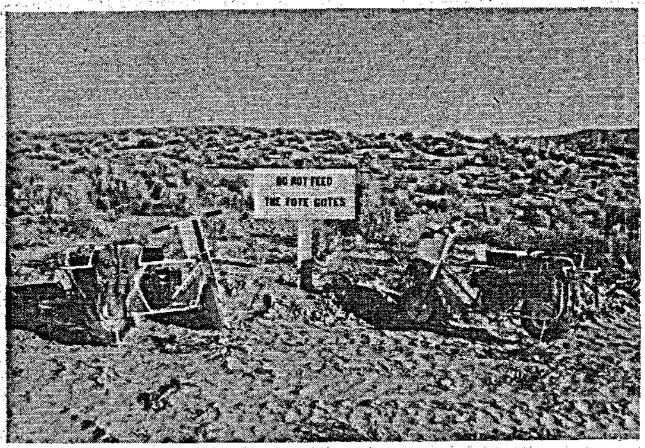


Figure 3. Two of the four Tote Gotes used during the geologic mapping phase.

The geological field work was greatly expedited by the use of four Tote Gotes purchased expressly for this job (see Figure 3). These amazingly rugged "motor scooters" are particularly adapted to this terrain. Their use helped to compensate for the difficulties and delays in mapping caused by adverse weather; without them the job could not have been completed in the allotted time.

Geophysics

Approximately 84 miles of line for gravity observations were surveyed and levelled by Sprout Engineers, Inc., operating under contract to Holmes & Narver, Inc. The layout of lines and observation stations is illustrated on Plate 7 in the folio. Field observations were made by Messrs. J. Gimlett, R. Horton, and J. Schilling, using a Worden gravity meter rented from Texas Instruments, Inc. Data reduction and interpretations were completed by J.Gimlett.

Some seismic velocity tests were made in the vicinity of Ground-Zero by Messrs. Gimlett and Horton, using Dynametric Inc. equipment. Seismic refraction surveys were planned and executed by J. Gimlett, assisted in the field by J. Soske, of Stanford University, and R. Horton. Calculations and interpretations are by J. Gimlett. Shot holes for the placement of dynamite were drilled by Sprout Engineers, Inc., under arrangement with the University.

Fairchild Aerial Surveys, Inc. was low bidder on the aeromagnetic survey of Area A which was planned and interpreted by J. Gimlett. To lay out flight lines Fairchild used Mark Hurd's 1:31,680 semicontrolled photomasiac. Lines are oriented east-west and are spaced half-a-mile apart. Average flight elevation was specified at 500 feet above mean terrain, a feat relatively easy to accomplish over the major valleys but difficult to impossible over the ranges. Fairchild's contour map, printed as an overlay on the photomosaic, is included in the folio as Plate 8.

Hydrogeology and Hydrology

Hydrologic work was begun in February and continues to the present time.

The four hydrologic test holes listed below were located by G. Maxey and drilled by Hill & Hill Drilling Co. under contract to Holmes & Narver, Inc.

Hole No.	*Location*	*Depth*	*Material at Bottom*
HS-1	Fairview Valley	699′	Alluvium
H-4	Fairview Valley	935′	Alluvium
H-2	Fourmile Flat	780′	Alluvium
H-3	Fourmile Flat	470′	Granite

These holes were logged and tested to help determine the lithology, position, and hydraulic characteristics of the aquifers and other strata, and the quality, mode of occurrence, and movement of ground water in Fourmile Flat and Fairview Valley. Gamma ray, neutron, and temperature logs were conducted by McCullough Tool Co. in H-4 and H-3. Well logs are included herewith as Appendices C, D, E, and F. The two wells at Frenchman's Station were tested by pumping.

Approximately 38 water points (wells, springs, intermittent streams) have been inventoried within a 15-mile radius of Ground-Zero. As integral parts of the inventory, water samples have been collected and analyzed by Abbott and Hanks for chemical constituents and by the U. S. Public Health Service for radiological constituents; water levels have been measured; depths and other dimensions of the wells have been recorded; discharges of springs and surface streams have been measured; and the uses to which the water is put have been determined. Other factors which might affect the contamination problem, such as topographic and geologic setting, have been observed and recorded. A geological reconnaissance of the valley fill has been completed, and a more detailed study will continue. Results of this work are shown on Plate 9.

DRI personnel P. Domenico, G. Maxey, G. Scudder, and D. Stephenson have been responsible for the hydrologic work.

Diamond Drilling

Two exploratory holes were diamond-drilled to test ground conditions in depth near Ground-Zero. The first, NX hole ECH-A, was directed N. 60° W., inclined −45°, and bottomed at 1,898 feet. It was contracted to Sprague and Henwood by Holmes & Narver, Inc. The latter organization also contracted with Core Drilling Inc. for ECH-D, a six-inch vertical hole bottomed at 2,017 feet, within 50 feet of Ground-Zero. (See Figure 4.) All directional surveying was done under the supervision of Holmes & Narver, Inc.

Although NBM personnel L. Agenbroad, L. Beal, R. Horton, S. Jerome, I. Lutsey, H. Mossman, and R. Wilson contributed to logging the core, J. Schilling was primarily responsible for this work and for reporting the results.

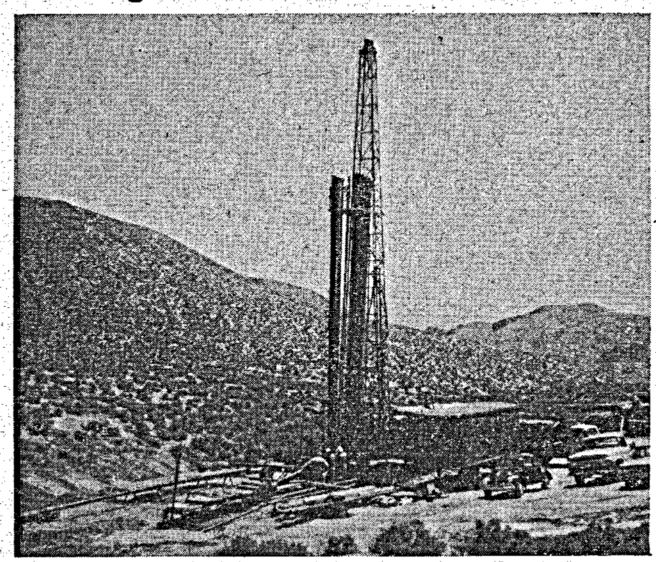


Figure 4. Drill rig of Core Drilling, Inc., on vertical hole, ECH-D.

The thermal conductivity and elastic properties of core from ECH-D were determined and interpreted by R. Horton; the permeability was determined by Core Labs, Inc. DRI personnel P. Domenico, G. Maxey, G. Scudder and D. Stephenson were responsible for hydrologic work on the diamond drill holes.

Report Preparation

All NBM and DRI personnel so far cited, contributed to the assembly, analysis, and reporting of results. The finished drafting and cartography are by NBM personnel B. Webb, R. Wilson, and R. Paul. Color separations for the geologic maps were made by B. Webb. J. Schilling coordinated map and report preparation.

The report was typed in its preliminary and final stages by H. Mossman (NBM) and C. Menzel (DRI). It was printed by Western Printing and Publishing Co., Sparks, Nev. The map folio was printed by the Stark-Rath Printing and Publishing Co., San Francisco, Calif. I. Lutsey and L. Rollin, NBM editors, saw the report and folio through publication.

GEOGRAPHIC SETTING

Location

The Sand Springs Range, a north-trending mountain range approximately 20 miles in length and 5 miles in maximum width, is in Churchill County, Nevada, about 28 miles southeast of Fallon, Nevada, the nearest community. (See Figure 1 and Plate 2.) This Range is separated from the Stillwater Range by a low pass crossed by U. S. Highway 50. The possible site for the Shoal Event is about 5 miles south of the highway in the SW¼ sec. 34, T. 16 N., R 32 E., M.D.B.&M.

To the south the mountain mass broadens and blends with adjacent ranges including the Cocoon Mountains on the west and the Fairview Peak-Slate Mountain range on the east.

Physiography

Maximum elevations in the northern part of the Sand Springs Range barely exceed 5,600 feet, whereas the southern summits average between 6,600 and 6,800 feet. Much of the northern half of the Range is rolling plateau with low relative relief, bordered on the east and west by steep scarps. This plateau is 1,000 to 1,300 feet above adjacent valley floors. The Range is asymetric in that numerous long, broad canyons lead gradually up from the eastern side, but those on the western side are very short, narrow, and steep-walled by comparison.

Fairview Valley lies east of the Sand Springs Range and is bounded by the Clan Alpine Range and the Fairview and Slate Mountains on the east. The valley is about thirty miles long, rising in the "Y" formed by the junction of the Sand Springs Range and Slate Mountain to the south, and extends northward to a relatively narrow constriction, about five miles wide, between the Stillwater and Clan Alpine Ranges. The valley is continuous with Dixie Valley to the north through this constriction. It has an area of 350 square miles, some 200 of which are underlain by alluvium, with the remainder consisting of bedrock slopes and hill crests. The elevations of the bounding ranges vary from 5,000 to about 10,000 feet, and the valley floor slopes northward from 5,500 feet to about 3,900 feet at the head of Dixie Valley. The south end of the valley is a bolson with a playa, Labou Flat, just south of U. S. Highway 50. About six miles north of the highway a low pass in the alluvium separates the bolson area from the north end of the valley through which flows a stream rising far to the east. This stream valley continues into Dixie Valley.

Fourmile Flat is an undrained surface depression on the west side of the Sand Springs Range. It is continuous with Eightmile Flat which extends northwestward and which is slightly up gradient from it. These two areas form one large alkali flat between the Stillwater Range to the north, the Bunejug and Cocoon Mountains to the south, and the Sand Springs Range. Fourmile Flat, the lowest part of the alkali flat, is also the lowest depression along the east side of the Fallon area and approximates the altitudes of Carson Sink to the north and Carson Lake to the west. Thus, some surface runoff from a broad area east of Fallon flows through Eightmile Flat into Fourmile Flat. Conditions of topography and relief are essentially the same as in Fairview Valley except that Fourmile Flat is lower (elevation about 3,900 feet) than Fairview Valley in the latitude of Ground-Zero.

Apart from drainage and irrigation canals in the Fallon area, the salt lake in Fourmile Flat, and small streams in the mountains to the north, perennial streams or other perennial water bodies are unknown within or near the study area. Most of the available water for ordinary use is ground water which issues from a few small, usually intermittent springs, or which is withdrawn from wells in the

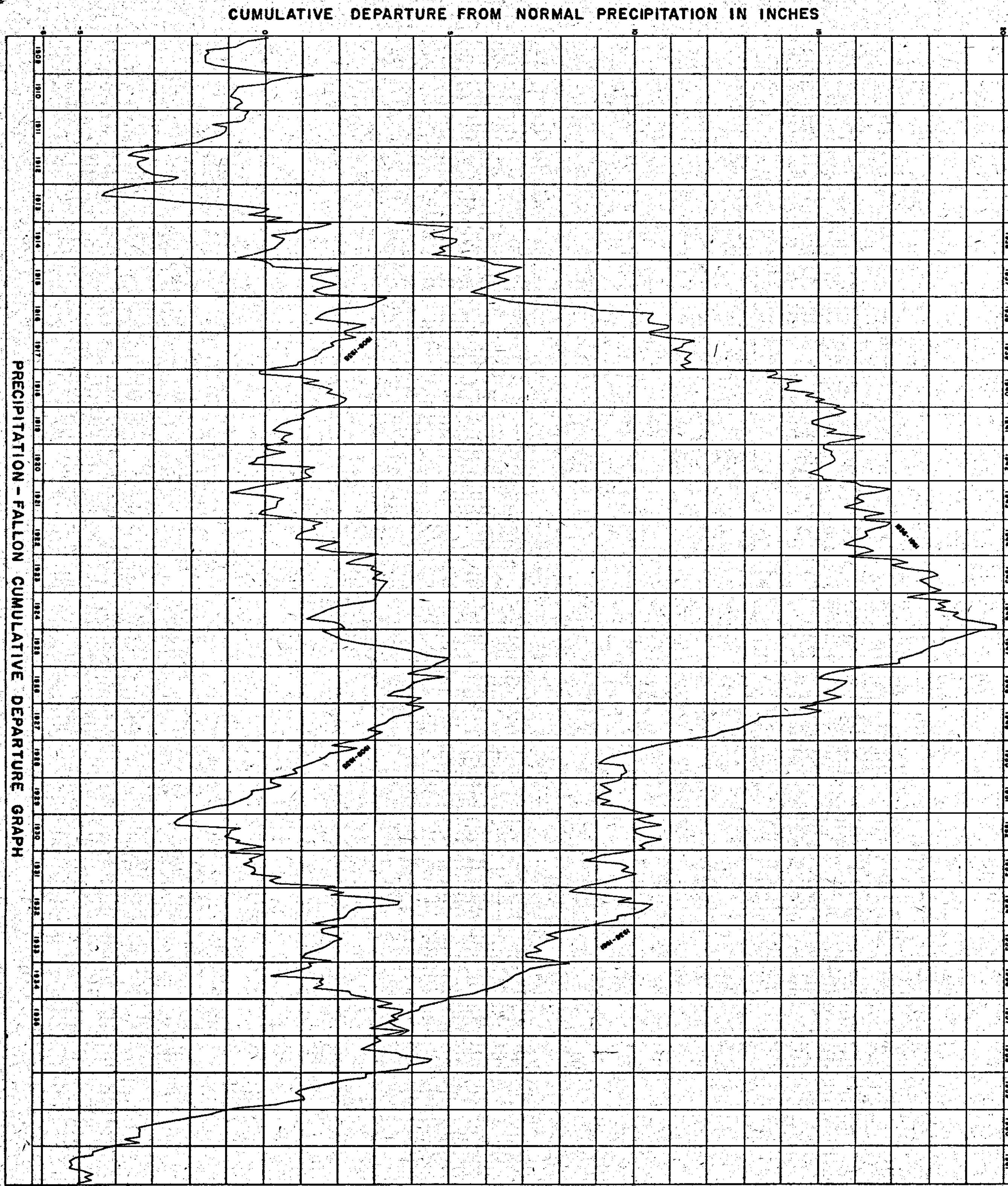


Figure 5. Fallon cumulative precipitation departure graph.

alluvial fill. The primary uses of ground water are domestic and stock-watering. Some water is also used by mining ventures.

Climate

The Sand Springs Range and environs are a typical Great Basin arid region with about 5 inches annual precipitation in the valleys and about 12 inches at the highest elevations, according to the studies by Hardman (1949). Records of precipitation at the Fallon Experiment Station, about thirty-five miles west of the test site, are given in Figure 5, showing the cumulative departure from running average monthly precipitation values for the 53-year period from 1909 through 1961, and in Table 1 showing mean monthly and annual precipitation values as reported in the 1961 annual summary by the U. S. Weather Bureau (1961).

TABLE 1—Annual and Monthly Average Precipitation, In Inches, Fallon Experiment Station

Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
.57	.66	.55	.51	.61	.42	.17	.12	.20	.50	.35	.68	5.34

Figure 5 shows that the amount of yearly precipitation fluctuates considerably and that longer periods of wet and dry years occur. Thus, precipitation increased rather considerably from 1932 until 1947, but since that time has fallen off, and has been below normal. July, August, and September are the driest months and late winter and early spring is the wettest period. Fallon receives about 10 inches of snowfall annually, most of it during the winter and early spring. The total precipitation and snowfall may be expected to be somewhat higher at Ground-Zero since the Sand Springs Range at this point is some 1,200 feet higher than Fallon. The absence of trees in the Range is testimony to the arid conditions.

Weather station records also are available at Eastgate, about 25 miles east of the site and about 200 feet lower. Because these records have been kept for only five years they may not be as representative of the precipitation pattern as those from Fallon. The average annual precipitation recorded at Eastgate is 6.70 inches, a figure that may confirm the idea that precipitation increases significantly with altitude.

At the Fallon Experiment Station the mean annual temperature is reported to be 50.6 degrees in the 1961 Annual Summary. January is the coldest month and July is the warmest. The average date for the last killing frost in spring is during the middle of May and the first killing frost occurs in late September, which gives a growing season of about 127 days.

On the basis of fragmentary pan records at Fallon, evaporation is estimated to be about five feet, somewhat more than 10 times the annual precipitation. Wind direction is usually from the west at an average velocity of about 4.5 miles an hour, according to fragmentary records.

Culture

Within the study area chief activities are grazing, limited mining and refining, and bombing practice. Fewer than twenty residents live within fifteen miles of the site except at the Nevada Scheelite mine near Rawhide where probably no more than 50 persons live at any one time. Larger population centers, including Fallon and the Fallon Auxiliary Naval Air Station, are between 25 and 35 miles distant. Water supply for personnel and for mining and refining operations at the Nevada Scheelite mine does not originate from within the 15-mile radius of the site, but is taken from wells five to six miles south of the operation, in a basin not closely related to the Sand Springs Range. No local water supply is available for the deserted townsite of Rawhide. All water used there was transported from beyond the limits of the 15-mile radius.

GEOLOGY

Geology of the Sand Springs Range

INTRODUCTION

The Sand Springs Range is made up chiefly of a Cretaceous granitic intrusive body bordered on both the north and south by Mesozoic(?) metamorphic rocks (see Plates 2 and 4). Locally both the granite body and metamorphic rocks are overlain by Tertiary and Quaternary volcanic rocks. Numerous aplite-pegmatite dikes cut the granitic body; most of these dikes are concentrated in a zone extending south along the western crest of the Range and swinging southeast to the granite-metamorphic contact. Many andesite and rhyolite dikes intrude the granitic body, the metamorphic rocks, and the aplite-pegmatite dikes. Tertiary and Quaternary alluvial and eolian deposits occupy the valleys to the east and west of the Range.

Although the Range is a north-south trending fault block, north-south faults are rare, the Range having been uplifted along a series of northwest- and northeast-trending high-angle faults, which form a sawtoothed pattern in plan. The down-dropped Fairview Valley block to the east contains over 5,000 feet of unconsolidated sediments; in contrast, the Fourmile Flat area to the west is a pediment, thinly veneered with alluvium near the Range, the alluvium thickening to about 1,300 feet immediately south of the salt flats.

The structural pattern is remarkably consistent throughout much of the Range. A system of steeply-dipping faults and joints trending about N. 60° W. cuts the granitic body; most of the dikes are intruded along these structures. A second system of steeply-dipping faults and parallel, closely-spaced fracture cleavage, trending more or less N. 30° E., cuts the granitic body and dikes. Other directions of faulting, jointing, and cleavage are common locally. A gently-north-dipping thrust cuts the metamorphic rocks just south of U. S. Highway 50; there is no evidence of thrusting elsewhere in the Range. (See Plates 2-6 for subsequent geology.)

ROCK TYPES

Mesozoic(?) metamorphic rocks

Mesozoic(?) metamorphic rocks crop out at the south end of the Range and along U. S. Highway 50 at the north end. Although no attempt was made to subdivide the metamorphic rocks, a general idea of the sequence was gained during mapping.

In the north, the metamorphic rocks in the lower plate of the thrust fault include interlayered phyllite, schist, slate, hornfels, and thin, locally marblized limestone beds. The foliated rocks probably are metamorphosed clastic, pelitic, and calcareous sedimentary rocks and volcanic material. In most cases the foliation parallels the original bedding of the rocks; both strike east-west and dip steeply. The upper plate of the thrust is bluish-gray, massive to thick-bedded, recrystallized dolomitic limestone. Along the sole of the thrust the limestone has been bleached and stained.

In the south (Figure 6), a northwest-trending belt of metamorphic rocks extends across the Range. The foliation and original bedding of the rocks in this zone are parallel, both striking northwest and dipping steeply southwest at the northwest end of the belt and vertically at the southeast end. A southern (upper ?) unit of gray to white, recrystallized, dolomitic limestone extends from one end of the belt to the other end. Along the Nevada Scheelite road, on the southeast, a middle unit of andesite breccia and flows, and a lower(?) unit of phyllite, slate, and hornfels occur below the limestone unit. These middle and lower(?) units grade or interfinger northwestward into a sequence consisting of inter-layered thin-bedded limestone, schistose graywacke and quartzite, conglomerate, hornfels, phyllite, and slate. This sequence apparently is composed predominately of metavolcanic layers at its top (?), which is at the same horizon as the andesite breccia and flows to the southeast, and predominately of metasedimentary layers at its base (?), which is at the same horizon as the phyllite-slate-hornfels unit.

No comprehensive petrographic examination was made of the various types of metamorphic rocks. Thin sections of the dolomitic limestone from the upper plate of the thrust at the north end of the Range show that the limestone is equigranular with 0.05 to 0.3 cm., parallel-oriented grains of calcite and lesser dolomite, and minor margarite mica, cut by dolomite and quartz veinlets. The limestone from the south end of the Range is similar, but specimens examined are finely layered, the banding resulting from alternating layers of coarse and fine grains and/or alternating more calcitic and more dolomitic layers.

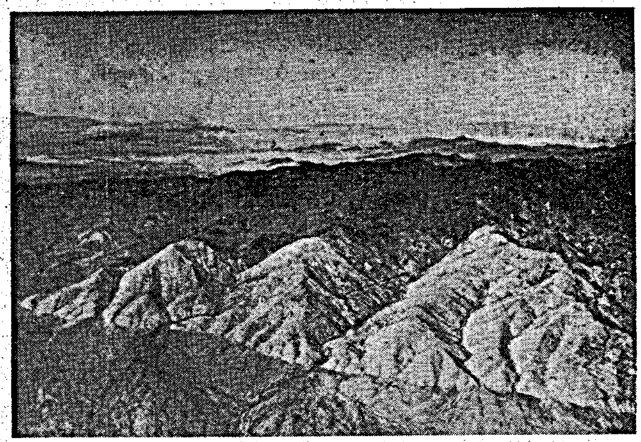


Figure 6. Southern contact between granite and metamorphic rocks. (looking west)

In thin section, the schist and phyllite are lepidoblastic, or porphyroblastic with a schistose matrix; the hornfels is granoblastic or porphyroblastic with a granoblastic matrix. Of the six thin sections examined, all contain abundant quartz and andalusite, several contain abundant biotite or muscovite, and at least one section contains quartzite and volcanic rock fragments, staurolite, and hornblende.

The metamorphic assemblage was intruded by the Cretaceous granitic body and is overlain unconformably by the Quaternary-Tertiary volcanic rocks. It is tentatively dated as Mesozoic, based on its metamorphic and lithologic similarities to Mesozoic rocks elsewhere in Nevada and its age relationships to other rock units in the area.

Cretaceous granitic body

A Cretaceous granitic body is exposed over much of the Sand Springs Range, and at the southeastern end of Fourmile Flat in the sloping area leading up to the Range. Several small exposures occur in "windows" in the volcanic rocks at the north end of the Range (see Plate 4). This intrusive rock ranges from granite to granodiorite. The porphyritic granite variety is exposed over much of the

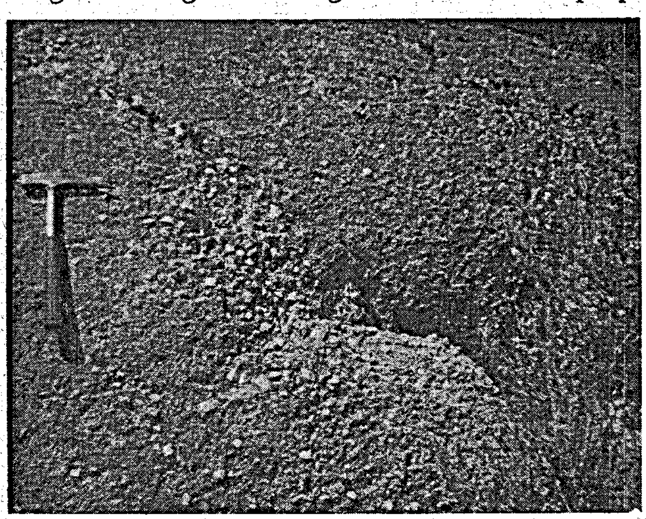


Figure 7. Ground-Zero granite showing feldspar phenocrysts weathered into relief.

Figure 8. Ground-Zero granite showing feldspar phenocrysts in clusters.

Range and has been termed "Ground-Zero granite"; the granodiorite variety predominates in the west-central part of the Range, to the west of the aplite-pegmatite belt. Along the western escarpment of the Range there is a mixed zone of both types.

Both the granite and granodiorite show typical spheroidal weathering. The granodiorite commonly appears to be less weathered than the granite, probably because its finer grain resists rapid weathering.

The Ground-Zero granite is most commonly a porphyritic biotite granite with abundant large orthoclase phenocrysts up to 2 inches long in a medium- to coarse-grained groundmass of quartz, orthoclase, plagioclase, varying amounts of small biotite flakes and/or books, and locally some hornblende (see Figure 7). At numerous places scattered throughout the granite, the orthoclase phenocrysts have been segregated into large clusters (see Figure 8), lenses, and streaks, some of which have dimensions of over 10 feet; locally the phenocryst segregations comprise up to 75 percent of the rock. Schlieren banding was noted but is not common. Locally the granite is coarsely inequigranular rather than porphyritic. In a few places it shows a rough foliation. In thin section, 20 to 50 percent of the Ground-Zero granite is a hypidiomorphic-granular groundmass of 35 to 60 percent strongly zoned, myrmekitic plagioclase (An_{10-25}), 25 to 40 percent quartz, 5 to 10 percent microcline, 5 to 10 percent biotite, 0 to 1 percent hornblende, and less than 1 percent sphene, apatite, and magnetite.

The granodiorite is an equigranular, medium-grained, hornblende granodiorite having much the same mineralological composition as the Ground-Zero granite, except that hornblende predominates while biotite is rare to abundant. It locally shows well developed gneissic structure. In thin section, the granodiorite is hypidiomorphic-granular and consists of 60 to 80 percent strongly-zoned, myrmekitic plagioclase (An_{10-35}), 5 to 10 percent quartz, 5 to 10 percent hornblende, 0 to 5 percent biotite, and a total of less than 1 percent sphene, apatite, zircon, and magnetite.

The granodiorite appears to have both intrusive and gradational relationships with the granite. These two varieties of granitic rock are very similar petrographically and mineralogically. Potassium-argon age determinations run by Geochron Laboratories, Inc. on biotite from the granite (AD-1) and granodiorite (AD-3) give ages of 79.6($\pm$2.0) and 76.0($\pm$2.0) million years respectively. These factors indicate that the two varieties probably are two phases of the same intrusive, and thus are closely related genetically and were emplaced at about the same time. However, the evidence is not conclusive enough to rule out the possibility that the granodiorite and granite are two distinct intrusive bodies.

The granitic body intrudes the metamorphic sequence, is intruded by the aplite-pegmatite, andesite, and rhyolite dikes, and is unconformably overlain by the Tertiary and Quaternary volcanic rocks. The stratigraphic relationships and isotopic age determinations indicate that the granitic body is of Cretaceous age.

Aplite-pegmatite dikes

Numerous aplite-pegmatite dikes, ranging from less than one inch to more than 20 feet in width, cut the granite. Most of these dikes are concentrated in a zone extending south along the western crest of the Range and swinging southeast to the granite-metamorphic contact (see Plates 2 and 4). There are several aplite-pegmatite "centers" within the zone; here the dikes are most abundant, commonly are larger than is the rule elsewhere, and have an irregular, criss-crossing pattern caused by the great variation in individual dips. As the dikes extend away from such "centers", they gradually pinch out, become less numerous, and assume the northwest trend and steep dip which is by far their most common attitude throughout the Range.

Aplitic and pegmatitic material commonly occurs in the same dike, usually with sharp contacts. In most cases the aplite forms the borders and the pegmatite occurs as lenses, stringers, and continuous layers in the centers. Some dikes change to quartz veins along their strike. The aplite-pegmatite dikes commonly are more resistant to weathering than the enclosing granite, and form bold, wall-like outcrops (see Figure 9).

Figure 9. Aplite dikes standing as resistant walls in granite in northwestern part of Area B. (looking northwest)

The aplite is white and sugary-textured. In thin section the aplite is allotriomorphic-granular, and consists of 30 to 40 percent quartz, 20 to 50 percent plagioclase (An_{5-20}), 20 to 50 percent microcline, 1 to 15 percent muscovite, and less than 1 percent biotite, epidote, chlorite, magnetite and rutile.

The pegmatite consists of coarse pink microcline and/or white albite containing cores of milky to gray quartz, and locally abundant coarse biotite flakes and some rutile, sphene and allanite. Small amounts of zircon, cordierite, and epidote were noted in thin section.

The aplite-pegmatite dikes cut the granitic body and the metamorphic sequence, and in turn are cut by the andesite and rhyolite dikes. The dikes probably were formed during the same period of igneous activity that produced the granitic body, the dikes reflecting late stage differentiation from its still plastic portions. However a potassium-argon age determination (AD-2) run by Geochron Laboratories, Inc. on biotite from a biotite-rich aplite-pegmatite dike gave an age of 39(±6) million years; "the sample behaved very peculiarly . . . . The precision on this determination is not good because the sample seemed to have very large amounts of atmospheric argon absorbed on the mineral, leading to larger air corrections than usual" (personal communication, Harold W. Krueger, Technical Director, Geochron Laboratories). For this reason, this isotopic age is not considered reliable. An alternate possibility is that the age is correct but that some of the aplite-pegmatite dikes are younger and are related to the rhyolite dikes in time; the particular dike used for the age determination is not typical of most of the dikes, as relatively few of the aplite-pegmatite dikes contain abundant biotite.

Andesite dikes

Many andesite dikes intrude the granitic body, metamorphic rocks, and aplite-pegmatite dikes (see Plates 4 and 5). Two andesite dikes cutting the volcanic rocks may also belong to this group. The dikes occur throughout the Range but are much more abundant in the north half (see Figure 10). These dikes are up to 50 feet wide; most trend roughly N. 50° W. in the north half of the Range, and northeast in the south half, and have steep dips. Individual dikes commonly are straight, long, and relatively even in width (see Figure 11). Some are more resistant to weathering than the enclosing rocks and form "walls". Weathered material is blocky. Their dark green to black color makes them easy to trace in the field.

Dikes of this group range from diabase to diorite in composition, but mostly are hornblende andesites. All are quartz poor. Many dikes are porphyritic with phenocrysts of plagioclase and/or hornblende; others are aphanitic, and a few of the larger ones have porphyritic centers grading into aphanitic margins. The dioritic variety of this group is quite similar to the granodioritic variety of the rhyolite group, making it difficult to tell them apart in the field. The hornblende andesite contains 30 to 65 percent plagioclase (An_{30-55}), 15 to 60 percent hornblende, 2 to 5 percent magnetite, 0 to 5 percent

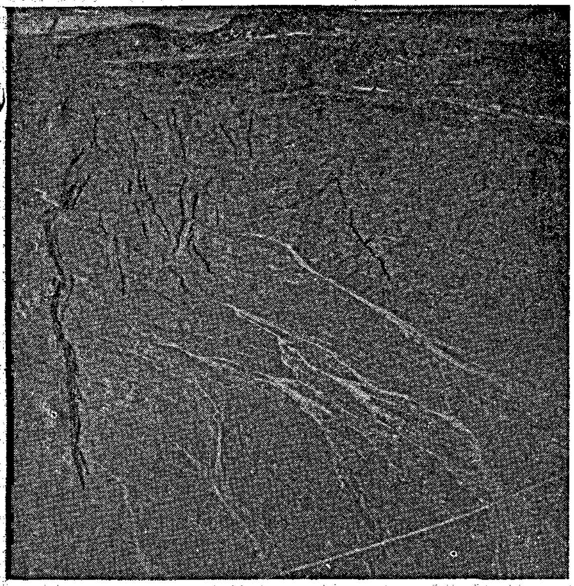


Figure 10. Andesite dike swarm in granite at north end of Range. Rocks in dark background are metamorphics and volcanics. (looking northwest) (photo retouched)

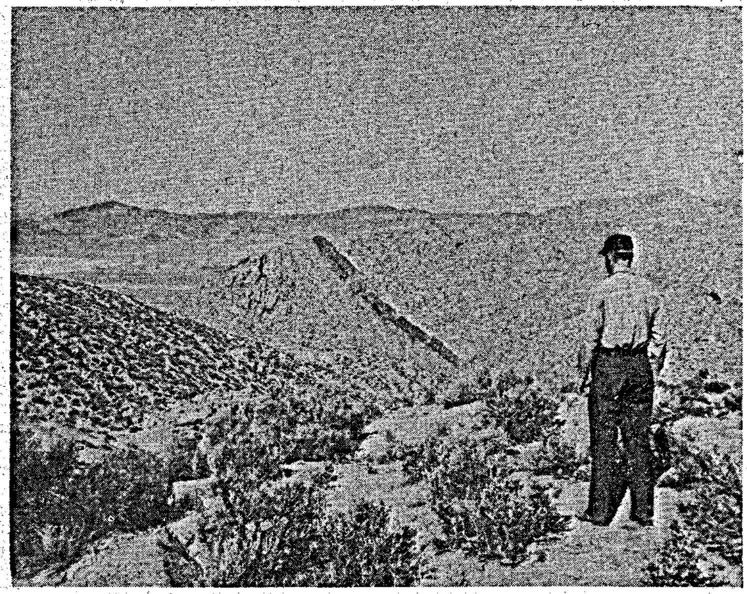


Figure 11. Andesite dike in granite in northwest corner of Area B. Dike is offset by northeast-trending fault. (looking north)

biotite, 0 to 3 percent quartz, and less than 1 percent apatite. Propylitization is common in these rocks; the propylitic minerals include: chlorite, epi dote, calcite, and quartz.

The andesite dikes cut the granific body, metamorphic rocks, and aplite-pegmatite dikes. In most cases the andesite dikes are cut by the rhyolite, but the reverse relationship has been observed at several places. Faults that offset andesite dikes commonly are cut without offset by nearby rhyolite dikes. These relationships indicate that most of the andesite dikes are older than most of the rhyolite dikes, but that the intrusion of the rhyolite and andesite groups was at least partially overlapping in time. The absence of any dikes which definitely belong to the andesite group in the volcanic rocks strongly suggests that the dikes are prevolcanic, early Tertiary or possibly Late Cretaceous, and genetically related to the granitic intrusive. Undoubtedly some dikes assigned to this group in the field, actually belong in the rhyolite group discussed below.

Two diabase dikes in the volcanic rocks and a diabase dike in the granitic body near its south end differ markedly from the dikes included in the andesite group. These diabase dikes are discussed in more detail under *Quaternary-Tertiary volcanic rocks below*, but were included with the andesite group on the geologic map.

Rhyolite dikes

Light-colored rhyolite dikes occur throughout the Range, and intrude the granitic body, metamorphic rocks, aplite-pegmatite dikes, and most of the andesite dikes (see Plates 4 and 5). The rhyolite dikes are most common north of GZ Canyon in the north-central part of the Range, south of the area of most abundant andesite dikes. These dikes are up to 50 feet wide; most trend roughly N. 50° W. in the north half of the Range and northeast in the south half, and have steep dips. Although many of the rhyolite dikes are straight, long, and of even width like the andesite dikes, the younger rhyolite dikes most commonly are curved, short, and variable in width. Some rhyolite dikes form "walls," more commonly they do not, but they often do form the backbone of ridges. Weathered material is blocky.

The dikes of this group range from rhyolite to dacite in composition, and are porphyritic, phaneritic, and/or aphanitic. The three most common varieties are aphanitic rhyolite, quartz porphyry without feldspar phenocrysts, and porphyry with both quartz and feldspar phenocrysts. The dikes are white to buff, but commonly are stained brown and/or reddish-brown (see Figure 12).

In thin section the aphanitic rhyolite is allotriomorphic-granular with poikilitic and cuneiform intergrowths of quartz and K-feldspar; no other primary minerals were noted, but the feldspar commonly is almost completely argillized and sericitized. The porphyritic varieties of rhyolite contain up to 30 percent phenocrysts of quartz, sanidine, and/or albite in a microcrystalline groundmass of the same minerals plus 0-5 percent biotite; some sections show evidence of propylitization, argillization, sericitization, and/or pyritization.

Figure 12. White rhyolite dike in metamorphic rocks at north end of range. Rocks on skyline are Quaternary-Tertiary volcanics. (looking north across U. S. Highway 50)

Intrusive breccia

A breccia, consisting of inclusions of several rock types in a groundmass of pink and white aplite and porphyritic rhyolite, is exposed along the northeastern front of the Range from Red Top Canyon to south of Breccia Canyon (see Plate 4).

Most of the inclusions consist of the several varieties of andesite; granite fragments are rare. Most of the inclusions are assimilated to the extent that their original character is masked. The inclusions range from gravel-sized, sub-rounded pieces to masses which have dimensions of hundreds of feet. Commonly, the inclusions make up 20 to 50 percent of the rock, but they may be absent over large areas.

The aplitic and porphyritic-rhyolite types of groundmass are gradational with each other, mineralogically and texturally. In thin section, the rhyolitic groundmass is porphyritic, with phenocrysts of albite and/or sanidine in a micro-crystalline groundmass of the same minerals and biotite. The aplite is composed of approximately equal amounts of quartz, K-feldspar, and albite. Variations in composition probably are due in part to the assimilation of other rock types. At the north end of the exposure, part of the groundmass is a medium-grained granitic rock composed of pink K-feldspar, quartz, and lesser white plagioclase feldspar. Locally, masses of coarse pink feldspar, with cores of gray quartz, occur in the granitic variety of the groundmass.

The intrusive breccia cuts the granite. The aplitic groundmass of the intrusive breccia extends outward from the main mass in the form of dikes which cut andesite dikes and granite. Where the andesite dikes extend into the intrusive breccia body they are broken and enclosed by the aplitic groundmass, and become increasingly difficult to trace as they extend further into the body. In contrast, the rhyolite dikes grade into the groundmass of the intrusive breccia body, the groundmass and dikes being quite similar both megascopically and microscopically, giving the impression that the dikes were feeders for the intrusive breccia body or were fed by it. Thus the intrusive breccia and rhyolite dikes may be closely related in time and genesis.

Quaternary-Tertiary volcanic rocks

Quaternary-Tertiary volcanic rocks unconformably overlie the metamorphic rocks at both ends of the Range and lie directly on the granite in several hills on Fourmile Flat to the west (see Plates 2 and 4 and Figure 13). An upper, Quaternary(?) unit of basalt flows rests with varied degrees of angular unconformity upon a Tertiary(?) unit consisting of an upper member of light-colored rhyolitic pyroclastics and flows and a lower member of dark-colored andesite flows.

North of U. S. 50 and east of Sand Springs Pass several small erosional remnants of rhyolite vitrophyre are present near the top of the rhyolitic sequence. Probably all of these are at the same stratigraphic position and represent one large tabular, horizontal, shallow, glassy intrusive body or possibly an extrusive dome. The base and top of the vitrophyre are not present in any one exposure, but the body is probably less than 100 feet thick.

The andesitic lower sequence rests with pronounced unconformity on the Mesozoic(?) metamorphic rocks in the northern end of the Range. Locally the rhyolitic sequence rests directly upon the metamorphics, indicating a profound local unconformity between the andesitic and rhyolitic sequences. In the southernmost part of the map area both the Quaternary(?) basalt and upper Tertiary(?) rhyolitic sequence are present, but the andesitic sequence is missing.

Figure 13. Quaternary-Tertiary volcanics at the north end of Range. Upper dark rocks are Quaternary(?) basalt flows resting on light-colored Tertiary(?) rhyolitic pyroclastics and flows. (looking north across U. S. Highway 50)

The Quaternary(?) basalts rest with discordances of up to 30° upon the Tertiary rhyolite and form horizontal to gently westerly-dipping "mesas" in contrast to the "badlands" topography developed in the rhyolites. A "baked" and highly oxidized reddish-orange zone 20-25 feet thick is commonly present at the upper contact of the rhyolitic sequence. The lowermost five feet or so of basalt is commonly an "erosional breccia". It consists of boulders up to 18 inches in diameter, which probably existed on an old erosion surface and have been incorporated into the base of the flow. The basalt is generally vesicular, rarely amygdaloidal, and is locally extremely scoriaceous. North of U. S. 50 the basalt sequence generally dips 15°-20° northwesterly to westerly.

Although the rhyolites at the north and south ends of the Range are undoubtedly stratigraphic equivalents, there are some noticeable differences in lithology. Felsite flows predominate more in the southern exposures than in the northern ones; the latter have considerable amounts of tuffaceous material. The glassy vitrophyre prominent north of U. S. 50, has not been noted in the southern exposures.

The volcanic rocks of the Sand Springs Range are dated as Quaternary(?) and Tertiary(?) on the basis of their relationship to other rocks in the area and their similarity to the Quaternary and Tertiary volcanic rocks in other nearby areas. The andesitic sequence is doubtless much older than the rhyolitic sequence and may be early Tertiary or perhaps pre-Tertiary, but for the purposes of this report it has been mapped and grouped with the basalts and rhyolites.

Quaternary-Tertiary sedimentary deposits

Quaternary and Tertiary alluvial and eolian deposits occupy the valleys east and west of the Range (see Plates 2, 4, and 9). Fairview Valley east of the Range is characterized by bolson deposits. On the basis of geophysical studies, this unconsolidated material is estimated to be as thick as 5,800 feet near the west margin of the valley a few miles south of U. S. Highway 50. In the same general area, at hydrological test hole H-4, the alluvium is known to be over 980 feet thick.

Fourmile Flat west of the Range is covered by alluvial fans, pediment sands and gravels, sand dunes, playa lake deposits, and Lake Lahontan beach deposits and tufa. Thick alluvial fans occur along the west front of the Sand Springs Range and along the northeast front of the Cocoon Mountains, sloping west and northeast to the playa lake of Fourmile Flat. Sand dunes are common around the edges of the playa, and wind-blown sand mantles large areas of the alluvial fans and granite pediment. Unusually large dunes, over 400 feet high, are present north of U. S. Highway 50 at the northeastern edge of the flat; sands are deposited here as the prevailing northeast winds lose velocity and carrying power at ground level in rising to pass over the Range. The slopes of both the alluvial fans and the volcanic rocks at the north end of the Range are conspicuously cut by lake terraces and covered by beach pebbles and tufa, to an elevation of about 4,380 feet. The thickness of the alluvial fill in Fourmile Flat is probably much less than that in Fairview Valley. In hole H-3 bedrock is believed to have been encountered at 310 feet; however, a refraction profile centered at the well gives a depth of 196 feet to a high velocity layer which was tentatively identified as being composed of metamorphic rocks. About one and one-half miles down the alluvial slope (northwesterly), at hole H-2, bedrock was not encountered at 780 feet, the total depth of the well. Gravity measurements reported in the subsequent geophysical section suggest depths of less than 1,300 feet to bedrock immediately south of the salt flat (For a more detailed description of the Quaternary-Tertiary sediments, see Hydrogeology and Hydrology section). Windblown silty material mantles several of the major depressions in the crest of the Sand Springs Range. The absolute extent of the silt is not indicated on Plate 5, but it is the major cover in the Ground-Zero area, averaging less than 10 feet.

STRUCTURES

Folding

Folding is not a prominent feature in the Sand Springs Range. The metamorphic sequence at the south end of the Range apparently forms the western limb of a south-plunging anticline, the eastern limb being in the Fairview Range. Smaller scale folding is uncommon in the Sand Springs Range except along the southern granitic-metamorphic-rock contact where some drag folding of the metamorphics was noted.

Faults

The Sand Springs Range is a north-south trending fault-block that has been subjected to intermittent tectonic activity (see Plates 2-6 for subsequent geology). The Range has been uplifted along a series of high-angle, northeast- and northwest-trending faults. These faults have a remarkably consistent pattern through the Range. The fault-block making up the Range appears to be tilted, with the western side remaining higher.

Undoubtedly the recurring faulting and accompanying joints and cleavage provided the majority of avenues and sites for the intrusion of the aplite-pegmatite, rhyolite, and andesite dikes.

Northwest-trending faults—These faults, trending more or less N. 50° W., are accompanied by parallel joints. Most of the aplite-pegmatite, andesite, and rhyolite dikes are intruded along these faults and joints. Several wide northwest-trending zones of alteration are associated with the faults. Because the dikes commonly follow rather than cross-cut these faults, the faults are difficult to detect; however, they probably are as common as the northeast-trending faults.

Although most of the faults are narrow, a few are wide, and some are grouped together to form fault zones. Many contain gouge and brecciated wallrock. Both the wider individual faults and the fault zones contain numerous irregular slips. Wallrock fragments in the faults, and the adjacent wallrock, commonly are iron-stained, bleached, propylitized, and brecciated.

Topographic expression, slickensides, and offsetting of the volcanic rocks and thrust fault all indicate that the predominate movement along most of these faults was vertical, in many cases being hundreds and even thousands of feet. However, the offsetting of vertical dikes and the northeast-trending faults, and the direction of slickensides, indicate that horizontal movement also has taken place along most of these faults. This horizontal movement is late and most commonly is small, being measurable in tens and rarely in hundreds of feet.

Faults of this group offset the metamorphic rocks, granite, and volcanic rocks, and in a few cases the Quaternary alluvium and various types of dikes. The thrust fault also is offset, while the northeast-trending faults both cut and are cut by these faults. Some of all three types of dikes, except the younger, curved rhyolites, are intruded along these faults, but show no evidence of post-dike movement. None of these faults was found to be cut by granite. The evidence thus indicates that these faults have been active intermittently from shortly after the intrusion of the granitic body until recent times, with the periods of greatest activity before injection of the dikes and after extrusion of the Quaternary volcanics.

Northeast - trending faults—The faults which trend more or less N. 30° E. are accompanied by closely spaced parallel fracture cleavage. Although many of these faults are narrow, some are wide, and others are grouped together to form fault zones. Most contain gouge and brecciated wallrock, and the wider individual faults and the fault zones contain numerous irregular slips. The brecciated wallrock fragments in the faults, and the adjacent wallrock, commonly are iron-stained, bleached, and propylitized.

Topographic expression, slickensides, and offsetting of the thrust fault indicate that in many cases the predominate movement along these faults was vertical. However, offsetting of the dikes (see Figures 10 and 14) and northwest-trending faults, and directions of slickensides, indicate that horizontal movement has been common along most of these faults, with total obvious displacement seldom being more than a few tens of feet. So many faults have this northeast orientation that only those with the most persistence and largest displacements could be mapped without obscuring other geologic features. As the amount of movement becomes smaller, the faults are lost in fracture cleavage.

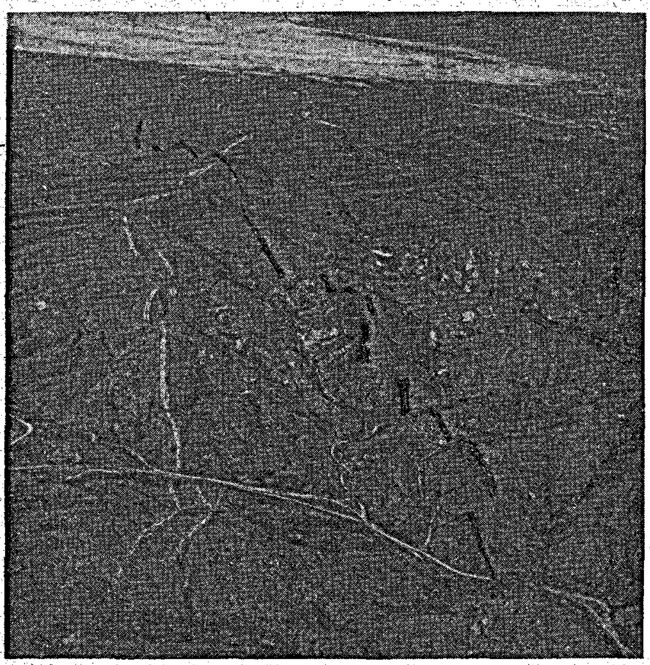


Figure 14. Dark gray andesite dike showing multiple offsets on northeast-trending faults. Light gray rhyolite dike is sub-parallel on ridge to left. (looking northwest across north end of Area B) (photo retouched)

Faults of this group offset the metamorphic rocks, granite, dikes, volcanic rocks, and in a few cases Quaternary alluvium. The thrust fault is offset by faults of this group, while the northwest-trending faults both offset and are offset by these faults. Most of the faults offset all the dikes except the younger, curved rhyolites, but are not cut by the granite. The evidence thus indicates that movement occurred intermittently from shortly after the intrusion of the granite until recent times, with the periods of greatest activity before the intrusion of the younger, curved rhyolite dikes and after the extrusion of the Quaternary volcanic rocks.

Thrust fault—A thrust fault cuts the metamorphic rocks at the north end of the Range (see Figure 15). It has a gently-north-dipping undulating surface. The upper plate is garnetiferous, recrystallized limestone. The lower plate is metamorphic rocks, except in two small areas where small offshoots of the granitic body are exposed in contact with the thrust. Along the sole of the thrust the rock is bleached and stained. The direction of movement is not known. The reconnaissance mapping suggested no thrust faulting elsewhere in the Range.

Joints

A well-developed system of joints parallels the northwest-trending faults (Figure 16). The joints can be recognized in the bold outcrops in the southeast corner of Plate 3. All the dikes except the younger, curved rhyolite ones are intruded along these joints. Apparently most of the joints had already been filled by the time the curved rhyolite dikes were intruded, and these dikes were forced in part to follow less regular fractures. However, numerous northwest-trending joints are present which do not contain dikes, suggesting that a second, post-dike period of joint-formation occurred or that the dike magma was insufficient to fill all joints. It is likely that the joints and the northwest-trending faults were formed simultaneously and by the same forces.

Figure 15. Thrust fault at north end of Range, south of U. S. Highway 50. Upper plate is recrystallized limestone dipping south. Lower plate is schist and phyllite with steep, irregular dips. (looking east)

Fracture cleavage

The well-developed fracture cleavage present throughout much of the granitic body commonly parallels the northeast-trending faults (see Figure 17). Locally the fracture cleavage has other orientations. Individual surfaces are irregular but roughly parallel to one another. In most cases, the fracture cleavage consists of sub-parallel planes 1/10 to 1/5 of an inch apart. Intersection of fracture cleavage and joint surfaces locally causes partially decomposed granite to break into "spindles."

Movements of less than an inch have taken place along many of the surfaces, and minor amounts of gouge are present on some surfaces. The division between faulting and fracture cleavage is arbitrary, and many of the more through-going surfaces could be considered as joints.

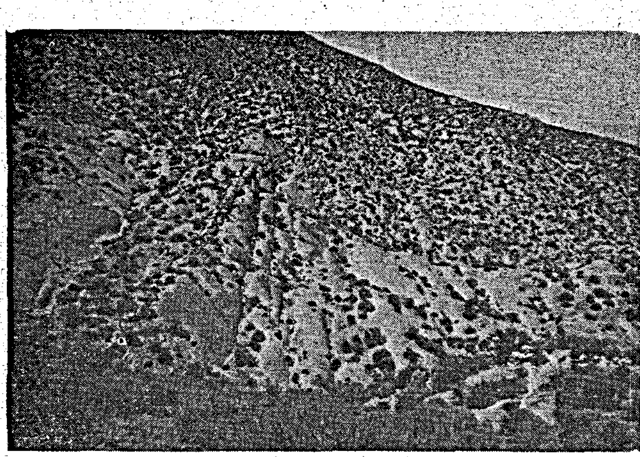


Figure 16. Northwest-trending joints in Ground-Zero granite in northwestern part of Area B. (looking northwest)

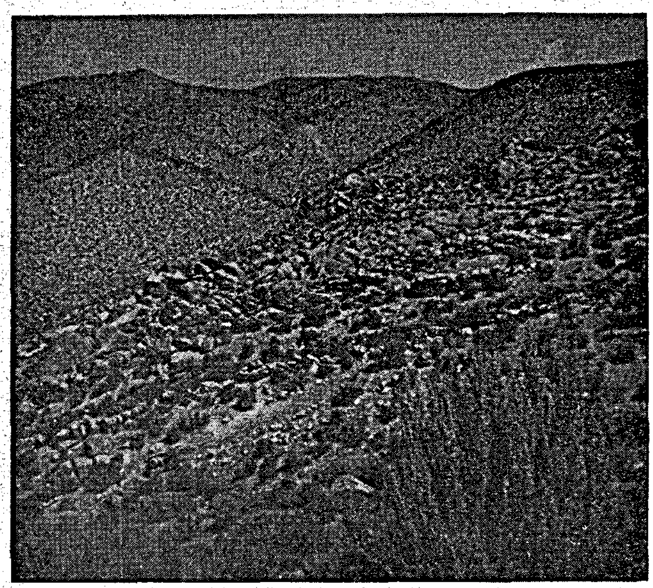


Figure 17. Aplite dikes standing as walls and showing jointing and fracture cleavage dipping east. In northwestern part of Area B. (looking north)

Well-developed fracture cleavage cuts the aplite-pegmatite dikes; fracture cleavage cuts the other dike types but is less well-developed. The fracture cleavage probably was formed at the same time as, and by the same forces that caused, the northeast faulting, with most of the fracture cleavage apparently formed during the post-granite, pre-andesite-dike period of the northeast-faulting. During the post-Quaternary volcanic period of faulting, pressures probably were relieved along pre-existing faults and fracture cleavage surfaces, and relatively little additional fracture cleavage developed at this late stage of faulting.

Other faults, fracture cleavage, and joints

Other directions of faulting, fracture cleavage, and jointing have been recognized but do not compare in prominence or consistency with those just described. Such fracture cleavage commonly parallels faults having unusual orientations.

ALTERATION

Little wall-rock alteration occurs along the aplite-pegmatite and andesite dikes. In contrast, many of the rhyolite dikes and nearby country rocks contain disseminated pyrite, and are bleached, argillized, and iron-stained. Propylitization, bleaching, argillization, and iron-staining also are common along many of the faults and some of the joints in the granitic body and volcanic rocks, and to a lesser extent in the metamorphic rocks. Except for a belt trending northwest across the Range at Breccia Canyon north of GZ Canyon and an area at the head of Lucky Boy Canyon, the alteration affects only a very small fraction of the total rock. At Breccia Canyon the fluids causing the alteration, as well as a swarm of rhyolite dikes, took advantage of the openings provided by a belt of northwest-trending faults.

Contact-metasomatism has taken place in the rocks in contact with the granitic body, and is discussed under *Ore Deposits* below.

ORE DEPOSITS

Contact metasomatic tungsten deposits

Contact metasomatic tungsten deposits occur in the metamorphic sequence at the north and south ends of the Range in contact with the granitic body, in most cases in limestone. Scheelite and minor powellite occur with garnet, cordierite, diopside, calcite, quartz, and other skarn minerals forming small, irregular replacement bodies. Small, irregular quartz veins containing scheelite cut the replacement bodies and surrounding rocks.

Extensive prospecting has been done in these deposits, but with unfavorable results. Although a small amount of tungsten ore has been mined, the deposits are too small, irregular, and low-grade to be worked profitably. Although some assessment work has been done, none of the mines was active in 1962.

Silver-gold veins

A system of east-west veins dipping steeply south and known as the Summit King system (see Plate 4), occur in a fault zone crossing the Range just south of U. S. Highway 50. The veins cut metamorphic rocks, Tertiary volcanic rocks, and andesite and rhyolite dikes that occupy many of the individual fault strands. The veins are offset short distances by cross-faults. At the surface the veins have a braided pattern. The main southernmost vein dips 70° to 80° south; the subsidiary veins to the north dip 50° to 70° south and intersect the main vein at shallow depths.

The veins are 2 to 10 feet thick, contain fine-grained to vuggy quartz, angular fault breccia, and locally abundant calcite and pyrite. Values reportedly occur in free gold, silver chloride, and argentite. The ratio of gold to silver is 1:40 in the upper level but increases to 1:80 in the deeper workings.

At the surface and in the upper level the vein is highly oxidized, and the quartz crumbles readily.

Extensive underground workings reach depths in excess of 450 feet. The principal workings are known as the Summit King mine. Several million dollars worth of silver and some gold were produced; values were recovered in a cyanide mill on the property.

Quartz veins

A north-south, gently-west-dipping quartz vein over 5 feet thick, crops out in a hill along the east front of the Range south of Lucky Boy Canyon. The vein is exposed on a "dip slope," thus has an extensive outcrop. It is a portion of an aplite-pegmatite dike in which quartz is the only mineral. The deposit has been prospected as a source of high-grade silica. A number of other narrow, gently dipping, vuggy, white quartz veins occur in the Range. Desultory prospecting suggests they are not worthy of exploitation.

Sodium Chloride deposit

Salt is harvested annually from the playa on Fourmile Flat. Winter snows and rains result in a portion of the playa being filled with salt-laden water. A crust of salt remains after the water evaporates during the hot summer weather. This crust is scraped up and sold as stock-salt.

Geology of Area B, Including Trenched Area

The lithologic and structural elements in the immediate Ground-Zero area (see Figure 2) have been disclosed by 1:6,000 scale mapping of Area B, by 1:2,400 scale mapping of bulldozer trenches, traverses on which mapping was done on 1:2,400 scale, and by an inclined drill hole (ECH-A, N. 60° W., −45°, bottomed at 1,898 feet) and a vertical drill hole (ECH-D, bottomed at 2,017 feet). Results of this work are presented on Plates 5 and 6 in the folio (see also Plate 3).

SURFACE GEOLOGY

The structural and lithologic elements are quite simple within 2,000 feet of tentative Ground-Zero, near the collar of ECH-D, and are relatively simple throughout Area B. The principal country rock is Ground-Zero-type granite whose petrographic characteristics have been detailed above.

Although the granite has a variety of joints with both steep and gentle dips, the most prominent and consistent joint set strikes N. 50°-60° W., and dips vertically to steeply NE or SW. This set is recognized throughout the Range. Some adjustment has taken place on a few of these joints in the Ground-Zero area (see Plate 6) east of the intersection of trenches 3N and 1W, north of the east end of 1S, at 3N-6W, and from 5S-2W and 5S-4W northwestward. These adjustments normally are expressed by thin seams of gouge less than an inch in width. Discontinuous siliceous breccia up to 4 in. wide is occasionally present. The planes of breaking and adjacent granite walls often show some propylitization and bleaching in bands that rarely exceed 10 feet in width. These planes have had recurrent movement and probably are related to the major northwest-trending zones several miles north of Ground-Zero, many of which show strong sericitization over substantial widths and are locally occupied by rhyolite and andesite dikes.

Along the west side of the bulldozer trench grid, aplite-pegmatite dikes, remarkable for their consistency in strike and dip, have invaded the northwest joint set (see Figure 9). This zone of abundant dikes extends north and south beyond the limits of Area B. Where exposed in the grid they vary from a few inches in width up to a maximum of about 6 feet. As these dikes are traced southeastward, they diminish in number and become narrower in width; most die out within a thousand feet of the road along the west side of the grid. In the east half of the grid all visible dikes were mapped, regardless of width, to disclose the structural pattern. Very few dikes were found within 1,000 feet of tentative Ground-Zero, and all but one or two are less than a foot wide. It will be evident from Plate 5 that west of the road the northwest-trending dike pattern, while still predominant, is complicated by a greater number of wider dikes showing more variable strikes and dips. Walls of the dikes usually are frozen to fresh granite but they occasionally show slippage, and the granite may be bleached for a few feet from the walls. The two hills along the range front west of the trenched area are held up by an

Figure 18. Ground-Zero granite in trenched area showing fracture cleavage as revealed by ripping.

Figure 19. Ground-Zero granite in trenched area with blocks arranged to show the strike of the fracture cleavage.

abundance of the erosion-resistant aplite-pegmatite dikes. The pattern of jointing and fracturing in these dikes is displayed in Figure 17.

In addition to the abundant aplite-pegmatite dikes, a single mass of porphyritic granodiorite, 50 feet wide by 100 feet long, was mapped west of 5W on 5S. Two narrow andesite dikes, also in this joint set, were recorded on 8S. Two short andesite dikes were mapped about 1,600 feet east of drill hole ECH-D. Numerous rhyolite dikes and several andesite dikes occur in Area B northeast of the trenched area; only a few rhyolite and andesite dikes crop out in Area B south of the trenched area. These dikes show the same features and relationships as elsewhere in the Range (see *Geology of the Sand Springs Range*).

Throughout the grid the granite mass and the aplite-pegmatite dikes are cut by fracture cleavage that varies in intensity from about 6 to 20 megascopic planes to the inch; an average for the grid exposures is about 10 to the inch. The strike of the cleavage averages about N. 30° E. and is impressive for its consistency; its dip is vertical to steeply NW or SE. Elsewhere in Area B the cleavage commonly has the same strike and dip, but other orientations are prominent locally. This phenomenon, spectacularly exposed in the ripped trenches (see Figures 18 and 19), probably is the consequence of horizontal compression and must be intimately related to the faults which angle northeasterly across the Range. In many cases slippage along cleavage planes offsets aplite-pegmatite dikes for short distances; however, no consistent pattern of offset is evident. These slip planes usually lack gouge or alteration and are not detectable except where they offset segments of the dikes.

The principal northeast-trending fault zones are designated on Plate 6, proceeding from east to west, as "A," "B," "C," and "D"; a fifth zone, "E," is unique in that it strikes about east-west.

"A" is a major zone which, with nearby elements, is one of the most prominent features of the Range. In the Ground-Zero area it is several hundred feet wide and is expressed at surface by a rib of silicified breccia up to a foot wide, dipping 55° to 80° NW. Granite adjacent to the rib is bleached, propylitized, and cut by numerous fracture planes.

"B" fault zone, about 50 feet wide, is marked at surface in a fashion similar to "A" except that it dips 75° SE. Thin gouge elements in the zone vary in their strike and in their degree of southeasterly dip. The "B" zone apparently is a hanging wall split of "A" zone.

"C" fault is identified at several places in the southern part of the grid by bands of bleached granite 20 to 30 feet wide, that are cut by multiple gouge seams. Reliable dips were not obtained there. On 1W between 3N and 4N, "C" zone includes 1½ inches of gouge and breccia and several half-inch-wide sympathetic gouge planes in a 40-foot band of somewhat bleached and propylitized granite. The only reliable dip obtained there was vertical. Another plane 30 feet to the west dips 85° SE. Three unnamed faults parallel to "C" were recognized between 3S and 8S, but evidence is lacking for carrying them through the northern part of the grid.

"D" fault zone includes several elements identified by offsets on aplite-pegmatite dikes; otherwise it is poorly exposed. What appear to be splits from the zone are exposed as thin gouge seams in somewhat bleached granite in the diagonal bulldozer trench between 3N-6W and 2N-7W.

Supplementary bulldozer trenching in August disclosed between 3N and 4N a 30-foot-wide zone, striking east-west, of strong bleaching and abundant gouge seams showing diverse strikes and dips. This is designated "E" fault zone. It is not known if it persists beyond "B" and "C" zones. Study of its elements, especially in the trench on the south side of the ridge, indicates the dips vary between vertical and 58° south. In the hanging wall of "E" are two 3- to 5-foot zones of slippage and bleaching which dip vertically to steeply north. These are sub-parallel to the northwest joint set.

The same northeast-trending pattern of faulting that is present on the grid is prominent throughout Area B except in the southeast corner of the area where a more random pattern is evident.

The details of the geological structure discussed above were, prior to trenching, obscured by fine silt commonly less than 10 feet thick, which is believed to have been blown in from Fourmile Flat to the west. The granite was apparently altered by shallow physical weathering before the rock was inundated by silt, because the granite ripped in the trenches, while commonly limonite-stained, shows little decompisition of its feldspars or ferromagnesian minerals. A narrow band of caliche and bleached granite often occurs between fresh granite and the silt cover. Caliche also occurs along some of the fault zones.

SUBSURFACE GEOLOGY

In order to test ground conditions in depth, holes ECH-A and -D were diamond drilled (see Plates 4, 5, 6, in folio, and Figure 2 and Appendices A and B).

Exploration core hole ECH-A (N. 60° W., −45°) was completed at a drill hole depth of 1,898 feet. The hole steepened to about 49° at its bottom, approximately 1,500 feet lower in elevation than the collar of ECH-D and approximately 150 feet S. 60° E. of the downward projection of ECH-D. The following was encountered (see Appendix A for more details):

0-55 ft.—soil and decomposed granite.

55-120 ft.—weathered granite.

120-450 ft.—FAULT ZONE; gouge and brecciated, bleached, and propylitized granite. The core is soft and crumbly.

450-600 ft.—fresh granite; hard, relatively solid and unaltered.

600-890 ft.—FAULT ZONE: (same as 120-450 ft.)

890-1898 ft.—fresh granite; (same as 450-600 ft.); some, less than 1-inch gouge (fault) seams.

Exploration core hole ECH-D (vertical) was completed at a drill hole depth of 2017 feet. The following was encountered (see Appendix B for more details):

0-307 ft.—no core. Cuttings indicate granite is fresh.

307-1440 ft.—fresh granite; (same as fresh granite in hole ECH-A).

1440-1675 ft.—FAULT ZONE: alternating breccia and gouge, and bleached, propylitized, and fresh granite.

1675-2017 ft.—fresh granite; some narrow gouge (fault) seams; bleaching along fractures and faults.

The fault zones in the upper part of ECH-A correlate with the northeast-trending high-angle faults (Zones A and B) observed southeast of the proposed Ground-Zero point during surface mapping. No significant high-angle faulting is present in the lower part of ECH-A; however, a number of gouge (fault) seams less than 1 inch in thickness were encountered. The fault zone in ECH-D (see Figure 22) is probably the downward extension of the "E" fault zone. Because of the uncertain nature of its dip at the surface, "C" fault may intersect ECH-D in the same interval. Many ribs of relatively solid granite occur in the fault zone; and an unusually large amount of core fell out of the core barrel while being pulled, then was reground during further drilling, producing material that makes the interval appear to be more broken up than it is. No evidence of thrust faulting has been noted in either hole.

The northeast-trending fracture cleavage and northwest-trending joints (see Figure 21) observed on the surface are present throughout the entire lengths of both holes but are increasingly "tight" with increasing depth. In the last 750 feet of ECH-A the core commonly breaks at 90° to the core axis rather than along joints or cleavage; in this interval exceptionally long pieces of core were recovered and many intervals of the granite approached "tombstone" quality. Except for the fault zone, the core from ECH-D compares favorably with the last 750 feet of core from ECH-A (see Figure 20).

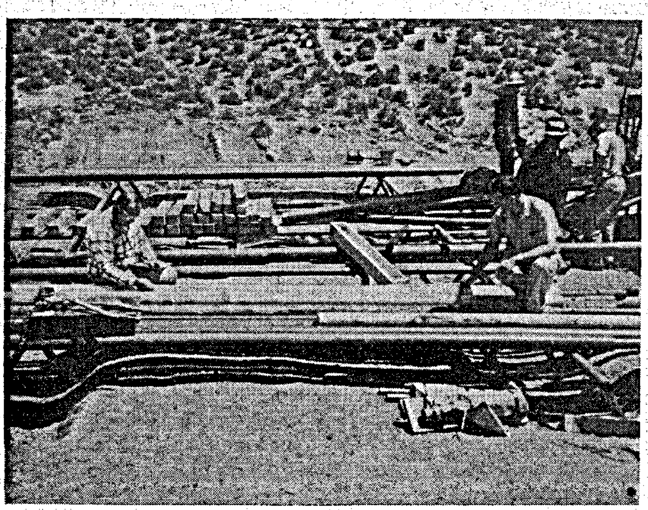


Figure 20. Impressive lengths of core from hole ECH-D. (selected from 600 feet to 800 feet)

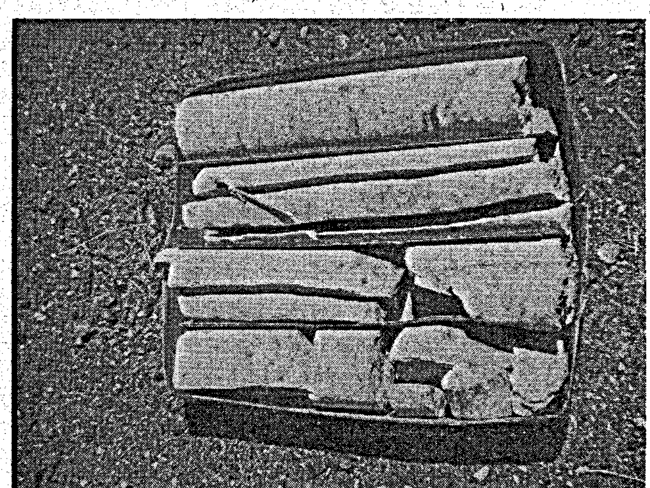


Figure 21. Core from diamond drill hole ECH-D showing splitting due to nearly vertical joints and fracture cleavage. (interval 1018 feet to 1026 feet)

Only two narrow aplite-pegmatite dikes have been encountered in ECH-D and none in ECH-A. This almost complete absence of dikes in the two holes and at the surface in the vicinity of proposed Ground-Zero makes it unlikely that a swarm of dikes might be present within several hundred feet of ECH-D.

Although alteration (propylitization, bleaching, and iron-staining) is common along joints, fracture cleavage, and faults, relatively little rock has been affected, and the rock a few inches from the structure usually is fresh, solid, and dense. However, the rock in the major fault zones commonly is highly altered (see Figure 22).

Figure 22. Core from hole ECH-D showing fracturing and brecciation in fault zone. (interval 1647 feet to 1655 feet)

GEOPHYSICS

Gravity Survey

INTRODUCTION

The gravity survey was designed to investigate the flanks of the Sand Springs Range and the neighboring valleys. It was expected that it would be possible to determine the Basin-Range fault pattern and arrive at reasonable estimates of the displacements involved. The efficacy of the gravimetric method for solving this type problem is due to the large density contrast between the dense metamorphic and granitic rocks comprising the Range and the less dense sedimentary (and possibly volcanic) deposits of the valleys.

It is obvious that the expected gravity pattern should correspond closely to the topography—a gravity high over the Range and gravity lows over the valleys. That this is so can be seen with a glance at Plate 7, which is the complete Bouguer anomaly map of the area.

A gravity profile along U. S. Highway 50 across this area was run by Thompson (1959). His paper should be referred to for the regional picture.

FIELD MEASUREMENTS

The location of all gravity profiles and the six isolated gravity stations are shown on Plate 7. All profiles are east-west, i.e., roughly perpendicular to the trend of the Range, except those along U. S. Highway 50. It is believed that increasing the number of profiles would not materially improve the gravity pattern obtained. A 500-foot station spacing was used on all of the profiles. This spacing is probably too tight in many cases, especially those with steep gravity gradients and those out in the valleys, and thus serves only as a redundancy check of data accuracy. For low-gradient areas near the Range, such a spacing is useful. Also, since most field time for the control surveying and for reading the meter is spent in finding and getting to the stations, rather than at a station, a 500 foot spacing does not take appreciably longer than, say, a 1,000 foot spacing.

The photogrammetric and gravity control were planned together as a unit. The stations on the east and west control traverses, which parallel the Range, also were utilized as gravity observation points. As these stations were, for the most part, less than 900 feet apart, these fifteen-mile-long gravity traverses provided detailed information on cross-trending (east-west) features.

The stations on all profiles and the two traverses were located using transit (or theodolite) and chain. All elevations were obtained by differential leveling. Six map-identifiable points were used as gravity stations in the Ground-Zero area. The elevations and locations of these points were taken directly from the topographic map of Area B. In all, 737 stations were occupied during the course of this survey.

Gravity measurements were made with two Worden gravity meters. Most readings were taken with a "Master" gravity meter, which had a sensitivity of 0.1064 mgal/division. The remaining stations were occupied with an "Educator" meter with a sensitivity of 0.4657 mgal/division.

U. S. Coast & Geodetic Survey B.M. X-46, at the intersection of U. S. Highway 50 and the road to the Nevada Scheelite mine, was selected as the primary gravity base station for this survey. Secondary base stations were established along both traverses by the method of loops. Normal field procedure involved reading the gravity meter at either the primary base or one of the secondary bases every two hours.

DATA REDUCTION

All field measurements were reduced to the B.M. X-46 base. Returning to the previously established base stations every two hours made it possible to simultaneously correct for both the tidal variation and the instrument drift. As a check, the tidal variations were computed for ten of the survey days. The "Master" gravity meter was found to drift as much as 0.5 mgal in 6 hours, often nonlinearly. In fact, the "Master" meter drift in mgal was about equivalent to the "Educator" drift. In view of the large anomalies encountered, the "Master" meter's drift was not excessive. However, it did negate, in part, the increased sensitivity advantage of the "Master" over the "Educator."

The complete Bouguer anomaly as used in this paper is defined (in mgal) as:

$$979{,}676.12 + g_m + 0.05998h - g_o + g_t$$

It should be noted here that the word "complete" means that terrain corrections (g_t) were computed; if they had not been, the word "simple" would have been used.

The first term in the expression, 979,676.12, is the measured gravity at B.M. X-46, as determined by Thompson (1959). According to D. Mabey of the U. S. Geological Survey (oral communication), Thompson's value may be in error as much as 1 mgal. This is not surprising as his survey was tied to the old U.S.C. & G.S. pendulum station at Mystic, California. This did not affect the survey of this report, which deals with the local, rather than the regional picture.

The second term of the equation, g_m, is the measured difference with respect to the B.M. X-46 base. Errors in reading and in the drift removal process are probably less than 0.1 mgal for the "Master" and less than 0.2 mgal for the "Educator" gravity meter. Another possible source of error is in the calibration constants of the two instruments. They were not checked, but it might be noted that the two meters were in agreement to within 0.1 percent.

The term 0.05998h is the combined free-air—Bouguer correction; h is the elevation in feet above sea level. The coefficient corresponds to an assumed density of 2.67g/cc for the underlying rock. This value is in accord with the standard practice of the U.S.C. & G.S., and was also used by Thompson. This figure is very close to the average density of the granitic rocks in the Sand Springs Range. For the small range of elevation encountered in this survey, errors in the assumed Bouguer density did not greatly affect the local anomalies. Since the elevations of all but six of the stations were obtained by double rodding or by traversing between bench marks, they should be accurate to less than a foot. Hence, errors in elevation should be a negligible source of error in the complete Bouguer anomaly.

The theoretical gravity at sea level, g_o, was determined by using the International Gravity Formula of 1930. Nevada Transverse Mercator coordinates were available for all gravity stations. Thus, it was a relatively simple matter to obtain the latitudes of all stations. In actual practice, a latitude correction was applied rather than calculating the latitudes and inserting them into the international formula. Inasmuch as the locations of all stations are known to within 50 feet and the latitude correction amounts to about 0.24 mgal/kft, the theoretical gravity term should introduce negligible error into the complete anomaly.

Terrain corrections, g_t, were computed for 52 stations using the Hammer method out through zone M (71,996 ft.). The terrain corrections for all other stations were then found using a graphical interpolation procedure much like that presented by Winkler (1962). The accuracy of the interpolation is greatly enhanced by the essentially two-dimensional nature of the topography. In addition, the smoothness of the simple Bouguer anomaly curves lends confidence to the graphical approach.

A density of 2.67 g/cc was used in determining the terrain corrections. This is the same as the Bouguer density, thus taking care of the "holes" in the Bouguer plate, and is close to the average density of the mountains above all the gravity stations. The largest terrain correction encountered was 7.69 mgal at the radio relay tower, the smallest 0.36 mgal near Frenchman Station. The average of all 52 stations is 1.54 mgal.

The uncertainty in the terrain correction is estimated to be on the order of 0.2 mgal. Thus it is the least accurate term in the formula for the complete Bouguer anomaly, at least insofar as the local (or relative) anomaly is concerned. As a result, the overall probable error of the local anomaly is estimated to be somewhat less than 0.3 mgal.

GRAVITY MAP AND PROFILES

The gravity data were plotted and contoured on a 1.0 mgal interval as shown on Plate 7. Over the top of the Range the contouring is conceptual rather than actual; there the contours are dashed. Where the gravity control is adequate the contours are shown as solid lines. Inasmuch as all gravity profiles and stations are shown on the map, the validity of the contouring in any area should be obvious.

The profiles are self explanatory. Omitting the westernmost 8,000 feet, the gravity data and geologic profile A″A‴ (except for the fault shown out from the Sand Springs Range) is taken from Thompson (1959).

QUALITATIVE INTERPRETATION

As was expected, there is a one-to-one correspondence between the gravity pattern and the topography. The steep gravity gradient along the eastern side of the Range would seem to indicate normal faulting with large displacements. Since the gravity contours closely parallel the front of the Range (notice particularly the −175 contour) it is evident that the present topography is largely controlled by this faulting. From surface evidence it is apparent that the Range is bounded on the east side by a series of northwest- and northeast-trending faults instead of by one north-south fault. These faults have similar vertical displacements and are perhaps contemporaneous.

The rather flat gravity gradient along the northwest flank of the Range would seem to indicate a rather featureless bedrock surface dipping basinward at a low angle beneath Fourmile Flat. No faulting with large displacements is noted here. If such faulting does exist, it does not bring rocks of markedly different densities into juxtaposition. The gravity picture here is somewhat obscured by a gravity high centered some ½-mile north of U. S. Highway 50. This feature is discussed later in this section.

There is a topographic and gravity high between the Sand Springs Range and the Cocoon Mountains south of Fourmile Flat. In view of the exposures of granitic and metamorphic rocks seen there, this saddle is more closely akin geologically to the Sand Springs Range than to the basalt-capped Cocoons. These relatively dense granitic and metamorphic rocks are responsible for the gravity high.

South of the saddle, along the southwest flank of the Range, steep gravity gradients again prevail. This would indicate normal faulting. As this area is some distance away from Ground-Zero, it will not be discussed further in this report.

Although the Range is marked by a gravity high, the crest of the high is displaced to the west. In the vicinity of Fourmile Flat the gravity high is located up to 3,500 feet west of the edge of the Range. The anomaly here is about 10 mgal higher than it is over the granites. The obvious conclusion is that this difference is caused by rocks heavier than the granites. In view of a similar high (with respect to the granites) both over the metamorphics in the southern half of the Range, and in the small "window" of metamorphics present at about the center of the northern high, it is likely that this feature is caused by a relatively thick metamorphic rock section along the west margin of the Range. The lack of large anomalies on the aeromagnetic profiles would seem to deny the presence of ultrabasics in this region.

The gravity nose extending out into Fairview Valley south of Lucky Boy Canyon (see Plate 4) is also marked by a small aeromagnetic high (Plate 8). This feature is interpreted as being the result of a shallow, buried horst, capped with metamorphics.

As to be expected over a high continental area, the Bouguer anomaly is strongly negative. Thompson's (1959) paper discussed the regional picture. He stated that the isostatic compensation in this area is regional, i.e., each range is not locally compensated, and that, if anything, this region may be slightly overcompensated.

QUANTITATIVE INTERPRETATION

The most important factor in interpreting gravity surveys is rock density. For the purposes of this survey all rocks were grouped into three density categories: (1) the intrusive rocks of the Sand Springs Range and all Quaternary and Tertiary volcanic rocks in the Sand Springs and neighboring Ranges, (2) the metamorphic rocks, and (3) the valley-fill deposits.

The rocks of group 1 are assumed to have a density of 2.67 g/cc. This figure is within 0.05 g/cc of the average of S. S. D. measurements made by the interpreter on specimens from this and similar intrusives. The volcanic rocks are unimportant for this survey except for those exposed in Fairview Peak. In the Sand Springs Range they provide only a thin cover in the areas of interest. The average density of these rocks depends greatly on the amount of pyroclastics and tuffaceous sediments in the volcanic section. 2.67 g/cc is probably a good estimate.

The metamorphic section includes rocks with measured densities ranging from 2.8 to 3.1 g/cc. Recrystallized limestone and phyllite-hornfels, the two most common metamorphic rock types, have densities at the low and high ends of the range, respectively. Assuming the metamorphic section to be composed of equal amounts of recrystallized limestone and phyllite-hornfels, the density of the group 2 rocks was somewhat arbitrarily taken as 2.97 g/cc, giving a contrast of 0.30 g/cc for use in constructing the geologic profiles of Plate 7.

The density of the valley-fill deposits is even more imperfectly known. By their very nature the valley-fill sediments do not outcrop in the Range. No wells are known to penetrate to "bedrock" in the thicker areas, hence, not even the lithology, much less the density, of this light material is known. Lacustrine and subaerial sediments of varying degrees of compaction probably predominate in the section. There also may be a sizeable thickness of volcanic, both pyroclastic and flow, rocks in the valley.

Following Thompson and other workers in the Great Basin, a density contrast of 0.50 g/cc was used to determine the depth to "bedrock" in the two geologic profiles. The valley-fill is thus assumed to have a density of 2.17 g/cc. The 0.50 figure has the one virtue of giving reasonable depth estimates in most areas. For this area the computed 5,800 foot depth in Fairview Valley is in good agreement with the depth obtained from the aeromagnetic data. In many valleys it may be that the most valid density contrast can only be determined gravimetrically using depths determined by drilling or from seismic surveys.

In most gravity surveys in the Basin-Range province, the "bedrock" surface beneath the valleys is a mathematical rather than a geologic surface, referring to the lower bounding surface of a volume of rocks, which, if the rocks have the assumed density contrast, would produce the observed gravity anomaly. Hence, in most cases little can be inferred about the "bedrock" itself. For this survey the geologic profiles of Plate 7 also made use of the aeromagnetic data in determining both structure and underlying rock types.

Profile A A‴ (see Plate 7) for the most part follows U. S. Highway 50. Except for the westernmost 8,000 feet, the section A″ A‴ was taken from Thompson (1959). Terrain corrections were added to Thompson's simple Bouguer anomaly at the six B.M.'s shown below the profile, and the resulting complete Bouguer anomaly plotted. Thompson's bedrock surface was also used except for the fault some 2½ miles out in the valley. The presence of this fault is indicated by the change in the gravity gradient and also by a small aeromagnetic anomaly.

The greatest depth to bedrock along U. S. Highway 50 occurs just east of Frenchman Station and is estimated by Thompson to be about 5,600 feet. This places the floor of the valley at some 1,300 feet below sea level. Along both cross-sections the shape of the valley floor is interpreted as being caused by a combination of step-faulting and downwarping. Actually either could have produced the observed gravity pattern. Alternatively, if we assume that the density contrast is smaller near the margins than in the center of the basin—relatively dense gravels versus light playa silts—then the gravity data would permit a flat-bottomed graben. The profile, above, was considered to be the most reasonable geologically. The maximum gravity gradient encountered in Fairview Valley is about 3.8 mgal/kft. Following Bott and Smith (1958) the maximum depth to the top (bottom in this case) of the anomalous mass would be about 5,800 feet.

The rocks labeled "Tv" (a symbol not used on the geologic map, Plate 4) on the eastern end of both profiles, are the rhyolites and andesites of Fairview Peak. These partially metamorphosed volcanic pyroclastic and flow rocks are believed to be early Tertiary in age (D. Slemmons, oral communication). They have no definite correlatives in the QTv of the Sand Springs Range. There is a magnetic high of some 500 gammas over the eastern end of BB‴, but no corresponding high is present on the eastern end of AA‴. In fact, the magnetic level seems to be close to that found over the Sand Springs granites. Since the Tv rocks do not actually outcrop along this section of U. S. Highway 50 it is possible that this block should have been marked "gr" on cross section AA′.

The maximum depth to bedrock in Fairview Valley along B″B‴ is estimated to be 5,800 feet; this is some 200 feet deeper than along U. S. Highway 50. Again a fault basinward (one mile) from the Range front is postulated on both gravimetric and aeromagnetic evidence.

The surface geology across both the Sand Springs Range, BB‴, and across what might be better termed the southern end of the Stillwater Range, AA‴, is taken directly from the geologic map of Plate 4. The gravity high along the western margin of the Range is interpreted as having been produced by a section of metamorphic rocks which is 2,300 feet thick along section AA‴ north of U. S. Highway 50 and 1,100 feet thick west of Ground-Zero on line BB‴. These thicknesses were computed using the assumed density contrast of 0.30 g/cc between the intrusive and metamorphic rocks. The metmorphic rocks outcrop but locally along AA‴. Even this is not the case along BB‴, or within several miles of it. However, it is possible that hydrology Test Hole H-3 did penetrate a thin section of metamorphics some 4,000 feet south of BB‴. (See the seismic section of this report.) H-3 is not on the gravity high itself, but 4,000 feet west on the flanks. The gravity data indicate that this postulated metamorphic section thins both vertically and horizontally southward from U. S. Highway 50 to just south of H-3. No estimate of the thickness of the metamorphic rocks in the southern portion of the Range was made because of the lack of gravity data over the top of the Range.

In the early part of this survey it was noted that the western side of the Range, east of Fourmile Flat, has considerably more topographic relief than the eastern side, without there being a corresponding steep gravity gradient. It is probable that the western side of the Range is bounded by a normal fault with a displacement of at least 2,100 feet—1,000 feet of topographic relief and 1,100 feet of stratigraphic displacement involving the metamorphics. The down-thrown block simply did not drop enough to permit the extreme sedimentation which occurred in Fairview Valley.

The valley fill in Fourmile Flat is estimated to be a maximum of 1,300 feet thick on BB′ and 1,000 feet thick on AA′. The QTv on the west end of BB‴ are the basalts of the Cocoon Mountains. The QTv on the west end of AA‴ are the basalts capping a spur of the Stillwater Range. The thicknesses of these basalt units are not known. From the magnetic map it is apparent that these more magnetic basalts do not extend appreciably basinward from their observed surface exposures.

The type of rocks immediately underlying Fourmile Flat is unknown. If they are dense metamorphics, then the valley fill is appreciably thicker than shown on Plate 7, depending on the thickness of the metamorphics. Thompson's estimate of 2,000 feet of alluvial fill along U. S. Highway 50 (AA′) was made without first removing the gravitational effect of the metamorphics. Hence, his local gravity low over Fourmile Flat was appreciably greater than that used in calculating the 1,000 foot thickness given in this report.

Aeromagnetic Survey

INTRODUCTION

The primary purpose of the aeromagnetic survey, as originally proposed, was to delimit the granitic body of the Sand Springs Range both vertically and horizontally. In addition, the aeromagnetic data was expected to help resolve various geologic problems which might arise during the geologic and gravimetric mapping.

To accomplish the survey a 20 mile square (Area A) was flown at a half-mile spacing. The terrain clearance was as close to 500 feet as was consistent with aircraft safety. As flown, the area was covered by 39 E-W profiles and 4 N-S cross profiles. Plate 8 is the aeromagnetic data contoured on a 50 gamma interval. The aircraft flight paths and the spotted photocenters are shown.

Because the aeromagnetic coverage was completed much later than had been planned, many of the items necessary for a detailed interpretation were not available prior to the writing of this report. Only the original aeromagnetometer tapes and a hurriedly-prepared pencil contour sheet were available. Therefore, the interpretation section following should be considered as preliminary as well as sketchy. If the examination of all of the aeromagnetic data reveals any features important to the project, a supplementary report will be submitted.

INTERPRETATION

Many of the rock units used in the geologic mapping can be identified by their characteristic "grain" on the aeromagnetic map, Plate 8.

The granitic rocks of the Sand Springs Range evidently have fairly low magnetic susceptibilities. The magnetic level is low, but all profiles show quite a bit of magnetic relief over the top of the Range. This irregularity of magnetic relief is a common feature over intrusives. The reason usually given is that the magnetic minerals tend to congregate in clots, i. e. the mixing is not complete. However, in this case the irregularity is, at least in part, the affect of both topography and structure.

Both Fairview Valley and Fourmile Flat are marked by magnetic surfaces of low relief and at low magnetic levels. This would indicate that the valley-fill deposits have much lower susceptibilities than the surrounding rocks and that they must either be very thick, or must overlie other essentially nonmagnetic rocks.

There is a smooth magnetic high over the southern end of the Range. This would indicate a rather homogeneous rock whose susceptibility is somewhat greater than that of the granite. This anomaly is interpreted as being due to the metamorphic rocks, which are predominantly phyllite-hornfels in this area. The Quaternary-Tertiary volcanic cover in this area consists mostly of rhyolitic flows and pyroclastics. It is too thin, and the rocks are too nearly nonmagnetic, to affect materially the magnetic pattern.

The metamorphics on the north end of the Range are in an area which is geologically complex, involving contact effects, mineralization, and Qtv intrusives and extrusives in addition to the metamorphics. As a result, no magnetic anomalies can be definitely attributed to the metamorphics alone.

The basalts of the Cocoon Range and the southern Stillwater Range produce a fairly typical magnetic pattern—very rough magnetic topography, having large anomalies (up to 1,300 gammas relief) with the lows being more conspicuous than the highs. These lows are not due to the simple geometric response to the inclined magnetic field, whereby there is a magnetic low on the north side of every high. Generally these prominent lows are ascribed to edge effects and/or to reversed polarization. The basalts, as to be expected, have greater susceptibilities than do the granites or metamorphics.

There are several large anomalies over Fairview Peak, in fact much larger than would be guessed from the "Tv" specimens examined. The largest anomaly (900 gammas) detected during this survey is over Slate Mountain, which is in the southeast corner of Area A (see Plate 8). No attempt will be made to explain these features as they are outside the area of prime interest.

The magnetic data helped to explain several features considered in the gravity section of this report. For instance, either the basalts on the south, west, and north sides of Fourmile Flat do not extend into the basin, or if they do, they are flows too thin to have much magnetic expression. The presence of the faults in Fairview Valley away from the Range front (see Plate 7) is based in part on small (several gamma) magnetic anomalies. The gravity "nose", extending out into Fairview Valley south of Lucky Boy Canyon coincides with a magnetic high. Taking into account the fact that the rocks producing this anomaly are buried beneath valley fill, the magnetic level here is greater than that over the granites to the north. Hence, it appears that these rocks have greater susceptibilities than do the granites. Thus, the gravity and magnetic anomalies are interpreted as having been produced by a horst composed, at least in part, of metamorphics.

The limits of the surface exposures of the granite can easily be seen on the aeromagnetic map (see Plate 8). The northern contact of the granite with the metamorphics is marked for its entire length by a prominent magnetic low, which is probably due to the geometric effect as well as to contact effects, hydrothermal alteration, etc. On the south the typical granite pattern abuts the large magnetic high over the metamorphics. It is impossible to determine magnetometrically the extent of the granite to the north and south of its surface exposure because of the masking effect of the overlying rocks.

A fair fit to the magnetic profiles across the granitic portion of the Sand Springs Range can be obtained by using a simple, flat-topped horst with vertical sides as an analytical model. Making a reasonable estimate as to the altitude of the aircraft (the altimeter tapes are not yet available), 5,700 feet was found as the maximum depth of fill in Fairview Valley. This is within 100 feet of the depth obtained in the gravity survey. The agreement is remarkable in view of the assumptions involved in both methods.

A depth of 2,500 feet was obtained in Fourmile Flat. This is greater than the gravimetrically determined depth, though it might be noted that 1,000 feet of valley fill plus 1,500 feet of metamorphosed sediments should be the magnetic equivalent of 2,500 feet of valley fill.

The calculated magnetic susceptibility (average of three determinations) is $1{,}400 \times 10^{-6}$ c.g.s., Assuming that the susceptibility of the granites depends (linearly) only on the magnetic content, we find that the granites should contain on the average 0.28 percent magnetite.

It was originally planned to have susceptibility and remnant magnetism measurements made on some 30 samples taken from widely separated points in Area A, and from the drill cores. This was not done because of the delay in obtaining aeromagnetic coverage and the delays in drilling. At the present time it is planned to make these measurements only on the core from ECH-D. They are not intended to help with the aeromagnetic interpretation, but rather to augment the before-the-blast catalog of the physical properties of the granite.

Refraction Survey

INTRODUCTION

It was apparent that several geological-geophysical problems might best be solved by seismic methods. Preliminary analysis of the gravity data indicated that the valley fill was very shallow in Fourmile Flat immediately west of the Sand Springs Range, and very deep in Fairview Valley to the east. It was also evident that the east side of the Range was bounded by steep, normal faults. The refraction survey was designed to serve as a check on, and to augment the gravity and aeromagnetic data.

The refraction method could be expected to provide accurate depth-of-fill data on the west. Also, it should be possible to determine something of the dip of bounding faults on the east by shooting in the high speed granites and by shooting a parallel series of profiles broadside to the Range. Although the third problem, the depth to "bedrock" in Fairview Valley, is made to order for the reflection method, the costs for drilling the shot holes were deemed too high, hence no reflection survey was planned. (It has been found both in this area and elsewhere, that to insure the transfer to the ground of an amount of elastic energy sufficient to produce strong reflections it is required that the shot be emplaced below the water table. The water table in the Fairview Valley opposite Ground-Zero is fairly deep, near 300 feet, and the ground is in such condition that the shot-holes would have to be cased.)

Some preliminary testing was done in the granitic mass on top of the Sand Springs Range with a DynaMetric seismic timer, because it was thought that the velocities obtained would be useful in later refraction surveys. However, the velocities determined using this "Flintstone" system were only about one half of those determined using an explosive energy source, a phenomenon also observed elsewhere. Also, using this system, calculated depths have been found to be less. The hammer impulses probably excite only the near-surface weathered material, not the deeper, more massive rock.

EQUIPMENT AND DRILLING

The refraction seismograph unit used to carry out this program was a 12-channel research model. The University of Nevada is especially indebted to Professor J. L. Soske of Stanford, who, in addition to furnishing the seismograph, also donated four days field time to the project.

The shot-hole drilling was contracted to Sprout Engineers, Inc. Eighteen holes (9 on each side of the Range for Profiles I and III) were drilled without difficulty in granite, 6 each at 5, 10, and 15 foot depths. The holes in the valley fill, drilled with a power auger, proved to be more troublesome. All of these holes were cased with galvanized drain pipe to prevent caving. This worked well on the west side, but on the east side where the alluvial debris is much coarser, all of the holes except for the top 5 feet were lost as the drill was removed. The two holes for Profile II were hand dug to a depth of 4 feet with a shovel. They proved satisfactory.

Atlas 60 percent and 40 percent "Gelodyn" blasting gelatines fired by "Staticmaster" caps were used as the explosives. In practice the sticks were slit and tamped in the holes.

PROFILES

Three east-west refraction profiles were shot and are shown on Plate 7. The location for refraction Profile I was selected on the basis of the very low gravity gradient encountered on Gravity Line

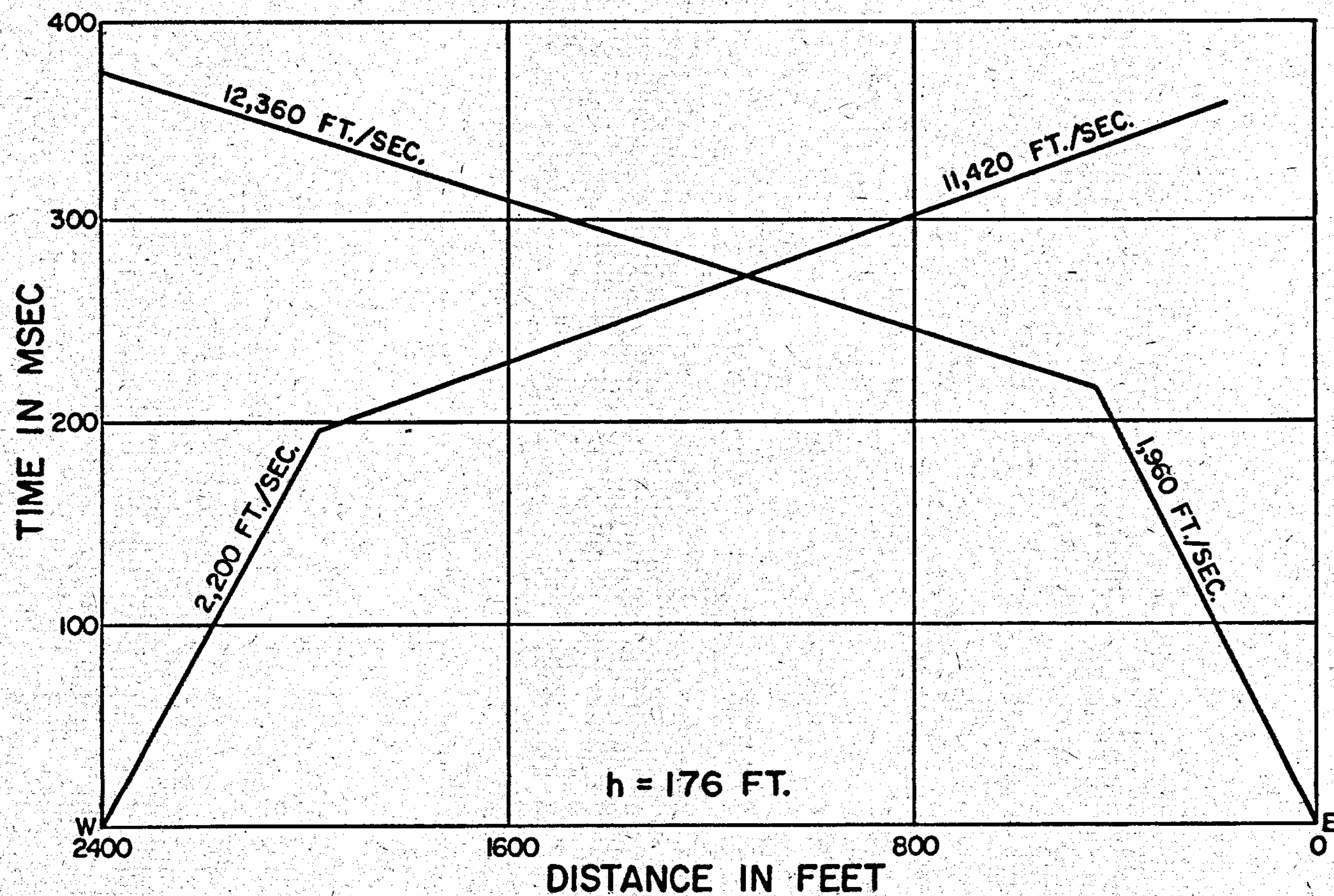


Figure 23. Time-distance curves, spread 3, Profile I

14, which is some 150 feet to the north of I. In fact there is less than one mgal variation on this line over its entire two-mile length.

Profile I consists of three 2,400-foot spreads (200 foot takeouts). Most of the pertinent data for the entire profile are given on Figure 23, which shows the time-distance curves for the westernmost of the three spreads. The calculated depth to the high velocity medium is only 176 feet at the center of this spread, which is 5,600 feet from any granite exposures in the Range.

The average velocity of the high-speed medium as determined from the shots emplaced in the granite is about 11,500 ft/sec. This is fairly typical for weathered granite or metamorphics. The low velocity is on the order of only 2,000 ft/sec, indicating that the valley-fill debris is unconsolidated in this area.

Profile II, consisting of one 2,400-foot spread, is centered at hydrology test hole H-3. The refraction data, shown in Figure 24, indicate that the high-velocity medium dips gently to the west at

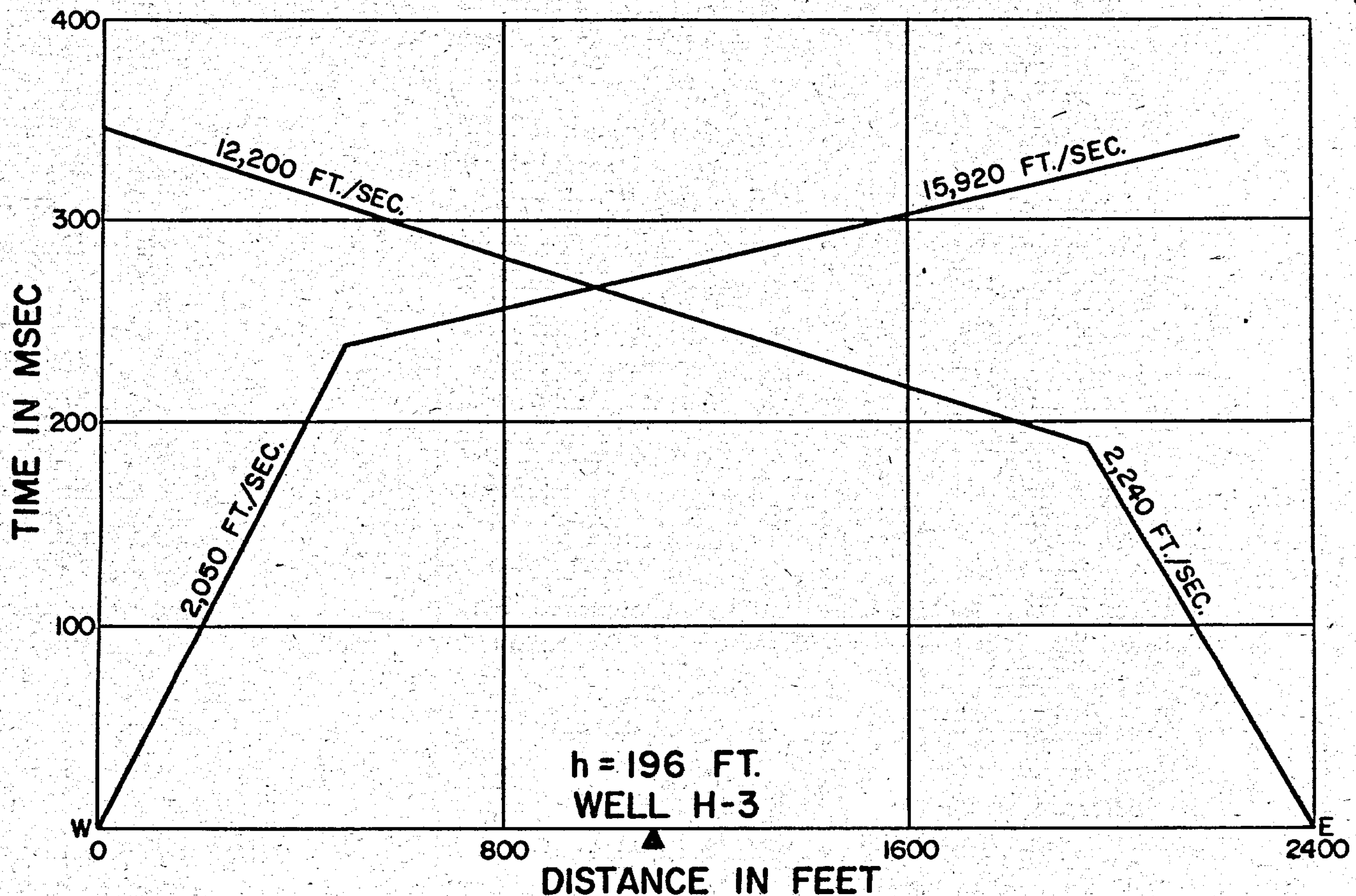


Figure 24. Time-distance curves, Profile II

1.2°. The depth to this medium at H-3 is 196 ft. The low velocity, encountered on II, is much the same as on Profile I. The high velocity, 13,810 ft/sec, is 2,300 ft/sec higher.

Unfortunately, the seismically determined depth (196 ft.), does not agree with the depth (310 ft.) shown on the well log of H-3 (see Appendix E). A possible explanation for this difference is as follows: the well log shows lithic fragments in the interval 140 to 205 feet. These rocks are reportedly metamorphic. In view of the fact that H-3 does not lie down drainage from any present metamorphic outcrops, it is postulated that the drill penetrated 114 feet of weathered metamorphics before entering the granite.

The drilling rate in the metamorphics could be expected to be greater than in the granites. The granites, valley-fill, and some of the schists and argillites of the metamorphic section are quite similar mineralogically. Hence, it is possible that the interface between the valley fill and the assumed metamorphics was not recognized during the drilling. As mentioned in the gravity section of this report, well H-3 lies just off the axis of a gravity high which might best be interpreted as being produced by buried metamorphics.

Profile III, two 2,400-foot spreads, is just south of and parallel to the GZ Canyon road. The time-distance curve for the shot into the Range on spread I is shown in Figure 25. No recognizable events were recorded on the shot out of the Range, i. e. with the shotpoint in the granite. (This is also the case for spread 1 of Profile I). This is a fairly common occurrence (J. L. Soske, oral communication) when shooting from a high-speed into a low-speed medium. From surface evidence the frontal fault should intersect spread I at about the 1,100-foot mark of Figure 25.

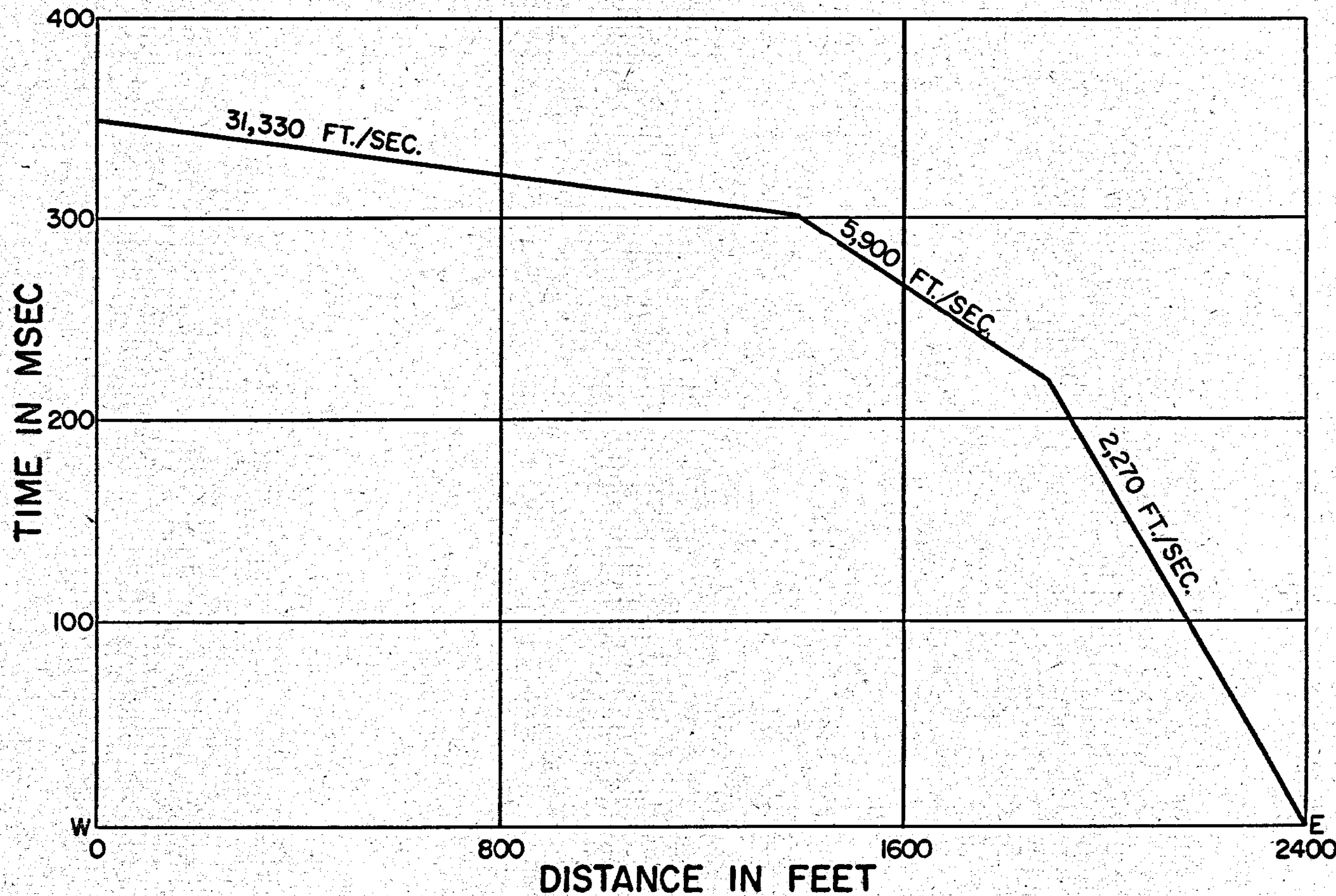


Figure 25. Time-distance curve, spread 1, Profile III

The highest velocity found on spread 2 was 7,870 ft/sec. Energy traveling at this velocity was recorded for all three shots, one at each end of the spread and one in the granite 2,400 feet west of the westernmost geophone. This velocity is too low for the medium to be granite; it is more likely to be compacted fill. The top of this high-velocity medium closely coincides with the water table as measured in hydrology test hole HS-1. The depth to a granite or metamorphic bedrock would have to be greater than 2,000 feet, as no higher velocity returns were recorded 4,800 feet out from the shotpoint.

No profiles were shot parallel to the Range, it being felt that with the gravity and aeromagnetic surveys sufficient data were already at hand for the purposes of this project. Furthermore, it is anticipated that more refraction work will be done in Fairview Valley at the time of some proposed HE shots of the U.S.G.S. and at the same time as the Shoal event. With the large energies involved it should be possible to obtain a depth figure for the bottom of Fairview Valley.

Physical Properties of the Drill Core

Tests were made of the thermal conductivity, permeability, and elastic properties of the granitic drill core from drill hole ECH-D. It was not expected that extreme variations would be found, thus the physical properties mentioned above were measured on segments of core taken at approximately 500 foot intervals. The results of the tests supported this expectation.

THERMAL CONDUCTIVITY

The thermal conductivity determinations were made using equipment constructed in the laboratory of the Nevada Bureau of Mines. A small hot plate, with a "variac" to control the current, was used as a heat source. Each core segment, 2 centimeters thick with a cross-sectional area of 80.1 square centimeters, was sandwiched between 3/16-inch-thick brass disks. This assembly was placed in an aluminum foil basket resting in a sand bath heated by the hot plate. The sand bath, aluminum foil basket, and brass disks acted to provide an even distribution of the heat. A 500 ml. Erlenmeyer flask was placed on top of the upper brass disk. The foil basket was then filled with pulverized calcined diatomite, completely covering and surrounding the core segment, brass disks, and Erlenmeyer flask, thus insulating the entire assembly against heat loss or undesired heat flow.

Two thermocouples were attached to the bottom of the core segment and two attached to the top. One top-bottom pair was connected in a differential circuit with a recording potentiometer to measure and record the difference in temperature between the top and bottom thermocouples. The other two thermocouples were connected to a sensitive potentiometer to measure the absolute temperatures of the top and bottom of the core—the hot and cold sides. To determine the thermal conductivity of a core segment, the hot plate was turned on and water allowed to flow through the Erlenmeyer flask from a steady-head supply. The water was introduced at the bottom of the flask through a glass tube and removed at the top. The temperature of the incoming water was measured with a mercury thermometer mounted in the steady-head supply, and the temperature of the discharge water was measured with a mercury thermometer mounted in the top of the Erlenmeyer flask, immediately adjacent to the outlet.

Measurements were begun when the recording potentiometer indicated that a constant temperature difference had been established between the hot and cold sides of the core segment. A graduated cylinder was placed under the water discharge, the temperatures of the water at the steady-head and flask outlet were recorded, and the temperatures of the hot and cold sides of the core were recorded. The discharge water was collected for 15 to 40 minutes, the temperature readings were repeated at the end of the time period and averaged with the first readings. Knowledge of both the volume of water collected in the graduated cylinder, and the increase in temperature from inlet to outlet, permitted calculating the calories of heat transferred during the time period. The temperature readings of the hot and cold sides of the core segment established the average temperature gradient. These temperature readings rarely varied more than 0.5 degree Celsius from the average, and were usually within 0.2 degree Celsius of the average. A temperature gradient of 40 degrees Celsius was usually maintained, with the lower temperature being about 90 degrees Celsius.

The above procedure was repeated until consistent results were obtained, further indicating the establishment of balanced conditions. Many of the observations were made during a 30 minute time period during which time over 750 ml. of water were collected, a volume 1.5 times the volume of the Erlenmeyer flask. The results of the testing are given in Table 2. These results compare with values of 0.0054 to 0.0059 gram calories per second per degree Centigrade per centimeter given for granites in Geological Society of America Special Paper 36, page 849. The slightly lower results obtained for the core segments are probably caused by the thermal resistance of the fracture cleavage.

MODULUS OF ELASTICITY

The modulus of elasticity (Young's modulus) was determined using a compression tester with a capacity of 250,000 pounds. The pressure gauge was tested using a proving ring certified by the National Bureau of Standards. Strain measurements were made using a feeler gauge with 0.0005 inch divisions. Readings could be made to 0.0001 inches with an accuracy of 0.0001 inches. Total deflections exceeded 0.0150 inches when a compressive load of 120,000 pounds was applied.

Segments of granitic core approximately 7 inches long by 4 inches in diameter were tested. The cores were obtained from drill hole ECH-D at depths of approximately 512 feet, 994 feet, 1,422 feet, and 2,004 feet. Each core was compressed with a maximum total load of 120,000 pounds, the pressure slowly released, recompressed to 120,000 pounds, and the pressure again slowly released. Strain readings were taken at 2,000 pound intervals for the 0 to 20,000 pound load range, and at 10,000 pound intervals for the 20,000 to 120,000 pound load range. Two hysteresis curves were constructed for each core and are shown in Figures 26 to 29.

The values obtained for the modulus of elasticity (Young's modulus) are given in Table 2. The uneven values for the compression loads are a result of dividing total loads of 20,000 and 120,000 pounds by the area of the core. The modulus of elasticity for any particular interval in the range 0 to 10,000 p.s.i. may be determined by using the proper hysteresis curve.

The values obtained for the modulus of elasticity compare with values of 3,440,000 p.s.i. to 8,280,000 p.s.i. for surface specimens of granite; and values of 5,000,000 p.s.i. to 6,820,000 p.s.i. ob-

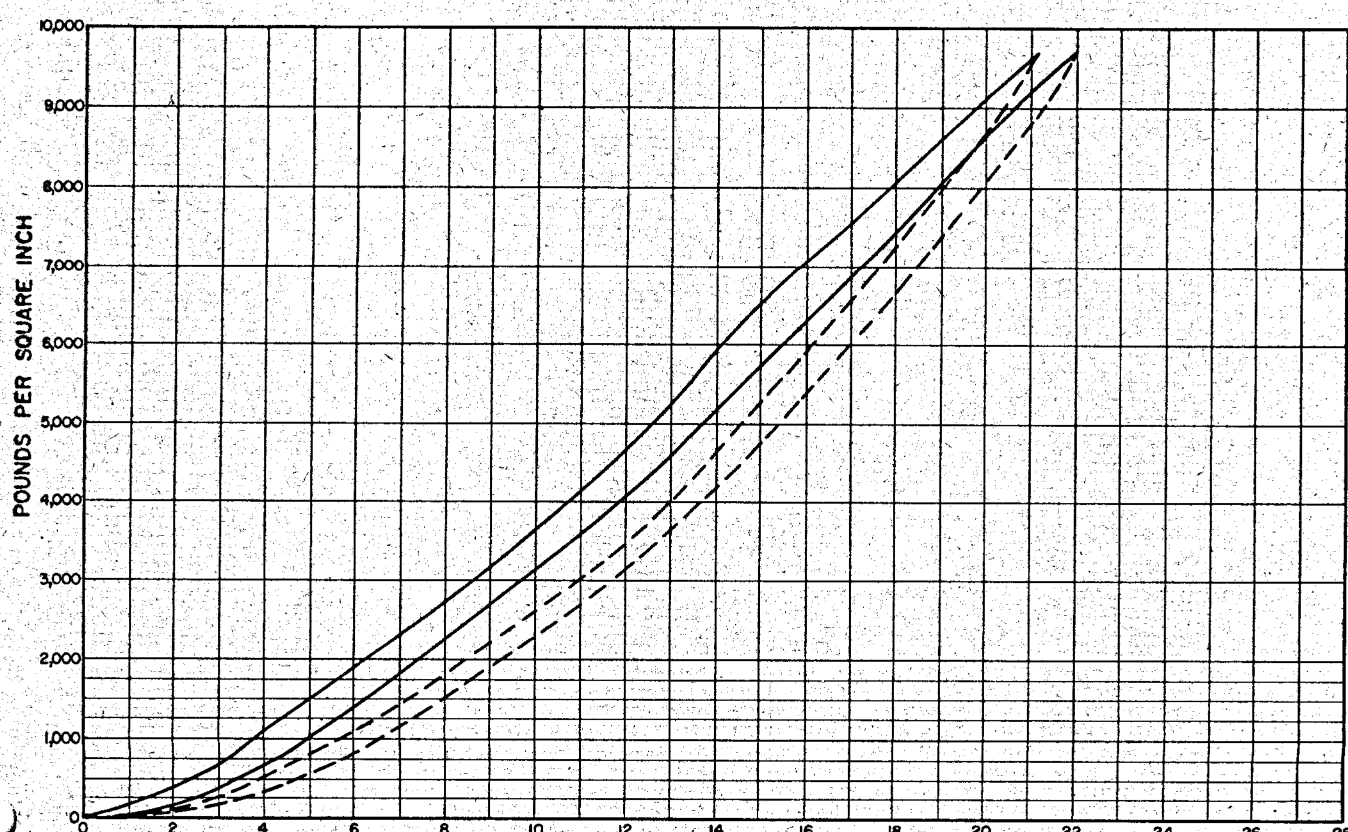


Figure 26. Stress-strain hysteresis load curves, core segment of granite at 512 feet in Core Hole ECH-D

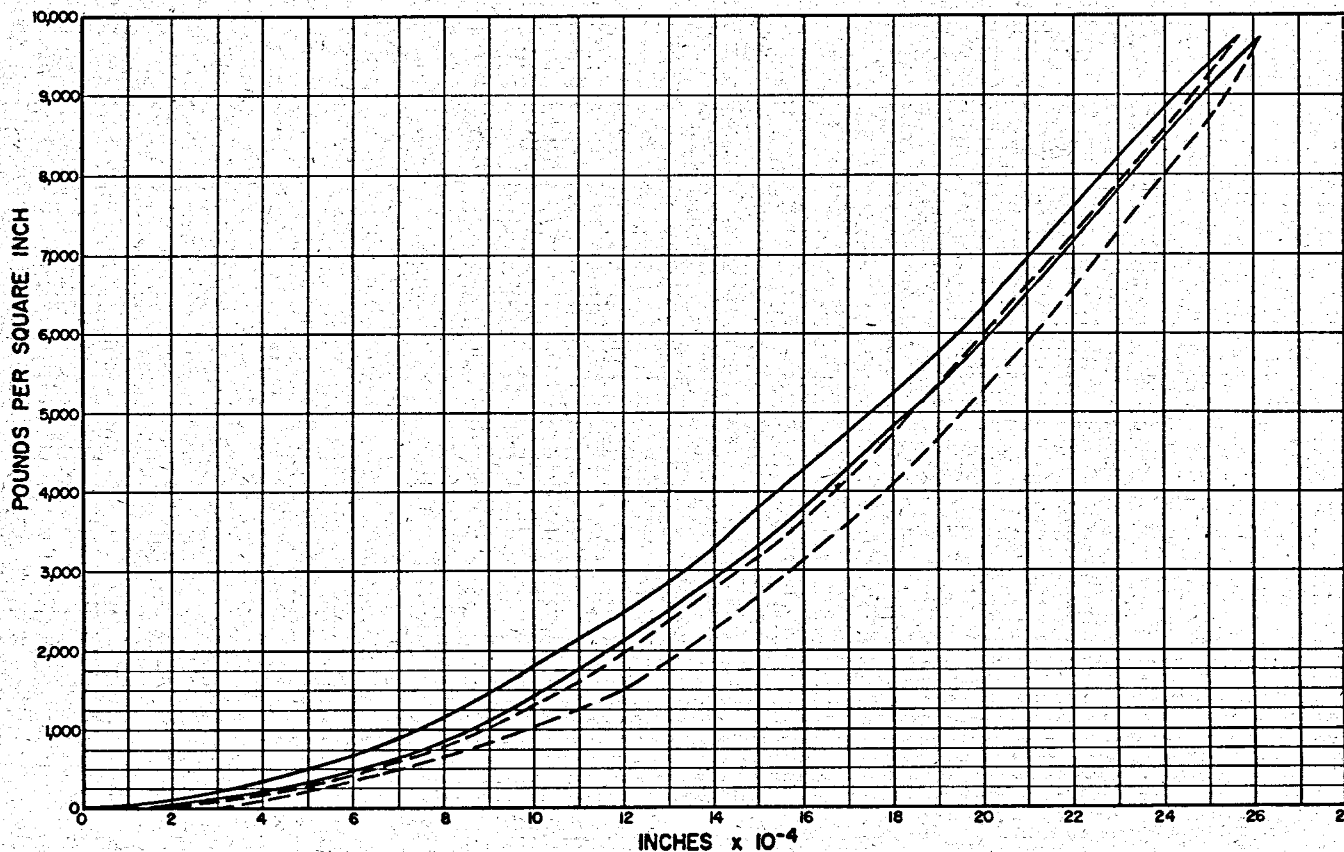


Figure 27. Stress-strain hysteresis load curves, core segment of granite at 995 feet in Core Hole ECH-D

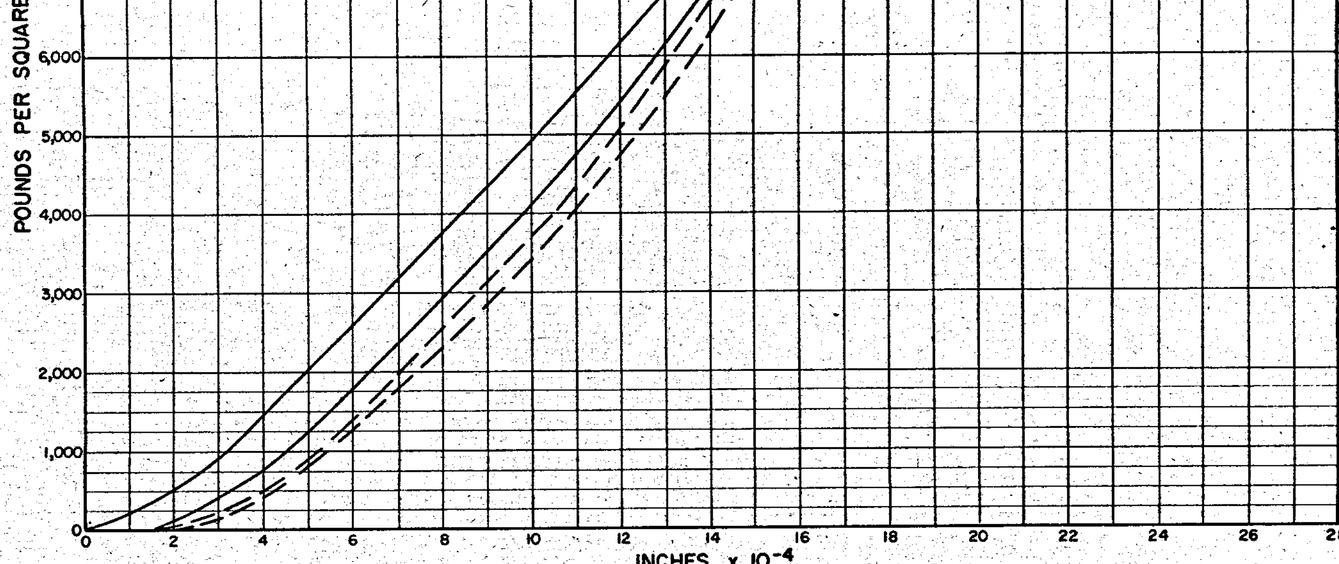


Figure 28. Stress-strain hysteresis load curves, core segment of granite at 1422 feet in Core Hole ECH-D

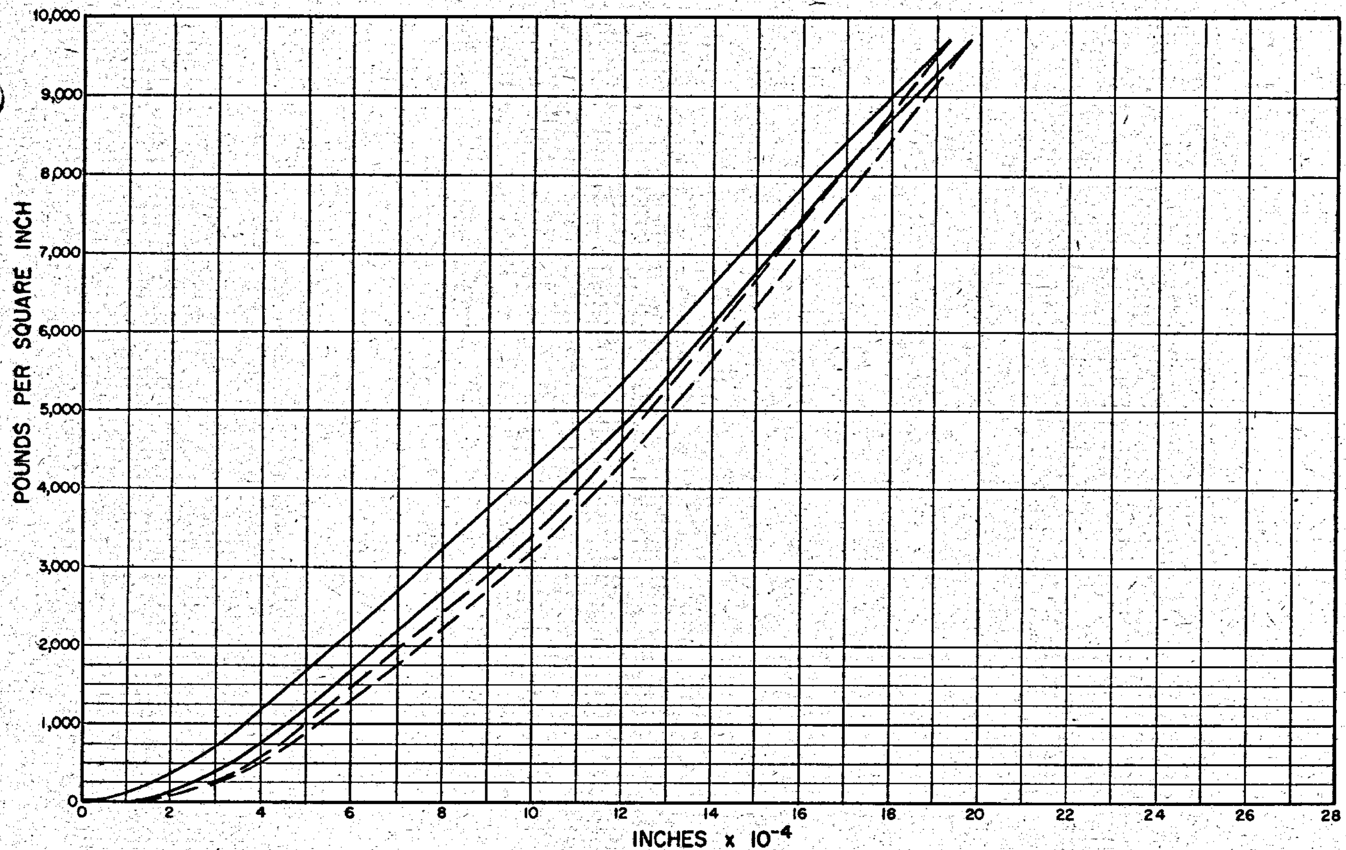


Figure 29. Stress-strain hysteresis load curves, core segment of granite at 2003 feet in Core Hole ECH-D.

tained for granite at a depth of 235 feet as given in Geological Society of America Special Paper 36, page 73.

PERMEABILITY

Tests to determine the permeability of the core were made by Core Labs, Inc., Dallas, Texas. Core segments from depths of approximately 512 feet, 994 feet, 1,422 feet, and 2,004 feet were tested. The results are given in Table 2. Permeability tests of granite are rarely made and no reliable figures for general ranges of permeability in granite could be found. The permeability is extremely low, being 1/1,000 to 1/1,000,000 of the low range for permeability in sedimentary rocks.

The permeability values were measured while the whole-core samples were subjected to simulated overburden pressure. The overburden pressure was simulated by establishing a pressure differential of approximately 0.6 p.s.i. per foot of depth between the external and average internal pressure applied to the core.

GENERAL OBSERVATIONS

The values obtained for the physical properties appear to be of the proper magnitude. A comparison of the various physical properties of individual cores reveals substantiating agreement. As an example, the core with the lowest thermal conductivity also has the highest permeability, while the core with the highest thermal conductivity has the lowest permeability. This is to be expected because the permeability represents, in a general way, the number of openings or discontinuity of solid rock within the core, while the thermal conductivity represents a continuity of solid structure. The same relationship is apparent when comparing the permeability and the modulus of elasticity. The specimen with the highest modulus of elasticity has the lowest permeability and the converse is also true. A definite relationship exists between the modulus of elasticity and the thermal conductivity. If the modulus of elasticity is plotted against the thermal conductiivty for the four core segments, a straight line will result, with the exception of the core segment taken at a depth of 994 feet. It thus appears that either the thermal conductivity or the modulus of elasticity may be readily determined if one value is known, and if the core has not somehow been altered or disturbed.

In the case of the core segment taken at 994 feet, visible cracks were apparent following determination of the modulus of elasticity. A few loud audible cracking sounds were heard during testing. The visible cracks are parallel to the axis of the core. No changes were noted in the other cores during or following testing. The low initial modulus of elasticity for this core, as compared to the others, suggests the presence of openings. As the modulus of elasticity for the high range is normal, these openings may have closed during the early stages of compression. The presence of minute openings is further suggested by the higher permeability and lower thermal conductivity.

The results of the testing on the core segment obtained at 994 feet should not be extrapolated throughout a large interval. The cores for physical testing were selected so that they would be as solid as possible and free from any apparent fractures or cracks. Testing of core with obvious flaws would yield little or no valuable information.

Other portions of this report describe the condition of the core throughout the length of hole ECH-D. The values obtained during the physical testing can be applied to the intervals where solid core without fracture or faulting was obtained. Segments of core so disturbed will have lower moduli of elasticity, higher permeabilities, and probably lower thermal conductivities. The presence of water will obviously alter the thermal conductivity.

TABLE 2

Core Depth	**Young's Modulus (E)**		**Thermal Conductivity**	**Permeability**
(Feet)	Range (p.s.i.) 0-1618	Range (p.s.i.) 1618-9708	Gram calories per sec. per cm. $\times 10^{-3}$ @ 100° C	Millidarcies $\times 10^{-6}$
512 *	3,000,000	5,090,000	3.6	13.8
	2,900,000	5,180,000		
994 *	1,700,000	5,030,000	3.1	3,100
	1,760,000	5,180,000		
1,422 *	3,860,000	6,160,000	4.5	less than 1
	3,860,000	6,730,000		
2,004 *	3,410,000	5,680,000	4.1	390
	3,510,000	5,910,000		

*The upper figure is derived from the first hysteresis compression curve; the lower figure from the second hysteresis compression curve.

HYDROGEOLOGY AND HYDROLOGY

Nature of the Problem

The purpose of this investigation is to determine the probability of contamination of water as a result of the proposed nuclear detonation in the granitic mass in the Sand Springs Range. In order to reliably predict the probability of contamination, it is necessary to ascertain the origin of the water, its rate and direction of movement, and the location of all points where water is removed from the system, either naturally or artificially. Further, as the study deals primarily with ground water, the geologic nature of the transmitting media assumes critical importance. This report, therefore, records evidence obtained from both hydrologic and geologic studies as they pertain to the occurrence and movement of water, and interprets this evidence in regard to the probability of ground-water contamination. Preliminary considerations indicated that the study might safely be confined to within a 15-mile radius of the proposed experiment and detailed studies here reported are so treated. Supplementary observations beyond this limit are included where justified by special considerations, such as present or potential water use and population density.

Summary of Drilling and Testing Program

At the outset it was recognized that available hydrogeologic and hydrologic data were sparse and inadequate for the purposes of the investigation. Further, sources of hydrologic data such as existing wells and springs were similarly limited. Therefore, a modest test-well drilling program was initiated to obtain information on the occurrence and nature of the geologic formations, their hydraulic characteristics, and on the occurrence, movement, storage, and chemical quality of the water.

On February 14, 1962, two cable-tool drill rigs started operations on Test Holes HS-1 and H-4 in Fairview Valley. The test holes were located 150 feet apart in Section 32, T. 16 N., R. 33 E. (see Table 3 and Plate 9). The holes were intended to be drilled and tested simultaneously, but when the lower boundary of the first aquifer system was encountered and the first pumping tests had been conducted, it seemed expedient to continue exploration in one hole only, and to move the other drill rig to a new location. Accordingly, operations were started on Test Hole H-3 in Section 29, T. 16 N., R. 32 E. in Fourmile Flat on March 16. Drilling was meanwhile continued in Test Hole H-4, and it was planned to deepen Test Hole HS-1 with the same drill rig as soon as results of exploratory drilling in Test Hole H-4 indicated the most logical program to follow. Similarly, the drilling operation at Test Hole H-3 was to guide further drilling in Fourmile Flat, specifically to determine the need for a nearby observation well. Following this plan, Test Hole H-4 was completed at 935 feet and the drill rig was moved to Test Hole HS-1, which hole was subsequently completed at 699 feet.

In Fourmile Flat, Test Hole H-3 was drilled to a depth of 480 feet. Because granitic bedrock of very low permeability was penetrated below the water table, and pumping tests in this area could not be successfully conducted, it was concluded that drilling an observation well at this location was not justified. Therefore, the drill rig was moved to a new site in Section 19, T. 16 N., R. 32 E. and Test Hole H-2 was drilled. This hole was completed at a depth of 768 feet in alluvial sediments.

Pumping and bailing tests at the Fairview Valley site were conducted both during drilling operations and after the wells were completed. One pumping test was run when both Test Hole H-4 and Test Hole HS-1 were at a depth of about 530 feet, at the top of the first clayey layer encountered. The second pumping test was conducted following the completion of both holes, when the lower aquifer

TABLE 3. WATER WELLS AND SPRINGS INVENTORIED FOR PROJECT SHOAL, CHURCHILL COUNTY, NEVADA

Well Number	Locations	Owner	Use	Depth in Feet	Diameter, in Inches	Discharge in gpm (est.)	Pump Type	Surface Elevation	Date and Depth to Water		Remarks
HS-1	SW¼ SW¼ NW¼ sec. 32 T16N R33E	A. E. C.	Test Well	699	8	70	Turbine	4243.76	2/17	300.14	Shoal Project Test Well
H-4	SW¼ SW¼ NW¼ sec. 32 T16N R33E	A. E. C.	Test Well	935	6	70	Submersible	4241.92	2/18	299.2	Shoal Project Test Well
H-2	SE¼ sec. 19 T16N R32E	A. E. C.	Test Well	768	8⅝	66	Reda	4017.3	7/30	110.88	Pump removed
H-3	SW¼ SE¼ NE¼ sec. 29 T16N R32E	A. E. C.	Test Well	480	8⅝	5 - 10	Peerless	4232.2	7/31	328.3	Pump removed
1	SE¼ NE¼ SW¼ sec. 36 T16N R31E	P. Cushman	Dom.	315	6	5 - 10	Cylinder	4192.7	6/1	285.0	Gas driven
2	NW¼ sec. 19 T16N R32E	P. Cushman	Stock	- - -	4	3 - 5	None	3900	6/1	G.S.	Flowing, water leak near casing
3	SE¼ SW¼ NW¼ sec. 5 T16N R32E	P. Cushman	Stock	27	6	0.5 - 1	None	3904.5	4/10 7/30	3.19 3.2	Gravity feed to tanks
4	NW¼ SE¼ SE¼ sec. 5 T16N R32E	F. Bennett	Aband.	162	6	- - -	None	3973.6	4/10 7/30	65.2 65.87	Tungsten Mill
5	SE¼ SE¼ SW¼ sec. 5 T16N R32E	B. Matthews	Dom. & Com.	- - -	6	20 - 25	Submersible	3961	4/13 7/30	29.1 29.25	Big Top Restaurant
6	NW¼ NW¼ NE¼ sec. 31 T17N R31E	Whitman	Stock	- - -	6	0.5 - 1	None	3928	7/30	1.3	Gravity feed to tanks
7	SW¼ NE¼ NW¼ sec. 31 T17N R31E	Whitman	Stock	- - -	6	0.5 - 1	None	3933	4/16 7/30	+2 +2.1	Flowing Well
8	SW¼ sec. 9 T16N R30E	R. Bass	Stock	- - -	6	1 - 2	Cylinder	3990*	4/17	21.45	Windmill
9	SW¼ sec. 20 T16N R30E	R. Bass	Stock	- - -	6	10 - 15	Cylinder	3990*	——		Gas driven
10	SW¼ SW¼ SW¼ sec. 31 T18N R31E		Stock	300	6	0.5 - 1	Cylinder	3976	4/13 7/30	32.4 31.96	Windmill
11	NW¼ sec. 6 T16N R32E	Dodge Cons. Co.	None	190	4	0.2	None	3893.4	5/22	+1	Flowing well
12	SW¼ sec. 27 T18N R31E		Stock	350	6	0.5 - 1	Cylinder	4226	5/29	300	Windmill
13	SE¼ sec. 12 T18N R29E	H. Pierce	Dom.	14	12 ft.	3 - 5	Gas Driven	3919.6	5/22	12	Water level influenced by irrigation returns
14	NE¼ sec. 35 T18N R29E	P. Schaffer	Stock	80	4.5	0.5 - 1	None	3907.6	5/25	+3	Flowing well

*Estimated

TABLE 3 (Continued). WATER WELLS AND SPRINGS INVENTORIED FOR PROJECT SHOAL, CHURCHILL COUNTY, NEVADA

Well Number	Locations	Owner	Use	Depth in Feet	Diameter, in Inches	Discharge in gpm (est.)	Pump Type	Surface Elevation	Date and Depth to Water		Remarks
15	SW¼ sec. 22 T18N R29E	S. Flippen	Dom.	- - -	- - -	1 - 2	None	3907.6	5/26	+2	Flowing well
16	SE¼ SE¼ SW¼ sec. 32 T16N R33E	B. L. M.	Stock	364	6	5	Cylinder	4262.78	4/17 7/10	319.20 319.28	Windmill
17	SW¼ SE¼ NW¼ sec. 3 T16N R33E	Ed Weyher	Dom.	280	6	15	Submersible	4153.3	4/17	224.10	At rear of garage
18	SW¼ SE¼ NW¼ sec. 3 T16N R33E	Ed Weyher	Dom.	288	8	17	Submersible	4153.3	4/17	224.60	In wood crib in pasture
19	NE¼ NW¼ NE¼ sec. 11 T16N R33E	B. L. M.	Not Used	373	8	5	Cylinder	4147.80	7/10 4/23	218.84 218.80	On bombing range
20	SE¼ sec. 35 T17N R34E	State	Not Used	365	8	None	None	4386	7/10 4/16	266.16 266.16	In Stingaree Valley
21	SE¼ sec. 32 T17N R35E	State	Used Not	110	6	None	None	4468	7/10 4/17	53.87 72.00	At old 3-C Camp
22	SW¼ sec. 33 T17N R35E	B. L. M.	Stock	51	6	10	Cylinder	4518	7/10 4/10	32.38 30.00	At Westgate large tank
23	NE¼ SW¼ SE¼ sec. 34 T17N R35E	Ed Weyher	Irr.	(Rep.) 202	10	1000*	Turbine	4615	7/10 4/23	93.00 92.35	At ranch at Middlegate
24	SW¼ sec. 18 T17N R34E	B. L. M.	Stock	334	6	10	Cylinder	4217	7/10 5/9	279.20 299.70	In north flats, tenant C. B. Stark
25	NE¼ sec. 21 T19N R34E	B. L. M.	Stock	335	6	2	Cylinder	3814	7/10 4/17	278.29 292.40	Hot well, tenant C. B. Stark
26	NW¼ sec. 13 T18N R32E	H. Kent	Stock	60	25 ft.	None	Piston	5500*	6/6	60	Bulldozed sump
27	SW¼ sec. 2 T18N R32E	H. Kent	Stock	80	6	10	Cylinder	5600*	6/6	14.2	Well at corral
28	SE¼ sec. 3 T18N R32E	H. Kent	Stock	(Rep.) 120	6	10	Cylinder	5600*	6/6	25.9	Windmill
29	SW¼ sec. 23 T15N R32E	B. L. M.	Stock	3	3 ft.	Dry	Siphon	5500*	Spring		Frenchman Spring
30	NW¼ sec. 36 T15N R32E	B. L. M.	Not Used	Land Surface	1 ft.	Very Small	None	5200*	7/3	Seep	In Ram's Head Canyon
31	NW¼ NE¼ NW¼ sec. 3 T16N R35E	I. Malendy	Dom.	- - -	- - -	- - -	- - -	4150*		——	Middlegate S. Station
32	SE¼ NW¼ sec. 35 T15N R33E	B. L. M.	Stock	3	3 ft.	Small	None	5500*	7/6	Spring	Slate Mountain Spring
33	NE¼ sec. 3 T18N R29E	F. Soars	Dom. Irr.	18 - 20	- - -	- - -	- - -	3934*	5/22	8	Water level poss. infl. by irrig.

*Estimated

was pumped and the upper aquifer was sealed off, at least in the pumping well. In addition, at Frenchman, farther north in Fairview Valley, wells which are 280 and 288 feet deep (Wells 17 and 18) were tested.

Pumping tests in Fourmile Flat were conducted after each test hole was completed. At Test Hole H-3 extensive bailing tests were run to determine whether a pump should be installed. Since these tests were inconclusive, a pump was installed and a conventional one-well test was conducted.

A series of recovery tests were performed on ECH-D, the vertical granite test hole near Ground-Zero. These consisted of bailing and blowing out the hole and observing water level recovery when the well had been drilled to a depth of 1,355 feet, and again when the well had been drilled to a depth of 1,575 feet.

Gamma ray, neutron, and temperature logs were run in Test Holes H-4 and H-3, and samples for chemical analysis, tritium content determination[1], and radiometric analysis[2] were taken from the test holes. The results of most of these analyses are given in a subsequent section of the report.

The information derived from the drilling and testing program is described in detail in the following parts of this report and in Appendices C through G.

Hydrogeology

Water occurs at the surface in a few places and at varying depths underground throughout the area. In nearly all instances ground water is found shallower in the valleys and deeper in the mountains, although a few seeps and springs in the Sand Springs and Stillwater Ranges and on Fairview Peak-Slate Mountain attest to the presence of some shallow, probably small bodies of perched or otherwise trapped water. Evidence from drilling operations in the Sand Springs Range granite is essentially inconclusive regarding the water-bearing characteristics of such rock, although it has been established that some water does occur in the granite. Continued study of this problem is anticipated. The detailed geology of the consolidated rocks of the Sand Springs Range is given in the Geology section of this report. Consolidated rocks of other ranges bordering the valleys have been examined by reconnaissance only, in order to determine their hydrologic significance. The consolidated rocks act as geohydrologic barriers and neither store nor transmit appreciable quantities of water—appreciable, at least, in relation to any probable contamination hazard that might occur as the result of the Shoal experiment. Therefore, the emphasis in the hydrogeologic study has been placed on investigation of the valley fill, because these sediments do contain and transmit appreciable quantities of water and form the reservoirs from which water supplies are withdrawn.

GEOLOGY OF THE VALLEY FILL

Plate 9-C is a geologic map of the valley fill in the area included within roughly a 15-mile radius of Ground-Zero. Plate 9-B shows geologic features outside this area that are of critical importance to the hydrogeologic and hydrologic problems. As is shown on the maps, the two areas containing widespread deposits of valley fill are Fairview Valley and the valley in which Fourmile and Eightmile Flats occur.

Fairview Valley

Fairview Valley is a structural bedrock basin which has been partly filled with alluvial sediments.

[1] The results of tritium studies had not been received at publication date.
[2] Radiometric analysis has been conducted and will be reported by the U. S. Public Health Service.

Gravity studies indicate that consolidated rocks are at least 5,800 feet deep near the west side of the south part of the valley, in the vicinity of Test Holes HS-1 and H-4. The surface of these consolidated rocks seems to slope upward to the east and to the north as indicated by gravity profiles, so that the depth to bedrock near the east side of the valley is about 4,000 feet and near the center of the valley along U. S. Highway 50 about 5,500 feet. Geophysical studies have not been made farther north in the valley but geomorphic interpretation would suggest that the bedrock is shallower in that direction.

Detailed information on the alluvial fill is limited to local areas around Frenchman and Test Holes HS-1 and H-4, where wells have been drilled. Driller's logs are available at Frenchman for wells that have penetrated 288 feet into the valley fill. These logs confirm data collected from Test Holes HS-1 and H-4 about six miles south. The drill log of a former well beneath the playa deposits of Labou Flat in the Bernard Navy Bombing Range south of Frenchman, reports essentially all "clay" (silt or silty clay?) to a depth of 400 feet. The logs of Test Holes HS-1 and H-4 provide the best available information on the alluvial fill to a depth of 935 feet (see Appendices C and F). These logs show that the alluvial fill is of very uniform lithology, consisting primarily of fine- to coarse-grained sand with some silt and very little clay. Only one layer of clayey material, with medium to high plasticity and a thickness of about 32 to 35 feet, occurs between depths of 530 and 565 feet. Even this layer contains only a little clay, and consists predominantly of silt and fine-grained sand. This layer serves as an aquitard between the two aquifers differentiated in valley fill in the drill hole vicinity. The mineralogical composition of the materials described in these two logs is characteristic of weathered granite and contains primarily sand and silt-sized particles of quartz and feldspar, with small amounts of accessory minerals including hornblende, magnetite, and zircon.

The valley fill is the result of deposition from streams carrying erosion products from the adjacent mountains. Because the streams flowed mainly in an easterly or westerly direction, and because many interstream areas occur with much finer sediments, it is almost impossible to correlate well logs in a north and south direction. Since these lens-shaped and finger-like strata change texture rapidly in both horizontal and vertical directions, correlation for long distances in any direction is difficult if not impossible. The latest deposition of these lenses and interfingering layers composing the alluvial fans makes up the present surface deposits in the valley and confirms this conclusion.

Four types of sedimentary deposits are found in the valley today; stream alluvium, alluvial fans, playa, and lake deposits. Most of the sediments have a common origin; they result from erosion and stream transport from the mountain ranges. In the southern end of the valley at elevations of about 4,300 feet, alluvial fans extend halfway across the valley. Large granite blocks four or five feet in diameter are found in the stream channels. When the streams flood, the roads may be covered in a few hours' time and several feet of sand, gravel, and boulders may be deposited. On the west side the fans are less dissected than those on the east side, and on Fairview Peak the streams are downcutting rapidly. At the northern end of Fairview Valley a large fan built out from the Stillwater Range extends almost across the valley. It is now modified on the east end by a small stream called Dixie Wash.

Several beaches of gravel and sand may be found on the east slope of the Sand Springs Range about seven miles south of Frenchman at an elevation of about 4,230 feet. Terraces and playa flats also occur near the 4,150 foot level. This is evidence that at one time a lake or lakes covered many square miles of the valley and might have been about 75 feet deep. The ages of these lakes are not presently known, nor is it known whether they were extensions of a lake in Dixie Valley. The sediments of these features are very fine and contain much clay due to the settling and reworking action of the lake waters. As mentioned above, 400 feet of clay was encountered by the well in the playa known as Labou Flat. About six miles north of this area several terraces mark the northern boundary of the lake in Fairview Valley. The lake deposits differ markedly in composition from the alluvial sediments, as the former are very fine sand, silt, or clay while the latter consist of coarse gravels, stones, boulders, or very coarse sand. On Plate 9-C the alluvial fan and lake deposits are mapped as a single unit (Quf). The playa deposits are mapped as a separate unit (Qp), as are the recent alluvial deposits, primarily stream alluvium (Qr).

Fourmile and Eightmile Flats

The thickness of the alluvial fill in Fourmile and Eightmile Flats is probably much less than that in Fairview Valley. In Test Hole H-3 granitic bedrock was encountered at a depth of 310 feet. About 1½ miles downslope (northwesterly), at Test Hole H-2, bedrock was not encountered at a depth of 780 feet, the total depth of the well. Gravity measurements given in the geophysical report suggest depths of at least 1,950 feet in the valley.

Fourmile and Eightmile Flats are a reentrant of the large basin of the Fallon agricultural area. The sediments and soils of this reentrant furnish a detailed history of late Quaternary sedimentation, erosion, soil development, and climatic change, as well as a history of fluctuation of Lake Lahontan. This lake was a result of pluvial conditions existing during the Tahoe-Tioga periods of glaciation and was actually the result of a series of lake rises and declines (Morrison, 1961b). Glacial advances were approximately synchronous with rises in lake levels. Most of the drainage into Lake Lahontan was from the Sierra Nevada.

The Quaternary history of the basin around Fallon (exclusive of Fourmile Flat) was extensively interpreted and recorded in an attempt to set up geochronologic type sections representative of Late Quaternary time in the northern part of the Great Basin (Morrison, 1961a). The Quaternary sediments are differentiated into three main stratigraphic units by Morrison on the basis of lithologic differences and soil horizons (see Figure 30):

1. the Paiute Formation, a subaerial alluvial and colluvial sequence of later Pleistocene age that overlies Quaternary and Tertiary volcanics;

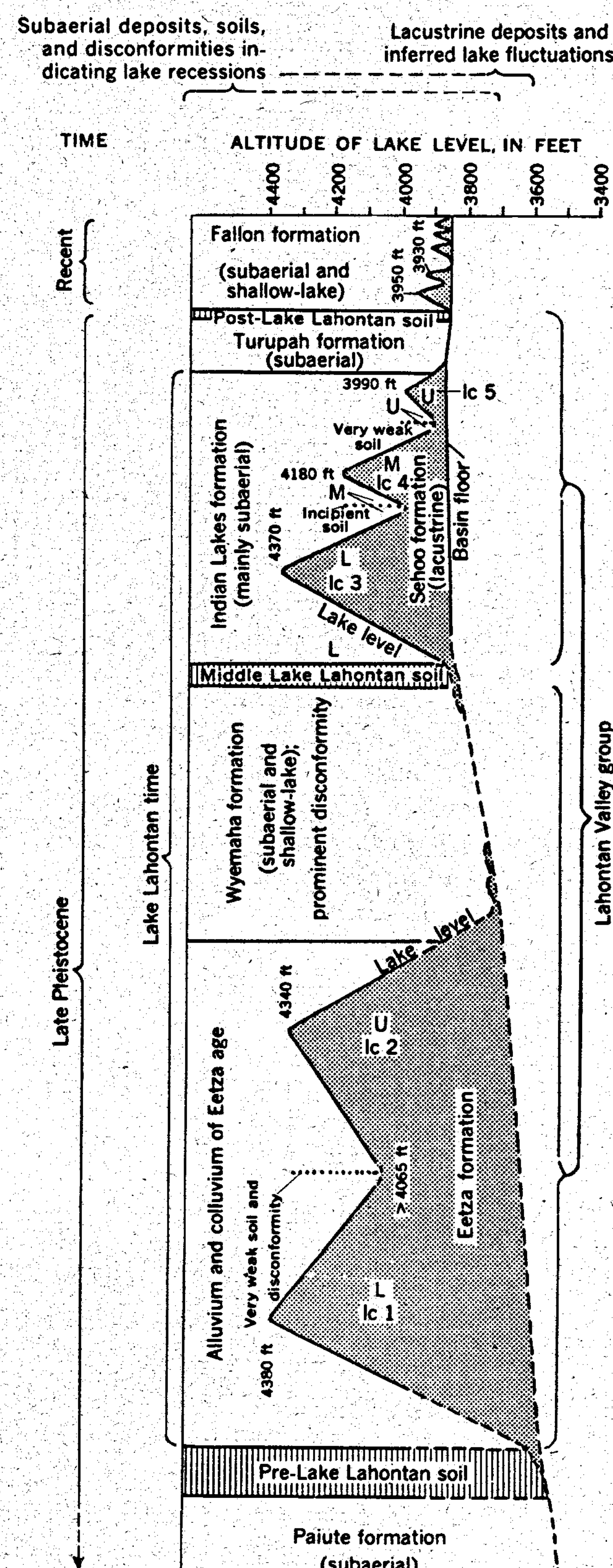


Figure 30. Stratigraphic section of alluvial fill deposits (after Morrison, 1961a)

2. The Lahontan Valley Group, a sequence of intertonguing deep-lake, subaerial, and shallow-lake sediments of Lake Lahontan and post-Lake Lahontan time and;
3. the Fallon Formation, a succession of intertonguing subaerial and shallow-lake deposits.

Within the Lahontan Valley Group, Morrison's main distinctions between deposits depend upon the differences between subaerial and lake sediment relationships as well as the presence of various soils which are effectively used as marker horizons.

Shorelines evident in the Carson Desert area are not by themselves good criteria for establishing the chronology of the Pleistocene lakes. Deposits must be identified and superposition of these deposits traced. Soils are an excellent criterion to use in this area in establishing a relative chronology.

Although the 869 square miles mapped by Morrison does not include the valley-fill deposits of Fourmile Flat, but terminates at the eastern edge of Eightmile Flat, the stratigraphic record depicted in Figure 30 is believed to be applicable to the valley-fill deposits in Fourmile Flat. Field work accomplished in the present investigation substantiates the presence of readily recognizable Lahontan Valley Group (Late Pleistocene) and Recent deposits, distinguished by gross lithologic differences and the presence of soil horizons, which were the basis of Morrison's correlations.

Because of the nature of this project, it was decided that the mapping of valley-fill deposits in Fourmile Flat in the detail of Morrison was not as important as creating a geologic map based on gross lithologic differentiations of these deposits (see (Plate 9-B and C).

The criteria used in establishing the mapping units were gross lithology and applicability to the hydrologic problems. Therefore, most of the presently established units are known to be time transgressive. An example of this is the Quaternary sand dune (Qsd) deposits mapped as a gross lithologic unit of eolian sand (predominantly fine- to medium-grained). This sand is of Turupah and Fallon age (see Figure 30), although a portion of these eolian sands (those sand dunes mapped south of Well No. 1) may even be Wyemaha age.

Bedrock symbols are those used by the Nevada Bureau of Mines personnel and are modified only to the extent of placing an "M" before the rock type abbreviation.

Lahontan bar deposits (Qlb) and Lahontan lacustrine deposits (Ql) are believed to be correlative to the intertonguing Sehoo-Indian Lakes Formations. The Indian Lakes Formation is a subaerial coarse alluvium and colluvium while the Sehoo Formation is lake sediment of predominantly fine-grained sand, silt, and clay composition.

Undifferentiated Lahontan Valley Group deposits (Qlu) are believed to be the age of sediments of the Lahontan Valley Group, with possibly some Recent alluvium.

The Recent lacustrine deposits (Qrl) mapped in Fourmile Flat are probably correlative in part to the Fallon Formation, a shallow-lake deposit (see Figure 30).

The high shoreline of Lake Lahontan, at the 4,380 foot elevation, is used to separate known Lahontan Valley Group sediments from the deposits described as undifferentiated fans. The ease of recognition of this shoreline both in the field and from aerial photos conveys the excellent preservation of the Quaternary geologic history of the area.

Sediments encountered in Test Holes H-2 and H-3 consist primarily of fairly uniform sand, fine sand, and silt deposited by Lake Lahontan, and of eolian sands of late Pleistocene-Recent time. Interbedded with these deposits are alluvial fan materials, some of which are very coarse (one stratum encountered at 80 feet in Test Hole H-3 is made up of boulders of large dimensions). The surface and subsurface geology cannot be accurately correlated without detailed work. Ostracods believed to be correlative to ostrocod faunas in Wyemaha or Sehoo deposits to the west, are present in samples taken from various levels of Test Hole H-2.

The alluvial fill in Fourmile and Eightmile Flats has been mapped in greater detail than that in Fairview Valley and south of the Cocoon Mountains because of the greater variety of sediments and other features available for outcrop study.

HYDROLOGIC CHANGES INDUCED BY EARTHQUAKES

Earth displacements known to have occurred in seismically active areas have been known to result in considerable hydrologic changes. For example, many authors report changes in discharge of springs and flowing wells as well as fluctuations in water levels. One of these reports (Zones, 1957) refers specifically to the region contiguous to the Sand Springs Range. In this paper he discusses water-level fluctuations on the order of four to eleven feet and discharge changes in the epicentral area where the intensity of the 1954 earthquake was VII based on the Modified Mercalli scale of 1931. Zones points out (1957, p. 387-396) that such phenomena result primarily from tilting of aquifers, compaction of sediments over large areas, fracturing of rocks, and movement along faults. Further, in all instances he suggests that either increased or decreased water level or discharge would be temporary, and that eventually the balance between ground-water recharge, discharge, and storage would be re-established with essentially no residual effect on the overall hydrologic picture.

It is doubtful that detonation of a device such as is proposed for Project Shoal would result in effects of even a sizeable fraction of those produced by the earthquake of 1954. Water level changes within a mile or so of the detonation point probably will be undiscernible.

OCCURRENCE OF GROUND WATER

The occurrence of ground water in the consolidated rocks has already been described in general. Occurrence in the alluvial fill is discussed in the following paragraphs. Knowledge of occurrence of ground water in the alluvial fill is based primarily upon the results of the test-drilling program and upon scanty records of previous drilling operations in the valleys.

Results of test drilling in Fairview Valley indicate the presence of two aquifers separated by an aquitard in the upper 935 feet of valley fill at Test Holes HS-1 and H-4. The upper aquifer, 218 feet thick, is composed of fine- to coarse-grained sand with some silt, and layers or lenses of highly silty beds. Below the aquitard, which is 32 to 35 feet thick, the lower aquifer was penetrated about 120 feet and consists of somewhat finer-grained sediments than those in the upper aquifer. About five feet of clayey material, lithologically comparable to the aquitard between 530 and 565 feet, was penetrated at the base of the lower aquifer. The beds below this level may form a third aquifer. They were not tested for hydraulic properties. However, it appears to be a geohydrologic unit comparable to the other two aquifers. Between a depth of 813 feet and the bottom of Test Hole H-4 better stratified and consolidated, finer-grained sediments with many beds cemented with calcareous and siliceous materials were encountered. These strata are questionably assigned a Tertiary age.

Thus, at the Test Hole site water occurs in at least three aquifers separated by two relatively distinct aquitards. Under natural conditions, these units act as a single hydraulic system. The horizontal extent of this aquifer system is unknown and may be limited because of lateral and vertical changes in lithology.

Shallow aquifers were also encountered in Well Nos. 16, 17, 18, 19, and 24. These wells range in depth from about 280 to 350 feet. The log of Well No. 18 is given below. This well log is representative of sediments in the vicinity of Frenchman.

From Feet	To Feet	Thickness Feet	Type of Material
0	30	30	Silt and sand
30	42	12	Clay
42	55	13	Sand and gravel
55	144	89	Sand and gravel
144	148	4	Coarse gravel
148	170	22	White clay
170	223	53	Sandstone
223	283	60	Sand and silt with thin gravel layers—water encountered at 227 feet.
283	288	5	White clay

On the west side of the Sand Springs Range, water was encountered in Test Hole H-3 in granite at a depth of 361 feet and the thickness of water-bearing granite penetrated was 119 feet. Down slope 6,000 feet from Hole H-3, in Hole H-2, water was encountered in a fine- to medium-grained, clean sand aquifer at a depth of 128 feet below land surface. This aquifer, 652 feet thick in Hole H-2, becomes coarser grained toward the bottom. Ground water occurs in predominantly finer-grained sediments than on the eastern side of the Range. These are lake sediments and occur up to approximately 4,380 feet above sea level, where often coarser alluvium underlies them. The alluvial and lacustrine sediments slope toward Fourmile Flat, except from the northwest. Thus, the Fourmile Flat playa is the major discharge area for both ground and surface water. From hydraulic gradients determined between Hole H-3, Hole H-2, and the playa, it appears that water occurring in the bedrock and in the alluvium is in direct hydraulic communication, established over a long period of time during which recharge and discharge rates were in approximate equilibrium.

Geohydrology

HYDRAULIC PROPERTIES

The hydraulic properties of the aquifers are determined primarily by pumping test analyses. The properties of greatest concern are the transmissivity and storage capacity of the aquifer. Values for these entities are most commonly expressed by the coefficient of transmissibility and the coefficient of storage that appear in the Theis non-equilibrium formula and recovery corollary (1935), and in Jacob's modified non-equilibrium formula (1950).

The Theis equation is:

$$s = \frac{114.6q}{T} \int_{\frac{1.87 r^2 S}{Tt}}^{\infty} \frac{e^{-u}\,du}{u}$$

Where s = drawdown in feet at any point of observation in the vicinity of a well discharging at a constant rate.

q = discharge in gallons a minute

T = coefficient of transmissibility in gallons a day per foot.

S = coefficient of storage

r = distance in feet from the pumped well to the observation well

t = time in days since pumping started

e = natural logarithm base

u = a dimensional variable between the given limits of integration

"The exponential integral is usually expressed as the well function of u or "W (u)".

The recovery method of determining the coefficient of transmissibility involves the use of the formula:

$$T = \frac{264q}{s'} \log_{10} \frac{t}{t'}$$

Where q and T are defined above

s' = residual drawdown in feet at any instant

t = time in minutes since pumping started

t' = time in minutes since pumping stopped

The value $\frac{t}{t'}$ over one log cycle of time reduces the logarithm to unity and $\Delta s'$ (the change in residual drawndown for one log cycle of time) may then be determined graphically over one log cycle. Thus, over one log cycle

$$T = \frac{264q}{\Delta s'}$$

A convenient way to express the transmissivity of the aquifer is by determination of the apparent permeability, P_a. The apparent permeability may be determined when the coefficient of transmissibility and the thickness of the beds, m, is known. Thus,

$$P_a = \frac{T}{m}$$

The values for apparent permeability as determined from the pumping tests are given in Table 4.

These formulas are readily adaptable to pumping test procedures that involve field measurement of values of discharge and drawdown for a known time. Several such pumping tests were run in Fairview Valley and Fourmile Flat and are described below in detail.

PUMPING TESTS IN FAIRVIEW VALLEY

On March 10, 1962, Test Hole HS-1 was pumped for 20 hours withdrawing water from the interval between 310 feet to 530 feet, and Test Hole H-4 was used for recording observations. Recovery observations were taken for 27 hours after pumping ceased. All measurements in the observation hole were taken with a Leupold-Stevens automatic water level recorder calibrated by steel tape measurements at frequent intervals. Measurements in the pumping well were made by an air line with an attached water-pressure gage.

The total drawdown in HS-1 at a pumping rate of 66 gpm was 37 feet, thus the specific capacity is about 1.8 gallons a minute per foot of drawdown. The pumping test data curve is shown in Figure 31. A summary of the results is given in Table 4.

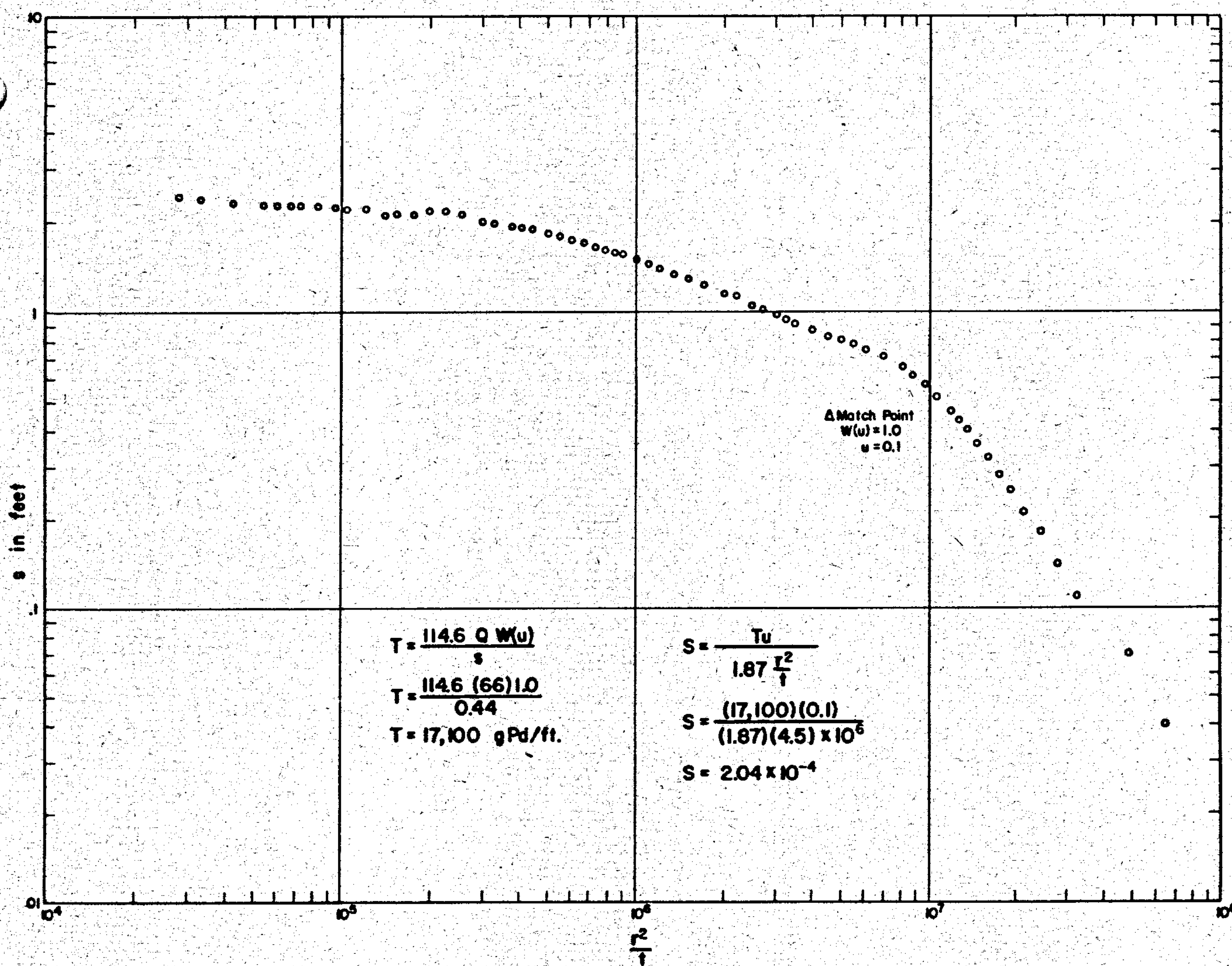


Figure 31. Pumping test data curve for the upper aquifer in Fairview Valley

On May 5, the lower aquifer system (570 feet to 685 feet) at this site was tested using Test Hole H-4 as a pumping well and recording observations in Test Hole HS-1. This operation called for a reduction in casing size and utilization of the natural seal provided by the clayey layer at about 530 feet. That this seal was effective was demonstrated by pumping the lower aquifer system at Test Hole H-4 for seven hours with no measurable drawdown in the upper aquifer system at Test Hole HS-1. Measurements were taken in the annular space between the casings. These preliminary tests were made while Test Hole HS-1 was being deepened to 699 feet. However, when the 8 ⅝-inch casing was emplaced at 685 feet, the seal between the casing and the clayey layer was broken. As a result, leakage occurred during the pumping test in Test Hole HS-1.

A semi-logarithmic plot of drawdown in Test Hole HS-1 against time indicated that movement of water to the lower aquifer from the upper aquifer occurred 10 minutes after pumping started. By extending the 10-minute section of the time-drawdown curve back to the line of zero drawdown, it was possible to obtain a time value at the intercept. An approximation of the coefficient of storage was then obtained by application of Jacob's formula: $S = 0.3\ Tt_o/r^2$, where T is equal to the coefficient of transmissibility of the lower aquifer system as determined from Test Hole H-4 recovery data (Figure 32), t_o is the time value at the intercept for the 10 minute portion of the time-drawdown curve (2.4), and r is the distance between HS-1 and H-4 (150 feet). A summary of the results is given in Table 4.

TABLE 4. SUMMARY OF TRANSMISSIBILITY, APPARENT PERMEABILITY, AND STORAGE COEFFICIENTS DETERMINED BY PUMPING TESTS

WELL AND AQUIFER*	SPECIFIC CAPACITY	PUMPING TEST METHOD	COEFFICIENT OF TRANSMISSIBILITY (T)	COEFFICIENT OF STORAGE (S)	EFFECTIVE THICKNESS	APPARENT PERMEABILITY
H-4, HS-1 Upper Aquifer	1.8	Drawdown	17,100 gpd/ft.	2.04×10^{-4}	219 ft.	78 gpd/ft^2
H-4, HS-1 Lower Aquifer	2.4	Recovery	11,000 gpd/ft.	2.45×10^{-4}	120 ft.	91 gpd/ft^2
Frenchman's Station Eight and Six Inch Diameter Wells	1.1	Drawdown	5,275 gpd/ft.	3.53×10^{-4}	88.5 ft.	60 gpd/ft^2
H-3 Bedrock (Granite) Aquifer	---	---------	$>$ 200 gpd/ft.	------------	-----	-----------
H-2, Fourmile Flat	20.0	Recovery	76,000 gpd/ft.	------------	640 ft.	118 gpd/ft^2

*Pumped well is underscored

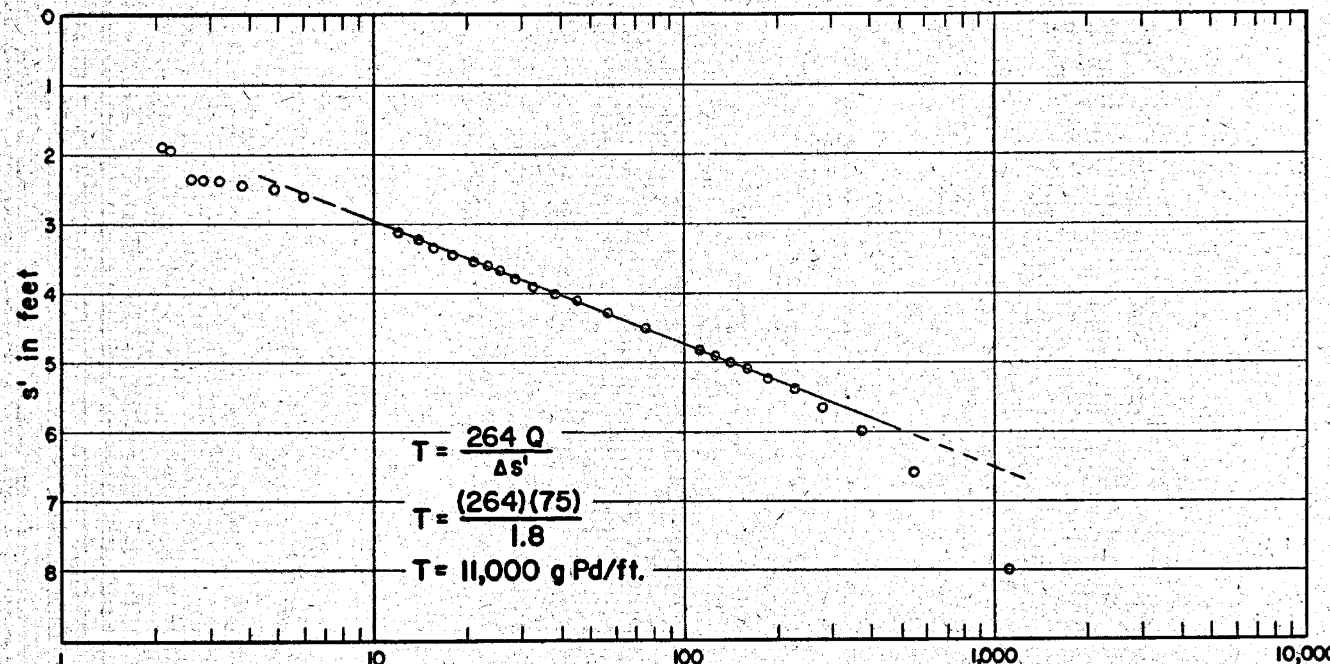


Figure 32. Pumping test data curve for the lower aquifer in Fairview Valley

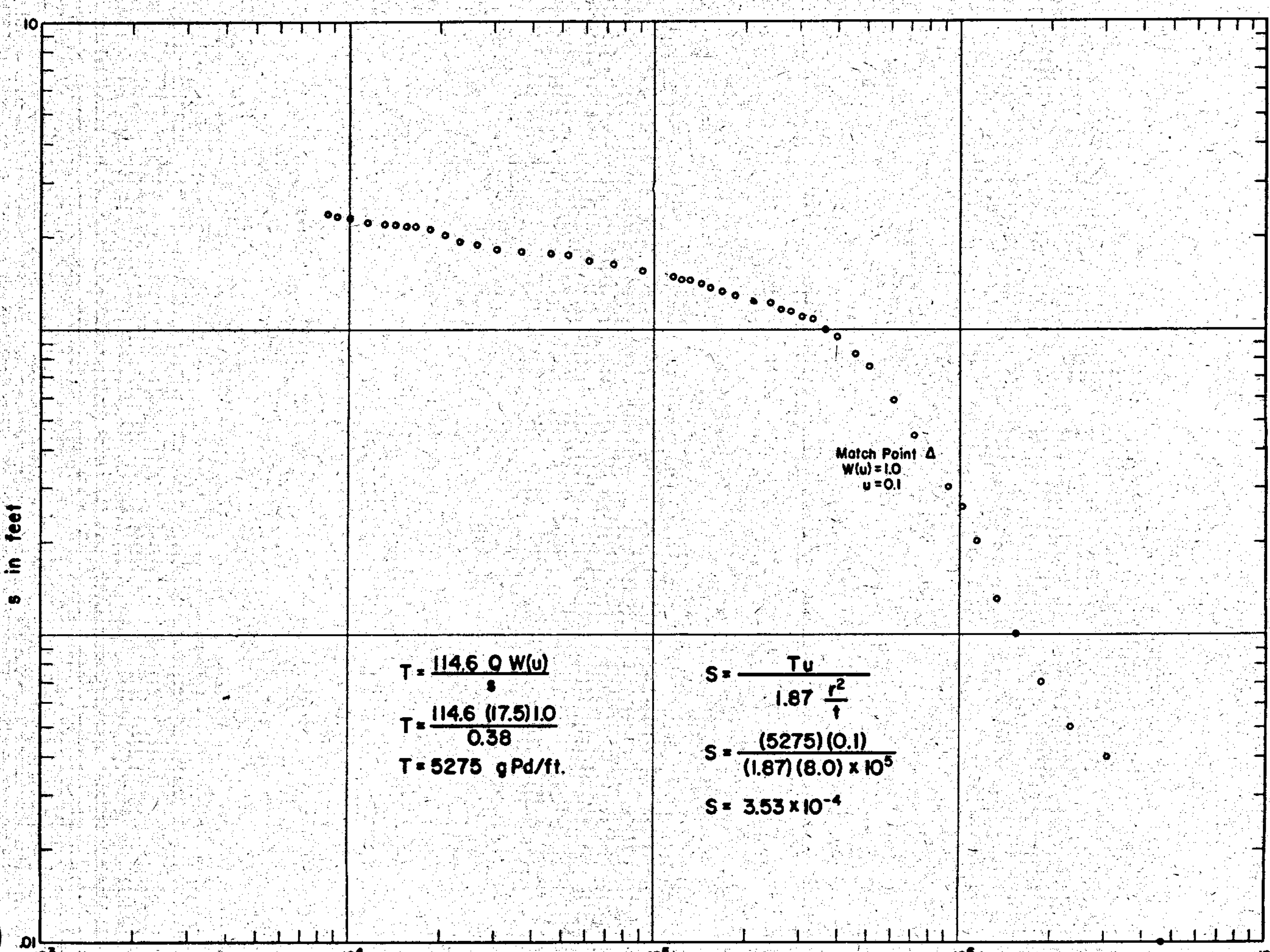


Figure 33. Pumping test data curve for Well 17 in Fairview Valley

On March 15, an 18-hour pumping test was conducted at the domestic wells at Frenchman in Fairview Valley. The wells are owned by Mr. Edward Weyher. Mr. Weyher's eight-inch diameter well (288 feet deep) was pumped and drawdown was measured in a six-inch diameter well 80 feet away. The total drawdown in the eight-inch diameter well at a pumping rate of 17.5 gpm was 20 feet, thus the specific capacity is 1.1 gallons a minute per foot of drawdown. The pumping test data curve is shown in Figure 33. A summary of the results is given in Table 4.

PUMPING TESTS IN FOURMILE FLAT

On April 25, a pumping test was conducted on the granitic aquifer penetrated by Test Hole H-3. The primary interest in this test was to determine the approximate characteristics of the aquifer and, therefore, to establish a basis for determining the necessity of an additional test hole in the vicinity. The aquifer penetrated failed to respond satisfactorily to pumping test analysis. In less than one hour (55 minutes), at a low pumping rate of 33 gpm, 125 feet of drawdown was observed. The pump broke suction at this level. Further, eight feet of residual drawdown remained four hours after pumping stopped. Although water-bearing, the bedrock at this location has a very low coefficient of transmissibility, probably less than 200 gallons a day per foot.

On May 28, Test Hole H-2 was pump-tested. During the first few hours of the test, the well pumped a large amount of fine sand. The well improved during the test, but the data collected were practically useless. A second test was attempted on June 1, the data obtained being considerably better but still not satisfactory. This was primarily due to the difficulty involved in accurately measuring the small increment of recovery and drawdown in the pumped well. Inasmuch as the data do

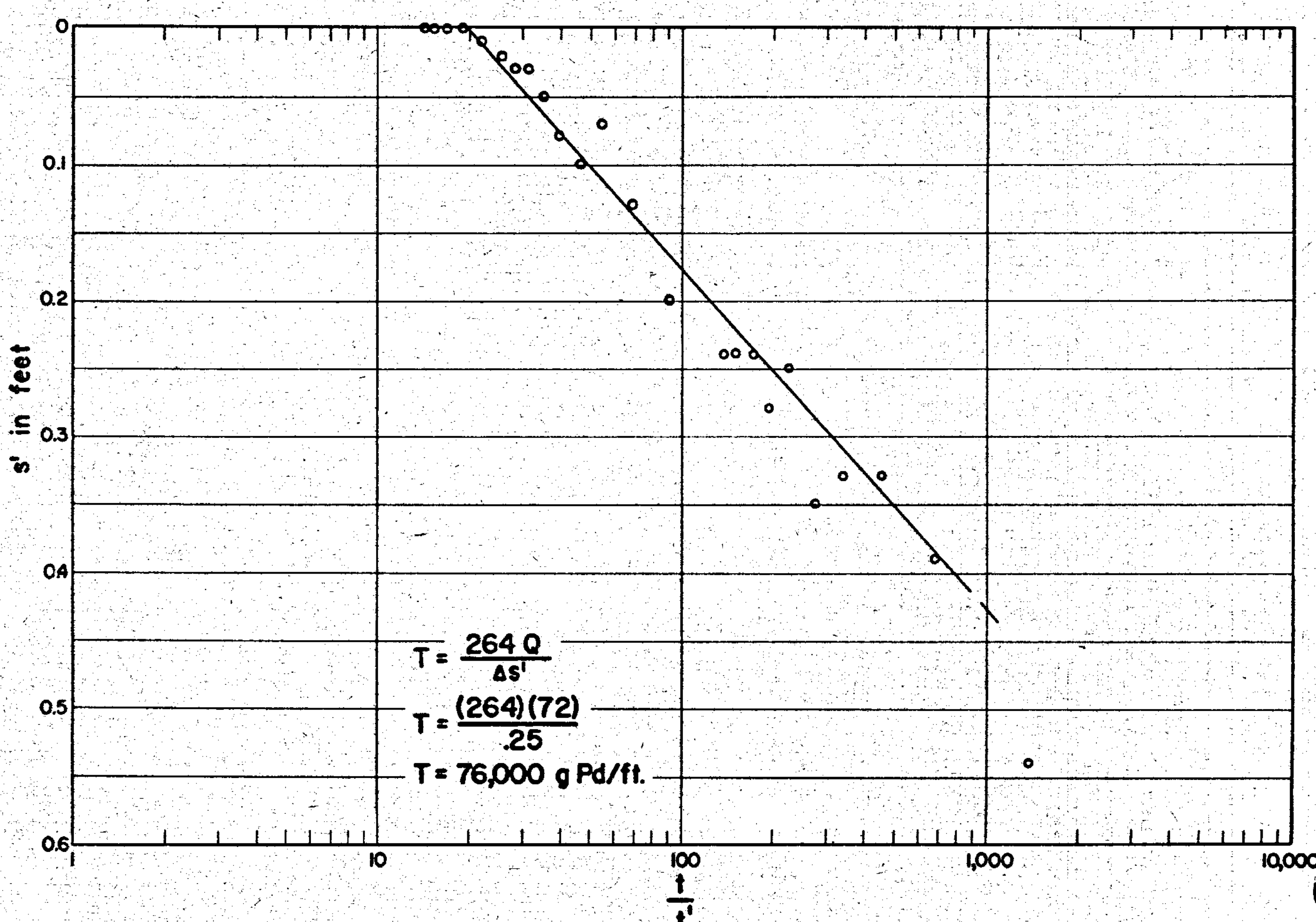


Figure 34. Pumping test data curve for Test Hole H-2 in Fourmile Flat

not indicate a straight-line relationship between s and log t (see Figure 34), the coefficient of transmissibility reported is considered an approximation.

HYDROLOGIC TESTS AT PROPOSED GROUND-ZERO

Hydrologic tests were conducted between July 13 and 21, and August 1 to 4, 1962, on Core Hole ECH-D (elevation 5,233 feet) at the Shoal Test Site. Included in the discussion of these tests are detailed geologic and operational data which are necessary to discuss properly the hydrologic situation near Ground-Zero. In regard to both technical and safety aspects of the Shoal Project, the following three questions pertaining to the occurrence of water in the granite appear to be of most significance:

1) What is the elevation of the natural zone of saturation and the condition of saturation at Ground-Zero?

The water level, as determined during and after several tests ending on July 21, 1961 (see Figure 35), consistently returned to an elevation of approximately 4,265 feet (approximately 968 feet from ground surface). Further tests conducted with a packer indicated that water was entering the hole at horizons above 4,061 feet (1,172 feet) in small quantities, and that it entered the hole in larger quantities, below an elevation of 4,014 feet (1,219 feet). It is estimated that perhaps 80 to 90 percent of the water entering the hole came in between 4,014 feet (1,219 feet) and the bottom of the hole at an elevation of 3,878 feet (1,355 feet), and that over half of the water entered below elevation 3,951 feet (1,282 feet). In other words, all fractures below elevation 4,265 feet (968 feet from ground surface) are saturated and yield water to some extent, but the fractures near the bottom of the hole as of July 21 (elevation 3,878) transmit more water.

Plate 6 shows the position of joints, fracture cleavages, and faults. The average direction of jointing is N. 60° W., the same bearing as exists between the core holes; these joints are predominantly vertical. The fracture cleavage has an average trend of N. 30° E., and is either vertical or dips eastward at 70° to 90°.

Between the collars of the core holes, a linear distance of 1,376 feet, two major fault zones are mapped at the surface and these same fault zones are encountered at depth, as were many weaker faults.

The continuity of any given fracture or fracture system and hydraulic connection with other fractures is unknown and may be extensive or extremely limited.

During the period July 21 to August 1, Core Hole ECH-D was deepened an additional 220 feet to elevation 3,658, or 1,575 feet below ground surface. At elevation 3,794 (1,439 feet below ground surface), a fault was encountered dipping approximately 70° S., and probably striking east. The width of the fault zone is uncertain because the drill bit probably was deflected somewhat into the softer material in the faulted zone, but may be at least 75 feet.

On August 1, another recovery test was conducted, the results of which are shown in Figure 35. Although the recovery rate appears similar to the earlier tests, approximately 118 feet of head was lost, and the water level returned to elevation 4,147, or 1,086 feet below ground surface. An explanation for this is not readily forthcoming but may develop as study of the problem progresses. Meanwhile, the interpretation that only water introduced during drilling operations is involved is not necessarily supported by this loss of head.

2) To what extent had this level been affected by injection of drilling water during operations at ECH-A and ECH-D?

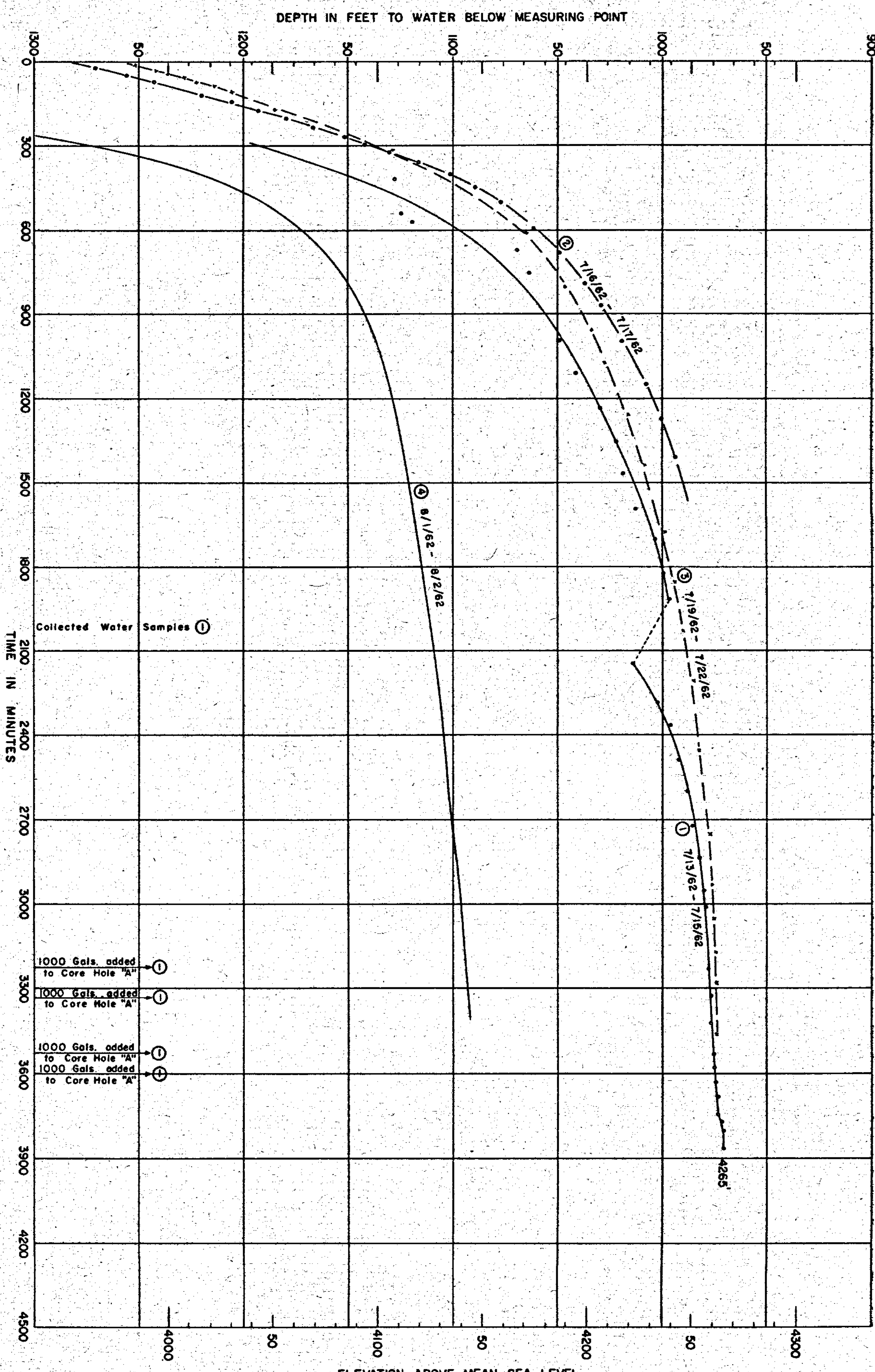


Figure 35. Recovery curves for Core Hole ECH-D

A total of 386,000 gallons of water were used in drilling ECH-A, of which an undetermined but relatively small fraction was recirculated to the surface. Circulation was lost almost consistently from the surface to approximately an elevation of 4,580 feet. The largest loss of circulation was at approximately an elevation of 4,950 feet, the position of a major shattered zone within the granite. Water that was not lost through this zone on the downward move may have been lost here with return circulation. Complete loss of circulation generally occurred as drilling proceeded through the major fault zones at about the 4,950 foot and 4,650 foot elevations.

Core Hole ECH-A was cased from the surface to an elevation of approximately 4,580 feet. The casing was later removed and a new casing inserted after the hole was drilled to an elevation of 4,140 feet. Below an approximate level of 4,580 feet circulation was never entirely lost, except for very small intervals, and even then the major loss may have been at the upper fault zones.

It is probable, then, that all voids within the fault zones are water-filled, and a combination of inclination of fault planes plus decrease in volume of void spaces below the fault zones, may serve as a more or less effective barrier to flow of water toward Core Hole ECH-D.

Because Core Holes ECH-A and ECH-D approach to within approximately 150 feet of each other, and considering the highly fractured granite, it is possible that some communication exists between the two drill holes. This is not to imply that a single, continuous system of fractures exists between the holes. During hydrologic testing of Core Hole ECH-D, 4,000 gallons of water were introduced into Core Hole ECH-A in an effort to determine any communications between the holes. Nothing conclusive can be determined from the test.

During the drilling of Core Hole ECH-D 191,000 gallons of water were used, of which an undetermined amount was recirculated to the surface. It is highly probable that the use of air under high pressure during drilling operations forced some water into fractures in the granite walls of the hole. However, the heat and other characteristics of the drilling method assure that a large proportion of the introduced water returns to the surface.

Chemical analyses of water taken from three levels within Core Hole ECH-D (4,120 to 3,892 foot elevations) during hydrologic testing, plus a sample from the total section of water within Core Hole ECH-D as of July 14, were compared to analyses of the water injected into the hole. This comparison offers no evidence that water in ECH-D is largely introduced or indigenous. The closest similarities exist between ECH-D water and water from the deep aquifer of H-4. In general, the ECH-D samples show the following differences from Fairview Valley water: Slight increase in pH; increase in total dissolved solids, calcium, magnesium, sodium, sulfate, chloride, carbonate, bicarbonate, and alkalinity; and decrease in potassium, iron, and silicon. These differences may be only a reflection of the soap solution used in ECH-D while drilling.

On the basis of the data presented in answer to 1) above and the relatively small quantity of introduced water believed to be remaining in Core Hole ECH-D during the tests, it is concluded that naturally-occurring water must be present, and that the introduced water recharged the saturated zone to an unknown extent.

3) What problems might result from the occurrence of natural water in the granite?

It must be emphasized that quantitatively accurate data are not yet available on occurrence, movement, and storage of water in the granite. This primarily results from test-drilling methods used to date, from lithologic conditions, and from depths at which observations were made. It is likely that drainage of water from the granite in the vicinity of Ground-Zero will be very slow, and completeness of drainage is unpredictable because the degree of fracturing and interconnection of fractures and faults is not predictable. Furthermore, because of geologic conditions such as lithologic and structural boundaries, it is not possible to accurately predict conditions of occurrence of ground water at even moderate distances (say 1,500 to 2,000 feet) from the core holes or from any other future test hole. Some additional data bearing on these problems will be forthcoming from logging operations and, possibly, from further hydrologic tests on Core Hole ECH-D, but it is unlikely that they will adequately answer the questions herein discussed.

MOVEMENT

The ultimate source of all the water in this area is from local precipitation and from influent seepage and surface flow from the Fallon area. In the Fourmile and Eightmile Flats most of the water is probably derived from the latter source, with only small contributions from precipitation on the low-lying surrounding mountains. In Fairview Valley south of U. S. Highway 50, essentially all of the ground water has originated as precipitation in the surrounding mountains and alluvial slopes. North of U. S. Highway 50 considerable, perhaps the major, contribution to ground-water recharge is made by Dixie Wash which drains a large area to the east. Some recharge is also supplied from the surrounding highlands. In both valleys, recharge from the Sand Springs Range is minimal, but some ground water does move toward the valleys through the alluvial and lacustrine sediments to points of discharge.

Fourmile Flat is a closed basin with a high water table. Essentially all discharge from the basin is accomplished by evapotranspiration. Fairview Valley ground water moves northward and discharges by underflow into Dixie Valley. Very small quantities of water are pumped for domestic and stock use and are eventually discharged by evapotranspiration.

In Fairview Valley the hydraulic gradient from Test Hole HS-1 northerly to Frenchman is about three feet per mile, and the gradient steepens considerably to 33 feet per mile from Well 24 to Well 25. The steepening over this reach is most likely a result of convergence of the valley walls (see Plate 9B) and consequent reduction in cross-sectional area. The steep gradient, therefore, can be readily explained by Darcy's law. Vertical movement probably does not occur, especially since pumpage is slight and has produced no "low pressure" zones of any great extent.

Fourmile Flat functions as a point sink and, therefore, a point of convergence and natural discharge for ground water in the valley. It is quite likely that Eightmile Flat is an extension of the sink, although there appears to be a component of movement toward Fourmile Flat. For all practical purposes, that part of the basin extending from the alluvial fans on the west side of the Sand Springs Range to a point somewhere in the vicinity of the Fallon Naval Auxiliary Air Station can be considered closed, with radial flow toward the Fourmile Flat playa.

Little ground-water movement occurs toward Fourmile Flat through the alluvial and lacustrine material flanking the Sand Springs Range. Assuming this flow direction, the hydraulic gradient determined from static levels in Test Holes H-3 and H-2 is almost flat, 0.56 foot per mile. This calculation may be inaccurate, however, due to grease and oil left in Test Hole H-3 as a consequence of a pumping test and which caused difficulties in obtaining an exact static level. Perhaps the most accurate gradient determination can be obtained by utilizing the static level in Well 1 and Test Hole H-2. The hydraulic gradient measured from these points is 1.46 feet per mile. That the water is circulating slowly with very little freshening from meteoric-derived water is best illustrated by its chemical nature. This substantiates the concept of little or no recharge to the aquifer in this area.

The static level of Well 5 at Salt Wells is higher than the water level in Fourmile Flat and indicates that ground water is moving eastward toward the latter. However, movement of ground water in that general vicinity and farther west near the Fallon Naval Auxiliary Air Station is extremely complex, and direction of ground-water flow is influenced mainly by the low-level Carson Lake to the south, the Carson Sink to the north, and Fourmile Flat. These sinks are all approximately at the same elevation and receive water that is subsequently discharged by evapotranspiration. The surface and ground water encountered in the area east of Fallon and west of the Sand Springs Range may be regarded as one flow system with three or more sinks that control the boundaries of individual flow fields.

The rate of movement in Fairview Valley and Fourmile Flat varies from place to place, but is everywhere slow. This can be illustrated by computing the apparent rate of movement in those areas where the hydraulic properties are known with reasonable accuracy. Velocity of ground-water movement can be estimated by the following formula:

$$v = \frac{PI}{p}$$

where v equals the velocity of the ground water in feet per day, P equals the permeability in cubic feet a day per square foot, I equals the hydraulic gradient in decimal form, and p equals the porosity in decimal form.

The hydraulic gradient in the alluvial materials in Fairview Valley between Test Hole HS-1 and Frenchman is three feet per mile, or 0.00568. The permeability is 78 gallons a day per square foot, or 10.4 cubic feet a day per square foot. The porosity of the alluvium is not known, but probably ranges from 10 to 20 percent. From the above equation:

$$v = \frac{10.4 \times 0.000568}{0.10} = 0.059 \text{ foot per day or } 0.71 \text{ inch per day}$$

If the porosity is estimated to be 20 per cent, the approximate velocity of ground-water movement is 0.03 foot a day or 0.36 inch a day. If the permeability is estimated to be as the upper limit determined (95 gallons a day per square foot) and the porosity to be 10 per cent, ground-water velocity is increased only slightly to 0.072 foot per day. It is concluded, therefore, that the low gradient is the significant control on the velocity of ground-water movement, and it is doubtful that average velocities exceed 25 feet a year. This would require over 1,000 years for water now in the vicinity of the test-hole site to move into the Frenchman area. The above figures are approximations and indicate only a general order of magnitude.

The hydraulic gradient in Fourmile Flat is at a maximum 1.46 feet per mile, or 0.000277. The permeability is estimated to be 118 gallons a day per square foot. The porosity is estimated to be between 10 and 25 per cent. Then,

$$v = \frac{15.8 \times 0.000277}{0.10} = 0.044 \text{ foot per day or } 0.53 \text{ inch per day}$$

If the porosity is estimated to be 25 per cent, the velocity decreases to 0.0175 foot per day, or 0.21 inch per day. As an approximation, the ground water then travels about 16 feet per year.

Little is known about vertical movement of water in the unsaturated zone, and essentially no data bearing on this matter have been collected in this investigation. Upward movement by capillary rise probably could not exceed approximately 40 feet, because essentially no fine-grained sediments (particles less than 10 microns in diameter) are known to exist in the valley fill. Downward movement resulting from gravity must occur because the aquifers are recharged from precipitation and surface flow.

In the saturated zone at the Test Hole site (HS-1 and H-4) in Fairview Valley, head differences in the various aquifers were not observed, although care was taken to detect such differences during drilling. Therefore, it is assumed that little or no vertical movement occurs between aquifers there.

In the Fourmile and Eightmile Flats flowing wells are known at widely separated points (see Well Nos. 2, 7, and 11, Plate 9). Water also stands at or near the surface in this area. Since the static level of water in these flowing wells must rise above the land surface and the water at lower head must be at or below the land surface, a hydraulic gradient occurs from the lower to the upper body of water. Since water moves from the points of high potential to lower potential, upward movement of water takes place.

The nature, direction, and rate of movement of ground water in the valley fill bears directly on the problem of probability of contamination from the Shoal experiment. As is demonstrated above, the lateral movement of ground water is very slow. In valley fill sediments in comparable areas the rate of vertical movement of water is usually a fraction of that of horizontal movement because of bedding and other sedimentary features of the rocks. Therefore, even in the unlikely event of contamination reaching the alluvial fill, the probability of contamination of present sources of ground water is very low.

Chemistry and Temperature of the Water

The chemical constituents of the water collected from all known water points in the study area are shown in the analyses in Appendix G. Illustration of some of the constituents from these analyses are shown in Plates 9-B and C. Concentrations of six ions, in equivalents per million, are shown by a method modified from that of Stiff (1951) and Sinclair (1962). The chief modification is that of scale. Where a linear scale was previously used, an expanding scale to make diagramatically possible the illustration of a large range of concentrations is adopted.

On the maps the pattern of diagrams clearly illustrates compositional differences that reflect environmental, recharge, and time factors. In Fairview Valley the ground water contains little dissolved solids and is potable. The concentration of total dissolved solids increases down-gradient, as between Test Hole HS-1 and the wells at Frenchman (Well Nos. 17 and 18). This normally occurs in an area of active circulation of ground water. The greater amount of sodium in the Frenchman wells may be related to movement of water over granitic terrain or through lake sediments, or both. Apparently the sodium increases in combination with bicarbonate, sulfate, and chloride.

Analyses of the water from Core Hole ECH-D are somewhat similar to that of a spring in the Sand Springs Range (No. 30 in Section 36, T. 15 N., R. 32 E.).

In Fourmile and Eightmile Flats, analyses of water known to have passed through lake and playa sediments exhibit gross chemical differences from analyses of water from wells in Fairview Valley and wells predominantly in alluvial apron sediments in Fourmile Flat valley. The constituents in the water from the lake sediments are predominantly sodium and chloride. Sulfate and bicarbonate occur as major constituents, whereas calcium and magnesium usually occur in concentrations of a few equivalents per million. This water is, of course, unpotable and odoriferous.

The high concentrations of sodium, chloride, sulfate, and bicarbonate verify the conclusion that the water is stagnant or almost stagnant as shown by the hydraulic gradients in this area. Further, this water undoubtedly has been in contact with or passed through the salt and alkali beds, peat bogs, and other sediments characteristic of lacustrine lagoonal deposits.

In water from the wells in the fan deposits (Well Nos. 1 and 4) the lower concentration of sodium and chloride relative to concentrations of calcium and magnesium indicate that recharge reaches these areas. Water from the recharge area probably has flushed salts out of these sediments and, of course, the fresh recharge water dilutes the preexisting water in the aquifer.

The water from Test Hole H-3 high on the alluvial slope comes from granite. Its quality is more characteristic of the saline waters of the Flat than of the waters from Well Nos. 1 and 4, although it contains considerable calcium and magnesium. Possibly this denotes some recharge by fresh calcic waters and consequent dilution of the saline water.

Calcium and magnesium occur in diminishing concentrations down the fans and into the Flat where they are relatively inconspicuous. Perhaps this denotes base exchange whereby the calcium and magnesium ions become fixed in the clay mineral elements of the sediments.

Temperature logs were run by McCullough Tool Company on April 14, 1962 in Holes H-4 and H-3. In Hole H-4 the logged interval was from an 875 foot depth to the surface with a static water level occurring at 300 feet. The temperature gradient decreased from 69° F. at 875 feet to a low of 51.5° at 340 feet. The gradient then increased to 54° at 300 feet, and then to the air temperature of 94° at the surface.

In Hole H-3 the logged interval was from 480 feet to the surface with a static water level at 329 feet. The temperature gradient decreased from 58° F. at 480 feet to a low of 55° F. at approximately 400 feet, then increased to 58° at 329 feet, and then to 86° at the surface.

TABLE 5.

Temperature (°F) of Water From Wells

Well No.	Temperature	Date Sampled	Well No.	Temperature	Date Sampled
1	60	3/23/62	16	64	5/16/62
3	66	3/24/62	18	60	5/22/62
6	60	4/10/62	19	59	5/22/62
7	70	4/13/62	20	61	5/25/62
9	64	4/16/62	21	60	5/26/62
10	60	4/16/62	HS-1	65	2/18/62
11	63	4/17/62	*H-4	50	4/23/62
12	64	4/17/62	32	55	6/ 6/62
14	68	4/10/62			

*Depth 320 feet.

Probability and Extent of Contamination

Preliminary study of distribution coefficients of material determined in other areas (Higgins, 1959) such as the Nevada Test Site and Hanford, indicates that the granite in the Sand Springs Range and the alluvial fill in adjoining valleys would rapidly fix the radionuclides resulting from the proposed test shot. It is presently deemed safe to say that under ordinary conditions of underground movement of water at the estimated gradients in the Range, the radionuclides will not travel beyond the range front.

If these estimates and this conclusion are in error and radionuclides should be carried by ground water into the alluvial fill, they will be fixed within a short distance of the range front. This conclusion is substantiated by the following:

1) The gradients in the valley fill are very low, and the more or less uniform permeability of any section of the alluvial fill precludes anomalously rapid movement. Velocities calculated from the known gradients and permeabilities are low, on the order of three feet per mile in Fairview Valley and 1.46 feet per mile in Fourmile Flat.

2) The distribution coefficient of the alluvium is certainly higher than that of the granite, for the alluvium is the weathered product of the granite, and is composed of discrete particles with much more exposed surface area.

The conclusions given above are based on the assumption that the shot will be wholly contained.

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APPENDIX A

Log of Diamond Drill Hole ECH-A

Location: N. 1,619,292.72–E. 558,740.32
(U. S. Coast & Geodetic Survey Coordinates)
Sand Springs Range
Churchill County, Nevada

Bearing: N. 60° W.

Inclination: –45°

Collar elevation: 5,158.90 ft.

Date begun: February 28, 1962

Date completed: June 21, 1962

Drilling contractor: Sprague and Henwood

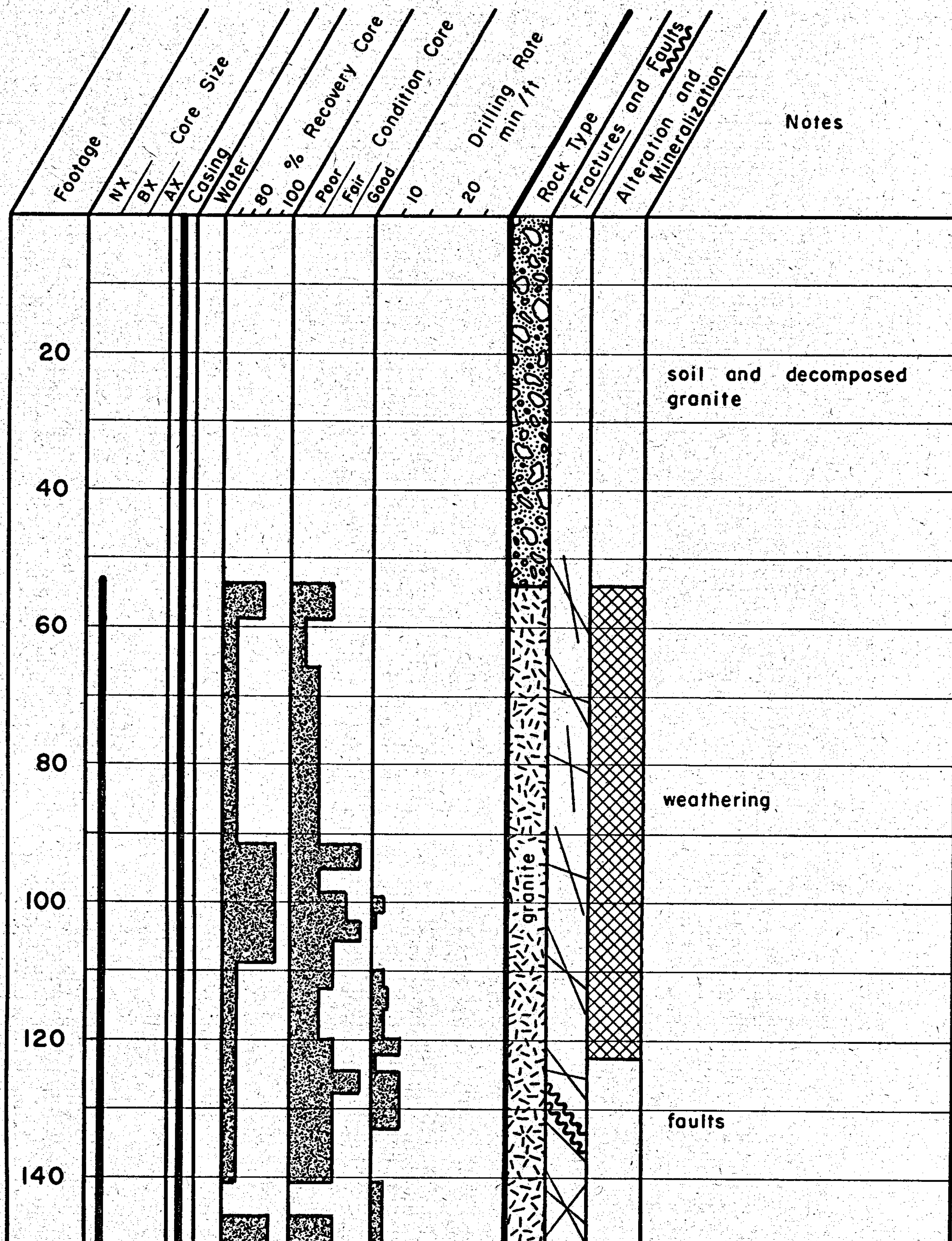
Logged by: NBM personnel: L. Beal, R. Horton, S. Jerome, I. Lutsey, H. Mossman, J. Schilling, and R. Wilson

Explanation: The orientation of fractures and faults shown in the log are given only in relation to the axis of the hole (which is parallel to the columns in the log), and not in relation to each other; their strikes and dips cannot be determined.

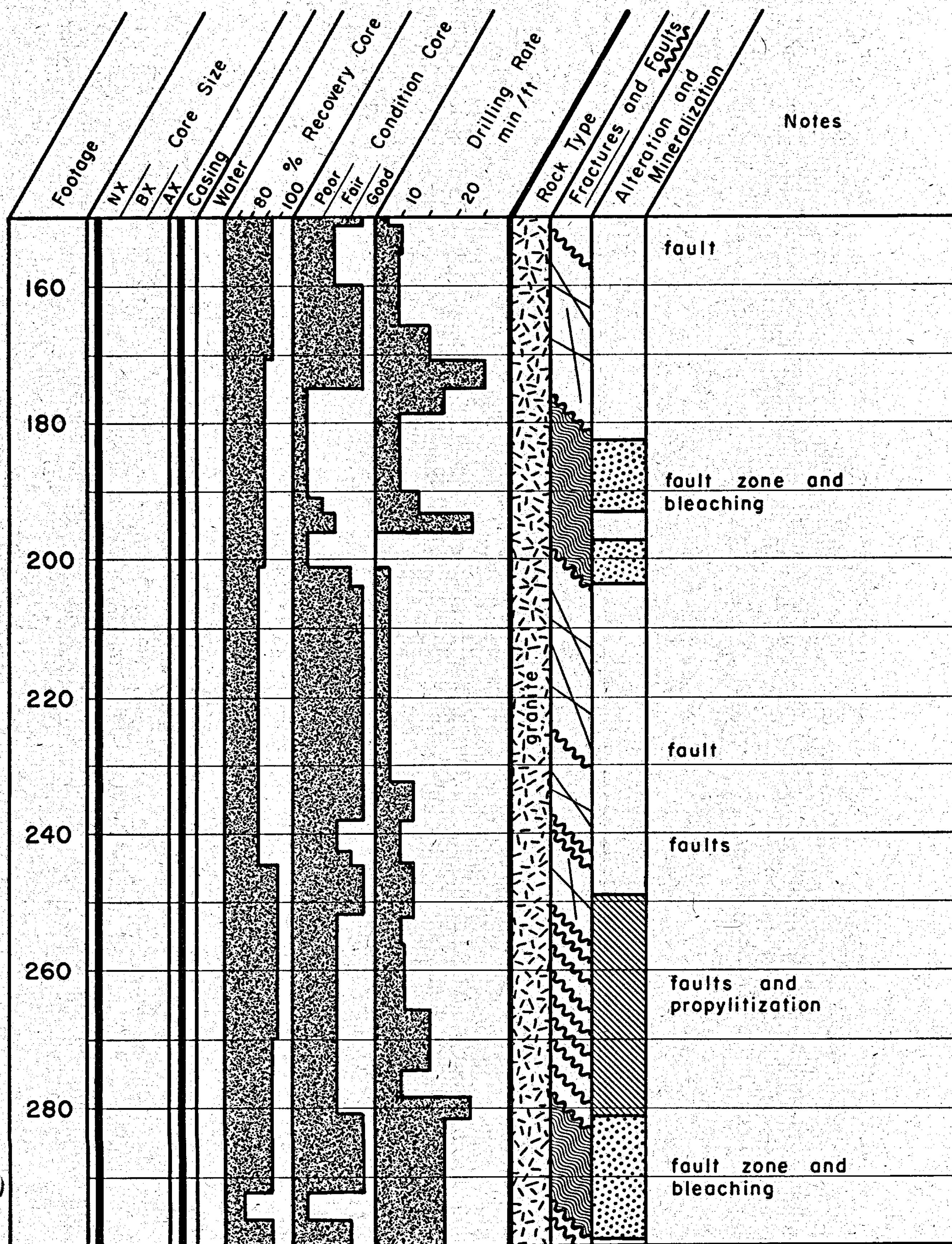
Core in cylindrical pieces is considered as in "good" condition, core in large angular pieces as in "fair" condition, and more finely broken-up (crumbled) core as "poor."

DIAMOND DRILL HOLE ECH-A

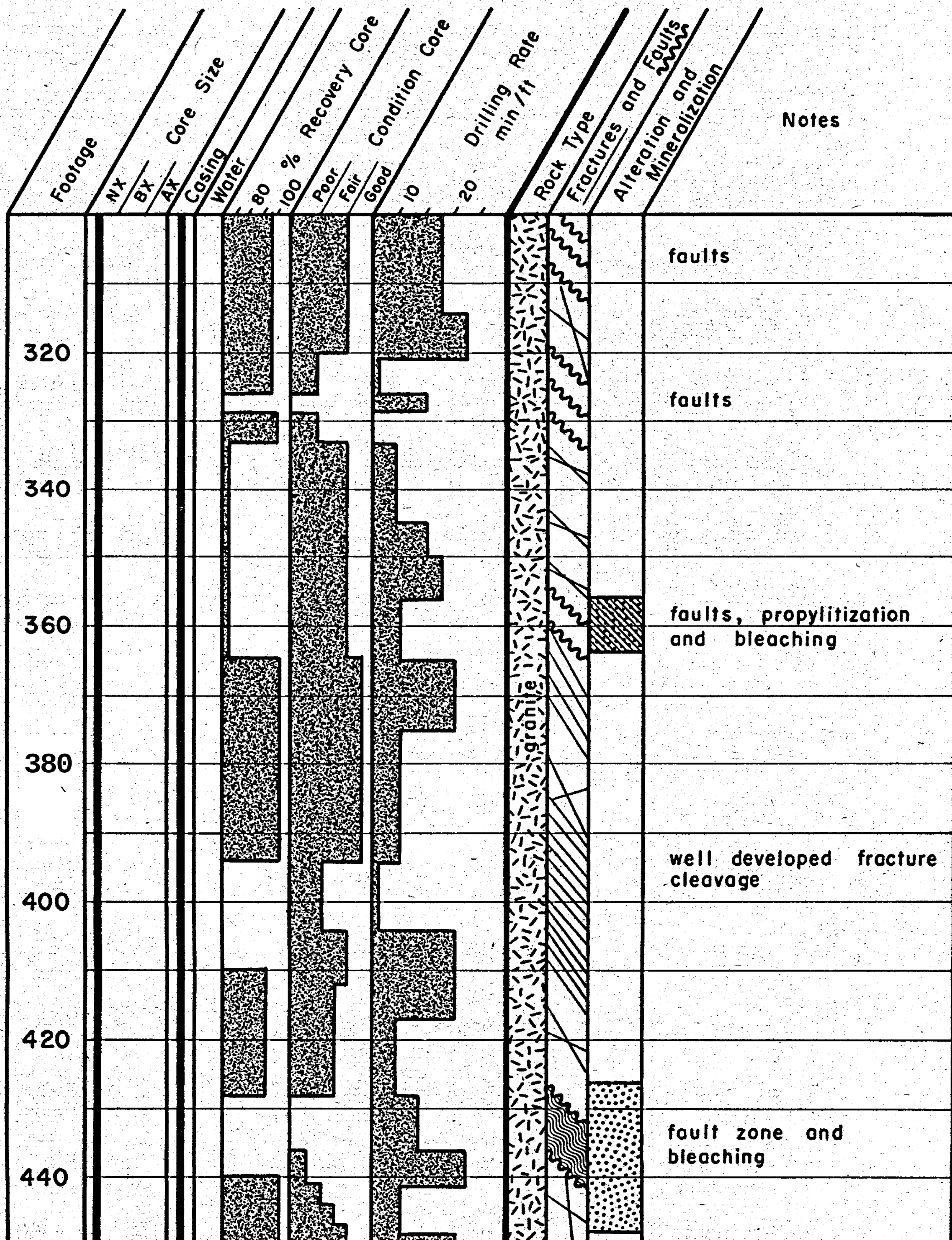
0-150 ft.



DIAMOND DRILL HOLE ECH-A 150-300 ft.

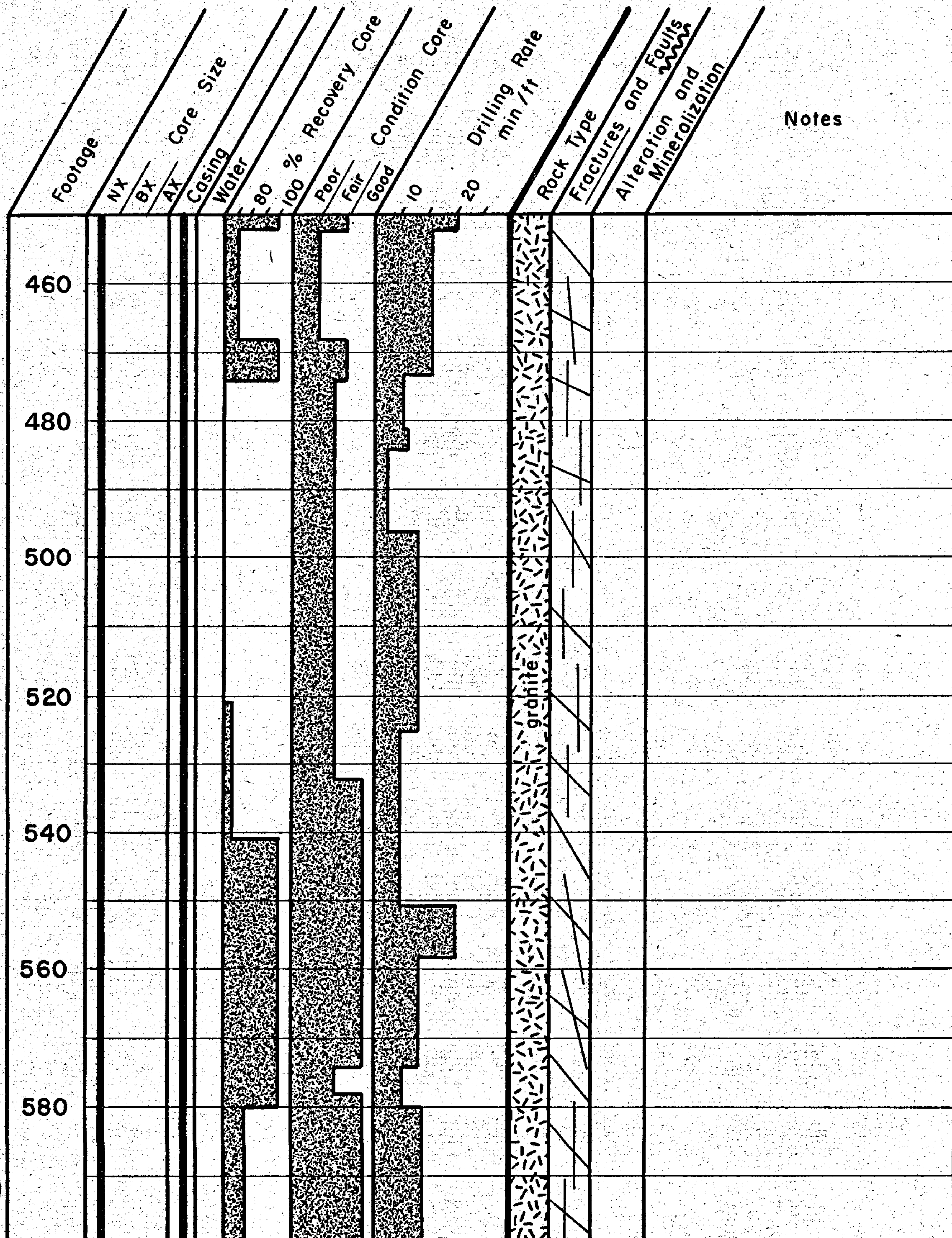


DIAMOND DRILL HOLE ECH-A 300 - 450 ft.

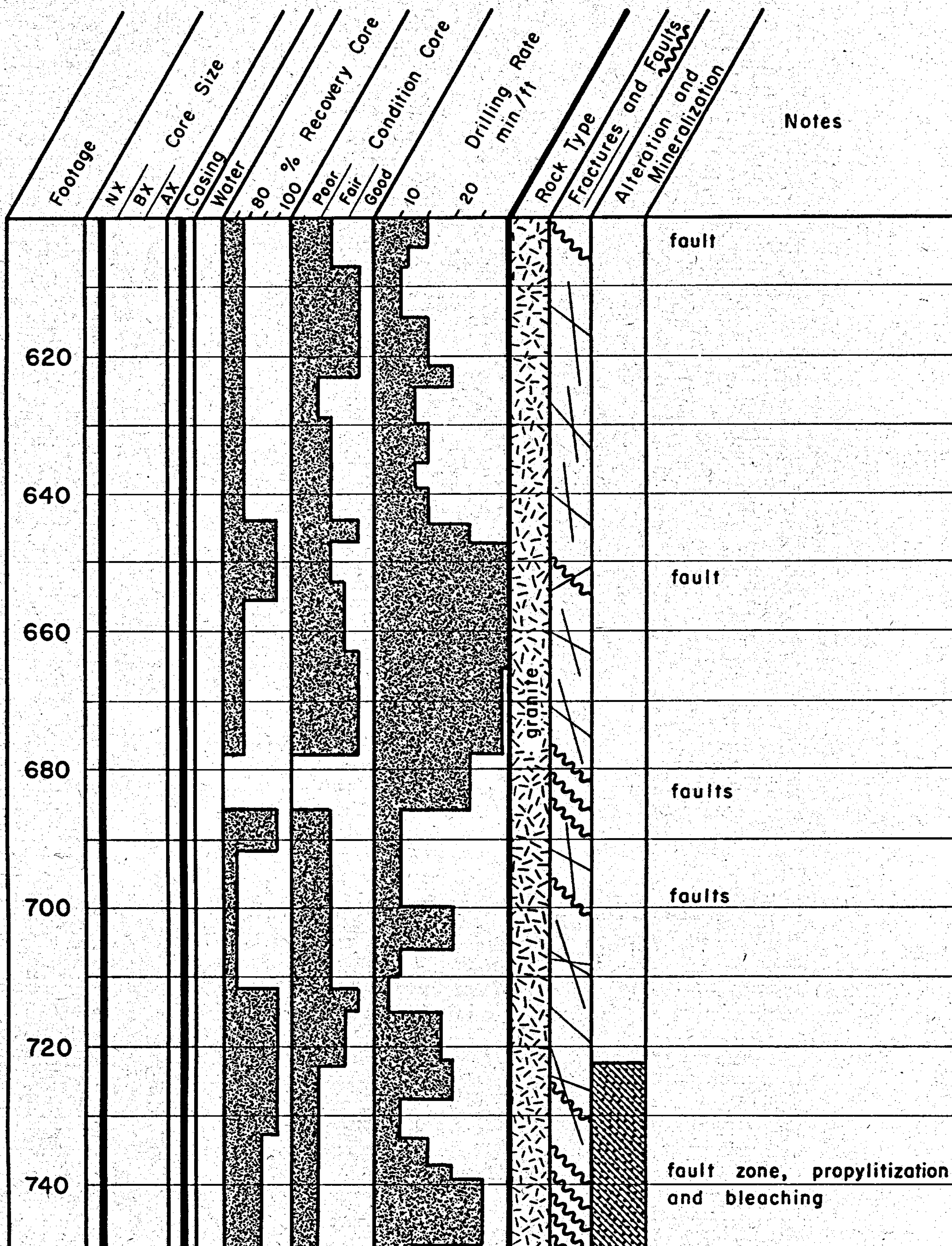


DIAMOND DRILL HOLE ECH-A

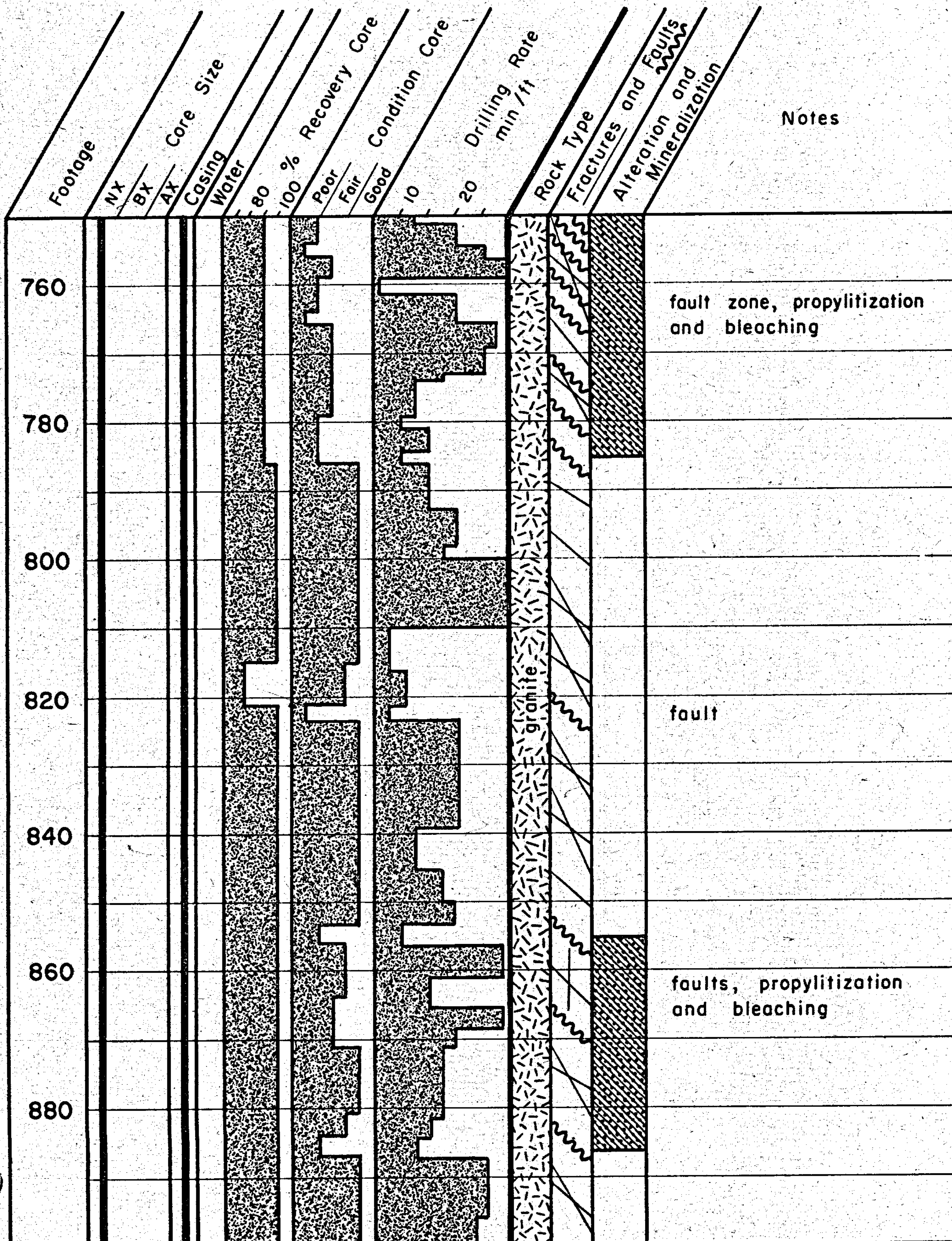
450 - 600 ft.



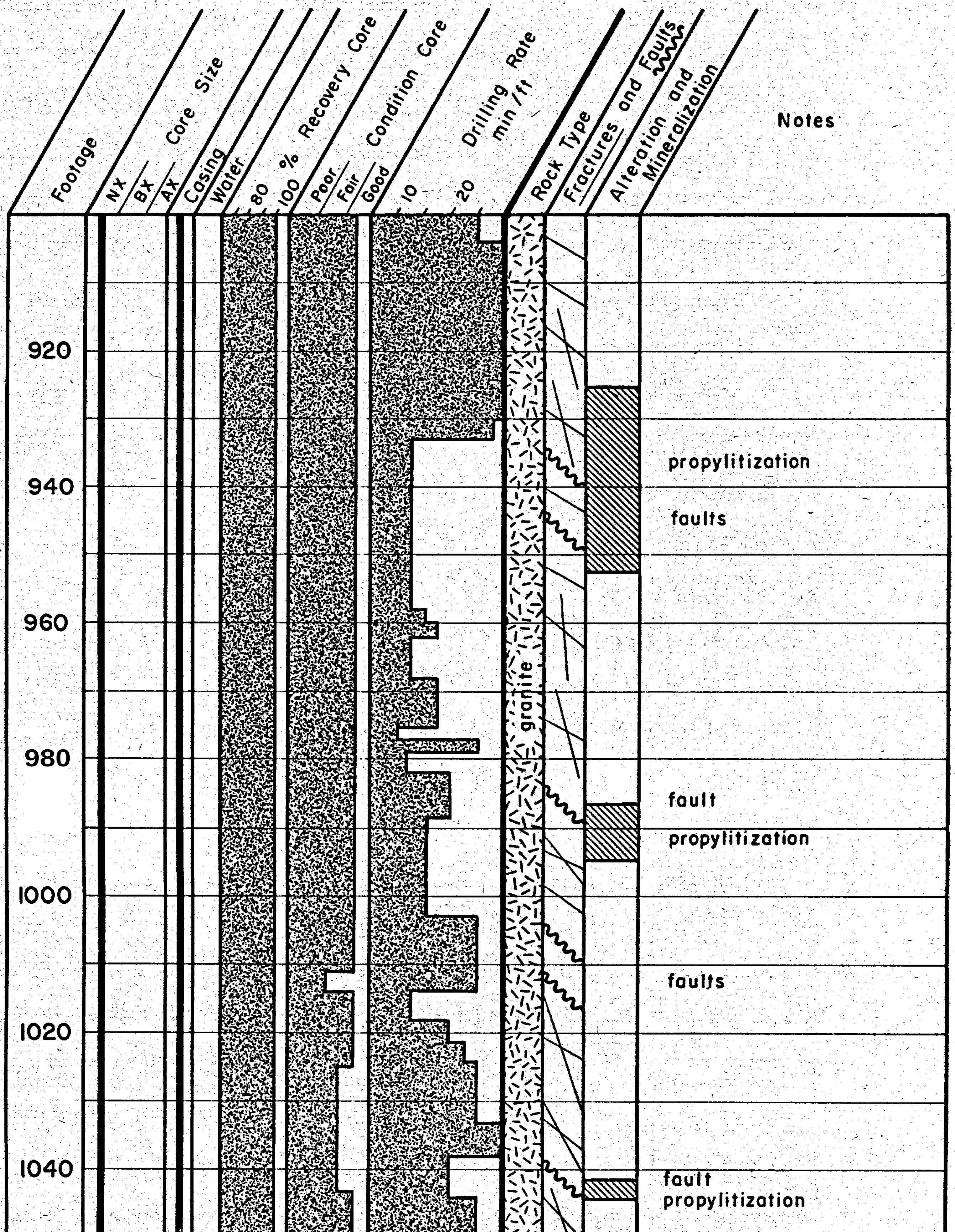
DIAMOND DRILL HOLE ECH-A 600-750 ft.



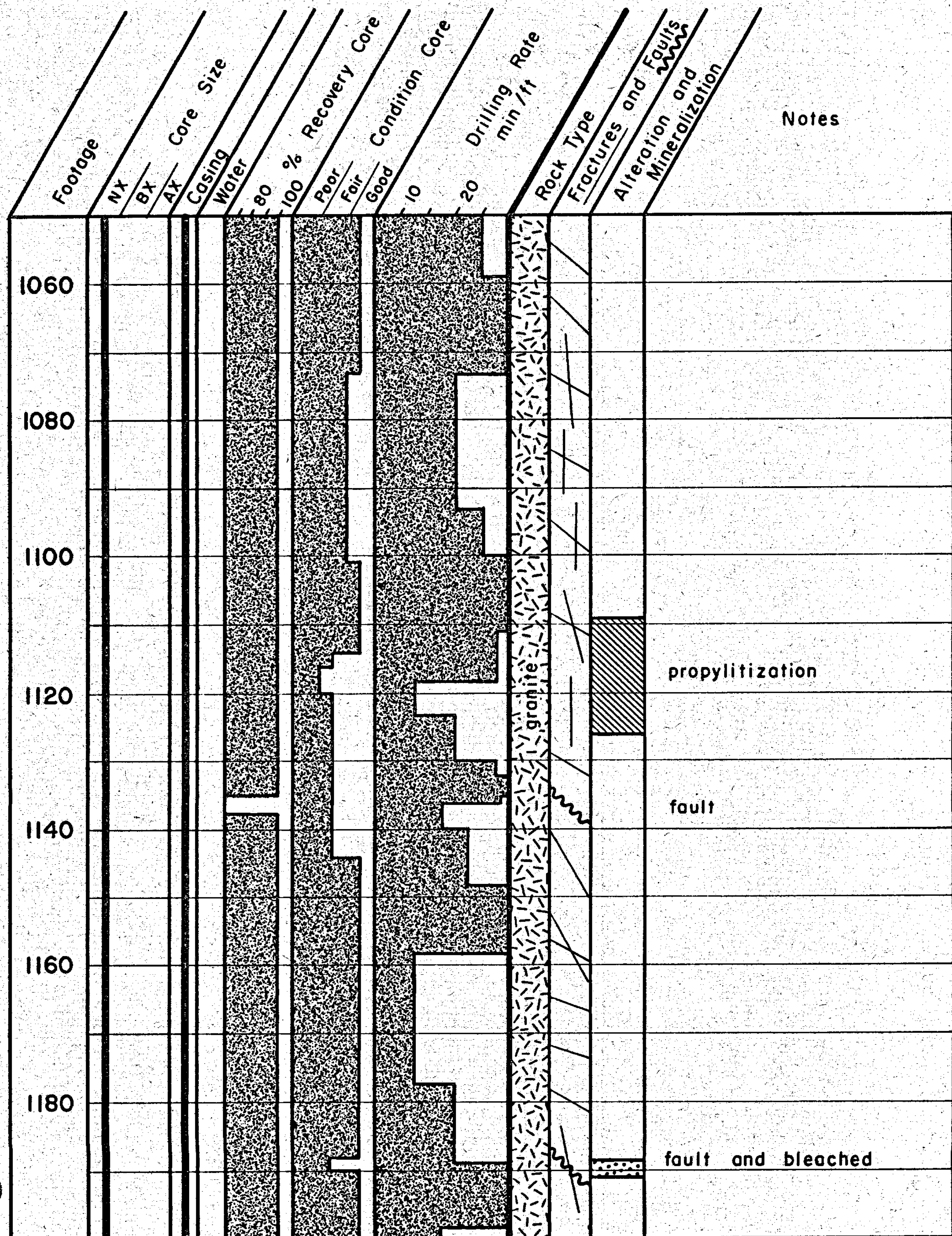
DIAMOND DRILL HOLE ECH-A 750 - 900 ft.



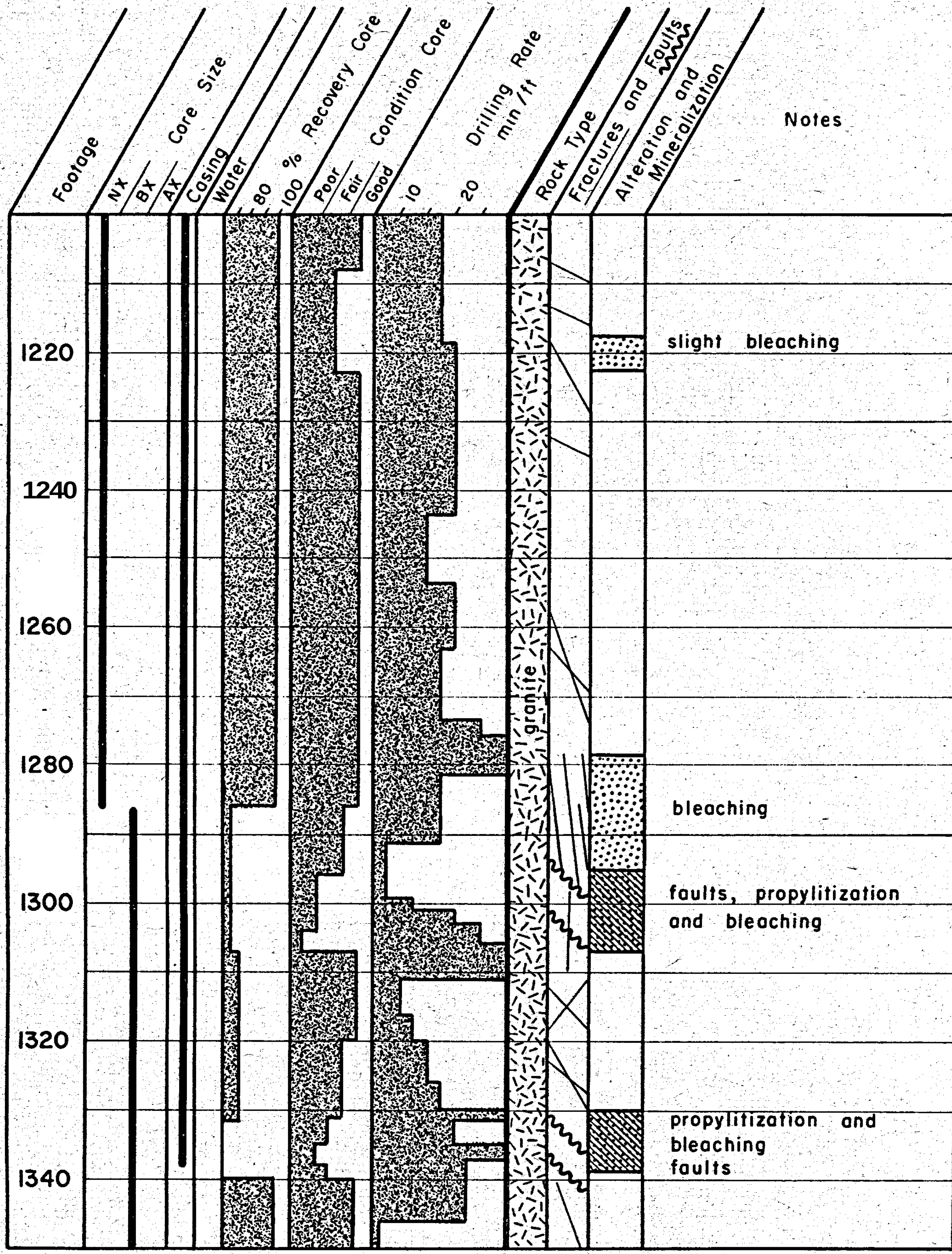
DIAMOND DRILL HOLE ECH-A 900-1050 ft.



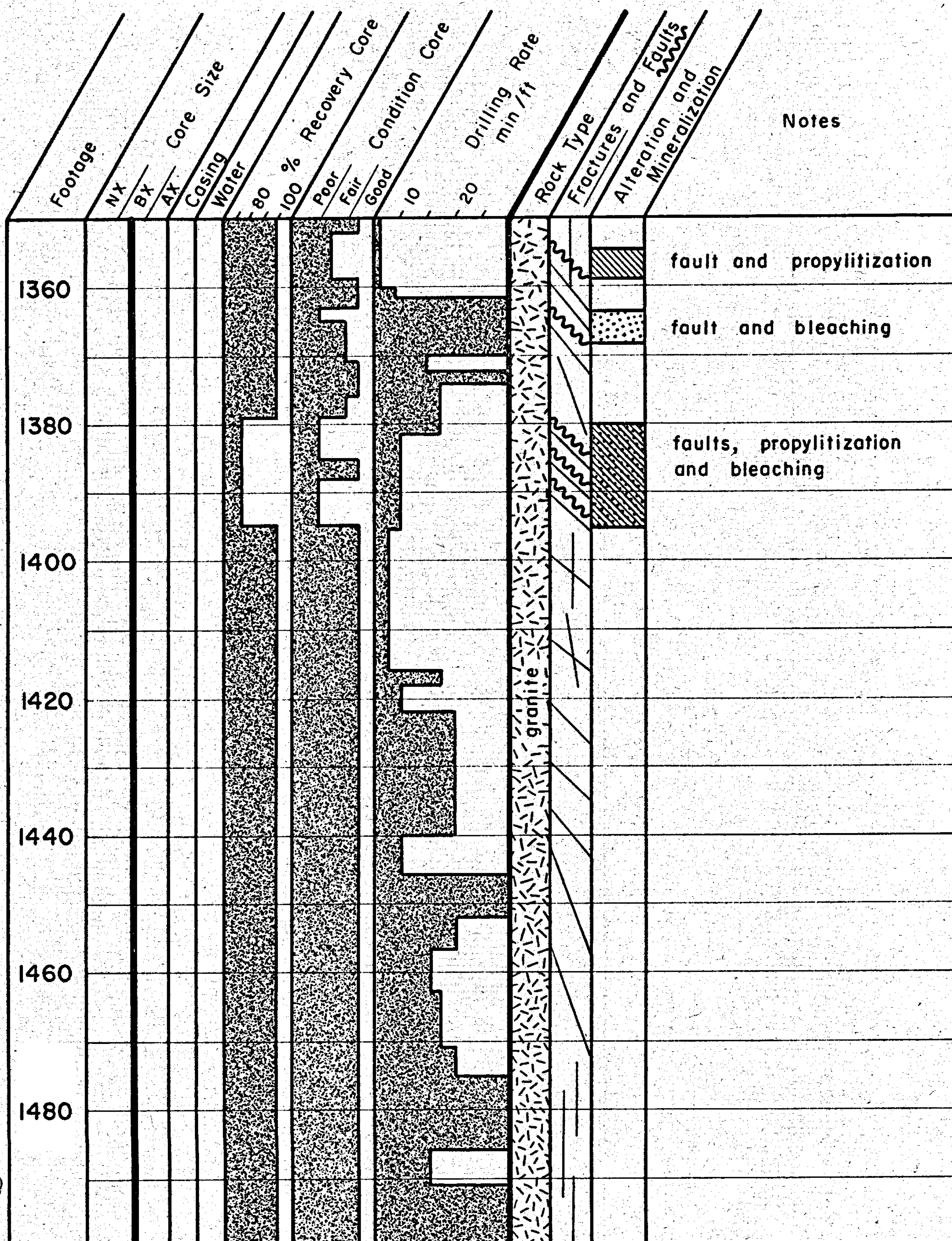
DIAMOND DRILL HOLE ECH-A 1050-1200 ft.



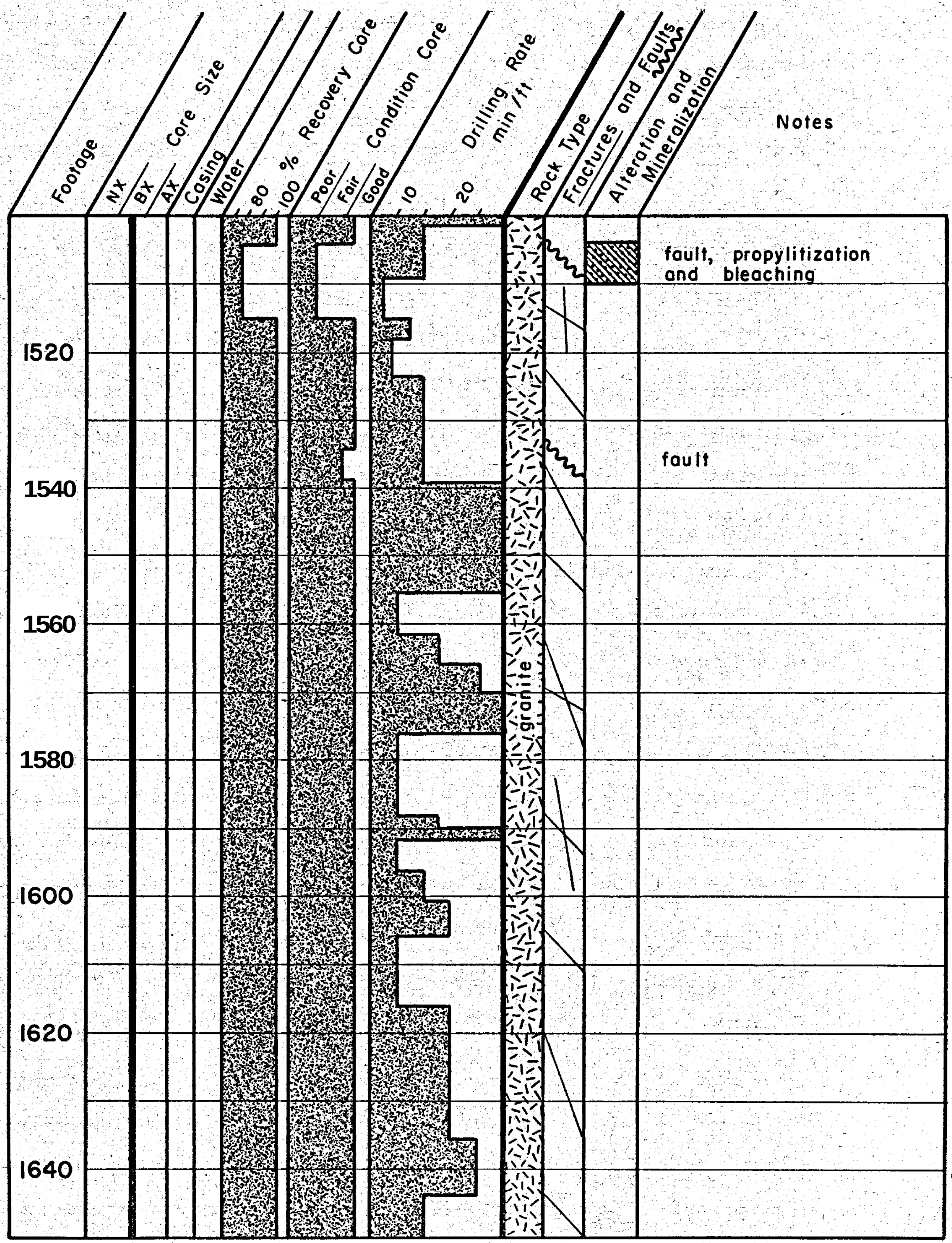
DIAMOND DRILL HOLE ECH-A 1200-1350 ft.



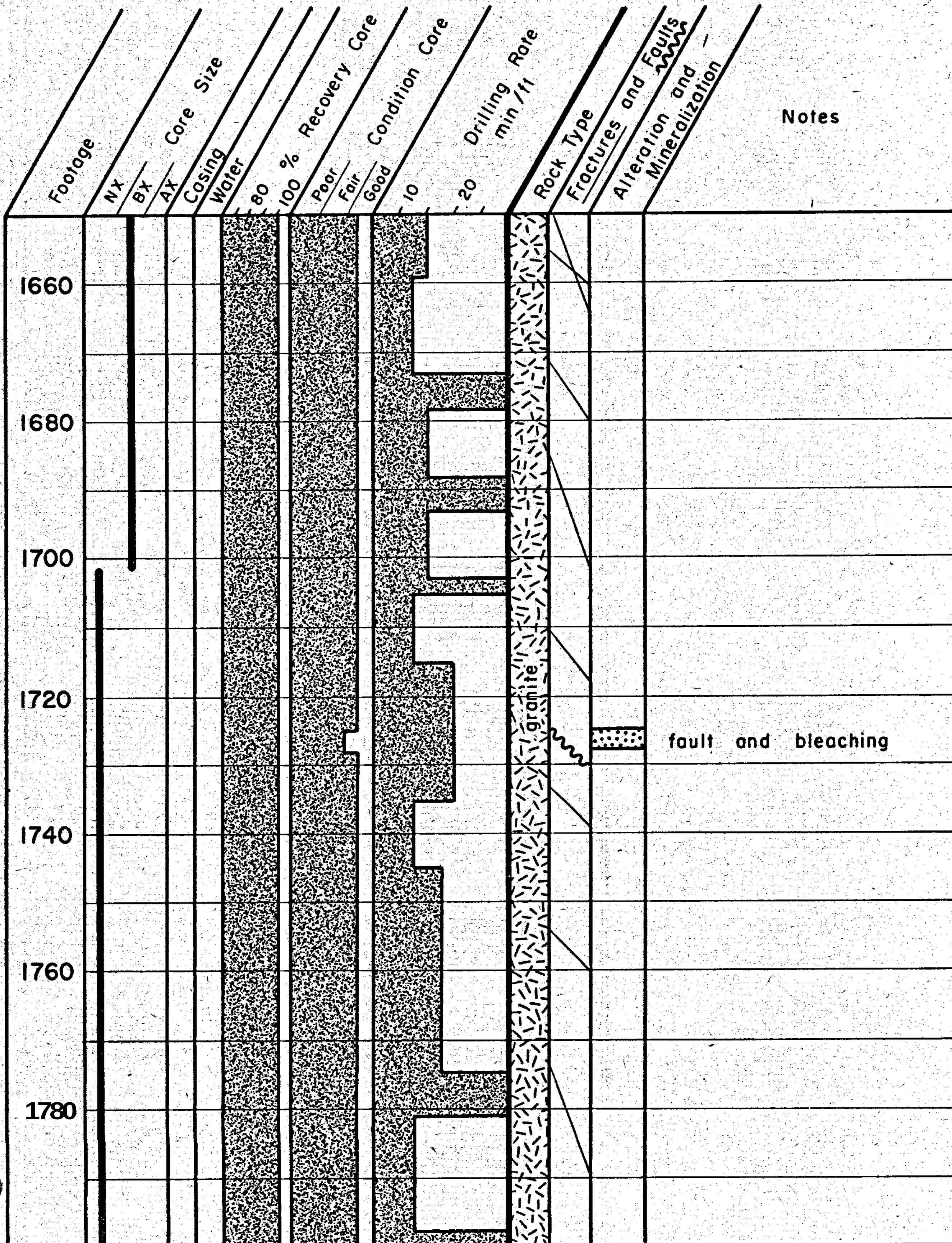
DIAMOND DRILL HOLE ECH-A 1350-1500 ft.

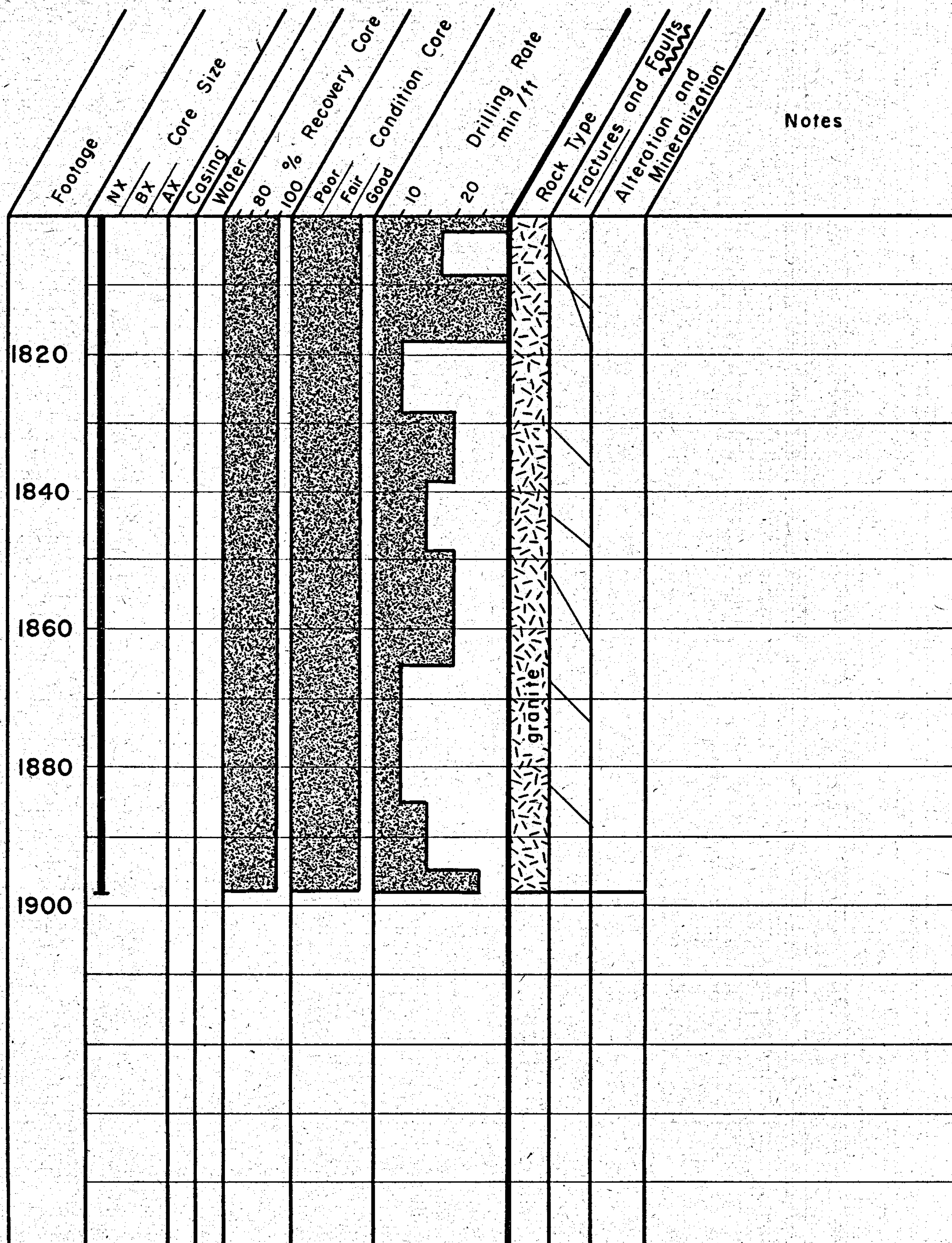


DIAMOND DRILL HOLE ECH-A 1500-1650 ft.



DIAMOND DRILL HOLE ECH-A 1650-1800 ft.




Footage
NX
BX
AX
Core Size
Casing
Water
80
100
% Recovery Core
Poor
Fair
Good
Condition Core
10
20
Drilling Rate
min / ft
Rock Type
Fractures and Faults
Alteration and
Mineralization
Notes
1820
1840
1860
1880
1900
granite

APPENDIX B

Log of Diamond Drill Hole ECH-D

Location: N. 1,619,975.66–E. 557,545.47
(U. S. Coast & Geodetic Survey Coordinates)
Sand Springs Range
Churchill County, Nevada

Inclination: Vertical

Collar elevation: 5,236.03 ft. (7.1 ft. above ground surface)

Date begun: May 26, 1962

Date completed: August 16, 1962

Drilling contractor: Core Drilling, Inc.

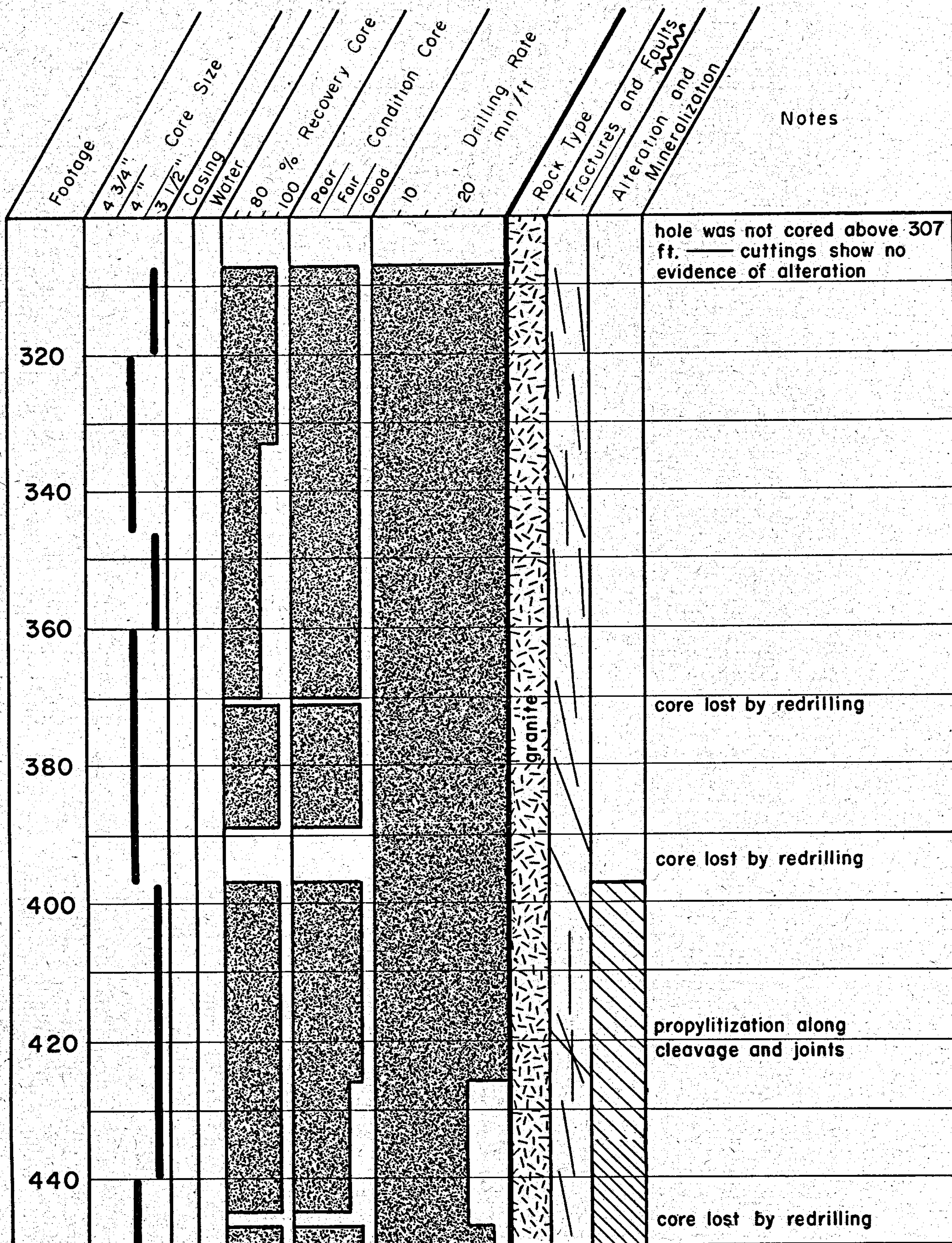
Logged by: NBM personnel: L. Agenbroad, R. Horton, S. Jerome, H. Mossman, and J. Schilling

Explanation: The orientations of fractures and faults shown in the log are given only in relation to the axis of the hole (which is parallel to the columns in the log), not in relation to each other. Their strikes thus cannot be determined, and fractures and faults which are shown as parallel in the log may have parallel strikes, and dip at the same angles but in the same or opposite direction; or may have different strikes, and dip at the same angle but in different directions.

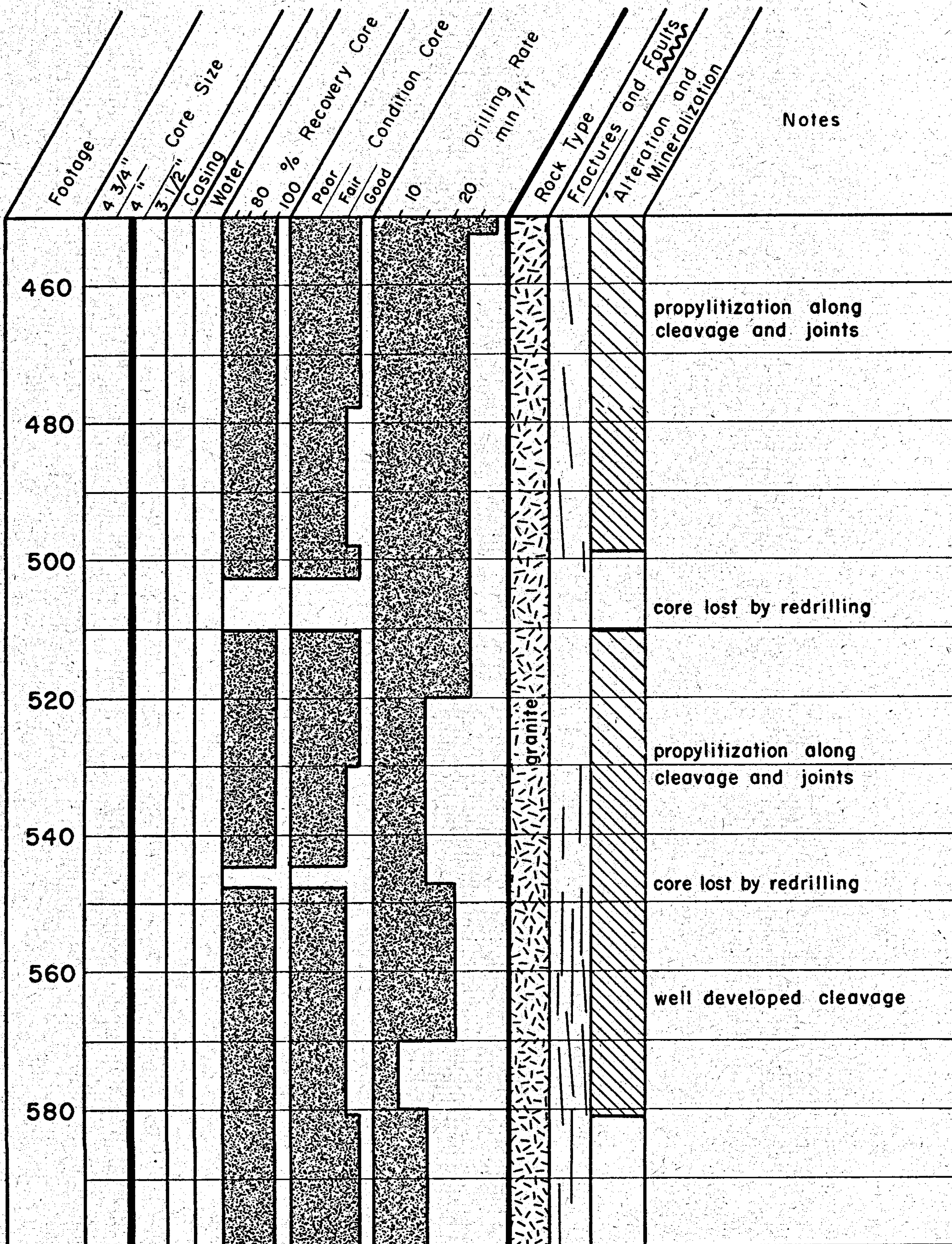
Core in cylindrical pieces was considered as in "good" condition, core in large angular pieces as "fair," and more finely broken-up (crumbled) core as "poor."

DIAMOND DRILL HOLE ECH-D

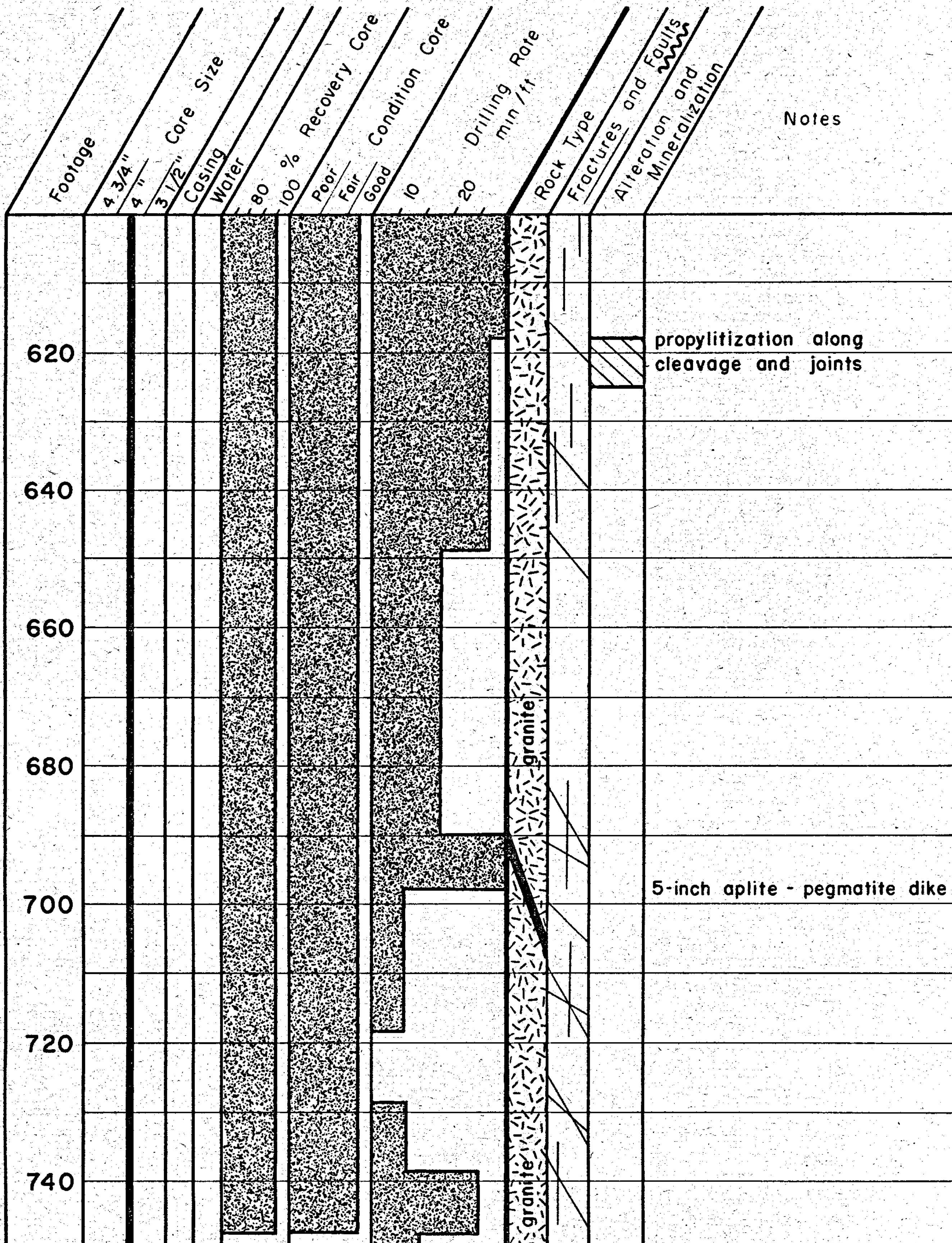
300-450 ft.



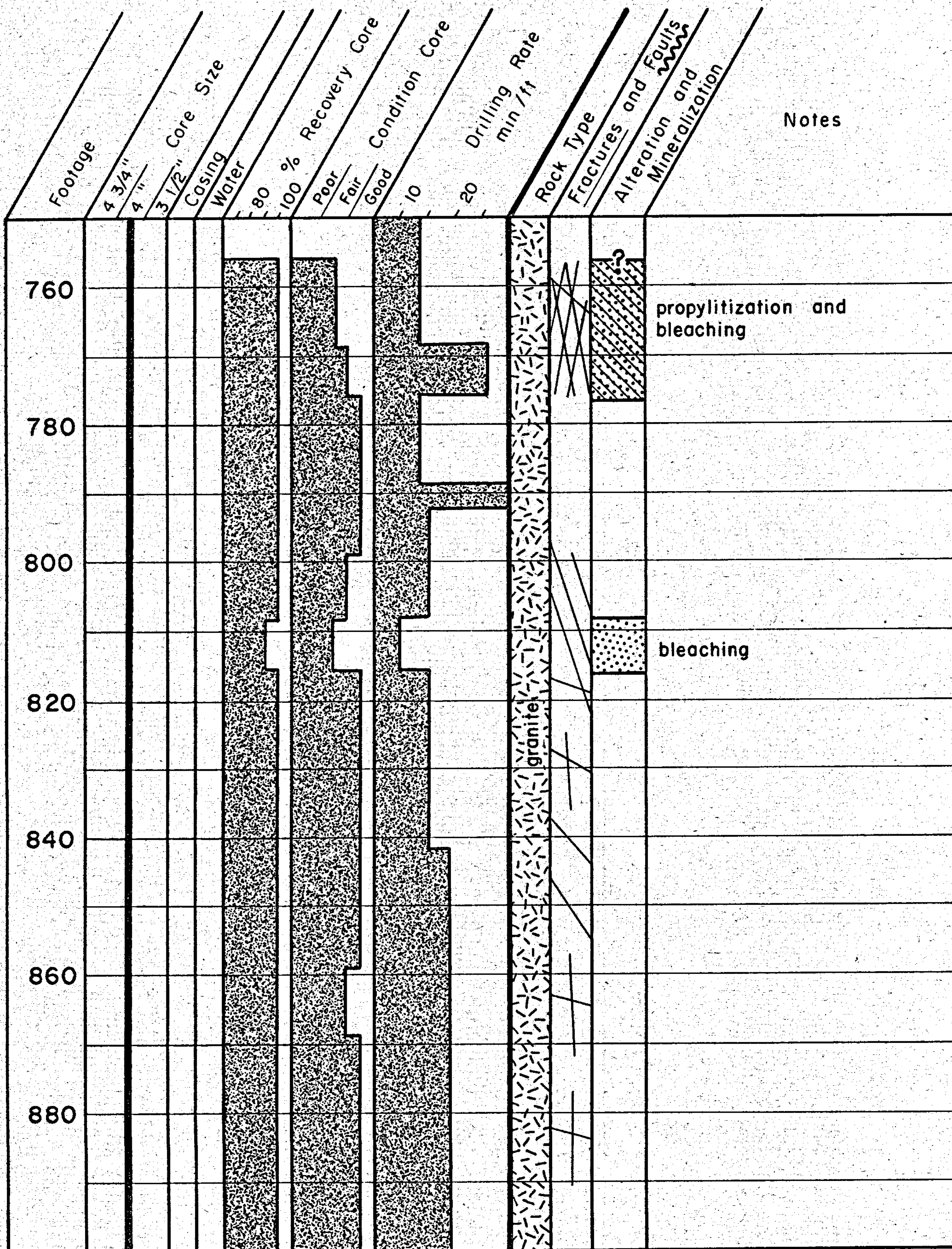
DIAMOND DRILL HOLE ECH-D 450-600 ft.



DIAMOND DRILL HOLE ECH-D 600-750 ft.

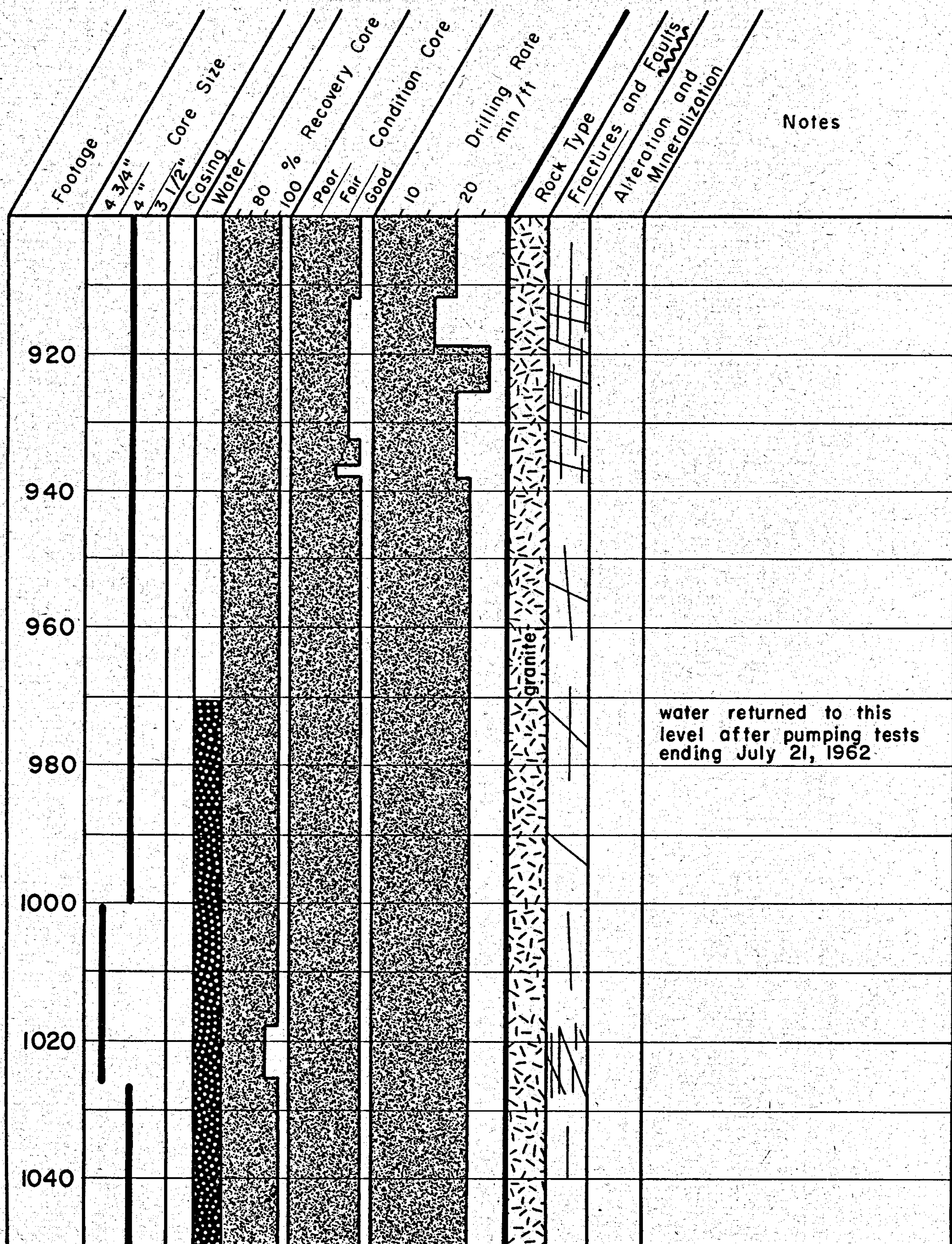


DIAMOND DRILL HOLE ECH-D 750-900 ft.

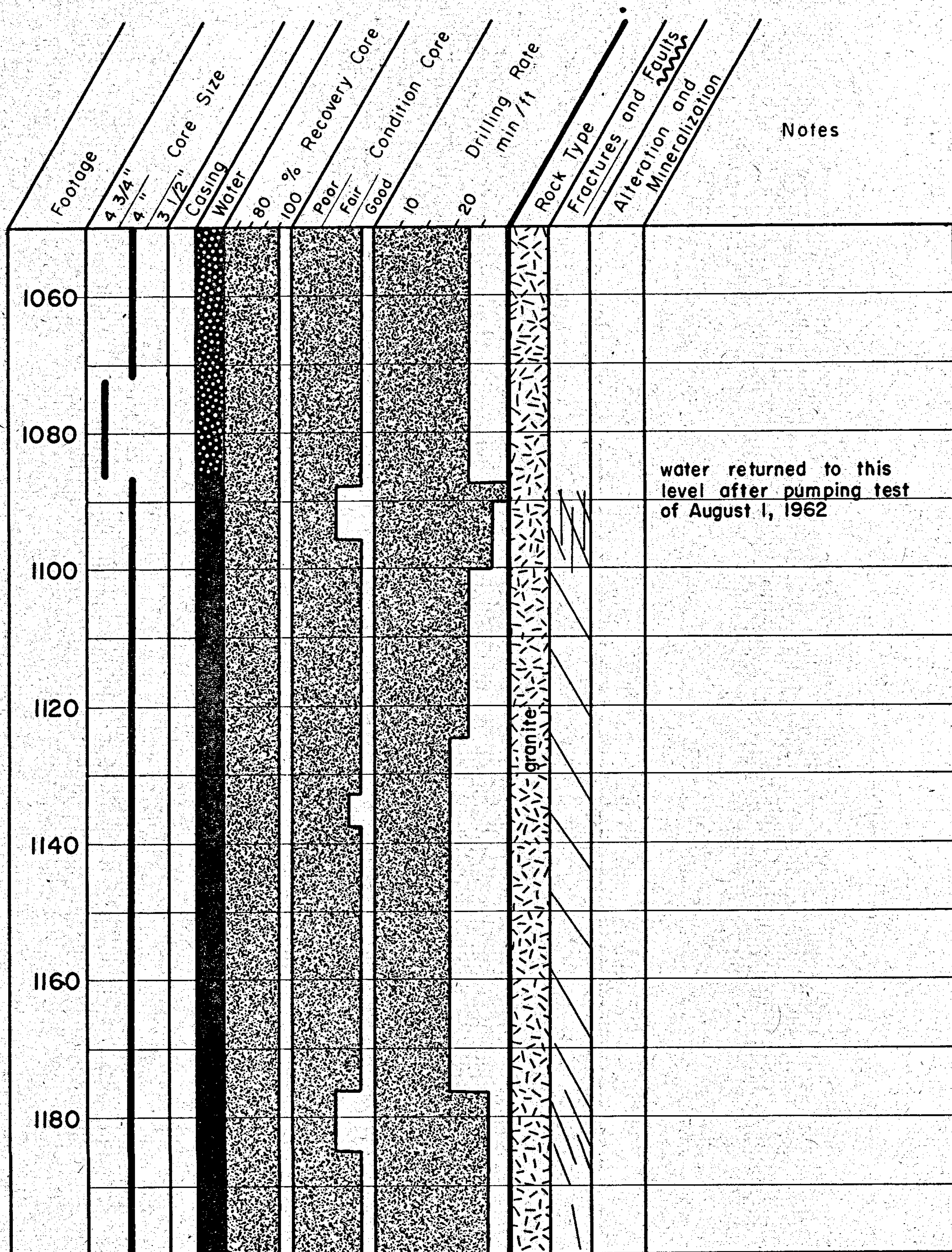


DIAMOND DRILL HOLE ECH-D

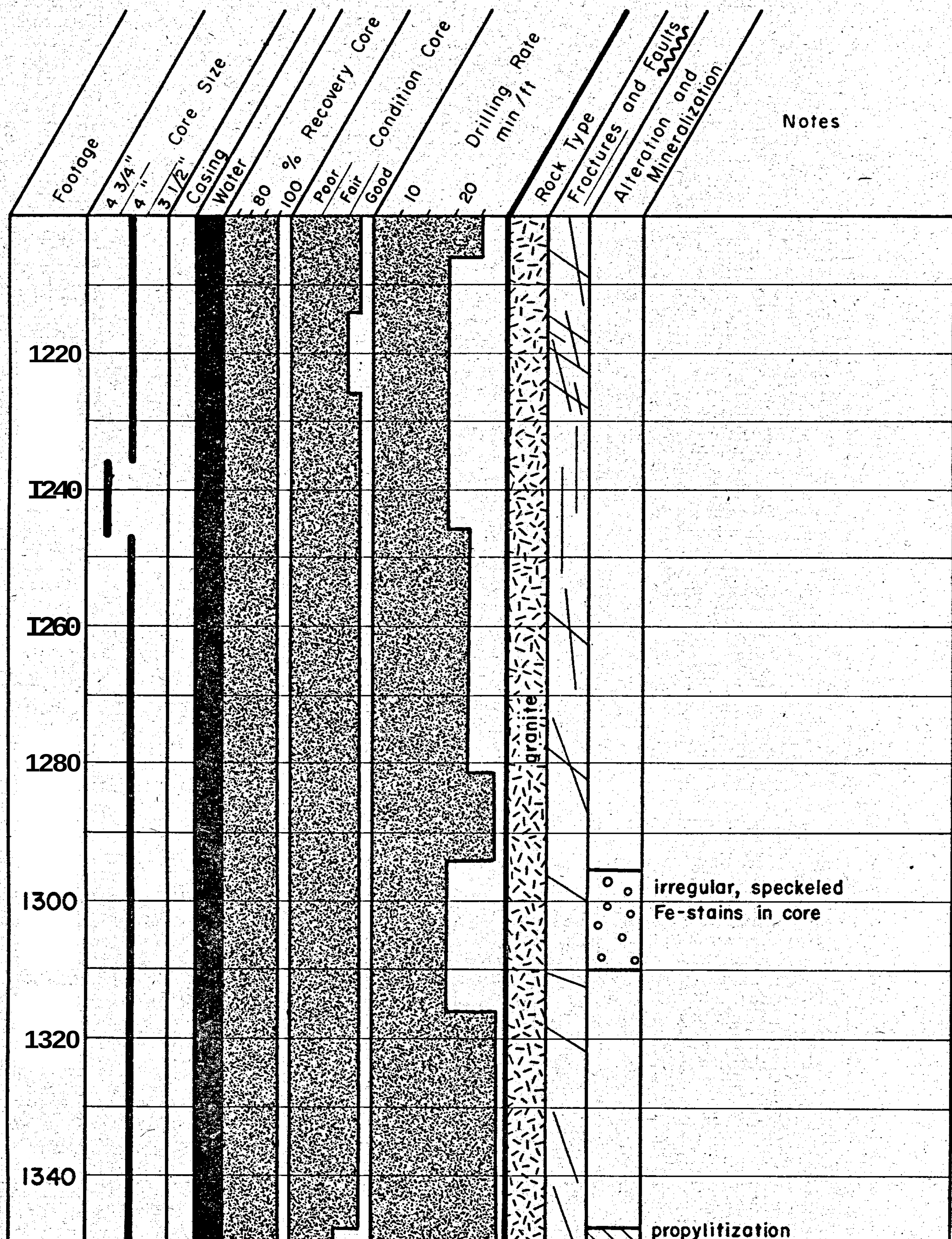
900-1050 ft.



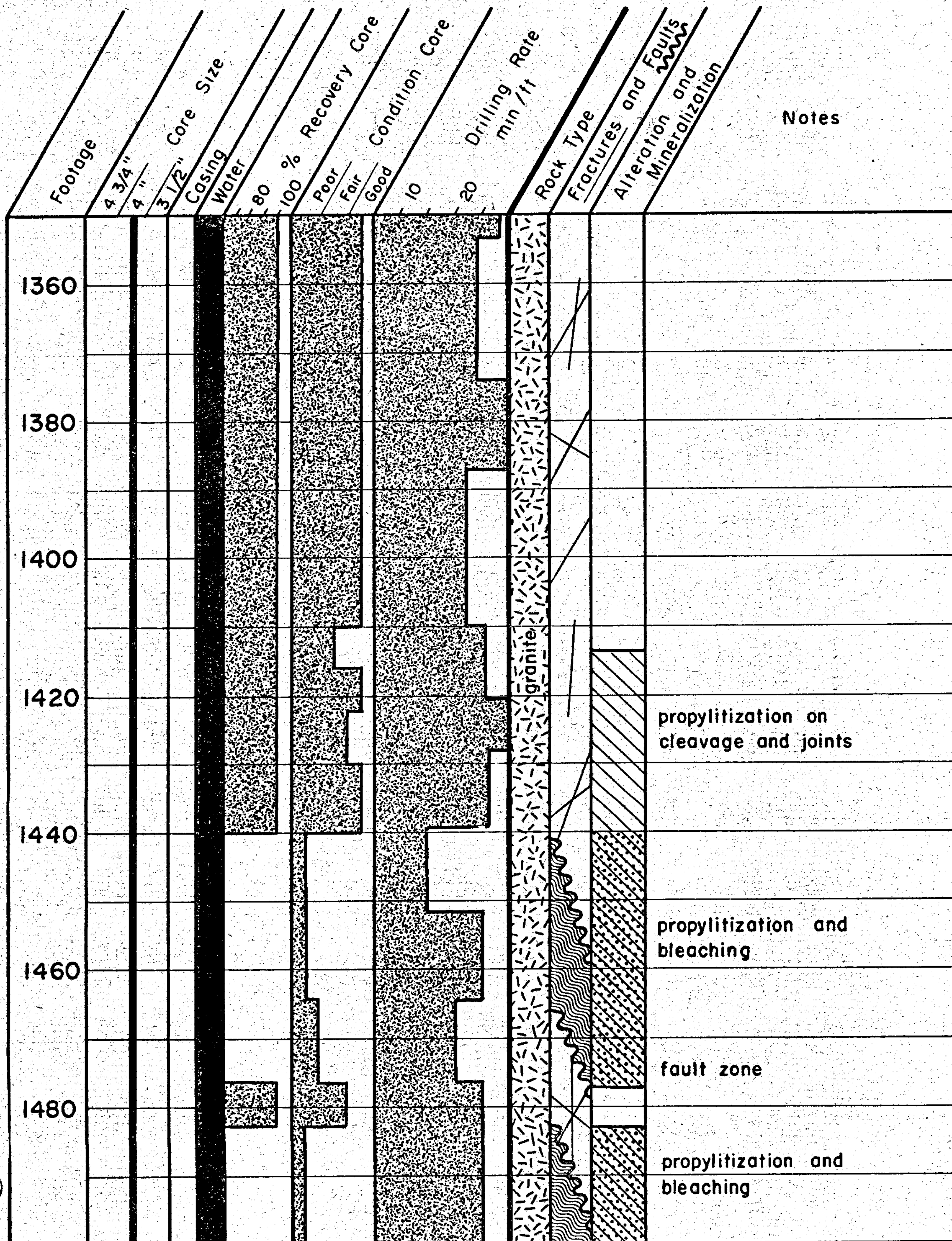
DIAMOND DRILL HOLE ECH-D 1050-1200 ft.

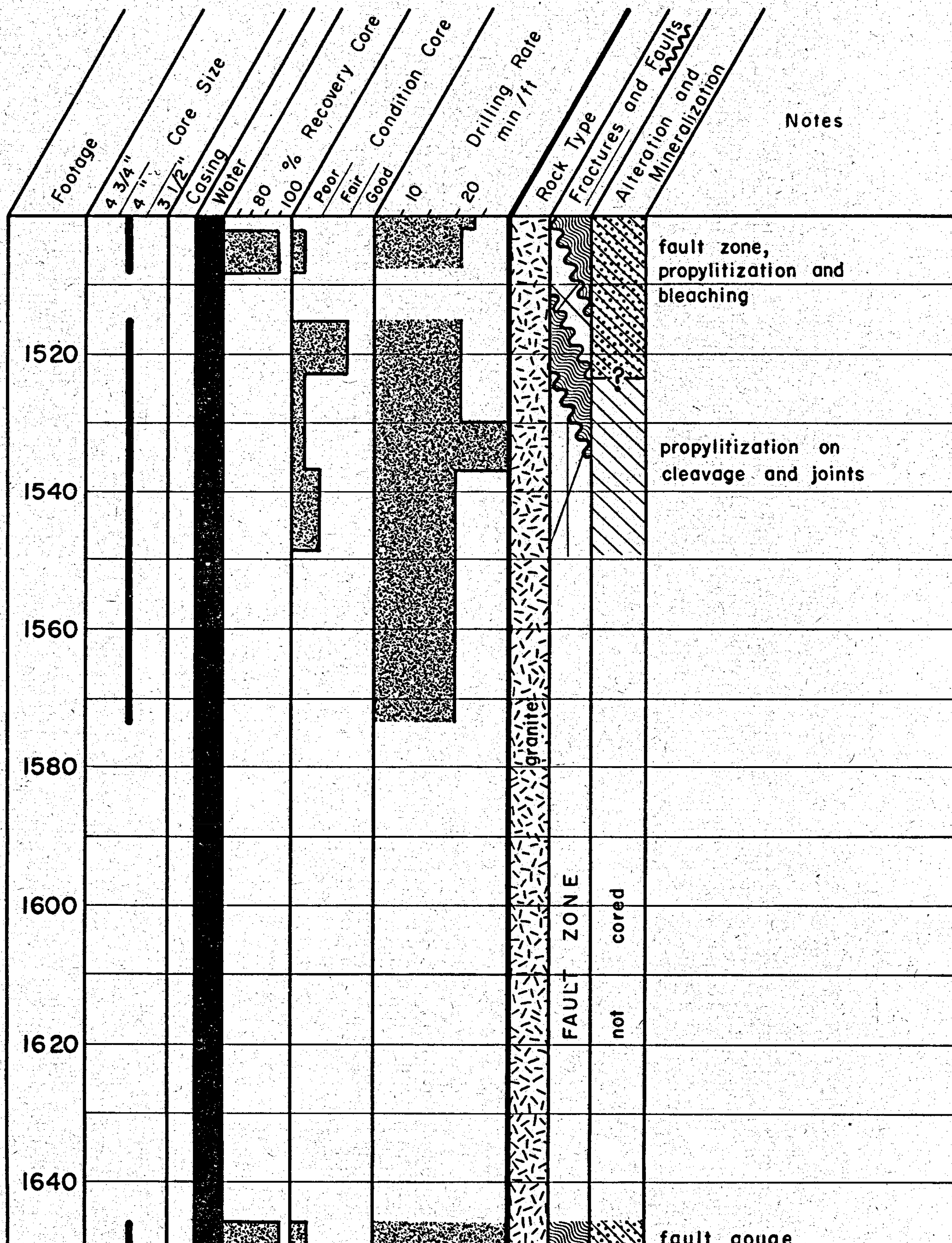


DIAMOND DRILL HOLE ECH-D 1200-1350 ft.



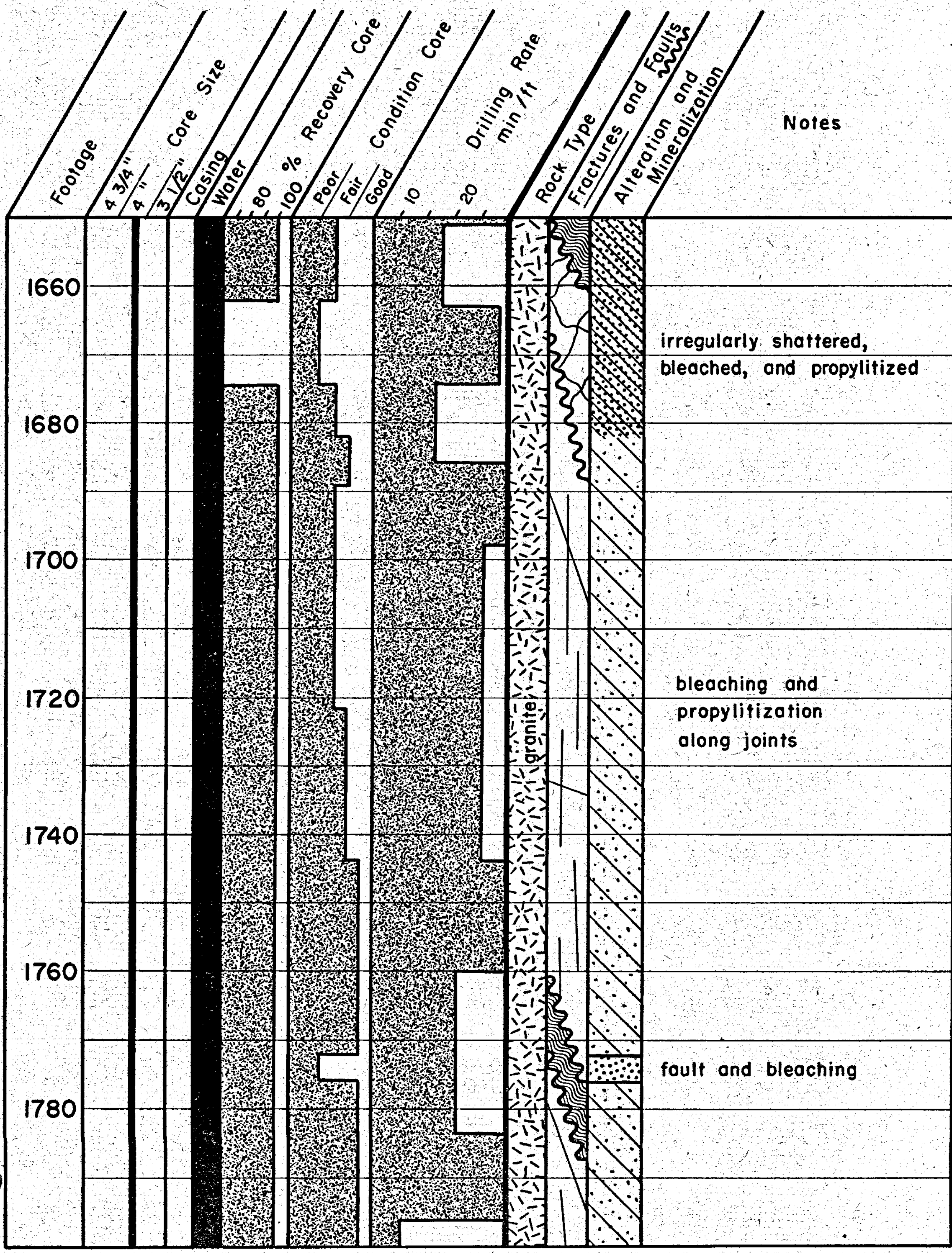
DIAMOND DRILL HOLE ECH-D 1350-1500 ft.



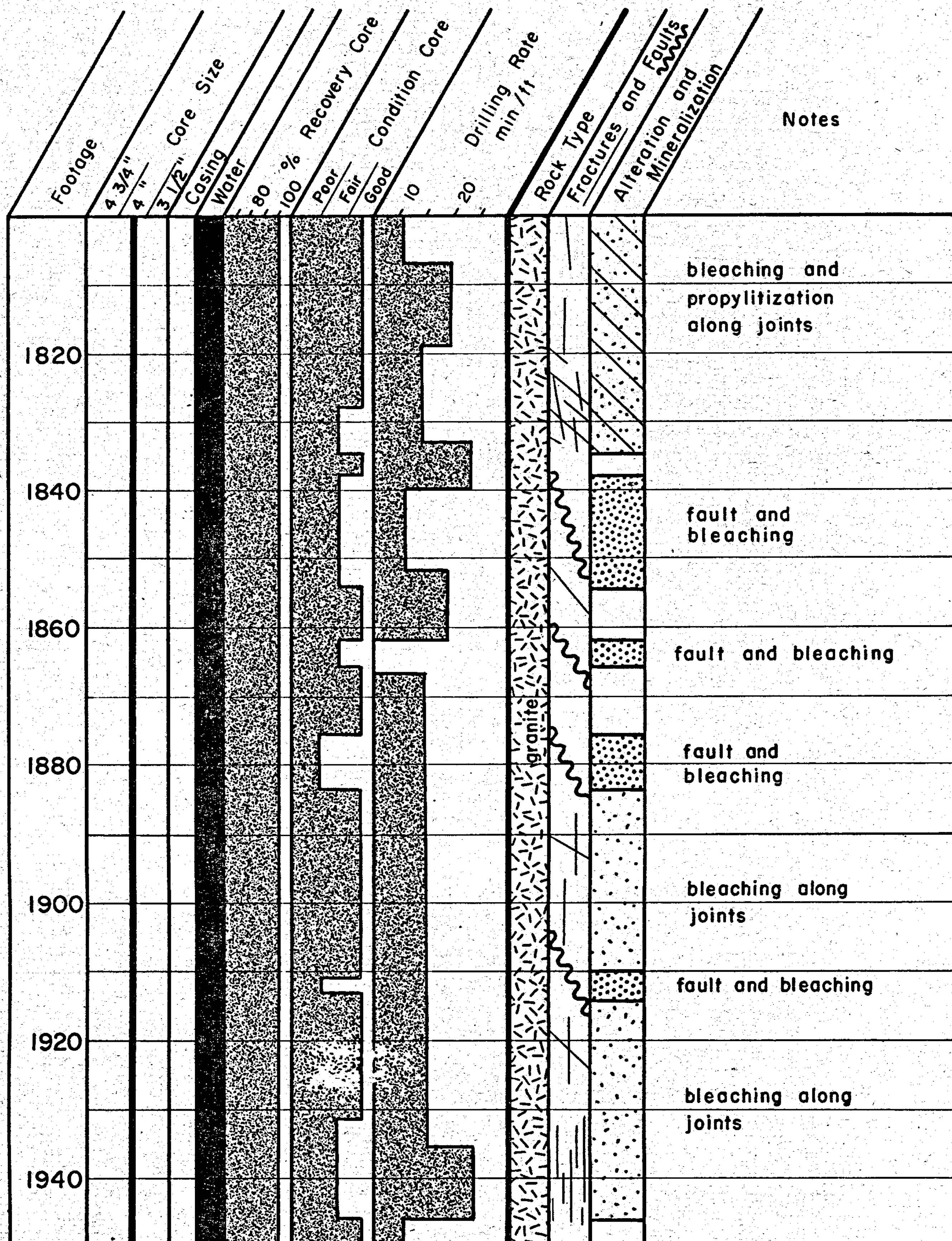

Footage
4 3/4"
4"
3 1/2"
Core Size
Casing
Water
80
100
% Recovery Core
Poor
Fair
Good
Condition Core
10
20
Drilling Rate min/ft
Rock Type
Fractures and Faults
Alteration and Mineralization
Notes
1520
1540
1560
1580
1600
1620
1640
fault zone, propylitization and bleaching
propylitization on cleavage and joints
granite
FAULT ZONE
not cored
fault gouge

DIAMOND DRILL HOLE ECH-D

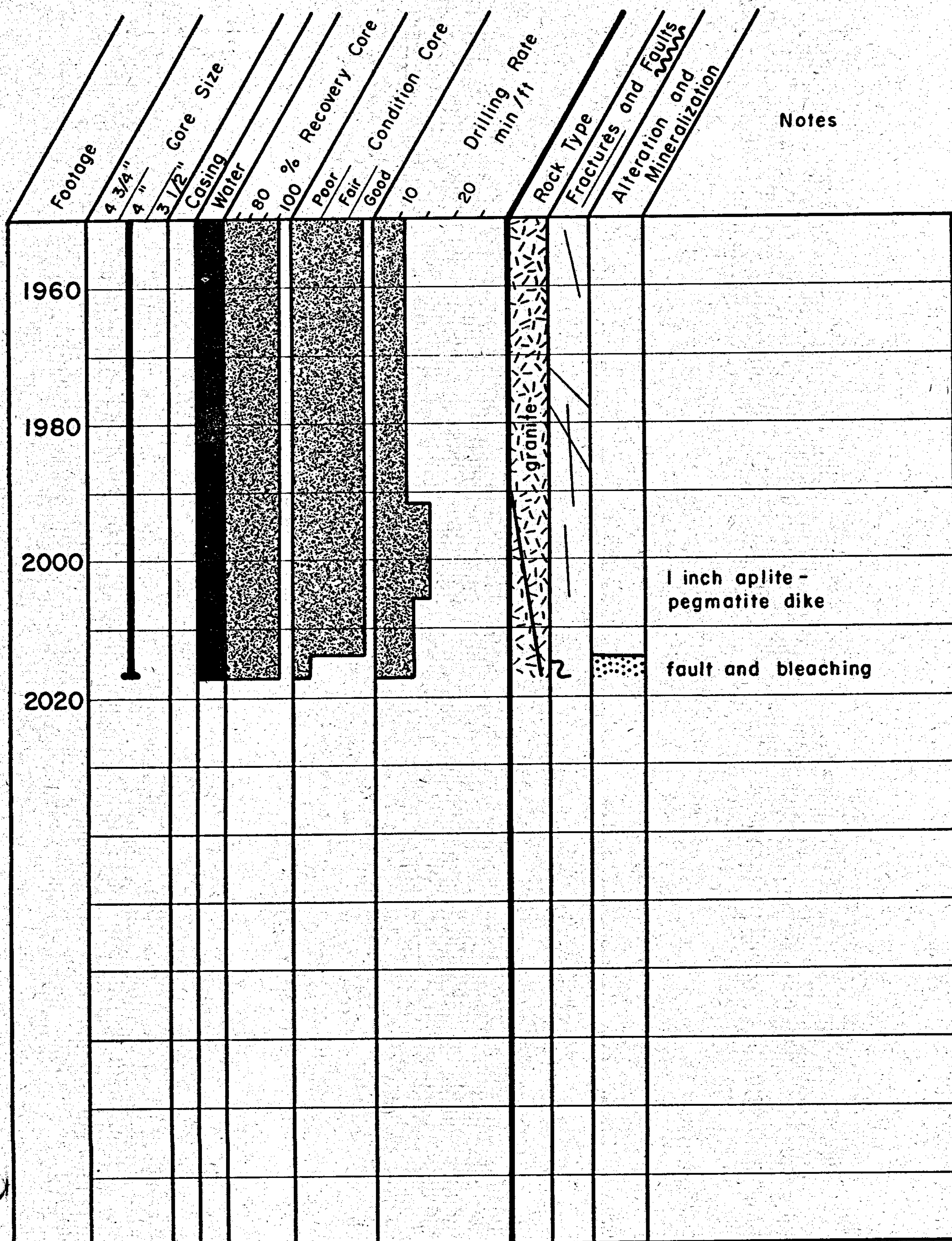
1650-1800 ft.



DIAMOND DRILL HOLE ECH-D 1800–1950 ft.



DIAMOND DRILL HOLE ECH-D 1950-2017.6 ft.



EXPLANATION FOR APPENDICES C, D, E, AND F

Hydrologic Test Holes

The procedure used in describing lithologies and water-bearing properties encountered in Hydrologic Test Holes HS-1, H-4, H-3, and H-2, Project Shoal, is as follows:

MAIN LITHOLOGY (preceded by qualifying adjective(s) if accessory lithologies are present as 15 percent or more of the total sample): color; texture characteristics (grain-size and shape), preceded by the percentage of that texture present in the total sample; percent of the total sample that is nonquartzose; accessory minerals; nature of the cementing material; fossils, if present; comments on genesis or other special remarks.

Clastic sediment textures were determined by comparison with particles of known size and shape standardized by the Wentworth scale, as summarized below:

Medium gravel	greater than 4.0 mm
Fine gravel	2.0 mm - 4.0 mm
Very coarse sand	1.0 mm - 2.0 mm
Coarse sand	1/2 mm - 1.0 mm
Medium sand	1/4 mm - 1/2 mm
Fine sand	1/8 mm - 1/4 mm
Very fine sand	1/16 mm - 1/8 mm
Silt	less than 1/16 mm

Percentages of clay were estimated by the plasticity of the sample, and described as being slightly or moderately plastic, plastic, or very plastic. If a particular sample interval was determined to be either plastic or very plastic, it was termed a clayey interval.

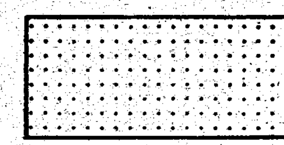
Each well log will be preceded by a summary of the lithology and water-bearing properties.

To conserve space on the accompanying logs, the following characteristics will apply to all sample intervals, unless otherwise specified:

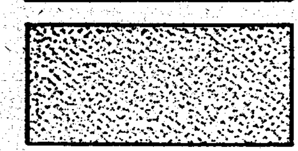
1. Sands are subangular to subrounded, and are quartzose.
2. Gravels are fine to medium grained, subangular to subrounded, and are quartzose and felspathic.
3. Rock fragments are fresh, angular particles, probably broken by the drilling tool, and are fine to medium grained.
4. Samples are calcareous or have some degree of calcareousness.
5. Color of the sample is light brown when dry, darker brown when wet.
6. The feldspathic portions of gravel in Test Holes HS-1 and H-4 are predominantly potassium feldspars, while in Test Holes H-3 and H-2, sodium and calcium feldspars are predominant.
7. In Test Hole H-2, the nonquartzose percentage of the sample interval consists of biotite mica, hornblende, olivine, zircon, fine-grained acidic and basic igneous and metamorphic materials.

Legend for Graphic Log

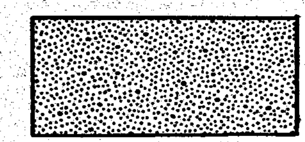
Very fine- to medium-grained sand (or very fine- to fine-grained)



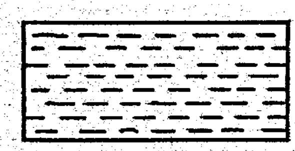
Medium- to coarse-grained sand (or medium- to very coarse-grained)



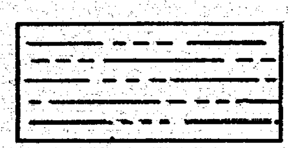
Very fine- to very coarse-grained sand (or fine- to coarse-grained)



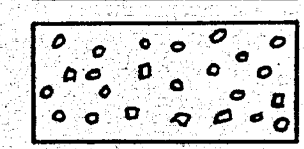
Clay



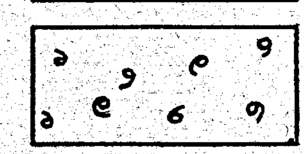
Silt



Gravel and rock fragments

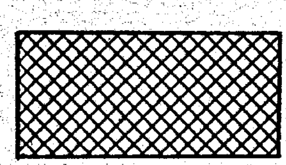


Microfossils

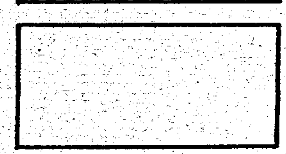


Bedrock—

weathered



unweathered



APPENDIX C

Lithologic Log of Test Hole HS-1, Project Shoal, Churchill County, Nevada

GEOGRAPHIC DESCRIPTION: East flank of the Sand Springs Range, in Fairview Valley.

NEVADA STATE COORDINATES: N. 1,622,141.28; E. 576,875.65.

GROUND ELEVATION: 4,243.76 feet above sea level.

TOTAL DEPTH: 699 feet below ground surface.

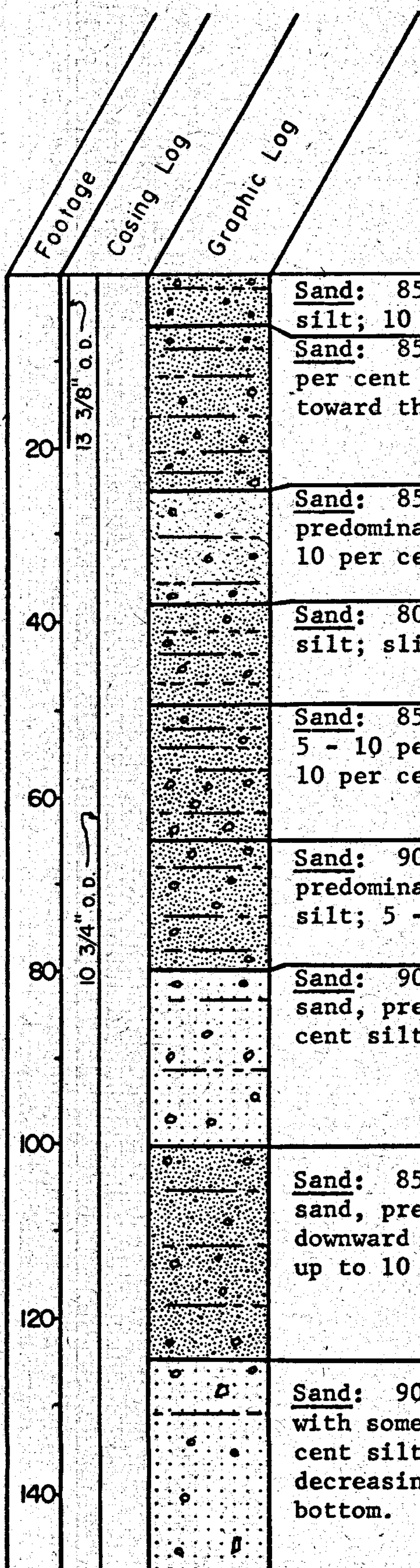
SAMPLED INTERVALS: Cable-tool cuttings taken either every five feet or at a distinct change of lithology.

SUMMARY OF THE LITHOLOGY AND WATER-BEARING PROPERTIES:

Hydrologic Test Hole HS-1 was drilled in Quaternary alluvium consisting predominantly of sands, with varying amounts of clay, silt, and gravel. The description of the alluvium is based on samples obtained by the cable-tool method of drilling, and consists of a binocular study of the total section. Procedure followed in describing the alluvial rock fragments is listed on page 98.

Confined ground water was encountered in sand at a depth of 312.0 feet below ground surface. Overlying the top of the sand aquifer are approximately 70.0 feet of fine-grained, silty sand. After drilling to a depth of 530.0 feet below ground surface a fine-grained, clayey, silty sand was encountered, approximately 32.0 feet thick. This interval serves as an aquitard between the upper and lower aquifers, the latter consisting predominantly of sand, with a higher percentage of clay and silt than the upper aquifer.

Surveys conducted by Holmes & Narver, Inc., after completion of HS-1 indicate a true depth of 699.0 feet, rather than the 690.0 feet reported by the driller.



Lithology and Water-Bearing Properties

Sand: 85 per cent fine- to coarse-grained sand; 5 per cent silt; 10 per cent gravel; organic debris.

Sand: 85 per cent fine- to very coarse-grained sand; 5 - 10 per cent silt; 5 - 10 per cent gravel, becomes more micaceous toward the bottom.

Sand: 85 per cent very fine- to very coarse-grained sand, predominantly medium- to very coarse-grained; 5 per cent silt; 10 per cent gravel.

Sand: 80 per cent fine- to coarse-grained sand; 5 per cent silt; slightly plastic; 5 per cent gravel.

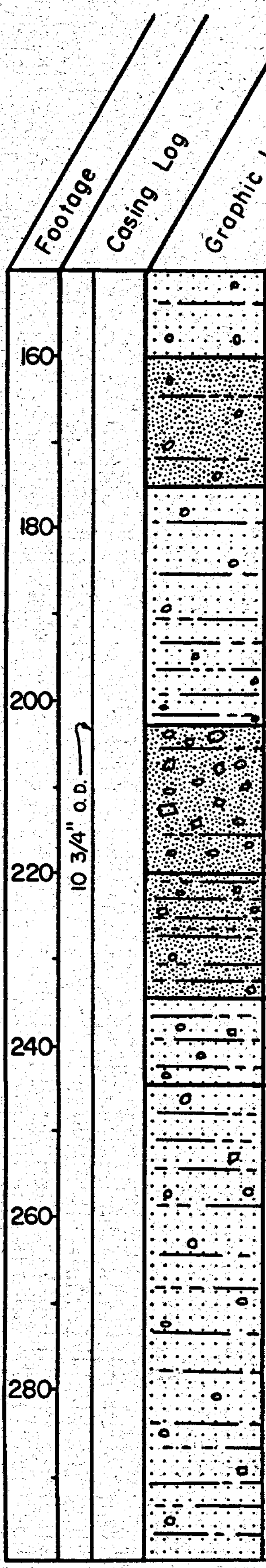
Sand: 85 - 90 per cent fine- to very coarse-grained sand; 5 - 10 per cent silt, decreasing toward the bottom; 5 - 10 per cent gravel, increasing toward the bottom.

Sand: 90 per cent very fine- to very coarse-grained sand, predominantly fine- and coarse-grained; up to 5 per cent silt; 5 - 10 per cent gravel.

Sand: 90 - 95 per cent very fine- to very coarse-grained sand, predominantly fine- to medium-grained; up to 5 per cent silt; up to 10 per cent gravel.

Sand: 85 - 95 per cent very fine- to very coarse-grained sand, predominantly fine- and coarse-grained, grading downward into mostly fine-grained; up to 5 per cent silt; up to 10 per cent gravel and rock fragments.

Sand: 90 - 95 per cent very fine- to medium-grained sand, with some coarse- and very coarse-grains; less than 5 per cent silt; 5 - 10 per cent gravel and rock fragments, decreasing to less than 5 per cent gravel toward the bottom.



Lithology and Water-Bearing Properties

Sand: 90 per cent very fine- to very coarse-grained sand, with little medium- or coarse-grained; 5 per cent silt; 5 per cent gravel, predominantly fine-grained.

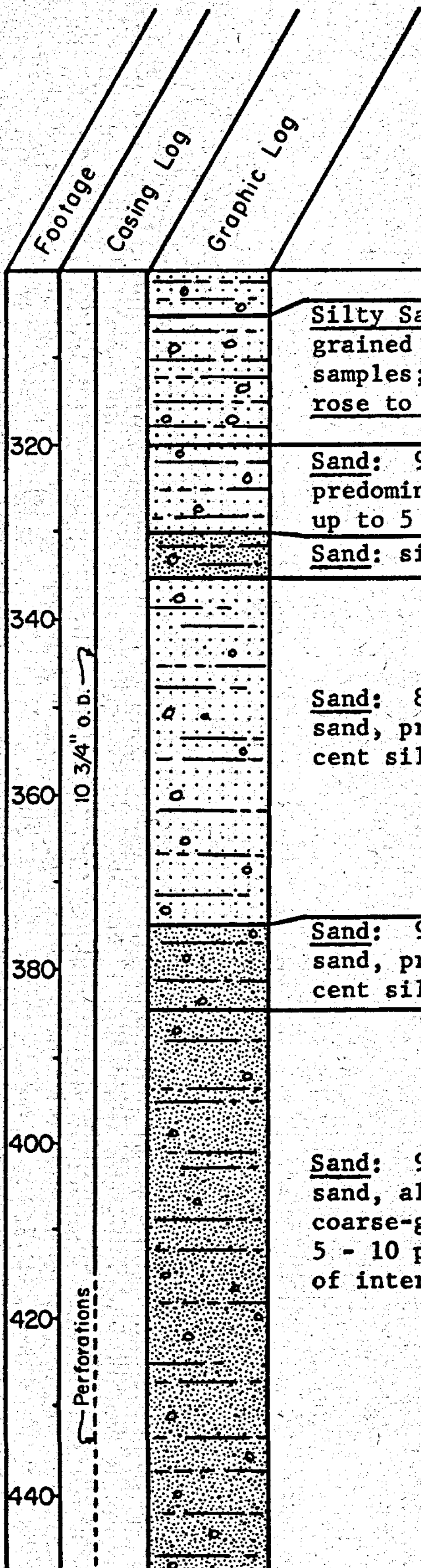
Sand: 85 - 90 per cent very fine- to very coarse-grained sand, predominantly fine-grained; 5 - 10 per cent silt, increasing toward the bottom; 5 per cent gravel; noncalcareous.

Gravelly Sand: 60 - 80 per cent fine- to coarse-grained sand; 5 per cent silt; 15 - 40 per cent gravel and rock fragments up to cobble size; boulder field encountered at this interval; samples become predominantly fine-grained sands, with up to 10 per cent gravel toward the bottom.

Silty Sand: 80 - 85 per cent very fine- to very coarse-grained sand; 10 - 15 per cent silt; slightly plastic in the middle five feet of the interval; up to 5 per cent gravel and rock fragments.

Sand: 85 - 95 per cent very fine- to coarse-grained sand, predominantly fine-grained toward the top; 5 - 10 per cent silt; up to 5 per cent gravel and rock fragments.

Silty Sand: 75 - 85 per cent very fine- to very coarse-grained sand, predominantly fine-grained becoming predominantly fine- to medium-grained toward the bottom; 15 per cent silt, becoming 20 per cent toward the bottom; 5 - 10 per cent gravel and rock fragments.



Lithology and Water-Bearing Properties

Silty Sand: similar to above interval, but more coarse-grained sand; iron oxide stains begin to appear on dried samples; water encountered at 312 feet, and subsequently rose to 300.14 feet below ground level.

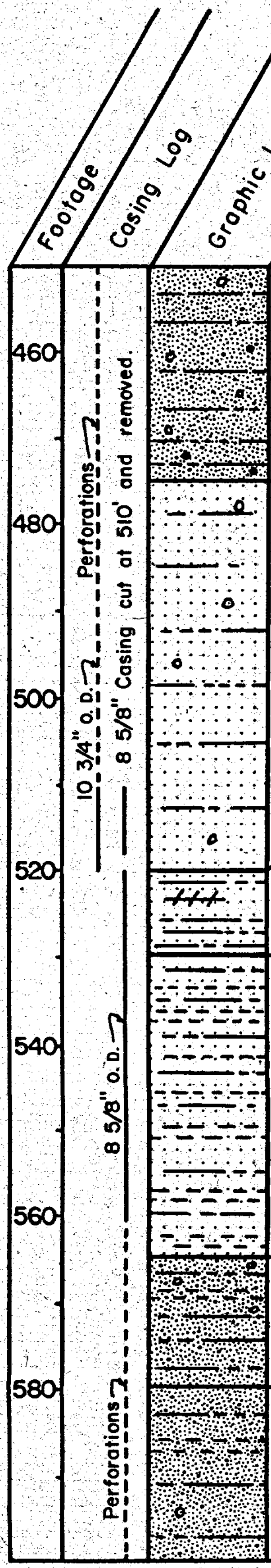
Sand: 90 per cent very fine- to very coarse-grained sand, predominantly fine- to medium-grained; 5 - 10 per cent silt; up to 5 per cent gravel.

Sand: similar to above, but coarser-grained.

Sand: 85 - 90 per cent very fine- to very coarse-grained sand, predominantly very fine- to medium-grained; 10 per cent silt; 5 per cent gravel.

Sand: 90 - 95 per cent very fine- to very coarse-grained sand, predominantly fine- and coarse-grained; 5 - 10 per cent silt; up to 5 per cent gravel.

Sand: 90 - 95 per cent very fine- to very-coarse-grained sand, alternating layers of predominantly medium- to very coarse-grains with predominantly fine- to medium-grains; 5 - 10 per cent silt; 5 per cent gravel; bottom five feet of interval is fine- and very coarse-grained sand.



Lithology and Water-Bearing Properties

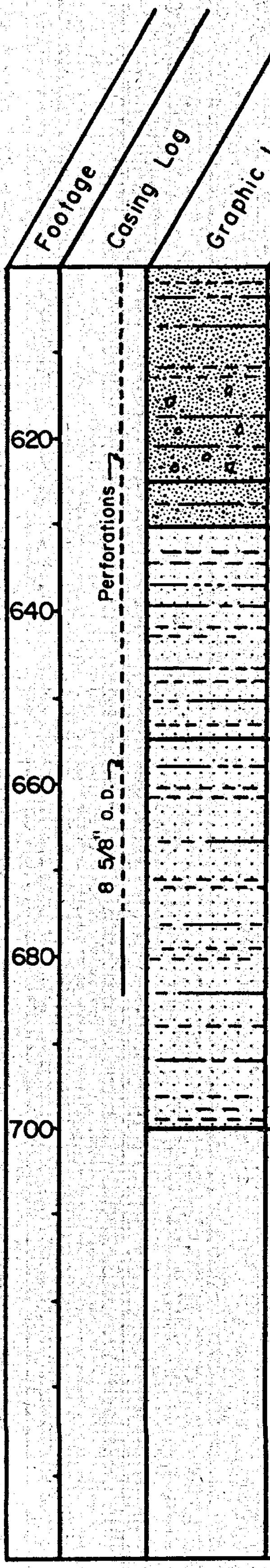
Sand: 95 per cent very fine- to medium-grained sand; 5 per cent silt; few gravels; this interval becomes coarser-grained toward the bottom.

Silty Sand: 85 per cent very fine- to very coarse-grained sand, predominantly very fine- to fine-grained; 15 per cent silt; some gypsum, variety selenite; coarser sand grains are angular to subangular.

Clayey, Silty Sand: 85 per cent very fine- to medium-grained sand, predominantly very fine- to fine-grained; 15 per cent silt; moderately plastic to plastic; becoming coarser-grained and less silty toward bottom of interval; this horizon serves as an aquitard between the two differentiated aquifers.

Sand: 90 - 95 per cent very fine- to very coarse-grained sand, angular to subrounded; 5 - 10 per cent silt toward the bottom; very slightly plastic; 5 per cent gravel toward the top.

Sand: 95 per cent very fine- to very coarse-grained sand, predominantly very fine- to medium-grained, becoming coarser toward the bottom; 5 per cent silt; non-plastic to very slightly plastic; some gravel and rock fragments toward the bottom.



Lithology and Water-Bearing Properties

Sand: 95 - 100 per cent very fine- to very coarse-grained sand, predominantly fine- to coarse-grained; less than 5 per cent silt.

Clayey, Silty Sand: 85 per cent very fine- to medium-grained sand, predominantly very fine- to fine-grained, becoming coarser-grained toward the bottom of the interval; 10 - 15 per cent silt; moderately plastic.

Sand: 90 - 100 per cent very fine- to medium-grained sand, some coarser grains; up to 5 per cent silt; alternating layers of slightly- to moderately plastic sands with non-plastic sands; bottom of interval is moderately plastic to 699 feet, the total depth of the well.

APPENDIX D

Lithologic Log of Test Hole H-2, Project Shoal, Churchill County, Nevada

GEOGRAPHIC DESCRIPTION: West flank of the Sand Springs Range, on the alluvial fan sloping toward Fourmile Flat.

NEVADA STATE COORDINATES: N. 1,631,585.0; E. 543,132.0.

GROUND ELEVATION: 4,017 feet above sea level.

TOTAL DEPTH: 780.0 feet below ground surface.

SAMPLED INTERVALS: Cable-tool cuttings taken either every five feet or at a distinct change of lithology.

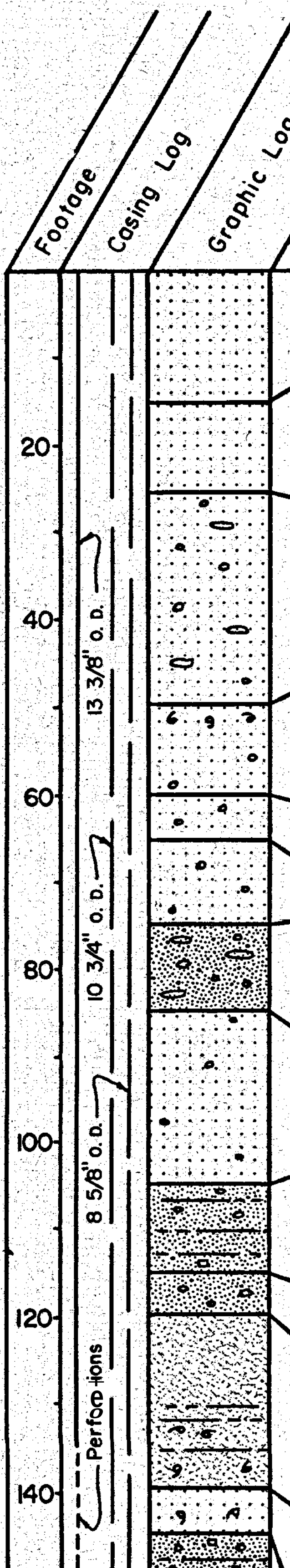
SUMMARY OF THE LITHOLOGY AND WATER-BEARING PROPERTIES:

Hydrologic Test Hole H-2 was drilled predominantly in subaerial and lacustrine sediments of Pleistocene to Recent age, and the section penetrated is possibly correlative to Lake Lahontan and post-Lake Lahontan stratigraphy as described by R. B. Morrison (U. S. G. S. Professional Paper 424-D, pp. 111-114, 1961). Description of the section is based on a binocular examination of the samples obtained by the cable-tool method of drilling. Procedure followed in describing the section is listed on page 98. The dominant lithology is fine- to medium-grained sand with varying amounts of clay, silt, and gravel. Several zones of cemented beach or near-shore deposits were encountered.

Some microfossils were found, almost always present in uniform, medium-grained sands.

Confined ground water was encountered in sand at a depth of 128.0 feet below ground surface. Overlying the sand aquifer is a possible beach or near-shore deposit of Lake Lahontan which was cemented by a calcerous and siliceous material.

HYDROLOGIC TEST WELL H-2 — 0-150 ft.



Lithology and Water-Bearing Properties

Sand: light-brown, with some green; 100 per cent very fine- to fine-grained sand, with medium grains, predominantly subrounded; non-frosted grains.

Similar to 0 - 15 feet, but predominantly fine- to medium-grained sand; up to 40 per cent of sand grains nonquartzose, including olivine, biotite mica, hornblende, fine-grained acid and basic volcanics, zircon.

Sand: 90 - 95 per cent very fine- to very coarse-grained sand, predominantly fine- to medium-grained; up to 30 per cent nonquartzose; slightly plastic at 45 - 50 feet; 5 - 10 per cent gravel, including some with ellipsoidal shape; possibly a beach or near-shore deposit of Lake Lahontan.

Sand: 100 per cent very fine- to medium-grained sand, predominantly subrounded; less than 10 per cent nonquartzose; some gravel toward bottom; microfossils present at 50 - 55 feet.

Similar to above, but light-green-brown; 30 - 40 per cent nonquartzose.

Similar to 50 - 60 feet, but subangular to subrounded; 25 per cent nonquartzose.

Sand: 90 per cent very fine- to very coarse-grained sand predominantly subrounded; 25 per cent nonquartzose; 10 per cent subrounded to ellipsoidal gravel; possibly a beach or near-shore deposit of Lake Lahontan.

Sand: 100 per cent very fine- to medium-grained sand, predominantly fine-grained, getting coarser-grained toward the bottom of the interval; up to 25 per cent nonquartzose; few gravels.

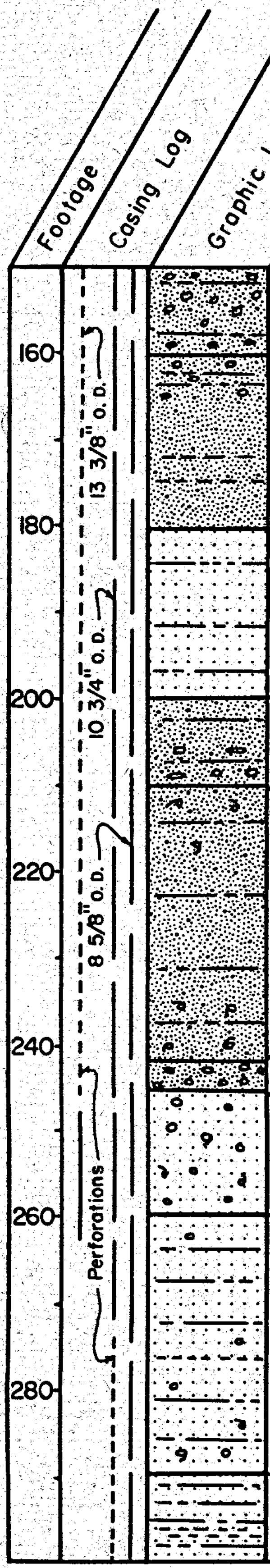
Sand: 90 - 95 per cent very fine- to very coarse-grained sand, predominantly subangular; up to 25 per cent nonquartzose; 5 - 10 per cent silt, increasing toward the bottom; 5 per cent subangular gravel; alluvium.

Similar to above, but more rounded sand and gravel; possibly beach or near-shore deposit of Lake Lahontan.

Sand: olive green-brown; 100 per cent very fine- to very coarse-grained sand, predominantly medium- to coarse-grained and subrounded; 25 - 30 per cent nonquartzose; water encountered at 128 feet and subsequently rose to 111 feet; 128-140: 5 per cent silt, slightly to moderately plastic, possibly contaminated by drilling mud; microfossils from 130-140 feet.

Sand: light-brown; 95 per cent very fine- to medium-grained; 20 per cent nonquartzose; microfossils.

HYDROLOGIC TEST WELL H-2 150-300 ft.



Lithology and <u>Water-Bearing Properties</u>

(145-160)
<u>Gravelly Sand</u>: gray-green-brown; 80 - 85 per cent very fine- to very coarse-grained sand, angular to subrounded; 40 per cent nonquartzose; up to 5 per cent silt; 10 - 15 per cent angular to subrounded gravel.

<u>Sand</u>: gray-green-brown; 90 - 100 per cent very fine- to very coarse-grained sand, becoming very fine- to medium-grained and angular to subrounded at 165 feet; 25 - 30 per cent non-quartzose; 5 per cent silt from 160 to 165 feet; slightly plastic from 170 to 180 feet, possibly contaminated; 5 per cent gravel from 160-165; alluvium.

<u>Sand</u>: light-gray-brown; 95 - 100 per cent very fine- to medium-grained sand; 20 per cent nonquartzose, increasing to 40 per cent at 195 feet; up to 5 per cent silt.

<u>Sand</u>: gray-light-brown; 95 per cent very fine- to very coarse-grained sand, angular to subrounded; 40 per cent nonquartzose; 5 per cent silt; rock fragments, subrounded to ellipsoidal gravel from 205 - 210.

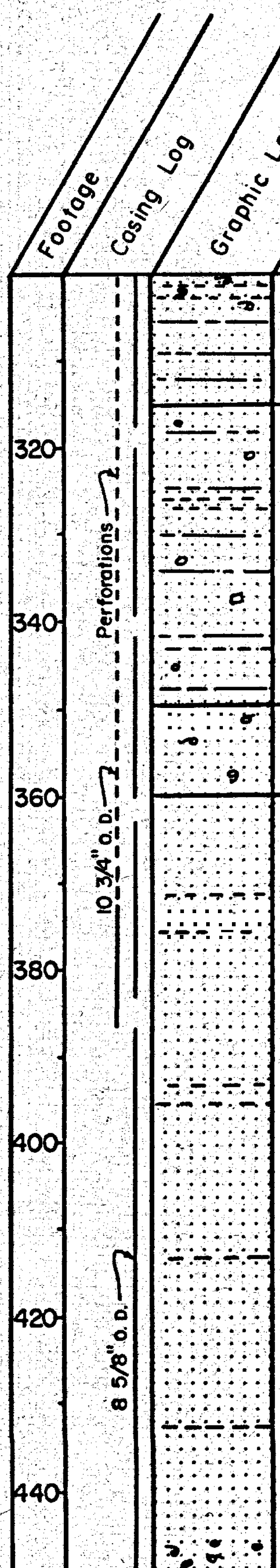
<u>Sand</u>: gray-green-light-brown; 95 - 100 per cent very fine- to very coarse-grained sand, predominantly very fine- to medium-grained from 210 to 215 feet; 30 - 40 per cent non-quartzose; 5 per cent silt; few gravels; microfossils present at 210 to 220 and 235 to 242 feet.

<u>Gravelly Sand</u>: gray-green-brown; 85 per cent very fine- to very coarse-grained sand; 40 per cent nonquartzose; 15 per cent gravel.

<u>Sand</u>: gray-green-brown; 95 per cent very fine- to coarse-grained sand, predominantly fine- to medium-grained; 15 - 20 per cent nonquartzose; 5 per cent gravel; microfossils present

<u>Sand</u>: gray-green-brown; 95 per cent very fine- to coarse-grained sand, predominantly very fine- to medium-grained; 15 - 25 per cent nonquartzose; 5 per cent silt; few gravels; very slightly plastic, may be apparent cohesion; microfossils present at 285 - 290 feet.

<u>Sand</u>: gray-light-brown; 90 per cent very fine- to very coarse-grained sand, (cont.)



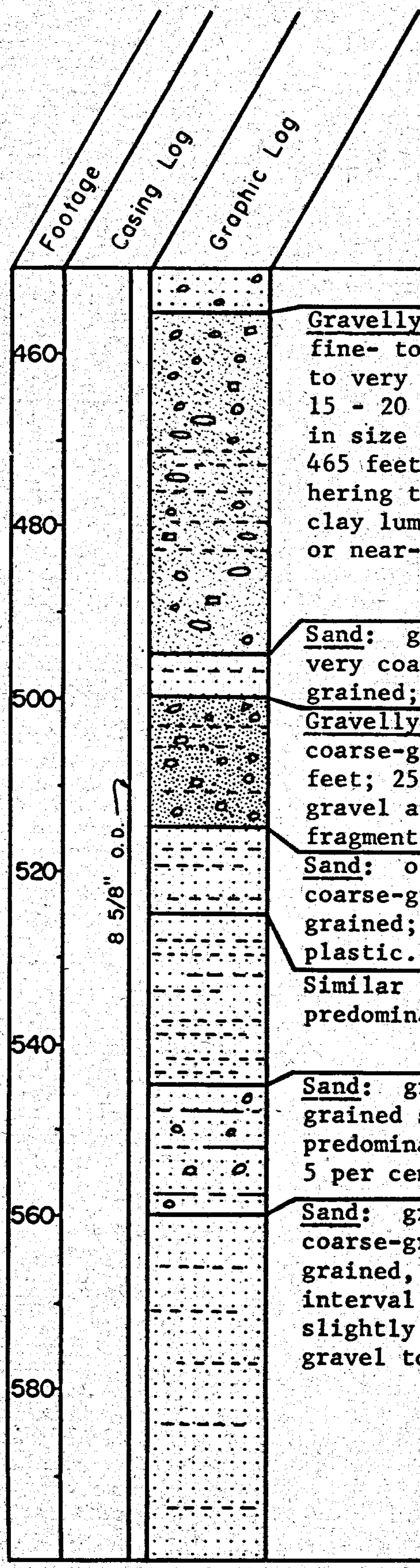
Lithology and Water-Bearing Properties

(cont. from 290 feet)
predominantly very fine- to medium-grained; 15 per cent nonquartzose; 10 per cent silt; slightly to moderately plastic; microfossils at 300 - 305 feet.

Similar to above, but up to 20 per cent nonquartzose; 5 per cent silt; nonplastic to slightly plastic; some gravel and rock fragments.

Similar to 315 - 350, but 100 per cent sand, microfossils present.

Sand: gray-green-brown; 95 - 100 per cent very fine- to very coarse-grained sand, predominantly very fine- to medium-grained from 360 to 445 feet; 20 per cent nonquartzose, becoming 25 - 30 per cent at 450 feet; nonplastic to slightly plastic; up to 5 per cent gravel from 445 feet; microfossils present at 445 to 450 feet.



Lithology and Water-Bearing Properties

Gravelly Sand: brown-green-gray; 80 - 85 per cent very fine- to very coarse-grained sand, predominantly medium- to very coarse-grained; 50 - 60 per cent nonquartzose; 15 - 20 per cent gravel and rock fragments, gravels increase in size and become more subrounded to ellipsoidal-shaped at 465 feet, some show a calcareous and siliceous cement adhering to their surface; some slightly to moderately plastic clay lumps present at 470 to 485; possibly a cemented beach or near-shore deposit of Lake Lahontan.

Sand: gray-green-brown; 95 - 100 per cent very fine- to very coarse-grained sand, predominantly very fine- to medium-grained; 15 per cent nonquartzose; slightly plastic.

Gravelly Sand: olive-green; 85 per cent very fine- to very coarse-grained sand, becoming 90 - 95 per cent sand at 505 feet; 25 per cent nonquartzose; slightly plastic; 15 per cent gravel and rock fragments, some cement present on larger fragments.

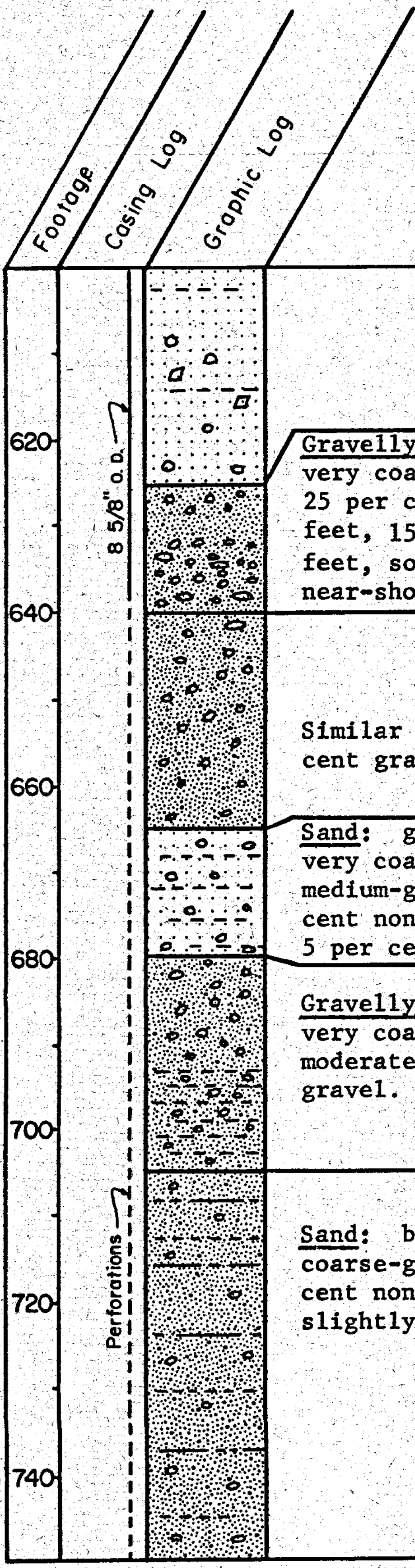
Sand: olive-green-brown; 95 - 100 per cent very fine- to coarse-grained sand, predominantly very fine- to medium-grained; 20 - 25 per cent nonquartzose; slightly to moderately plastic.

Similar to 515 - 525 feet, but plastic to very plastic; still predominantly a sand lithology.

Sand: gray-brown; 90 - 95 per cent very fine- to medium-grained sand, becoming coarser-grained toward the bottom, predominantly subangular; 20 - 25 per cent nonquartzose; 5 per cent silt; up to 5 per cent gravel.

Sand: gray-green-brown; 100 per cent very fine- to very coarse-grained sand, predominantly very fine- to medium-grained, becoming coarser-grained toward the bottom of interval; 15 - 20 per cent nonquartzose; non-plastic to slightly plastic; up to 5 per cent angular to subrounded gravel toward the bottom of the interval.

HYDROLOGIC TEST WELL H-2 600-750 ft.



Lithology and Water-Bearing Properties

<u>Gravelly Sand</u>: gray-green-brown; 85 per cent very fine- to very coarse-grained sand, becoming 60 per cent at 630 feet; 25 per cent nonquartzose, becoming 25 - 50 per cent at 630 feet, 15 per cent gravel becoming 40 per cent gravel at 630 feet, some of gravels are ellipsoidal; possible beach or near-shore deposit of Lake Lahontan.

Similar to above, but 15 - 20 per cent nonquartzose, 15 per cent gravel.

<u>Sand</u>: gray-green-brown; 95 - 100 per cent very fine- to very coarse-grained sand, predominantly very fine- to medium-grained toward the bottom of interval; 15 - 20 per cent nonquartzose; slightly to moderately plastic; up to 5 per cent gravel.

<u>Gravelly Sand</u>: brown-gray; 85 - 90 per cent very fine- to very coarse-grained sand; 20 - 25 per cent nonquartzose; moderately plastic from 695 to 705 feet; 10 - 15 per cent gravel.

<u>Sand</u>: brown-gray; 90 - 100 per cent very fine- to very coarse-grained sand, angular to subrounded; 15 - 25 per cent nonquartzose; up to 5 per cent silt; nonplastic to slightly plastic; 5 per cent gravel.

Footage	Casing Log	Graphic Log	Lithology and Water-Bearing Properties
760	8 5/8" O.D.?		**Gravelly Sand**: gray-brown; 80 per cent very fine- to very coarse-grained sand; 40 - 50 per cent nonquartzose; slightly plastic to plastic, decreasing in plasticity above and below the 760 to 765 foot interval.
780	OPEN HOLE		

APPENDIX E

Lithologic Log of Test Hole H-3, Project Shoal, Churchill County, Nevada

GEOGRAPHIC DESCRIPTION: West flank of the Sand Springs Range, on the alluvial fan sloping toward Fourmile Flat.

NEVADA STATE COORDINATES: N. 1,627,331.86; E. 548,884.86.

GROUND ELEVATION: 4,232.2 feet above sea level.

TOTAL DEPTH: 480.0 feet below ground level.

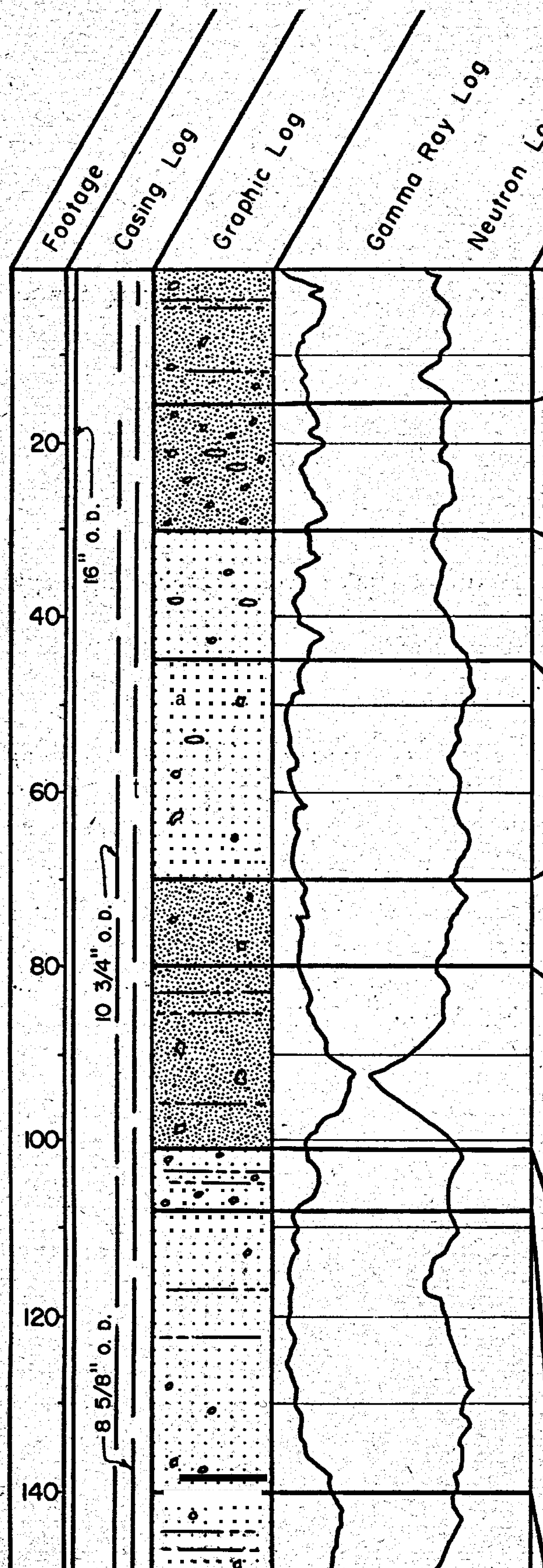
SAMPLED INTERVALS: Cable-tool cuttings taken either every five feet or at a distinct change of lithology.

SUMMARY OF THE LITHOLOGY AND WATER-BEARING PROPERTIES:

Hydrologic Test Hole H-3 was drilled in Quaternary alluvium, consisting of sands with varying amounts of clay, silt, and gravel, and in a weathered granitic bedrock of late Mesozoic(?) age. Description of the section is based on a binocular examination of the samples obtained by the cable-tool method of drilling. Procedure followed in describiing the section is listed on page 98.

Confined ground water was encountered in slightly to heavily weathered granitic bedrock at a depth of 361.0 feet below the ground surface. Approximately 70 feet of silty, sandy alluvium and residual, clayey, silty, sand-sized particles derived from the weathering of granite bedrock overlie the top of the aquifer, which is probably a fractured and weathered zone in the bedrock.

HYDROLOGIC TEST WELL H-3 — 0-150 ft.



Lithology and Water-Bearing Properties

Sand: 95 - 100 per cent very fine- to very coarse-grained sand; up to 5 per cent silt; some gravel and rock fragments; subaerial sediments.

Gravelly Sand: 85 per cent very fine- to very coarse-grained sand; less than 5 per cent silt; 10 - 15 per cent gravel, subrounded and ellipsoidal-shaped; possible Lake Lahontan beach or near-shore deposit.

Sand: green-gray-brown; 95 - 100 per cent very fine- to medium-grained sand, a few coarse-grains, predominantly subrounded, ellipsoidal; very calcareous; beach or near-shore deposit of Lake Lahontan.

Similar to 30 - 45, but brown again; more coarse-grained; some angular rock fragments; noncalcareous to slightly calcareous.

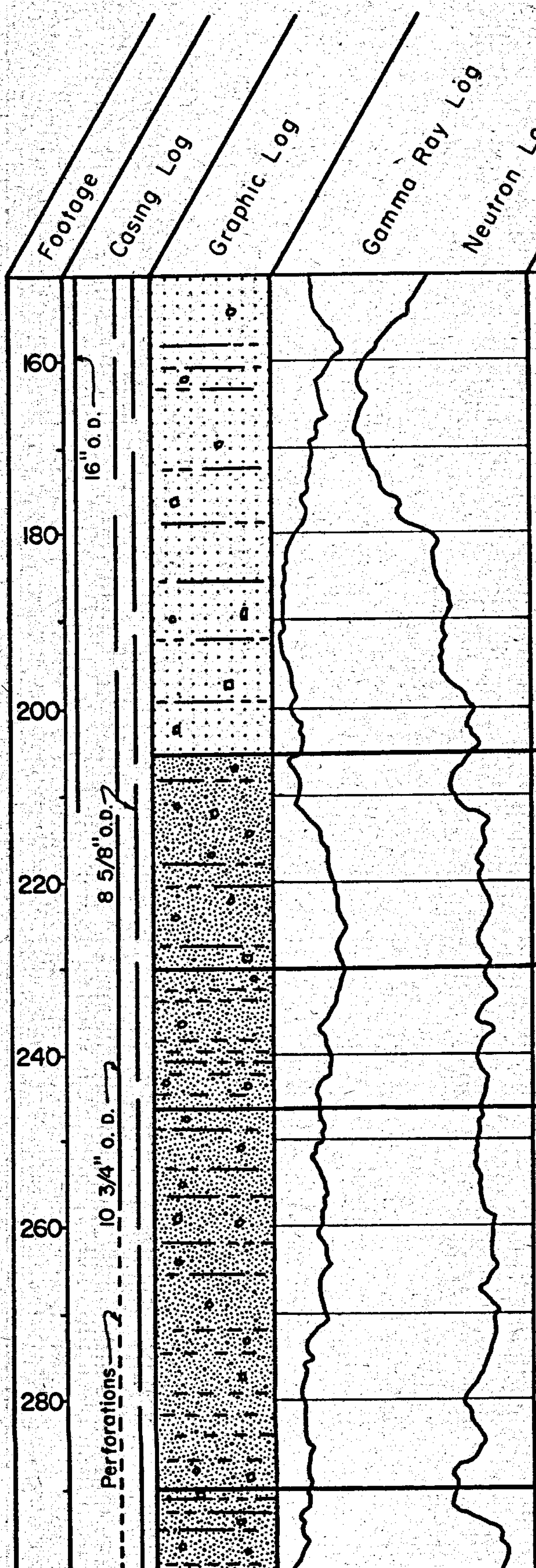
Sand: 95 per cent very fine- to very coarse-grained sand; less than 5 per cent silt; up to 5 per cent gravel and rock fragments; subaerial sediments.

Sand and Sand-sized Particles: 90 - 95 per cent very fine- to very coarse-grained sand-sized particles angular to subrounded; up to 10 per cent silt-sized particles; 5 - 10 per cent rock fragments up to one inch in diameter; sample becomes finer toward the bottom of interval; at 80 to 101 feet a boulder field was encountered.

Sand: 80 - 90 per cent very fine- to very coarse-grained sand, predominantly very fine- to medium-grained; up to 10 per cent silt; 10 per cent gravel, with suggestions of reworking by waves; many basic rock fragments; trace of water encountered at 101 feet, but possibly was drilling water.

Sand: 90 - 95 per cent very fine- to very coarse-grained sand, predominantly very fine- to medium-grained, not all quartzose; 5 per cent silt; up to 5 per cent gravel and some rock fragments; becomes coarser toward the

NOTE: Gamma Ray - Neutron Log Horizontal scale reduced to 1/4 of Vertical scale.



Lithology and Water-Bearing Properties

bottom of the interval.
(cont. from 140 feet)

Sand: 85 - 90 per cent very fine- to medium-grained sand, some coarser grains; 10 - 15 per cent silt; some gravels and rock fragments; more rock fragments toward the bottom of the interval.

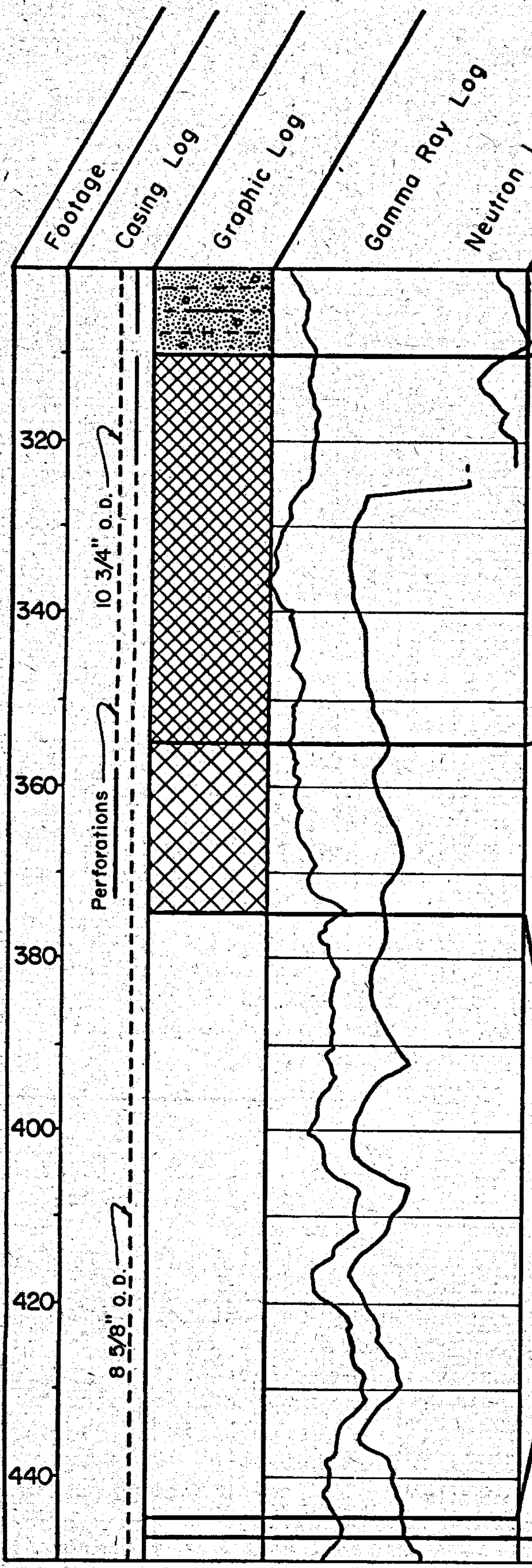
Sand: 85 - 90 per cent very fine- to very coarse-grained, angular to subrounded; 5 - 10 per cent silt; 5 - 10 per cent gravel and rock fragments of both acid and basic igneous origin; many dark, heavy minerals.

Clayey Sand: 85 - 90 per cent very fine- to very coarse-grained sand; up to 5 per cent silt; slightly plastic to plastic; up to 5 per cent gravel.

Sand: same as the 205 - 220 sample interval, becoming slightly plastic to moderately plastic at 270 feet.

Silty Sand: 85 - 90 per cent very fine- to very coarse-grained sand, angular to subrounded; 10 - 15 per cent silt; 5 per cent gravel and rock fragments, angular to subrounded, including much basic igneous material; sample becomes slightly to moderately plastic and color becomes more yellow-brown at 295 feet.

HYDROLOGIC TEST WELL H-3 — 300-450 ft.



Lithology and Water-Bearing Properties

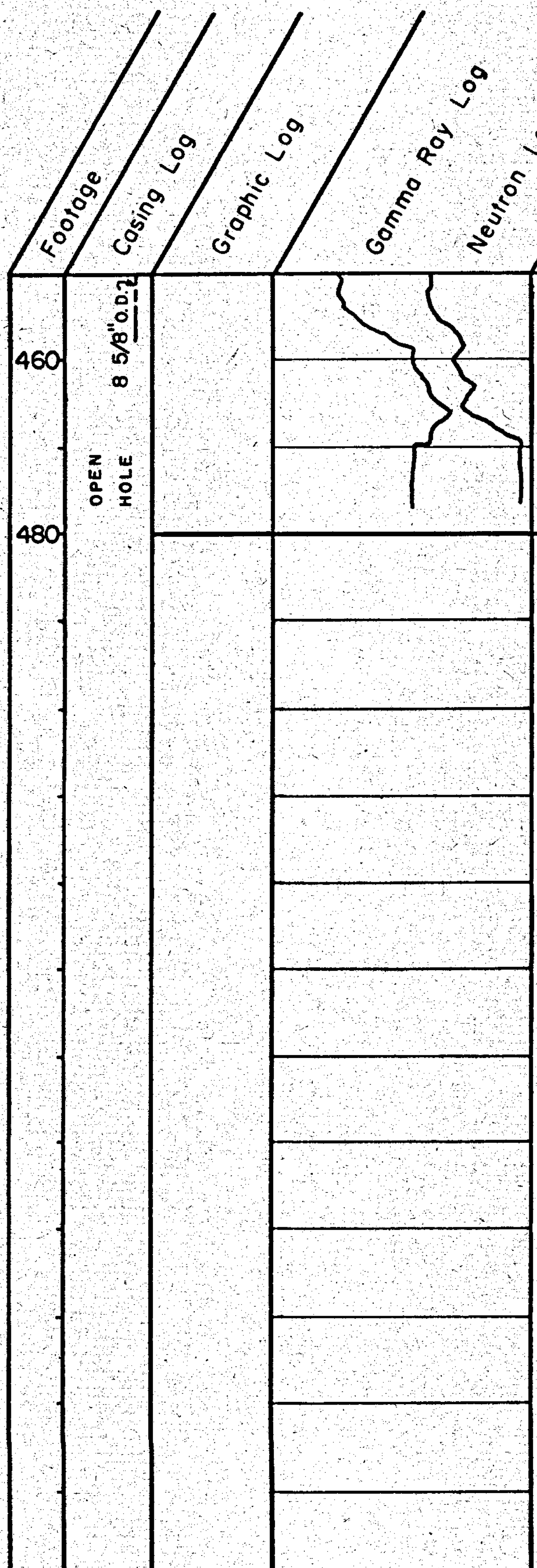
Clayey, Silty Sand-sized Particles: yellow-brown; 85 per cent very fine- to fine-grained sand-sized particles, some coarser materials, angular to subrounded, predominantly angular; up to 15 per cent silt or silt-sized particles; moderately plastic to plastic; apparently a weathered bedrock surface was encountered at 310 feet, with some alluvial material present (possibly as contamination from above); much limonite staining; biotite present in larger amounts than previously; becomes less plastic toward bottom of interval.

Similar to above interval, but only slightly weathered bedrock; a make-shift core barrel brought up a three-inch core of acidic, coarse-textured igneous material; core has limonite and clay streaks; feldspars are all plagioclases; water was encountered at 361 feet below the ground and subsequently rose to 329 feet; a possible fractured zone occurs at 361 feet as the drilling tool was caught there; differences in percentage of fine to coarse fragments may be due to differences in degree of hardness of bedrock.

Sand-sized Particles: 100 per cent very fine- to very coarse-grained sand-sized particles, angular to subangular; noncalcareous; sample clean and fresh, becoming slightly to moderately plastic toward bottom of interval.

Clayey Sand-sized Particles: gray; very fine- to very coarse-sized, angular to subangular; 5 per cent silt-sized particles; plastic; slightly calcareous; probably a clay streak in weathered bedrock.

HYDROLOGIC TEST WELL H-3 450-480 ft.



Lithology and Water-Bearing Properties

Sand-sized Particles: very fine- to very coarse-sized, angular to subangular; 5 - 10 per cent silt-sized particles; moderately plastic toward the bottom of the interval.

APPENDIX F

Lithologic Log of Test Hole H-4, Project Shoal, Churchill County, Nevada

GEOGRAPHIC DESCRIPTION: East flank of the Sand Springs Range, in Fairview Valley, 149.50 feet N. 15° 01′ 18″ E. of HS-1.

NEVADA STATE COORDINATES: N. 1,622,285.67; E. 576,914.39.

GROUND ELEVATION: 4,241.92 feet above sea level.

TOTAL DEPTH: 935.0 feet below ground surface.

SAMPLED INTERVALS: Cable-tool cuttings taken either every five feet or at a distinct change of lithology.

SUMMARY OF THE LITHOLOGY AND WATER-BEARING PROPERTIES:

Hydrologic Test Hole H-4 was drilled in Quaternary alluvium consisting predominantly of sands with varying amounts of clay, silt, and gravel, and Tertiary (?) bedrock. Description of the section is based on a binocular examination of samples obtained by the cable-tool method of drilling. Procedure followed in describing the alluvial rock fragments is listed on page 98.

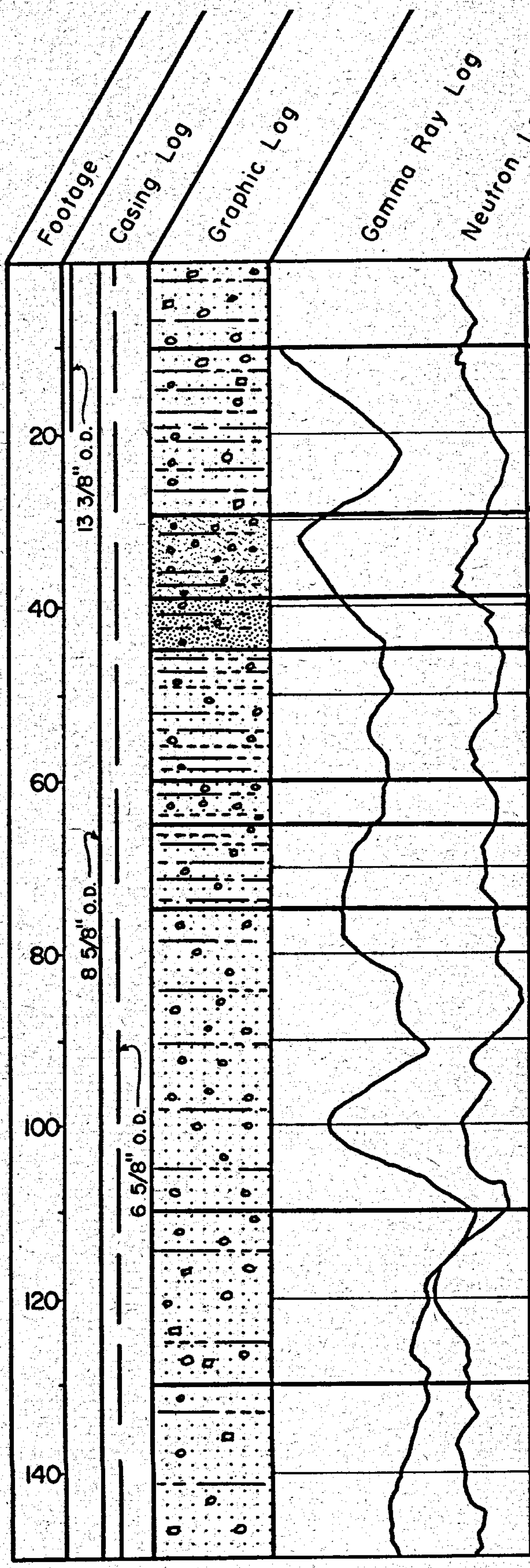
Confined ground water was encountered in sand at a depth of 310.0 feet below ground surface. Overlying the top of the sand aquifer is approximately 65.0 feet of fine-grained, silty sand. After drilling to a depth of 530.0 feet below ground surface a fine-grained, clayey sand was encountered, approximately 35.0 feet thick. This interval serves as an aquitard between the upper and lower aquifers, the latter consisting predominantly of sand, with a higher percentage of clay and silt than the upper aquifer.

At a depth of 813.0 feet below ground surface a distinct lithologic change was encountered, with subsequent changes in the sample of color, texture, percentage and nature of the accessory minerals, as well as an increase in the drilling time required per foot. The possibility of Tertiary bedrock from 813.0 feet to the bottom of the hole at 935.0 feet exists.

H-4 was later plugged at a depth of 708 feet below ground surface.

HYDROLOGIC TEST WELL H-4

0-150 ft.



Lithology and Water-Bearing Properties

Sand: 85 per cent fine- to medium-grained sand; 5 per cent silt; 10 per cent gravel; organic debris.

Silty Sand: 75 per cent very fine- to coarse-grained sand, predominantly very fine- to fine-grained; 15 - 20 per cent silt; 5 - 10 per cent gravel.

Sand: 85 per cent fine- to very coarse-grained sand, predominantly medium- to very coarse-grained; 5 per cent silt, increasing toward the bottom of interval; 10 percent gravel, decreasing toward the bottom of interval.

Sand: 80 per cent fine- to coarse-grained sand; 5 per cent silt; slightly plastic; 5 per cent gravel.

Silty Sand: 70 per cent very fine- to very coarse-grained sand, predominantly very fine- to medium-grained; 15 - 20 per cent silt; slightly plastic; up to 5 per cent gravel.

Sand: 90 per cent very fine- to medium-grained; less than 5 per cent silt; 5 - 10 per cent gravel; very slightly plastic.

Silty Sand: 80 - 85 per cent very fine- to coarse-grained sand, predominantly very fine- to medium-grained; 10 - 15 per cent silt; very slightly plastic toward top of interval; up to 5 per cent gravel.

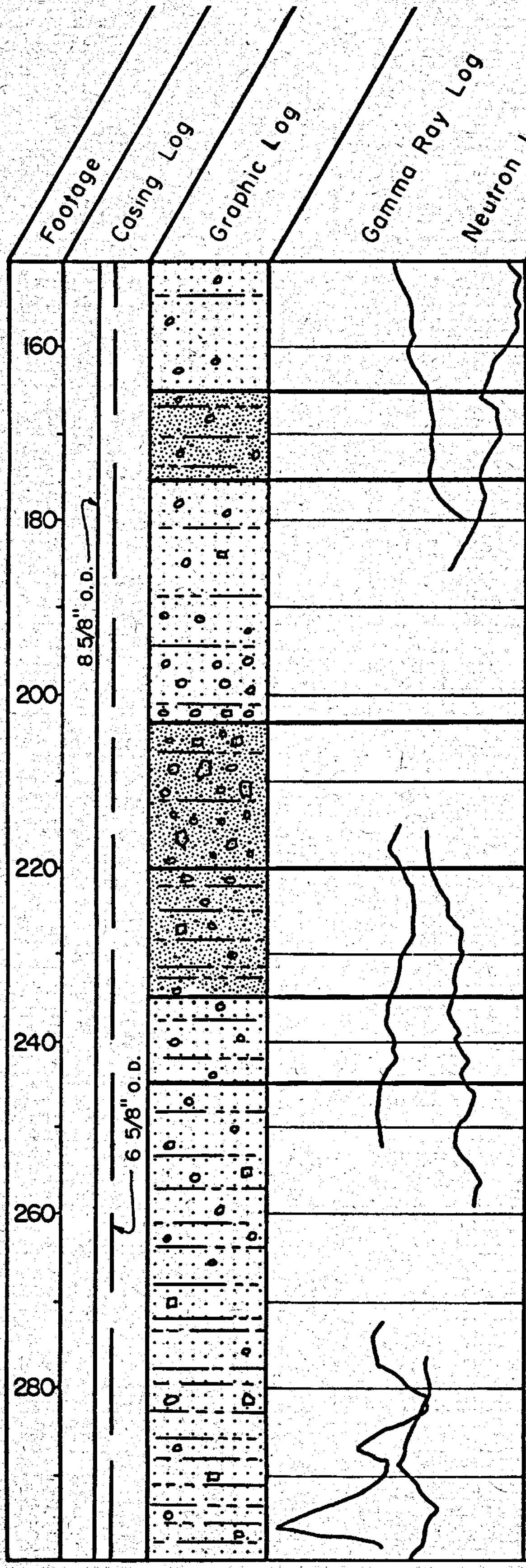
Sand: 85 - 95 per cent very fine- to very coarse-grained sand, predominantly very fine- to medium-grained; 5 per cent silt; 5 - 10 per cent gravel.

Sand: 90 per cent very fine- to fine-grained sand, some medium- and coarse-grained; less than 5 per cent silt; 5 - 10 per cent gravel and rock fragments.

Sand: 90 per cent very fine- to medium-grained sand, some coarser-grained; 5 per cent silt; 5 per cent gravel and rock fragments.

NOTE: Gamma Ray - Neutron Log Horizontal scale reduced to 1/4 of Vertical scale.

HYDROLOGIC TEST WELL H-4 150-300 ft.



Lithology and Water-Bearing Properties

Sand: similar to sample interval 130-150, but less silt and rock fragments.

Sand: 85 - 90 per cent very fine- to very coarse-grained sand, with little medium- to coarse-grains toward the top of interval; 5 - 10 per cent silt; 5 per cent gravel.

Sand: 85 - 90 per cent very fine- to very coarse-grained sand, predominantly fine-grained; 5 per cent silt; 5 - 10 per cent gravel and rock fragments; becomes coarser with more gravels toward the bottom of interval.

Gravelly Sand: 60 - 80 per cent fine- to coarse-grained sand; 5 per cent silt; 15 - 40 per cent gravel and rock fragments, up to cobble size; boulder field encountered at this interval; becomes 85 - 90 per cent very fine- to very coarse-grained sand below the bottom five feet of interval.

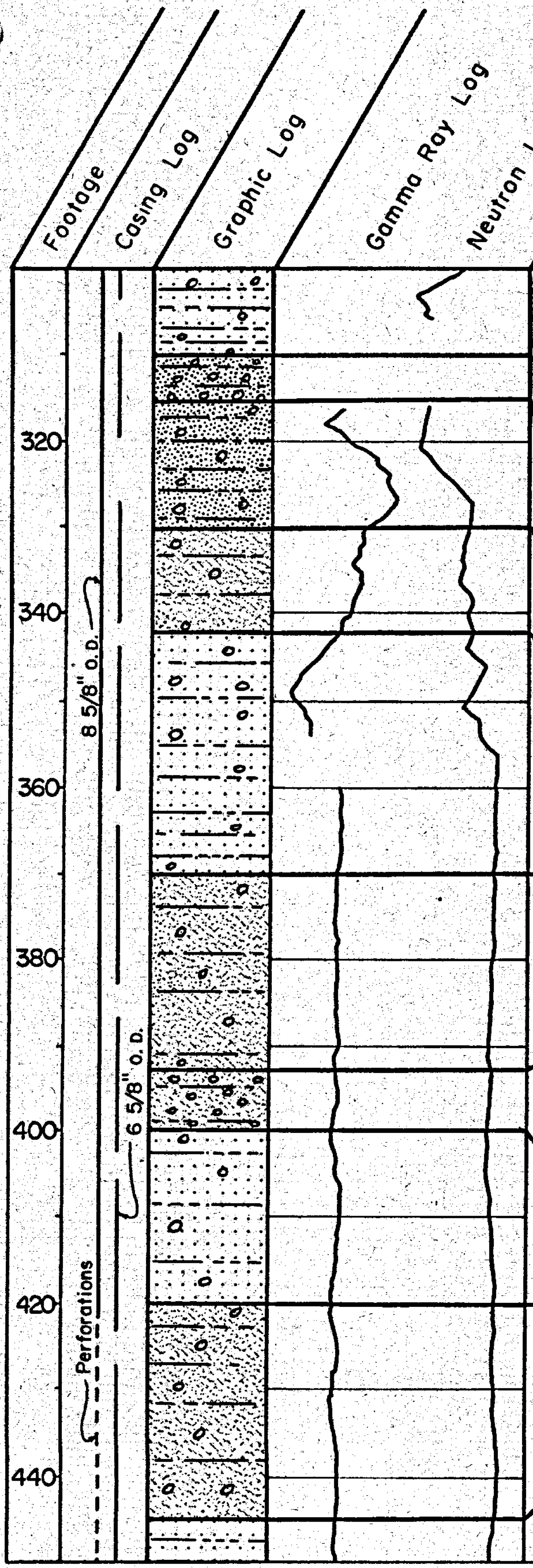
Silty Sand: 80 - 85 per cent very fine- to very coarse-grained sand; 10 - 15 per cent silt; 5 per cent gravel and rock fragments.

Sand: 90 - 95 per cent very fine- to very coarse-grained sand, predominantly fine-grained; 5 per cent silt; up to 5 per cent gravel.

Silty Sand: 80 - 85 per cent very fine- to very coarse-grained sand, predominantly fine-grained; 15 per cent silt; 5 per cent gravel and rock fragments; becomes siltier toward bottom of interval.

NOTE: Neutron Log plotted .2" right of actual reading.

HYDROLOGIC TEST WELL H-4 300-450 ft.



Lithology and Water-Bearing Properties

Silty Sand: similar to interval 245-300, but more coarse-grained sand and gravel; water encountered at 310 feet and subsequently rose to 299.2 feet below ground level.

Gravelly Sand: 80 per cent very fine- to very coarse-grained sand; up to 10 per cent silt; 10 - 15 per cent gravel; iron oxide stains begin to appear on dried sample.

Sand: 85 - 90 per cent very fine- to very coarse-grained sand; 10 - 15 per cent silt; 5 - 10 per cent gravel.

Sand: similar to above sample, but predominantly medium- to very coarse-grained sand, 5 per cent silt.

Sand: 85 - 90 per cent very fine- to very coarse-grained sand, predominantly very fine- to medium-grained; 10 per cent silt, increasing toward bottom of interval; 5 per cent gravel, decreasing toward bottom of interval.

Sand: 90 - 95 per cent very fine- to very coarse-grained sand, predominantly medium- to very coarse-grained but becoming finer-grained toward the bottom of interval; 5 per cent silt; 5 per cent gravel.

Gravelly Sand: 80 - 85 per cent very fine- to very coarse-grained sand, predominantly medium- to very coarse-grained; 5 per cent silt; up to 15 per cent gravel.

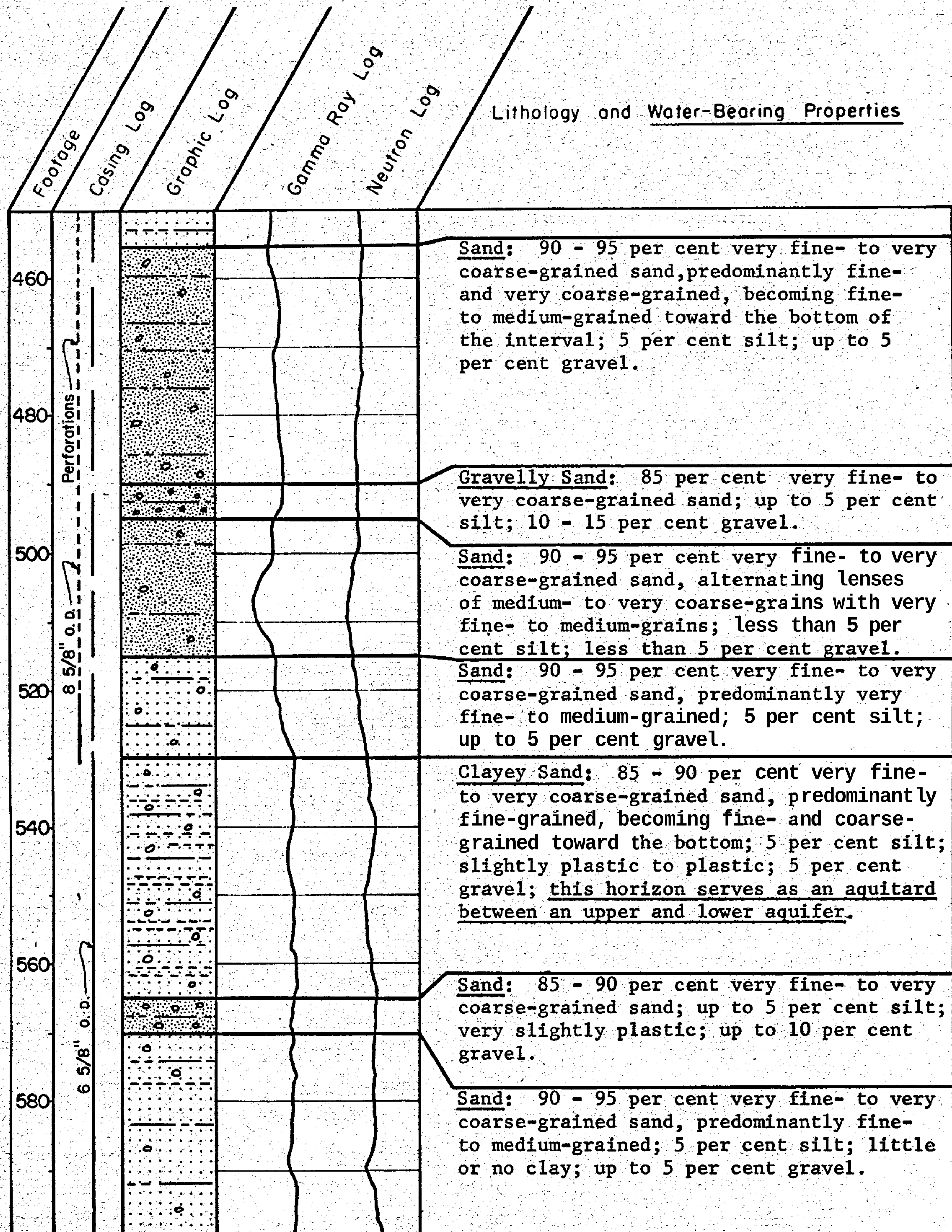
Sand: 90 per cent very fine- to very coarse-grained sand, predominantly very fine- to medium-grained; 5 per cent silt; 5 per cent gravel.

Sand: 85 - 90 per cent very fine- to very coarse-grained sand, predominantly medium- to very coarse-grained; 5 per cent silt; 5 per cent gravel.

Sand: 95 per cent very fine- to medium-grained sand; 5 per cent silt.

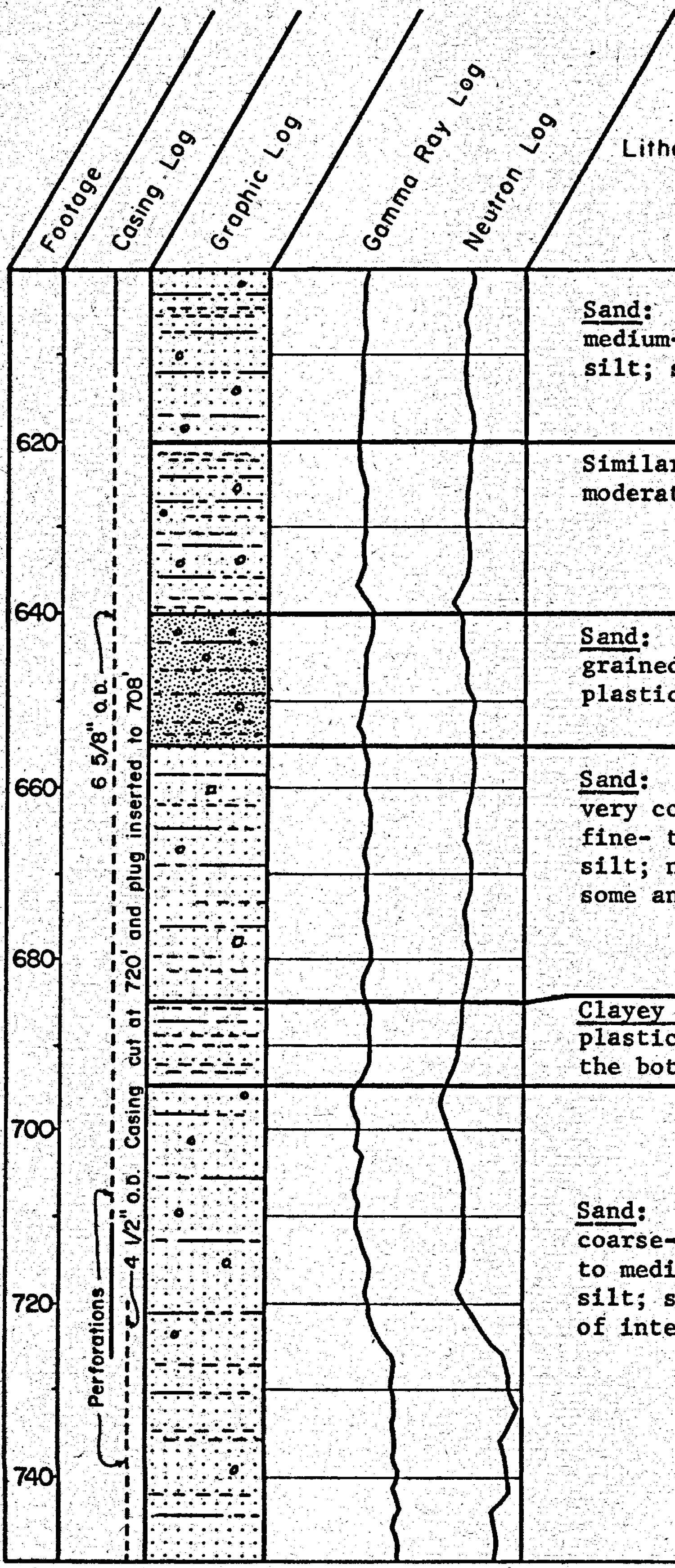
NOTE: Neutron Log plotted .5" right of actual reading.

HYDROLOGIC TEST WELL H-4 450-600 ft.



NOTE: Neutron Log plotted .25" right of actual reading.

HYDROLOGIC TEST WELL H-4 600-750 ft.



Lithology and Water-Bearing Properties

<u>Sand</u>: 85 - 90 per cent very fine- to medium-grained sand; 5 - 10 per cent silt; slightly plastic; few gravels.

Similar to 605 - 620, but slightly to moderately plastic.

<u>Sand</u>: 90 per cent very fine- to coarse-grained sand; 5 per cent silt; slightly plastic; few gravels.

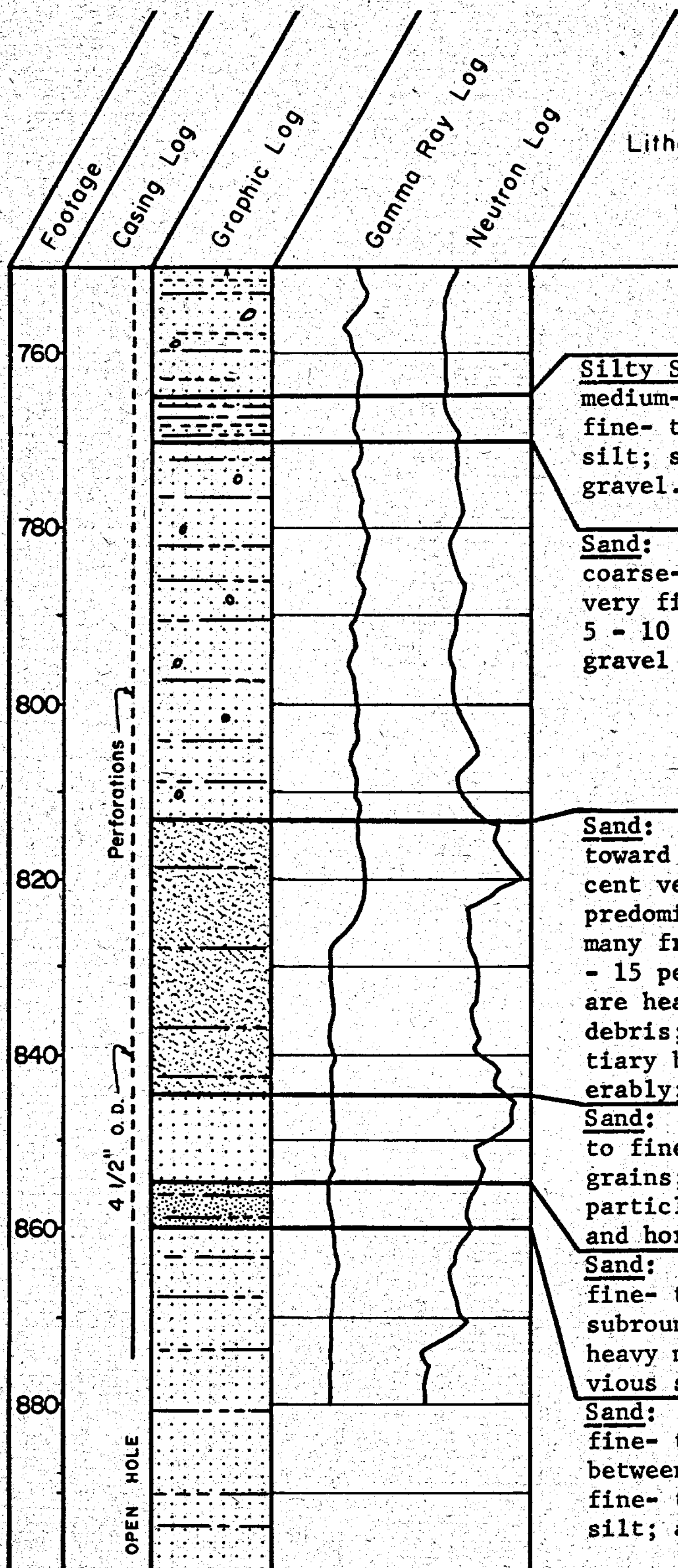
<u>Sand</u>: 90 - 95 per cent very fine- to very coarse-grained sand, predominantly fine- to medium-grained; 5 per cent silt; non-plastic to slightly plastic; some angular gravel.

<u>Clayey Sand</u>: similar to 655 - 685, but plastic, decreasing in plasticity toward the bottom of the interval.

<u>Sand</u>: 95 - 100 per cent very fine- to coarse-grained sand, predominantly fine- to medium-grained; less than 5 per cent silt; slightly plastic in the lower half of interval; few gravels.

NOTE: Neutron Log plotted .25" right of actual reading.

HYDROLOGIC TEST WELL H-4 750-900 ft.



Lithology and Water-Bearing Properties

Silty Sand: 80 - 85 per cent very fine- to medium-grained sand, predominantly very fine- to fine-grained; 10 - 15 per cent silt; slightly to moderately plastic; no gravel.

Sand: 90 - 95 per cent very fine- to very coarse-grained sand, becoming predominantly very fine- to medium-grained at 780 feet; 5 - 10 per cent silt; few gravels, but all gravel is of basic igneous debris.

Sand: light-brown, becoming light-gray toward the bottom of the interval; 95 per cent very fine- to coarse-grained sand, predominantly medium- to coarse-grained, many frosted grains; 5 per cent silt; 10 - 15 per cent of the sand-sized particles are heavy minerals and basic igneous debris; possibility of consolidated Tertiary bedrock; drilling rate slowed considerably; many oxidation stains.

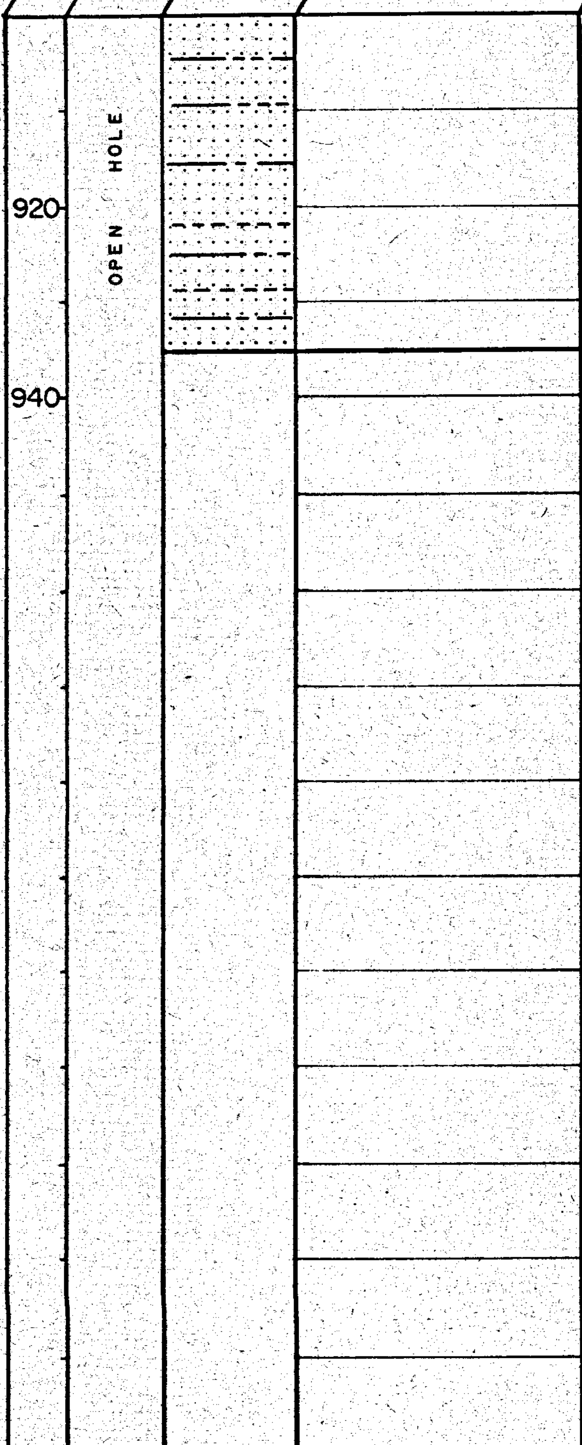
Sand: gray; 95 - 100 per cent very fine- to fine-grained sand, with some medium-grains; up to 20 per cent of sand-sized particles are nonquartzose; much biotite and hornblende.

Sand: light-gray; 95 - 100 per cent very fine- to very coarse-grained, angular to subrounded; up to 5 per cent silt; many heavy minerals; definite change from previous sample, may indicate bedding.

Sand: light-brown; 90 - 95 per cent very fine- to medium-grained, alternating between predominantly fine-grained and fine- to medium-grained; 5 - 10 per cent silt; accessory minerals 5 per cent.

NOTE: Gamma Ray Log plotted .25" left of actual reading.

Footage | Casing Log | Graphic Log | Gamma Ray Log | Neutron Log | Lithology and Water-Bearing Properties



Sand: similar to 860 - 900, some slight plasticity or apparent cohesion to sample; heavy minerals increase toward the bottom of the interval; calcareousness increases toward the bottom of the interval; absence of gravels since 813 feet may be significant in indicating a non-alluvial sequence.

APPENDIX G

ANALYSES OF WATER FROM WELLS, SPRINGS, AND INTERMITTENT STREAMS INVENTORIED FOR PROJECT SHOAL, CHURCHILL COUNTY, NEVADA

Analyses by Abbot A. Hanks, Inc., San Francisco, California

Quantities in Parts Per Million

Analysis No.*	pH	Total Solids (600° C)	Calcium	Magnesium	Sodium	Potassium	Iron	Silica	Sulfate	Chloride	Carbonate (As $CaCO_3$)	Bicarbonate (As $CaCO_3$)	Alkalinity (Methyl Orange) (As $CaCO_3$)
HS-1	7.4	282	27	4	77	33	4	58	53	43	—	115	115
H-4[1]	7.9	265	27	3	108	9	3	51	39	22	1	132	133
H-4[2]	8.0	338	33	5	50	3	4	59	42	28	10	149	138
H-3	7.7	1360	121	70	280	11	1	14	150	705	1	106	107
H-2	7.7	31930	321	313	11600	34	1	32	3570	15950	16	1370	115
1	7.4	704	83	8	416	28	10	42	64	33	—	78	78
2	8.4	9155	5	2	3745	55	2	37	1220	4080	6	541	547
3	8.9	2230	1	1	1023	32	3	29	240	860	10	406	416
4	9.4	970	4	2	370	11	2	11	109	246	77	327	395
5	7.5	3865	53	15	1415	82	4	93	410	1760	5	316	321
6	8.1	2910	11	2	1170	38	2	14	260	1350	5	313	318
7	7.7	3170	73	10	1160	74	3	7	342	1460	7	317	324
8	8.5	5660	5	5	2610	46	2	2	588	2360	15	820	835
9	8.9	3115	1	1	1490	20	1	8	464	1110	13	473	486
10	8.7	4820	1	1	2015	95	3	46	495	2155	12	423	435
11	9.5	35150	5	2	14250	26	3	51	550	12760	3980	3290	9325
12						No analysis							
13	8.6	775	10	12	280	9	2	42	115	46	48	525	545
14	8.5	3120	2	4	1380	32	2	34	6	1300	84	104	1090
15	8.0	934	3	7	340	16	2	47	9	37	25	760	870
16	7.4	260	24	6	76	25	4	50	42	281	—	116	116
17	7.6	918	10	4	475	37	6	50	186	142	0.8	391	392
18	8.3	990	9	3	345	18	1	70	184	131	34	475	445
19-22						No analysis							

*Refer to Plate 9 for location of water point corresponding to each analysis number.
[1]Upper aquifer.
[2]Lower aquifer.

ANALYSES OF WATER FROM WELLS, SPRINGS, AND INTERMITTENT STREAMS INVENTORIED FOR PROJECT SHOAL, CHURCHILL COUNTY, NEVADA

Quantities in Parts Per Million

Analysis No.*	pH	Total Solids (600° C)	Calcium	Magnesium	Sodium	Potassium	Iron	Silica	Sulfate	Chloride	Carbonate (As $CaCO_3$)	Bicarbonate (As $CaCO_3$)	Alkalinity (Methyl Orange) (As $CaCO_3$)
23	7.4	440	50	9	88	8	2	43	111	71	2	186	152
24	8.2	334	16	1	139	6	3	29	58	71	1	112	113
25	8.2	302	29	1	110	5	2	40	76	34	1	92	93
26	7.9	3995	950	108	55	3	1	8	1730	1090	4	125	108
27-29	No analysis												
30	8.0	645	95	14	86	12	1	4	88	89	4	345	290
31	7.9	362	43	7	107	12	2	39	91	57	0	143	143
32	7.9	200	28	5	39	7	2	13	20	25	1	162	135
33	8.6	645	1	2	235	3	2	30	149	44	24	315	340
A[3]	8.0	342	16	5	106	6	10	100	55	39	0	103	103
B	7.7	288	23	4	95	4	16	74	41	25	0	107	107
C	7.7	253	24	3	94	5	8	51	37	25	0	112	112
Top[4] Sample	8.1	363	78	7	81	5	1	24	85	106	8	198	177
Middle[4] Sample	8.2	398	83	10	74	4	1	13	98	114	8	168	151
Bottom[4] Sample	8.1	402	79	7	77	8	3	15	90	120	5	170	147
Total[4] Sample	8.5	388	63	10	86	9	2	49	92	100	15	184	176

*Refer to Plate 9 for location of water point corresponding to each analysis number.
[3]Letters refer to surface water (intermittent streams).
[4]These are ECH-D samples taken from elevations 3892 to 4120.