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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Federal Center, Denver, Colorado 80225

GEOLOGY, PHYSICAL PROPERTIES, AND SURFACE EFFECTS AT DISCUS THROWER SITE, YUCCA FLAT, NEVADA TEST SITE

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GEOLOGY, PHYSICAL PROPERTIES, AND SURFACE EFFECTS AT DISCUS THROWER SITE, YUCCA FLAT, NEVADA TEST SITE

By

W. J. Carr, C. H. Miller, and H. W. Dodge, Jr.

ABSTRACT

Geologic studies in connection with Project Discus Thrower have furnished detailed stratigraphic and structural information about northwestern Yucca Flat. The Paleozoic rocks consist of a lower carbonate sequence, argillite of the Eleana Formation, and an upper carbonate sequence. The distribution of these rocks suggests that both top and bottom of the Eleana are structural contacts, probably thrusts or reverse faults. The overlying tuff includes several units recognized in the subsurface, such as the Fraction Tuff and tuff of Redrock Valley. Other units recognized include bedded tuff associated with the Grouse Canyon Member of Belted Range Tuff, and the Rainier Mesa and Ammonia Tanks Members of the Timber Mountain Tuff. The Timber Mountain and Grouse Canyon are extensively altered to montmorillonite (a swelling clay), possibly as a result of ponding of alkaline water. The overlying alluvium locally contains at the base a clayey, tuffaceous sandstone.

Geophysical logs were used as an aid in locating geologic contacts and determining in situ physical properties. Graphic logs are presented that show the correlation of lithology and geophysical logs. Many of the rock units have characteristic log responses, but alteration within rock units affects the logs strikingly in some drill holes.

The most significant surface effect of the experiment was the formation of a 4-foot fault scarp northwest of the site.

INTRODUCTION

This report on the Discus Thrower site summarizes present (1967) knowledge of the geology and geophysics of selected drill holes, and gives an interpretation of the geology of the site and surrounding area. Geologic requirements of the site were outlined by T. L. Prather and R. E. Davis (written commun., 1965). Basic general requirements were for a good seismic discontinuity at a nearly horizontal lithologic contact approximately 1,000 feet below the surface.

The Discus Thrower (U8a) site is located in the southern part of Area 8, which lies (fig. 1, and fig. 2 in pocket) in the northwestern part of Yucca Flat. Initial geophysical surveys and drill holes in the area suggested a reasonably horizontal lithologic contact and a good seismic velocity contrast between the Tertiary tuffs and the Paleozoic rocks. Subsequent drilling revealed some irregularities in this contact. The apparent uniformity of the contact, as interpreted from surveys is attributed to the presence of a moderately dense tuff unit filling in the irregular Paleozoic surface. This tuff has seismic characteristics similar to those of the Paleozoic rocks.

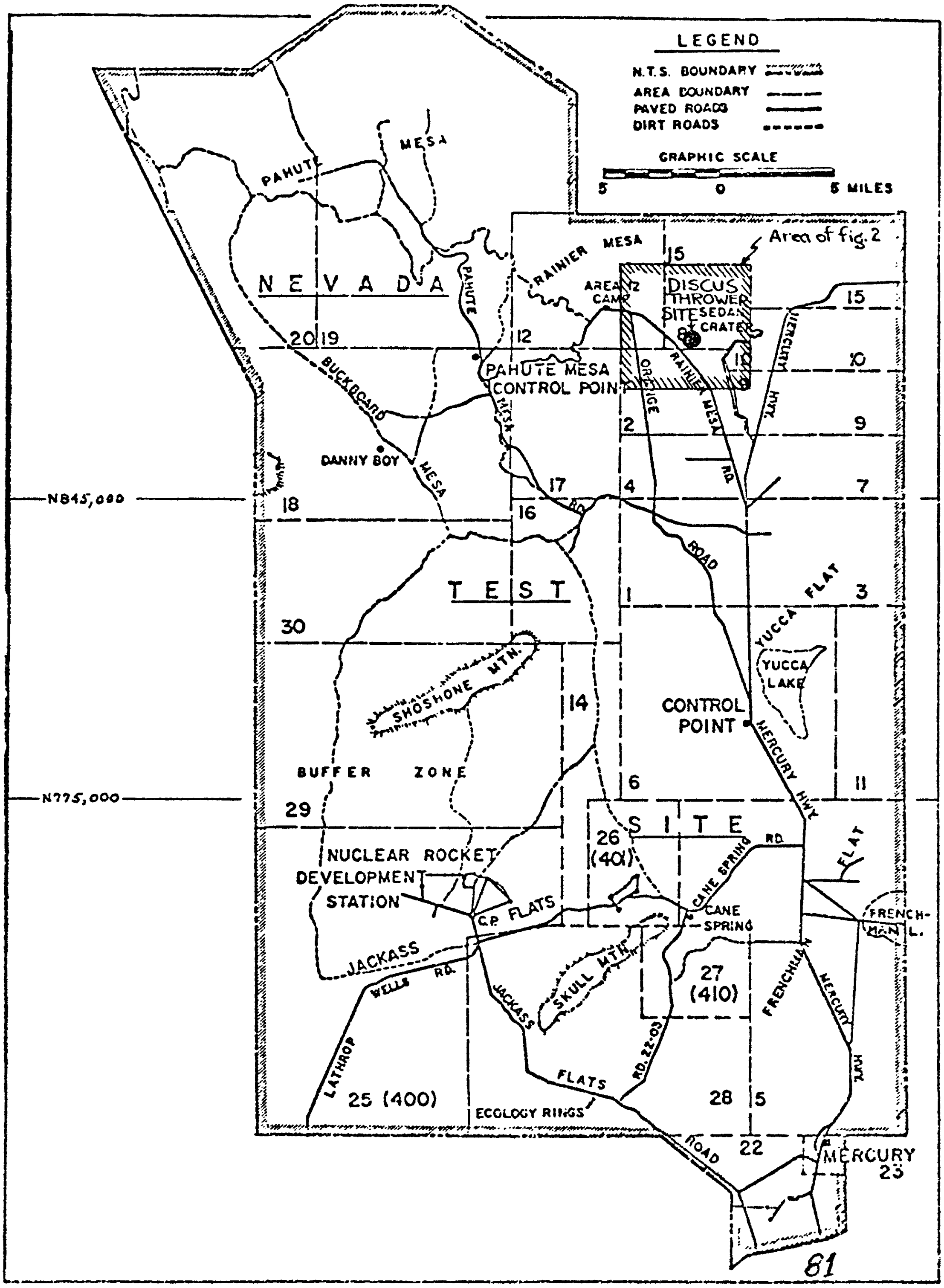

Figure 1.--Index map showing the Nevada Test Site and location of the Discus Thrower site.

STRATIGRAPHY

The lowest group of the Paleozoic rocks is dominantly gray to very light gray or tan, medium- to fine-grained dolomite; a little dolomitic limestone, limestone, and calcareous siltstone occur in some holes, particularly U8a12. Some of the limestone is oolitic. The cores show considerable brecciation, but the fractures are well sealed with calcite or dolomite. These rocks are tentatively identified as belonging to Bonanza King Formation of Cambrian age, or possibly to the Pogonip Group of Ordovician age.

Above the rocks of Cambrian or Ordovician age lies about 70 to 315 feet of black shaly pyritic argillite of the Eleana Formation (possibly unit j) of Devonian and Mississippian age (Poole and others, 1965). The lithology of this unit as penetrated in the drill holes is quite uniform, except for a few local beds of brown silty limestone and calcareous siltstone, encountered mainly in hole U8a9. The argillite cored is highly sheared and contains abundant slickensides. In the Discus Thrower area the upper and lower boundaries of the Eleana are believed to be faults (see STRUCTURE, p. 10, and figs. 2 and 3, in pocket).

The upper unit of Paleozoic rocks consists of gray to light-gray and grayish-brown dolomite, minor amounts of limy dolomite and limestone, and a few local beds of sandy dolomite. One bed of tan, faintly laminated, poorly sorted calcareous medium-grained quartzite was cored at about 1,430 feet in U8a9. As much as 250 feet of this upper carbonate rock unit is penetrated by the drill holes, but the rock thins or is absent in the northernmost holes. These rocks are tentatively identified as middle Paleozoic, probably Devonian, in age. They are even more highly brecciated and sheared than the carbonate rocks below the Eleana, and in many places are represented by only a few feet of clayey weathered colluvium and iron-stained boulders of dolomite. The upper surface of the Paleozoic rocks is somewhat irregular. The depression in the surface in the vicinity of U8a11 is believed to be due to pretuff erosion.

The distribution of the tuffs of Tertiary age in the Discus Thrower area is complex, partly because of numerous erosional unconformities. The lower part of the tuff section includes several informal members of the Indian Trail Formation. The oldest tuff unit, found only in U8a12, consists of 80 feet of bedded tuff and tuffaceous sedimentary rock and 25 feet of claystone. This is probably equivalent to part of the units mapped in the Rainier Mesa quadrangle by Gibbons, Hinrichs, Hansen, and Lemke (1963) as units 3 and 4 of the lower member of the Indian Trail Formation at Whiterock Spring, the location of which is shown in figure 2. This claystone-tuff unit is overlain in U8a12 by about 125 feet of nonwelded ash-flow and bedded tuff which may be equivalent to the tuff in the lower part of the unit mapped as unit 5 at Whiterock Spring in the Rainier Mesa quadrangle.

Overlying the lower tuff units is the Fraction Tuff (Ekren and others, 1967), a massive ash-flow tuff as much as 250 feet thick in the drill holes (fig. 3). It is generally nonwelded and devitrified, except in U8a12 where it is locally vitric and slightly welded in the middle part. The Fraction is characterized by fairly abundant lithic inclusions of porphyritic volcanic rock, Paleozoic carbonate rock and quartzite, and Precambrian schistose rocks. It also contains abundant feldspar crystals, ranging from 2 to 4 mm in size, and biotite and quartz. Approximately the lower two-thirds of map unit 6 at Whiterock Spring is Fraction Tuff.

Unconformably above the Fraction Tuff is the tuff of Redrock Valley (fig. 3), which occurs only in the middle part of the Discus Thrower array. The unit is as much as 150 feet thick in the drill holes. Like the Fraction it is generally nonwelded to slightly welded but is locally dense as a result of silicification and argillic alteration. The Redrock Valley is a fine-grained, shardy, devitrified tuff that contains only a few phenocrysts, mostly of feldspar, biotite, and sparse green hornblende. There are commonly several feet of bedded tuff between the Redrock Valley and the top of the Fraction. The Redrock Valley corresponds very nearly to the part of unit 7 at Whiterock Spring that is shown in a hatch pattern on the Rainier Mesa geologic quadrangle map.

Unconformably overlying the tuff of Redrock Valley are mostly bedded light-colored locally zeolitic tuffs. These are overlain by about 50 feet of light-greenish-gray to yellowish-gray bedded tuffs associated with the Grouse Canyon Member of the Indian Trail Formation. The upper part of this unit is more distinctly bedded than the lower part and consists mainly of interbedded fine and coarse, generally vitric, pumice. The lower part of the unit is commonly zeolitized and contains sparse phenocrysts and scattered small dark-brown spots. The scarcity of crystals and the distinctive gray-green color distinguish this unit. An erosional unconformity is present at the base of the Grouse Canyon.

About 50 feet of partly vitric light-gray to tan or white bedded tuffs lie between the top of the Grouse Canyon Member of the Indian Trail Formation and the base of the Rainier Mesa Member of the Timber Mountain Tuff. These beds are quite soft and friable and, together with the overlying Rainier Mesa and underlying Grouse Canyon, are locally altered to clay. This alteration is discussed in more detail below.

Both the Rainier Mesa and Ammonia Tanks Members of the Timber Mountain Tuff are present in the subsurface in the Discus Thrower area. They are separated by a few feet of bedded tuff and are identified in some of the holes at the north end of the line of drill holes. The Rainier Mesa ash-flow tuff consists of a lower nonwelded to slightly welded zone of pink and gray partly vitric tuff 30 to 130 feet thick; a middle densely to moderately welded black to brown partly vitric zone as much as 100 feet thick, and an upper nonwelded zone about 40 feet thick. Total thickness of the Rainier Mesa is about 250 feet. The densely welded middle zone has a black vitrophyre at the top, which is especially well developed in drill holes from U8a5 northward. The Rainier Mesa contains 10-30 percent phenocrysts of feldspar, quartz, and biotite.

Overlying the Rainier Mesa and separated from it by a few feet of bedded tuff is the Ammonia Tanks Member. The Ammonia Tanks is a soft nonwelded and light-colored ash-flow tuff in this area. Locally, it is clayey and cemented by calcium carbonate, as in the U8a10 and U8a11 holes. The Rainier Mesa-Ammonia Tanks contact is difficult to identify from drill cuttings, but the Ammonia Tanks is probably as much as 200 feet thick in places. It is mineralogically similar to the Rainier Mesa.

In holes U8a, U8a3, and U8a4 a small lens of soft bedded tuff, possibly of Tertiary age, is probably present above the Ammonia Tanks. Good samples are lacking from this interval.

The alluvium at the site can be divided into two main units, a lower soft, tuffaceous, clayey sandstone and colluvium as much as 200 feet thick, and an upper gravelly or bouldery alluvium. The contact between the two is probably gradational in most places. The lower finer grained clayey alluvium is characterized by a smoother electric log response and relatively lower electrical resistivity (tables 1-4).

Clay alteration

Clay alteration of the tuff in holes U8a5 through 11, principally in U8a9, 10, and 11, is believed to have been at least partly responsible for caving and blockage of some of these holes during and after drilling. Difficulty was encountered in emplacing instrument packages in several of the holes. A coring attempt at 1,970 feet in hole U8a11 encountered several hundred feet of fill, some of which was picked up in the core barrel. The fill consisted largely of chunks of nonwelded tuff of the Rainier Mesa Member and of the lower part of the tuff associated with the Grouse Canyon Member. Both of these, which are normally vitric, were altered to swelling clay. X-ray analysis by A. O. Shepard showed the clay to be of the Ca-Na montmorillonite type. This clay hydrates easily and increases in volume at least 50 percent upon contact with moisture. Montmorillonite most commonly forms as a result of weathering of porous glassy rocks, particularly under highly alkaline conditions. It may also form as a result of weak hydrothermal alteration. It seems likely that swelling of the clay was caused by absorption of the water from the drilling fluid or from perched water encountered by the drill hole. It is possible that subsequent drying and shrinkage of the clay caused material to slough from the walls, undercutting some of the more resistant rock, such as the welded zone in the Rainier Mesa. In order to prevent caving during reaming operations, high-viscosity mud was used with some success. The postreaming caliper log of hole U8a11, however, shows hole enlargement in the originally glassy nonaltered porous parts of the Ammonia Tanks, Rainier Mesa, and underlying bedded tuffs, including those associated with the Grouse Canyon. In addition, the sonic velocity 3D log of hole U8a11 shows numerous discontinuities, possibly fractures (R. D. Carroll, oral commun., 1966), in nearly the same intervals as the clay alteration. We suggest that these cracks are caused by drying and shrinkage of the clay minerals in the montmorillonitic zones. The tuffs affected are not considered brittle enough to favor formation of abundant tectonic fractures.

The persistence of the alteration zone from the Grouse Canyon up through the Ammonia Tanks suggests a rather prolonged period of alteration under structural conditions that favored ponding of alkaline waters. In a closed basin such a condition might tend to perpetuate itself once an impervious clay layer were built up on the floor of the basin. A small amount of the same clay was noted in hole Ue10j (fig. 2) about a mile northeast of the Discus Thrower line of drill holes. We suggest that near the close of Indian Trail time small closed structural basins were formed in this area. These may be reflected by local topographic lows on the Paleozoic surface.

STRUCTURE

The structural interpretation shown in figures 2 and 3 is a result of information gained from the Discus Thrower drilling program and from geologic mapping of the surrounding area. Interpretation would have been aided greatly by one or two additional holes drilled at right angles to the geologic section line (fig. 2, A-A'). The present array of holes is almost exactly parallel to the strike or trace of the major faults in the area (fig. 2). This report partially reinterprets major structural features of Yucca Flat as described by Harley Barnes, E. N. Hinrichs, and F. A. McKeown (written commun., 1963) who favored the hypothesis that the upper Paleozoic rocks of the western part of the Yucca Flat area were generally thrust eastward over the lower Paleozoic rocks of the eastern Yucca Flat area. Partly on the basis of information gained from the Discus Thrower exploratory program we believe that in general the lower Paleozoic rocks of the Smoky Hills and much of the eastern Yucca Flat area are the upper plate of the C P thrust which is downfaulted into the Yucca basin along the fault trend that parallels the Discus Thrower geophysical array.

Interpretation of pre-Tertiary or pretuff structure at Discus Thrower is based in large part upon tentative identification of the three units of Paleozoic age that were penetrated in the drill holes. These units, in descending order as encountered in the drill holes, are: (1) the carbonate rocks, probably of Devonian age; (2) the Eleana Formation, mostly of Mississippian age; and (3) the lower carbonate sequence, probably of early Paleozoic age. The lithologic characteristics indicate that the carbonate rocks above and below the Eleana argillite are not part of the Eleana, nor are they rocks found in normal stratigraphic sequence with it. Therefore, contacts above and below the Eleana must be structural. The cores taken are highly sheared and brecciated, although the fractures in rocks beneath the Eleana are fairly well healed by recementation. The fault that marks the lower boundary of the Eleana in the drill-hole area is believed to be a relatively high-angle reverse fault dipping westward, and may be an extension of the Tippinip fault in Oak Spring Wash (fig. 2). The exact displacement and dip of this fault in the Discus Thrower area are unknown. Its strike is probably very nearly parallel to, or a few degrees west of, the line of drill holes. The fault that defines the top of the Eleana is believed to be a thrust, probably the Mine Mountain thrust, dipping eastward at a fairly low angle. Remnants of the same thrust are believed present about a mile west of Whiterock Spring and along the faults immediately northwest of the Smoky Hills (fig. 2). This thrust brings older rocks over younger (mostly Devonian and Silurian over Eleana Formation). West of Quartzite Ridge the Mine Mountain(?) thrust dips westward. Its present eastward and westward dips may be due to a combination of downdropping and rotation into Yucca Flat along younger normal faults, rotation or sagging into the volcanic centers west of Rainier Mesa, and folding by later overriding thrust faults.

The other large fault in the Paleozoic rocks shown on figure 2 is inferred as possibly being part of the C P thrust as mapped southeast of Yucca Flat and elsewhere. Where exposed this fault generally brings lower Paleozoic rocks (mostly Cambrian and Ordovician age) over the Eleana Formation and other upper Paleozoic rocks. In general it rides above the Mine Mountain thrust; however, the Mine Mountain may be transected in places by the C P thrust. Exposures of what may be the C P thrust are present in the fault zone northwest of the Smoky Hills where the Ordovician Pogonip Formation is locally in contact with the Eleana. These small exposures may represent segments of the C P thrust exposed by erosion.

At least two arguments may be advanced in favor of postulating that the C P thrust underlies the eastern Yucca block and the Discus Thrower line of drill holes: (1) the magnitude of high-angle fault displacement that would be required to bring Eleana against Cambrian rocks is on the order of 15,000-20,000 feet, an unreasonably large displacement for a single fault or fault zone; and (2) the rocks of the Eleana seem too incompetent to act as the upper plate of a major thrust. In ground-water test well 2 (fig. 2) geophysical logs and core indicate a major fault zone between two carbonate rock sequences at a depth of about 3,000-3,150 feet. The upper rocks are probably part of the Pogonip Group of Ordovician age; the lower group of rocks is mainly light-gray dolomite that could be middle Paleozoic in age. If so, this fault zone could be the C P thrust.

Numerous minor faults undoubtedly cut the tuffs in the Discus Thrower drill holes. Several small tight faults were seen in the U8a4 core between depths of 1,140 and 1,160 feet. The dip of several of these faults was low angle, 37° in one case. Two faults having about 100 feet of displacement in the tuff are shown on the cross section (fig. 3) between U8a8 and U8a9, and U8a4 and U8a1. The evidence used to infer the fault through U8a8 and U8a9 is based on (1) the apparent thinning of Eleana in U8a9, (2) the apparent offset in the Paleozoic rock surface, and (3) possible offset within the tuffs and thinning of the tuff associated with the Grouse Canyon. Although a fault seems the most plausible explanation, these discontinuities could also be explained by erosional and depositional irregularities in the tuff and by a relatively minor swing or local change in dip of the Tippinip(?) reverse fault between the Eleana and lower carbonate rocks at U8a9.

An inferred fault is also shown (fig. 3) intersecting holes U8a1, U8a, and U8a4. Even though relatively steep dips are known to be present in the tuff in U8a4, the dip seems inadequate to explain the much lower position of the Rainier Mesa in U8a1. The Rainier Mesa in U8a5, however, has a dip of only 10° or less, suggesting that other small faults may be present in the northern end of the line of drill holes (fig. 3).

The distance between U8a11 and U8a12 is too great for complete understanding of the marked stratigraphic changes between the holes, but erosional unconformity rather than a fault seems to be the most likely explanation.

Other faults in the general area of Discus Thrower are shown on figure 2. In the vicinity of the drill holes the most important of these is the north-trending fault zone between the Discus Thrower line and ground-water test well 2 about 4,000 feet east-southeast of the line. Based on obvious displacements between the Discus Thrower line and test well 2 this zone probably is one of normal faults dipping eastward. The total displacement is about 500 feet in the tuffs and 1,000 feet in the Paleozoic rocks. Little is known about other possible buried faults; however, several having a northwest trend are indicated on the map (fig. 2). These faults are inferred mainly from displacements of contacts within the Eleana Formation. It is not known whether these faults cut the alluvium, although two photolineaments that have northwest trends have been mapped (R. H. Morris, written commun., 1965), one about 2,000 feet northeast of U8a, the other about 2,500 feet southeast of U8a. No surface cracks could be found along these lineaments either before or after the Discus Thrower event. The major northeast-trending fracture in the alluvium formed by the event (fig. 5) probably does not project into the line of section (fig. 3) through the drill holes.

GEOPHYSICAL LOGS

Interpretation of the geophysical logs of drill holes at the Discus Thrower site was done to (1) help determine lithology and geologic contacts, and (2) provide quantitative physical property data. For the purpose of this report, logs of drill holes U8a12, U8a10, U8a5, and U8a4 (tables 1-4) were chosen as representative of the geologic section in different parts of the Discus Thrower array. The logs of U8a10 are used as the main examples in the following discussions concerning log response in relation to geology.

Log response in alluvium

Cuttings, core, and geophysical logs show that there is a crude layering in the alluvium. Tuff detritus with clay predominates in the lower part of the alluvium, and a soft residuum of weathered partially reworked tuff is probably present at the base of the alluvium. Paleozoic rock detritus, mainly carbonate rock and quartzite, predominates in the upper part of the alluvium.

The electric, neutron, and density logs of U8a10 show a slight gradual decrease in magnitude in the interval of 650-905 feet. The electrical resistivity decreases with depth because of a probable increase in total water and clay content. An increase in clay content with depth is also indicated by an increase in response of the natural gamma-ray log and an increase in the positive direction of the response of the SP (spontaneous-potential) log.

The slight divergence of the density and velocity logs of U8a10 with depth (650-905 ft) seems contradictory. The decrease in density with depth seems to conform to the general layering in the alluvium, where the less dense clayey tuff detritus predominates at the base. The slight increase in velocity may be explained by increased overburden pressure.

Log response in tuff

Vitric units in the upper part of the tuff section, principally the Ammonia Tanks and Rainier Mesa Members, and the bedded tuff below, including bedded tuff associated with the Grouse Canyon Member, are largely altered to montmorillonite clay in the center of the Discus Thrower array. Minor cementation by calcium carbonate occurs locally, particularly in the Ammonia Tanks Member. The alteration affects rocks in holes U8a5 through U8a11 but is particularly well developed in U8a9, U8a10, and U8a11.

In U8a10, the electric, gamma-ray, and neutron logs show similar deflections at the upper surfaces of the Ammonia Tanks and Rainier Mesa Members. The SP log does not differentiate between the two members but it does show a deflection at the upper surface of the Ammonia Tanks. The density and continuous velocity logs are more diagnostic. Both show the upper contacts of both members, as well as delineating a less altered welded zone in the middle of the Rainier Mesa Member. None of the geophysical logs shows a contrast between the base of the Rainier Mesa Member and the underlying bedded tuff.

The Indian Trail Formation contains several units in which geophysical logs react characteristically. In U8a10 all but the density log show the bedded tuff associated with the Grouse Canyon Member to be a slightly harder zone, compared to the bedded tuffs above and below it. The apparent decrease in density in this zone, as shown on the density log, is at least partly due to enlargement of the hole by caving, as indicated by the caliper log. The gamma-ray log shows that natural radioactivity increases with hardness.

In U8a10 the base (at 1,370 ft) of the unit below the Grouse Canyon Member is clearly defined by the emphatic response of the logs to the hard top of the tuff of Redrock Valley.

Much of the tuff of Redrock Valley in U8a10 is a very hard, silicified, but only slightly welded tuff. The hard part of the unit is well defined by all logs, including the caliper log, because of the soft beds above and below the hard unit. The gamma-ray log reacts in the same direction as the neutron log. The high radioactivity on the gamma-ray logs indicates that the tuff of Redrock Valley may provide a lithologic marker on geophysical logs in the parts of Yucca Flat where it is present.

The Fraction Tuff is the lowest major unit of the Indian Trail Formation and is best represented by the section in U8a12 drill hole (table 1). The logs show a relatively unaltered tuff of rather low density and low to intermediate velocity. Samples show the Fraction is partly vitric in this drill hole. Uniformity of response of the logs is evident, as might be expected from a single cooling unit of non-welded ash-flow tuff.

The bedded and ash-flow tuffs below the Fraction Tuff in U8a12 are evident as a soft, rather nondescript zone, with interbedded hard zones near the base. The beds of claystone and clay below this are well defined by the electric logs as a soft clayey zone. This zone and the corresponding log response is characteristic of the material immediately overlying the Paleozoic rocks.

Log response in Paleozoic carbonate and clastic rocks

The dense Paleozoic limestone and dolomite in holes U8a11, U8a10, and U8a5 cause maximum log response that is unmistakable in comparison to the overlying tuff and underlying argillite, but is indistinguishable from the lower carbonate sequence. Some of the logs show an erratic response near the base of the upper carbonate section; this is probably due to the presence of faults and fractures, and possibly to interbedded silty or sandy material.

Response of the logs to the argillite unit (Eleana Formation) is likewise marked, in contrast to the dense rock above and below. Generally, the logs indicate rather uniform lithology in this interval, although the uppermost and lowermost few feet are shown on the electric logs as slightly more conductive, perhaps as a result of alteration near the contacts.

QUANTITATIVE PHYSICAL PROPERTY DATA

The following discussion of analyses of the geophysical logs is in two general parts: (1) the physical properties interpreted directly from the logs, and (2) the relation between empirical and calculated physical properties and elastic constants determined from laboratory measurements.

Electric logs

The levels of the normal and lateral traces of the electric logs of U8a10 are consistently alike, although some of the more resistive formations produce divergence of the traces.

Resistivities of U8a10 that are typical throughout the alluvium range from about 15 to 120 ohm-meters and average approximately 60 ohm-meters in the upper part (Paleozoic rock detritus) and 20 ohm-meters in the lower part (clayey tuff detritus). Resistivities of less than about 20 ohm-meters in alluvium are generally associated with very high clay content.

Because of clayey alteration the resistivity of the tuff section in U8a10 is also low. The resistivities of the Ammonia Tanks and Rainier Mesa Members are abnormally low (6-10 ohm-meters) and are even lower than the underlying nonwelded and ash-fall tuffs (5-40 ohm-meters). Tuffs having resistivities of less than 20 ohm-meters are generally indicative of clay (R. D. Carroll, written commun., 1963). The welded parts of the two members usually have resistivities of several hundred ohm-meters and, commonly, more than 1,000 ohm-meters. The bedded tuffs between the Rainier Mesa Member and tuff of Redrock Valley also contain abundant clay and zeolites and are resistive in the range of 5 to 40 ohm-meters. The tuff of Redrock Valley is an exception--the siliceous parts of this unit have resistivities exceeding 1,600 ohm-meters.

The upper sequence of Paleozoic carbonate rock in U8a10 exhibits resistivities of from 100 ohm-meters in the soft clayey interbeds near the base to greater than 3,000 ohm-meters in the harder parts. The soft material near the base (1,552-1,568 ft) shows resistivities that decrease to about 100 ohm-meters on the normal logs, but the lateral log trace does not react.

Radioactivity logs

The gamma-ray and neutron logs were used qualitatively, and only the density log was interpreted; the results are entered in tables 1-4. The rock densities interpreted from the density logs were compared with the saturated bulk densities determined in the laboratory and found to be in close agreement. The proximity logs generally did not function, but the caliper logs were used as control where hole enlargement occurred.

Sonic velocity logs

A comparison is made on figure 4 of P-wave velocities of U8a10 from three sources, CVL (continuous velocity log), 3-DVL (three-dimensional velocity log), and 3-DVL with X-Y picture control (interpreted by Birdwell logging company).

The CVL values, entered in table 2 as well as on figure 4, were taken from the log at a level within a given geologic interval that is considered representative of the formation. In addition, the levels were picked below values indicated by the maximum deflections on the log because these maximums are unrealistically high velocities. Nevertheless, even with the lowered levels the CVL velocities are consistently higher, as much as 21 percent, than those interpreted from the 3-DVL logs in the same geologic interval.

Three-DVL values were obtained (table 2) at the same points as the CVL values. These equivalent 3-DVL velocities were interpreted from two 3-DVL logs having different tool spacings, and were computed by dividing the difference in first-arrival time (microseconds) by the difference in tool length (feet) and taking the reciprocal.

The following 3-DVL logs were run in U8a10:

No.	Tool length center to center (feet)	Approximate time-interval scale (10^{-6} sec/in)
1	5.833	330
2	5.833	750
3	11.708	750
4	11.708	1,450

Runs 1 and 3 were chosen for interpretation of P-wave velocities because of their greater time resolution. Logs having smaller time scales (runs 2 and 4) are required to show some structural and stratigraphic features. The velocities interpreted from runs 1 and 3 are low to intermediate compared to those of the CVL and the 3-DVL interpretation by Birdwell.

The velocities of the 3-D log having X-Y control were interpreted and digitized at 4-foot intervals throughout most of the hole by Birdwell

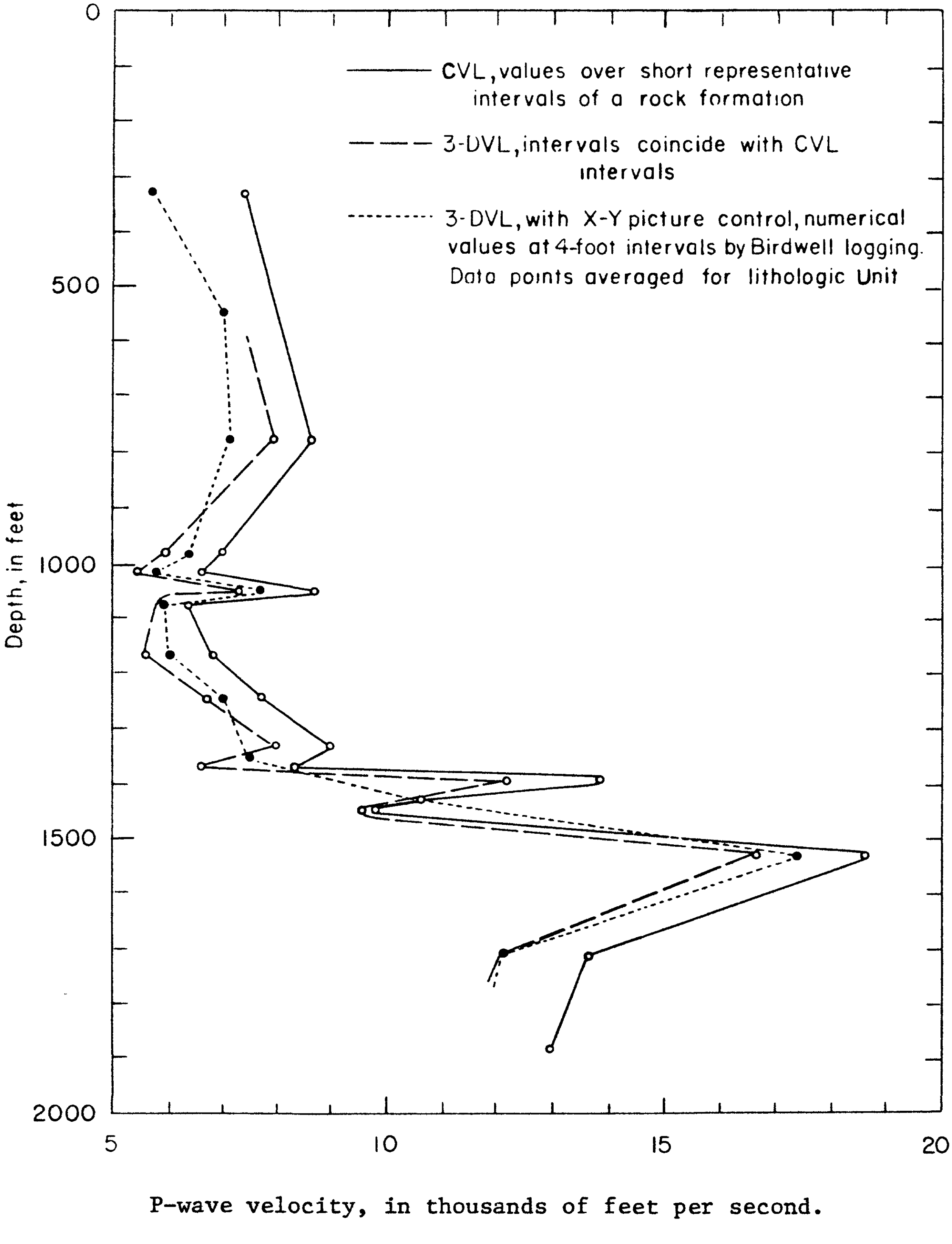

Figure 4.--Comparison of P-wave velocity interpretations in U8a10 drill hole.

logging company. These data points were averaged throughout a given geologic interval (table 2) and the results are plotted on figure 4.

PHYSICAL PROPERTIES

Physical properties from U8a12, U8a10, U8a5, and U8a4 cores (tables 1-4) are divided into three groups: (1) in situ values, calculated and empirical, (2) values determined from laboratory analysis of core, and (3) in situ elastic constants, calculated by Birdwell.

In situ values

Physical properties derived from geophysical logs consist of (a) shear and compressional velocities interpreted from 3-D logs, which were previously discussed and appear in table 4, and (b) elastic constants determined by empirical methods. The latter include shear wave velocities, Young's modulus, and porosity. These are all taken from empirically constructed graphs by R. D. Carroll (written commun., 1966).

Laboratory analysis

Cores from each drill hole were submitted for laboratory analysis and the results are entered in tables 1-4. Differences in values are expected between laboratory and in situ measurements, and these values in tables 1-4 compare favorably within reasonable limits.

In situ elastic constants

Elastic constants were computed by Birdwell logging company from 3-D and density logs. The shear velocities and Young's moduli derived from the continuous velocity log by the empirical method are consistently higher and the porosities are proportionately lower than corresponding averages derived by the Birdwell method. This is, of course, due to the fact that the interpreted P-wave velocities differ for the two logs. The use of the empirical charts and the Birdwell P-velocity would yield closer agreement between the two values. Although the values derived by the two methods are comparable there is no rigid standard for comparison.

Acoustic impedances were also calculated and shown in tables 1-4 in units of $g/cm^3 X10^3$ ft/sec. This unit may be converted to g/cm^2sec by multiplying by $3.048X10^4$.

SURFACE EFFECTS

The low-yield underground explosion at site U8a produced an irregular sink that had a maximum diameter of about 750 feet and a depth of about 70 feet (fig. 5). Concentric surface fractures developed as far as 1,000 feet from surface ground zero (fig. 6).

The most conspicuous surface effect, other than the sink itself, is a fault scarp (fig. 7) approximately 800 feet northwest of ground zero. This scarp trends N. 45° E. and is about 1,000 feet long. Its maximum height is about 4 1/2 feet; the southeast side is downdropped relative to the northwest side. It is significant that the concentric fractures, common on all other sides of the sink, did not develop on the northwest side of the fault scarp. This suggests that the scarp formed in lieu of the concentric fractures, and that the entire area between the scarp and the sink moved relatively downward, most of the displacement occurring along a preexisting fault in the tuff and lower part of the alluvium.

The somewhat rectangular shape of the sink also suggests preexisting lines of weakness trending northeastward. The linear southeast edge of

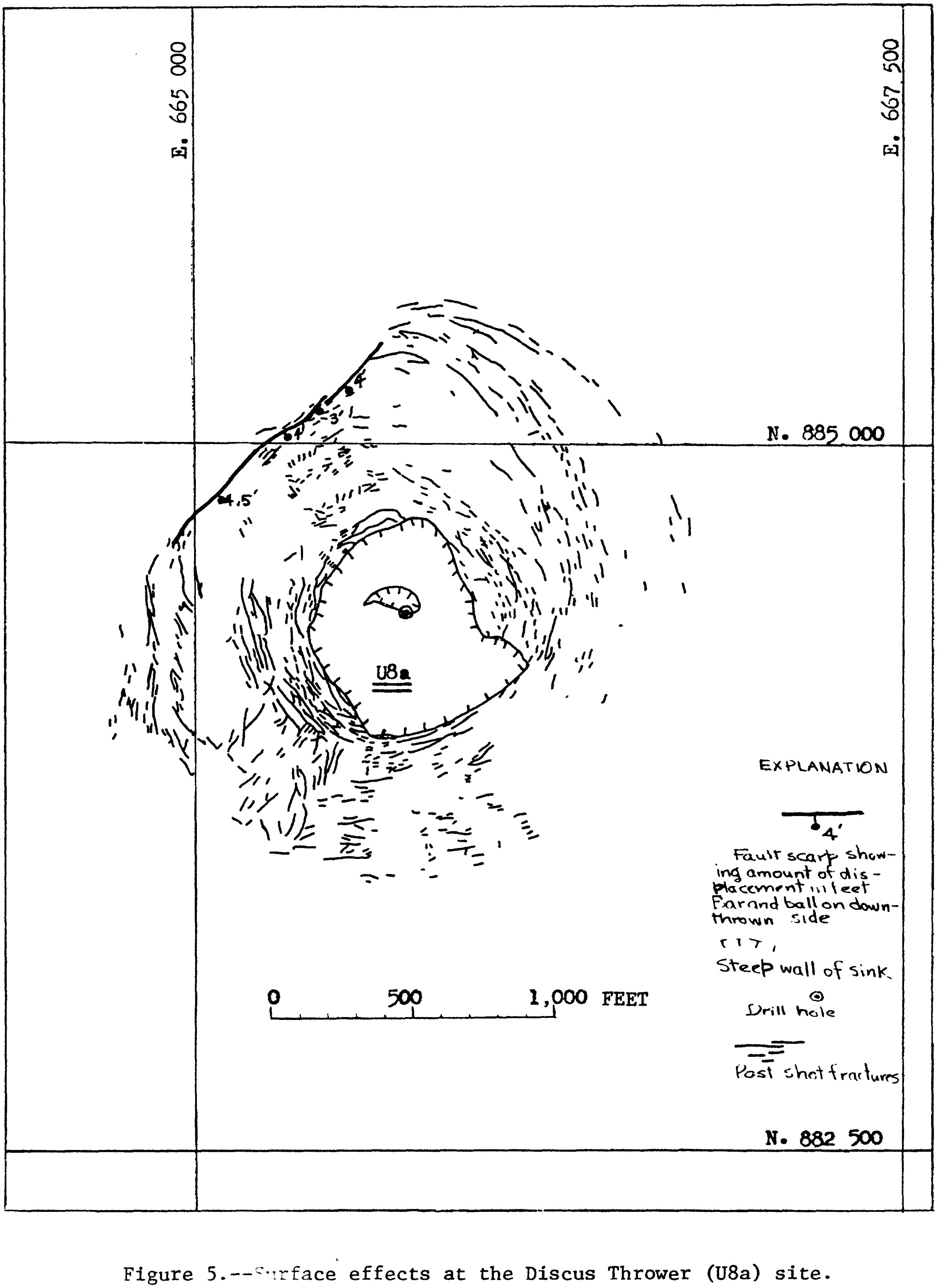

Figure 5.--Surface effects at the Discus Thrower (U8a) site.

Figure 6.--Deep concentric cracks at south edge of sink that formed after Discus Thrower (U8a) event.

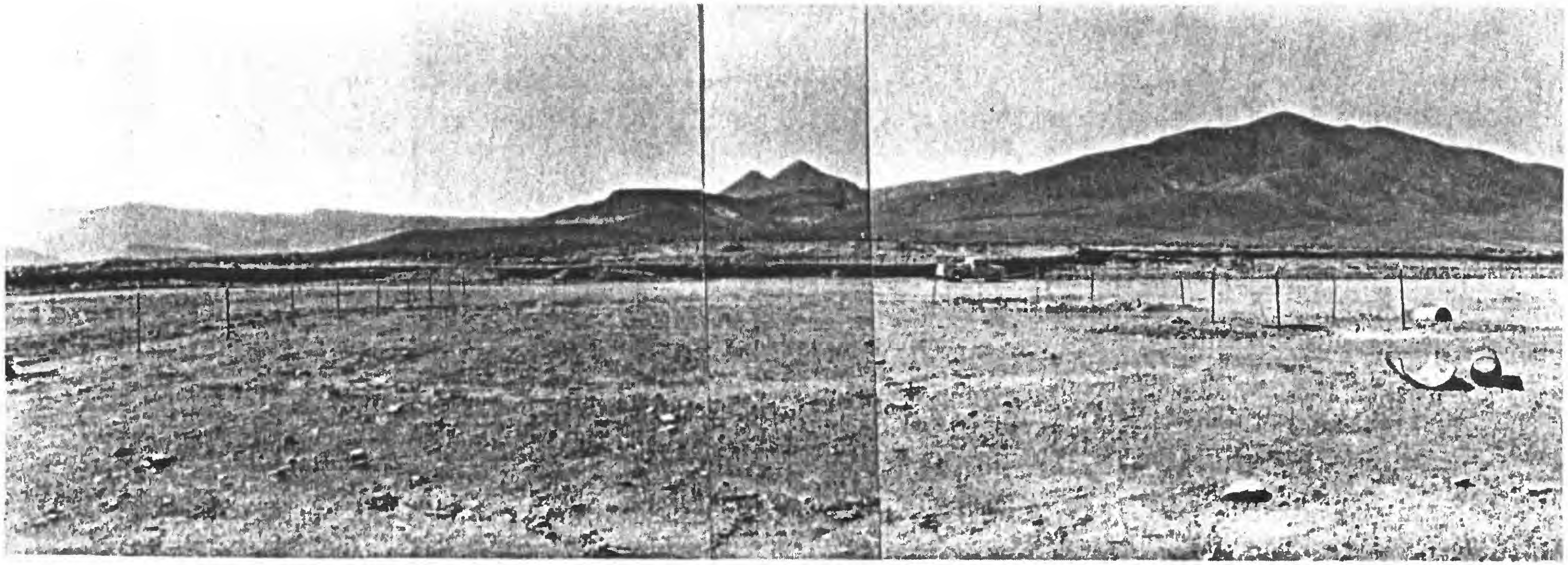

Figure 7.--Fault scarp produced by Discus Thrower event, view to northwest side of sink.