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PRELIMINARY REPORT ON THE GEOLOGIC EFFECTS OF THE FAULTLESS EVENT

By

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ABSTRACT

The Faultless event, an intermediate-yield nuclear explosion, produced fractures as much as thousands of feet in length, most of which are along preevent lineaments. Vertical displacements on the fractures are as much as about 15 feet and horizontal displacements are as much as 3 feet. The displacements, particularly vertical offsets on fractures that bound a quasi-sink area around ground zero, may have occurred hours after initial fracturing related to the explosion.

The quasi-sink is a graben bounded on the northwest, southeast, and south by faults; the greatest displacement occurred on a fault at the south margin. The northeast margin of the graben appears to be a hinge line zone characterized by many small tension fractures.

Preliminary study of data from pre- and postevent surveys indicates that definite strain patterns existed along principal fractures as well as within the quasi-sink. High-speed motion picture photographs taken from a helicopter during the event show clearly the development of two principal fractures about 1.1 second after the explosion.

The Faultless event was a contained intermediate-yield underground nuclear explosion at Nevada State coord., central zone; N. 1,414,340 ft, E. 628,921 ft, in Hot Creek Valley, Nevada (fig. 1). The explosion occurred at a depth of 3,200 feet on January 19, 1968, at 10:15 a.m. PST The main purpose of the explosion was to acquire seismic data to predict responses from higher yield explosions in the same area.

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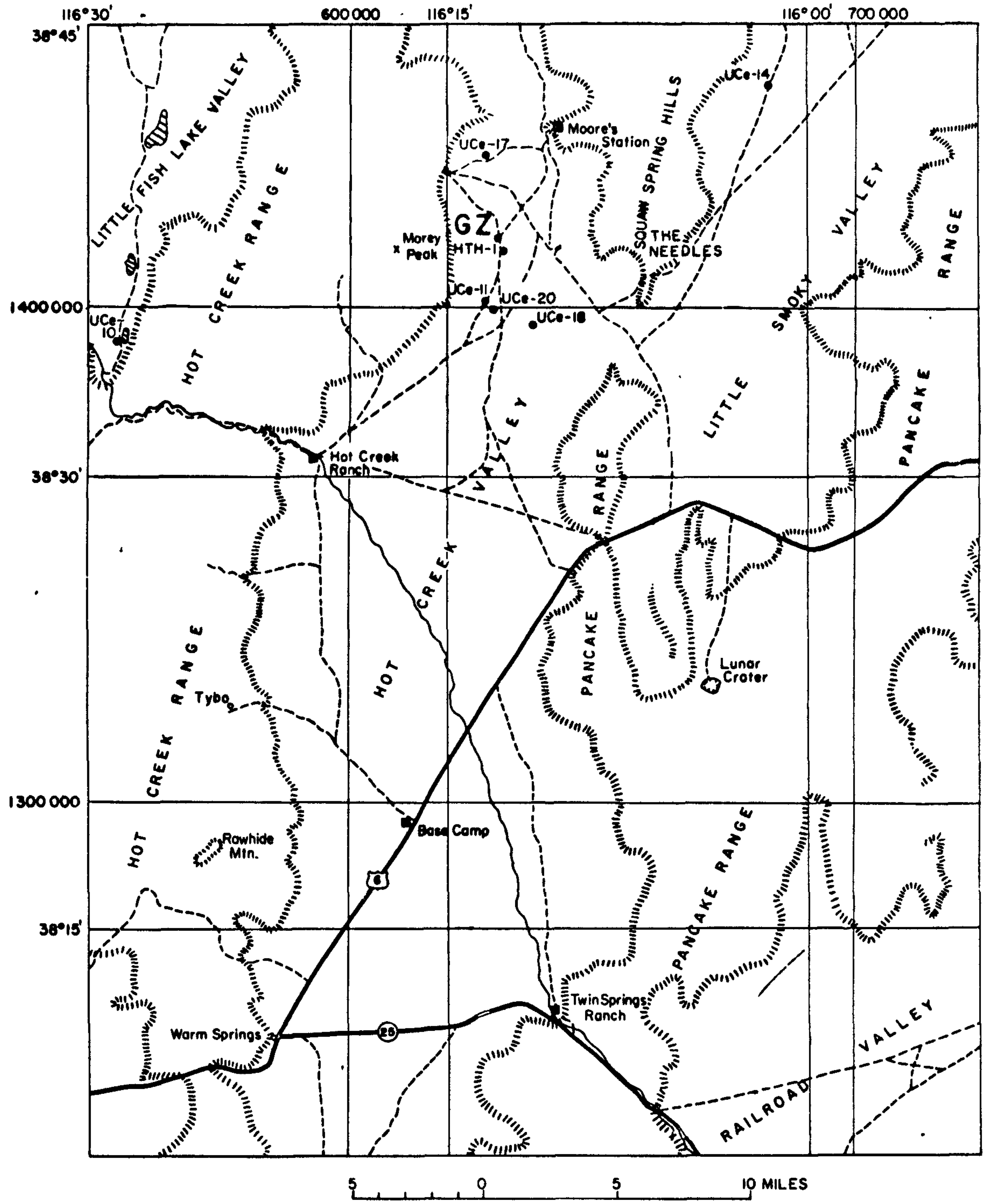

Figure 1- Index map of part of Central Nevada showing location of Faultless ground zero (GZ).

Effects of the explosion were mapped on aerial photographs at scales of 1:3,600 and 1:6,000. In general, only fractures more than 100 feet long were mapped. Ground elevations were measured using a Wild N3 level with a precision micrometer plate and invar rods. Horizontal distances were measured using a Model 6 geodimeter and angles were measured with a Kern DKM3 theodolite.

In order to obtain a maximum of information,both fracture mapping and geodetic surveys had to be completed as quickly as possible after the explosion. A relatively large number of people were, therefore, required in the field immediately after the event. In addition to the authors, the following people made substantial contributions to the fracture mapping: G. S. Corchary, R. E. Davis, A. T. Fernald, D. L. Hoover, and W. S. Twenhofel. Level line and triangulation were done by: L. E. Bentley, R. C. Foley, L. R. Riebe, L. D. Shuler, J. E. Magner and D. R. Miller. Geodimeter surveying was done by: D. D. Dickey, W. L. Ellis, G. E. Brethauer, M. J. Cunningham and J. E. Magner.

GEOLOGY

Geologic mapping and study of Hot Creek Valley are still in progress; however, some of the data required to select and evaluate the emplacement hole (UC-1) and the results of a preevent lineament study that is pertinent to evaluation of geologic effects are summarized below.

The emplacement hole is reported by Barnes (1968, p. 18) to have penetrated alluvium from the surface to a depth of 2,400 feet and tuffaceous sediments and zeolitized tuff from 2,400 to 3,275 feet (total depth). Ekren (1967) mapped some lineaments and faults within a few thousand feet of UC-1 that are nearly the same as A, B, C, and D, and infrared imagery lineaments shown in figure 2a of this report. After completion of the emplacement hole and shortly before the Faultless event another lineation map was prepared because the explosion was expected to cause fracturing for a distance of at least 10,000 feet from ground zero. This map (fig. 2a) is a selected composite of lineations that were identified on three different sets of aerial photographs by G. S. Corchary, F. A. McKeown, and Paul P. Orkild. Most of these lineations are shown on figure 2a. But many were eliminated because figure 2a is at a smaller scale than some of the photographs.

The thick alluvial fill of Hot Creek Valley displays little evidence of the structural framework of the valley. Only a few of the lineaments could be demonstrated or inferred from scarps in the alluvium to have been faults before the Faultless event; these are shown with bar and ball on figure 2a. The infrared imagery lineaments, in particular, were of dubious origin and location. No evidence of their origin could be found by trenching (Ekren, 1967, p. 4). Further, because of the distorted scale characteristics inherent in photographic prints of the infrared imagery, the location of the lineaments on figure 2a may be in error by as much as several hundred feet.

Inspection of the lineaments shown in figure 2a indicates that in order of length and abundance a first (strongest) set of lineaments trends about N. 25° E. to N. 45° E.; a second set trends from about N. 70° E. to due east; and a third, very weak set trends nearly due north. The first set is in part subparallel to the trend of the local mountain ranges (fig. 1). As this set also contains more lineaments that are known or inferred faults than other sets, it presumably represents the principal structural grain of Hot Creek Valley. Furthermore, scarps in the alluvium along some faults in this set are evidence of recent movement and indicative of the principal direction of the current tectonic stress field.

GEOLOGIC EFFECTS

The principal geologic effect of the Faultless explosion was fracturing along preexplosion faults for distances of thousands of feet. Compared with fractures produced by intermediate-yield nuclear explosions at Nevada Test Site, however, fractures caused by the Faultless explosion were neither uncommon in displacement and geographic extent nor unexpected. Enough experience has been acquired from Nevada Test Site events and from the Long Shot explosion to predict that large explosions in tectonically active regions will initiate displacements on some preexplosion faults that are within several thousand feet of the explosions. The structure of the quasi-sink around ground zero, however, was not anticipated and a satisfactory explanation for it has not been found. Furthermore, as all data were not available for incorporation into this report, detailed description and interpretation of the quasi-sink will be deferred to a subsequent report.

Three of the principal fractures produced by the explosion occurred on lineaments A, B, and C (figs. 2a and 2b), which had been mapped prior to the explosion. Nearly all other fractures may be related spatially in various degrees of coincidence to lineaments.

Fractures within about 2,000 feet of ground zero

Figure 3 shows in considerable detail most of the fractures in the quasi-sink area within about 2,000 feet of ground zero. The principal fractures that bound the area on the northwest, south, and southeast are clearly evident, as is a prominent fracture that passes within 200 feet of ground zero on the south. Figure 2b shows most of the same fractures at a smaller scale and, when compared with figure 2a, the spatial relations of fractures to lineaments. The nearly exact coincidence of explosion-produced fractures to lineaments B and C leave little doubt that these lineaments were expressions of preexplosion faults. On the other hand, the fracture that passes near ground zero lies between and is subparallel to an infrared imagery lineament and a conventional photographic lineament but is coincident with neither. The plotting of lineaments, particularly infrared lineaments, is not always precise. Thus, these lineaments may or may not be expressions of a fault that controlled the location of the explosion-produced fracture.

Displacements on the northwest-bounding fracture range from about 7 feet vertically down on the southeast side nearest ground zero (fig. 3) to zero near the ends of the fracture. Right-lateral displacement of nearly a foot also occurred.

The southeast-bounding fracture has a maximum vertical displacement of about 15 feet nearly due south of ground zero (figs. 4A and 4B). Displacement decreases gradually and irregularly to the northeast and rapidly to the west from the locus of maximum displacement. Almost 3 feet of right-lateral movement occurred on this fracture west of a point about S. 30° E. (fig. 5) from ground zero. About 2,500 feet northeast of this point about 2 feet of left-lateral displacement occurred; displacement decreases to less than an inch at the end of the fracture 6,500 feet to the northeast.

The northeast and southwest boundaries of the quasi-sink are unlike the other boundaries and unlike each other. About 1,500 feet northeast of ground zero is the inner margin of a multitude of northwest-trending fractures less than 50 feet in length that form a northwest-trending zone about 1,500 feet wide. Little or no displacement occurred on these fractures except for a fraction of an inch dilation. The zone appears to be bounded crudely on the north by several northwest-trending fractures 1,300-1,800 feet in length.

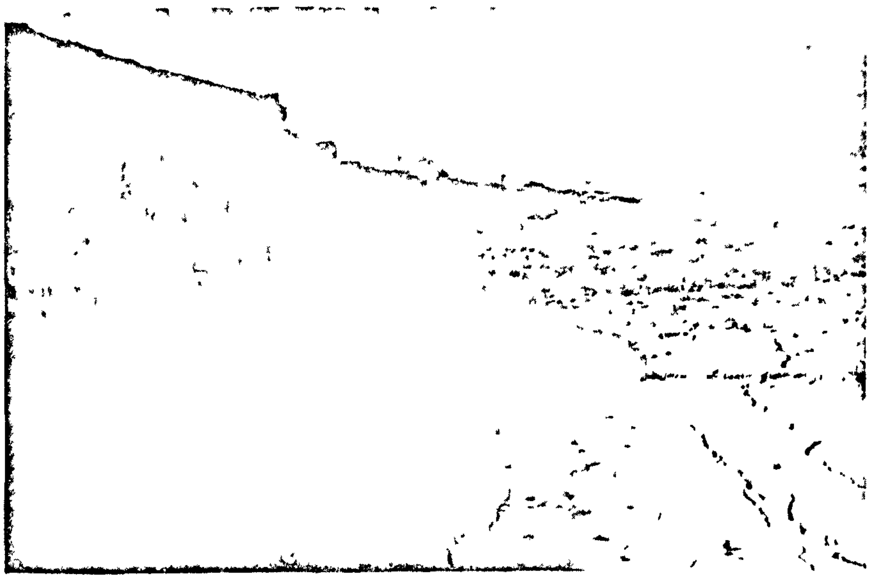

Figure 4A.--View looking west along southeast-bounding fracture. About 2,000 feet south of ground zero. Maximum height of scarp is about 15 feet.

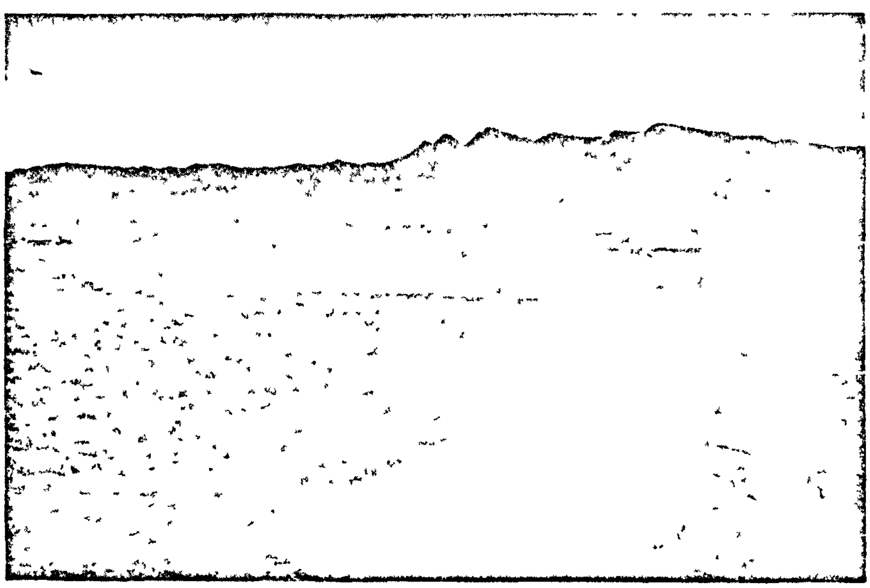

Figure 4B.--View looking northeast along southeast-bounding fracture from cable runway about 2,000 feet south of ground zero.

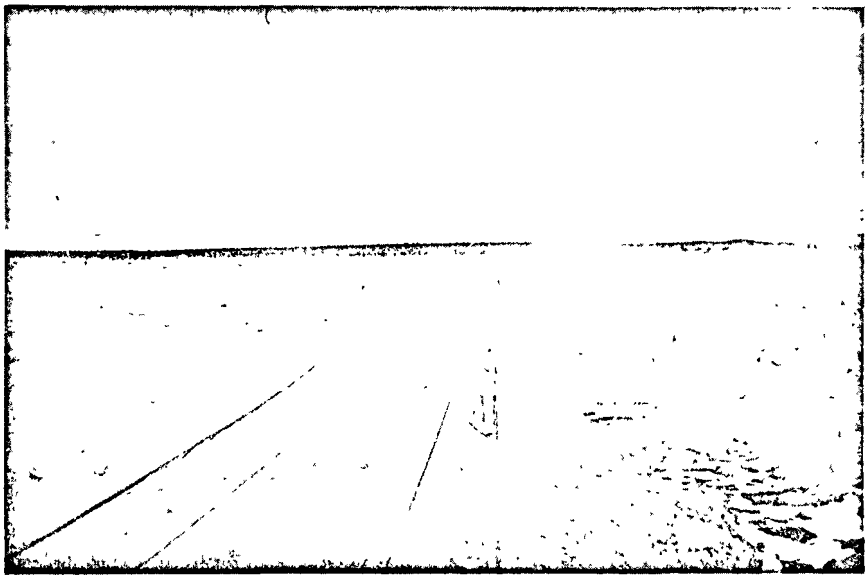

Figure 5.--View looking north along cable runway and showing right-lateral displacement of runway fence where it crosses the southeast-bounding fracture.

About 2,000 feet southwest of ground zero fractures as much as 600 feet in length form a northwest-trending zone that bounds the quasi-sink on the southwest side. Right-lateral movement (not shown on fig. 3) of a few inches is common on many of these fractures, but they have little or no vertical displacement.

Within 2,000 feet of ground zero the most conspicuous fracture is the one that passes 200 feet southeast of it. This fracture has as much as 10 feet vertical displacement on it at a point due south of ground zero and has left-lateral movement everywhere along it.

Another conspicuous structural feature within the quasi-sink area are the pressure ridges (fig. 3) within about 900 feet of ground zero. Presumably, where these occur may be the most depressed part of the quasi-sink.

The remaining fractures within 2,000 feet of ground zero occur in crude concentric and radial patterns around ground zero. They are more abundant near large fractures and preevent lineaments.

<u>Fractures beyond 2,000 feet from ground zero</u>

Principal fractures that occur beyond 2,000 feet from ground zero are (1) the fractures that bound the quasi-sink on the northwest and southeast, (2) the fracture that passes 200 feet southeast of ground zero, (3) a very long fracture system on and associated with lineament A, (4) a fracture in a preexplosion lineament about 6,000 feet southwest of ground zero, (5) a range front fracture, and (6) a fracture 8,000 feet S. 70° E. of ground zero.

The fractures that bound the quasi-sink on the northwest and southeast extend total distances of 6,500 and 9,000 feet, respectively. The fracture that passes 200 feet southeast of ground zero has a total length of about 5,000 feet. That these fractures extend several thousand feet beyond the northeast margin of the quasi-sink is evidence of the control that preexplosion faults exercise on explosion-produced fractures.

The most significant fracture beyond 2,000 feet from ground zero is along lineament A. The Faultless explosion was expected to cause movement along this lineament because it is a scarp in the alluvium produced by faulting in Holocene time; explosions near this type of fault at Nevada Test Site always trigger movement on the fault. The Faultless explosion caused a total strike length of 12,000 feet of fracturing along the scarp. Most of the relative displacement was down on the southeast side; it ranges from indiscernable near the ends of the fracture to about 2 feet near the middle. Right-lateral movement was found at a few places and is confirmed by preliminary analysis of the geodetic surveys. Although most of the displacement occurs on one principal fracture, many other fractures with little or no displacement parallel the principal fracture or intersect it at oblique angles to form a zone as much as 1,000 feet wide.

In addition to lineament A and its associated fractures, two other fractures that intersect it have vertical displacement on them and are located on lineaments (figs. 2a and 2b). One of these fractures strikes westerly from a point 4,000 feet N. 35° W. of ground zero; maximum displacement on this fracture is 1 foot down on the south side. The other fracture has nearly the same strike as lineament A and starts from a point about 3,500 feet N. 45° W. of ground zero. Unlike the displacement on the lineament A fracture, this fracture is vertically down on the northwest about 1 foot.

The fracture along the preexplosion lineament 6,000 feet southwest of ground zero has no discernable vertical displacement on it. Because of the trend of the well-developed scarp that defines the lineament, this lineament may reflect a preexplosion fault coextensive with that at lineament B. The area between the scarp and lineament B is underlain by modern alluvium and is covered with thick brush at many places, which very probably covers all surface evidence of this fault.

The most distant explosion-produced fracture is about 9,000 feet west of ground zero where it transects the uppermost parts of the alluvial fans that lap against the outcrops of bedrock of the Hot Creek Range. At a few places the fracture is within 300 feet of outcrop; at most places, however, it is 1,000-2,000 feet from outcrop. The northern end of the fracture is probably located about as shown on figure 3. It probably extends farther south than shown on figure 3, but no search was made in that area. Also, no search was made midway between the northern and southern parts, though the fracture is very likely present there. The total length of this "range-front" fracture is greater than 10,000 feet. The maximum displacement observed on it is 0.1 foot down on the west, but this is only local and may not be representative.

One fracture, 2,500 feet in length and located 8,000 feet S. 70° E. of ground zero, is the only evidence of movement on an inferred major fault, which may be one of the largest structures in Hot Creek Valley. This fault, as determined from seismic survey data, has more vertical displacement than any other fault in the valley (R. M. Hazlewood, 1968, oral commun.).

RESULTS OF GEODETIC SURVEYS

In order to estimate the depth of fracturing produced by the Faultless event, horizontal displacements of stations in two grids (fig. 2a) were determined by geodimeter and angulation surveys before and after the event. In addition, pre- and postevent elevations were determined for stations along a line extending from about 3 miles east-southeast of ground zero to a point about 2 miles northwest of ground zero. Parts of the survey nets were surveyed twice before and twice after the event. The data from the surveys has not yet been analyzed. A few of the initial conclusions are summarized below.

Probable maximum downward displacement of about 15 feet is indicated at station UEH about 800 feet south of ground zero. Greater vertical displacements may have occurred elsewhere in the quasi-sink, but data are not yet available to confirm this probability.

The fracture along lineament A has a right-lateral displacement of about 7 inches northwest of ground zero.

Nearly all stations in the survey net west of ground zero appear to have moved towards ground zero; stations closest to ground zero moved the greatest distance. A maximum decrease in horizontal distance of more than 8 feet occurred between stations 9A and 49A on opposite sides of 62. Each station probably moved towards ground zero.

Horizontal movements of stations in the eastern survey grid show a definite strain pattern indicative of downward displacements on the east side of the major north-trending fault that lies near the west side of the grid. The level-line data are also indicative of this strain pattern. The only surface expression of the fault in this area is the fracture 8,000 feet S. 70° E. of ground zero.

RESULTS OF MOTION PICTURE PHOTOGRAPHY

As part of the documentation on the Faultless event the U.S. Geological Survey requested high-speed motion picture photography of the event. The pictures were taken by J. Popovitch and R. Poole under the direction of L. Donovan of Edgerton, Germeshausen & Grier, Inc. Two 16-millimeter cameras were operated in a helicopter at a radial distance of 10,000 feet from ground zero at an altitude of about 6,000 feet above ground elevation. One camera was fitted with a 10-millimeter focal length lens; the other camera had a 75-millimeter lens. Both cameras operated at about 400 frames per second. A third camera operating at about 48 frames per second also was used, but no pictures were obtained because of a malfunction.

The most significant information obtained from preliminary study of the pictures shows clearly that both the fracture that passes near ground zero and the fracture that bounds the quasi-sink on the southeast side developed about 1.1 seconds after the explosion. The resolution of the pictures is not sharp enough, however, to determine whether the fractures had much, if any, vertical displacement on them at this time. The southern part of the southeast boundary fracture, where the largest vertical displacement occurred, is not evident in the pictures. This large vertical displacement probably formed minutes or hours later than the 40-second time interval that was documented on film. None of the fractures west of ground zero can be found in the pictures, probably because these fractures were about 3 miles from the cameras and the film and lens systems were inadequate to resolve minute images at great distances.

Also recorded on film is the movement at the ground surface of the pressure pulse that was induced by the explosion. This pulse first appears about 3,000 feet around ground zero as a dark zone moving in towards ground zero about 1 second after the explosion. The pictures show that the shape of this zone is strongly controlled by the southeast bounding fault and the fault that lies near ground zero. This control further confirms the existence of these faults before the explosion.

CONCLUSIONS

The Faultless event caused fractures along lineaments that were expressions of preevent faults. The fractures are similar to fault-controlled fractures that were produced by explosions at Yucca Flat and Pahute Mesa, Nevada Test Site. Two of the principal fractures are known from motion picture photography taken during the Faultless event to have formed about 1 second after the event. All other principal fractures are at greater distances from the explosion. They are presumably more sensitive to seismic wave energy than the fractures nearest the explosions if they too formed when the seismic wave train reached them. The amount of displacement that occurred at this time, however, is unknown. Certainly much of the vertical displacement on the fractures that bound the quasi-sink occurred minutes to hours after the passage of seismic waves.

The quasi-sink lacks many of the internal structural characteristics of most sinks in Yucca Flat. Though some concentric fractures and a depression around ground zero are present, no rotation of blocks of ground towards ground zero is apparent. Further, the apparent ratio of depth to radius of the sunken area is anomalously large. Both horizontal and vertical displacement measurements confirm that the quasi-sink is at least 4,000 feet wide. It is part of a graben bounded on the northwest, southeast, and south by faults. The north-eastern part of the graben seems to be a hinge zone for downward displacement which, at the edges of the graben, is greatest along the southern fault boundary. The hinge zone is characterized by many small tension fractures. Right-lateral movement on the northwest-bounding fault and left-lateral movement on the southeast-bounding fault support the tension concept, except that the lateral movements extend far northeast of the zone of tension fractures.

Even though a depressed area with some structural characteristics of sinks can be delimited around ground zero, the available data do not permit synthesis of a mechanical model that can satisfactorily account for such a large area being affected by the filling of what is probably a relatively small cavity. Further speculation is not warranted without additional data and study.

References cited

Barnes, William, 1968, Report of exploration progress, Central Nevada Period August 1, 1967-December 31, 1967: U.S. Geological Survey Technical Letter Central Nevada-3-2.

Ekren, E. B., 1967, Indicated and inferred faults in the vicinity of UC-1, and results of exploratory trenching, Hot Creek Valley, Nevada: U.S. Geological Survey Technical Letter Central Nevada-5.

ADDENDUM

Since this report was prepared and just before it was to be sent to the printer, a few photographs were received that provide significant information on the northeast-trending fault that passes near ground zero. As mentioned in the text, the EG&G high-speed movie film shows clearly the period of development of this fault. Figure 6 is a print of frame 520 from one of the films and shows the fault as it appears at about 1.1 seconds after shot time. More important, however, is that by viewing stereoscopically frames 520 and 450 (which shows the fault in a slightly earlier stage of development) a large vertical displacement is evident along the fault. The displacement is down on the northwest as shown in figure 3.

F. N. Houser (1968, oral commun.) points out that this evidence makes volume calculations of the quasi-sink of questionable value, because obviously a significant fraction of the total volume would be the result of faulting that occurred so soon after shot time as to preclude it as a phenomenon of cavity collapse.

Tentatively the authors and Houser believe that this fault is the surface evidence of a small earthquake induced by the explosion. A volume of 2.85 X 10^6 cu. yds. is computed for the subsided region around the Faultless site when the volumetric effect of this fault and the southeast-bounding fault of the quasi-sink, which was formed at the same time, is discounted. Houser observes from preliminary studies of the area around sinks in Yucca Flat that this adjusted volume for the Faultless subsidence is comparable in terms of yield to the subsidence of the surface around the Yucca Flat sinks. Extrapolating on the basis

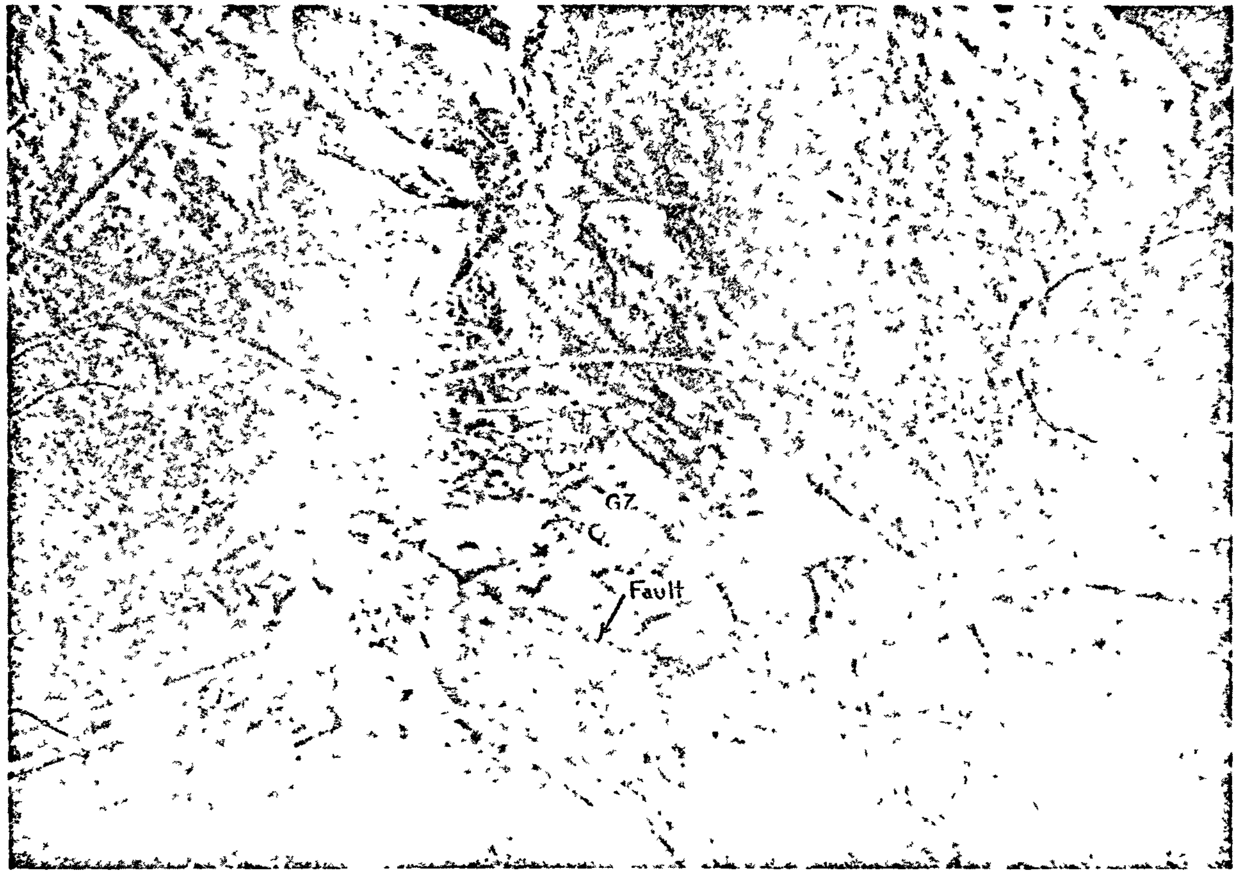

Figure 6.--Print from movie film frame 520 showing fault near ground zero at about 1.1 seconds after the Faultless event. View is to the northwest.

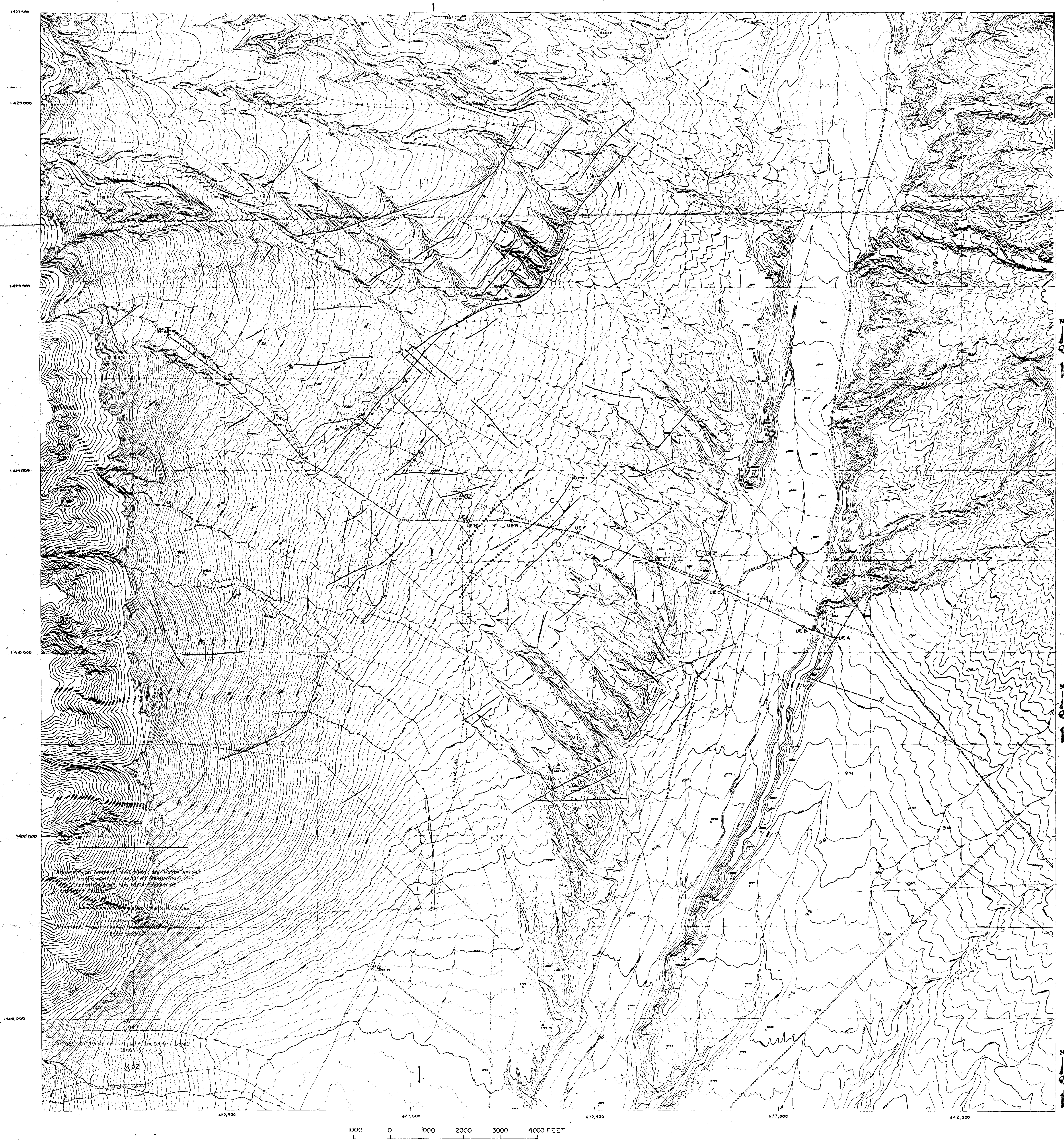

Figure 2a.-Topographic map showing preevent lineaments in vicinity of Faultless ground zero.

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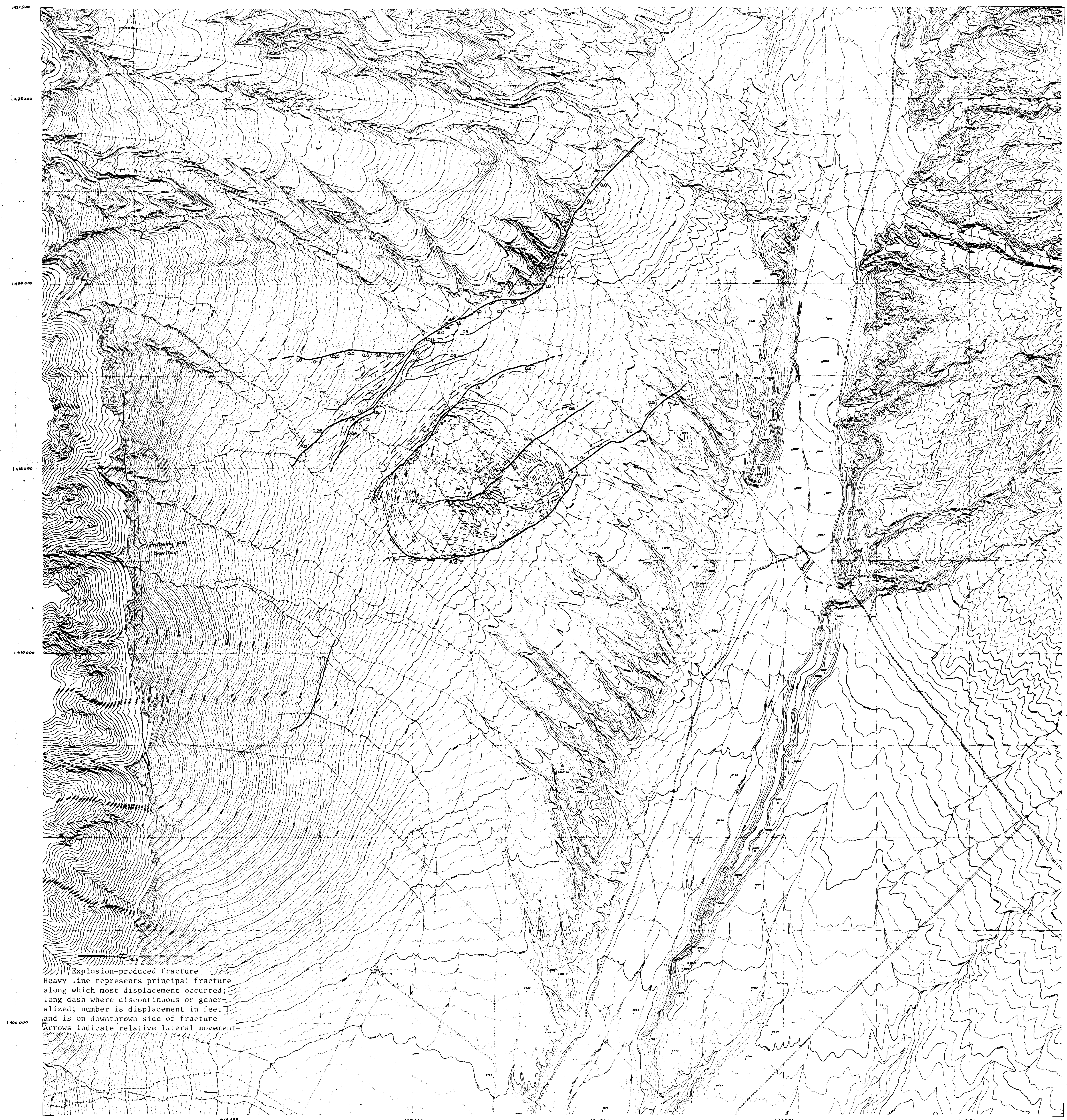

Figure 2b.—Fractures produced by Faultless event in vicinity of ground zero

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