TEI-784

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGIC ASPECTS OF THE NOVEMBER 1960 HIGH-EXPLOSIVE TEST AT THE PROJECT CHARIOT SITE, NORTHWESTERN ALASKA*

By

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May 1961

Report TEI 784

This report is preliminary and has not been edited for conformity with Geological Survey format.

*Prepared on behalf of the U. S. Atomic Energy Commission

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GEOLOGIC ASPECTS OF THE NOVEMBER 1960 HIGH EXPLOSIVE TEST AT THE PROJECT CHARIOT SITE, NORTHWESTERN ALASKA

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ABSTRACT

In November 1960, a 256-pound high explosive cratering experiment was conducted at the Chariot test site, northwestern Alaska. The explosive was detonated at a depth of 8.7 feet in steeply dipping thinly bedded mudstone of the Tiglukpuk(?) Formation of Late Jurassic age. The mudstone was frozen to a depth of 1.5 feet, thawed between 1.5 and 4.0 feet below the surface, and permanently frozen below 4.0 feet from the surface.

A symmetrical crater 8 feet deep and 26 feet in diameter was produced. An asymmetrical apron of ejected debris was deposited within a 550-foot radius around ground zero. Three zones of debris were recognized: 1) an inner zone, closest to ground zero, composed of very coarse debris derived from the upper frozen zone, 2) an intermediate zone composed of fine debris derived from the thawed zone, and 3) an outer zone composed of coarse debris derived from the thicker beds of the permanently frozen zone. In addition, a very fine grained tonguelike sheet of fallout debris was mapped.

The spatial distribution of the debris was controlled by the proximity of the parent material to the explosive. Debris derived from close to the center of the explosive was thrown the greatest distance from the crater. Debris fragment size was controlled by the cementation of the mudstone by ice and proximity to the center of the explosion. Debris derived from unfrozen zones was fine, in contrast with coarse debris derived from frozen zones. Debris from the permafrost zone close to the center of the explosion was finer than debris from the frozen zone near the surface. Asymmetry

of the debris apron was probably controlled by the attitude of the mudstone. Fallout distribution was controlled by the wind direction.

The cloud resulting from the detonation was about 190 to 200 feet in average height and was about 175 feet wide. However, in the center of the cloud a streamer about 30 feet wide rose to a height of about 250 feet. This streamer of cloud debris probably marks the trajectory of the concrete stemming that was thrown out 335 feet south of ground zero.

INTRODUCTION

In October 1960, the Atomic Energy Commission requested the Geological Survey to provide engineering geological advice to the Lawrence Radiation Laboratory, Livermore, California, which had been authorized to conduct a pre-Chariot chemical explosive experiment at the Chariot test site in northwestern Alaska. Accordingly, Reuben Kachadoorian of the U. S. Geological Survey spent from November 6 to November 19, 1960, at the Chariot test site locating the site for the high-explosive test and making pre- and post-shot geological observations.

The Chariot test site is about 110 miles north of the Arctic Circle on the northwestern coast of Alaska (fig. 1). It is about 125 miles northwest of the town of Kotzebue and 32 miles southeast of Point Hope.

Acknowledgments

The author wishes to acknowledge the cooperation of Clifford Bacigalupi, Roland Wallstedt, Robert Petrie, Thomas Jones, and Milo Nordyke of the Lawrence Radiation Laboratory in providing post-shot engineering and photographic data of the detonation. The author also wishes to express his appreciation to Ralph Chase of Holmes and Narver, Inc., for providing

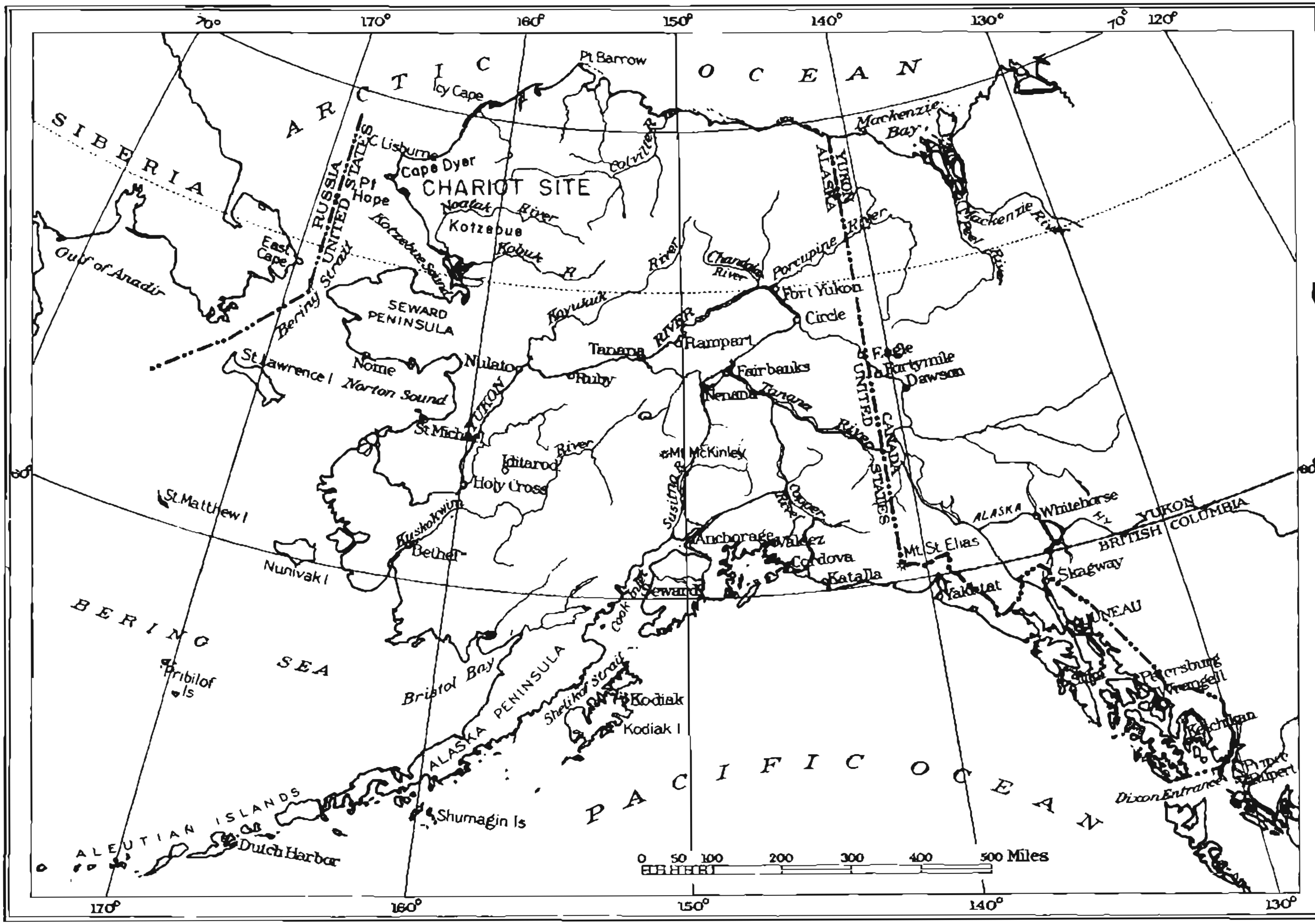


Figure 1.- Index map showing location of Chariot site, northwestern Alaska

logistic support.

GEOLOGY

General statement

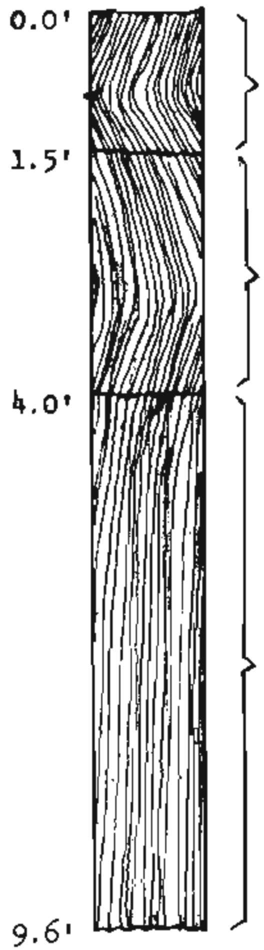
The experiment consisted of the detonation of a 256-pound spherical charge of TNT in the Tiglukpuk(?) Formation of Late Jurassic age. The center of the charge was placed in a 26-inch diameter hole at a depth of 8.7 feet. A sand cushion was placed around the charge and to a height of 2 feet above the center of the sphere. The remaining 6.7 feet of the hole was stemmed with concrete which had an average weight of 144 pounds per cubic foot (Lawrence Radiation Laboratory, personal communication, 1960). The charge was detonated at 11:30 a.m. on November 19, 1960.

Pre-shot studies

The test was conducted in the Tiglukpuk(?) Formation which basically is a mudstone-sandstone unit. However, the charge was placed in the mudstone part of the unit. The hole in which the charge was placed (ground zero) was mapped and the rocks were subdivided into 3 zones: frozen active zone, thawed active zone, and permafrost zone (fig. 2).

Frozen active zone

The top 1.5 feet of the hole is in the frozen active zone and the rocks consist of thinly bedded mudstone. The average thickness of the beds is about a quarter of an inch. However, some beds as much as 2 inches thick were noted. Owing to the annual freezing and thawing cycle, the beds were highly fractured and distorted. Although the strike of the beds was fairly constant at N. 55° E., the dips ranged from 80° SE. to



Frozen active zone; mudstone, thinly bedded, average thickness of beds ¼ inch, locally 2 inches thick; beds highly fractured and distorted due to ice action; very little clear ice noted, although locally, some fractures healed by ice.

Thawed active zone; mudstone similar to frozen active zone material, however, interbeds are loose.

Permafrost zone; mudstone, thinly bedded; beds range from 1/16 to 2 inches thick and average ¼ inch; locally beds of clay-like material to 1/8 inch thick; ¼-inch beds about 60 percent of unit; ice lens and vugs common, locally 7 inches thick; from 4.0 to 5.0 feet ice content about 30 percent, however, average ice content in this unit is about 10 to 15 percent; from 8.6 to 9.6 feet no clear ice noted although fractures and joints healed by ice; beds strike N. 55° E. with average dip of 85° NW.

Figure 2. Geologic section exposed in test hole at ground zero. Plane of section strikes N35°W which is normal to strike of beds, N55°E.

70° NW. Although the unit was frozen, clear ice vugs or lenses were not noted. The fractures, however, were healed by ice. The moisture content of this unit based on one sample collected at a depth of 1.3 feet was 3.1 percent (table 1). All moisture determinations in this report, unless

Table 1.--Moisture content-determinations of rocks in the frozen active, thawed active, and permafrost zones at ground zero

Zone	Depth (ft)	Percent moisture
Frozen active	1.3	3.1
Thawed active	3.4	3.6
Permafrost	4.0	12.5
Do.	4.5	7.5
Do.	6.5	4.4
Do.	6.5	9.3
Do.	9.0	5.0

otherwise indicated, were conducted in the field in the following manner: a sample was collected, weighed, and placed upon a stove (approximately 90° C), and heated to a constant weight. The loss of weight was recorded and the moisture content determined. It should be pointed out that the results may be slightly low because moisture determinations are usually done at a temperature of 105° C.

Thawed active zone

The thawed active zone that underlies the frozen active zone was 2.5 feet thick and extended from 1.5 to 4.0 feet below the surface. The rocks in this unit were similar to those of the overlying frozen active zone rocks, with one exception. Whereas the rocks of the frozen active zone were well cemented by ice, the thawed zone rocks were not. The fractures in this zone were loose, and the rocks, as a whole, were relatively more friable than the overlying frozen rocks. The moisture content of the thawed active zone rocks, based on one determination of a sample collected at 3.4 feet below the surface, was 3.6 percent.

Permafrost zone

Permafrost was encountered at a depth of 4.0 feet in the test hole at ground zero and existed to the bottom of the hole, which was 9.6 feet deep. The mudstone of this unit was thinly bedded, ranging from 1/16 inch to 2 inches thick, and averaged a quarter of an inch thick. Locally, beds of claylike material up to an eighth of an inch thick were observed. The 1/4-inch fraction of the beds comprised about 60 percent of the total unit. The beds in the permafrost unit showed very little fracturing and distortion. The strike of the beds was fairly constant at N. 55° E. and the dip, although ranging from 70° NW. to 85° SE., was rather uniform at 85° NW.

The moisture content of the permafrost zone rocks varied greatly (table 1). Ice lenses and vugs were common, especially from 4.0 to 5.0 feet, where an ice lens 7 inches thick and 2 feet long was present. The average moisture content of this 1-foot zone, based on a visual estimate, was about 30 percent. Several samples were collected in the permafrost zone. One of the samples collected at 6.5 feet with a moisture content of 4.4 percent represents the minimum moisture content of the permafrost zone. The other sample collected at 6.5 feet with a moisture content of 9.3 percent represents approximately the average moisture content of the permafrost zone.

Post-shot studies

Crater

The diameter of the crater resulting from the high-explosive detonation was remarkably uniform and averaged 26 feet at the original ground level. However, the vertical configuration of the crater appears to vary (pl. 1). Time and weather did not permit a thorough examination of the crater and, therefore, it must be stated that the following discussion on the vertical configuration of the crater could be subject to change upon a more thorough examination.

Based on an analysis of sections A-A' and B-B' (pl. 1), the dip of the crater wall ranges from 50° to 60° in the permafrost zone, from 30° to 60° in the frozen active zone, and from 20° to 25° in the thawed active zone. It is unknown at this time whether this rather uniform dip, especially in the permafrost and thawed active zones, is characteristic and could be demonstrated again in future high-explosive tests under similar conditions at the Chariot test site.

Clifford Bacigalupi, of the Lawrence Radiation Laboratory, Livermore, Calif., reported (written communication, 1960) that the apparent volume of the crater was 78.5 cubic yards, the volume of the lip of the crater 110 cubic yards. Bacigalupi has calculated the swell of the debris as 40 percent.

The distribution of debris fractured by the detonation and left in the crater is indicated on the geologic map and sections A-A' and B-B' (pl. 1). Although some intermingling of debris from the different zones occurred, the intermingling was only minor, and the debris on the crater walls consisted chiefly of debris as indicated on plate 1.

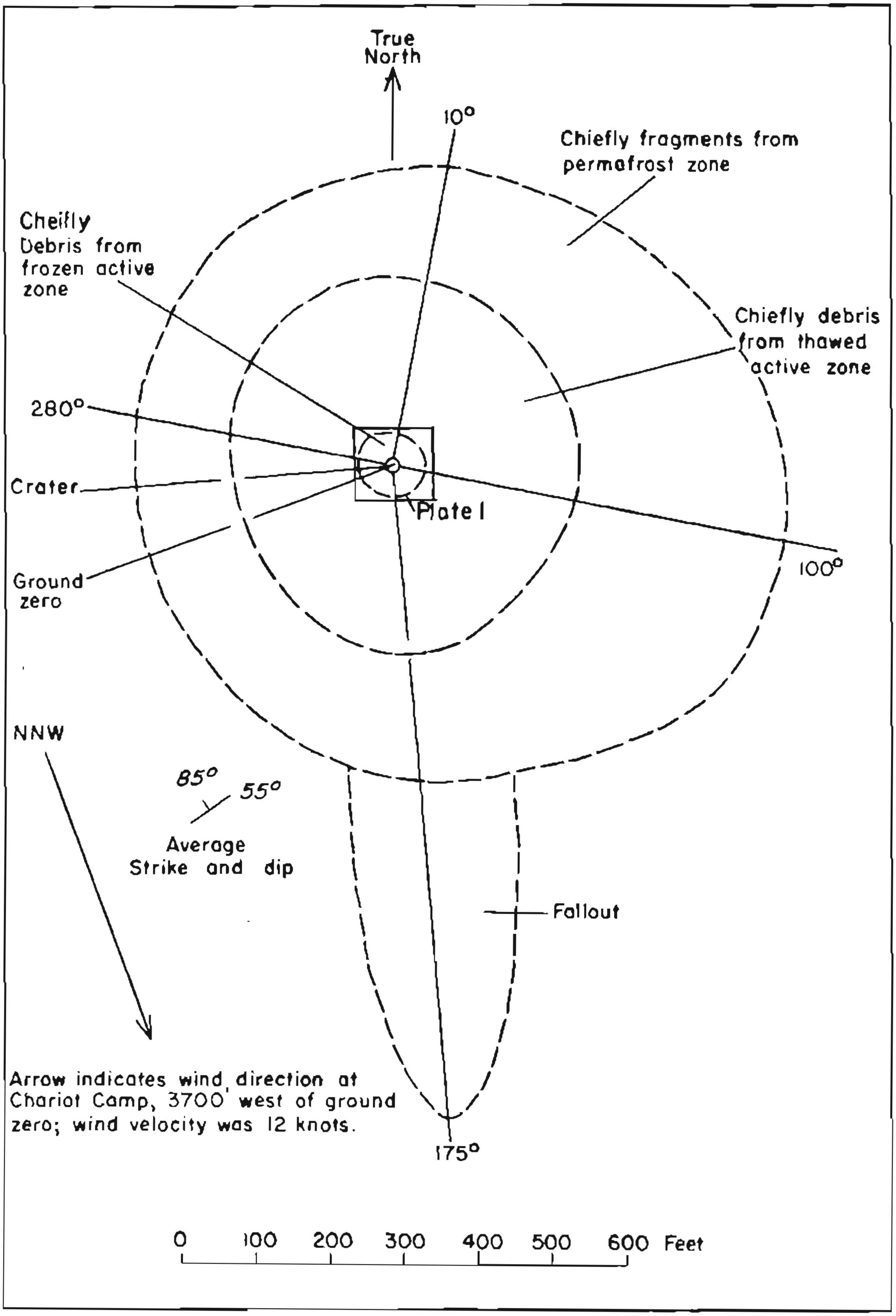


Figure 3.—Map showing distribution of throwout and fallout debris

Throwout debris

Throwout as used in this report consisted of material which followed ballistic trajectories to its site of deposition. It was distinguishable from fallout debris on the basis of its coarser size and rather uniform spatial distribution pattern. The throwout debris from the high-explosive detonation could easily be mapped and subdivided into the same units that were used in mapping the hole at ground zero.

The diameter of the distribution apron of throwout debris ranged from a minimum of 800 feet in a northeast-southwest direction to a maximum of 900 feet in a northwest-southeast direction (fig. 3). The minimum radius of the distribution apron of throwout debris is about 350 feet in a northwesterly direction, the direction of the average dip of the beds. The maximum radius is 550 feet in a southeasterly direction, 180° from the direction of the average dip. In northeasterly and southwesterly directions, along the strike, the radii are 450 and 360 feet, respectively. The asymmetry of the debris apron suggests that the dip may have had an effect upon the distribution of the throwout debris.

The debris outward from the crater lip to within 45 to 50 feet of ground zero consisted chiefly of material derived from the frozen active zone, with some material from the underlying thawed active and permafrost zones. The largest boulder noted was in this area and was 5 x 4½ x 1½ feet. The frozen-unfrozen interface, 1.5 feet below the surface, controlled one dimension of the fragments derived from upper frozen active zones. No fragments with a minimum dimension larger than 1½ feet were noted. The debris in this zone traveled only a short distance, and the large platy fragments were mostly overturned. Although the majority of the large fragments had only been overturned and moved short distances, the top 2 to 3 feet of the concrete stemming landed 335 feet from ground zero on an azimuth of 185°. The median diameter of the throwout debris became rapidly smaller toward the outside boundary of the zone (45 to 50 feet from ground zero) where the median diameter of the fragments was about 2 inches (fig. 4).

From a radius of 45 to 50 feet to an average radius of about 250 feet from ground zero, the throwout debris consisted chiefly of material derived from the thawed active zone. The thickness of debris deposit was much less than that derived from the frozen active zone. Figure 4 shows that the median diameter of the debris in this throwout zone was much less than that of fragments obtained from the frozen-rock zones. This is expected because the rocks of the thawed zone were not cemented by ice and the rocks were somewhat more friable than the frozen rocks.

In the area from 250 feet to the maximum distance of throwout (550 feet, see fig. 3), the rocks consisted chiefly of scattered fragments of rocks derived from the more massive beds of the permafrost zone. The median diameter of the rocks was larger than the debris in the 45- to 250-foot throwout zone but smaller than that of the rocks in the throwout zone from the crater lip to about 50 feet from ground zero. However, the number of fragments was much lower. Beyond 300 feet from ground zero only an occasional fragment was noted.

Fallout debris

Fallout as used in this report is non-radioactive debris arrested in its ballistic flight by atmospheric drag. Subsequent deposition was controlled by free fall and atmospheric currents. In contrast to the generally coarse throwout debris, fallout consisted almost wholly of fine-grained debris whose spatial distribution was not uniform around ground zero.

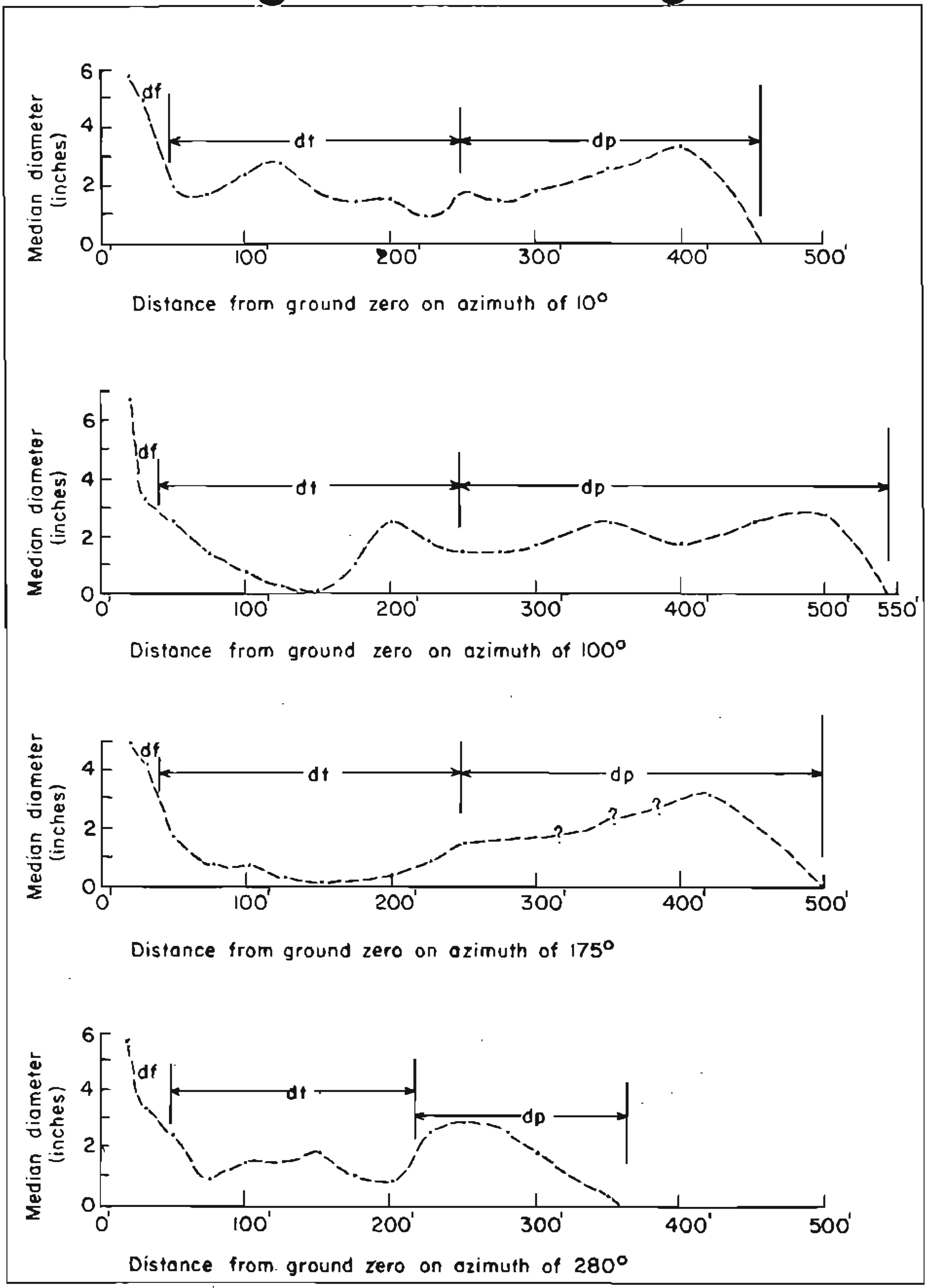


Figure 4.—Graphs showing size distribution of throwout debris (Letter symbols same as on plate 1)

Undoubtedly some fallout debris was intermingled with throwout debris in the throwout zone but the amount could not be established visually. However, outside of the throwout zone differentiation on the basis of size was readily possible. The only fallout noted outside of the outer margin of the throwout zone occurred south of ground zero (fig. 3). This fallout distribution pattern was the result of the direction of the wind at time of the detonation. At that time the wind, 3,700 feet west of ground zero, was from the north-northwest (340°) at a velocity of 12 knots. Fallout debris was noted at least 875 feet from ground zero on an azimuth of 175° and was about 215 feet wide 550 feet from the crater center.

Material comprising the fallout consisted chiefly of mudstone from the thinner beds. Based on the information now available, it is difficult to state with any degree of certainty which of the 3 zones (frozen active, thawed active, and permafrost) was the major source of fallout debris. There is no doubt, however, that the fallout debris represented material from the thinner mudstone beds. Kermit H. Larson, University of California at Los Angeles determined particle size distribution along the estimated fallout midline (azimuth of 175°), and reports that 390 feet from ground zero, 100 percent of the particles are smaller than 2000 microns (written communication, 1961).

Cloud height and width

The calculation of the height and width of the cloud resulting from the detonation is based on data obtained with a Brunton compass and from pacing, and is therefore, only approximate. The average height of the cloud was about 190 to 200 feet and the width was approximately 175 feet.

However, in the center of the cloud a streamer about 30 feet wide rose to a height of approximately 250 feet. This streamer of cloud debris probably marks the trajectory of the concrete stemming that landed 335 feet south of ground zero.

SUMMARY

In general, the rock properties and geologic environment played a major role in the distribution and size of throwout debris and the source of fallout debris. Some of the more specific conclusions are:

(1) The crater was remarkably symmetrical; however, minor irregularities were present.

(2) The deposition of throwout debris was controlled by its distance from the charge. Material from the area close to the charge traveled the farthest. Most of the debris from the surface frozen active zone was overturned and traveled only a short distance. Material from the more massive beds of the permafrost zone was thrown further than material derived from the thin beds in the permafrost zone.

(3) The size of the ejected fragments was dependent upon the cementation by freezing of moisture in the rocks. The largest fragments were derived from the frozen active zone and consisted of debris that had been overturned by the detonation. In contrast, fragments from the thawed active zone were small.

(4) Very little fracturing of bedrock in the crater was noted.

(5) There is a correlation between the attitude of the beds and the radius asymmetry of the distribution of throwout debris. The minimum radius (350) feet of throwout debris occurred in the direction of the

dip. The maximum radius of 550 feet occurred 180° from the direction of dip.

(6) Fallout debris consisted chiefly of material from the thin beds in contrast to the thick beds. The direction of fallout distribution was controlled by the direction of the wind at time of detonation.

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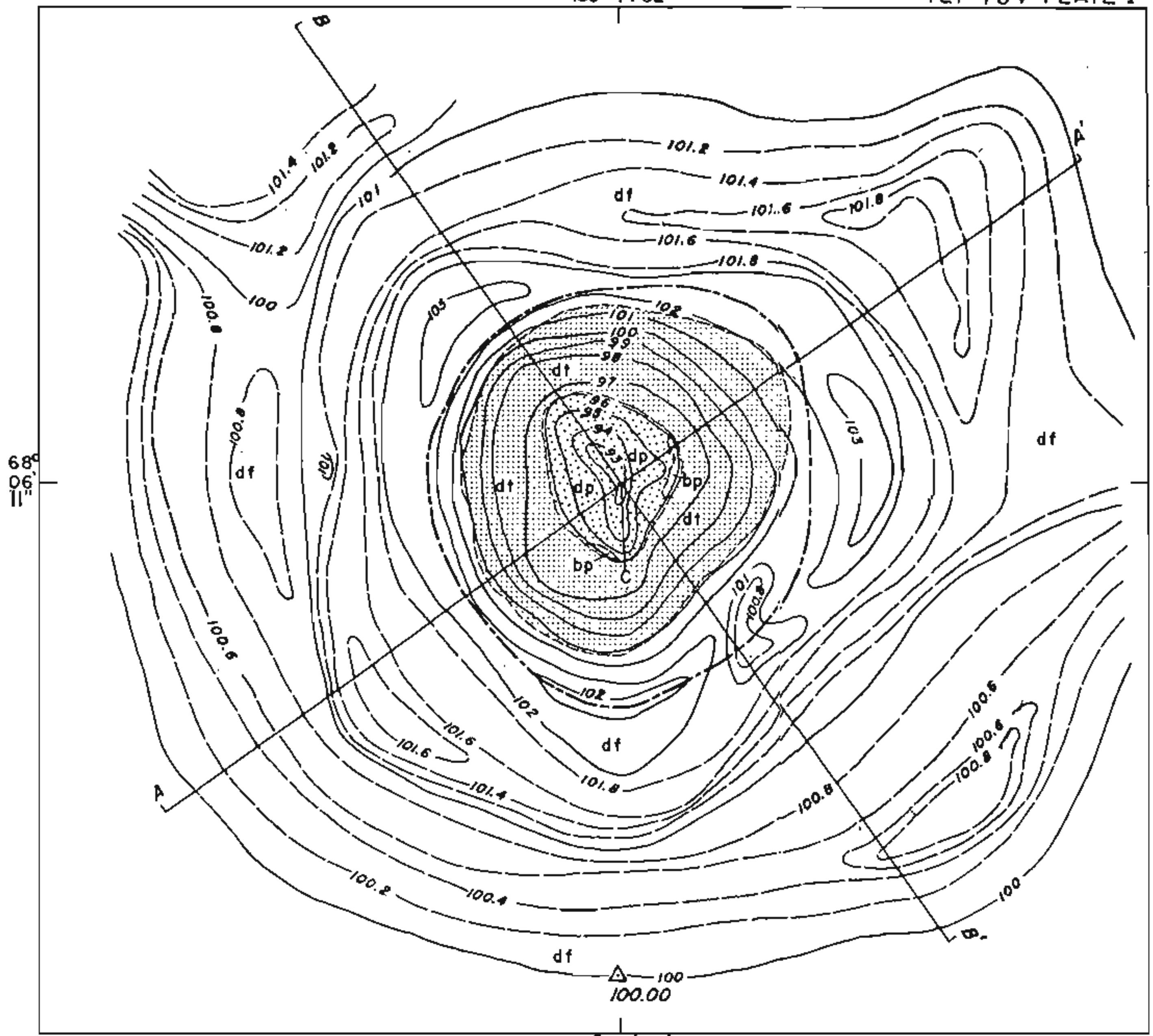
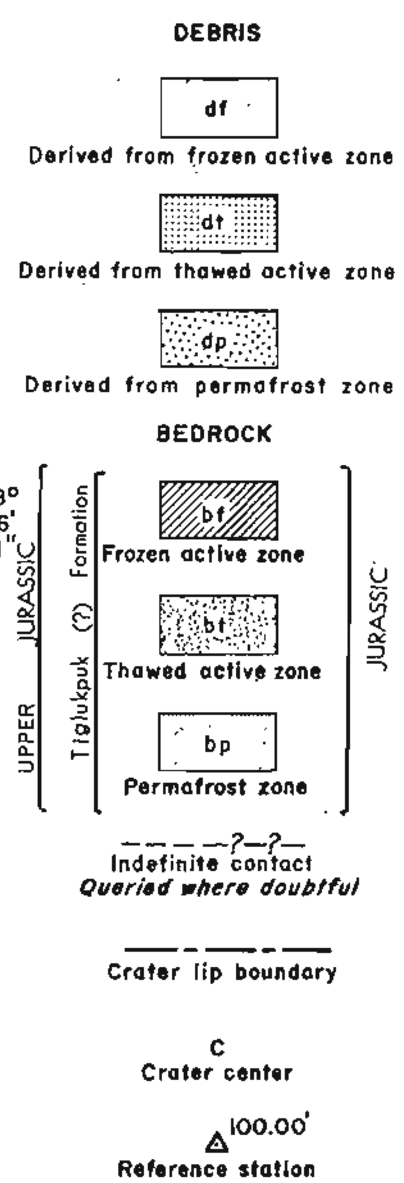
THE U.S. ATOMIC ENERGY COMMISSION

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

TEI-784 PLATE 1



EXPLANATION

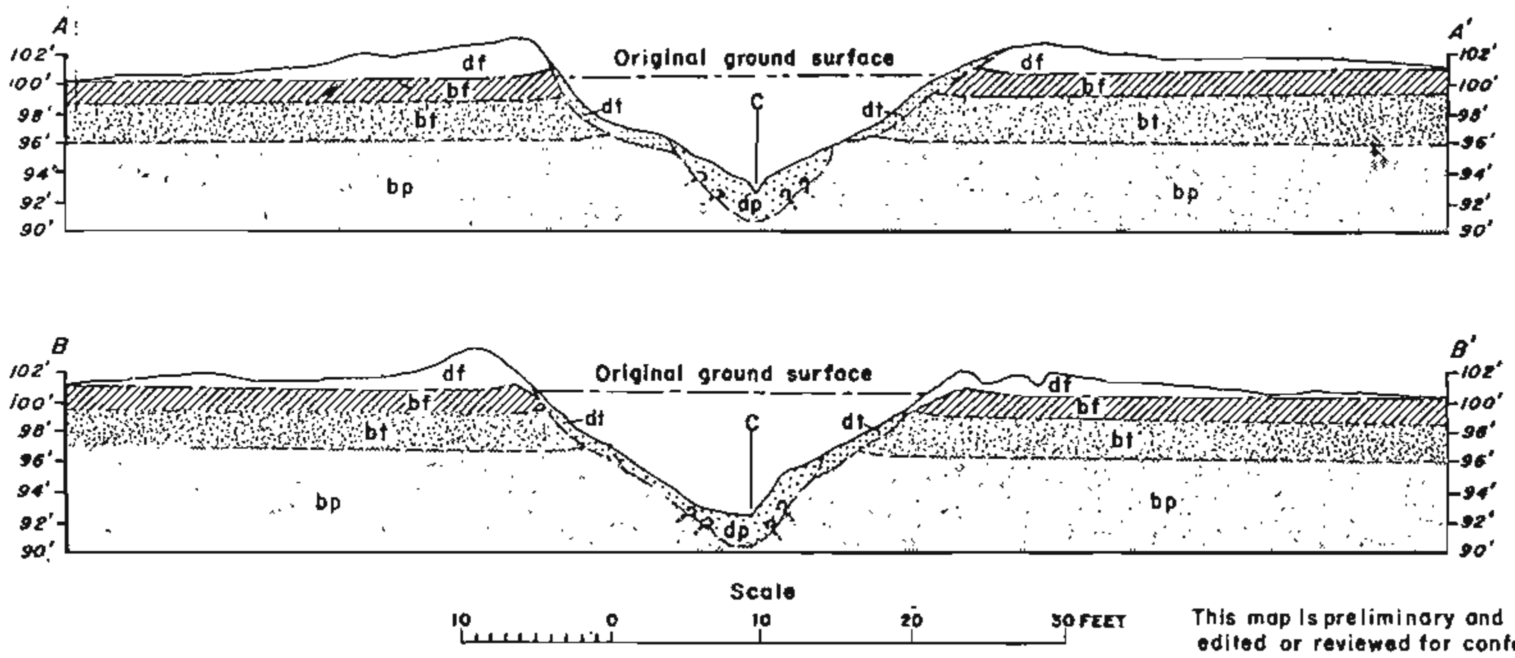


Topography based on data supplied by Lawrence Radiation Laboratory, Livermore, California and U.S. Geological Survey, 1960

165° 44'02"

Geology by Reuben Kachadoorian November 1960

Post shot topography
Contour interval 1 foot
Dashed lines represent 0.2 foot contours
Datum is △ with assumed altitude of 100.00'



This map is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards

DETAILED GEOLOGIC MAP AND SECTIONS OF THE CRATER AREA, PROJECT CHARIOT HIGH-EXPLOSIVE TEST
NOVEMBER 1960