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INVESTIGATION OF THE FEASIBILITY OF
MANUFACTURING AGGREGATE BY
NUCLEAR METHODS

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PREFACE

The study described herein was performed by the U. S. Army Engineer Waterways Experiment Station (WES) during the period April through June 1963 for the U. S. Army Materiel Command (AMCRD-DE-N) as a part of the project on Military Engineer Application of Nuclear Weapons Effects Research (MEANWER). The project was under the supervision of Messrs. J. M. Polatty and R. L. Curry of the WES Concrete Division. Mr. Curry prepared this report.

Analyses of the grid photographs to determine particle size distribution were made by personnel of the WES Soils Division. Constructive suggestions concerning the report were made by personnel of the Soils and Nuclear Weapons Effects Divisions of WES, Col. E. E. Graves, Jr., and Capt. John Toman of the U. S. Army Engineer Nuclear Cratering Group, and others.

Col. Alex G. Sutton, Jr., CE, was Director of WES, Mr. J. B. Tiffany was Technical Director, and Mr. Thomas B. Kennedy was Chief, Concrete Division, during the course of the study and the preparation and publication of this report.

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SUMMARY

This report covers a limited study of preshot and postshot characteristics of basalt in the area of the Danny Boy nuclear event, to determine if it would be practical to manufacture aggregate for construction purposes by nuclear means.

In this event approximately 20 percent of the ejecta could have been made available for use as concrete aggregate by sieving. Secondary crushing would have produced a greater quantity. Other studies would be necessary to determine the effect of nuclear blasts upon other types of rock.

INVESTIGATION OF THE FEASIBILITY OF MANUFACTURING AGGREGATE
BY NUCLEAR METHODS

PART I: INTRODUCTION

Background

1. The use of a nuclear detonation to manufacture aggregate appears to hold considerable promise from the standpoint of economy, based on data obtained from recent rock-cratering tests conducted at the U. S. Atomic Energy Commission's Nevada Test Site by Department of Defense/Defense Atomic Support Agency. From these tests it appears that the aggregate manufactured by nuclear methods can be classified into two types: (a) rough aggregate, with no secondary crushing, which is separated into various sizes by using only such devices as the rock rake and screening apparatus; and (b) processed aggregate, which has been further manufactured by screening and crushing in a secondary crushing plant.

Purpose

2. The purpose of this study was to investigate the feasibility of the use of nuclear methods to manufacture aggregate for construction purposes.

Scope of Investigation

3. Personnel of the U. S. Army Engineer Waterways Experiment Station (WES) visited the crater formed by the Project Danny Boy nuclear detonation in basalt at the Nevada Test Site to examine the ejecta from the blast and select rock samples for laboratory examination. The detonation had been made about a year before this inspection, and field readings at the time of the inspection indicated radiation levels of 5 mr*/hr or less in the ejecta. No samples were taken within the crater where field readings showed

* Milliroentgens.

radiation levels on the order of 10 to 40 mr/hr.

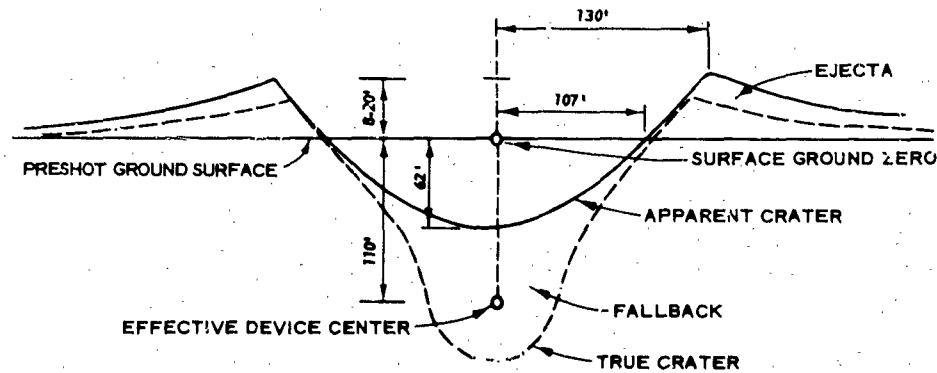
4. The ejecta was inspected to determine rock types and the percentage of rock of different size ranges. Also, the total amount of usable aggregate in the ejecta was estimated by means of a grid overlay. Samples of small and large rock sizes were then selected and carefully tested for radioactivity before shipment to WES for laboratory examination. In the laboratory the specific gravity and absorption characteristics of the rock samples were determined.

5. The information obtained in this investigation is applicable only to the ejecta from the Danny Boy crater. Results concerning characteristics of this material were influenced by the rock type, depth of burst, fractural frequency, and other factors.

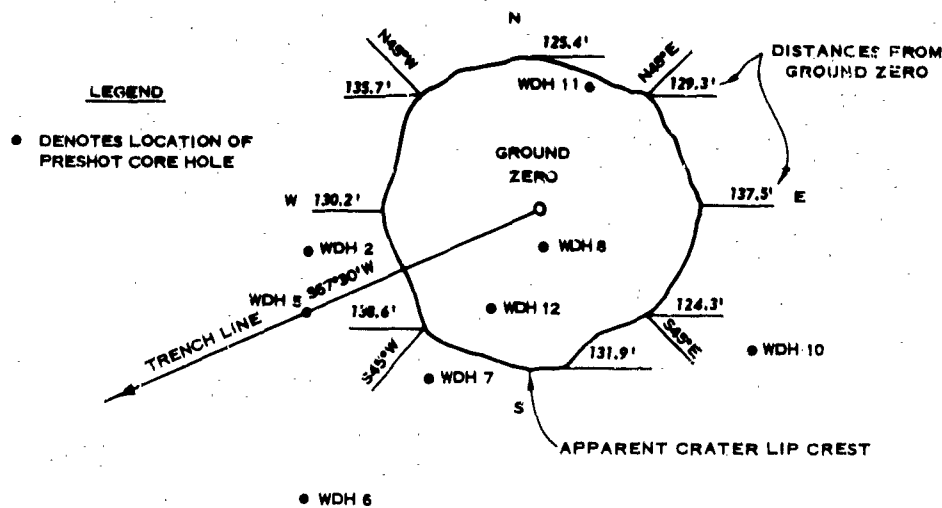
PART II: TEST AREA AND SAMPLING OPERATIONS

Basalt Crater

6. The Danny Boy basalt crater was formed on 5 March 1962 by detonating a 0.42-kt nuclear device at a depth of 110 ft in a 36-in.-diameter core hole that was stemmed with sand. Photograph 1 shows the crater area on 29 April 1963. The crater shape resembled an inverted cone. Fig. 1 shows the approximate dimensions of the crater, and the locations of



CROSS SECTION



NOTE: MEASUREMENTS WERE ALL APPROXIMATE AVERAGES.

PLAN

Fig. 1. Crater cross section and plan

preshot core holes. The apparent depth of the crater was approximately 62 ft. Photographs 2-9 are views of the interior of the crater taken from eight directions.

Trench and Road Fill

7. To permit a better study of the nature of the explosive effect, a trench was excavated to ground level from the outer circumference of the ejecta to the lip of the crater along survey line $S67^{\circ}30'W$ (see fig. 2).

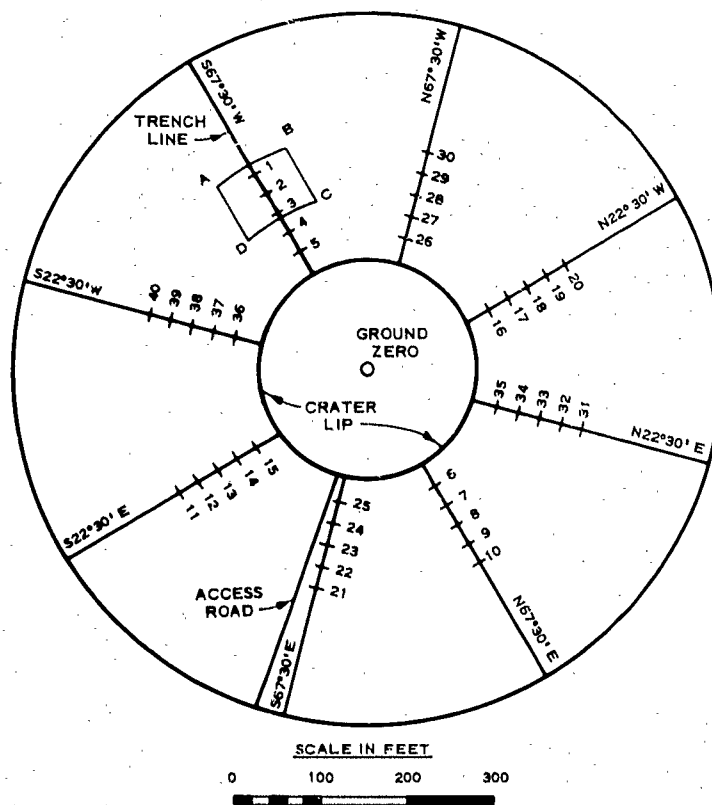


Fig. 2. Sampling locations

This trench was approximately 10 ft wide at the ground level; distances from ground zero (GZ) were marked along the center line of the trench. Photograph 10 is a view of the trench from directly across the crater. Using the sides of the trench as a means of determination, it was estimated that the ejecta piled up to heights varying from 8 to 20 ft above the

original ground surface, and tapered down to scattered pieces of rock at 380 to 430 ft from GZ. Some scattered pieces of rock were observed more than 530 ft from GZ. Even as far as approximately 340 ft from GZ there was sufficient depth of crushed rock to make sampling practicable.

8. An access road of earth fill had been constructed to the edge of the crater along survey line S67°0'E (fig. 2). Photograph 11 shows the outer end of this road and illustrates scattering of the rock in the area beyond approximately 380 ft from GZ.

Fragment Sizes

9. The rock fragments in the ejecta and within the crater were inspected, and the diameter of some of the larger fragments was measured. The largest fragments were in the crater, some of them being approximately 20 ft in diameter. However, some of the fragments in the ejecta measured as much as 15 ft in diameter. The presence of caliche or calcite on a majority of the particle surfaces reflected fragmentation along joint planes. An estimate of the percentage of the various sizes of fragments in the ejecta, made from a visual inspection of the surface, was as follows:

| <u>Fragment Diameter</u> | <u>Approximate Percent by Volume</u> |
|--------------------------|--|
| > 3 ft | 30 |
| 3 ft to 7 in. | 30 |
| 7 in. to 3 in. | 25 |
| 3 in. to 1-1/2 in. | 10 |
| < 1-1/2 in. | <u>5</u> |
| Total | 100 |

This estimate of the sizes of aggregate observed at the surface is included in the report only to reflect the percentage distribution of sizes not covered by the actual counts from photographs described below. Some of the larger fragments are shown in photograph 12, and some of the smaller ones in photograph 13.

10. Photograph 14 illustrates a 1-ft-square grid overlay laid along the ejecta surface along the south line. From photographs of this type, particle counts of the various sizes of fragments were made; percentages of particle distribution were determined; and cumulative percentages passing sieve sizes 12, 9, 6, and 3 in. were calculated. This study showed that

there was layering of different sizes, and that observations of the surface of the ejecta did not necessarily indicate true particle percentages in the total ejecta.

11. The WES Geology Branch provided other sequential, overlapping photographs of the surface of the crater along radial lines extending: (a) east, (b) north, (c) west, and (d) slightly east of south (this line was 25 to 30 ft east of true south at a distance of about 130 ft from GZ). Percentages finer than arbitrarily selected sizes and based on the counts along these lines, cumulated with distance from GZ, are plotted in fig. 3.

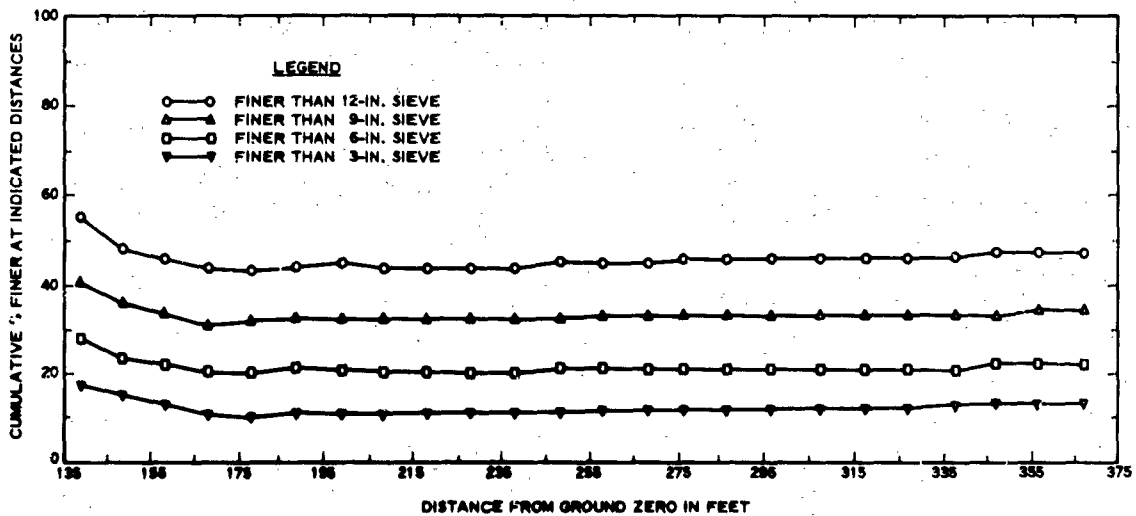


Fig. 3. Cumulative average particle size distribution at designated distances from ground zero

12. In determining particle distribution, particle sizes were arbitrarily designated as follows: size A, larger than 12 in.; size B, 9 to 12 in.; size C, 6 to 9 in.; size D, 3 to 6 in.; and size E, smaller than 3 in. These sizes refer to the smaller diameter (width) on bulky particles and to the longest dimension on large slender particles. These dimensions refer to plane dimensions only. For fig. 3, percentages were corrected for thickness of particles by assuming the particles to be nominally spherical in shape.

13. Sheets were devised for recording the particle size count in a 10- by 10-ft grid pattern. An example of such a sheet is shown in fig. 4. On this standard sheet a count of particle size was made for each square foot and each running foot along the center line by averaging the

STATION
FROM GZ 121
FROM CRATER RIM O

| | | | | | | | | | | | | | | | | | |
|---|----|---|----|---|-----|---|-----|---|-----|---|-----|---|-----|---|-----|---|----|
| A | 50 | A | 50 | A | 10 | A | 30 | A | 40 | A | 30 | A | 50 | A | 50 | A | 30 |
| B | 50 | B | 50 | B | 25 | B | 40 | B | 40 | B | 30 | B | 50 | B | 50 | B | 40 |
| C | 50 | C | 50 | C | 25 | C | 30 | C | 30 | C | 30 | C | 50 | C | 50 | C | 30 |
| D | 50 | D | 50 | D | 65 | D | 20 | D | 20 | D | 20 | D | 70 | D | 70 | D | 30 |
| E | 50 | E | 95 | E | 70 | E | 10 | E | 70 | E | 10 | E | 100 | E | 100 | E | 70 |
| A | 30 | A | 30 | A | 100 | A | 30 | A | 40 | A | 30 | A | 30 | A | 30 | A | 30 |
| B | 30 | B | 30 | B | 60 | B | 10 | B | 40 | B | 10 | B | 30 | B | 30 | B | 20 |
| C | 30 | C | 30 | C | 20 | C | 20 | C | 30 | C | 20 | C | 20 | C | 20 | C | 20 |
| D | 30 | D | 30 | D | 20 | D | 20 | D | 20 | D | 20 | D | 20 | D | 20 | D | 20 |
| E | 30 | E | 5 | E | 5 | E | 100 | E | 40 | E | 10 | E | 60 | E | 60 | E | 60 |
| A | 30 | A | 30 | A | 50 | A | 30 | A | 40 | A | 30 | A | 30 | A | 30 | A | 30 |
| B | 30 | B | 30 | B | 10 | B | 10 | B | 40 | B | 10 | B | 30 | B | 30 | B | 20 |
| C | 30 | C | 30 | C | 20 | C | 20 | C | 30 | C | 20 | C | 20 | C | 20 | C | 20 |
| D | 30 | D | 30 | D | 30 | D | 30 | D | 30 | D | 30 | D | 30 | D | 30 | D | 30 |
| E | 30 | E | 30 | E | 30 | E | 30 | E | 30 | E | 30 | E | 30 | E | 30 | E | 30 |
| A | 20 | A | 20 | A | 10 | A | 10 | A | 10 | A | 10 | A | 10 | A | 10 | A | 10 |
| B | 20 | B | 20 | B | 20 | B | 20 | B | 20 | B | 20 | B | 20 | B | 20 | B | 20 |
| C | 20 | C | 20 | C | 20 | C | 20 | C | 20 | C | 20 | C | 20 | C | 20 | C | 20 |
| D | 20 | D | 20 | D | 40 | D | 40 | D | 40 | D | 40 | D | 40 | D | 40 | D | 40 |
| E | 20 | E | 10 | E | 30 | E | 30 | E | 30 | E | 30 | E | 30 | E | 30 | E | 30 |
| A | 10 | A | 10 | A | 50 | A | 60 | A | 100 | A | 100 | A | 5 | A | 5 | A | 5 |
| B | 10 | B | 10 | B | 25 | B | 40 | B | 10 | B | 10 | B | 20 | B | 20 | B | 20 |
| C | 10 | C | 10 | C | 25 | C | 10 | C | 10 | C | 10 | C | 10 | C | 10 | C | 10 |
| D | 10 | D | 10 | D | 25 | D | 20 | D | 20 | D | 20 | D | 20 | D | 20 | D | 20 |
| E | 10 | E | 80 | E | 80 | E | 70 | E | 70 | E | 70 | E | 80 | E | 80 | E | 70 |
| A | 10 | A | 10 | A | 10 | A | 10 | A | 10 | A | 10 | A | 10 | A | 10 | A | 10 |
| B | 10 | B | 10 | B | 10 | B | 10 | B | 10 | B | 10 | B | 10 | B | 10 | B | 10 |
| C | 10 | C | 10 | C | 10 | C | 10 | C | 10 | C | 10 | C | 10 | C | 10 | C | 10 |
| D | 10 | D | 10 | D | 10 | D | 10 | D | 10 | D | 10 | D | 10 | D | 10 | D | 10 |
| E | 10 | E | 10 | E | 10 | E | 10 | E | 10 | E | 10 | E | 10 | E | 10 | E | 10 |

Fig. 4. Example of particle size counting sheet

STATION
FROM GZ 131
FROM CRATER RIM 10

PHOTOGRAPH No. 1-3 Sheet 1/24

Note 1
Numbers within a square (1 sq ft) represent the percent of area occupied by a particle of a given size.
Note 2
Numbers along center line represent the average distribution along the center line.
Average 0 - 10

A 15
B 5
C 11
D 23
E 46

PARTICLE SIZE DISTRIBUTION
DAIRY BOY CRATER
Along center line of proposed trench at S67°30'W
Don Banks 1 May 1963

PARTICLE SIZE DESIGNATION
A 12 in. or larger
B 9 to 12 in.
C 6 to 9 in.
D 3 to 6 in.
E 0 to 3 in.

distribution for the 5 sq ft on each side of the center line.

14. A count was made as follows. For a given square foot, the particle size could be estimated by comparison with the 1-ft grid. Each particle within the square foot was designated A, B, C, D, or E, and then an estimate was made of the percentage of the 1 sq ft that the particle occupied. Usually this count started with the largest size and proceeded downward so that the remaining percentage (i.e. 100 minus the combined percentage of A, B, C, and D particles) was assigned to the size E particle. A given square foot recorded as A 30, B 10, C 20, D 20, and E 20 meant that 30 percent of the square foot was occupied by a size A (12 in. or larger) particle; 10 percent was occupied by a size B particle; etc.

Rock Types

15. The rock fragments at the site included the types designated as subandesite, caliche or calcite, and basalt with small-, medium-, and large-size vesicles. Field geologists at the site noted layering of the ejecta by types with approximately the top 1-1/2 ft being called "dense (subandesite)," the next 3 to 4 ft called "vesicular," and the next 3 to 4 ft "dense," below which weathered browner rock occurred. The layering noted was determined by geologically mapping the walls of the trench, and its significance or relation to the preshot geology will be covered separately in a report to be published at a later date (Postshot Exploration of the Danny Boy Crater). Along surface planes of many fragments there was a pronounced layer of caliche or calcite (this indicated that fragmentation had occurred along joint planes), and there were some independent fragments of this material scattered through the ejecta. The percentages of the types of rock in the ejecta were estimated to be as follows:

| Type of Rock | Approximate Percent by Volume |
|--|----------------------------------|
| Subandesite | 10 |
| Basalt with small-size vesicles (1/16 to 1/4 in. in diameter) | 50 |
| Basalt with medium-size vesicles (1/4 to 1/2 in. in diameter) | 22 |
| Basalt with large-size vesicles (diameter over 1/2 in.) | 17 |
| Caliche | <u>1</u> |
| Total | 100 |

Photograph 15, a close-up of the Danny Boy crater ejecta, clearly illustrates basalt with different sizes of vesicles, and caliche along surface planes of some fragments. Particles of light gray subandesite are not readily distinguished in the photograph.

Samples

16. Forty bags of rock sieved to pass a 1-1/2-in. sieve were selected from the ejecta for laboratory testing. One bag was collected from each of locations 1 through 40 shown in fig. 2. These locations, five in each of eight areas spaced around the crater, were approximately 160, 190, 210, 240, and 270 ft from GZ.

17. Twenty-four large and 18 smaller pieces of rock were selected for laboratory testing from the area bounded by ABCD in fig. 2, line CD being 205 ft from GZ, line AB being 280 ft from GZ, and lines AD and BC being approximately 50 ft from the center line of the trench at S67°30'W. The 24 large pieces of rock, each weighing 75 to 115 lb, were selected to approximately represent on a percentage basis the rock types present in the ejecta. The 18 small pieces of rock, each approximately 3 to 6 in. in diameter, were selected to represent small aggregate of the six different rock types listed below, three pieces for each type. The rock types were selected in an attempt to cover the range of specific gravities thought likely to be present in the ejecta. These types are referred to herein as (a) basalt with small-size vesicles, (b) weathered basalt with small-size vesicles, (c) subandesite, (d) caliche, (e) basalt with large-size vesicles, and (f) basalt with medium-size vesicles.

PART III: FIELD INSPECTIONS FOR RADIOACTIVITY

Sieved Samples

18. The 40 bags of rock which had been sieved over the 1-1/2-in. sieve were monitored at the Danny Boy test site for radioactivity before shipment to WES for laboratory testing. The radiation detection instruments were placed in and around the rock fragments in each bag, and gamma radiation readings were 3 to 5 mr/hr.

Single Fragments

19. The 24 large fragments and the 18 pieces of 3- to 6-in. rock were also monitored before shipment to WES. These fragments showed gamma readings of 0.5 to 2 mr/hr.

Personnel Check

20. The personnel who selected the samples were monitored daily with dosimeters to detect radioactivity pickup. The daily readings varied from 30 to 50 mr/hr.

Shipment Inspection

21. The material was inspected after it had been loaded on a truck just prior to shipment from the Nevada Test Site. The highest reading in or around the rock was 6.5 mr/hr gamma, and 400 milliradians/hr gamma and beta. In the truck cab, the reading was 0.1 mr/hr gamma.

PART IV: LABORATORY TESTS

Specific Gravity and Absorption

22. The eighteen 3- to 6-in. fragments were tested for saturated surface dry specific gravity and absorption at WES. Results are given in table 1 as postshot test data. The preshot specific gravities listed in the table were taken from a previous report. The variations in the specific gravities are due to a number of causes, one being the considerable variation in rock structure within the individual rock types. Also the amount of weathering, and vesicle distribution and size varied between rock fragments. However, the same general types of rock were tested in the preshot and postshot studies, and except for the caliche, the specific gravity and absorption results indicated that these rocks would probably be suitable for use as concrete aggregate.

Compressive Strength

23. A number of preshot tests for compressive strength had been made on rock cores from core holes designated by WDH numbers in fig. 1, page 3, and the results have been reported in a previous report.⁴ The compressive strengths indicate good sound rock (see table 1).

Laboratory Radiological Test Data

24. In preparation for further laboratory testing planned for the ejecta material, it was necessary to determine (a) the dust hazard that would result from crushing and pulverizing processes, and (b) necessary waste-disposal procedures. This necessitated radiological studies of gamma, beta, and alpha radiations. WES personnel determined the gamma and beta radiations to be essentially the same as those measured in the pre-shipment check at the Nevada Test Site.

25. Reynolds Electrical and Engineering Co., Inc. (see reference 2), cites the April 1958 Addendum to National Bureau of Standards Handbook No. 59 as source of the following maximum permissible doses of radiation:

| <u>Critical Organ</u> | <u>Maximum Permissible Dose</u> | | |
|------------------------|---------------------------------|--|---|
| | <u>Occupational</u> | <u>Provisional*</u> <u>Occupational</u> | <u>Emergency</u> <u>(Once in a Lifetime)</u> |
| Total body | 5 rem**/yr | 12 rem/yr | 25 rem |
| Most individual organs | 15 rem/yr | --- | -- |
| Thyroid or skin | 30 rem/yr | --- | -- |

* The dose indicated in this column is allowable if the previous exposure history is known. The records of previous exposures must show that the addition of such a dose will not cause the individual to exceed the age-proportioned allowance $5 \times (n - 18)$, where n = age in years and must be greater than 18.

** A rem is a roentgen equivalent for man.

26. The radiations picked up on the dosimeters and the beta-gamma counts were so small as to all but preclude any possibility of the maximum permissible dose being attained, even from daily contact with the material from the Danny Boy crater for a period of a year from the time it was sampled.

27. Small particles were found which had a fused appearance and higher beta-gamma radiation than the average fragments. These were suspected of having a high alpha radiation. Further inspections by representatives of the Atomic Energy Commission, the Edgewood Arsenal, and the Office, Chief of Engineers, revealed that for selected samples the gamma plus beta radiation was approximately 400 milliradians/hr. It was decided that the WES laboratory was not equipped to handle this material safely on subsequent crushing or properly dispose of the waste resulting therefrom. The material was therefore shipped back to the Nevada Test Site, and the area where it had been stored and tested at WES was scrubbed and determined to be radioactively safe.

Particle Shape

28. Detailed study of the particle shapes was not made because of the limited scope of the study; however, the fragments looked the same as those which would be obtained from use of conventional explosives in basalt. The edges of the pieces were sharp, and while the larger pieces tended to be blocky, as can be seen in the photographs included herein, the pieces smaller than about 3 in. tended to be splintery in shape, with

tendency toward splinterness increasing with decreasing particle size. It is well known from many studies of operations involved in fragmenting brittle solids (crushing, grinding, comminution) that the tendency of the fragments to have a flat or an elongated shape increases with the reduction ratio; i.e. the product of any single reduction operation, if graded, will be progressively flatter and more elongated the smaller the particle size.

PART V: AGGREGATE PRODUCTION PROBLEMS

Decay Schemes

29. Fig. 3.2 in Project Danny Boy Report POR-1819 indicates that the gamma dose-rate in an area just outside the crater was 1000 r/hr at H + 1 hr as determined from ground-survey measurements and extrapolation by the $T^{-1.3}$ formula. Fig. 3.9 in the same report indicates a gamma dose-rate of 3000 to 3200 mr/hr (3.0 to 3.2 r/hr) in the same area at D + 15 and D + 16 days, again determined from ground-survey measurements. A formula for the determination of rate of disintegration varied between $A \cdot T^{-1.3}$ and $A \cdot T^{-1.4}$ as expressions of necessary calculations, where A = a constant and T = the time in hours after explosion. The actual exponent should probably be slightly higher than the determined value due to the fact that shielding influenced the film detector instruments used in the crater. The radioactivity of the aggregate is of concern, and might be theoretically calculated, but this would not be practicable for prediction purposes at the present time. The decay curve of the aggregate would depend on the composition of the nuclear explosive, the efficiency of the particular blast involved (both the fission products and the unused original material), the characteristics (such as chemical composition) of the medium in which the blast took place, and perhaps other factors.

Size Separation

30. Suitable equipment is needed for the separation of the aggregate size groups in the ejecta from a nuclear detonation. Rock rakes mounted on truck tractors have been used for similar purposes, and are available with spacings between teeth as small as 6 in. By using a rock rake with a 6-in. clearance, those fragments smaller than 6 in. in diameter could be separated from the larger fragments of the ejecta. From the planometer percentage values determined from aerial photographs, it is estimated that the bulk volume of the ejecta from the Danny Boy crater was 56,000 cu yd. From fig. 3 it can be estimated that approximately 20 percent of this, or 11,200 cu yd, could be separated out by the 6-in. rock rake. The estimate of 20 percent was based on total of the area under the curve.

Crushing Equipment

31. Various types of crushers are available to the U. S. Army Corps of Engineers for further crushing ejecta from nuclear shots or materials separated therefrom by rock rakes. The Department of Mechanical and Technical Equipment, U. S. Army Engineer School, Fort Belvoir, Virginia, lists manuals for the following:

| <u>Type Crusher</u> | <u>Maximum Rock Size Crusher Will Take, in.</u> |
|------------------------|---|
| DJ-50 | 13 by 38 |
| 25-ton-per-hr | 13 by 22 |
| 75-ton-per-hr | 18 by 34 |
| 200- to 400-ton-per-hr | 28 by 40 |

From fig. 3 it can be seen that approximately 20 percent of the ejecta from the Danny Boy crater has a fragment diameter between 6 and 12 in. This size rock could be crushed with a 25-ton-per-hr crusher to pass a 6-in. sieve.

PART VI: CONCLUSIONS

Mechanical Preparation

32. Aggregates for use in base course, and asphalt and concrete construction could be manufactured by nuclear blast, after which a rock rake and a crusher would facilitate separation into sieve size groups.

Yield

33. The Danny Boy basalt cratering event discussed herein yielded approximately 56,000 cu yd of rock fragments, of which at least 11,200 cu yd could be manufactured into aggregate by using a rock rake and crusher. It would be necessary to ensure that radioactivity had decayed to a low enough level so that construction or subsequent maintenance of roads or structures containing the aggregates would present no health hazard. The reader should keep in mind that the very limited findings reported herein apply only to a cratering event in basalt. An event of equal yield in granite, limestone, or other rock would probably produce different results. The amount of usable material as well as size and shape of fragments would vary with rock type and depth of burst. Particle shape and size would depend upon the bedding planes, joint system, and other structural features of the rock. Suitability of the processed rock for use in concrete would necessarily depend upon the rock type and the crushing characteristics.

Sphericity Ratio

34. The presence or absence of a correlation between rock type, particle size, and particle shape (sphericity ratio) along traverses from the crater rim should be established. Rock fragments should be examined petrographically in the laboratory, particularly for schistosity, to establish reasons for the size and shape distribution of the rock fragments about the crater.

Desirable Data

35. Cores extracted from large fragments of debris after the event

would have afforded an idea of the strength of the rock after the blast. Petrographic examination of thin sections of the preshot and postshot material under the microscope would have afforded a qualitative idea of how the strength of the rock was affected. However, such tests were beyond the scope of this investigation.

PART VII: RECOMMENDATIONS

Completion of Present Work

36. It is recommended that the investigation described in this report, and prosecuted only through its preliminary phases, be completed by determining through sieve analysis in the field the particle size distribution within usable size ranges and particle shape, and through petrographic examination in the laboratory the macroscopic evidence of alteration caused by blast that might affect suitability of the aggregate for construction purpose. Concrete specimens utilizing such aggregate should be made for strength testing in addition to the standard tests to determine suitability of aggregates. The radioactivity of the aggregates and the concretes made with them should be determined.

Future Work

37. It is recommended that when a cratering shot is planned in sound hard rock sufficient cores be taken prior to detonation to permit thorough examination and processing into aggregate to compare with material resulting from the blast that appears to be suitable aggregate.

38. It is believed that a complete study of aggregate production potential by nuclear methods should include:

- a. A detailed study of block size distribution to determine variations as a function of depth of burst.
- b. A detailed study of block size distribution to determine dependence upon preshot geologic conditions such as fracture frequency, jointing, type of rock, etc.

REFERENCES

1. Samuel Glasstone, ed., The Effects of Nuclear Weapons. Prepared by the U. S. Department of Defense, published by the U. S. Atomic Energy Commission, June 1957.
2. _____, Emergency Radiation Monitoring Team Training Manual. Radiological Safety Division, Industrial Health and Medicine Department, Reynolds Electrical and Engineering Co., Inc., Mercury, Nev., November 1959.
3. _____, Atomic Radiation, Part II, Monitoring, Radiation Protection, Radioactive Shipment, Waste Disposal. Prepared by RCA Service Co., a division of Radio Corporation of America, Government Service Department, Camden, N. J., 1962.
4. U. S. Army Engineer Waterways Experiment Station, CE, Project Danny Boy: Petrographic Examination and Physical Tests of Selected Cores. Miscellaneous Paper No. 6-570, Vicksburg, Miss., January 1963.

Table 1
Laboratory Test Results

| Rock Type | Time of Test | Specimen No. | Bulk Specific Gravity Saturated Surface Dry | Absorption % | Compressive Strength psi | |
|-----------------------------------|--------------|--------------|---|--------------|--------------------------|--------|
| Subandesite | Postshot | c-1 | 2.67 | 3.0 | | |
| | | c-2 | 2.74 | 1.3 | | |
| | | c-3 | 2.64 | 1.7 | | |
| | | Avg | 2.68 | 2.0 | | |
| | | | | | | |
| | Preshot | A-8-6 | 2.72 | | | |
| | | A-8-7 | 2.70 | | | |
| | | A-11-3 | 2.68 | | | |
| | | A-11-6A | 2.76 | | | |
| | | A-11-6B | 2.72 | | | |
| | | Avg | 2.72 | | | |
| | | | | | | |
| | | | | | | 29,300 |
| | | | | | | 24,930 |
| | | | | | | 26,420 |
| | | | | | | 28,740 |
| | | | | | | 28,980 |
| | | | | | | 28,280 |
| | | | | | | 40,420 |
| | | | | 48,650 | | |
| Avg | | | | 31,970 | | |
| Basalt, small-size vesicles | Postshot | a-1 | 2.62 | 1.4 | | |
| | | a-2 | 2.60 | 0.8 | | |
| | | a-3 | 2.62 | 0.8 | | |
| | | Avg | 2.61 | 1.0 | | |
| | | | | | | |
| | Preshot | B-2-1 | 2.43 | | | |
| | | B-8-10A | 2.55 | | | |
| | | B-8-10B | 2.53 | | | |
| | | B-8-10C | 2.55 | | | |
| | | B-12-3 | 2.36 | | | |
| | | Avg | 2.48 | | | |
| | | | | | | |
| | | | | | | 10,700 |
| | | | | | | 27,160 |
| | | | | | | 14,880 |
| | | | | | | 15,260 |
| | | | | | | 16,510 |
| | | | | | | 15,070 |
| | | Avg | | | | 16,600 |

(Continued)

Table 1 (Concluded)

| Rock Type | Time of Test | Specimen No. | Bulk Specific Gravity Saturated Surface Dry | Absorption % | Compressive Strength psi |
|---|--------------|--|--|--------------|--------------------------|
| Basalt, small-size vesicles, weathered | Postshot | b-1 | 2.41 | 1.2 | |
| | | b-2 | 2.21 | 1.4 | |
| | | b-3 | 2.64 | 1.0 | |
| | | Avg | 2.42 | 1.2 | |
| Basalt, medium-size vesicles | Postshot | f-1 | 2.29 | 1.5 | |
| | | f-2 | 2.69 | 1.1 | |
| | | f-3 | 2.58 | 1.3 | |
| | Preshot | C-8-1A C-8-1B C-11-1C C-11-12 | 2.28 | 1.5 | |
| | | | 2.44 | 1.1 | |
| | | | 2.50 | 1.3 | |
| | | | 2.34 | | |
| Avg | 2.39 | | | | |
| | | C-8-9(A) | | | 10,790 |
| | | C-8-9(B) | | | 10,980 |
| | | C-8-9(D) | | | 12,090 |
| | | | | Avg | 11,290 |
| Fine- to medium- grained glassy basalt | Preshot | 10-A | 2.73 | | |
| | | 10-B | 2.70 | | |
| | | Avg | 2.72 | | |
| Basalt, large- size vesicles | Postshot | e-1 | 2.28 | 2.3 | |
| | | e-2 | 2.29 | 2.6 | |
| | | e-3 | 2.11 | 1.8 | |
| | | Avg | 2.23 | 2.2 | |
| Caliche | Postshot | d-1 | 2.14 | 13.0 | |
| | | d-2 | 1.95 | 17.1 | |
| | | d-3 | 2.00 | 18.2 | |
| | | Avg | 2.03 | 16.1 | |



Photograph 1. Crater area, approximately one year
after formation of crater



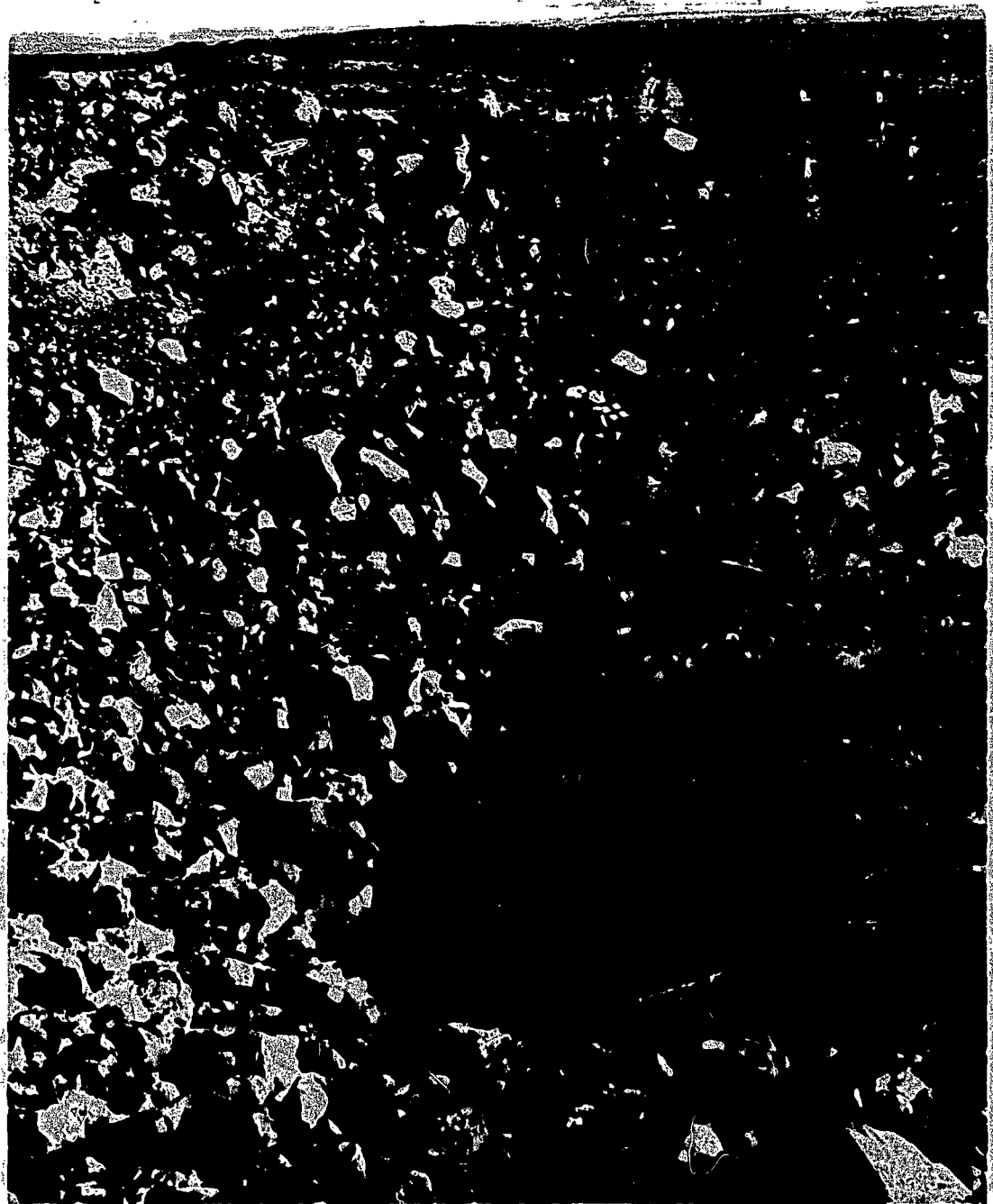
Photograph 2. Interior of crater, looking north



Photograph 3. Interior of crater, looking northeast



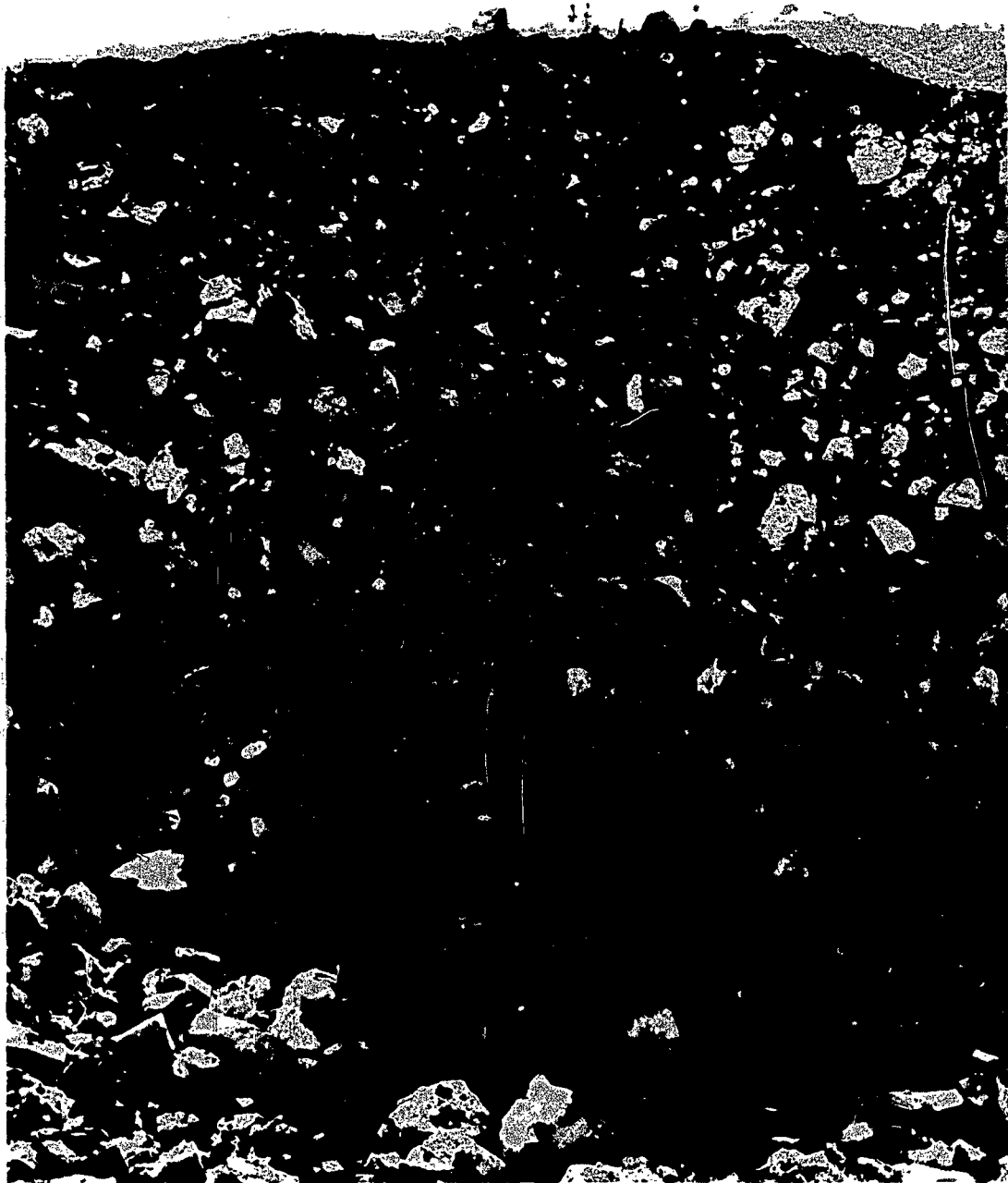
Photograph 4. Interior of crater, looking east



Photograph 5. Interior of crater, looking southeast



Photograph 6. Interior of crater, looking south



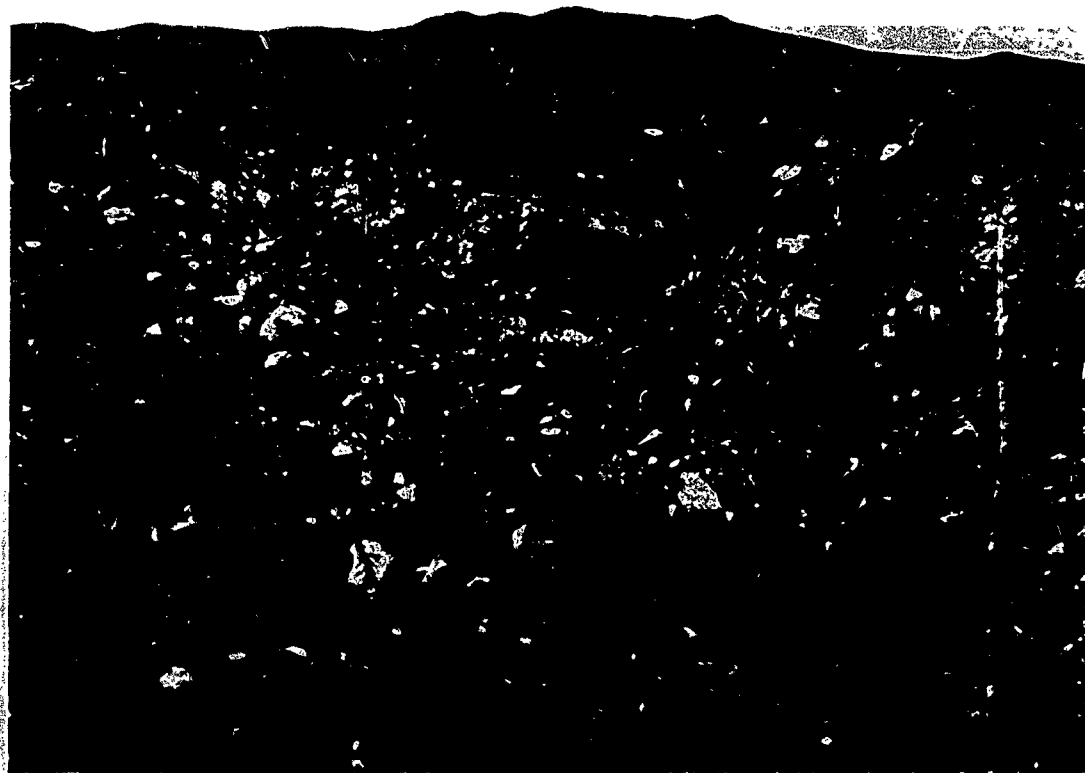
Photograph 7. Interior of crater, looking southwest



Photograph 8. Interior of crater, looking west



Photograph 9. Interior of crater, looking northwest



Photograph 10. Trench excavated to ground level at S67°30'W
as viewed from across the crater



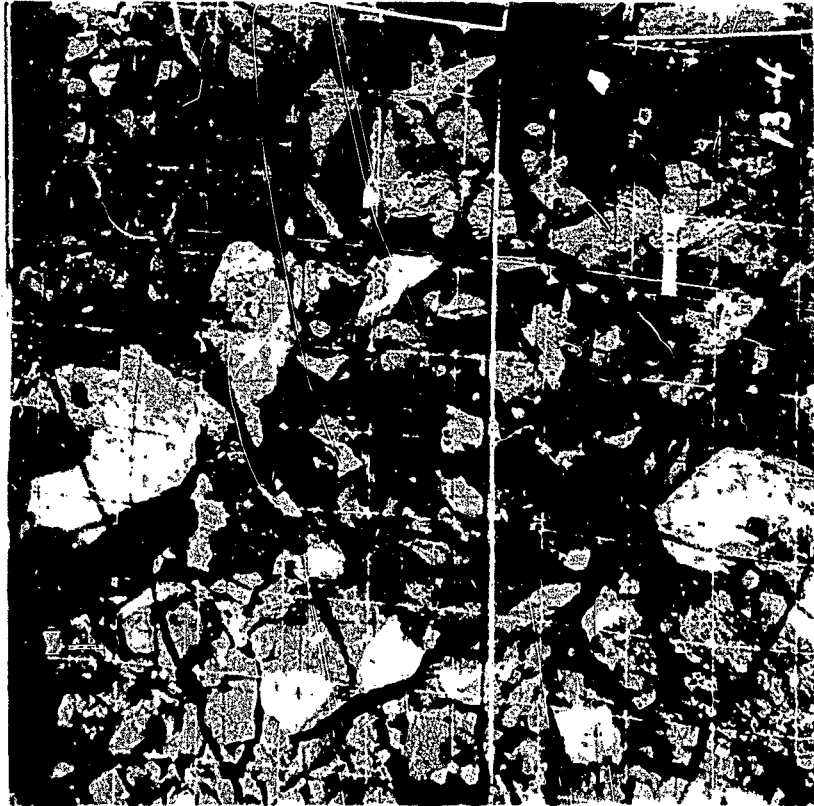
Photograph 11. Outer end of access road viewed from lip of crater



Photograph 12. Large fragments in ejecta area.



Photograph 13. Small fragments in ejecta area. Pencil in foreground was 6 in. long



Photograph 14. 1-foot-square grid overlay used in counts of rock fragments



Photograph 15. Close-up of rock types noted in ejecta.