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Data from the Screening of the Rubble from Eight Cratering Experiments in Oil Shale

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by

M. D. Harper and R. Oliver

ABSTRACT

The rubble excavated from eight cratering experiments in oil shale was separated into various piles by passing the rubble through screens of different sizes. The volumes of rubble in each screened size category are presented along with the background of the experiments. The plots of the cumulative percentage of the volume of rubble screened are also included.

INTRODUCTION

Explosive cratering experiments were conducted by the Los Alamos National Laboratory in the Colony Oil Shale Mine near Rifle, Colorado, during 1978 and 1979. These experiments were part of the research effort at Los Alamos to study the explosively produced fracture of oil shale. The field operations consisted of experiments designed to identify and analyze the major factors involved in the fracturing of oil shale as well as to provide data for the verification of the computer models. This report presents data obtained from the screened rubble from eight cratering experiments. These data represent only part of the results obtained from the field operations. The analysis of these data along with other data will be presented in a later report.

The design of the cratering experiments consisted of between 5 and 110 kg of ammonium nitrate/fuel oil (ANFO) explosive emplaced in either an 11- or 15-cm-diam borehole. The explosive was detonated from the bottom in either one explosive borehole or four explosive boreholes simultaneously. These experiments vary in purpose, design, and results. Table I lists one possible

TABLE I

INTERMEDIATE SCALE COLONY MINE EXPERIMENTS
FROM NOVEMBER 1978 TO SEPTEMBER 1979

	Single Explosive Borehole		Four Explosive Boreholes
Highly Instrumented Experiments	79.02 79.03*		79.16
Instrumented Cratering Experiments	79.05 79.06 79.07	79.08 79.09 79.10	79.12
Cratering Experiments	78.01 78.02 78.03*	79.01 79.11*	79.15*
Blasting Mat Experiments	79.04 79.09		
Cable Survival Experiments	79.13 79.14		

*Rib Experiment

classification of the cratering experiments by the primary purpose of each experiment along with identifying the number of explosive boreholes (one or four) and the configuration of the experiments (rib or floor). Each experiment is designated by the year and the order in which it was conducted within that year (e.g., experiment 79.03 was the third experiment conducted in the year 1979). The design data for the ANFO explosive are listed in Table II for the single explosive borehole experiments and in Table III for the four explosive borehole experiments. Table IV presents general experimental information on each experiment.

A variety of data was taken during the field operations in the Colony Mine. One set of data important to the analysis of the breakage of oil shale is the size distribution of the fragments generated from the cratering experiments. The size distribution of the rubble from various experiments can be used to compare the effects of different experimental designs on the overall fragmentation results. To obtain this set of data, the rubble was separated

TABLE II

EXPERIMENTAL DESIGN DATA
SINGLE BOREHOLE EXPERIMENTS

Experiment	Diameter of ANFO (cm)	Depth to Bottom of ANFO (cm)	Depth to Top of ANFO (cm)	Weight of ANFO (g)
78.01	11	198	133	5220
78.02	11	255	191	5220
78.03	11	259	193	5220
79.01	11	378	312	5220
79.02	15	864	315	90720
79.03	15	899	318	90720
79.04	15	259	198	9660
79.05	15	335	104	25670
79.06	15	413	340	5940
79.07	15	457	358	14510
79.08	15	330	231	14510
79.09	15	259	192	9660
79.10	15	330	157	24680
79.11	16	348	194	14510
79.13	13	411	320	7350
79.14	13	254	173	7350

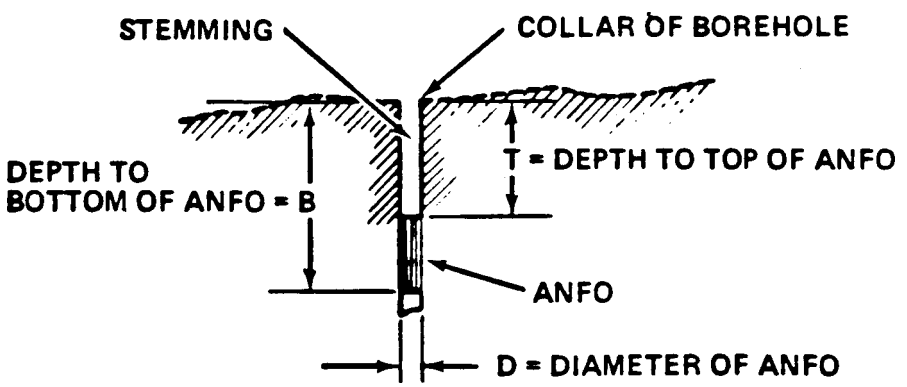

TABLE III

EXPERIMENT DESIGN DATA
FOUR BOREHOLE EXPERIMENTS

Experiment	Diameter of ANFO (cm)	Depth to Bottom of ANFO (cm)	Depth to Top of ANFO (cm)	Weight of ANFO (g)	Bore-hole No.	Depth of Collar (cm)	Spacing of Boreholes (cm)
79.12	15	381	194	27250	1	0	(1-2) 323
79.12	15	380	192	27250	2	1	(2-3) 305
79.12	15	359	167	27250	3	22	(3-4) 312
79.12	15	350	174	27250	4	31	(4-1) 323
79.12*	15	366	180	27250	Eff.	15	Ave. 316
79.15	11	386	193	14550	1	0	(1-2) 213
79.15	11	386	193	14550	2	0	(203) 213
79.15	11	386	193	14550	3	0	(3-4) 213
79.15	11	386	193	14550	4	0	(4-1) 213
79.15*	11	386	193	14550	Eff.	0	Ave. 213
79.16	11	309	151	11900	1	5	(1-2) 214
79.16	11	295	141	11900	2	14	(2-3) 217
79.16	11	302	146	11900	3	12	(3-4) 214
79.16	11	308	149	11900	4	6	(4-1) 219

*Effective experimental design data for the experiment.

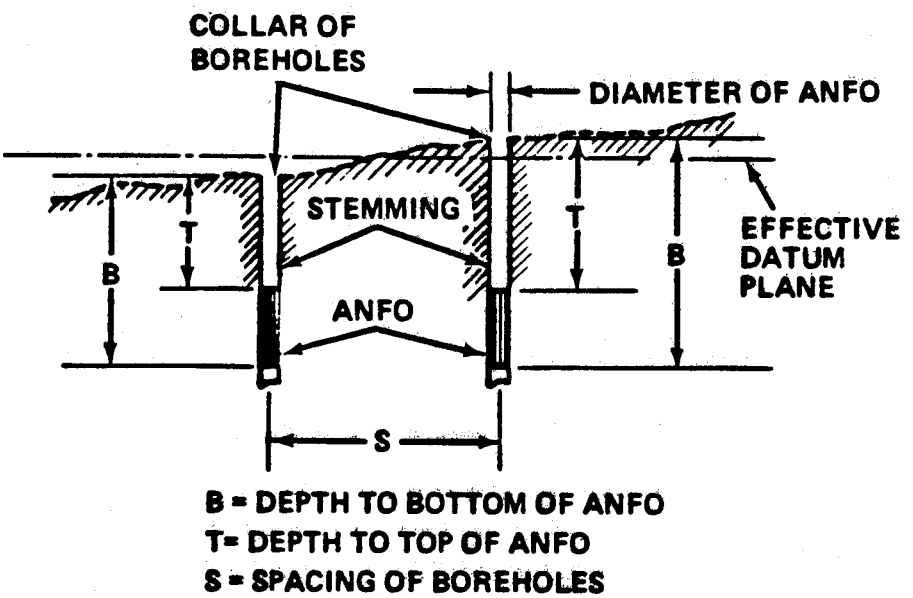

TABLE IV

EXPERIMENTAL DESIGN INFORMATION
SINGLE AND FOUR BOREHOLE EXPERIMENTS

Experiment	Floor or Rib	Single or Four Explosive Boreholes	Detonator and Booster	Stemming	Results
78.01	Floor	Single	No. 6 Cap/Atlas G Booster	Oil Shale Fines	Crater
78.02	Floor	Single	No. 6 Cap/Atlas G Booster	Oil Shale Fines	Crater
78.03	Rib	Single	No. 6 Cap/Atlas G Booster	Oil Shale Fines	Crater
79.01	Floor	Single	No. 6 Cap/Atlas G Booster	Fines and Grout	No crater. Few radial surface fractures.
79.02	Floor	Single	No. 6 Cap/Atlas G Booster	Grout	No crater. Many radial and concentric surface fractures.
79.03	Rib	Single	No. 0 Cap/Atlas G Booster	Grout	Crater
79.04	Floor	Single	No. 0 Cap/Atlas G Booster	Grout	Crater
79.05	Floor	Single	No. 0 Cap/Atlas G Booster	Grout	Incomplete detonation of ANFO. No crater.
79.06	Floor	Single	No. 0 Cap/Atlas G Booster	Grout	Firing cable damaged. Experiment aborted.
79.07	Floor	Single	EBW/Atlas G Booster	Oil Shale Fines	No crater. No fractures.
79.08	Floor	Single	EBW/Atlas G Booster	Oil Shale Fines	Crater. Cavity formed around ANFO.
79.09	Floor	Single	EBW/Atlas G Booster	Oil Shale Fines	Blasting mat contained.
79.10	Floor	Single	EBW/Atlas G Booster	Oil Shale Fines	Crater
79.11	Rib	Single	EBW/Mine Gel & RDX	Oil Shale Fines	Crater
79.12	Floor	Four	EBW/Atlas G Booster	Oil Shale Fines	Crater
79.13	Floor	Single	EBW	Oil Shale Fines	Cables survived
79.14	Floor	Single	EBW	Oil Shale Fines	Cables survived
79.15	Rib	Four	EBW	Oil Shale Fines	Crater
79.16	Floor	Four	EBW	Oil Shale Fines	Crater. Explosive borehole #2 failed to detonate.

into the various size ranges by dumping the fragments through screens of appropriate sizes.

The screening operation for most of the experiments was accomplished in two stages. First, the larger fragments were screened by dumping the excavated rubble through three static screens with sizes of 18-in., 12-in., and 8-in. squares. The remaining rubble that passed through the 8-in. screen was then run through a portable screening unit, Cedarapids model M6016, which contained three screen sizes of 6-in., 4-in., and 2-in. squares. The screened rubble was stacked in seven piles with the designations: <2 in., 2 to 4 in., 4 to 6 in., 6 to 8 in., 8 to 12 in., 12 to 18 in., and >18 in. The volume of these piles was then determined and recorded, assuming a porosity within the pile of 0.5. The only deviation from this procedure was on the screening of the rubble from experiment 79.03. Four static screens were used with sizes of 18-in., 12-in., 8-in., and 4-in. squares. The remaining rubble (<4-in.) was run through a 2-in. square screen with the M6016 screening unit.

The explosives were detonated in the floor and in the rib of the Colony Mine. In the field, efforts were made to keep the errors created by the excavation process and the subsequent handling of the rubble before the screening at a minimum.

PRESENTATION OF SCREENING DATA

Three of the experiments were conducted in the rib of the Colony Mine: experiments 79.03, 79.11, and 79.15. Experiments 79.03 and 79.11 contained a single explosive borehole and experiment 79.15 consisted of four explosive boreholes detonated simultaneously. The rubble from experiments 79.03 and 79.15 consisted of fragments that were both thrown into the room of the mine from the explosion and scaled from the rib subsequent to the shot. The fragments scaled from the rib were screened separately from the rest of the rubble on experiment 79.11.

The scaling of the rib was necessary for the personnel to safely work at the experiment site after the explosion. The scaling operations were conducted interior to the crater and along the perimeter of the crater. The purpose in screening the scaled rubble separately from the other rubble on experiment 79.11 was to examine the differences between the two size distributions.

TABLE V

EXPERIMENT 79.03
SCREENED RUBBLE SIZE DISTRIBUTION

Screen Size (in.)	Volume of Rock (m^3)
<2	17.9
2 to 4	7.8
4 to 8	36.0
8 to 12	24.0
12 to 18	24.8
>18	7.6
Total	118.1

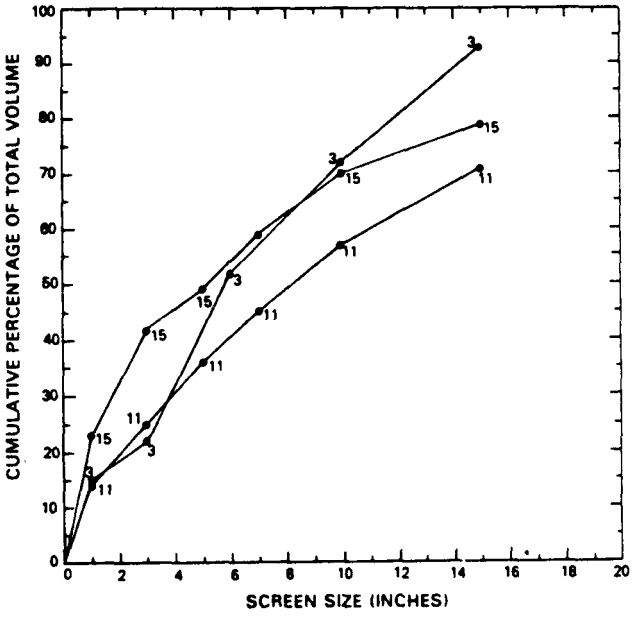

Fig. 1.
Cumulative percentage of the volume of rubble screened from experiments 79.03, 79.11, and 79.15.

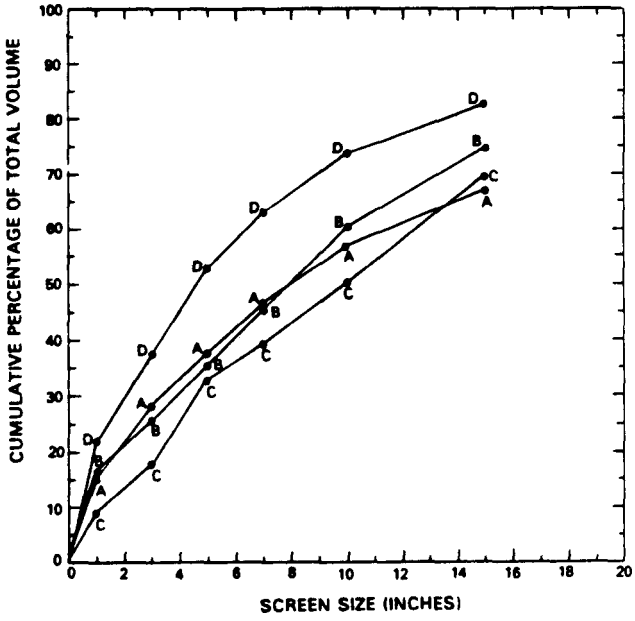

Fig. 2.
Cumulative percentage of the volume of rubble screened for Zones A, B, C, And D from experiment 79.11.

The total volume of rubble measured on experiment 79.03 was 118.1 m^3. Table V lists the volume of rubble screened in each size category. The cumulative percentage of the total volume for experiment 79.03 is the plotted line labelled "3" in Fig. 1.

The total volume of rubble screened on experiment 79.11 (excluding the fragments scaled from the rib after the experiment) was 52.0 m^3. After the rubble that was thrown free from the crater during the explosion was collected into a large pile, zones of the pile were screened separately. Since the distribution of the sizes of rocks within the pile was assumed to be random, the purpose of the screening of the different zones of the rubble pile was to investigate the errors involved in the screening procedure. One end of the pile was removed and screened. The results from this screening operation are referred to as coming from zone A. A center portion of the remaining pile was then screened and these results are labelled zone B. Zone C represents the results from screening one quarter of the remaining pile. Finally, zone D is the label for the screening results of the scaled fragments from the rib. The volume of rubble in each screened size category for each zone is presented in Table VI.

The cumulative percentage of the total volume for each of these zones from experiment 79.11 is plotted in Fig. 2. The cumulative percentage for the average distribution of zones A, B, and C is plotted in Fig. 1 with the label "11".

TABLE VI

EXPERIMENT 79.11
SCREENED RUBBLE SIZE DISTRIBUTION

Screen Size (in.)	Volume of Rock (m^3)			
	Zone A	Zone B	Zone C	Zone D
<2	2.0	2.1	0.4	2.6
2 to 4	1.8	1.2	0.4	1.9
4 to 6	1.3	1.3	0.7	1.9
6 to 8	1.2	1.3	0.3	1.2
8 to 12	1.4	1.9	0.5	1.3
12 to 18	1.4	1.9	0.9	1.1
>18	4.5	3.3	1.4	2.1
Total	13.6	13.0	4.6	12.1

TABLE VII

EXPERIMENT 79.15
SCREENED RUBBLE SIZE DISTRIBUTION

Screen Size (in.)	Volume of Rock (m^3)
<2	18.8
2 to 4	15.0
4 to 6	5.7
6 to 8	7.7
8 to 12	8.7
12 to 18	7.6
>18	17.0
Total	80.5

The total volume of rubble screened on experiment 79.15 was 80.5 cubic meters. The volume of rubble in each screened size category is listed in Table VII. The plot of the cumulative percentage of the total volume for experiment 79.15 is shown in Fig. 1 with the line labelled "15".

The design of three of the floor experiments contained a single explosive borehole. All of the excavated rubble was screened from these experiments. Table VIII lists the volume of rubble in each screened size category along with the total volume of rubble excavated from each of these three floor experiments.

TABLE VIII

EXPERIMENTS 79.04, 79.08, and 79.10
SCREENED RUBBLE SIZE DISTRIBUTION

Screen Size (in.)	Volume of Rock (m^3)		
	79.04	79.08	79.10
<2	3.5	1.8	14.1
2 to 4	2.0	1.1	2.9
4 to 6	0.7	1.0	1.8
6 to 8	2.6	0.7	2.4
8 to 12	2.2	0.5	3.2
12 to 18	1.9	1.6	3.6
>18	8.5	3.3	6.2
Total	21.4	10.0	34.2

The plots of the cumulative percentage of the total volume for experiments 79.04, 79.08, and 79.10 are shown in Fig. 3.

The design of two of the floor experiments contained four explosive boreholes detonated simultaneously. Experiment 79.12 utilized 6-in. boreholes and experiment 79.16 utilized 4.25-in. boreholes. Zones of the rubble beds were excavated and screened separately.

Rubble from two zones of the crater on experiment 79.12 was screened separately. Zone A was chosen to be the volume between the four explosive boreholes. Zone B was chosen to be the remaining volume of rubble excavated which mainly consisted of fragments occurring along the perimeter of the crater and due to surface spall. The total volume of rubble excavated was 189.3 m^3. The volume of rubble in each of the screened size categories for each zone is presented in Table IX. The plot of the cumulative percentage of the total volume for each zone excavated on experiment 79.12 is shown in Fig. 4.

Three zones were excavated and screened on experiment 79.16. Zone A is the volume of rubble that occurred between the four explosive boreholes and below the top of the charges. Zone B is the volume of rubble that occurred between the four explosive boreholes and above the top of the charges. The remaining rubble which consists of flyrock and fragments that occurred along the perimeter of the crater comprises zone C. The total volume of rubble excavated was 36.6 m^3. Table X presents the volume of rubble in each size category for each zone.

TABLE IX

EXPERIMENT 79.12
SCREENED RUBBLE SIZE DISTRIBUTION

Screen Size (in.)	Volume of Rock (m^3)	
	Zone A	Zone B
<2	3.0	9.6
2 to 4	1.9	8.0
4 to 6	0.7	5.3
6 to 8	0.9	4.9
8 to 12	0.5	12.1
12 to 18	0.7	11.6
>18	0.5	13.7
Total	8.2	65.2

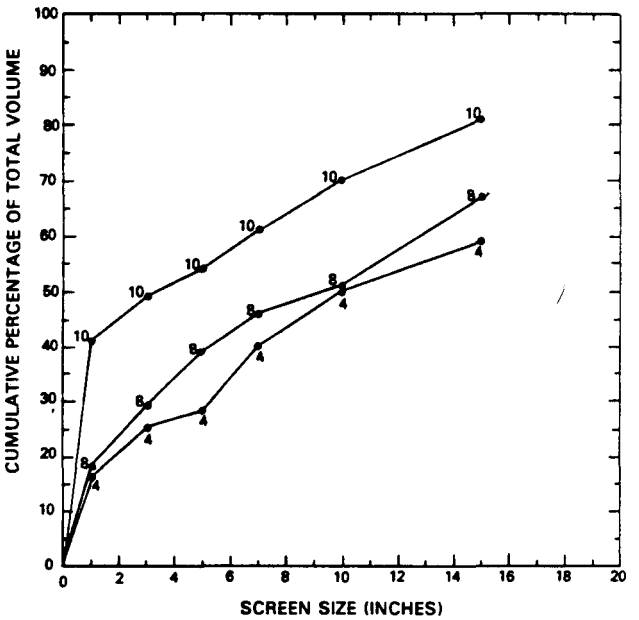

Fig. 3.
Cumulative percentage of the volume of rubble screened from experiments 79.04, 79.08, and 79.10.

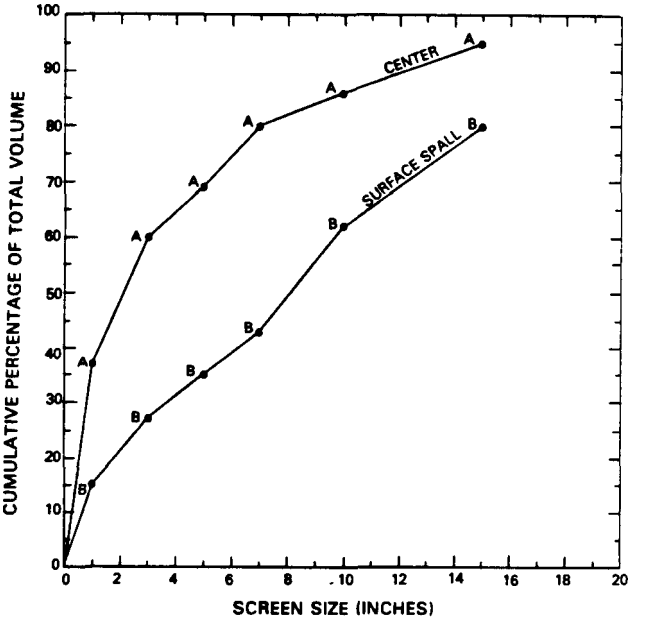

Fig. 4.
Cumulative percentage of the volume of rubble screened for zones A and B from experiment 79.12.

TABLE X

EXPERIMENT 79.16
SCREENED RUBBLE SIZE DISTRIBUTION

Screen Size (in.)	Volume of Rock (m^3) Zone A	Zone B	Zone C
<2	2.6	1.1	3.6
2 to 4	0.9	1.2	2.4
4 to 6	1.0	0.4	2.1
6 to 8	0.6	0.4	1.4
8 to 12	0.7	0.6	4.4
12 to 18	0.8	0.4	6.4
>18	0.6	0.6	4.4
Total	7.2	4.7	24.7

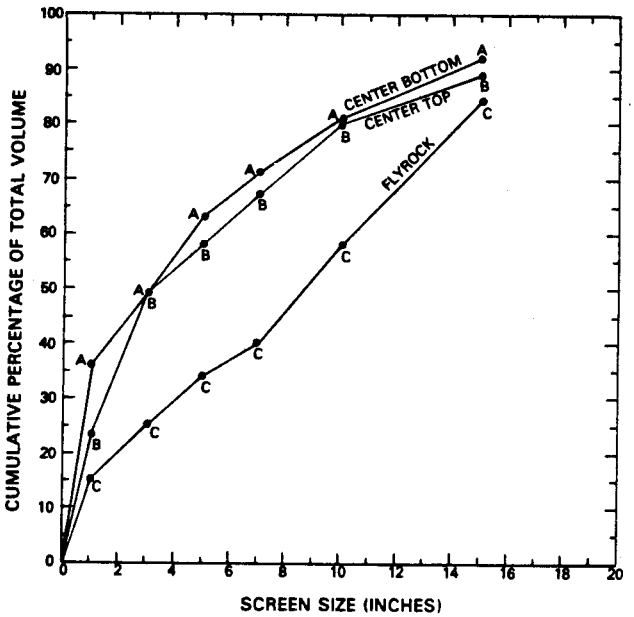

Fig. 5.
Cumulative percentage of the volume of rubble screened for zones A, B, and C from experiment 79.16.

The plot of the cumulative percentage of the total volume for each zone is shown in Fig. 5.

ACKNOWLEDGMENTS

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