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SINGLE-CHARGE CRATERS EXCAVATED DURING SUBSURFACE HIGH-EXPLOSIVE EXPERIMENTS AT BIG BLACK TEST SITE, MISSISSIPPI

Wayne R. Woodruff and Jon B. Bryan

October 19, 1978

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CONTENTS

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ABSTRACT

Lawrence Livermore Laboratory performed single-charge and row-charge subsurface cratering experiments to learn how close-spacing enhances single-crater dimensions. Our first experimental phase established cratering curves for 60-lb charges of the chemical explosive. For the second phase, to be described in a subsequent report, we designed and executed the row-cratering experiments. This data report contains excavated dimensions and auxiliary data for the single-charge cratering experiments. The dimensions for the row-charge experiments will be in the other report. Significant changes in the soil's water content appeared to cause a variability in the excavated dimensions. This variability clouded the interpretation and application of the cratering curves obtained.

INTRODUCTION

Lawrence Livermore Laboratory (LLL) performed single-charge and row-charge cratering experiments and calculations to learn how close-spacing enhances single-crater dimensions. We did this to improve our ability to assess the technical feasibility of possible international peaceful nuclear energy projects. The Energy Research and Development Administration's Division of Military Application sponsored this effort. We performed the field experiments in late 1976 and early 1977 at the U.S. Army Corp. of Engineers, Waterways Experimental Station, Big Black Site, south of Vicksburg, Mississippi. The Explosive Excavation Division at the Waterways Experiment Station provided experimental, operational, and construction support for the experiments. The Soils and Pavements Laboratory of the Soil Dynamics Division provided a site geologic description (see Appendix A for information on the material properties).

The first experimental phase established cratering curves for the 60-lb charge of the DuPont EL-836 explosive in the geologic material. A cratering curve shows the single-charge crater dimension (diameter, depth, or volume) as a function of depth-of-burial (DOB) of the high-explosive (HE) charge. The optimum DOB for the desired excavated dimension is the largest for the given size of charge and experimental-site conditions. Using the optimum depth, we designed and executed the row-cratering experiments (second experimental phase). Table 1 summarizes the important design features of the experiments. Appendix B provides information on the DuPont EL-836 HE equation-of-state used in our cratering calculations.

EXPERIMENTAL PROCEDURE

We made three types of measurements in all experiments. Free-field radial acceleration at shot depth was measured at several ranges from the charge(s). For the row experiments, the acceleration was measured perpendicular to the center line of the row, and in some cases, on the center line of the row at various ranges from the end charge. We also measured ground surface velocity using high-speed photography.[1] Surveys of the pre-shot surface and post-shot excavation permitted determination of the excavated crater depths, widths, and volumes in this report.

Table 1. Summary of cratering experiments.

Shot	Date	Central standard time (h)	Charges	DOB (ft)	Spacing (ft)	Design enhancement	Remarks
Calibration	10-28-76	~1400	1	6.5			MS-80-20 HE; not grout-stemmed
CC-1A	11-12-76	1212	1	5.5			
CC-1B	11-13-76	1408	1	5.5			
CC-1C	12-03-76	1516	1	5.5			Charge and instrument not grout-stemmed.
CC-2A	11-10-76	1057	1	7.5			
CC-2B	11-13-76	1259	1	6.5			Buried at wrong depth; gauges at 7.5 ft.
CC-3	11-11-76	1503	1	4.5			
CC-4	11-12-76	0958	1	6.5			
CC-5	11-13-76	0920	1	3.5			
CC-6	11-10-76	1518	1	8.5			
CC-7	11-12-76	1531	1	2.5			
CC-8	11-12-76	1442	1	10.5			
CC-9	11-13-76	1055	1	9.5			
CC-6W	2-03-77	1515	1	6.0			
CC-8W	2-04-77	1400	1	8.0			
CC-10W	2-05-77	1158	1	10.0			
CC-12W	2-02-77	1550	1	12.0			
R-1	12-01-76	1340	6	6.5	15.0	1.00[a]	
R-3	11-30-76	1536	8	9.4	12.0	1.44[a]	
R-3R (repeat)	12-08-76	1415	8	9.4	12.0	1.44[a]	
R-4	12-02-76	1218	8	9.4	7.3	1.44[a]	
R-6	12-07-76	1515	10	11.1	5.2	1.71[a]	
R-6W	2-07-77	1532	10	11.1	5.2	1.71[a]	
R-21	12-13-76	1410	10 (-2)	5.0	11.5, 12.5, 10.5	1.00[b]	Wrong spacing; 2 charges misfired.
R-21 (makeup)	12-15-76	~1300	2	5.0	11.5	1.00[b]	
R-23	12-14-76	1420	10	8.5	8.1	1.71[b]	
R-24	12-10-76	1253	10	8.5	5.3	1.71[b]	
R-24W	2-10-77	1027	10	8.5	5.3	1.71[b]	
R-26	12-15-76	1435	12	10.8	3.3	2.15[b]	
R-26W	2-08-77	1432	14	10.8	3.3	2.15[b]	
R-28W	2-05-77	1550	14	13.6	2.1	2.71[b]	

[a]Design optimum DOB = 6.5 ft.

[b]Design optimum DOB = 5.0 ft.

PARTICIPANTS

Waterways Experiment Station personnel provided construction support for such experimental tasks as surveying; hole drilling; HE-charge and accelerometer emplacement; stemming (holes were stemmed with a material-matching grout); high-speed photography for surface-velocity measurements; and handling the "prima-cord," booster charges, detonators, and arming.

LLL provided the high explosive, the accelerometers, recording for the free-field acceleration measurements, and timing and firing. We were also responsible for data reduction and interpretation.

DATA REPORTS

Data from the experiments are being published in several reports rather than in a single report. R. F. Rohrer published a report on some of the surface-velocity data obtained from the high-speed photography.[1] A second report (in preparation) will discuss computer calculations of selected cratering experiments.[2]

This report contains and those to follow will contain data on the excavated dimensions of the single- and row-charge experiments and on concomitant free-field acceleration. These data reports provide final data with all the requisite calibrations, filtering, baseline shifts, etc., performed. This report contains all the excavated dimensions from the single-charge cratering experiments. Data are presented in order of increasing DOB of the explosive charge and in two parts: the first is referred to as "dry," the second as "wet."

RESULTS

We did not complete the operation according to the planned time-scale. This resulted in part of the experiments being done before the first of the year (1976) and part done afterward (1977). There appeared to be a marked change in the geologic-material properties over the holidays because the adjacent Big Black River rose sufficiently to have saturated the site materials before the second series of experiments began. Appendix C summarizes the test site static water-level measurements. The higher saturation apparently increased excavated crater dimensions. Thus four more single-charge experiments were performed to establish, as best we could, the cratering curve for the modified soil properties. There also appears to be a scatter in crater size for experiments fired during the same time periods. This scatter has been attributed to variations in material properties throughout the site, which determine the energy-coupling and excavation efficiency. A variability in the performance of the explosive charges is another possible source of this scatter, which cannot be completely excluded because their reproducibility was not experimentally monitored in the individual high explosives.

The second series wet experiments have the designator "W" following the other shot designation to distinguish them from the first series dry set.

Each experimental-data set has several entries describing the experiment:

- A table summarizing the shot-excavated dimensions.
- A documentary photograph of the crater.
- Eight plots of the survey data.

All plots are a spline fit[3] to the field-measured survey data. The spline-fit routine performs a cubic spline fit. Given the values of a function (both X and Y) plus the slope of the curve at both end points, a spline will determine the derivatives at all intermediate points. The values of X, Y, and Y' can then be used to interpolate or fit (smooth) the given data.

For all survey data, single-charge and rows, a profile is defined to be the south-to-north survey and a cross-section is the west-to-east survey. We surveyed several cross-sections on each row. There were both pre-shot and post-shot surveys. A rectangular (X, Y) grid system was established, with the coordinates (0, 0) at the southwest corner. For single-charge cratering experiments, the charge at the middle of the grid was normally at station 6.01-m north and station 6.01-m east. A title at the top of each plot gives the profile or cross-section station at which the data were surveyed.

The *first plot* is a profile with an exaggerated vertical scale. The *second plot* is the same profile but with the same horizontal and vertical scale to depict the true crater shape. The *third plot* is a "normalized" profile with an exaggerated vertical scale. We generate the normalized plots by taking the difference between the pre-shot and post-shot surveys at a fixed station. This takes out the effect that the pre-shot ground was not perfectly level and normalizes it to 0 elevation; thus, the true excavated dimensions can be more easily perceived. The *fourth plot* is the normalized profile with the same vertical and horizontal scale. It is from this latter normalized data that the excavated centerline depth, ground-level width, and below-ground-level volume are obtained. All these data appear in Table 2.

Table 2. Single-charge summary excavation data.

Shot	Charge DOB (m)	Centerline depth (m)			Surface width (m)			Excavated vol (m^3)	Maximum depth (m)		
		profile	x-section	av	profile	x-section	av		profile	x-section	av
					Dry series						
CC7	0.76	1.26	1.26	1.26	4.75	5.00	4.88	11.15	1.26	1.26	1.26
CC5	1.07	1.63	1.63	1.63	6.42	6.26	6.34	24.74	1.65	1.73	1.69
CC3	1.37	1.91	1.94	1.92	6.76	6.69	6.73	32.01	1.91	1.94	1.93
CC1A	1.68	1.40	1.40	1.40	5.74	5.73	5.73	21.11	1.44	1.47	1.46
CC1B	1.68	1.55	1.59	1.57	6.37	6.28	6.32	25.13	1.58	1.59	1.59
CC1C	1.68	2.30	2.30	2.30	7.12	7.32	7.22	40.83	2.33	2.31	2.32
CC2B	1.98	1.60	1.60	1.60	6.60	6.60	6.60	27.19	1.63	1.68	1.66
CC4	1.98	1.43	1.44	1.43	6.51	6.45	6.48	24.53	1.55	1.45	1.50
CC2A	2.29	1.14	1.01	1.08	6.68	6.53	6.61	25.32	1.45	1.41	1.43
CC6	2.59	0.60	0.59	0.60	6.85	6.49	6.67	20.12	1.09	1.29	1.19
CC9	2.90	0.10	0.08	0.09	6.55	5.79	6.17	14.32	0.78	0.82	0.80
CC8	3.20	1.31	1.04	1.17	5.66	5.21	5.44	9.28	1.04	1.06	1.05
					Wet series						
CC6W	1.83	2.20	2.20	2.20	8.25	8.61	8.43	55.26	2.20	2.20	2.20
CC8W	2.44	1.33	1.33	1.33	7.62	7.56	7.59	42.44	1.80	1.77	1.79
CC10W	3.05	0.99	1.00	1.00	7.56	7.44	7.50	33.34	1.64	1.57	1.61
CC12W	3.66	1.47	1.46	1.46	6.00	6.42	6.21	20.75	1.50	1.53	1.52

An identical series of four plots are given for the cross-section. There are two exceptions to the above: there is no photograph of CC1C available; for CC7 the last two plots compare the spline fit to the actual surveyed data points, with straight lines between adjacent survey points to enable perception of the spline fit to the data. The spline fit more nearly represents actual excavated dimensions than straight lines between survey data points. An asterisk on the plot shows the location of the HE charge. Some of the exaggerated vertical scale plots do not show the charge location; to do so would compress the exaggeration, which provides little advantage over the plot with identical horizontal and vertical scales.

A series of cratering curves precedes the individual-shot data. These are graphs of the various excavated dimensions plotted as a function of HE-charge DOB. We fit these data with a second-order polynomial curve using the curve-fitting algorithm that is part of the SOCKITTOME code.[4] All data are plotted as points with and without the second-order fitted curve overlayed. The equation for the fitted curve is listed on the figure along with its maximum value, associated abscissa (HE-charge burial depth), and other statistics.

We plotted the dry and wet data separately and as composites. Both the dry and wet plots of crater centerline depth are fit with two curves to the data. One curve includes all data available, the other ignores the last point in each data set. The last point (i.e., largest DOB) in both data sets was assumed to be anomalous, although it seems to be in agreement with the width and volume cratering curves. Because the centerline depth is not usually the maximum excavated depth (e.g., when fallback occurs: see CC6 and CC9) the final set of cratering curves plots the maximum excavated depth vs HE-charge burial depth.

The cratering curves should yield an optimum HE burial depth for a maximum in the desired dimension. Unfortunately, for the wet series, we never found a maximum, except to say it is somewhat less than 1.83 m. For the dry series of shots, Table 3 summarizes the optimum HE burial depths as derived from the maximums in the second-order fits to the data.

Table 3. Dry optimum HE burial depths.

	Max centerline depth (m)	Max surface width (m)	Max excavated vol (m)
HE DOB	1.47[a] 1.20	2.05	1.82
Av HE DOB	1.78 ± 0.29[a] 1.69 ± 0.44		

[a]Excludes last "anomalous" data point.

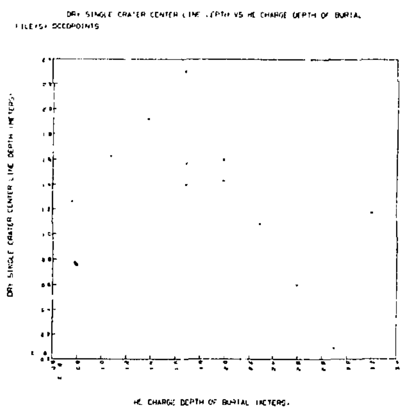
EXPERIMENTAL-DATA SETS

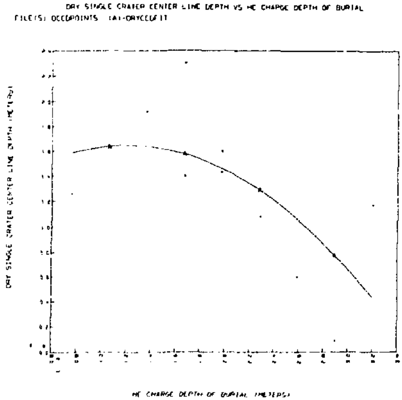
The rest of this section contains computer-generated plots of the experimental data and results discussed earlier.

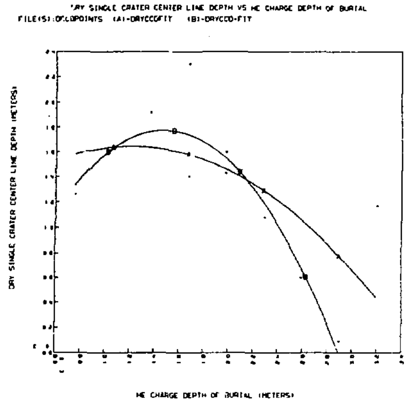
We begin our data series with 28 plots of cratering curves. After that we provide two maps and an illustration: Fig. 1 locates the test site, Fig. 2 focuses on LLL's experimental area at the test site, and Fig. 3 shows typical HE-charge emplacement. Then we provide the data sets for the individual shots, starting with CC7. Summaries of the survey data (Tables 4 to 19) and photographs of the craters (Figs. 4 to 19) precede the plots for the shots.

CRATERING CURVES

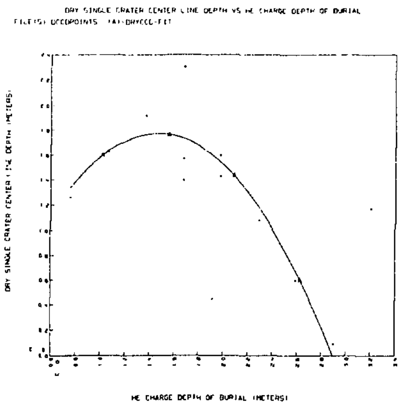
Dry Data



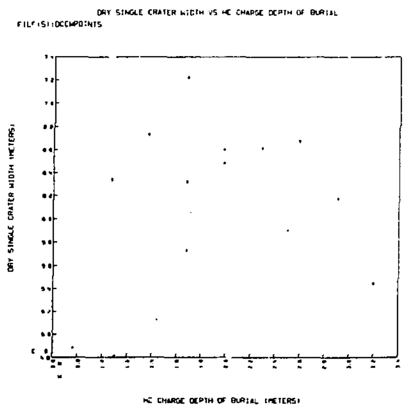


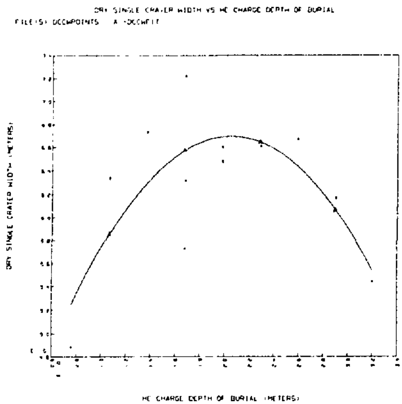


x: depth-of-burial (m)
y: crater depth (m)
Second-degree fit: $y = 1.202 + 0.733x - 0.305x^2$
Number of points: 12
Optimum depth-of-burial x_o: 1.20 m
Maximum $y(x_o)$: 1.64 m

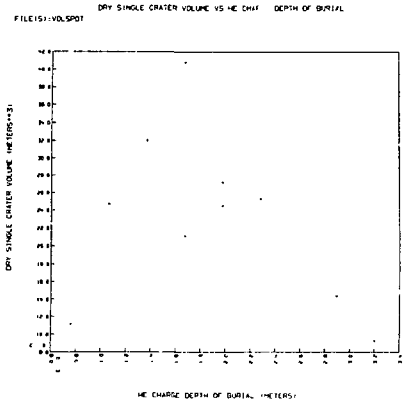


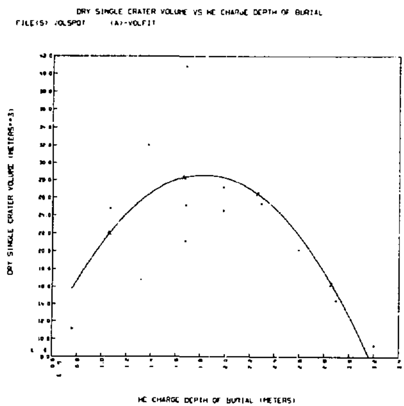
x: depth-of-burial (m)
y: crater depth (m)
Second-degree fit: $y = -0.115 + 2.571x - 0.875x^2$
Number of points: 11
Optimum depth-of-burial x_o: 1.47 m
Maximum $y(x_o)$: 1.77 m





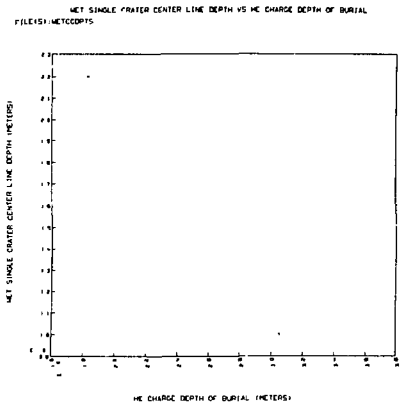
x: depth-of-burial (m)
y: crater width (m)
Second-degree fit: $y = 3.040 + 3.569x - 0.871x^2$
Number of points: 12
Optimum depth-of-burial x_o: 2.05 m
Maximum $y(x_o)$: 6.69 m

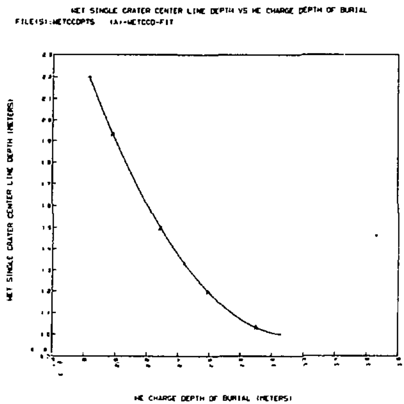




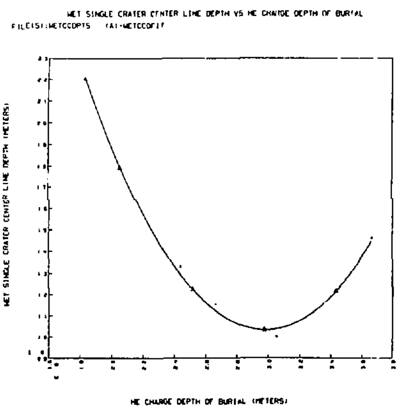
x: depth-of-burial (m)
y: crater volume (m^3)
Second-degree fit: $y = -9.486 + 41.831x - 11.485x^2$
Number of points: 12
Optimum depth-of-burial x_o: 1.82 m
Maximum $y(x_o)$: 28.61 m^3

Wet Data

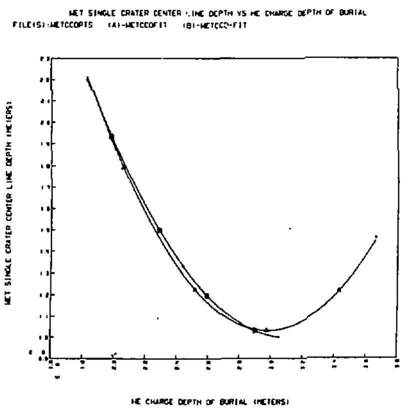


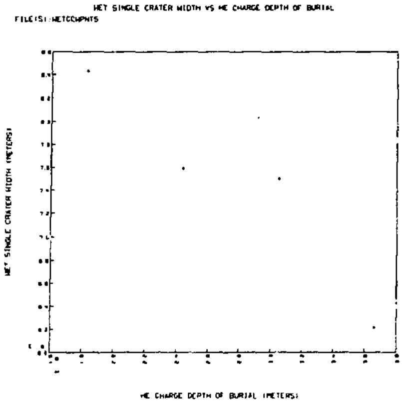


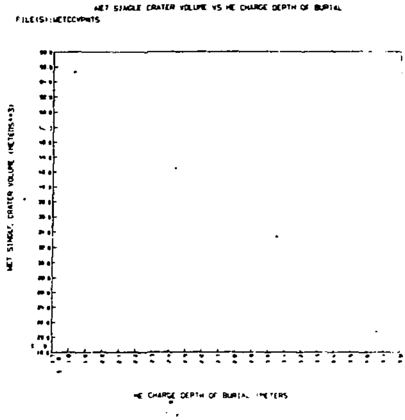
x: depth-of-burial (m)
y: crater depth (m)
Second-degree fit: $y = 8.050 - 4.525x + 0.726x^2$
Number of points: 3

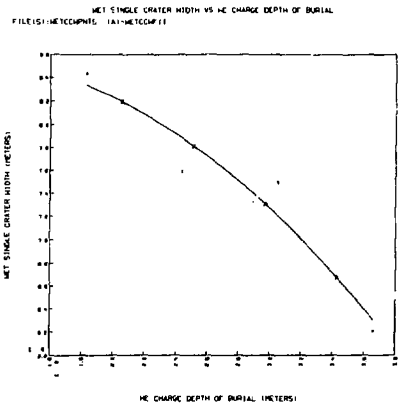


x: depth-of-burial (m)
y: crater depth (m)
Second-degree fit: $y = 8.963 - 5.324x + 0.894x^2$
Number of points: 4

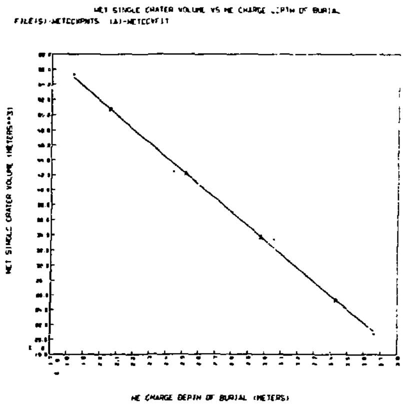






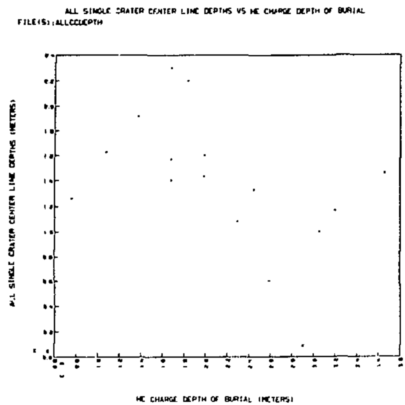


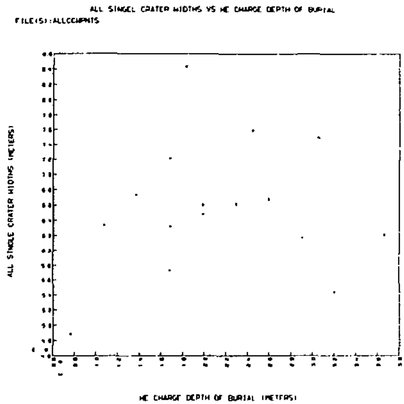
x: depth-of-burial (m)
y: crater width (m)
Second-order fit: $y = 8.333 + 0.553x - 0.302x^2$
Number of points: 4

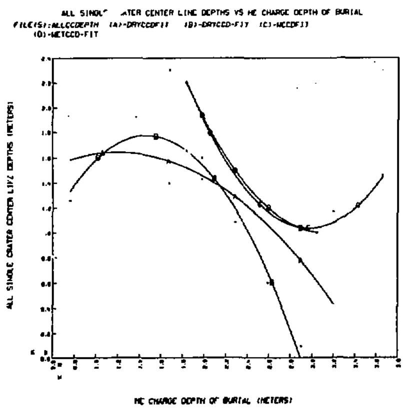


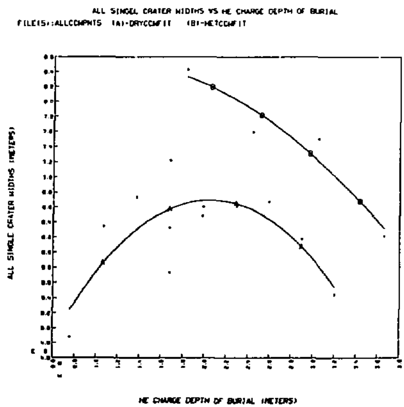
x: depth-of-burial (m)
y: crater volume (m^3)
Second degree fit: $y = 89.724 - 19.312x + 0.155x$
Number of points: 4

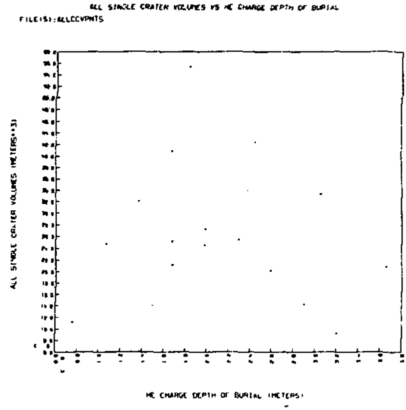
Composites of Dry and Wet Data










ALL SINGLE CRATER VOLUMES VS HE CHARGE DEPTH OF BURIAL
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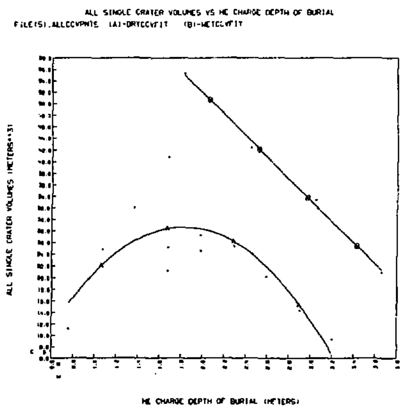
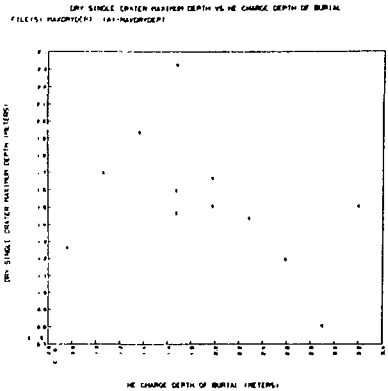
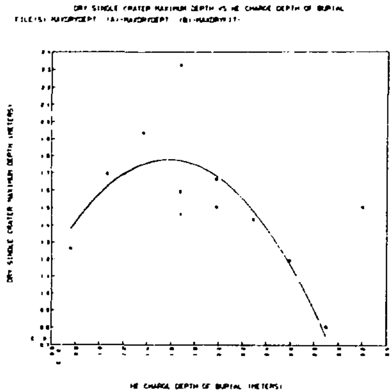
ALL SINGLE CRATER VOLUMES (METERS**3)
HE CHARGE DEPTH OF BURIAL (METERS)

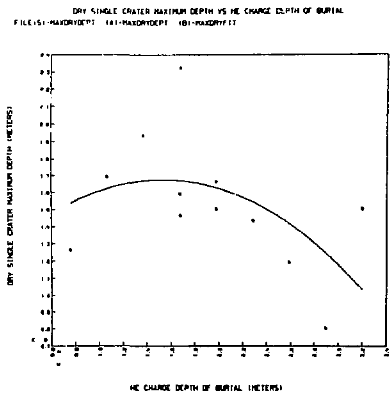

ALL SINGLE CRATER VOLUMES VS HE CHARGE DEPTH OF BURIAL
FILE(S):ALLCCVPNTS (A)-DRYCCVFIT (B)-WETCCVFIT
ALL SINGLE CRATER VOLUMES (METERS**3)
HE CHARGE DEPTH OF BURIAL (METERS)

Maximum Excavated Depths

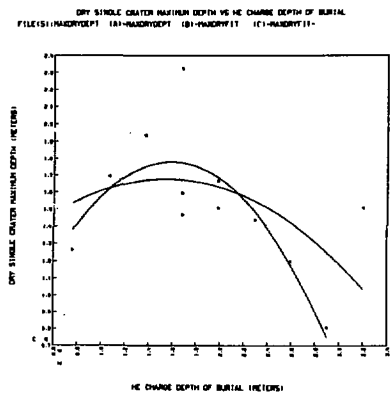


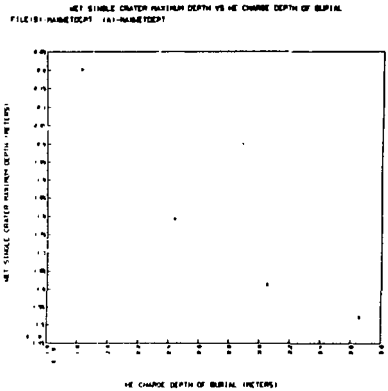


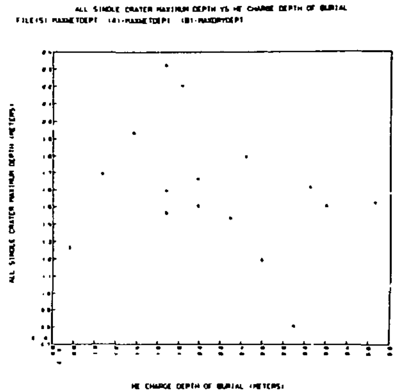
x: depth-of-burial (m)
y: crater depth (m)
Second-degree fit: $y = 0.295 + 1.875x - 0.593x^2$
Number of points: 11
Optimum depth-of-burial x_o: 1.58 m
Maximum $y(x_o)$: 1.78 m

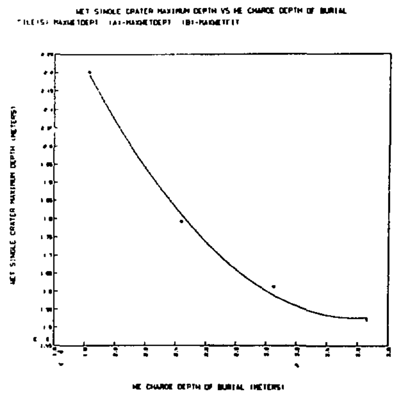


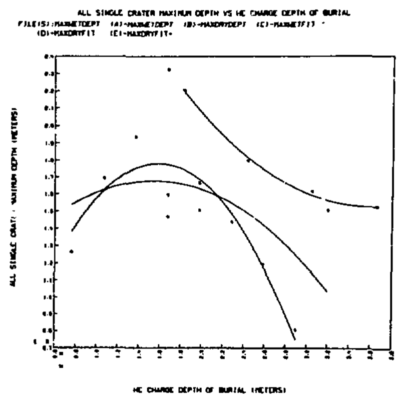
x: depth-of-burial (m)
y: crater depth (m)
Second-degree fit: $y = 1.129 + 0.711x - 0.232x^2$
Number of points: 12
Optimum depth-of-burial x_o: 1.53 m
Maximum $y(x_o)$: 1.67 m











x: depth-of-burial (m)
y: crater depth (m)
Second-degree fit: $y = 4.299 - 1.544x + 0.215x^2$
Number of points: 4

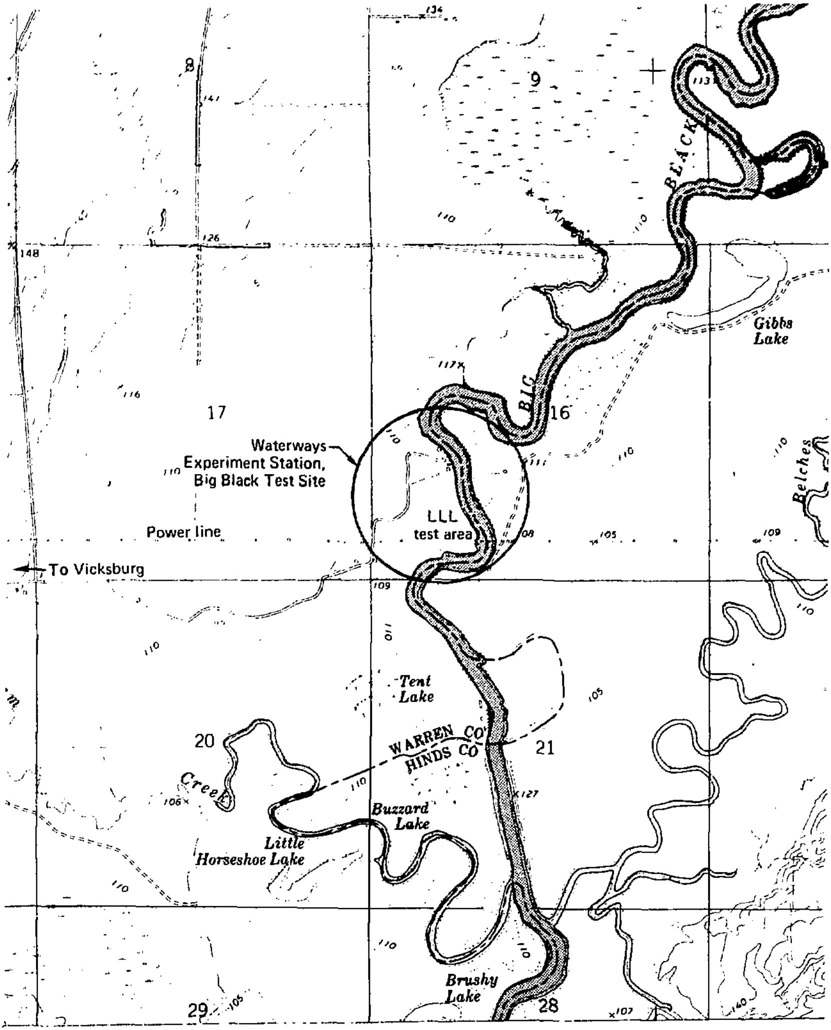


FIG. 1. Locale of the cratering experiments, south of Vicksburg, Mississippi.

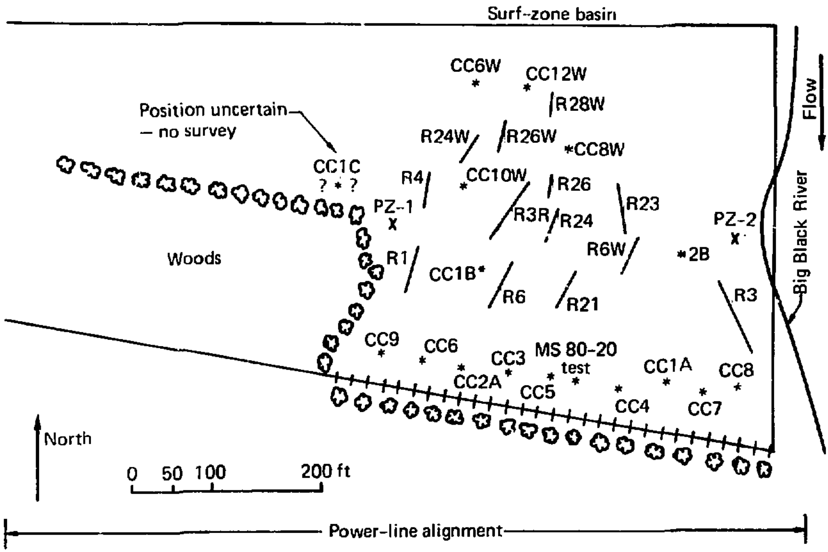


FIG. 2. Lawrence Livermore Laboratory's experimental area at the Big Black Test Site.

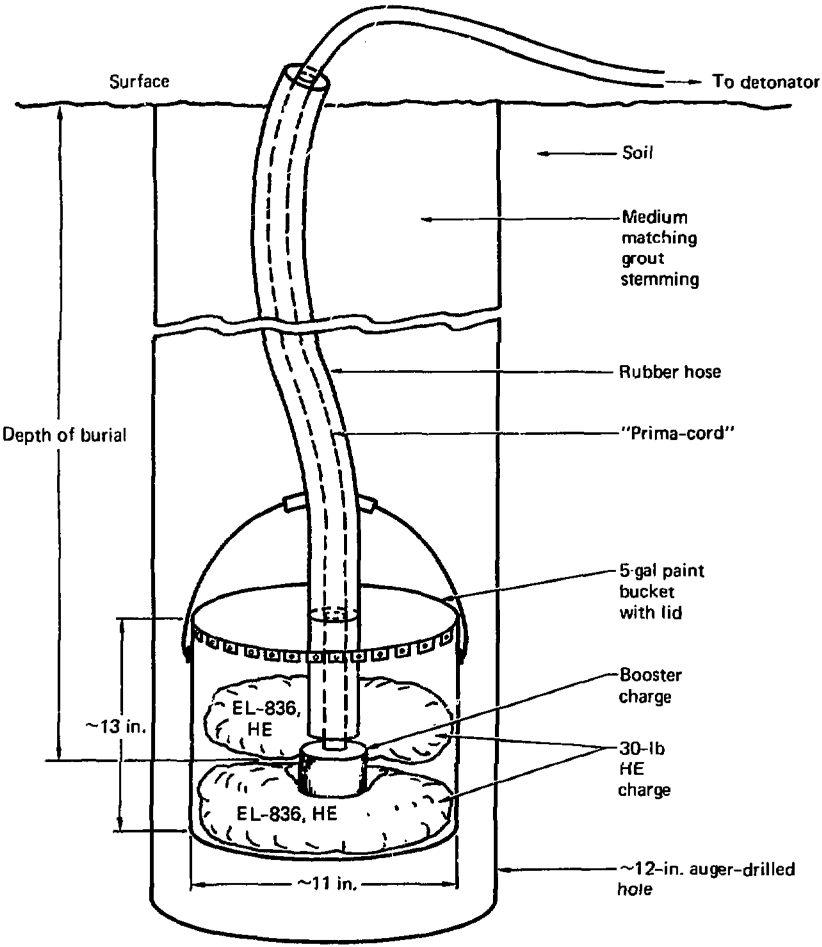


FIG. 3. Typical high-explosive charge emplacement.

SINGLE-CHARGE CRATER DIMENSIONS

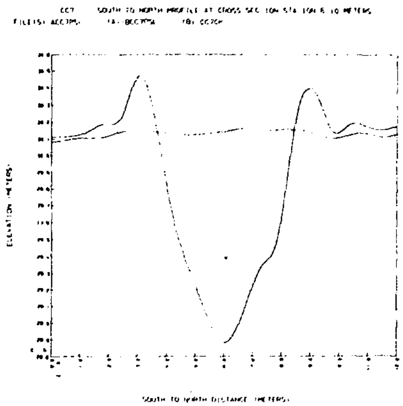
The following tables, photographs, and plots represent the data sets for the individual shots.

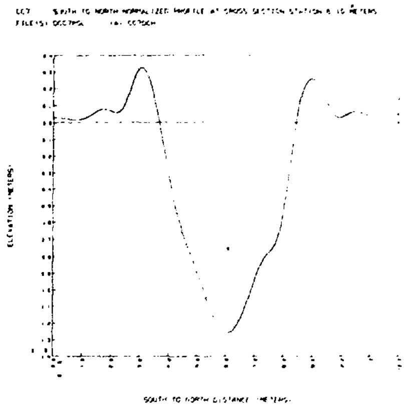
CC7

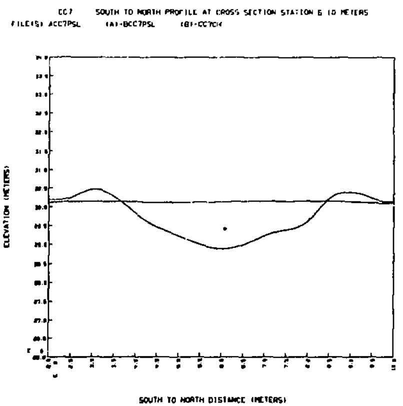
Table 4. Survey data summary for shot CC7 (0.76-m depth).

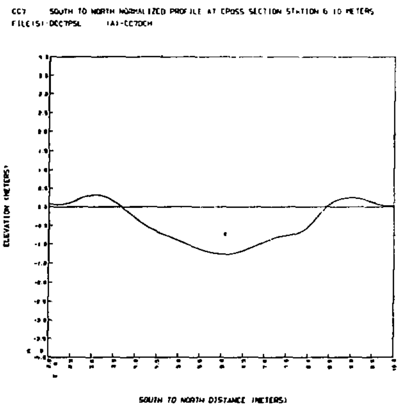
		Spline fit to survey data	
		m	(ft)
Crater depth:	Profile	1.26	(4.13)
	Cross section	1.26	(4.13)
	Av	1.26	(4.13)
Crater width:	Profile	4.75	(15.59)
	Cross section	5.00	(16.40)
	Av	4.88	(16.00)
Crater volume		11.15 m^3	(394 ft^3)

FIG. 4. CC7 excavation.

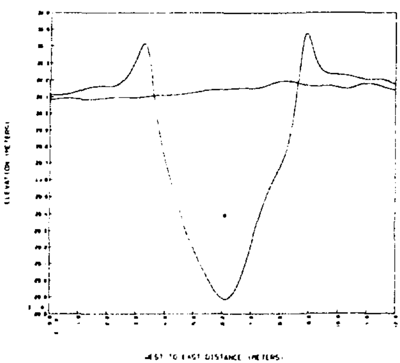

CC7 SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 6 10 METERS
FILE(S) ACC7PSL (A)-BCC7PSA (B)-CC7CH
ELEVATION (METERS)
SOUTH TO NORTH DISTANCE (METERS)


CC7 SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 6 10 METERS
FILE(S) DCC7PSL (A)-CC7DCH
ELEVATION (METERS)
SOUTH TO NORTH DISTANCE (METERS)

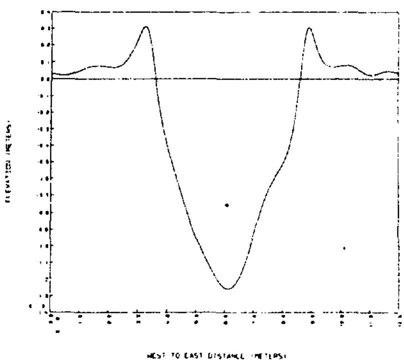

CC7 SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 6 10 METERS
FILE(S) ACC7PSL (A)-BCC7PSL (B)-CC7CH
ELEVATION (METERS)
SOUTH TO NORTH DISTANCE (METERS)


CC7 SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 6 10 METERS
FILE(S) DCC7PSL (A)-CC7DCH
ELEVATION (METERS)
SOUTH TO NORTH DISTANCE (METERS)

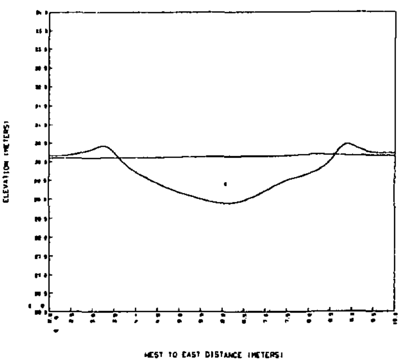
CC7 WEST TO EAST CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) ACC7XSL (A)-BCC7XSL (B)-CC7CH



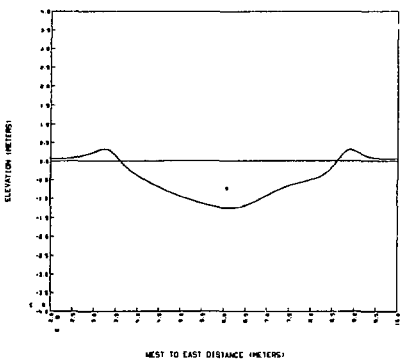
CC7 WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) DCC7XSL (A)-CC7DCH



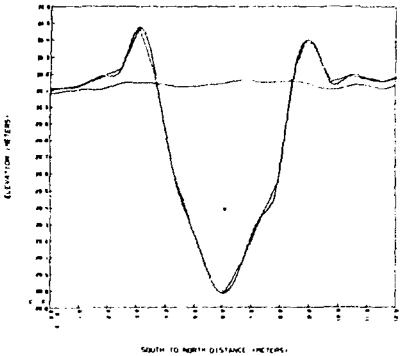
CC7 WEST TO EAST CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) ACC7XSL (A)-BCC7XSL (B)-CC7CH



CC7 WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S):DCC7XSL (A)-CC7DCH



CC7 SOUTH TO NORTH PROFILE AT CROSS SECTION [illegible] METERS
FILE(S) ACC7PSL (A)-BCC7PSL (B)-CC7CH (C)-ACC7P



CC7 WEST TO EAST CROSS SECTION AT PROFILE STATION 5 10 METERS
FILE(S) ACC7XSL (A)-BCC7XSL (B)-CC7CH (C)-ACC7X

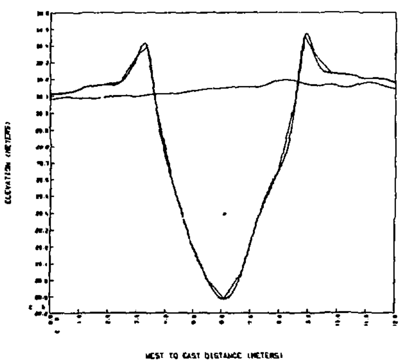


Table 5. Survey data summary for shot CC5 (1.07-m depth).

		Spline fit to survey data	
		m	(ft)
Crater depth:	Profile	1.63	(5.36)
	Cross section	1.63	(5.34)
	Av	1.63	(5.35)
Crater width:	Profile	6.42	(21.06)
	Cross section	6.26	(20.53)
	Av	6.34	(20.80)
Crater volume		24.74 m^3	(874 ft^3)

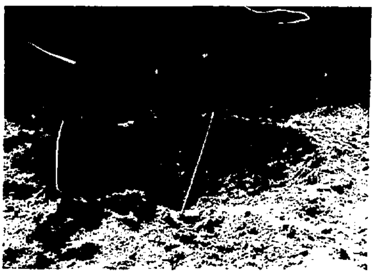
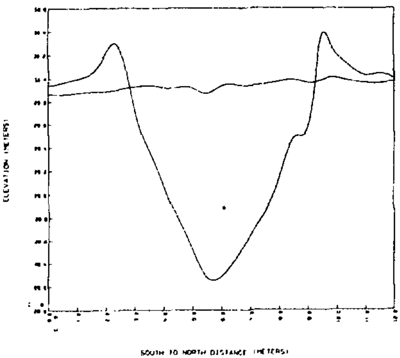
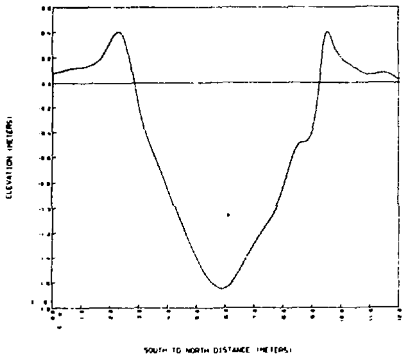


FIG. 5. CC5 excavation.

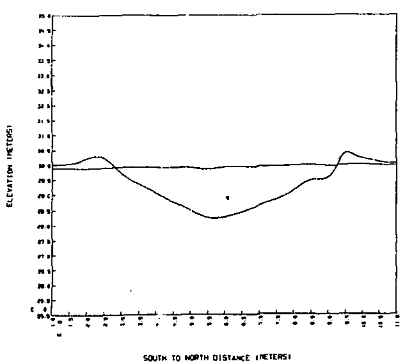
CC5 SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S) ACC5PSL (A) BCC5PSL (B) CC5CH



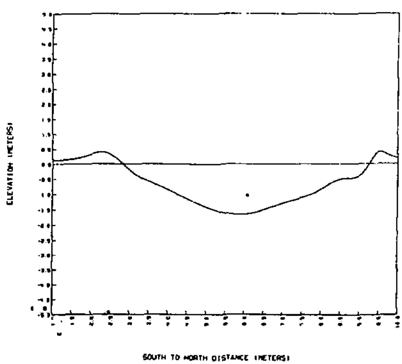
CC5 SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S) DCC5PSL (A) CC5DCH



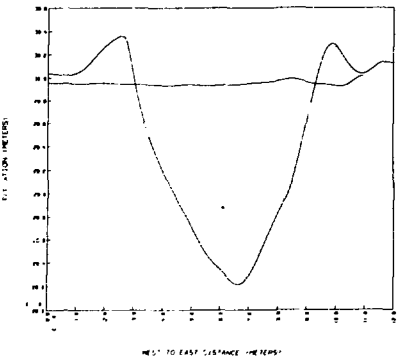
CC5 SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S) ACC5PSL (A) BCC5PSL (B) CC5CH



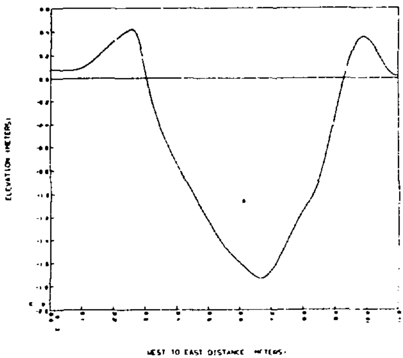
CC5 SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S) DCC5PSL (A) CC5DCH



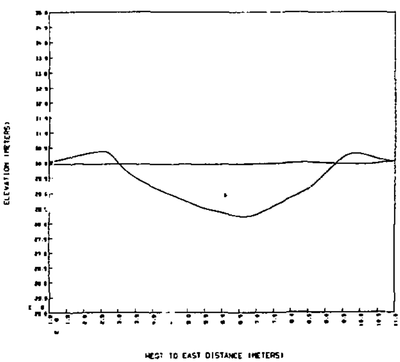
CC5 WEST TO EAST CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) ACC5XSL (A)-BCC5XSL (B)-CC5CH



CC5 WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) DCC5XSL (A)-CC5DCH



CC5 WEST TO EAST CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) ACC5XSL (A)-BCC5XSL (B)-CC5CH



CC5 WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) DCC5XSL (A)-CC5DCH

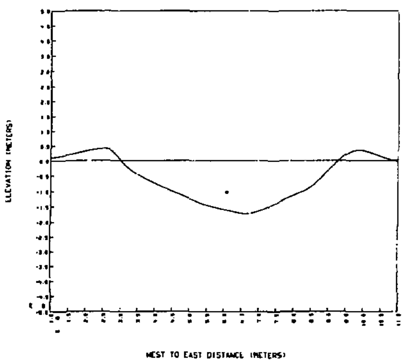
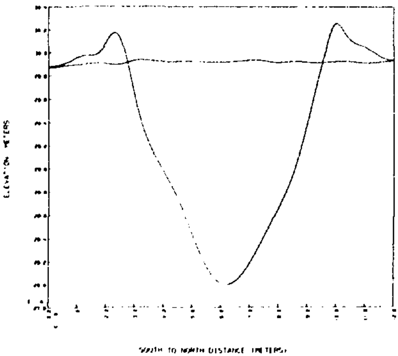


Table 6. Survey data summary for shot CC3 (1.37-m depth).

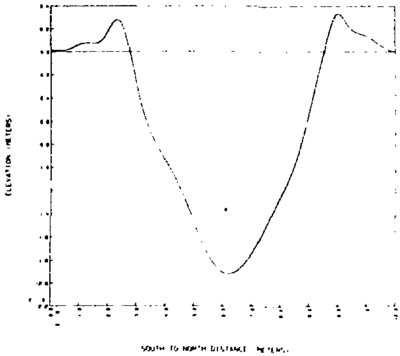
		Spline fit to survey data	
		m	(ft)
Crater depth:	Profile	1.91	(6.27)
	Cross section	1.94	(6.36)
	Av	1.92	(6.32)
Crater width:	Profile	6.76	(22.18)
	Cross section	6.69	(21.95)
	Av	6.73	(22.06)
Crater volume		32.00 m^3	(11.30 ft^3)

FIG. 6. CC3 excavation.

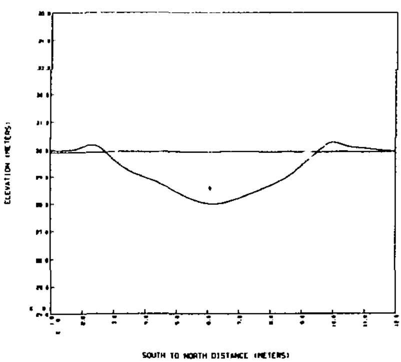
CC3 SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 6 10 METERS
FILE(S) ACC3PSL (A)-BCC3PSL (B)-CC3CH



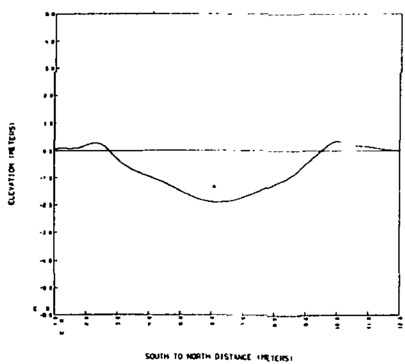
CC3 SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 6 10 METERS
FILE(S) DCC3PSL (A)-CC3DCH



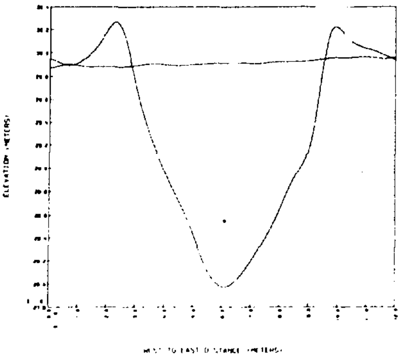
CC3 SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 6 10 METERS
FILE(S) ACC3PSL (A)-BCC3PSL (B)-CC3CH



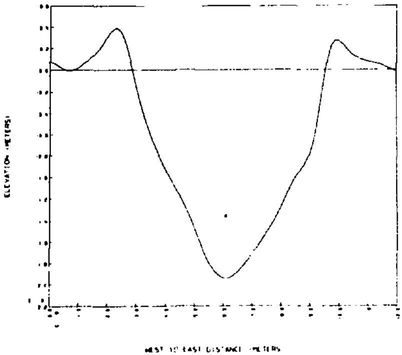
CC3 SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 6 10 METERS
FILE(S) DCC3PSL (A)-CC3DCH



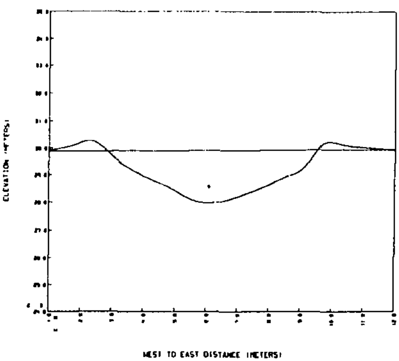
CC3 WEST TO EAST CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) ACC3XSL (A)-BCC3XSL (B)-CC3CH



CC3 WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) DCC3XSL (A)-CC3DCH



CC3 WEST TO EAST CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) ACC3XSL (A)-BCC3XSL (B)-CC3CH



CC3 WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) DCC3XSL (A)-CC3DCH

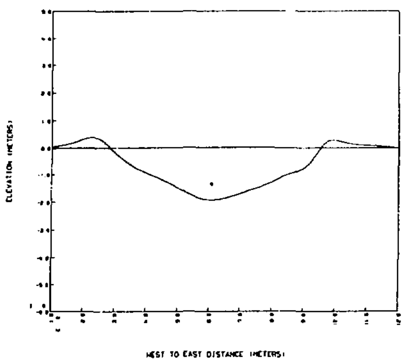
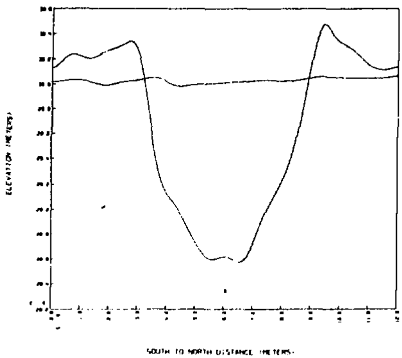


Table 7. Survey data summary for shot CC1A (1.68-m depth).

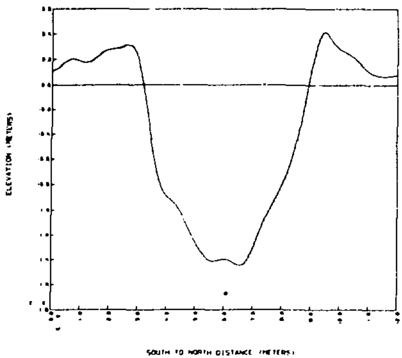
		Spline fit to survey data	
		m	(ft)
Crater depth:	Profile	1.40	(4.59)
	Cross section	1.40	(4.60)
	Av	1.40	(4.60)
Crater width:	Profile	5.74	(18.82)
	Cross section	5.73	(18.81)
	Av	5.73	(18.81)
Crater volume		21.11 m^3	(745 ft^3)

FIG. 7. CC1A excavation.

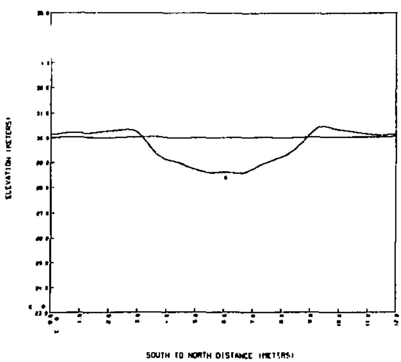
CC1A SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 6.1 METERS
FILE(S) ACC1APSL (A)-BCC1APSL (B)-CC1ACH



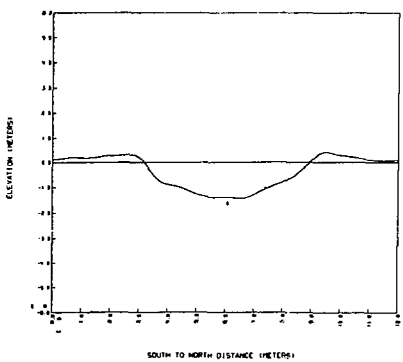
CC1A SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S) DCC1APSL (A)-CC1ADCH



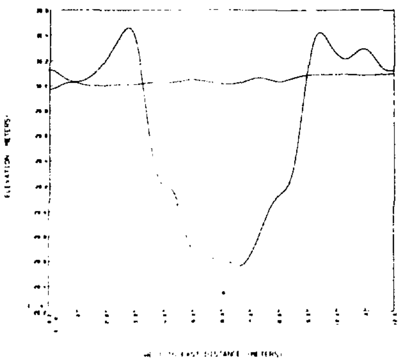
CC1A SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 6.1 METERS
FILE(S) ACC1APSL (A)-BCC1APSL (B)-CC1ACH



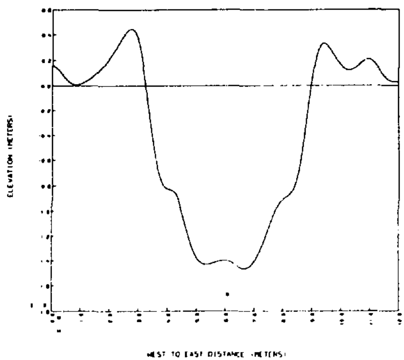
CC1A SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S) DCC1APSL (A)-CC1ADCH



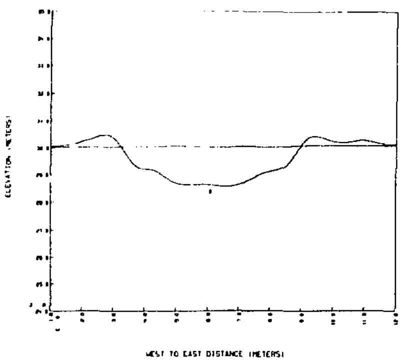
CC1A WEST TO EAST CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) ACC1AXSL (A) BCC1AXSL (B)-CC1ACH



CC1A WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) DCC1AXSL (A)-CC1ADCH



CC1A WEST TO EAST CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) ACC1AXSL (A) BCC1AXSL (B) CC1ACH



CC1A WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) DCC1AXSL (A)-CC1ADCH

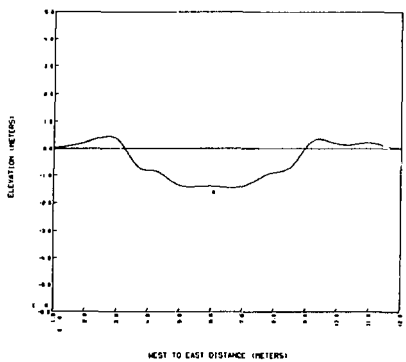
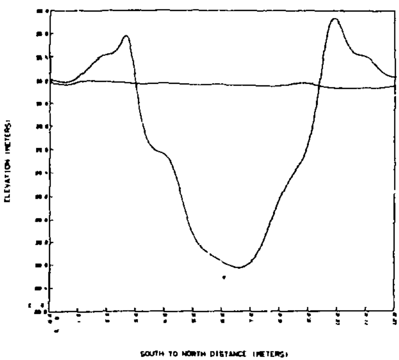


Table 8. Survey data summary for shot CC1B (1.68-m depth).

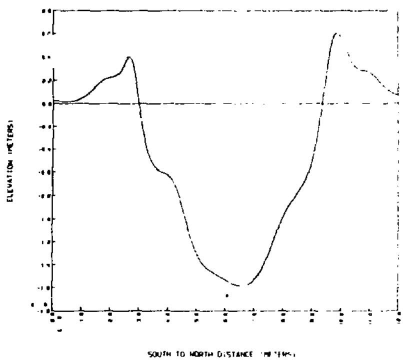
		Spline fit to survey data m	(ft)
Crater depth:	Profile	1.55	(5.07)
	Cross section	1.59	(5.20)
	Av	1.57	(5.14)
Crater width:	Profile	6.37	(20.89)
	Cross section	6.28	(20.60)
	Av	6.32	(20.74)
Crater volume		25.13 m^3	(887 ft^3)

FIG. 8. CC1B excavation.

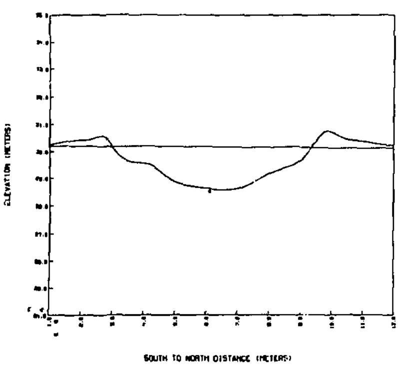
CC1B SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 6 10 METERS
FILE(S) ACC1BPSL (A)-BCC1BPSL (B)-CC1BCH



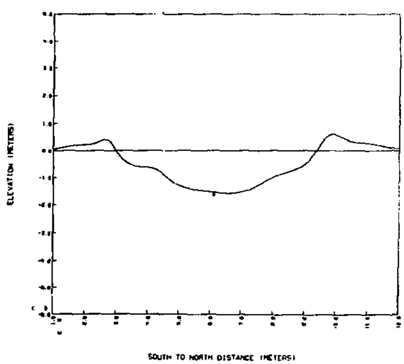
CC1B SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 6 10 METERS
FILE(S) DCC1BPSL (A)-CC1BDCH

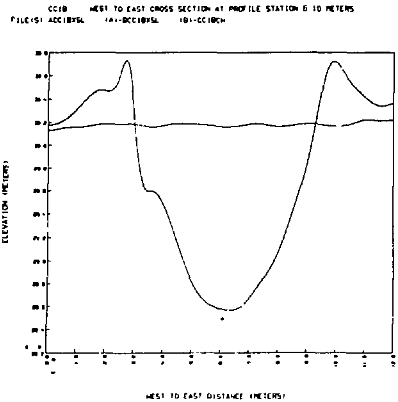


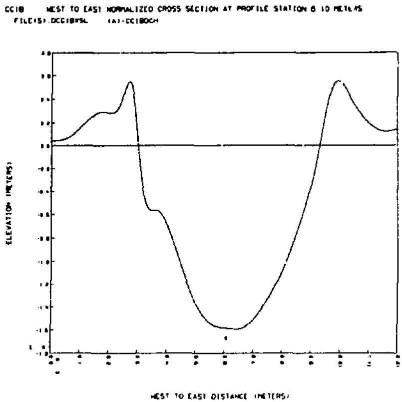
CC1B SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S):ACC1BPSL (A)-DCC1BPSL (B)-CC1BCH

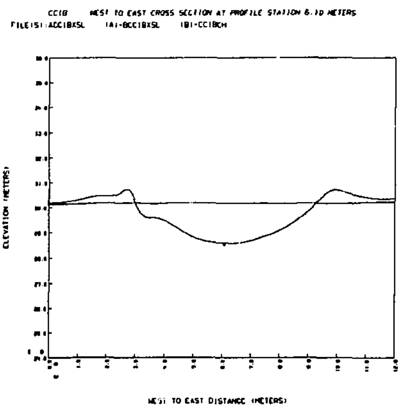


CC1B SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 6 10 METERS
FILE(S):DCC1BPSL (A)-CC1BDCH




CC1B WEST TO EAST CROSS SECTION AT PROFILE STATION 6.10 METERS
FILE(S) ACC1BXSL (A)-BCC1BXSL (B)-CC1BCH
ELEVATION (METERS)
WEST TO EAST DISTANCE (METERS)


CC1B WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 6.10 METERS
FILE(S) DCC1BXSL (A)-CC1BCH
ELEVATION (METERS)
WEST TO EAST DISTANCE (METERS)


CC1B WEST TO EAST CROSS SECTION AT PROFILE STATION 6.10 METERS
FILE(S):ACC1BXSL (A)-BCC1BXSL (B)-CC1BCH
ELEVATION (METERS)
WEST TO EAST DISTANCE (METERS)

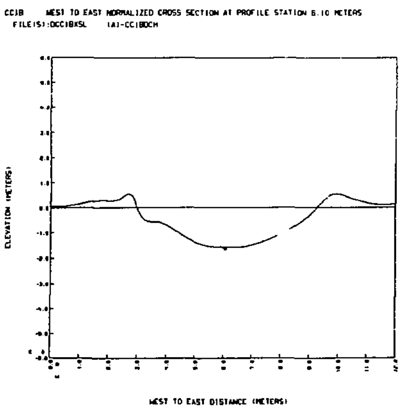
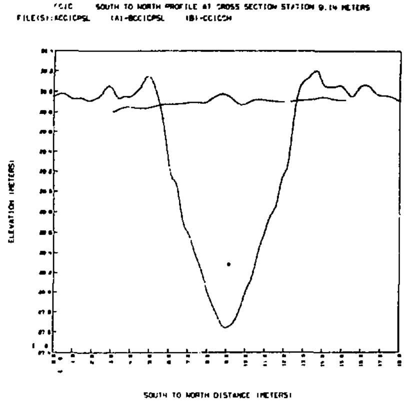
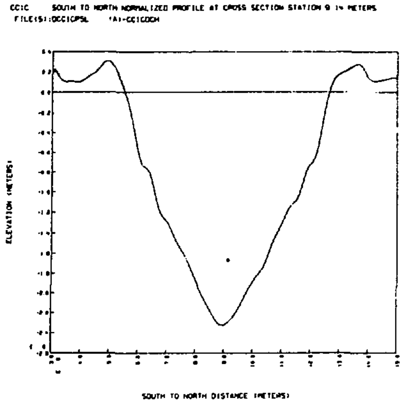

CC1B WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 6.10 METERS
FILE(S):DCC1BXSL (A)-CC1BCH
ELEVATION (METERS)
WEST TO EAST DISTANCE (METERS)

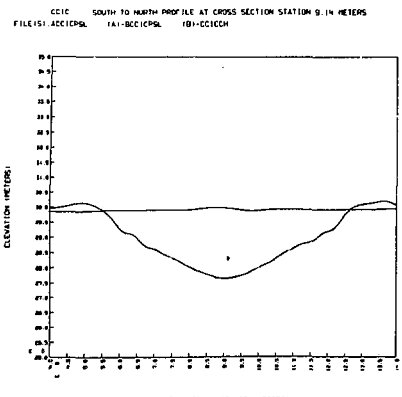
Table 9. Survey data summary for shot CC1C (1.68-m depth).[a]

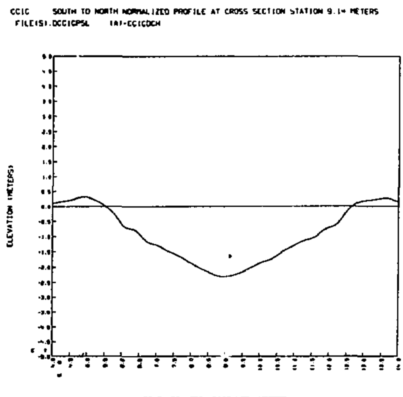
		Spline fit to survey data	
		m	(ft)
Crater depth:	Profile	2.30	(7.54)
	Cross section	2.30	(7.54)
	Av	2.30	(7.54)
Crater width:	Profile	7.12	(23.37)
	Cross section	7.32	(24.00)
	Av	7.22	(23.68)
Crater volume		40.83 m^3	(1440 ft^3)

[a] No photograph available.

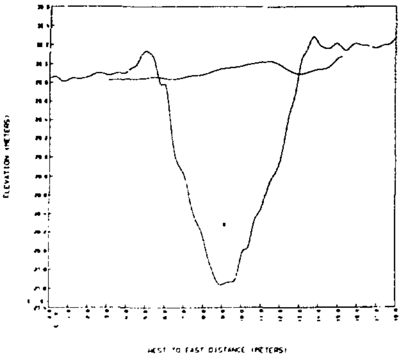

CCIC SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 9.14 METERS
FILE(S):ACCICPSL (A)-BCCICPSL (B)-CCICCH
ELEVATION (METERS)
SOUTH TO NORTH DISTANCE (METERS)


CCIC SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 9.14 METERS
FILE(S):DCCICPSL (A)-CCICDCH
ELEVATION (METERS)
SOUTH TO NORTH DISTANCE (METERS)

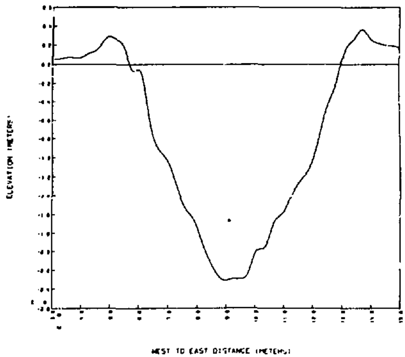

CCIC SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 9.14 METERS
FILE(S):ACCICPSL (A)-BCCICPSL (B)-CCICCH
ELEVATION (METERS)
SOUTH TO NORTH DISTANCE (METERS)


CCIC SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 9.14 METERS
FILE(S):DCCICPSL (A)-CCICDCH
ELEVATION (METERS)
SOUTH TO NORTH DISTANCE (METERS)

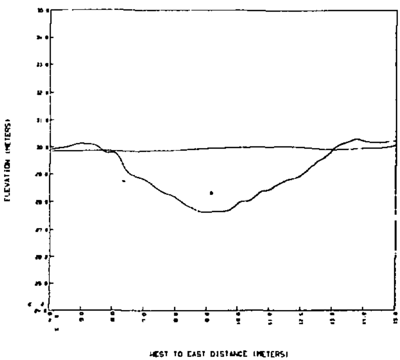
CC1C WEST TO EAST CROSS SECTION AT PROFILE STATION 9.14 METERS
FILE(S) ACC1CXSL (A)-BCC1CXSL (B)-CC1CCH



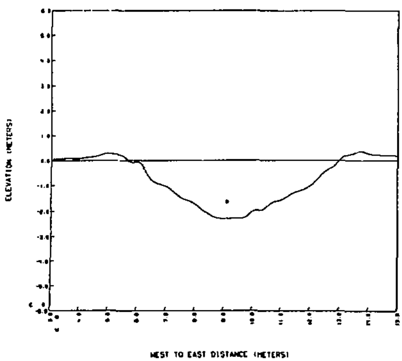
CC1C WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 9.14 METERS
FILE(S):DCC1CXSL (A)-CC1CDCH



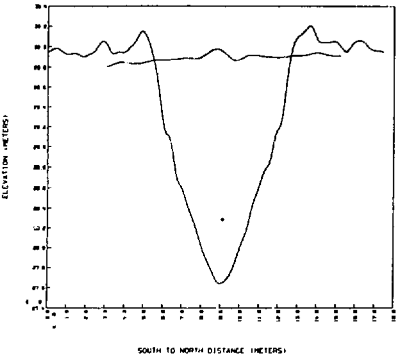
CC1C WEST TO EAST CROSS SECTION AT PROFILE STATION 9.14 METERS
FILE(S) ACC1CXSL (A)-BCC1CXSL (B)-CC1CCH



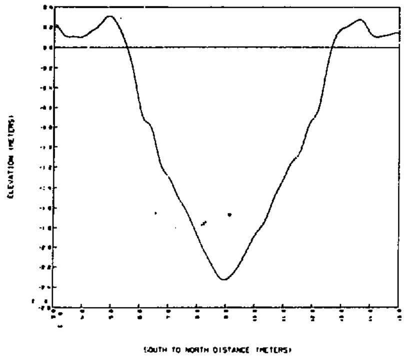
CC1C WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 9.14 METERS
FILE(S):DCC1CXSL (A)-CC1CDCH



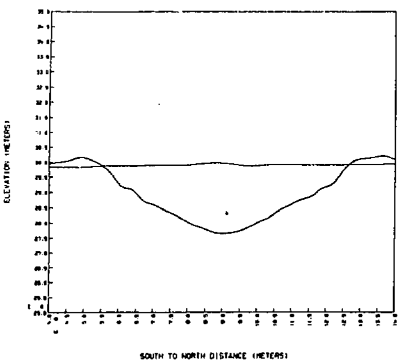
CCIC SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 9.14 METERS
FILE(S):ACCICPSL (A)-BCCICPSL (B)-CCICCH



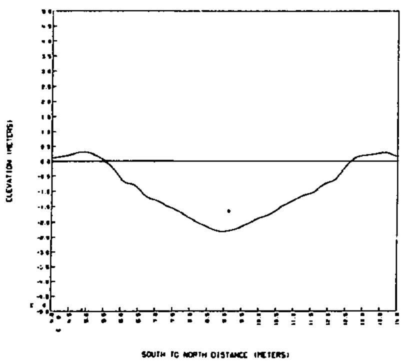
CCIC SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 9.14 METERS
FILE(S):DCCICPSL (A)-CCICCCH



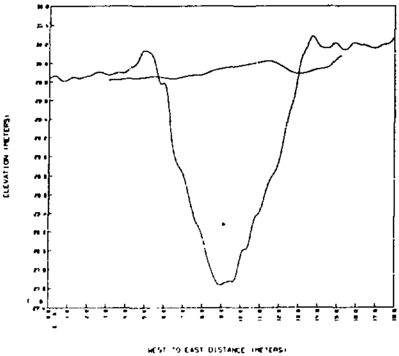
CCIC SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 9.14 METERS
FILE(S):ACCICPSL (A)-BCCICPSL (B)-CCICCH



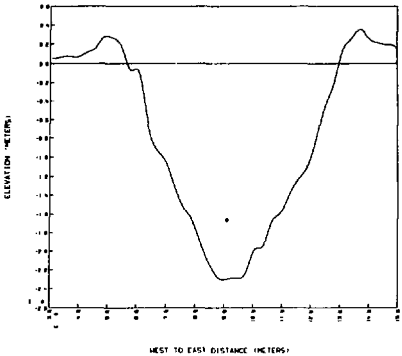
CCIC SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 9.14 METERS
FILE(S):DCCICPSL (A)-CCICCCH



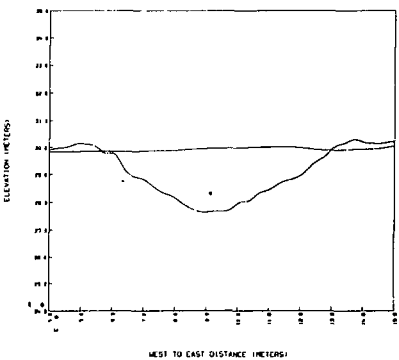
CC1C WEST TO EAST CROSS SECTION AT PROFILE STATION 9.14 METERS
FILE(S):ACC1CXSL (A)-BCC1CXSL (B)-CC1CCH



CC1C WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 9.14 METERS
FILE(S):DCC1CXSL (A)-CC1CDCH



CC1C WEST TO EAST CROSS SECTION AT PROFILE STATION 9.14 METERS
FILE(S):ACC1CXSL (A)-BCC1CXSL (B)-CC1CCH



CC1C WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 9.14 METERS
FILE(S):DCC1CXSL (A)-CC1CDCH

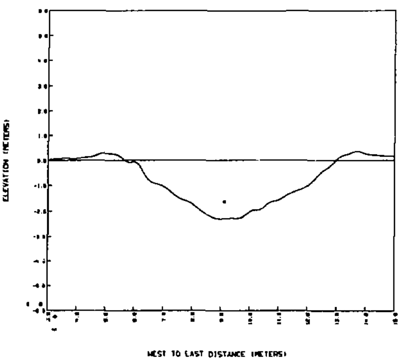


Table 10. Survey data summary for shot CC2B (1.98-m depth).

		Spline fit to survey data	
		m	(ft)
Crater depth:	Profile	1.60	(5.25)
	Cross section	1.60	(5.24)
	Av	1.60	(5.25)
Crater width:	Profile	6.60	(21.66)
	Cross section	6.60	(21.64)
	Av	6.60	(21.65)
Crater volume		27.19 m^3	(960 ft^3)

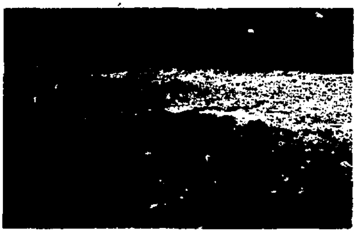
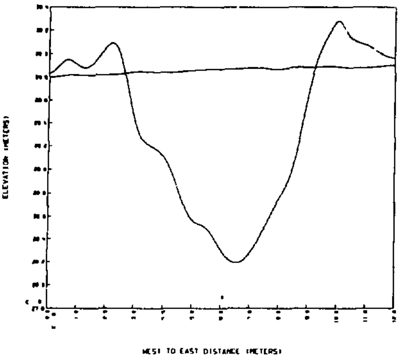
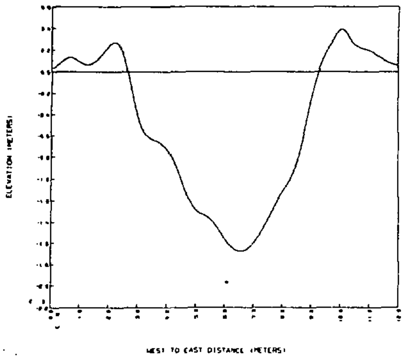


FIG. 9. CC2B excavation.

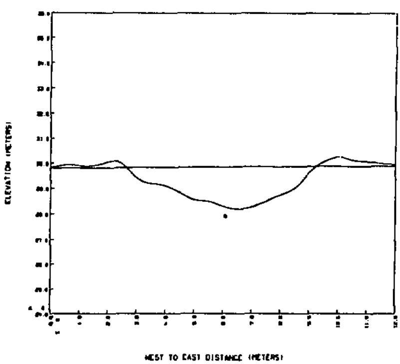
CC2B WEST TO EAST CROSS SECTION AT PROFILE STATION 6.10 METERS
FILE(S):ACC2BXSL (A)-BCC2BXSL (B)-CC2BCH



CC2B WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 6.10 METERS
FILE(S):DCC2BXSL (A)-CC2BDCH



CC2B WEST TO EAST CROSS SECTION AT PROFILE STATION 6.10 METERS
FILE(S):ACC2BXSL (A)-BCC2BXSL (B)-CC2BCH



CC2B WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 6.10 METERS
FILE(S):DCC2BXSL (A)-CC2BDCH

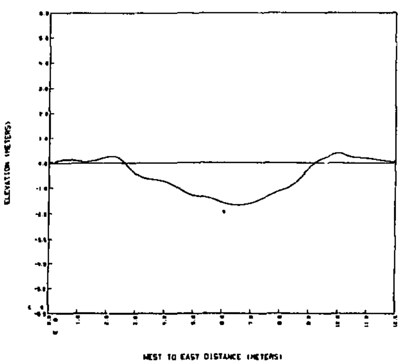


Table 11. Survey data summary for shot CC4 (1.98-m depth).

		Spline fit to survey data	
		m	(ft)
Crater depth:	Profile	1.43	(4.70)
	Cross section	1.44	(4.71)
	Av	1.43	(4.70)
Crater width:	Profile	6.51	(21.36)
	Cross section	6.45	(21.16)
	Av	6.48	(21.26)
Crater volume		24.53 m^3	(866 ft^3)

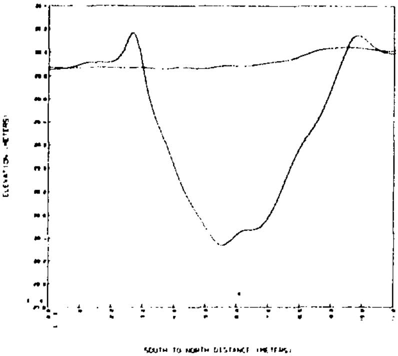
FIG. 10. CC4 excavation.

Table 11. Survey data summary for shot CC4 (1.98-m depth).

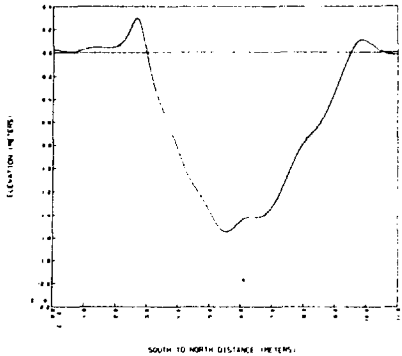
		Spline fit to survey data	
		m	(ft)
Crater depth:	Profile	1.43	(4.70)
	Cross section	1.44	(4.71)
	Av	1.43	(4.70)
Crater width:	Profile	6.51	(21.36)
	Cross section	6.45	(21.16)
	Av	6.48	(21.26)
Crater volume		24.53 m^3	(866 ft^3)

FIG. 10. CC4 excavation.

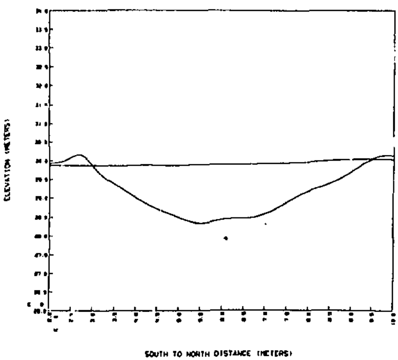
CC4 SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S):ACC4PSL (A)-BCC4PSL (B)-CC4CH



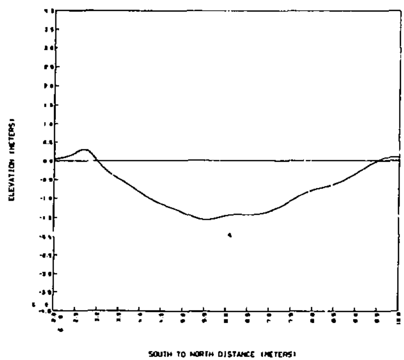
CC4 SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S):DCC4PSL (A)-CC4DCH



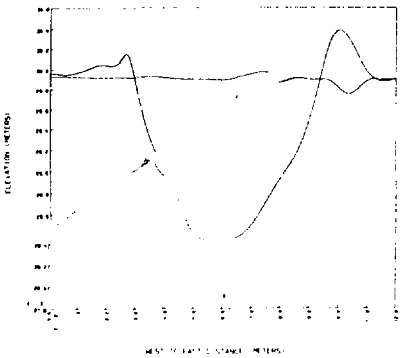
CC4 SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S):ACC4PSL (A)-BCC4PSL (B)-CC4CH



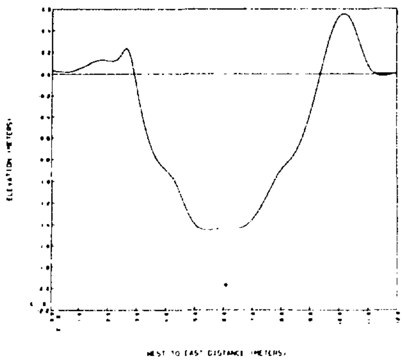
CC4 SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S):DCC4PSL (A)-CC4DCH



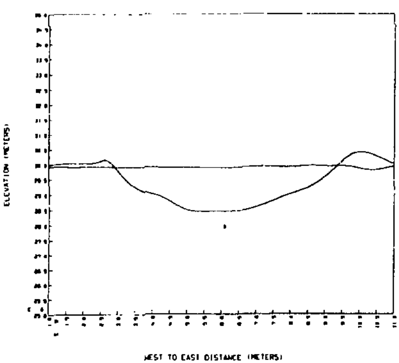
CCW WEST TO EAST CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) ACCWXSL (A)-BCCWXSL (B)-CCWCH



CCW WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) DCCWXSL (A)-CCWDCH



CCW WEST TO EAST CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) ACCWXSL (A)-BCCWXSL (B)-CCWCH



CCW WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATIC 10 METERS
FILE(S) DCCWXSL (A)-CCWDCH

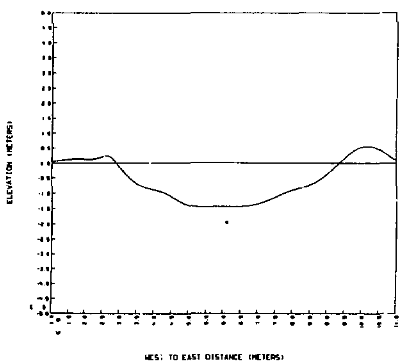


Table 12. Survey data summary for shot CC2A (2.29-m depth).

		Spline fit to survey data	
		m	(ft)
Crater depth:	Profile	1.14	(3.75)
	Cross section	1.01	(3.33)
	Av	1.08	(3.54)
Crater width:	Profile	6.68	(21.90)
	Cross section	6.53	(21.44)
	Av	6.61	(21.67)
Crater volume		25.32 m^3	(894 ft^3)

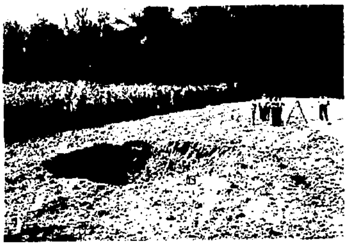
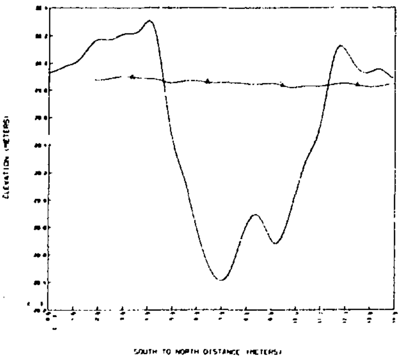
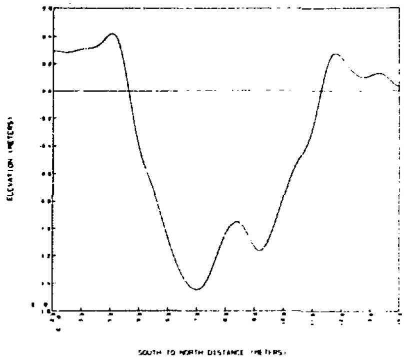


FIG. 11. CC2A excavation.

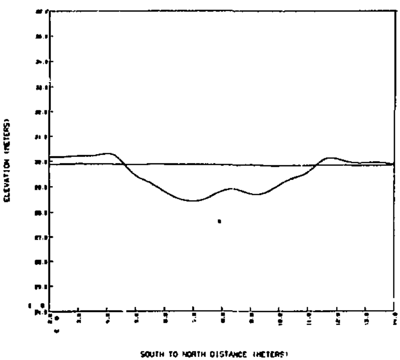
CC2A SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S) ACC2APSL (A)-BCC2APSL



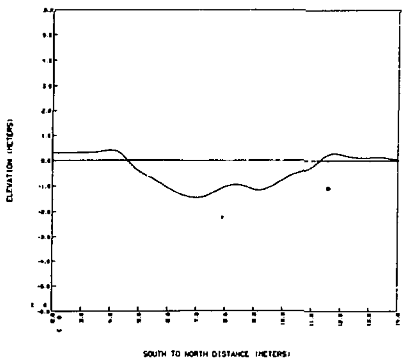
CC2A SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S) DCC2APSL



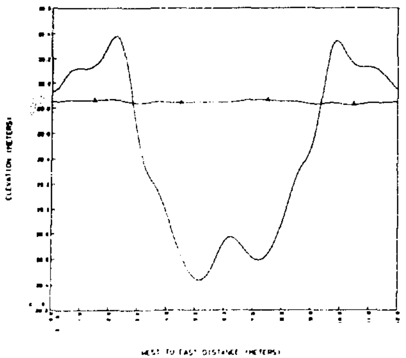
CC2A SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S):ACC2APSL (A)-DCC2APSL (B)-CC2ACH



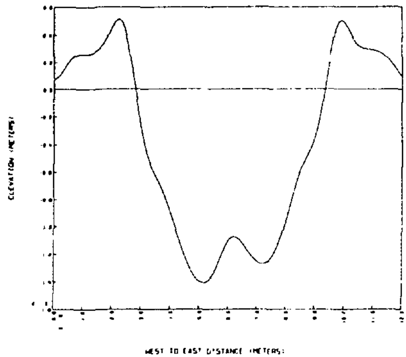
CC2A SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S):DCC2APSL (A)-CC2ADCH



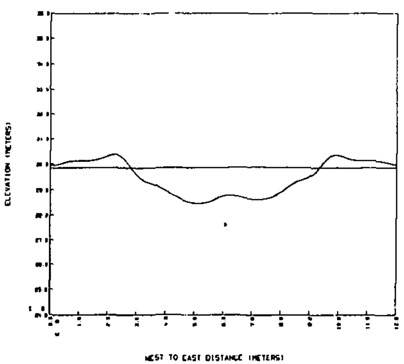
CC2A WEST TO EAST CROSS SECTION AT PROFILE STATION 7.92 METERS
FILE(S) ACC2AXSL (A)-BCC2AXSL



CC2A WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 7.92 METERS
FILE(S) DCC2AXSL



CC2A WEST TO EAST CROSS SECTION AT PROFILE STATION 7.92 METERS
FILE(S):ACC2AXSL (A)-BCC2AXSL (B)-CC2ACH



CC2A WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 7.29 METERS
FILE(S).DCC2AXSL (A)-CC2ADCH

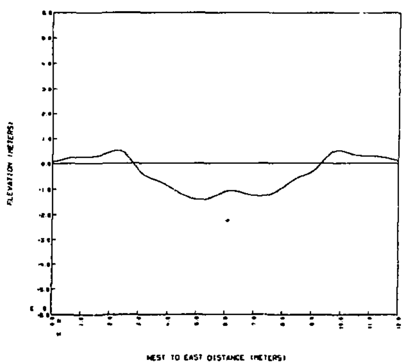


Table 13. Survey data summary for shot CC6 (2.59-m depth)

		Spline fit to survey data	
		m	(ft)
Crater depth:	Profile	0.60	(1.98)
	Cross section	0.59	(1.92)
	Av	0.60	(1.95)
Crater width:	Profile	6.85	(22.47)
	Cross section	6.49	(21.30)
	Av	6.67	(21.89)
Crater volume		20.12 m^3	(711 ft^3)

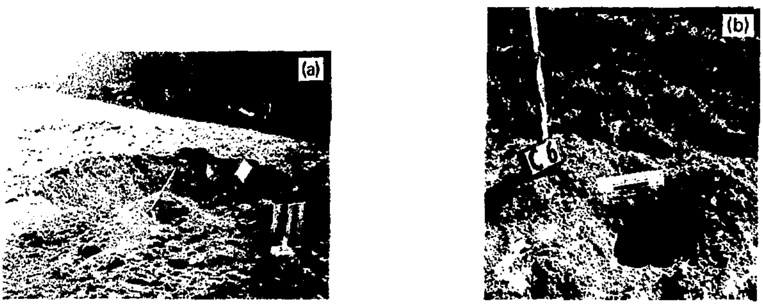
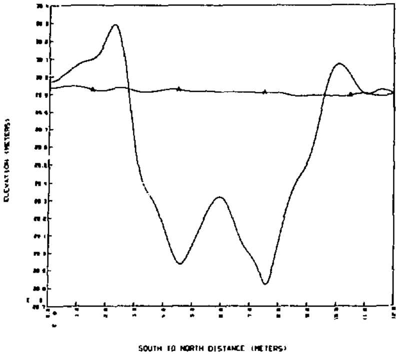
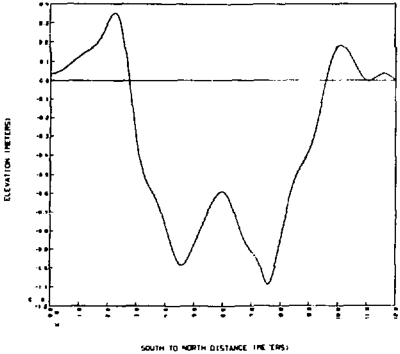


FIG. 12. CC6 excavation. Note the (a) fallback mound and (b) high-explosive emplacement hole.

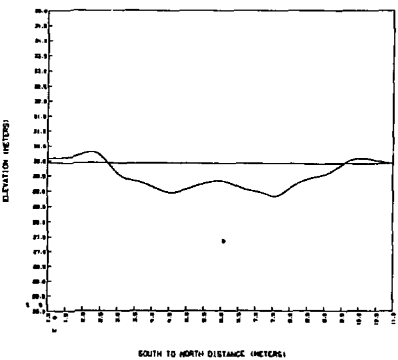
CCB SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S):ACCBPSL (A)-BCCBPSL



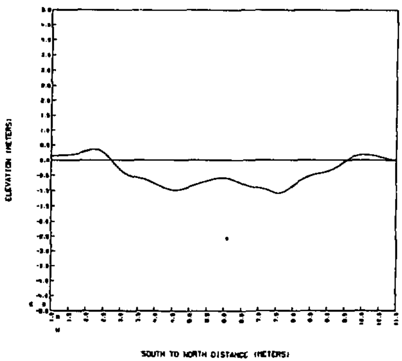
CCB SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S):DCCBPSL



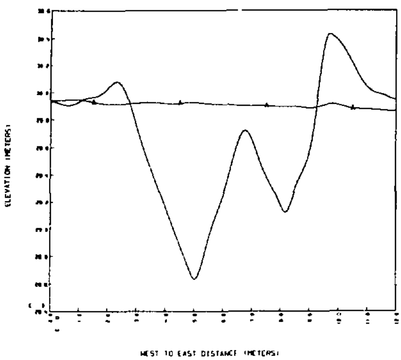
CCB SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S):ACCBPSL (A)-BCCBPSL (B)-CCBCH



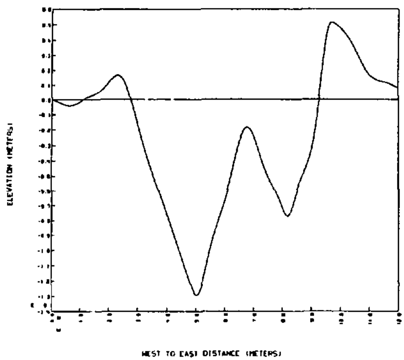
CCB SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S):DCCBPSL (A)-CCBDCH



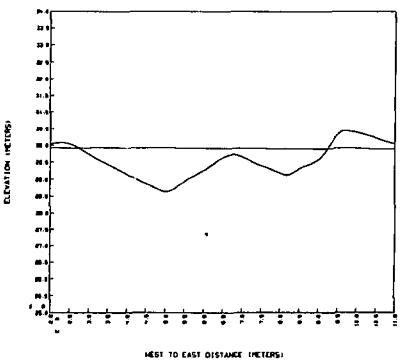
CC6 WEST TO EAST CROSS SECTION AT PROFILE STATION 6.10 METERS
FILE(S):ACC6XSL (A)-BCC6XSL



CC6 WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 6.10 METERS
FILE(S):DCC6XSL



CC6 WEST TO EAST CROSS SECTION AT PROFILE STATION 6.10 METERS
FILE(S):ACC6XSL (A)-BCC6XSL (B)-CC6CH



CC6 WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 6.10 METERS
FILE(S):DCC6XSL (A)-CC6DCH

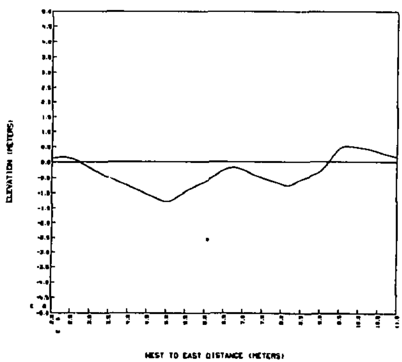
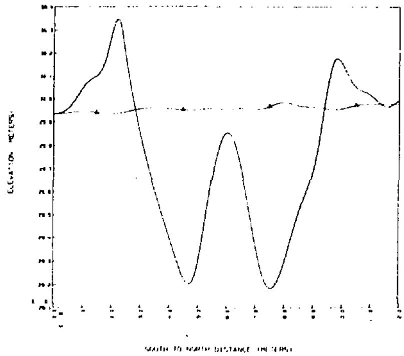


Table 14. Survey data summary for shot CC9 (2.90-m depth).

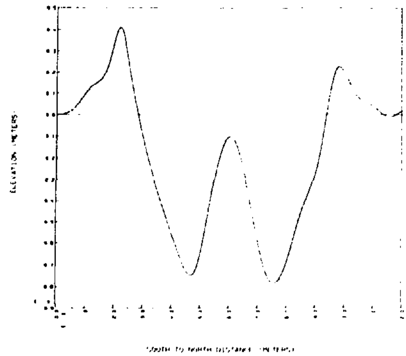
		Spline fit to survey data	
		m	(ft)
Crater depth:	Profile	0.10	(0.34)
	Cross section	0.08	(0.25)
	Av	0.09	(0.30)
Crater width:	Profile	6.55	(21.49)
	Cross section	5.79	(18.98)
	Av	6.17	(20.24)
Crater volume		$14.32\ m^3$	$(506\ ft^3)$

FIG. 13. CC9 excavation.

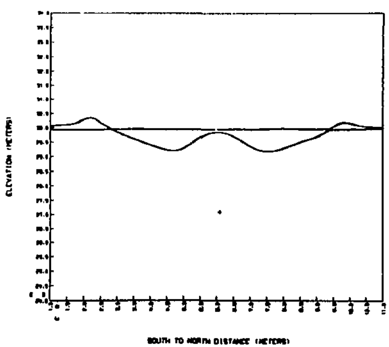
CC9 SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S) ACC9PSL (A) BCC9PSL



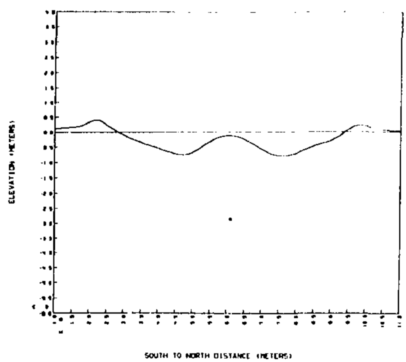
CC9 SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S) BCC9PSL

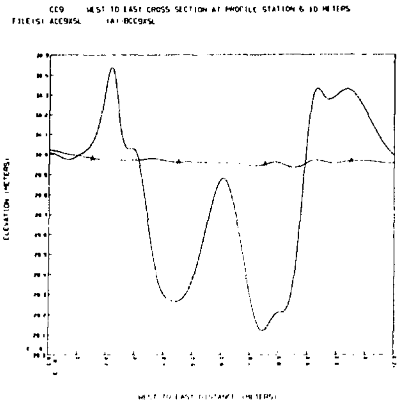


CC9 SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S):ACC9PSL (A)-BCC9PSL (B)-CC9CH

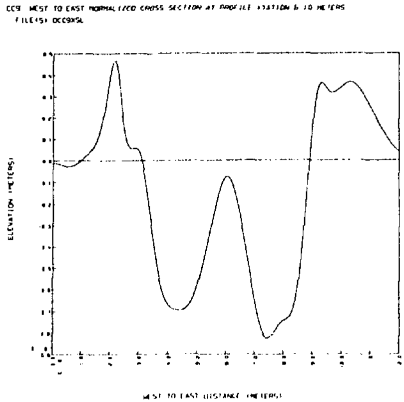


CC9 SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S) BCC9PSL (A)-CC9CH

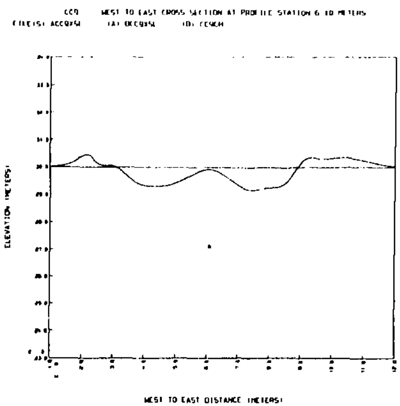




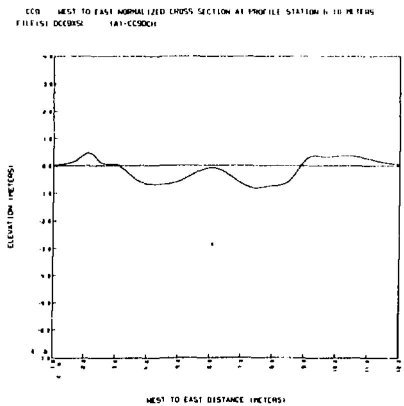
CC9 WEST TO EAST CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) ACC9XSL (A) BCC9XSL
ELEVATION (METERS)
WEST TO EAST DISTANCE (METERS)



CC9 WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) DCC9XSL
ELEVATION (METERS)
WEST TO EAST DISTANCE (METERS)



CC9 WEST TO EAST CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) ACC9XSL (A) DCC9XSL (B) CC9CH
ELEVATION (METERS)
WEST TO EAST DISTANCE (METERS)



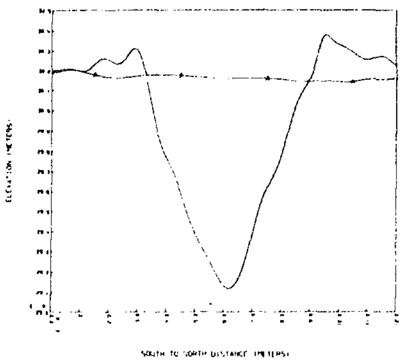
CC9 WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) DCC9XSL (A)-CC9DCH
ELEVATION (METERS)
WEST TO EAST DISTANCE (METERS)

Table 15. Survey data summary for shot CC8 (3.20-m depth).

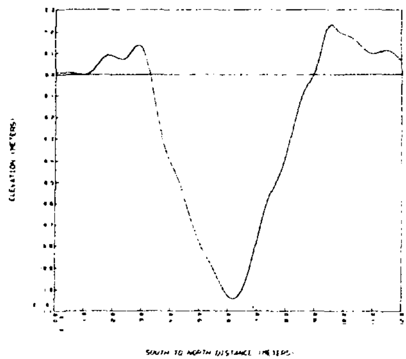
		Spline fit to survey data	
		m	(ft)
Crater depth:	Profile	1.31	(4.30)
	Cross section	1.04	(3.41)
	Av	1.17	(3.85)
Crater width:	Profile	5.66	(18.56)
	Cross section	5.21	(17.10)
	Av	5.44	(17.83)
Crater volume		9.28 m^3	(328 ft^3)

FIG. 14. CC8 excavation.

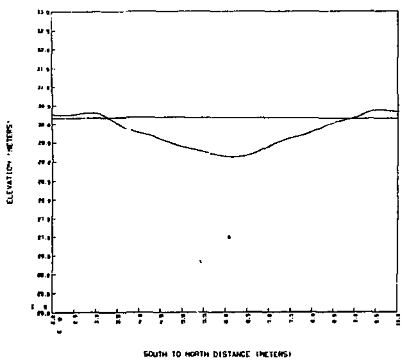
CCB SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S) ACCBPSL (A)-BCCBPSL



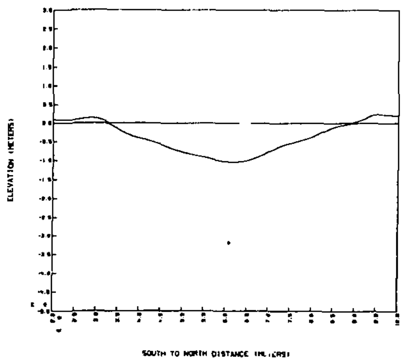
CCB SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S) DCCBPSL



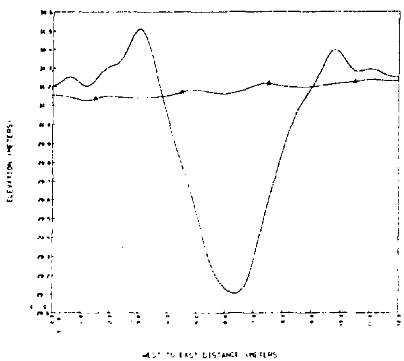
CCB SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S) ACCBPSL (A)-DCCBPSL (B)-CCBCH



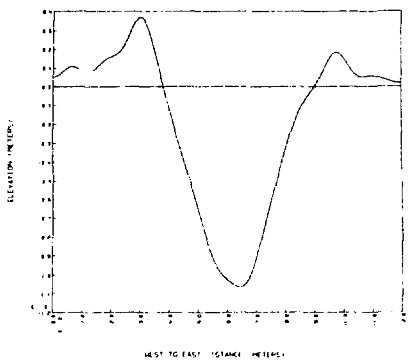
CCB SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 6.10 METERS
FILE(S):DCCBPSL (A)-CCBDCH



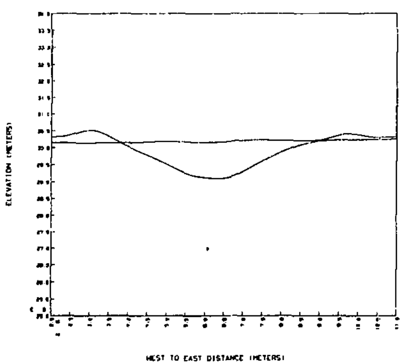
CCB WEST TO EAST CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) ACCBXSL (A)-BCCBXSL



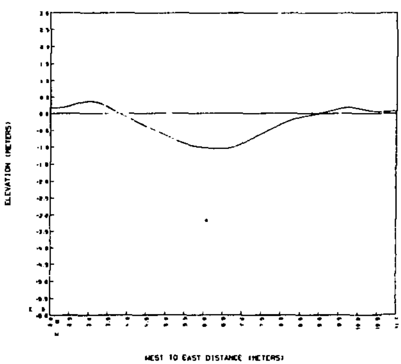
CCB WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) DCCBXSL



CCB WEST TO EAST CROSS SECTION AT PROFILE STATION 6.10 METERS
FILE(S) ACCBXSL (A)-BCCBXSL (B)-CCBCH



CCB WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 6 10 METERS
FILE(S) DCCBXSL (A)-CCBDCH



CC6W

Table 16. Survey data summary for shot CC6W (1.83-m depth).

		Spline fit to survey data m	(ft)
Crater depth:	Profile	2.20	(7.21)
	Cross section	2.20	(7.21)
	Av	2.20	(7.21)
Crater width:	Profile	8.25	(27.08)
	Cross section	8.61	(28.24)
	Av	8.43	(27.66)
Crater volume		55.26 m^3	(1950 ft^3)

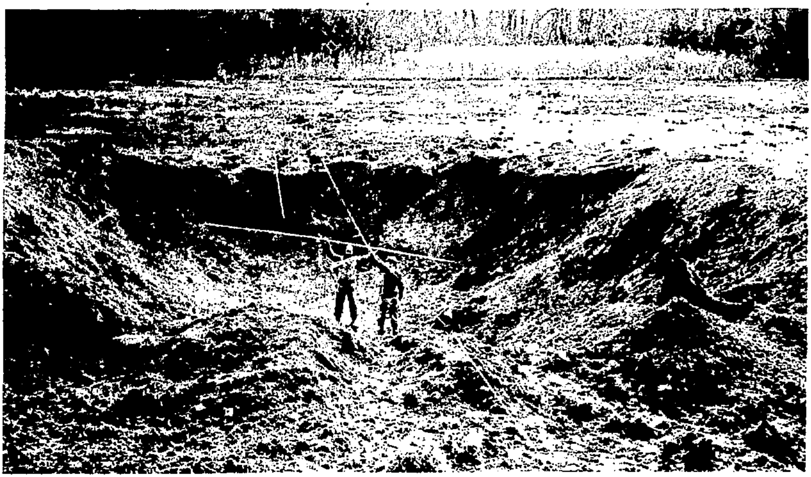
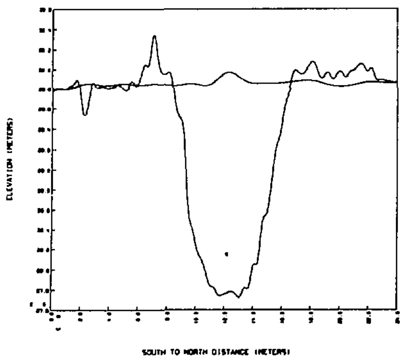
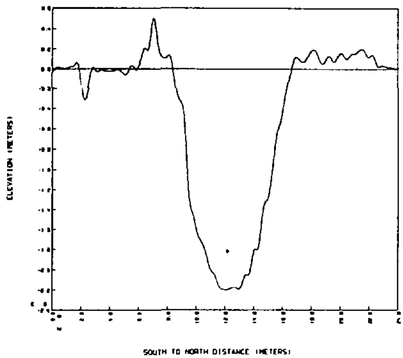


FIG. 15. CC6W excavation.

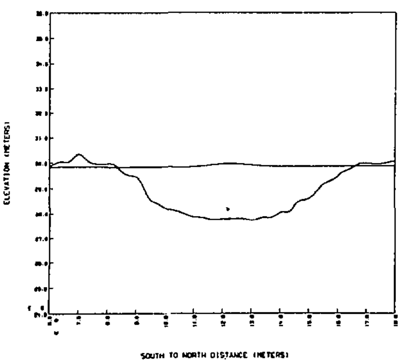
CC6H SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 12.19 METERS
FILE(S):ACC6HPSL (A)-BCC6HPSL (B)-CC6HCH



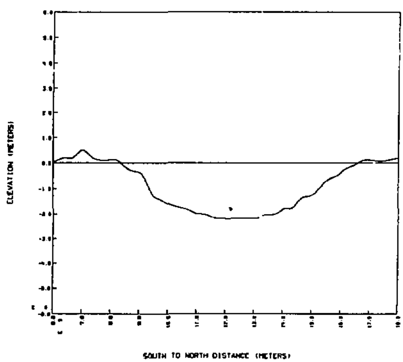
CC6H SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 12.19 METERS
FILE(S):DCC6HPSL (A)-CC6HDCH



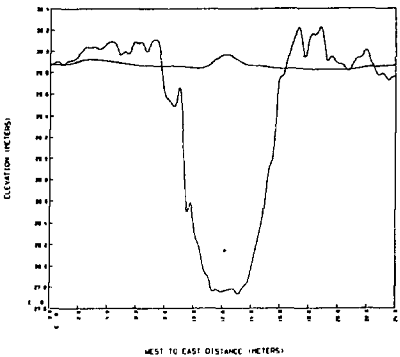
CC6H SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 12.19 METERS
FILE(S):ACC6HPSL (A)-BCC6HPSL (B)-CC6HCH



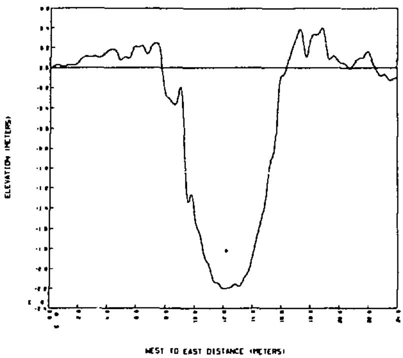
CC6H SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 12.19 METERS
FILE(S):DCC6HPSL (A)-CC6HDCH



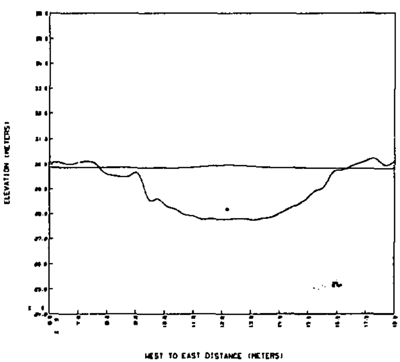
CCBM WEST TO EAST CROSS SECTION AT PROFILE STATION 12.19 METERS
FILE(S): ACCBMXSL (A)-BCCBMXSL (B)-CCBMCH



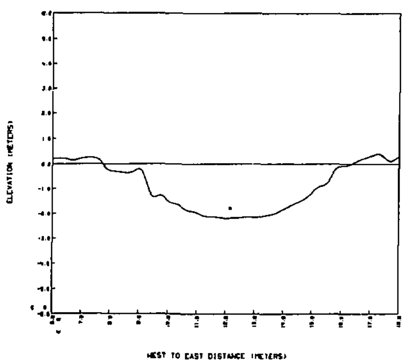
CCBM WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 12.19 METERS
FILE(S): DCCBMXSL (A)-CCBMDCH



CCBM WEST TO EAST CROSS SECTION AT PROFILE STATION 12.19 METERS
FILE(S): ACCBMXSL (A)-BCCBMXSL (B)-CCBMCH



CCBM WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 12.19 METERS
FILE(S): DCCBMXSL (A)-CCBMDCH



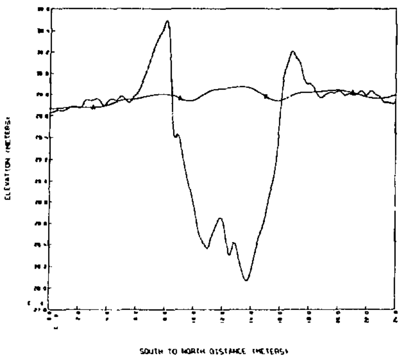
CC8W

Table 17. Survey data summary for shot CC8W (2.44-m depth).

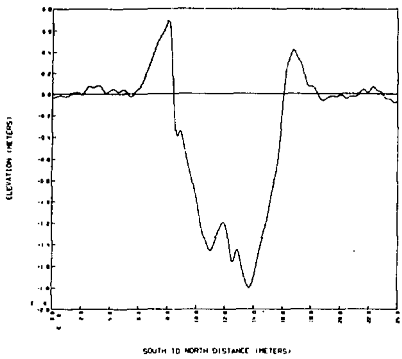
		Spline fit to survey data	
		m	(ft)
Crater depth:	Profile	1.33	(4.37)
	Cross section	1.33	(4.36)
	Av	1.33	(4.37)
Crater width:	Profile	7.62	(25.00)
	Cross section	7.56	(24.80)
	Av	7.59	(24.90)
Crater volume		42.44 m^3	(1500 ft^3)

FIG. 16. CC8W excavation.

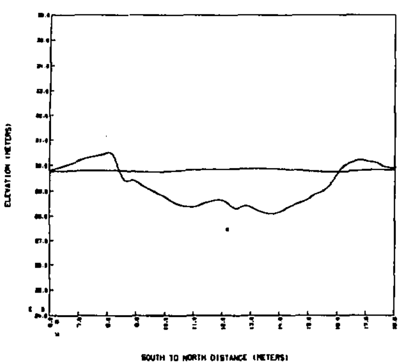
CCBM SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 12.19 METERS
FILE(S):ACCBMPSL (A)-BCCBMPSL



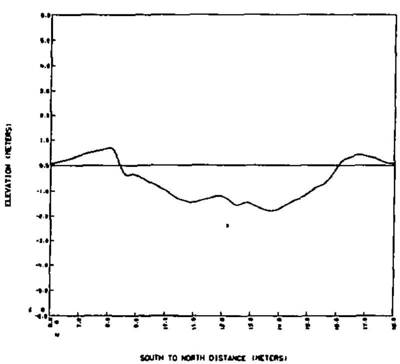
CCBM SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 12.19 METERS
FILE(S):DCCBMPSL



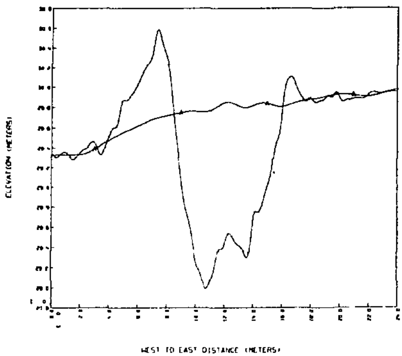
CCBM SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 12.18 METERS
FILE(S):ACCBMPSL (A)-BCCBMPSL (B)-CCBMCH



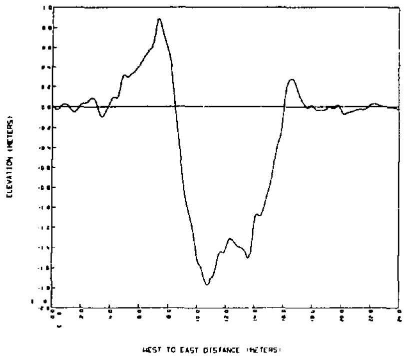
CCBM SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 12.18 METERS
FILE(S):DCCBMPSL (A)-CCBMDCH



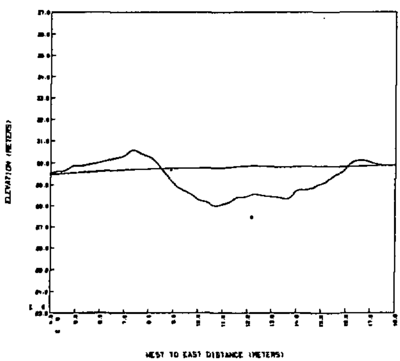
CCBW WEST TO EAST CROSS SECTION AT PROFILE STATION 12.19 METERS
FILE(S):ACCBWXSL (A)-BCCBWXSL



CCBW WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 12.19 METERS
FILE(S):DCCBWXSL



CCBW WEST TO EAST CROSS SECTION AT PROFILE STATION 12.19 METERS
FILE(S):ACCBWXSL (A)-BCCBWXSL (B)-CCBWCH



CCBW WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 12.19 METERS
FILE(S):DCCBWXSL (A)-CCBWDCH

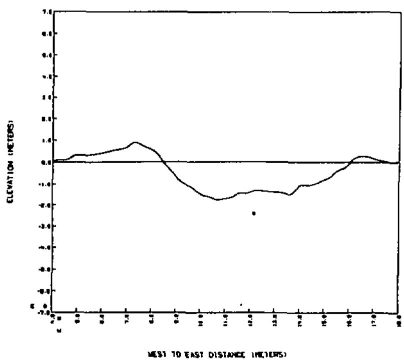


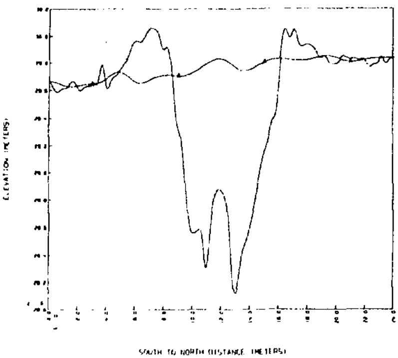
Table 18. Survey data summary for shot CC10W (3.05-m depth).

		Spline fit to survey data	
		m	(ft)
Crater depth:	Profile	0.99	(3.26)
	Cross section	1.00	(3.28)
	Av	1.00	(3.27)
Crater width:	Profile	7.56	(24.80)
	Cross section	7.44	(24.42)
	Av	7.50	(24.61)
Crater volume		33.34 m^3	(1180 ft^3)

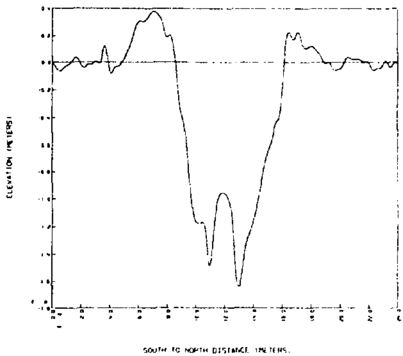
FIG. 17. CC10W excavation.

FIG. 18. CC10W shot.

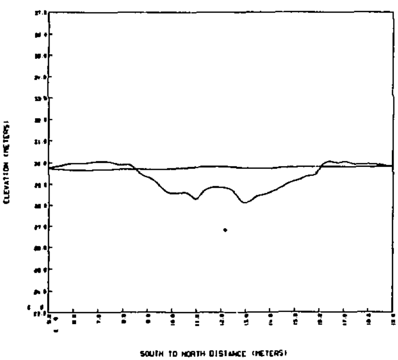
CC10W SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 12.19 METERS
FILE(S) ACC10WPSL (A) BCC10WPSL



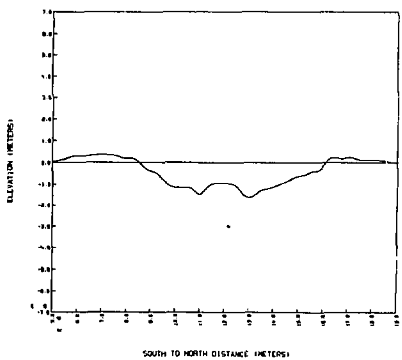
CC10W SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 12.19 METERS
FILE(S) DCC10WPSL



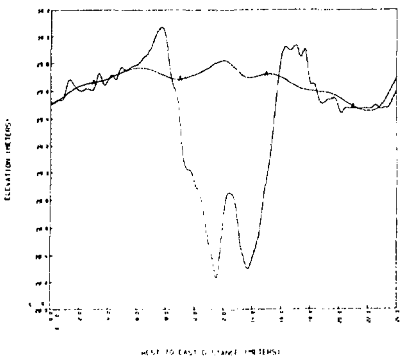
CC10W SOUTH TO NORTH PROFILE AT CROSS SECTION STATION 12.19 METERS
FILE(S):ACC10WPSL (A)-DCC10WPSL (B)-CC10WCH



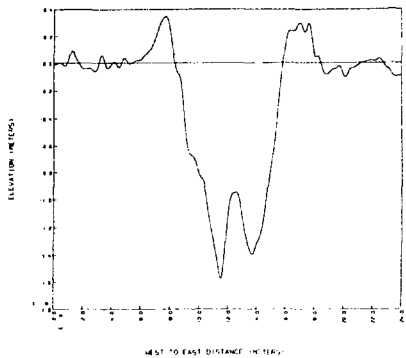
CC10W SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 12.19 METERS
FILE(S):DCC10WPSL (A)-CC10WDC



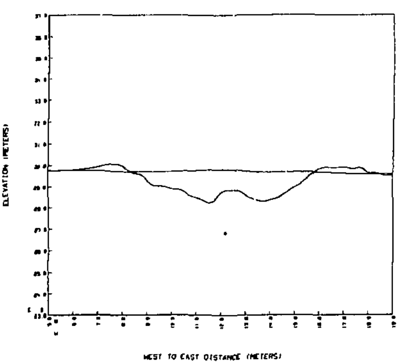
CC10W WEST TO EAST CROSS SECTION AT PROFILE STATION 12.19 METERS
FILE(S) ACC10WXSL (A)-BCC10WXSL



CC10W WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 12.19 METERS
FILE(S) DCC10WXSL



CC10W WEST TO EAST CROSS SECTION AT PROFILE STATION 12.19 METERS
FILE(S):ACC10WXSL (A)-BCC10WXSL (B)-CC10WCH



CC10W WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 12.19 METERS
FILE(S):DCC10WXSL (A)-CC10WDC

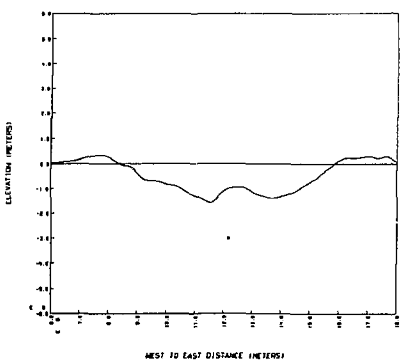
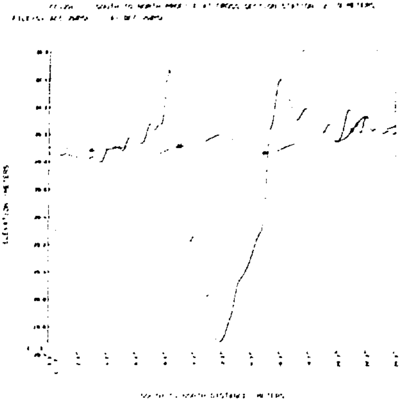
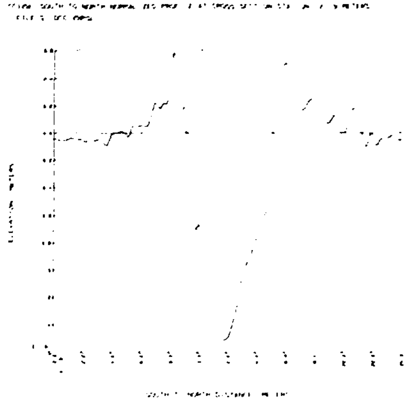


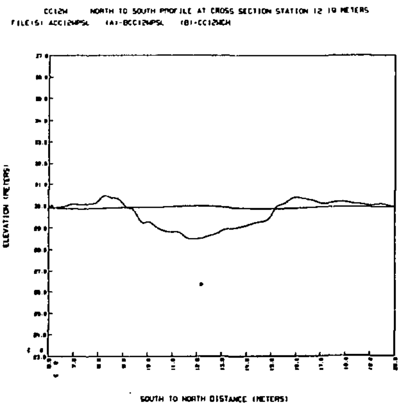
Table 19. Survey data summary for shot CC12W (3.66-m depth).

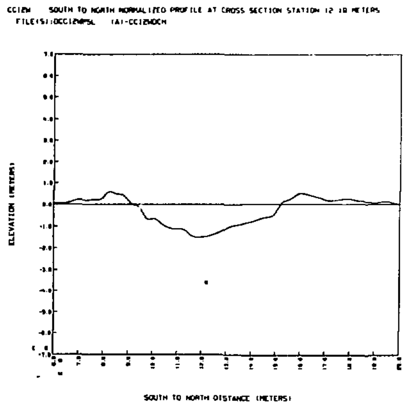
		Spline fit to survey data	
		m	(ft)
Crater depth:	Profile	1.47	(4.81)
	Cross section	1.46	(4.79)
	Av	1.46	(4.80)
Crater width:	Profile	6.00	(19.69)
	Cross section	6.42	(21.05)
	Av	6.21	(20.37)
Crater volume		20.75 m^3	(733 ft^3)

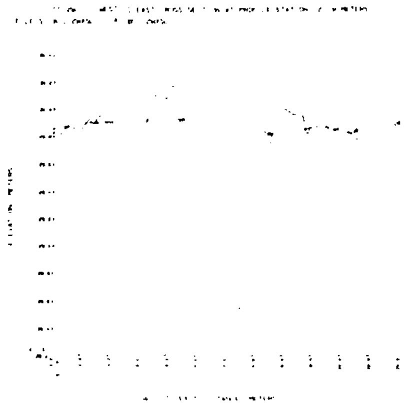
FIG. 19. CC12W excavation.

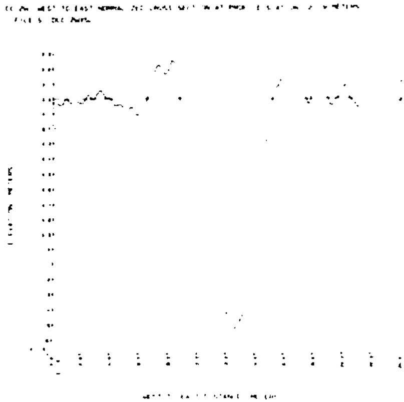


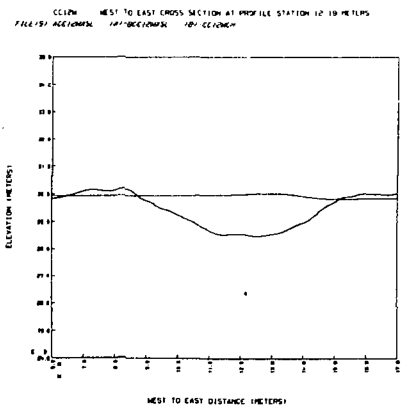


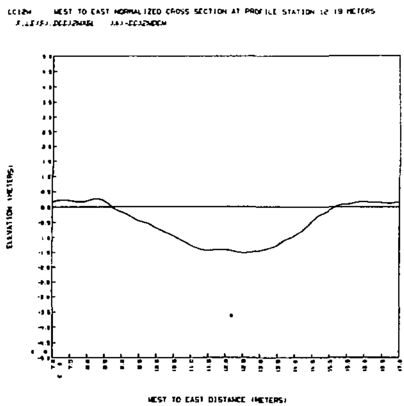

CC12W NORTH TO SOUTH PROFILE AT CROSS SECTION STATION 12 19 METERS
FILE(S) ACC12WPSL (A)-BCC12WPSL (B)-CC12WCH
ELEVATION (METERS)
SOUTH TO NORTH DISTANCE (METERS)


CC12W SOUTH TO NORTH NORMALIZED PROFILE AT CROSS SECTION STATION 12 19 METERS
FILE(S):DCC12WPSL (A)-CC12WDCH
ELEVATION (METERS)
SOUTH TO NORTH DISTANCE (METERS)






CC12W WEST TO EAST CROSS SECTION AT PROFILE STATION 12.19 METERS
ELEVATION (METERS)
WEST TO EAST DISTANCE (METERS)


CC12W WEST TO EAST NORMALIZED CROSS SECTION AT PROFILE STATION 12.19 METERS
ELEVATION (METERS)
WEST TO EAST DISTANCE (METERS)

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Lynden B. Ballou	Program manager
Jon B. Bryan	Physicist
Manuel (Abe) M. Guzman	Electronic technician
Otto H. Krause	Recording Engineer
Robert F. Rohrer	Physicist
Sam J. Spataro	Recording engineer
Norman W. Stewart	Mechanical technician
Wayne R. Woodruff	Physicist
David L. Wooster	HE engineer

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APPENDIX A
CRATERING-AREA-MATERIAL (SOIL) DESCRIPTION

This appendix provides some information about the LLL test site's earth-material properties. Figure A-1 shows a plan view and a subsurface-profile view of borings. In Table A-1 you will find some properties of the material at the site. Figure A-2 recommends idealized profile and composition properties for the site. These material descriptions are based on the Waterways Experimental Station's laboratory measurements of core samples taken from four boreholes (Q1, Q2, PZ1, and PZ2) prior to any of the cratering experiments. Hence, these descriptions are presumably representative of the dry (1976) rather than the wet (1977) site.

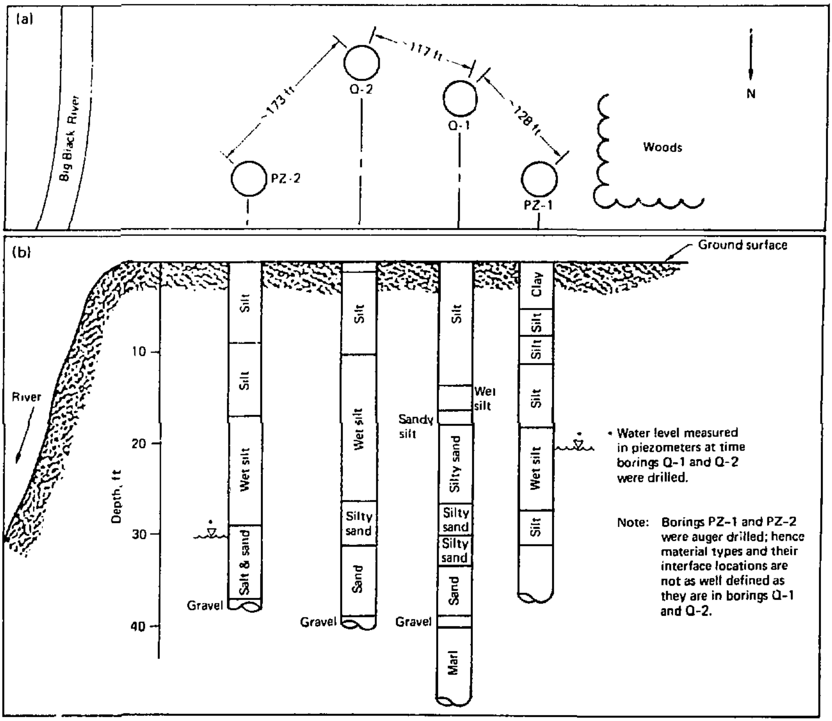

FIG. A-1. (a) Plan view of borings and (b) subsurface profile through borings.

Table A-1. Some material properties for Big Black Site. (This is based on data from J. Ehrgott, Waterways Experimental Station.)

Depth interval (m)	Zone 1 0.0 to 0.9	Zone 2 0.9 to 3.0	Zone 3 3.0 to 6.0
Independent parameters			
Bulk density, ρ_0 (g/cc)	1.63	1.76	1.94
Water content, W	0.20	0.28	0.27
Air-filled porosity, ϕ_a	0.218	0.100	0.015
Dependent parameters			
Grain density, ρ_g (g/cc)	2.662	2.670	2.668
Water saturation, S_w	0.555	0.794	0.965
Total porosity, ϕ_0	0.490	0.485	0.427
Water content, Z (weight fraction)	0.167	0.219	0.213
Density of solids, ρ_s (g/cc)	1.358	1.375	1.528

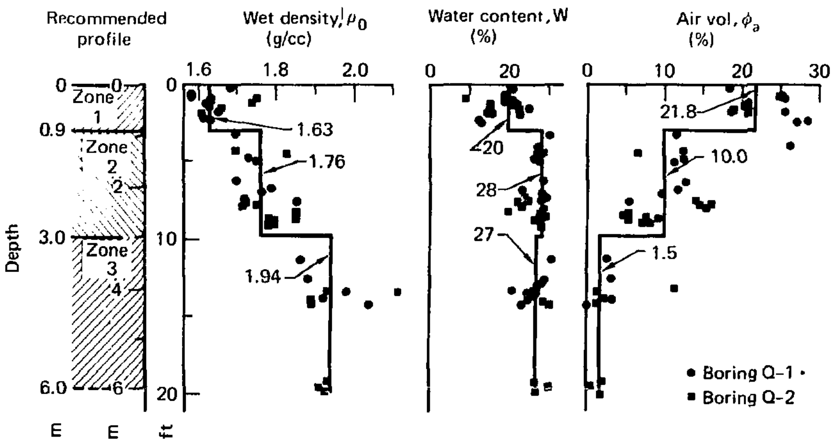

FIG. A-2. Recommended idealized profile and composition properties for Lawrence Livermore Laboratory's test site.

APPENDIX B
CHEMICAL EXPLOSIVE USED IN BIG BLACK CRATERING EXPERIMENTS

LLL used a chemical explosive called EL-836, or Pourvex III, in the Big Black cratering experiments. This blasting explosive, manufactured by DuPont, has been described as a heavily aluminized water slurry based on ammonium nitrate (Lee et al., 1975). Earlier, LLL personnel used this energetic explosive at Hoe Creek, Wyoming, in coal studies emphasizing fracture and permeability enhancement. We selected this explosive because it was available to us as excess from coal studies for cost of transportation a it was previously characterized so that computer cratering simulations were possible.

The explosive properties for EL-836 were tested and characterized by Lee et al. (1975). The Jones-Wilkins-Lee (JWL) equation of state formulation defines the pressure P in terms of specific volume V and energy E. The JWL equation of state has the form

$$P = A\left(1 - \frac{\omega}{R_1 V}\right)e^{-R_1 V} + B\left(1 - \frac{\omega}{R_2 V}\right)e^{-R_2 V} + \frac{\omega E}{V} , \qquad (1)$$

where $V = \rho_0 / \rho$ (ρ_0 is the loading density). This formulation is used to describe the detonation of the explosive in computer simulations. The expression for the JWL isentrope is

$$P_s = Ae^{-R_1 V} + Be^{-R_2 V} + \frac{C}{V^{(w+1)}} . \qquad (2)$$

A, B, C, R_1, R_2, and ω are constants specified in Table B-1. Further details about the JWL formation are described in a report by Lee et al. (1968).

Past cratering studies (Glenn and Thomsen, 1976; Burton et al., 1975; Bryan et al., 1974; Sisemore et al., 1974; O'Connor et al., 1973; and Terhune et al., 1970) have demonstrated the importance of using well-characterized explosives in cratering experiments so that accurate computer simulations are possible. Descriptions such as those listed in Table B-1 are based on manufacturer's specifications and adjusted to fit thermodynamic criteria and measurements (including expansion of spherical and cylindrical charges) as described by Lee et al. (1968). Table B-1 lists the Chapman–Jouguet (CJ) parameters and JWL coefficients for five explosives—El-836, trinitrotoluene (TNT), nitromethane (NM), Teledet, and MS-80-20. Table B-2 shows that EL-836 is e most energetic of these five explosives (based on values derived from Table B-1). Butkovich (1975) has compared the explosive characteristics of EL-836 with those for nitromethane and Teledet. This JWL description for EL-836 was used previously by Butkovich et al. (1977) for one-dimensional (SOC) and two-dimensional (TENSOR) simulations of fracture in the Hoe Creek coal seam.

In the cratering experiments conducted near the Big Black River, each explosive charge of EL-836 weighed about 60 lb. The charge shape was nearly cylindrical, with an aspect ratio (length/diameter) near one. Each row experiment, involving 6 to 14 charges buried at a constant depth with fixed spacing, used a linear array of charges detonated at essentially the same time. This timing and firing configuration made it possible with approximations to use two-dimensional, plane-strain computer calculations to simulate the cross section of a row crater perpendicular to the array of charges.

Table B-1. Chapman-Joquet (CJ) state parameters and Jones-Wilkins-Lee (JWL) coefficients for several chemical explosives.

	Chemical explosive				
	EL-836	TNT	Nitromethane	Teledet	MS-80-20
CJ-state parameters					
Loading density, ρ_0 (g/cc)	1.49	1.63	1.128	1.36	1.1
Pressure, P_{CJ} (Mb)	0.115	0.210	0.125	0.150	NA[a]
Detonation velocity, D (cm/μs)	0.535	0.693	0.6287	0.652	NA
Energy, E_0 (Mb-cc/cc)	0.090	0.070	0.051	0.041	0.063
Gamma, Γ_{CJ} (-)	2.708	2.727	2.538	2.854	NA
JWL coefficients					
A	2.174	3.738	2.092	3.0409	NA
B	0.02908	0.03747	0.05689	0.05804	NA
C	0.01189	0.00734	0.00770	0.00347	NA
R_1	4.4	4.15	4.4	4.3	NA
R_2	1.4	0.9	1.2	1.5	NA
ω	0.16	0.35	0.3	0.2	NA
Reference	Lee et al. (1975)	Lee et al. (1973)	Lee et al. (1968)	Lee (1974)	Shaler (1978)

[a]Not available.

Table B-2. Comparison of exploxive energies of one-ton (2000-lb) quantities of five chemical explosives.

	Chemical explosive				
	EL-836	TNT	Nitromethane	Teledet	MS-80-20
W[a] (energy in tons)	1.31	0.93	0.98	0.60	1.24

[a]The "ton" unit of energy is defined to be 4.186×10^{16} erg or 10^9 g-cal. These numbers were computed using values for ρ_ι and E_0 from Table B-1. Other conversion factors: 1 ton (2000 lb) = 9.072×10^5 g; 1 Mb-cc = 10^{12} erg.

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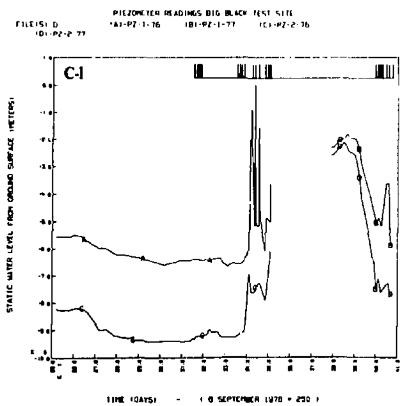
APPENDIX C
STATIC WATER-LEVEL MEASUREMENTS

The "Results" section of this report stated that the material at the Big Black Test Site changed significantly in water saturation during the experimental period. Probably, the water saturation changed sufficiently to alter the properties so that the data collected during the first set of experiments and then used to design the subsequent ones, in late November and in February, were probably no longer completely valid. Indeed, a set of four single-charge experiments performed after the water table rose gave larger excavated dimensions than like depths-of-burial detonated earlier. This appendix gives the data on the static water level at the test site during the experimental period. Its understanding may help in the interpretation of the experimental results.

The Big Black Test Site is located adjacent to the Big Black River, not too far from its confluence with the Mississippi. During the period from latter November to early February the river rose significantly, to almost flood stage, and then receded. Two piezometers were located adjacent to the LLL test area: one near the woods (west end), designated PZ1, and the other near the river (east end), designated PZ2. The piezometers, used to measure the static water level from the ground surface, were nominally read once every working day. During the middle set of experiments around the end of November, having noticed a prompt and strong response by the water level to the detonations, we read the piezometers frequently, particularly just minutes before and after a detonation.

All the piezometer data collected is shown in Fig. C-1. The set of vertical lines across the top of each figure represents individual shot times. The gap in the data is between the middle of December 1976 and late-January 1977 when no data were collected. The upper curve (shallower water table) represents piezometer data taken near the woods; the lower curve represents piezometer data taken near the river. It would nominally be expected that the water table adjacent to the river is lower than that some 120 m away, with no recharge source other than rain and the river level below either of these two levels (Fig. C-2). Figure C-3 shows the water level adjacent to the river shifted to match that near the woods. A uniform shift of 2.83 m for the data between September 6 and the end of November and the resultant good agreement indicate a constant hydraulic gradient (2.3 cm/m) during that period.



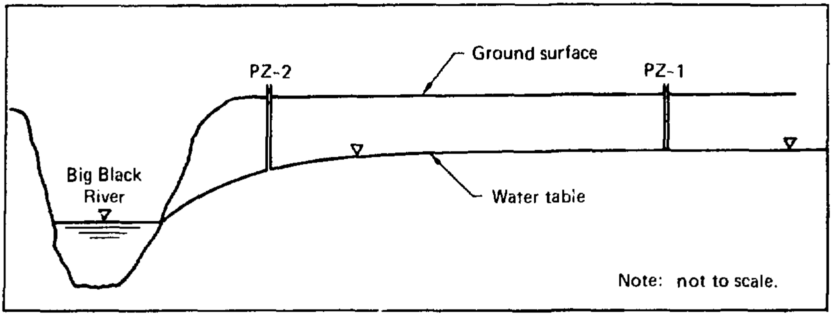
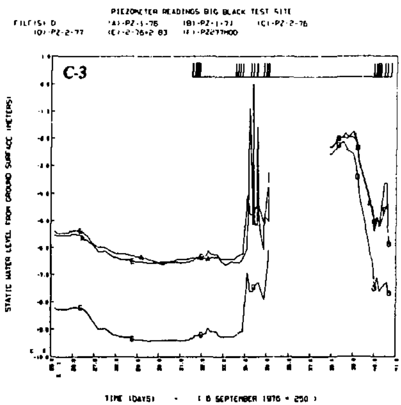
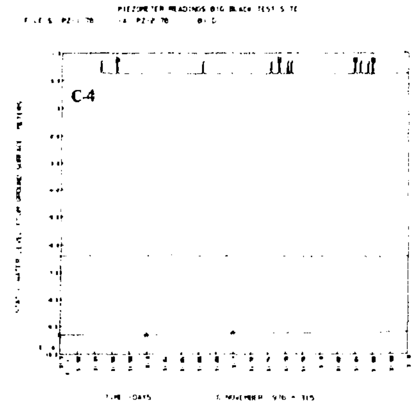


FIG. C-2. Cross section through Lawrence Livermore Laboratory's test site showing the site's assumed subsurface water level.

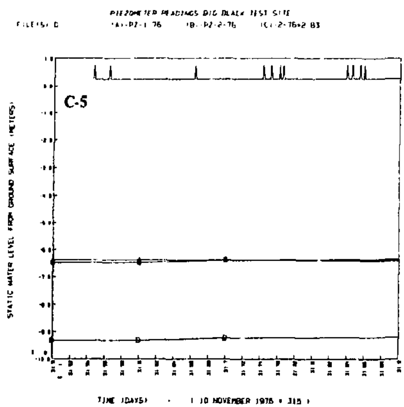
Figure C-4 shows the piezometer readings and detonation times during the first experimental set. Figure C-5 shows the same period with the piezometer readings nearest the river adjusted upward 2.83 m. Figure C-5 indicates that for the detonations shown there was little effect on the piezometer surface. During the first detonation series the piezometric surface was ≥3 m below the detonation points.

Figure C-6 shows the readings during the second detonation series. Figure C-7 shows the same data with the near-river readings raised by 2.83 m. Referring to Fig. C-1, after November 1 (day 306), there appeared to be a trend beginning toward a shallower piezometric surface indicated on both gauges. Figure C-7 indicates the first several detonations had no major effect on the piezometric surface. The latter detonations, however, engendered abrupt changes in the piezometric surface, particularly nearest the woods. Such abrupt changes were likely noticed only because the piezometers were read more frequently than before. We made more readings because of concern over experimental validity when we found subsurface water running in newly excavated rows immediately after detonation.





We detonated CC1C during this period, on day 338; its data are shown in the summaries as part of the dry series of detonations. In retrospect, the CC1C data might have better been shown with the wet single-crater data. CC1C was buried at 1.68 m and was further west than piezometer PZ1. Thus, the water level was likely shallower than that shown for piezometer PZ1. Considering the abrupt changes in the piezometric surface occurring three days later, it is possible the earth-material properties had changed from that during the other single-crater detonations conducted earlier.



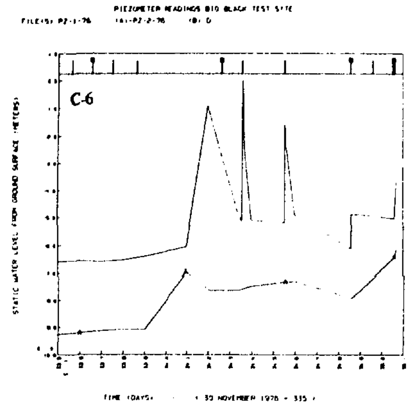
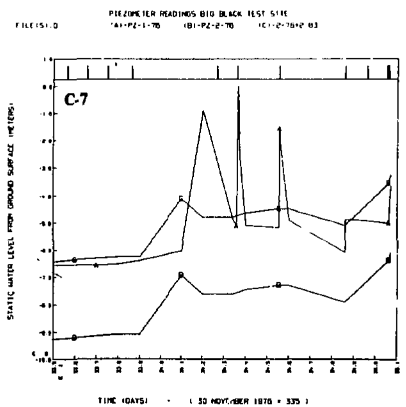


Figure C-8 shows the piezometric readings during the period from early to mid-February. Figure C-9 shows the set of river readings adjusted upward. That adjustment was not uniform. A constant adjustment upward was used for the first few days and then a linear-increasing adjustment with time. If we take first differences between the readings, we could make a straight line fit the data after the first few days. Thus, we presume that the piezometric surface adjacent to the river was going down at a constant but more rapid rate than that at the west end of the site.



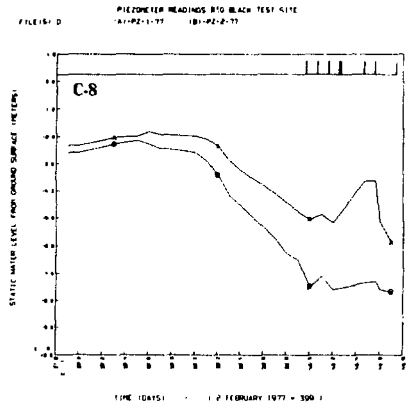
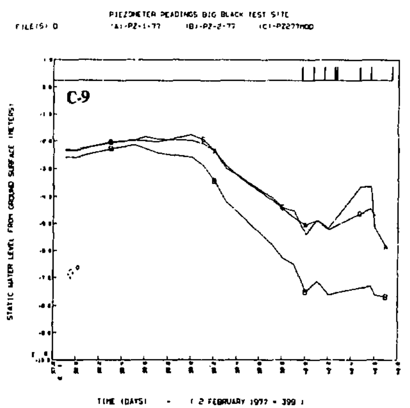
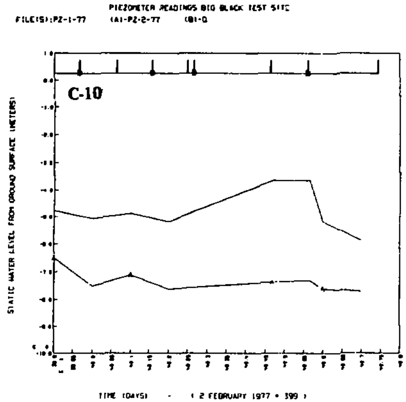


Figure C-10 shows the piezometric surface during the period of the last set of detonations. Figure C-1[1] shows the near-river readings adjusted upward as discussed above. The detona‹ions appeared to have little effect on the piezometric surfaces as in the initial test series; this was probably because the piezometric surface had fallen and was still falling.





We detonated the wet single-charge series during the last set of experiments. While the response to the detonations of the piezometric surface was not as observed earlier, all the excavated dimensions were larger than those for earlier comparable experiments. Thus we conclude that there was a more completely saturated medium than experienced earlier. And we question the validity of combining data from the series of experiments.