AD-A110 067 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 14/2
SITE CHARACTERIZATION FOR AAH/HELLFIRE BATTLEFIELD OBSCURATION --ETC(U)
DEC 81 J B MASON, K S LONG
UNCLASSIFIED WES/MP/EL-81-10 NL

END
DATE FILMED
2 82
DTIC

1.0 1.1 1.25 1.4 1.6 1.8 2.0 2.2 2.5 2.8 3.2 3.6 4.0 4.5 5.0 5.6 6.3

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

MISCELLANEOUS PAPER EL-81-10

# SITE CHARACTERIZATION FOR AAH/HELLFIRE BATTLEFIELD OBSCURATION VALIDATION TESTS AT REDSTONE ARSENAL, ALA.

by


James B. Mason, Katherine S. Long

Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180



December 1981

Final Report





Prepared for U. S. Army Missile Command
Redstone Arsenal, Ala. 35809




[illegible]

Destroy this report when no longer needed. Do not return
it to the originator.

The findings in this report are not to be construed as an official
Department of the Army position unless so designated
by other authorized documents.

The contents of this report are not to be used for
advertising, publication, or promotional purposes.
Citation of trade names does not constitute an
official endorsement or approval of the use of
such commercial products.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER<br>Miscellaneous Paper EL-81-10 | 2. GOVT ACCESSION NO.<br>AD-A110 067 | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle)<br>SITE CHARACTERIZATION FOR AAH/HELLFIRE BATTLEFIELD OBSCURATION VALIDATION TESTS AT REDSTONE ARSENAL, ALA. | | 5. TYPE OF REPORT & PERIOD COVERED<br>Final report<br>6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s)<br>James B. Mason, Katherine S. Long | | 8. CONTRACT OR GRANT NUMBER(s)<br>Intra-Army Order No. 80X1 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>U. S. Army Engineer Waterways Experiment Station<br>Environmental Laboratory<br>P. O. Box, 631, Vicksburg, Miss. 39180 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>U. S. Army Missile Command<br>Redstone Arsenal, Ala. 35809 | | 12. REPORT DATE<br>December 1981<br>13. NUMBER OF PAGES<br>28 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) | | 15. SECURITY CLASS. (of this report)<br>Unclassified<br>15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Military operations
Site investigation
Terrain factors
Weapon systems

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

During FY 80 the AAH/HELLFIRE Battlefield Obscurants Program, Phase III Test Operations were conducted by the Test and Evaluation Directorate (TED) of U. S. Army Missile Command (MICOM) at Redstone Arsenal, Ala. The purpose of this test series was to validate weapons systems performance models for various obscurant conditions which included dust and debris of terrain origin. The U. S. Army Engineer Waterways Experiment Station was requested to provide site

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

411-08

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

20. ABSTRACT (Continued).

characterization data to MICOM-TED for the purpose of describing obscurant material. This report describes the site characterization procedures used and discusses the data obtained.

The site of the test was the TA-3 range at Redstone Arsenal. This characterization includes general obscurant-related features, such as soil classification, roughness, and vegetation based on test samples and observations taken in October 1979. It was also intended to include more detailed data and observations covering a particular phase of testing in the late spring of 1980 in which explosive cratering and vehicle dust would be employed. As it happened that phase took place in June and was repeatedly interrupted by heavy rain so that site data directly related to specific tests were not possible. Some additional data were obtained at that time, however, and all results are discussed.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

## PREFACE

The work reported herein was conducted by the U. S. Army Engineer Waterways Experiment Station (WES) in September 1979 and May 1980 under Intra-Army Order No. 80X1 for reimbursable services. The work was sponsored by the Project Manager for Smoke/Obscurants in support of the AAH/HELLFIRE validation tests being conducted by the U. S. Army Missile Command at Redstone Arsenal, Ala., under the direction of Mr. W. Wahlheim.

This work was conducted under the general supervision of Dr. John Harrison, Chief, Environmental Laboratory (EL), and Mr. Bob O. Benn, Chief, Environmental Systems Division, EL, and the direct supervision of Dr. Lewis E. Link, Chief, Environmental Constraints Group. The work was performed by Messrs. James Mason and Carlos Lebron, EL. This report was prepared by the Mr. Mason and Ms. Katherine Long, research botanist.

Commanders and Directors of WES during the period of this work and the preparation of this report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Mr. Fred R. Brown was Technical Director.

This report should be cited as follows:

> Mason, J. B., and Long, K. S. 1981. "Site Characterization for AAH/HELLFIRE Battlefield Obscuration Validation Tests at Redstone Arsenal, Ala.," Miscellaneous Paper EL-81-10, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

CONTENTS

## SITE CHARACTERIZATION FOR AAH/HELLFIRE BATTLEFIELD OBSCURATION VALIDATION TESTS AT REDSTONE ARSENAL, ALA.

### PART I: INTRODUCTION

#### Background

1. The development of families of sophisticated weapons systems that depend upon optical guidance and tracking has fostered in recent years a series of large-scale field trials to test such systems in realistic battlefield environments. A major element of such environments is dust or other debris of terrain origin suspended by the atmosphere. The suspended particles interact strongly with optical radiation and in sufficient quantities can result in severe degradation in the performance of optical systems. The need to describe the physical properties of obscurants, therefore, has acquired an increased emphasis.

2. A further need is the ability to predict obscurant levels in potential battle areas. This has led to the more basic requirement for developing relations between weather, terrain surface characteristics, and military activities (e.g., munition bursts and vehicle traffic) on the battlefield. Such relations must describe the character, extent, and time history of the resulting atmospheric obscurants.

3. A prediction capability must begin with a knowledge of the terrain. Certainly, munition bursts in saturated organic soils such as swamps or in heavily vegetated regions will generate very little dust. However, munition bursts on the surface of a dry or fine-grained soil with little vegetation cover can produce significant loading of the atmosphere with obscurants. Of course, many combinations of conditions between these extremes can and do occur, and the weather as well as battlefield activities ensures that these conditions are dynamic in nature.

4. The ability to forecast quantitatively the amount and character of obscurants that are suspended in the atmosphere for a given

activity in a given terrain situation does not yet exist. It is, however, of keen interest to a number of research efforts. At the U. S. Army Engineer Waterways Experiment Station (WES) a current effort is focused on defining quantitatively the relations between soil surface conditions and the amount of material suspended in the atmosphere as a result of high explosive (HE) munition bursts. The initial objective of the work has been to obtain a sufficient data base of terrain surface characteristics and debris cloud racteristics resulting from HE explosions on that surface. These data will form an empirical base for the development of relations between terrain surface descriptors and debris cloud character. The ultimate objective is a physically based debris (dust) potential (DP) forecast procedure.

5. Work at the WES has emphasized field data collection efforts both in-house and in conjunction with field experiments conducted by such organizations as the U. S. Army Atmospheric Sciences Laboratory, the Night Vision and Electro-Optics Laboratory, and by the DARCOM Program Managers (PM) for Smoke/Obscurants and Advanced Attack Helicopter/HELLFIRE. The work reported herein was performed for the U. S. Army Missile Command (MICOM) in conjunction with PM AAH/HELLFIRE.

6. Because quantitative relations for atmospheric loading from HE bursts are not available, the set of terrain surface descriptors that relate most directly to debris cloud character is not defined. As such, the criteria for terrain characterization have been based on fundamental topography, soil, and vegetation properties that are hypothesized to influence the formation of debris clouds. A more thorough discussion on the explosive process and its interaction with the terrain surface is presented in Appendix A.

7. One of the major system performance models is that developed by the U. S. Army Missile Command and known as Laser Designator Weapons System Simulation (LDWSS). Initially a purely system-oriented model, it has been updated to include battlefield environments with the designation Battlefield Environments Laser Designator Weapons System Simulation (BELDWSS). The BELDWSS model is applied to a number of weapons systems employing laser designators including the AAH/HELLFIRE systems. In

FY 79, under the sponsorship of the Project Manager for AAH/HELLFIRE, an extensive field test series was conducted by the MICOM Test and Evaluation Directorate at Redstone Arsenal, Ala. The test series was designed to last for 8 to 10 months, and to simulate a wide range of battlefield environments including smokes, natural aerosols, and dust. For the dust portion of the series, the need for a terrain characterization oriented toward the electro-optical (EO) environment was recognized, and the WES was asked to provide that characterization.

## Objective and Scope

8. The objectives of the WES participation in the MICOM, AAH/HELLFIRE tests were (a) to provide consultive assistance in the preparation of the test site for the HE dust events and (b) to characterize site conditions during the tests to establish a basis for relating the particulate obscuration measured during the tests to site conditions.

9. The site characterization work included a general documentation of vegetation, surface roughness, and drainage conditions as well as measurements of specific soil properties and acquisition of soil samples for subsequent laboratory analysis. Because the actual locations of the HE explosive tests proved to be on unvegetated, prepared soil areas, the soil properties were emphasized in the field data collection. The MICOM tests were held over a period of 9 months from September 1979 to May 1980. Field data acquisition by WES personnel was accomplished during the months of September 1979 and May 1980 to document site conditions at the beginning and end of the test series. Data collection during the interim was to be accomplished by MICOM.

## PART II: SITE CHARACTERIZATION

### Site Characterization Procedure

10. The site characterization was comprised of a general site description and measurements of soil properties hypothesized to be related to atmospheric loading of obscurants (see Appendix A). The general site description was accomplished by simple physical measurements and observations. The soil measurements were the only detailed data obtained because the test site surfaces where the explosives were placed had no vegetation cover and were constructed from local soils common to the test site.

11. The specific soil parameters of interest and their method of determination were as follows:

a. Cone index. Made by pressing a calibrated metal cone into the soil; the cone index (CI) yields information that can be related to its shearing properties and bearing strength. The measurement is made on the site and consists of recording the force required to penetrate the soil with the cone at successive 5-cm intervals to a depth of 45 cm. Typically, two or three soil measurements are obtained at each sample point and the results averaged.

b. Size gradation. Obtained from bulk samples, this property is essential because it describes the raw material from which obscurants are formed. It is obtained by passing soil samples through calibrated screens or sieves of successively finer mesh and weighing the material retained on each. Material passing the No. 200 sieve (0.074-mm diameter) is graded by means of a hydrometer. The results are presented in the form of a graph of the percentage by weight of material finer than the selected diameter (percentage fines).

c. Mineralogy. The mi[illegible] content of the soil allows the inference of its optica[illegible] [illegible]erties, provided that the minerals have been so measu[illegible] [illegible]n bulk form. The mineral content is obtained by means o[illegible] [illegible]y diffraction spectroscopy.

d. Organic content. Organic matter alters t[illegible] [illegible]hanical as well as optical properties of the soil. The o[illegible] content is determined in the laboratory by weighing t[illegible] [illegible]lk material before and after heat processing.

e. Atterberg limits. The Atterberg limits refer to the liquid limit (LL) and plastic limit (PL) of the material and are expressed as moisture contents. They are obtained by testing samples of the soil of varying moisture contents in the laboratory to establish the values at which the soil exhibits liquid and plastic properties according to the prescribed criteria. A related parameter that is useful is the plastic index (PI), which is the difference of the two limits. Atterberg limits are obtained using a simple laboratory test procedure.

f. Moisture content. Moisture content is the amount of moisture in the soil expressed as a percentage of the soil's dry weight. It is an essential part of all EO characterizations, and its variability with time and weather must be considered. Moisture content can be measured in the field or in the laboratory using gravimetric techniques.

g. Bulk density. Bulk density is the density of dry bulk material including voids (air spaces) and figures in calculations of ejecta. Bulk density can be estimated by simple gravimetric techniques in the field.

h. Specific gravity. This is the average density of the solid soil material excluding water and voids.

12. Soil samples were obtained in two manners. Samples to determine volume-related properties, such as moisture and density, were obtained with a Hvorslev core sampler. Samples for laboratory analysis, such as grain size distribution and mineralogy, were obtained using a shovel or with the Hvorslev sampler (for samples at significant depths below the surface).

## Site Description

13. A site plan for the area in which the HE explosive tests were conducted is shown in Figure 1. WES personnel visisted the site on 12 and 13 September 1979 and 20-23 May 1980. The following is a brief synopsis of site conditions.

14. Having once been used as an airfield, the site was level and had a relatively smooth surface for approximately 2 km in the north-south direction and for approximately 200 m in east-west. The entire area was covered more or less uniformly by grass of 15-30 cm height.

The lack of variety suggested seeding but no evidence of harvesting was noted.

15. The center of the area was marked by a line of air samplers extending for several hundred metres along the long axis. The test area in which dust was to be generated lay on either side of this line, extending out for approximately 50 m. Within that area two surface conditions were found. On the east side the soil was a homogeneous reddish silty clay or sandy clay with no gravel to a depth of 0.45 m or more at every point sampled. On the west the surface layer of 12-15 cm contained a large percentage of blackish gravel overlaying material similar to that on the east. This surface appeared to have been artificially constructed.

16. Drainage of the entire area was generally west-to-east, the west boundary being a low ridge crested by shrubs and small trees. The east boundary was a line of trees marking the path of a small creek (Indian Creek). Surface drainage was west-to-east and was expected to be slow due to the level topography and clay content.

17. The test area was bounded by graveled roads of a lighter colored material than that found in the soil as mentioned, and a third connecting road bisected the area.

18. Because of the gravel layer in the test area, it was recommended that testing not be made on the existing surface. The lack of native soil, it was felt, would reduce the dust generated and lead to results that would be difficult to compare with data obtained at other test sites. It was suggested that the alternatives were, in order of decreasing desirability, the following: to use only the east portion of the site; to move the test area; to strip away the graveled surface; or to cover the surface with soil layer deep enough to minimize the effect of the gravel surface. The last two were not favored because they eliminated the sod and vegetation layer, lessening the realism of the test. Ultimately, however, the fourth alternative was chosen (i.e., to cover the surface with a soil layer deep enough to minimize the effect of the gravel surface).

19. Soil was transported in to form two mounds on which to

conduct the HE dust tests. These mounds stood 0.75 to 1.0 m above the terrain surface and were 3 to 4 m wide and 100 m long (see Figure 1). They were flat on top and compacted by traffic. Their composition was similar to the native surface soil, but the absence of organic matter suggested that the material was obtained from a source below the surface. This was further indicated by the size distribution.

20. The sampling carried out during September 1979 was on the natural terrain surface because the mounds mentioned in the previous paragraph were not yet constructed. During the 20-23 May 1980 site visit, rains prevented conduct of actual explosive tests; however, soil samples and measurements were obtained on the test mounds. Because of the rain, the soil surface was nearly saturated and some craters from earlier tests made on the original surface and other depressions were filled with standing water. This also prevented meaningful measurements of craters produced by previous HE explosive tests. MICOM personnel collected soil moisture and density data during the period between the WES measurements as a normal part of the test program. The MICOM data are not presented in this report.

## PART III: DATA PRESENTATION AND SUMMARY

### Data Presentation

21. The site of the tests is depicted in Figure 1. Bulk samples from the site were analyzed in the laboratory to obtain size distribution, plastic properties, organic content, and mineralogy. These results are presented for both the native soil and the transported material in Table 1. The sample numbers identify the locations shown in Figure 1b where the "Y" coordinate is measured in the east-west direction from the center line and the "X" coordinate in the north-south direction from the center of Target Road. These coordinates locate the sample points.

22. The depths shown in the table refer to the appropriate sampled layers. For 12 September and 22 May the samples were obtained with a Hvorslev core sampler which allowed computations of density and moisture content as well as supplying material for laboratory analysis. The samples of 13 September were collected by shovel and extended slightly deeper. On 21 May, only CI was measured so that depths shown correspond to that data.

23. Lower values obtained near the craters (21 May) as compared to September results may reflect the effects of the blasts in loosening the soil and also the higher soil moisture due to recent rains. Higher values on the test mounds (22 May) indicate the packing of that material and lower moisture content (MC) due to better drainage conditions. Note the contrast in the structure of these with the measurements on native terrain (12 September). Average values are given for each of the three layers, 0-15, 15-30, 30-45 cm depth.

24. Table 2 lists the bulk properties of the soil. In nonorganic soils PI tends to be larger for clays than for silts, while in sands it approaches zero (nonplastic). The values obtained from the mounds are seen to be larger than those of the native surface material.

25. Two samples from the test mounds (locations 2 and 3 in Figure 1) were analyzed by X-ray diffraction and found to be identical in

mineral content. Both were high in iron (nonmineral) as indicated by their reddish color and high background intensities of the diffraction patterns. The nonclay mineral composition of the samples, in order of decreasing abundance, was quartz, potassium feldspar (orthoclase), and hematite. The clays were kaolinite, mica/illite, vermiculite, and chlorite.

26. The size gradations appear in Figures 2-5, the first two being for the natural surface material and the last two for the material on the mounds. The higher percentages of clay-sized material in the mounds is evident. Provided they can be separated by the explosion, such material can be expected to yield substantially more particles in suspension in the dust cloud.

27. From the gradation results the classifications of soils are obtained and these are customarily displayed on diagrams of the type shown in Figure 6. Along with the Redstone Arsenal samples a number of results from other battlefield obscuration tests have been presented for reference purposes. Note that the material from the mound is almost alone on this chart while the native surface material is similar to a number of others. Only the subsurface clay at Ft. Polk, La., site of the DIRT-III series is similar to that of the mounds here.

## Summary

28. This report is primarily for presentation and discussion of the site characterization data obtained in support of the MICOM, AAH/HELLFIRE field tests. For this reason, a potential problem exists in that the data were not collected simultaneously with the HE explosive tests, and therefore, extrapolation of the data to span conditions during the entire test period may be required before the inherent relationship can be demonstrated. It is important to discuss in general terms the inherent relationship between the measured soil properties and dust potential for use in subsequent data analyses. It is not feasible to make a detailed analysis of site condition or dust potential. The following paragraphs, however, present a brief discussion in this context.

29. The soil classification is probably the most important single determinant for DP since it is based on size distribution. Fifty-five percent by weight of the material from the mounds was less than 10-μm in diameter. From Stoke's Law, it is possible to estimate the rate at which spherical particles will settle in the atmosphere. Typical times required for 10-μm spheres of the materials identified in these samples to fall through a distance of 1 m at sea level are:

quartz ---------- 124 sec
hematite -------- 64 sec
clay ------------ 148 sec

30. Thus, for individual particles of the site material deposited at an initial height of 10 m one may expect 55 percent by weight to remain above 7.5 m after five minutes, assuming uniform gradation.

31. The mechansim by which particles are deposited is complex and presently under study by WES and other researchers. It is clear, however, that at least two processes are important: the lifting of agglomerations or clumps of soil on ballistic trajectories from the surfaces of which finer particles are eroded aerodynamically, and the entrainment of particles by the rising heated gases. Whatever the manner of deposition the size gradation of the source material will ultimately control the relative amounts of material available to form clouds and the Redstone Arsenol soil contains a relatively large fraction of fines.

32. An equally important factor is moisture, which also plays a role here. The electrostatic forces produced by thin films of water hold particles together, especially clay particles, with the result that when wet, clays tend to flow rather than separate and when dry, they tend to agglomerate. In both cases, the erosion of individual grains requires considerable effort. As a result, clays have not been found generally to produce as much dust as, for example, silts under similar conditions. This would not necessarily be so where the clay surface had been pulverized by traffic or other activity. Dust from clay soils, however, can be expected to remain in the air for longer periods. The

Atterberg limits (PL and LL) indicate the moisture contents at which a soil exhibits plastic and liquid behavior, respectively, under mild stress. The difference between them is often related to the cohesive strength of the soil. As such, it is expected to be an indicator of the propensity of a soil to yield dust.

33. The moisture conditions observed at Redstone Arsenal must be evaluated in relation to the soil properties. Since the PL is found to be at 16 percent moisture content, the amount of depression below that value would indicate the dryness of the soil. The values observed (by WES) on the mounds where HE dust tests occurred were 17-20 percent, placing them just above that limit. (It should be noted that the PL does not define a point of sharp transition.) The DP for this soil would not be high under those conditions. For tests made following rainfall, even after two or three days, the soil moisture may be elevated and must be taken into consideration.

34. Earlier measurements of MC in the native soil where the PL is 33-37 percent showed it to be 10 percent or more below the PL. This condition together with the smaller PI would indicate a higher DP for that soil. Of course, the evaluation of a particular test would depend on conditions at the time of that test. It should also be remembered that this comparison does not include the effect of the vegetation.

35. A final comment is made in reference to crater dimensions. The practice among modelers has been to compute crater volumes and thereby to estimate the amount of material ejected as a way of obtaining dust quantities. This has been done because crater dimensions are all that could readily be modeled on the basis of existing data. The visible crater, however, is not a reliable indicator of the true crater or of the amount of ejecta. Furthermore, one cannot compute dust concentrations by simply taking size fractions of the ejecta. What is needed at this point is a more complete model of the ejection process that includes the aerodynamic ablation of particles from massed material and the entrainment of dust by the rising gases. Until such a model is available it will be necessary to continue the use of crater volume data. In either event, the information derived from proper site characterization

and the concept of dust potential are expected to be useful indicators of obscurant conditions.

Table 1

Soil Properties for Tests conducted at Redstone Arsenal, Ala.

| Date | Sample No. | Location,* m X | Location,* m Y | Depth of Sample, cm | MC* percent | Density,** gm/cc Wet | Density,** gm/cc Dry | Cone Index 0-15 | Cone Index 15-30 | Cone Index 30-45 | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 Sep 79 | D1 | 457.5 | -4.5 | 0 - 10 | 21.4 | 1.91 | 1.57 | 330 | 285 | 225 | |
| 12 Sep 79 | D2 | 412.0 | -4.8 | 0 - 10 | 17.8 | 1.77 | 1.50 | 330 | 285 | 215 | |
| 12 Sep 79 | D3 | 354.5 | -8.5 | 0 - 10 | 22.4 | 1.78 | 1.45 | 330 | 295 | 235 | |
| 12 Sep 79 | D4 | 486.5 | -71.5 | 0 - 10 | 26.7 | 1.67 | 1.31 | 235 | 360 | 265 | |
| 12 Sep 79 | D5 | 477.5 | -41.5 | 0 - 10 | 21.7 | 1.62 | 1.33 | 420 | 375 | 245 | |
| 13 Sep 79 | B6 | 445.0 | 60 | 0 - 20 | 16.0 | -- | -- | 540 | 750+ | 750+ | Bulk sample |
| 13 Sep 79 | B7 | 412.5 | 55 | 0 - 20 | 20.0 | -- | -- | 550 | 750+ | 750+ | Gravelly soil |
| 21 May 80 | 1 | 33.9 | 0 | 0 - 45 | -- | -- | -- | 215 | 200 | 115 | Craters, full of rainwater |
| 21 May 80 | 2 | 30.0 | 0 | 0 - 45 | -- | -- | -- | 140 | 190 | 135 | |
| 21 May 80 | 3 | 22.0 | 0 | 0 - 45 | -- | -- | -- | 135 | 165 | 120 | |
| 21 May 80 | 4 | 12.5 | 0 | 0 - 45 | -- | -- | -- | 165 | 200 | 160 | |
| 21 May 80 | 5 | 7.0 | 0 | 0 - 45 | -- | -- | -- | 130 | 145 | 115 | |
| 21 May 80 | 6 | -8.8 | 0 | 0 - 45 | -- | -- | -- | 165 | 250 | 210 | |
| 21 May 80 | 7 | -14.5 | 0 | 0 - 45 | -- | -- | -- | 260 | 215 | 215 | |
| 21 May 80 | 8 | -20.0 | 0 | 0 - 45 | -- | -- | -- | 145 | 185 | 130 | |
| 22 May 80 | 1 | 497.5 | 20.0 | 0 - 10 | 21.4 | 1.85 | 1.52 | 255 | 330 | 530 | Red clay |
| 22 May 80 | 2 | 502.5 | 22.5 | 0 - 10 | 21.2 | 1.95 | 1.61 | 240 | 300 | 460 | (CH)† |
| 22 May 80 | 3 | 513.0 | 15.0 | 0 - 10 | 22.4 | 1.96 | 1.60 | 210 | 295 | 430 | Red clay |
| 22 May 80 | 4 | 490.0 | 12.5 | 0 - 10 | 20.9 | 2.02 | 1.67 | 225 | 340 | 485 | Red clay |
| 22 May 80 | 5 | 475.0 | 15.0 | 0 - 10 | 22.1 | 1.93 | 1.58 | 210 | 380 | 525 | (CH) over native soil |
| 22 May 80 | 6 | 460.0 | 12.5 | 0 - 10 | 24.3 | 1.89 | 1.52 | 265 | 435 | 555 | |

* See Figure 1.
** Data obtained by MICOM personnel.
† Unified Soil Classification System.

Table 2

Bulk Soil Properties for Tests Conducted at Redstone Arsenal, Ala.

| Sample Number | Depth of Sample, cm | Specific Gravity | Atterberg Limits | USGS Classification | Organic Content |
|---|---|---|---|---|---|
| D2 | 0 - 10 | 2.65 | LL37, PL21, PI16 | CL | 4.8 |
| D4 | 0 - 10 | 2.60 | LL52, PL33, PI19 | MH | -- |
| 1 | 0 - 15 | 2.72 | LL47, PL16, PI31 | CL | 4.4 |
| 5 | 0 - 15 | 2.72 | LL46, PL16, PI30 | CL | 4.3 |

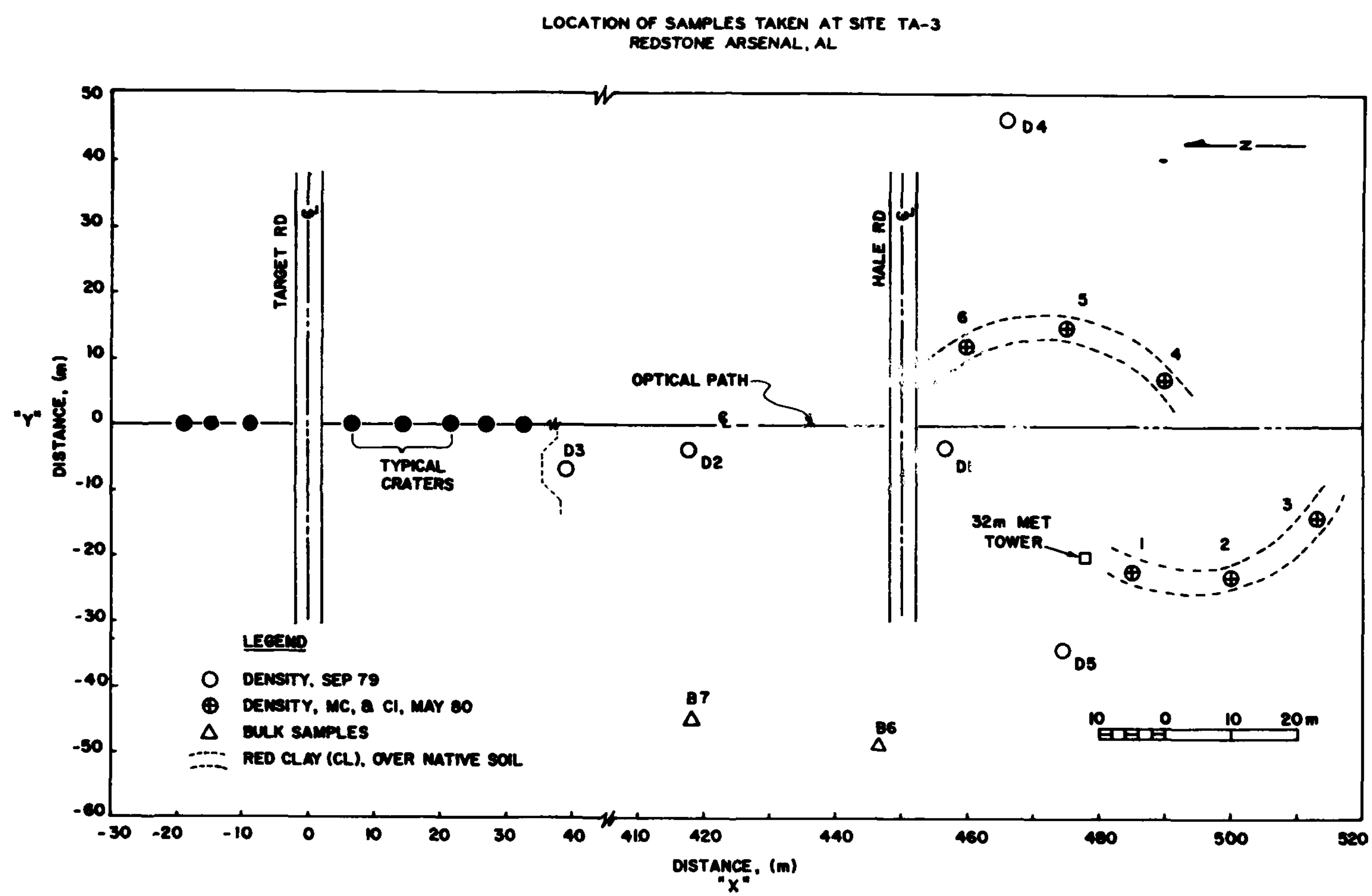
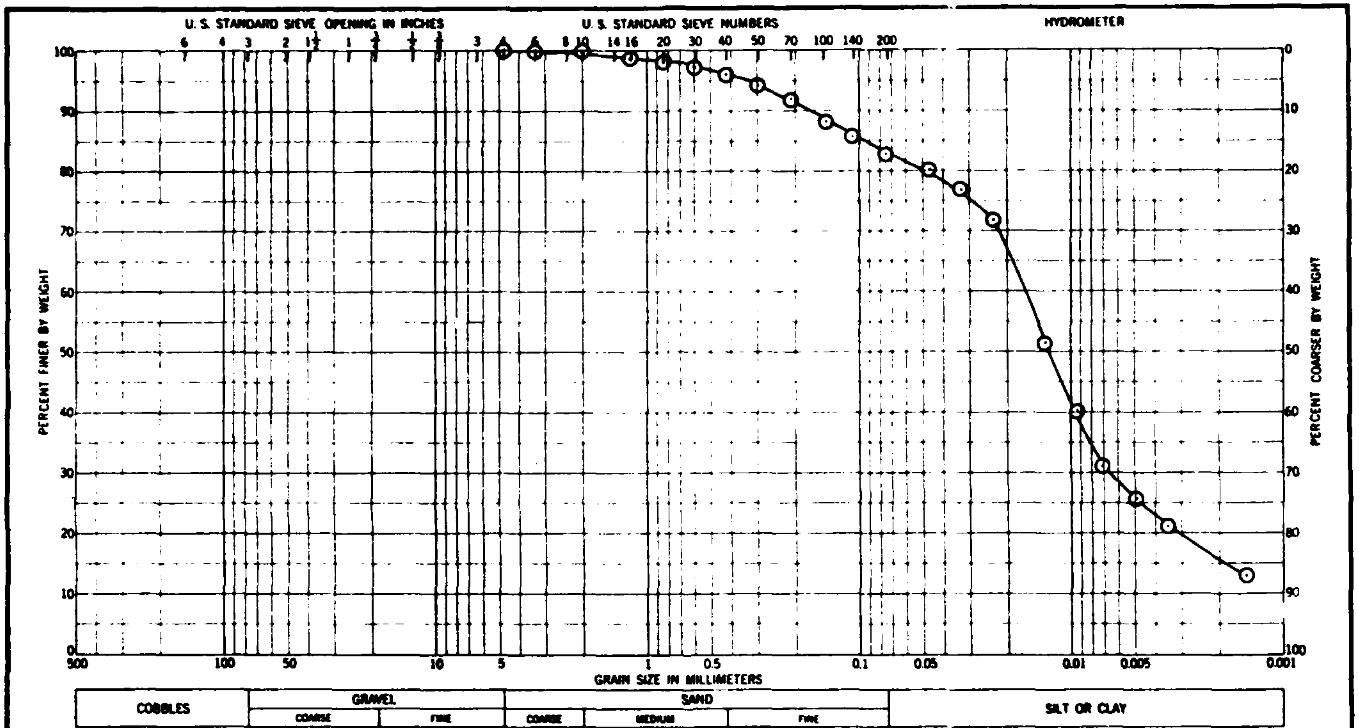



Figure 1. Site plan showing locations of sample points



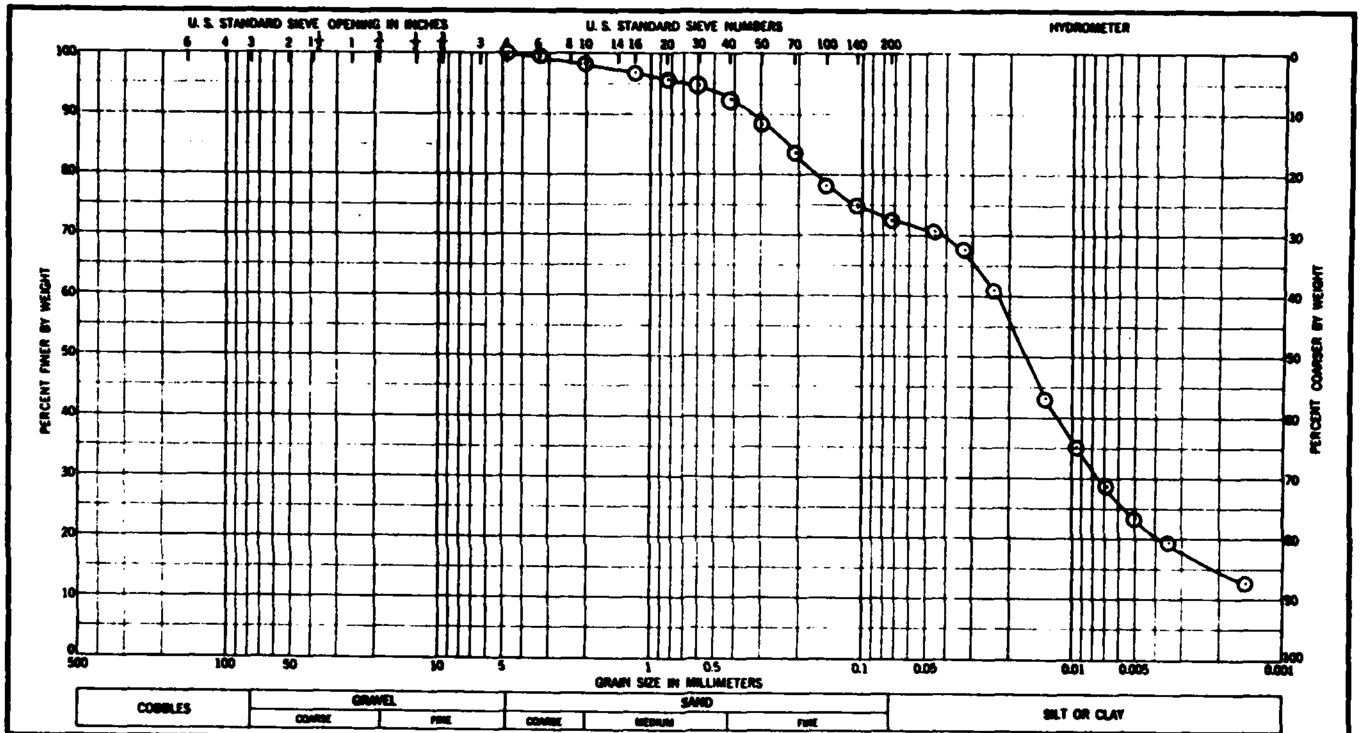

| Sample No | Elev or Depth | Classification | Nat w % | LL | PL | PI |
|---|---|---|---|---|---|---|
| D-4 | 0 - 10 cm | SANDY SILT, (MH), BROWN<br>Gs = 2.60 | | 52 | 33 | 19 |

Project AAH/HELLFIRE
REDSTONE ARSENAL, AL
Area TA-3
Boring No. BULK SAMPLE
Date 7 APR 80

GRADATION CURVES

ENG FORM 1 MAY 63 2087

Figure 2. Size gradation for sample D4



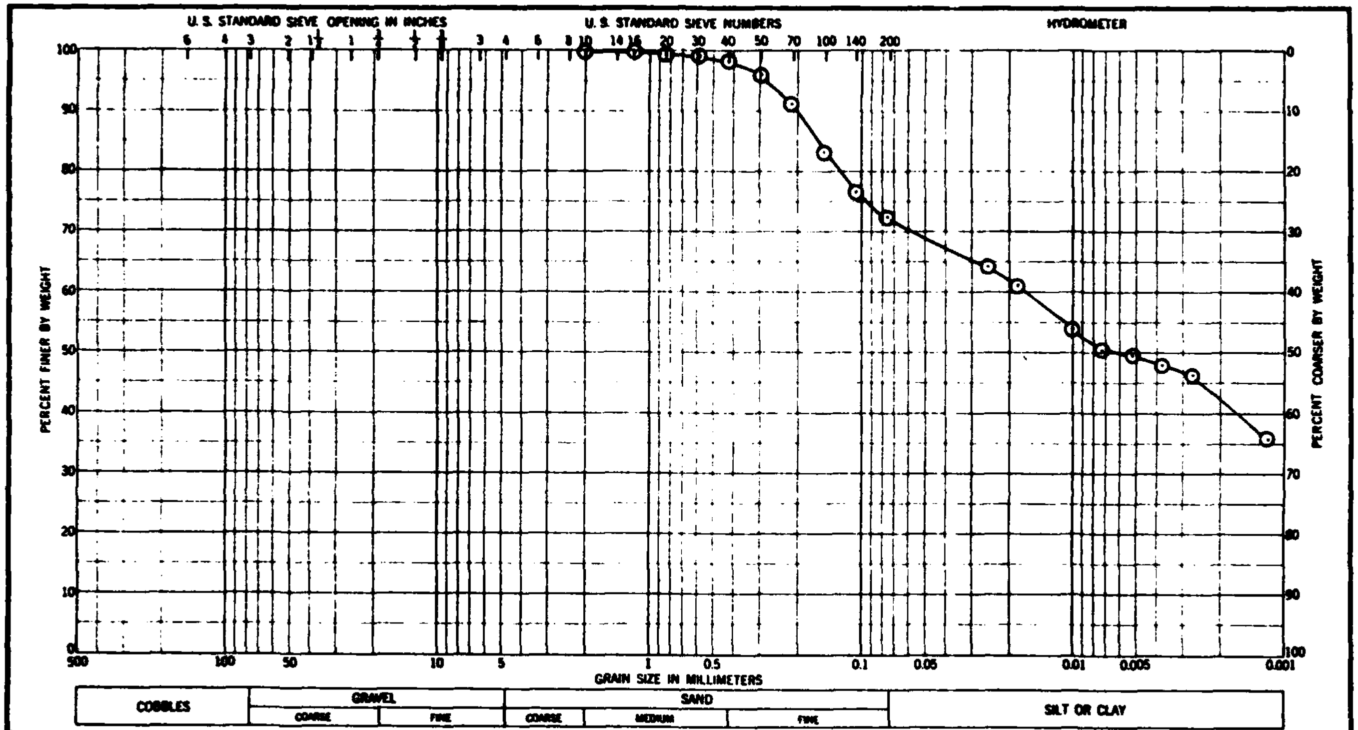

| Sample No. | Elev or Depth | Classification | Nat w % | LL | PL | PI |
|---|---|---|---|---|---|---|
| D-2 | 0 - 10 cm | SANDY CLAY (CL), BROWN | | 37 | 21 | 16 |
| | | Gs = 2.65 | | | | |

Project AAH/HELLFIRE
REDSTONE ARSENAL, AL
Area TA-3
Boring No. BULK SAMPLE
Date 7 APR 80

GRADATION CURVES

ENG FORM 1 MAY 63 2087

Figure 3. Size gradation for sample D2



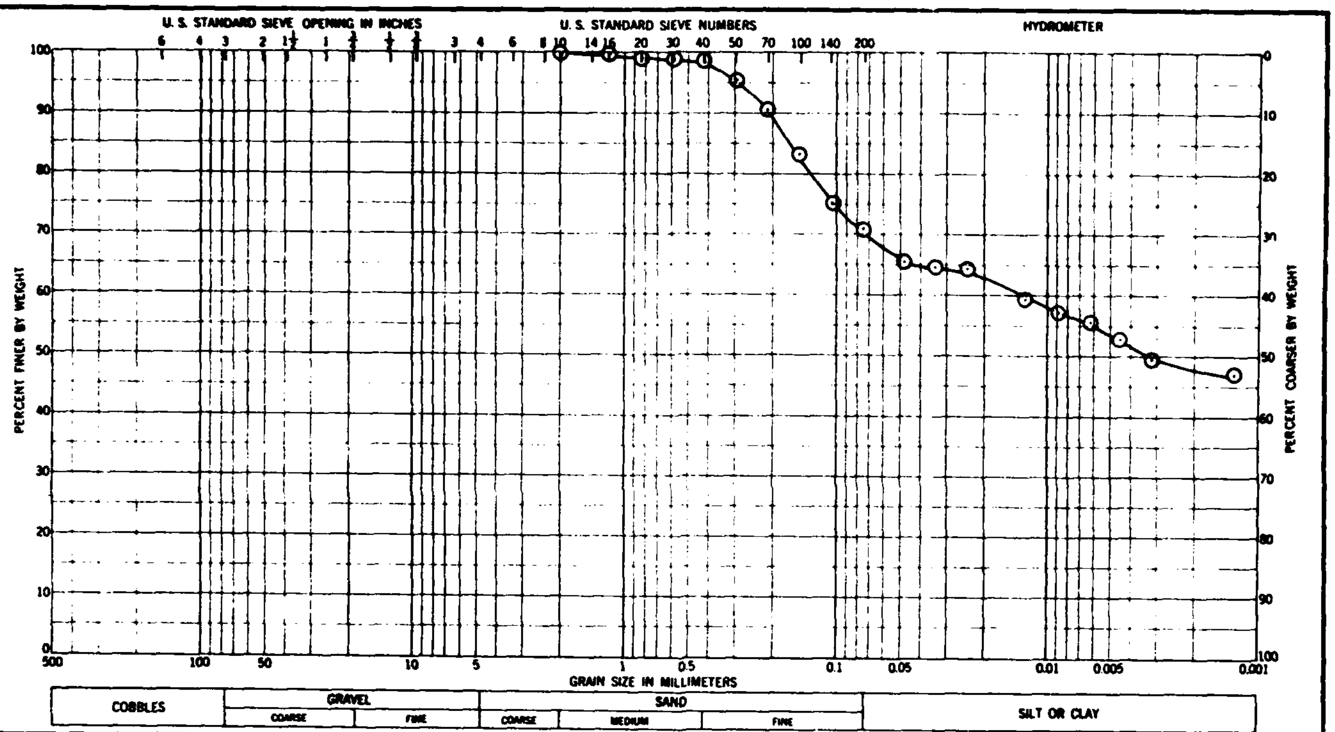

| Sample No. | Elev or Depth | Classification | Nat w % | LL | PL | PI |
|---|---|---|---|---|---|---|
| 1 (⊙) | 0 - 15 cm | SANDY CLAY (CL), RED |  | 47 | 16 | 31 |
|  |  | $G_s$ = 2.72 |  |  |  |  |
|  |  | ORGANIC CONTENT = 4.4% |  |  |  |  |

**GRADATION CURVES**

Project: AAH/HELLFIRE
REDSTONE ARSENAL, AL
Area: TA - 3
Boring No. BULK SAMPLE
Date: 28 AUG 80

ENG FORM 1 MAY 63 2087

Figure 4. Size gradation for mound sample 1




| Sample No | Elev or Depth | Classification | Nat w % | LL | PL | PI |
|---|---|---|---|---|---|---|
| 5 (⊕) | 0 - 15 cm | SANDY CLAY (CL), BROWN<br>Gs = 2.72<br>ORGANIC CONTENT = 4.3 % | | 46 | 16 | 30 |

| | |
|---|---|
| Project | AAH/HELLFIRE<br>REDSTONE ARSENAL, AL |
| Area | TA - 3 |
| Boring No. | BULK SAMPLE |
| Date | 28 AUG 80 |

GRADATION CURVES

ENG FORM 1 MAY 63 2087

Figure 5. Size gradation for mound sample 5

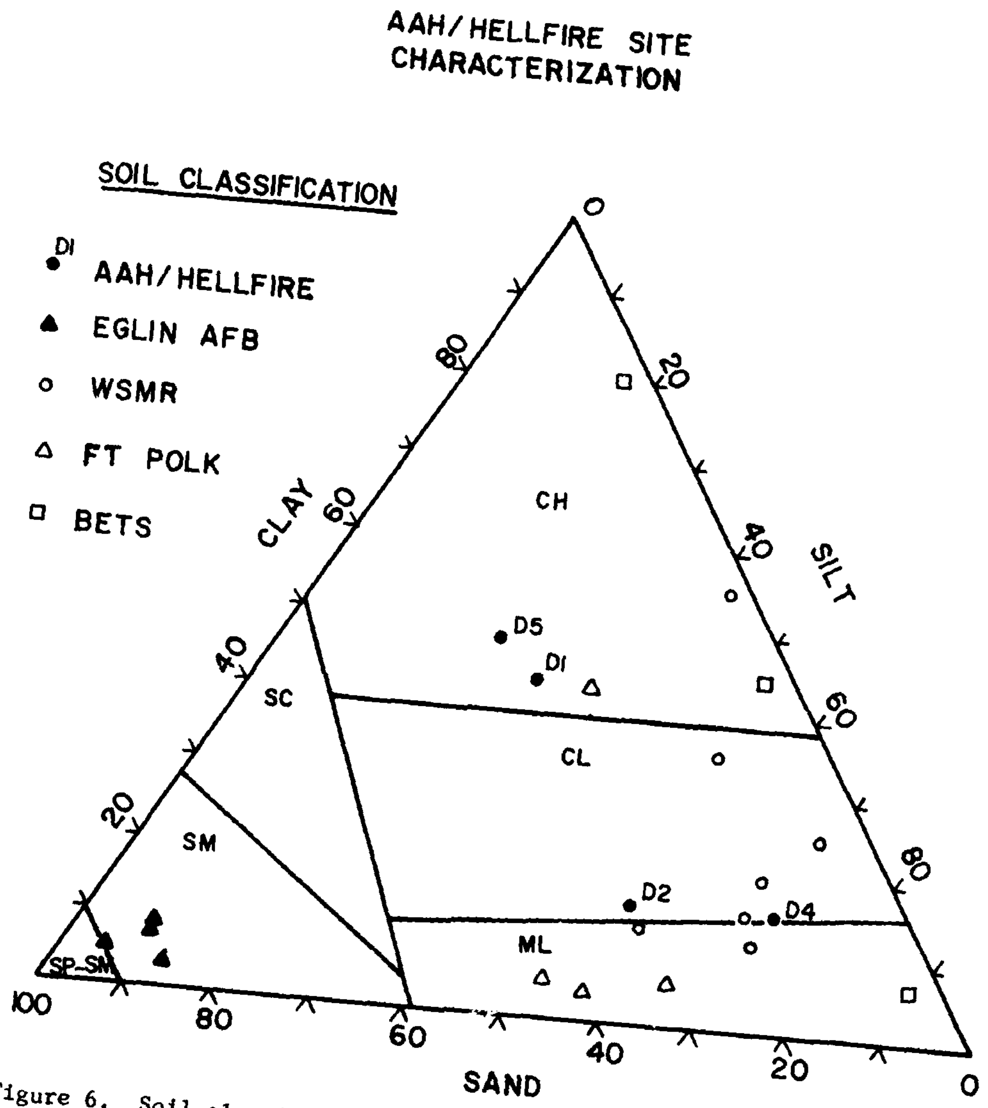



Figure 6. Soil classification chart showing locations of the Redstone samples together with data from other similar tests for comparison (Eglin AFB is the site of the Smoke Week II test (November 1978); WSMR is the site of the DIRT II test (July 1979); Ft. Polk is the site of the DIRT III test (April 1980). The BETS series consists of selected "tailored" soils and is being conducted at WES.)

## APPENDIX A: RELATIONS BETWEEN TERRAIN CONDITIONS AND ATMOSPHERIC LOADING

### Explosive Process

1. In considering the dust-producing effects of explosive munitions, it is necessary to begin with a description of the explosive phenomena as they interact with the soil. The detonation of uncased explosives may be described for this purpose as the instantaneous release of a highly compressed and superheated gas of mass equal to that of the explosive charge.

2. Three important effects are associated with the expansion of this gaseous envelope: the shock front, the kinetic energy transfer from the moving gas to the soil, and later the buoyant rise of the expanded envelope. The first two of these are active in the removal of material to constitute the dust cloud, while the latter is related to the cloud formation.

3. When cased munitions are used, the effects of rupturing the case and the resulting fragments must be included. For a 105-mm projectile, it is estimated that 80 percent of the explosive energy is required to rupture the casing. Since that energy is mostly converted into the kinetic energy of the fragments, a large part will eventually be transferred to the soil to aid in the excavation and dust generation processes. A smaller amount of energy will be available for the shock front and expanding gases, and a different geometry is necessary for describing the source of dust material. These will be considered later.

4. The amount of dust is also affected by placement. Airbursts yield greater amounts of dust with little or no crater depending on height. Subsurface bursts yield larger craters while confining the ejecta to exit angles more nearly normal to the surface. At sufficient depths, dust amounts will be reduced (but not necessarily eliminated) and vertical cloud growth may be restricted. This treatment will be confined to surface bursts.

## Excavation Process

Gas dynamics

5. For an uncased explosive charge located at the surface plane above a homogeneous soil the large-scale movement results from the thrust of the expanding gas envelope acting downward and outward from the point of detonation. Preceding this, the passage of the shock front that forms the leading edge of the envelope may loosen or remold the soil, depending on the soil's composition. The principal source of ejecta, however, is the action of the expanding gases against the soil surface. Material in the surface layer is subjected to extreme pressures and shearing stresses. As the gases expand, the surface is eroded downward and subsurface plastic flow is developed. As the crater grows, eroded material is ejected at its rim in a direction roughly tangent to the wall. This ejected stream forms a conical sheet of increasing diameter and relatively constant angle as the crater expands.

Soil dynamics

6. As kinetic energy is transferred from the expanding gas to the soil, the mass flow increases while velocity decreases. In the final stages of formation, material is slumped over the rim of the crater, a portion forming the lip and the remainder sliding back to partially refill the crater. This material originates at the greatest depth and is the least representative of the dust. Most of the dust material originates on or near the surface and is probably deposited in the initial stages.

7. The crater that is observed is not the true excavation, but the result of backfilling as mentioned and, depending on the soil, a certain amount of compaction. While relating the dimensions of this apparent crater to the actual amount of material removed is probably possible, it is not likely that the result would bear any relation to the amount of dust produced. Some of the rationale for this statement has already been touched upon. For further discussion, it is necessary to describe the cloud formation process.

## Dust Cloud Formation

### Particle sources

8. Dust clouds arising from explosives are observed to consist generally of two parts that result from separate processes. One part is the directly ejected material thrown out by the expanding gases at the rim of the developing crater. This portion is immediately lifted by the buoyancy of the heated gases to form a columnlike feature. The other part is composed of material that is jarred loose from the surrounding surface by the shock wave and carried upward by turbulence. Because of its much lower exit velocity, this material forms a lower feature sometimes referred to as the skirt and may extend outward to many times the crater diameter. Because of the buoyancy of the gas envelope, it rises to a height of perhaps tens of metres. This results in the entrainment of adjacent air, and the material suspended in it. Thus, some of the dust that is raised by impacting ejecta and by the shock wave in the immediate vicinity of the crater will be drawn into the column.

9. Another process that adds to the dust cloud is the ablation of particles from ejecta fragments. The amount contributed by this process is uncertain but is probably less than others. To understand the mechanism, consider the ejecta as it emerges from the surface as massed material. In that condition, it travels as a unit displacing the ambient air. As it moves outward radially, its bulk density diminishes and separation of individual fragments allows ambient air to pass between them, eroding particles from exposed surfaces. This erosion will be much less effective than that of the expanding gas envelope described earlier because the velocity and gas temperature involved here are much lower. Most of the material eroded will be added to the column portion of the cloud.

10. The last dust-producing mechanism is the impact of ejecta fragments. Depending on the soil and surface conditions, this can be significant and it represents an extension of the source area. Most of this dust enters the skirt or portion of the cloud remaining near the ground.

Recall that this is an important mechanism in munitions dust because of the casing fragments.

Controlling factors

11. Based upon estimates of fall velocities, it can be assumed that dust cloud particles are primarily less than 100 μm in diameter and that 10 μm represents a realistic upper limit after one minute or so. If the requirements for separating such particles from the soil mass are considered, it becomes apparent that the process is not a simple one and that they do not merely come apart. All soils except the purest sands exhibit cohesive forces of varying degree that result from electrostatic attraction. The predominant source of that attraction is water which may be a film on particle surfaces (adsorbed) or absorbed into the grains as interstitial water. In either case, it strengthens the band between grains but adsorbed water is by far the most important for our purposes. Closely associated with water in controlling cohesive forces are the shapes of the soil grains. More spherical particles and larger sizes tend to produce less cohesive soils, hence, sands and silt-sands. Nonspherical shapes and smaller sizes tend to increase cohesion as evidenced by clays. The greater surface area leads to a greater capacity to retain absorbed moisture. Thus, the very soil features that would yield a greater volume of dust-sized particles also enhance the factor that binds them.

12. The cohesive properties of the soil can also be strongly affected by the soil's organic content, and the effect of a vegetation cover in suppressing dust is evident. Vegetation can reduce or eliminate the dust that arises on the surrounding surface due to shock and impacts. It can, if dense enough, even prevent dust production from the crater itself. In this case, the root structure and density appear to dominate.

## Soil Properties and Tests

13. The role of the expanding heated gases in establishing shearing stresses in the surface layer has been discussed. The effectiveness

of these stresses in producing comminution of the material will depend on the surface cohesive properties, its mineral and organic content, and its current condition. To characterize the soil material adequately requires a knowledge of both static and dynamic soil properties.

Static properties

14. "Static" refers here to those soil features that are exhibited under a quiescent as opposed to a stressed condition. The most prominent of these properties is moisture, whose relation to cohesion has already been discussed. Another function of moisture is its filling of voids, reducing compressibility and increasing density of the soil. This promotes shock wave propagation and increases excavated mass. However, these effects are probably offset by the increased cohesion.

15. Particle size and composition are important in several ways. The size gradation of the soil provides the primary basis for predicting dust. However, the organization of grains in the soil as well as their composition can be important. A clean sand for example may contain no fines of a diameter less than 10 μm, yet because of the rigidity of its structure and brittleness of the grains, a substantial amount of fines (sand flour) may be produced by the blast pressure. In addition, it is expected that an angular sand would be more effective in this than a round-grained sand.

16. Clays are characterized by elongated and platey grains of very minute size, typically less than 2 μm. The behavior of wet clays has been mentioned. For dry clays, especially heavy clays, the most important property is the condition of the soil. Undisturbed dry clays are often cemented and can be very hard, depending on chemical composition. Initially, they may strongly resist ablation. Repeated stress, however, can pulverize the surface, leading to potentially severe dust conditions. Such stress may result from traffic, repeated bombardment, or natural conditions such as prolonged dry winds accompanied by saltation.

17. Static terrain surface properties hypothesized to be important are soil grain size, mineral content, moisture content, and density (voids ratio) and vegetation type, structure, and vigor.

Dynamic properties

18. These are the properties exhibited by a soil under stressed conditions. Stresses produced by explosives have already been mentioned; the main concern is the extent to which the soil will "come apart" under such stress. Most of the measurements that might reveal this require laboratory apparatus. The properties to be determined are the soil's compaction or compressibility, cohesive strength, and shearing strength.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.


Mason, James B.
Site characterization for AAH/HELLFIRE Battlefield Obscuration Validation Tests at Redstone Arsenal / by James B. Mason, Katherine S. Long (Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. : The Station ; Springfield, Va. : available from NTIS, 1981.
28 p. in various pagings ; ill. ; 27 cm. -- (Miscellaneous paper / U.S. Army Engineer Waterways Experiment Station ; EL-81-10)
Cover Title.
"December 1981."
Final report.
"Prepared for U.S. Army Missile Command under Intra-Army Order no. 80X1."



Mason, James B.
Site characterization of AAH/HELLFIRE ... 1981.
(Card 2)

1. Dust. 2. Military topography. 3. Terrain study (Military science). 4. Weapons systems. I. Long, Katherine S. II. United States. Army Missile Command. III. U.S. Army Engineer Waterways Experiment Station. Environmental Laboratory. IV. Title. V. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; EL-81-10.
TA7.W34m no.EL-81-10

END

DATE
FILMED
2-82

DTIC