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SITE SELECTION INVESTIGATION FOR THE MINE SHAFT SERIES

by

W. J. Farrell
J. R. Curro

October 1968

Sponsored by
Defense Atomic Support Agency

Conducted by
U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

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ABSTRACT

Geological investigations were conducted to locate a site to be used for surface blast experiments in rock for the Mine Shaft Series (formerly Hard Rock).

Geologic field reconnaissance and geophysical evaluations of nine areas in the western United States were conducted in conjunction with office studies of available literature and geologic and topographic maps. Where a site appeared promising, a seismic survey was made to determine compressional wave velocities of the rock. The method used in conducting the seismic investigations is discussed in Appendix A. Time versus distance plots and subsurface profiles from seismic investigations are presented in Appendix B.

Six possible sites in homogeneous quartz monzonite were finally selected at The Three Peaks Range, near Cedar City, Utah, and recommended for more extensive subsurface investigations.
PREFACE

The U. S. Army Corps of Engineers was requested by the Defense Atomic Support Agency to find a site suitable for a series of high-explosive experiments initially designated Operation Hard Rock and finally called the Mine Shaft Series. The task was assigned to the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi.

Geological investigations were conducted by Messrs. R. W. Hunt and W. J. Farrell and SP 4 David P. Ripley under the supervision of Mr. W. B. Steinriede, Jr., Chief, Civil Projects Section, and Dr. R. J. Lutton, Geology Branch, Soils Division.

The seismic surveys were performed by Messrs. J. R. Curro, Jr., Soils Division; Wallace Gay and F. W. Skinner, Jr., Nuclear Weapons Effects Division (NWED); and B. F. Beard, Technical Services Division.

Field investigations were coordinated by Mr. J. M. Pinkston, Jr., Engineering Research Branch, NWED. Mr. L. F. Ingram, Chief, Physical Sciences Branch, NWED, was technical director for Operation Mine Shaft.

The geological portion of this report was prepared by Mr. Farrell under the supervision of Dr. C. R. Kolb, Chief of the Geology Branch. Acknowledgement is made to the following individuals and agencies for
assistance and cooperation during this investigation: Mr. Hal Richey and Dr. Pierre St. Amant, Naval Weapons Center, China Lake, Calif.; LTC R. B. Peterson, USA, Fort Irwin, Calif.; Mr. Paul Knowles of the Atomic Energy Commission, Nevada Operations Office; Mr. Delmar Vail, District Manager, U. S. Bureau of Land Management, Cedar City, Utah; Dr. Lawrence Cooper, College of Southern Utah, Cedar City, Utah; Dr. A. Eardley, University of Utah, Salt Lake City, Utah; and LT H. Pratt and Dr. Richard Zbur, Air Force Weapons Laboratory, Kirtland Air Force Base, N. Mex.

The seismic portion of this report was prepared by Mr. Curro under the supervision of Mr. Z. B. Fry, Chief, Vibratory Loads Section, Soil Dynamics Branch.

Directors of the WES during the preparation of this report were COL John R. Oswalt, Jr., CE, and COL Levi A. Brown, CE. Technical Director was Mr. J. B. Tiffany.
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CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows.

<table>
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<th>Multiply</th>
<th>By</th>
<th>To Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>inches</td>
<td>2.54</td>
<td>centimeters</td>
</tr>
<tr>
<td>feet</td>
<td>0.3048</td>
<td>meters</td>
</tr>
<tr>
<td>miles</td>
<td>1.609344</td>
<td>kilometers</td>
</tr>
<tr>
<td>pounds per square inch</td>
<td>0.070307</td>
<td>kilograms per square centimeter</td>
</tr>
<tr>
<td>feet per second</td>
<td>0.3048</td>
<td>meters per second</td>
</tr>
</tbody>
</table>
CHAPTER 1
INTRODUCTION

1.1 PURPOSE AND SCOPE

The purpose of the project reported herein was to locate suitable sites meeting certain selection criteria for surface blast experiments in rock. This report encompasses all investigations by the U. S. Army Engineer Waterways Experiment Station (WES) leading up to and including those conducted at the selected site through mid-March of 1968.

1.2 SITE SELECTION CRITERIA

The sites were examined on the basis of the following criteria:

(1) a minimum radius of 300 feet;\(^1\) (2) homogeneous, preferably granitic, rock; (3) a rock thickness of 200 feet or greater; (4) a relatively flat surface (no more than 10 feet of relief) with a maximum slope of 10 degrees; (5) exposed rock at or very near the surface, with less than 5 feet of overburden; (6) a field compression wave velocity averaging 12,000 ft/sec or more (later modified to about 10,000); (7) an unconfined compressive strength of 15,000 psi or more; (8) a site on a military base or on similar government land

\(^1\) A table of factors for converting British units of measurement to metric units is presented on page 10.
with support facilities; (9) location in a sparsely populated area, with a buffer zone of 5 miles separating the site from the nearest community; and (10) a site that can be made accessible with only a moderate amount of road construction or improvement.

1.3 METHODS OF INVESTIGATION

A study was made of available literature and various types of geologic and topographic maps to locate granitic rock areas occurring in topographically suitable terrain. Military installations and federally administered lands were given priority in these studies, and a number of prospects were located within such areas in southwestern United States. This region had an added advantage in that climatic conditions were generally more suitable, i.e. less rigorous, than elsewhere in the United States. In addition, the region is characterized by a thin soil cover and sparse population.

Surface reconnaissance was made of nine selected areas (Figure 1.1). An overflight was made in one area to permit a more rapid survey of a particularly inaccessible region of granitic outcrops. Field surveys included determination of slopes, relief, the strike and dip of rock joints, a preliminary assessment of the bedrock lithology and the quality of the rock, and estimates of overburden thickness based on probes with a thin iron rod. Results of these surveys are presented in Chapter 2. Where a site appeared
promising, a seismic survey was made to determine compressional wave velocities of the rock. The method used in conducting the seismic investigations is discussed in Appendix A.
Figure 1.1 Location map of areas selected for field study.
CHAPTER 2

DESCRIPTION OF AREAS EXAMINED

The nine areas selected for study are listed below:

<table>
<thead>
<tr>
<th>Area No.</th>
<th>Location</th>
<th>Ownership</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>China Lake, Calif.</td>
<td>Military reservation and public domain</td>
</tr>
<tr>
<td>2</td>
<td>Fort Irwin, Calif.</td>
<td>Military reservation</td>
</tr>
<tr>
<td>3</td>
<td>Cima Dome, Calif.</td>
<td>Privately leased lands of public domain</td>
</tr>
<tr>
<td>4</td>
<td>Fallon, Nev.</td>
<td>Military reservation</td>
</tr>
<tr>
<td>5</td>
<td>Nevada Test Site, Nev.</td>
<td>Military reservation</td>
</tr>
<tr>
<td>6</td>
<td>Cedar City, Utah</td>
<td>Public domain (Federal) and State land</td>
</tr>
<tr>
<td>7</td>
<td>Beaver, Utah</td>
<td>Public domain</td>
</tr>
<tr>
<td>8</td>
<td>Pedernal Hills, N. Mex.</td>
<td>Privately owned lands</td>
</tr>
<tr>
<td>9</td>
<td>White Sands Missile Range, N. Mex.</td>
<td>Military reservation</td>
</tr>
</tbody>
</table>

Forty-four sites were examined within the nine areas considered. These are identified in Tables 2.1 and 2.2 either by name or an assigned number. General descriptions of conditions at each area and at each site are given in the following sections. Sites not meeting selection criteria are described briefly, and their deficiencies are
given. Sites meeting most of the selection criteria are discussed in some detail.

2.1 CHINA LAKE

For convenience, in this report China Lake is divided into Area 1A and Area 1B. Area 1A (Figure 2.1) consists of the Argus Mountain Range portion of the Naval Weapons Center (NWC), and Area 1B (Figure 2.2) includes the part of the Coso Mountain Range that was investigated.

2.1.1 Area 1A. The Argus Range, a north-south mountain range, extends north from the southern boundary of the NWC for approximately 45 miles. The range is bordered on the southwest by Indian Wells Valley and Coso Mountain Range and on the east by Panamint Valley and Searles Lake. Mesozoic granitic rocks of various types make up the range. The rock varies from granite to diorite (Reference 1) in the area investigated. The oldest exposed rocks within the area are the granitics, and the youngest are the Cenozoic volcanics, which consist of basalts, rhyolites, and andesites (Reference 1). Faults strike northwesterly and are concentrated in the southern half of the range.

China Lake Area 1A is located near Ridgecrest in western California approximately 130 miles northeast of Los Angeles on the border of Kern and Inyo Counties. The area is easily accessible by U. S.
Highway 395 and California State Highway 14. A spur of the Southern Pacific Railroad traverses part of the area. The NWC Headquarters is the only portion of the area with dense population.

Wilson Mesa, the only site investigated in China Lake Area 1A, is located just south of Wilson Canyon in the Argus Mountain Range, approximately 15 miles northeast of the NWC Headquarters (Figure 2.1). It is accessible by way of the surfaced G-2 Tower Road north to the Wilson Canyon Road, a rough, mountainous, dirt road that leads to the site. With the exception of several abandoned mines in the surrounding vicinity, the buffer zone for Wilson Mesa exceeds a radius of 5 miles.

Wilson Mesa Site is located in granitic rock that varies locally from granite to quartz diorite (Reference 2).

Structure at Wilson Mesa includes one major and several minor faults. The major fault, or the Wilson Fault, parallels the north side of Wilson Canyon in a northwesterly direction. The surface exposure is represented by a zone of crushed rock 300 feet in width (Reference 2). All minor faults but one strike perpendicular to the major fault. Jointing is apparent in granite ridges flanking the site on the west. Spacing between joints ranges from about 2 to 5 feet, with local zones less than 2 feet. Joints appear randomly oriented and variably weathered. A more detailed observation within the site indicated a complex system of jointing, with measured
strikes of N30W, N40E, and N87W. The dips appear to be nearly vertical. Joints are mostly tight and are often sealed with siliceous mineralization.

Wilson Mesa Site consists of rock intermittently covered with thin overburden across an area approximately 500 feet wide and 700 feet long. The slope ranges between 2 and 5 degrees. Observed relief is very slight, not exceeding 5 feet locally. Surface weathering of rock is slight. In one part of the site, an exposure of rock at a depth of 1 foot was observed to be fresh with very slight alteration. A partial alluvial cover, very shallow and intermittent with an average depth of 3 feet (measured with steel rod), thickens toward the base of the slope.

Nine seismic traverses were run along three major lines oriented in north-south, east-west, and northwest-southeast directions (Figure 2.3). Compression wave velocities ranged from 500 to 1,000 ft/sec in overburden that varied up to 6 feet in thickness. Local layers of what was interpreted as weathered or nonhomogeneous material were encountered at the extreme ends of Traverses S-1/S-2 and S-3/S-4 to depths of 33 feet, with velocities ranging from 1,800 to 5,000 ft/sec. Competent rock with velocities ranging from 10,000 to 11,000 ft/sec was encountered to an indeterminate depth. See Appendix B, Figures B.1 through B.7, for details at this site.

On the basis of geologic criteria, Wilson Mesa was considered
favorable for further evaluation; however, because the area of shallow rock was not large enough for more than one experiment and because proposed scheduling of Operation Mine Shaft would conflict with activities of the NWC, this area was considered unacceptable. In addition, marginally low velocities were obtained at the extreme ends of two of the seismic traverses.

2.1.2 Area 1B. The Coso Mountains in this area consist primarily of Mesozoic granitic rocks that vary from granite to diorite. The granitic rocks are partially overlain by Cenozoic basalt, rhyolite, andesite, and pyroclastics (Reference 3). The mountains situated within the eastern border of the area reach a maximum elevation of approximately 6,300 feet. This portion of China Lake is separated from a mountain ridge to the west by a series of three relatively flat, northwest trending, depositional areas named Cactus Flat, Upper Cactus Flat, and McCloud Flat.

Area 1B (Figure 2.2), situated in the western part of the Coso Mountain Range, extends 12 miles northwest from Coso Hot Springs. Accessible dirt roads traverse the area. The southern area can be reached by way of a dirt road from U. S. Highway 395 at Coso Junction. This road is maintained by Inyo County to the NWC boundary. The northern part of the area can be reached by a dirt road that intersects U. S. Highway 395 approximately 2 miles northeast of Loco Station. Sites 1 through 6 are located within the NWC boundary;
Site 7 is on the boundary, and Sites 8 through 10 are located on lands of public domain.

Ten sites were investigated in and around the flats comprising China Lake Area 1B (Tables 2.1 and 2.2), but none met the geologic criteria for the project site. Sites 1, 2, 3, and 4 consist of granitic rock generally covered by a variable thickness of overburden exceeding 5 feet. Surface slopes average 4 degrees. There are few rock exposures of sufficient size to meet the minimum requirements for Operation Mine Shaft. Site 5, a granitic rock slope consisting of small rock exposures, has low relief, but is mostly covered with granitic alluvium that probing with an iron rod indicated to be in excess of 5 feet thick. There is no area of exposed or shallowly covered rock that would be of sufficient size. Site 6 is a granite slope with an inclination varying from 3 to 8 degrees. Granite exposures on the slope, ranging from 20 to 50 feet in diameter, are separated by areas of thick overburden. Site 7, the most promising of the sites investigated, consists of a broad granitic slope with inclinations ranging between 2 and 5 degrees. The slope consists of rock exposures varying from 20 to 100 feet in diameter. The exposures are separated by areas of overburden varying up to 50 feet in width. Low compression wave velocities were recorded at the site. Overburden and deeply weathered or nonhomogeneous material were encountered to a depth exceeding 200 feet. See Appendix B,
Figures B.8 through B.11, for details of the seismic survey at this site. The site was eliminated because of the low compression wave velocities and the highly variable zone of weathering. Site 8 consists of an alluvially covered slope with occasional outcrops of granite. Probes with an iron rod indicated depths of alluvium in excess of 5 feet. Slopes average about 4 degrees. Site 9 consists of boulder-strewn slopes of granitic and volcanic rock that encircle the McCloud Flat area. Slopes are on the order of 2 degrees and are covered by a variable thickness of alluvium. Site 10 consists of granitic rock slopes flanking Cactus Flat. The granitic rock is heavily intruded by volcanic rock. Slopes in alluvially covered areas average 2 degrees. Thickness of alluvium is in excess of 5 feet in most of the areas probed.

In summary, China Lake Area 1B consists of granite or granite and volcanic rock covered by a variable thickness of alluvium. The most promising of the 10 sites investigated in the area, Site 7, was surveyed seismically. Low velocities were encountered to excessive depths.

2.2 FORT IRWIN AREA

Fort Irwin, Area 2 (Figure 2.4), is located 35 miles northeast of Barstow, Calif., adjacent to Death Valley. The only access to the fort is by way of the Fort Irwin-Barstow Road, which is accessible
from U. S. Highway 66, Interstate Highway 15, and California State Highway 58. Within the boundaries of the fort, surfaced and unsurfaced roads traverse most of the area. There is no habitation except in the headquarters area. The National Aeronautics and Space Administration Goldstone satellite tracking stations limit the use of the western part of the fort.

Reconnaissance of the Fort Irwin area included an overflight of the mountains within the boundaries of the fort. Followup ground studies were made of possible sites observed during the flight.

The boundaries of Fort Irwin encompass three granitic bodies: Granite Mountain on the north, Tiefort Mountain on the east, and the eastern half of the Paradise Range located in the southwest corner of the fort.

Granite Mountain, Tiefort Mountain, and Paradise Range all consist of granitic rocks of Mesozoic age (Reference 1) and comprise a large part of the area. Mountains and ridges of Tertiary volcanic material are mainly concentrated in the western part of the area between Paradise Range and Granite Mountain. Covering of the granitic material by the volcanics is relatively slight in the mountains. The local occurrence of small hypabyssal Quaternary volcanic rocks near Goldstone represents the youngest rock in the area, while pre-Cretaceous metamorphic rocks near Coyote Lake fault in the southern part of the area represent the oldest rocks (Reference 1).
Granite Mountain, which is approximately 26 miles in length and 5 miles in maximum width, is rugged with highly dissected, steep slopes along the mountain and on the flanks. The maximum elevation is approximately 5,300 feet, and the average relief is approximately 1,200 feet (Reference 1). Local flat areas, which are developed on the mountain and along the outer margins, were the primary areas of investigation.

Tiefort Mountain covers a much smaller area, consisting of finely and coarsely crystalline granitic material. The maximum elevation is 5,043 feet. The maximum relief is approximately 2,000 feet. The slopes of the mountains are steep, highly weathered, and dissected. An overflight and a brief ground reconnaissance eliminated Tiefort Mountain as an area of search.

Paradise Range is a relatively broad area of low elevation and gentle relief. The maximum elevation is approximately 3,900 feet, and the maximum relief is about 1,000 feet. The granitic rock is intricately eroded with steep, heavily dissected slopes on the south side of the range. To the north, granitic terraces, or steps, were considered the most favorable for site selection investigations within the range.

Faulting in the area is principally oriented in east-west and

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1 All elevations are in feet referred to mean sea level.
southeast-northwest directions. Northeast of the borders of Area 2 lies a large fault complex where many regional faults converge. The Leach Lake fault, north of Area 2, extends in an east-west direction for a distance of more than 30 miles.

The Coyote Lake fault trends south of Paradise Range near Site 14 (Reference 1). One east-west zone of faulting is known to occur near Site 6 and continues west across Granite Mountain into the volcanic area south of the mountain. A minor east-west fault has been mapped in the vicinity of Site 8.

Fourteen sites were selected for ground reconnaissance. Observations at these sites are summarized below and in Tables 2.1 and 2.2. Of these, only Sites 1, 9, 10, 11, 13, and 14 were considered good enough for further investigation. Sites 2, 3, 4, 6, 7, and 8 were all characterized by a thick alluvial overburden and only small areas of rock outcrop. Sites 5 and 12 contained more rock at the surface but were badly dissected and generally too rugged to meet the criteria for site selection.

Site 1 is a granitic slope partially covered with alluvium and granitic rock boulders ranging up to 10 feet in diameter. Dissection has resulted in relief of 4 to 10 feet. A seismic survey at the site indicated low compression wave velocities. See Appendix B, Figures B.12 and B.13, for details at this site.

Site 9 is a relatively flat area with fairly gentle slopes and
with considerable rock exposed. However, the area is badly dissected and relief reaches 10 feet or more. Overburden between surface rock exposures may also be excessive for the project. Moreover, accessibility is relatively poor, requiring construction of about 1\frac{1}{4} miles of access road with the last mile through rugged mountain terrain.

Site 10 is an area of granitic rock with fairly rugged topography. Relief in the area ranges up to 12 feet, and rock excavation would be required to prepare the site for use. Access to the location would require blading and maintaining about 13 miles of road with approximately 1 mile of mountainous road.

Site 11, located approximately 25 miles northwest of the headquarters area, is the most suitable of those examined at Fort Irwin. The site is accessible by way of a surfaced road to Goldstone, thence north about 12 miles by dirt roads and tank tracks across an impact area. Light construction across the impact area and heavier construction through about 1 mile of rugged mountain terrain would be necessary for final access to the site. The buffer zone is considered sufficient. About 6 miles separate the site from the northernmost Goldstone tracking station.

Site 11 exhibits a relatively flat surface partially encircled by ridges and knobs and consists of finely to coarsely crystalline granite. A complex fault zone has been mapped approximately 4 miles north of Site 11. This consists of an area of converging faults.
including the northeast-southwest trending Garlock fault, the east-west trending Leach Lake fault, and many other smaller faults.

Jointing in the rock at Site 11 appears to be relatively uniform. The predominant joint system appears to strike northeast-southwest. One measured system of joints strikes N70E with near vertical dips. Most joints appeared to be tight. A few scattered mineralized joints varying in widths up to 1 inch were noted. Spacing of joints generally exceeds 5 feet, with local zones of less than 2 feet.

The usable surface of Site 11 covers an area approximately 600 feet in diameter. The inclination of the slope is slight, varying from 2 to 4 degrees maximum. The slope is relatively smooth, with variations in relief from 0 to 3 feet.

The exposed surface rock appears to be slightly weathered. Rock beneath the overburden is more deeply weathered. The surface typically consists of exposed rock with a thin (2 to 6 inches) veneer of overburden covering the depressions. Downslope the overburden gradually increases. The average overburden within the site area is less than 1 foot.

Two north-south seismic traverses were run at Site 11. The results indicate an average of 1 foot of overburden and 6 to 14 feet of nonhomogeneous or weathered rock overlying bedrock of an indeterminate depth, with compression wave velocities of 10,000 ft/sec. See Appendix B, Figures B.14 and B.15, for details at this site.

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Site 13 is situated on one of a series of rock terraces. The surface is flat to gently sloping. Site 13 meets all of the geologic site selection criteria except the regional seismic velocities. Maximum compression wave velocities of 8,750 ft/sec approached minimum requirements but were considered insufficient. See Appendix B, Figures B.16 and B.17, for details at this site. Site 13 is less than 1 mile from the Fort Irwin-Barstow Road and approximately 7 miles from the populated area of the fort. Because a Goldstone satellite tracking station is located within 5 miles of the site, the buffer zone was considered inadequate by fort officials.

Site 14 is on a granitic rock slope with inclinations varying between 2 and 5 degrees. Intrusions by several dikes probably decrease the rock homogeneity of the location. The area is approximately 6 miles from the headquarters area of Fort Irwin. Maximum compression wave velocities of 5,000 ft/sec make Site 14 unsuitable for the project. See Appendix B, Figures B.18 and B.19, for details at this site.

In summary, most of the sites visited in the Fort Irwin area were either covered with excessive overburden or were in terrain that is too rugged. Site 1 met most criteria, but a seismic survey indicated the rock had very low compression wave velocities. Sites 9, 10, and 11 are relatively inaccessible and would require the building of a fairly extensive access road. Site 11, considered the best of
these three sites based on simple field observation, was tested seis-
mically. Compression wave velocities of 10,000 ft/sec, the highest
recorded in the area, were obtained beneath a surficial weathered
zone of 6 to 14 feet. Accessibility is no problem at Sites 13 and
14. However, both are so close to the Fort Irwin Headquarters or to
a tracking station that the proper buffer zone may not be available.
Moreover, rock at Site 14 proved to have undesirably low compression
wave velocities (5,000 ft/sec). Site 13 more closely fits the de-
sired seismic criterion with velocities of 8,750 ft/sec.

2.3 CIMA DOME AREA

Cima Dome, Area 3, is located in San Bernardino County, Calif.,
about 80 miles southwest of Las Vegas, Nev. The broad dome is ap-
proximately 6 miles northwest of the small town of Cima, Calif. (Fig-
ure 2.5). The area is accessible from U. S. Highways 91 and 466,
and California State Highway 31 by way of the surfaced Valley Wells-
Cima Road. Several dirt roads traverse the dome area, and the Union
Pacific Railroad runs through Cima. The land is administered by the
Bureau of Land Management and is leased by several ranchers. Ranch
houses are sparsely scattered throughout the area.

Because Cima Dome is located about 100 miles from the nearest
military reservation and because of the land ownership situation,
the area was not considered favorable for this project. Consequently,
only a hasty geological reconnaissance of the northeast slope of the dome was made. It is possible that other sites more favorable than the one selected for seismic evaluation are available on other portions of the large dome.

Cima Dome, a broad, smooth-surfaced dome approximately 10 miles in diameter, rises about 1,500 feet above the town of Cima to an elevation of approximately 5,740 feet. Teutonia Peak, situated on the northeast part of the dome near the crest, rises a few hundred feet above the dome (Reference 4). Kessler Peak, situated in the southern part of the north-northeast trending Ivanpah Mountain, lies about 2 miles northeast of Teutonia Peak and rises to an elevation of approximately 6,160 feet (Reference 4). Cima Dome, Teutonia Peak, and Kessler Peak are made up of Teutonia quartz monzonite of Cretaceous-Tertiary age. Three varieties of dikes intrude the quartz monzonite: aplite, monzonite porphyry, and hornblende porphyry. A few pegmatite dikes are also recorded. Cima Dome is thought to have been formed when the Ivanpah upland was developed and is only slightly affected by erosion (Reference 5).

Major nearby faulting consists of the Clark Mountain normal fault and the Mesquite and Mescal thrust faults, located within 8 miles north of the dome and trending northwest-southeast, and the Cedar Canyon fault, a southwest-northeast trending normal fault located about 6 miles southeast of the southeast rim of the dome.
Site 1 (Figure 2.5) is located adjacent to the Valley Wells-Cima Road and is situated on the relatively smooth northeast slopes of the dome. Ranch buildings and a church are within 2 miles of the site. The slopes at the site consist of broad, relatively flat outcrops of quartz monzonite, ranging in diameter from 25 to 325 feet.

Jointing appears to be inconsistent. Spacing of major joints varies from about 20 to over 100 feet. Minor joint spacing ranges from about 6 inches to 5 feet. Measured strikes of joints were N30W and N50W. Several granitic dikes dissect the monzonite within the vicinity. Measured strikes of three dikes were N-S, N30W, and N85E. One such dike striking northeast was diagonally cut by a small fault or fracture. Displacement of 3 feet was noted. The dips of the dikes appeared to be vertical.

The outcrop selected for seismic evaluations is approximately 200 feet wide by 200 feet long, which is fairly representative of the larger outcrops in this area of study. The slope inclination varies between 2 and 5 degrees and is considered relatively slight. The general relief of the site is less than 6 feet.

Surface weathering of the exposed rock appears slight. Chemical weathering beneath the overburden, which lies between the rock outcrops, appears to vary considerably in depth.

Two north-south seismic traverses were run adjacent to a quartz monzonite rock outcrop. The results showed 1 foot of overburden and
up to 20 feet of weathered or nonhomogeneous material overlying a hard, dense material with compression wave velocities ranging from 11,500 to 16,500 ft/sec to an indeterminate depth. See Appendix B, Figures B.20 and B.21, for details at this site.

It is possible that further reconnaissance could locate a site in the Cima Dome area where surficial weathering would be less pronounced and where a 5-mile buffer zone is available. However, as previously mentioned, the problems of land ownership and support would remain.

2.4 FALLON AREA

Area 4 includes the Sand Springs Mountain Range and Fairview Mountain (Figure 2.6) about 30 and 40 miles, respectively, southeast of Fallon, a small town in central Nevada (Reference 6). U. S. Highway 50 crosses the low pass that divides the Sand Springs Range from the Stillwater Range to the north. Access to Area 4 from Highway 50 is by way of a paved road leading south on the east side of the range and thence west to the Project Shoal Site (Reference 7), or by the dirt road along the west side of the range.

The buffer zone is adequate in size, with the nearest inhabitants a few miles west at a cattle camp and at Frenchman about 7 miles to the northeast.

The Sand Springs Range is made up of a Cretaceous granitic
intrusive body bordered on both the north and south by metamorphic rocks probably of Mesozoic age. The granitic rock ranges from granite to granodiorite. Tertiary and Quaternary volcanic rocks, consisting of basalt, rhyolite, and andesite, overlie the metamorphic rocks at both ends of the range. Locally, these volcanics overlie both the granitic body and the metamorphic rocks.

Although Sand Springs Range is a north trending fault block, the main trend of the faulting is northeast and northwest. The general strike of the fault is N50W and N30E. There are a few wide individual faults, but most of the faults are narrow.

The major joint system parallels the northwest fault trend, and was probably formed simultaneously by the same forces (Reference 8). Aplitic-pegmatite, andesite, and rhyolite dikes ranging in size from 1 inch to 50 feet in thickness dissect the granitic rock. It appears that most of the dikes have intruded the faults and compensating joints. Commonly, the dikes are resistant to weathering and stand out as ridges above the granite. The slopes and shallow valleys of the range are covered by a mantle of grus and silt that probably averages about 2 to 3 feet in thickness.

Reconnaissance of Area 4 resulted in the investigation of five sites. Because of the rugged topography in the southern part of the range, the site reconnaissance was conducted only in the northern part in the plateau area.
Site 1 consists of an outcrop of granite located on a gently inclined silt-covered slope. Silt also covers the adjoining slope and valley. The granite shows convex, spheroidal weathering. Narrow dissections are filled with silt and granite grus. The granite is highly jointed, with both vertical and horizontal joint planes.

Two northwest-southeast seismic traverses were run at Site 1, the results of which indicate 2 feet of overburden, a layer of 28 to 54 feet of nonhomogeneous or weathered rock with velocities of 2,800 to 3,000 ft/sec, and material with a maximum velocity of 5,000 ft/sec extending below this layer. See Appendix B, Figures B.22 and B.23, for details at this site.

On the basis of the low compression wave velocities encountered, Site 1 is not considered suitable for this project.

Site 2 is located in a relatively gently east dipping valley bounded on the north and south by low rolling hills. The valley is one of a series of small valleys separated by low rolling hills along Gote Flat. The surface of most of the valleys and hills is covered with windblown silt. Only one outcrop of granitic rock was found within this site. The granite is weathered smooth. The joints appear tight. Because of the apparent similarity of exposed rock with the low velocity rock at Site 1, no further exploration was considered warranted. Moreover, access to the site would require construction of a 2-mile-long road through a rugged area.
Site 3 is located on a bare, massive, porphyritic granite slope. The jointing in the rock is moderate, and appears to be tight. The slope inclines to the north at 8 degrees. The relief is relatively rugged, but the overall relief does not exceed 10 feet.

Two northeast-southwest traverses were run with results indicating 1 foot of overburden, 25 to 39 feet of nonhomogeneous or weathered material, and maximum velocities of 8,000 to 9,400 ft/sec below this weathered zone to indeterminate depths. See Appendix B, Figures B.24 and B.25, for details at this site. Because of the deep weathered zone indicated by the seismic velocities, Site 3 was not considered suitable for this project. Access to the site would also have been difficult, particularly for the last mile into the site.

Site 4 is a granitic site selected for seismic evaluation because of its proximity to the Shoal Command Post. The possibility of utilizing this site in the same capacity for this project warranted a seismic investigation. Two northeast-southwest traverses were run, with results indicating 3 feet of overburden. The maximum velocities of 3,500 to 4,000 ft/sec from 3 feet to indeterminate depths did not meet seismic criteria for site selection. See Appendix B, Figures B.26 and B.27, for details at this site.

Site 5 is located on the northeast slopes of Fairview Mountain, about 8 miles east of the Sand Springs Range. Available geologic
maps and literature did not cover this area. A brief reconnaissance of the site disclosed that very rugged topography and highly jointed metamorphic and volcanic rocks characterized the mountain mass. No site was found meeting the selection criteria.

To summarize, the four sites in Sand Springs Range were eliminated from further consideration because of low seismic velocities and/or inaccessibility. Site 5, in Fairview Mountain, was eliminated because of rugged topography, heterogeneous rock types, and inaccessibility.

2.5 NEVADA TEST SITE AREA

Nevada Test Site, Area 5 (Figure 2.7), includes three sites located west, northwest, and north of Yucca Flat, in the northwest part of the Nevada Proving Ground.

Site 1, Cat Canyon, consists of three relatively small exposures of granite porphyry situated on the slopes of Cat Canyon, an area accessible only by 4-wheel-drive vehicle. A reconnaissance of the site revealed rugged topography with relief averaging 15 feet. No area of sufficient size meeting site criteria was found.

Site 2, Rainier Mesa, is located northwest of Yucca Flat. Rainier Mesa has a relatively flat surface about 3 miles in length and 2 miles in width. The mesa rises about 3,500 feet above Yucca Flat to an elevation of 7,679 feet.
The mesa consists of a welded tuff cap approximately 200 feet thick, below which lie thick beds of friable and bedded tuff (Reference 9). Previous seismic reconnaissance on Rainier Mesa showed velocities on the order of 3,000 ft/sec throughout the welded tuff, discouraging further investigation of this site.

Site 3, Climax Stock, is located in the northern end of Yucca Flat. The site is accessible from Yucca Flat by the Climax Mine Road. Climax Stock, trending north-south, covers an area about 1-1/2 miles long and 1 mile wide. The maximum elevation of about 6,100 feet is on the northeast edge of the stock, and the minimum elevation of about 4,950 feet occurs along the southern border.

The Climax Stock is a Tertiary granitic intrusive body composed largely of granodiorite and quartz monzonite (Reference 10). The stock is bordered on the west by Paleozoic metamorphic rocks and on the north by tuffaceous material of the Oak Springs formation (Reference 11).

A reconnaissance of the site, a 300- by 500-foot exposure, disclosed deep weathering of the granitic material. Available vertical exposures revealed weathered material to depths in excess of 8 feet. The limited size and deep weathering of the site eliminated the area from further consideration.
2.6 CEDAR CITY AREA

Cedar City, Utah, Area 6 (Figure 2.8), is located approximately 190 miles northeast of Las Vegas, Nev. U. S. Highway 91 and Interstate 15, which pass through Cedar City, connect Las Vegas with Salt Lake City, Utah, about 230 miles north. The Union Pacific Railroad traverses the area, and serves the iron ore mining area. Cedar City is the largest town in the area with a population of about 7,500.

Consideration was given to several localities in the Cedar City area, among which are the three small prominences of iron-rich quartz monzonite (Reference 12) known as Iron Mountain, Granite Mountain, and The Three Peaks. These three oval-shaped mountains, ranging from 3 to 5 miles in diameter, form a northeast alignment for a distance of about 20 miles. Maximum elevations are 7,831 feet at Iron Mountain, 6,725 feet at Granite Mountain, and 6,416 feet at The Three Peaks. Local relief varies from about 1,700 feet at Iron Mountain to about 1,000 feet at The Three Peaks. Iron Mountain and Granite Mountain were eliminated as potential sites because of the extensive pit mining operations being carried on in both areas. The mines nearest The Three Peaks are operated by Utah Construction and Mining Company (UCMC). Stoddard Mountain, which is composed of quartz monzonite, was also considered for investigation.

The Three Peaks and other quartz monzonite intrusive bodies are considered to be laccoliths. The intrusive bodies are encircled or
partially encircled by sedimentary rocks of Jurassic, Cretaceous, and Tertiary age. The oldest exposed sedimentary rock is the Homestake formation, a massive marine limestone of Jurassic age (References 12, 13, and 14). Where exposed, the limestone is found adjacent to the intrusive body. Iron ore is presently mined from these intrusive areas. Although small amounts of ore are mined from veins within the intrusive mass, the bulk of the ore is taken from replacement ore bodies within the limestone.

Six possible sites were selected on The Three Peaks monzonite. All sites are located on Federal lands administered by the Bureau of Land Management, except Site 4, which is located on State lands. All sites are located within 10 miles of Cedar City.

Accessibility to all sites is very good by dirt roads that enter The Three Peaks from the east and south. These dirt roads lead to Cedar City by way of State Highways 254 and 19.

The nearest house is about 3 miles southeast of Site 2, and a livestock well is located 2-1/2 miles from Site 2. At present, the only mining operation in The Three Peaks is a small open pit owned by UCMC located about 1/2 mile southwest of Site 4. According to a company official, the pit could be shut down for a short time should it be necessary. The main office and operation facilities of UCMC, which include a railroad yard, are located in a pass along State Highway 253, about 1-1/2 miles southwest of Site 5. Site 6 has the largest
buffer zone. In descending order of the size of their buffer zones, the sites are rated as follows: 6, 4, 3, 1, 2, and 5.

Sites 1, 2, 3, and 5 are situated on a very gentle slope inclined to the east and surrounded by hills 400 to 500 feet high. Sites 4 and 6 are located on open flat slopes that dip gently to the northeast. Jointing on all exposed rock is moderate, and all joints appear to be tight at all sites. At least two prominent sets of joints with similar orientation were observed at each site. One set strikes north-northeast, while the other strikes about east-west and tends to terminate against the north-northeast trending joints. Minor disoriented joints were also observed. Joint spacing varies from 1 to 15 feet, with an average of 4 feet at each site. The main joint set, or the north-northeast trending joints, appears to parallel the strike of the predominant regional faults in the Cedar City area.

Generally, all sites reveal very little weathering. Thickness and dimensions of overburden vary at each site but overall it appears to be relatively thin.

Sites 1, 2, 4, and 6 appear to be of sufficient size, but vary in the extent and size of bare rock exposures. Sites 3 and 5 are marginal in size. Seismic velocities of Sites 1 and 2 have been evaluated and are discussed in subsequent paragraphs. Seismic velocity surveys are planned for Sites 3 through 6 and will be submitted in a later report.
Site 1 had the smallest amount of rock exposed, but the alluvial cover appeared slight. Four seismic traverses were run at this site. The test layout for these traverses is shown in Figure 2.9. The time-distance plots for Traverses S-1/S-2 and S-3/S-4 are shown in Appendix B, Figures B.28 and B.29, respectively. The subsurface profiles for the traverses are shown in Appendix B, Figures B.30 and B.31. The near-surface material ranged in velocity from 400 to 625 ft/sec and extended to a maximum depth of 2 feet. Below the near-surface zone, materials with velocities ranging from 1,700 to 5,000 ft/sec were encountered. As shown in Figure B.31, these velocities reached depths of 73 and 47 feet at the extremities of Traverses S-3/S-4. Elsewhere on the same traverse, the thickness of the low velocity zone was considerably less, agreeing more closely with a similar zone encountered on Traverses S-1/S-2 (Figure B.30). This suggests that an elongate area with its long axis in a north-south direction has velocities of 9,000 to 12,500 ft/sec from an average of about 12 feet below the surface to an indeterminate depth.

Site 2 consists of a massive rock exposure about 200 feet wide and 600 feet long. The slope varies from 2 to 3 degrees to the east. The maximum relief of the entire surface is about 3 feet. The test layout for the seismic traverses is shown in Figure 2.10. The time-distance plots for Traverses S-1/S-2, S-3/S-4, and S-5/S-6 are shown in Appendix B, Figures B.32, B.33, and B.34, respectively.
subsurface profiles for the six traverses are shown in Appendix B, Figure B.35. The near-surface overburden at this site ranged from 500 to 625 ft/sec in velocity to a maximum depth of 2 feet. Velocities of 1,000 and 5,000 ft/sec were detected below the near-surface overburden and extended to competent rock. The thickness of the zone within which these velocities occurred averaged about 2 feet, but reached a maximum of 41 feet in the extreme southeast corner of the area. Rock with velocities ranging from 9,500 to 12,000 ft/sec was detected at the surface in many instances and extended to an indeterminate depth.

Site 3 consists of a fairly level surface covered with alluvium up to 3 feet thick with a few small flat rock exposures scattered across the surface. The usable area does not appear to be large enough to meet project needs.

Site 4 centers on a single massive rock exposure with dimensions of 300 by 150 feet. The overall surface is smooth and rounded, but is pitted with numerous potholes, which are intermittently filled with rainwater. Alluvium up to 3 feet thick covers a shallow rock area estimated to be 600 by 1,000 feet in size.

Site 5 consists of a large area, with slight easterly inclinations of 3 degrees and a relief of about 2 feet. The surface consists of a thin cover of silt through which numerous flat bare rock
exposures are revealed, indicating the possibility of massive rock beneath.

Site 6 consists of large, smoothly rounded exposures of moderately hard rock separated by narrow troughs and depressions filled with a thin veneer of sandy silt. The area is about 1,000 feet long and 800 feet wide. The slope is gentle, but the relief is relatively rugged, ranging up to 4 feet. Numerous potholes and depressions are intermittently filled with rainwater.

In summary, of the two sites (1 and 2) where seismic surveys were made at Cedar City, Site 1 was not considered suitable for this project because of deep, low velocity material encountered. Also, surface exposures of rock were generally only moderately hard. Site 2, on the other hand, exposed hard, competent rock at the surface, and the seismic survey encountered high velocity rock (9,500 to 12,000 ft/sec) generally from the surface to an indeterminate depth. Only in the extreme southeast corner of the site did a low velocity material extend to a depth of 43 feet. Sites 4, 5, and 6 met all geologic site selection criteria and were recommended for seismic evaluation. All sites at Cedar City were characterized by a limited buffer zone. In order of desirability from the standpoint of this criterion, the sites are rated 6, 4, 3, 1, 2, and 5.

Site 7, Stoddard Mountain, is located about 20 miles southwest of Cedar City, about 2 miles south of Iron Mountain. From State
Highway 56, which traverses the area about 1-1/2 miles north of the mountain, access roads are in bad condition making entry to the site very difficult. Lack of mining operations gives the site a good buffer zone.

Stoddard Mountain, roughly a circular body of quartz monzonite porphyry, measures approximately 4 miles in diameter. Stoddard Mountain differs from the other intrusive bodies, such as Iron Mountain and The Three Peaks, by the absence of iron ore deposits (Reference 13). The brief reconnaissance made at this area revealed very rugged topography, with no site meeting the established criteria.

2.7 BEAVER AREA

Mineral Mountain, Area 7, is located in Beaver County, Utah, approximately 55 miles north of Cedar City and 15 miles west of Beaver, a town of about 4,400 population (Figure 2.11). The Pass Road, which crosses the southern part of the mountain near the southern limit of the granitic body, is passable. However, mountain roads leading from the Pass Road toward possible sites within the mountain mass are impassable.

Mineral Mountain is a north-south trending granitic mountain that rises to a maximum elevation of 9,598 feet at Granite Peak, with a relief of about 4,600 feet above the town of Milford, located
in the Escalante Valley to the west.

A brief reconnaissance of the area revealed rugged topography and very poor accessibility. Bad roads prevented further investigation. Further study of Mineral Mountain was discontinued in favor of other areas scheduled for investigation.

2.8 PEDERNAL HILLS AREA

Pedernal Hills, Area 8, is located about 65 miles southeast of Albuquerque, N. Mex. (Figure 2.12). The area parallels U. S. Highway 285, which connects with U. S. Highway 66 at Clines Corner and U. S. Highway 60 at Encino. The selected area extends from the town of Pedernal, which lies 10 miles west of Encino, north a distance of about 30 miles. The maximum width is about 7 miles from east to west. A pipeline crosses the area within 1/2 mile of the site and may pose a limitation on the buffer zone. Accessibility is good, with dirt roads traversing the area from U. S. Highways 60 and 285. The land in this area is privately owned.

The Pedernal Hills are a series of low, gently rolling hills, covered mostly with silt varying from 2 to 10 feet in thickness, which form a north trending ridge. Elevations of the area range from about 6,400 feet in the south to about 7,580 feet, the highest peak at the north. The area is complex in structure, consisting of undifferentiated sedimentary, metamorphic, and igneous rocks of
Precambrian age (Reference 15). A reconnaissance of the southern part of the area confirmed this complexity. Various types of granitic and metamorphic rocks were observed to have no relation to the topography of the area. A large area of schistose material with nearly vertical bedding planes was noted about 2 miles north of U. S. Highway 60.

On the basis of results of a seismic survey made by the U. S. Air Force previously on a granitic outcrop near U. S. Highway 60, a site about 1-1/2 miles north of Highway 60 was selected for seismic evaluation. Two traverses were run at this site in a N70E to S70W direction. The time-versus-distance plot and the subsurface profile for the two traverses are shown in Figures B.36 and B.37, respectively. The near-surface material exhibited a velocity of 500 ft/sec for a depth of 1 foot. This was underlain by a 2,500-ft/sec velocity layer that was 3 feet thick. A 5,000-ft/sec velocity zone was detected below the second layer and varied in thickness from 27 to 31 feet. Below 35 feet, an 8,300- to 9,000-ft/sec zone was encountered extending to an indeterminate depth.

Because of the complexity of the structure of the exposed rock and the results of seismic investigation, Area 8 is not considered suitable for this project. A limited buffer zone and private ownership of the land also affect its acceptability.
2.9 WHITE SANDS MISSILE RANGE AREA

The Mockingbird Gap Site is located in the northwestern part of the White Sands Missile Range, Area 9, about 50 miles northwest of White Sands Monument and about 30 miles southeast of Socorro, N. Mex. (Figure 2.13). The area is accessible from U. S. Highway 380 by way of a paved road that traverses Mockingbird Gap in a northwest-southeast direction.

Mockingbird Gap is situated in the northern part of the San Andres Mountains, which form the northwest border of the large Tularosa Valley. Mockingbird Gap connects Tularosa Valley with Jornada Del Muerto (Valley), which lies west of the mountains. The San Andres Mountains are represented stratigraphically in the area by rock ranging in age from Precambrian to Pennsylvanian (Reference 14). The predominant fault system trends northwest. Faults trending northeast and east-west are also present.

The objects of investigation in this area were the slopes of the Precambrian granitic rock. A reconnaissance of Area 9 revealed a rugged mountain consisting chiefly of granitic rock in contact with steeply dipping limestone beds outcropping along the slopes. The surface within the granitic area was considered too steep and rugged. In addition, there were associated problems of accessibility and the required buffer zone. No site was found meeting site selection criteria.
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**Footnotes:**
- "M18" indicates the test site is part of the Nevada Test and Training Site.
- Access comments and notes vary for each site, indicating different road conditions and accessibility.
- Personal accommodation and transportation facilities vary, with some sites requiring specific vehicles or equipment.
- Remarks on acceptability indicate challenges such as limited buffer zones and difficult access.

**Table Notes:**
- The table includes various site designations, elevations, and access considerations.
- Access comments mention mild to moderate conditions, with some sites requiring special equipment or vehicles.
- The table highlights the diversity of site characteristics, including desert and mountainous areas.

**Additional Notes:**
- The data reflects operational conditions as of the date the document was produced.
- The information is specific to the Nevada Test and Training Site and its associated test sites.
- The table is intended to provide a comprehensive overview of site accessibility and operational conditions.
**Table 2.2**

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Figure 2.1 Location of Site 1, China Lake, Area 1A. Granitic area is outlined.
Figure 2.2 Locations of Sites 1 through 10, China Lake, Area 1B. Granitic areas are outlined.
Figure 2.3 Refraction seismic layout at China Lake, Area 1A, Wilson Mesa Site.
Figure 2.4 Locations of Sites 1 through 14, Fort Irwin, Area 2. Granitic areas are outlined.
Figure 2.5 Location of Site 1 and general geology of Cima Dome, Area 3.
Figure 2.6 Locations of Sites 1 through 5, Fallon, Area 4. Granitic area is outlined.
Figure 2.7 Locations of Sites 1 through 3, Nevada Test Site, Area 5. Granitic areas are indicated by diagonal lines. Crosshatched area (Site 2) consists of welded tuff.
Figure 2.8 Locations of Sites 1 through 7, Cedar City, Area 6. Areas of quartz monzonite are outlined.
Figure 2.9 Refraction seismic layout, Cedar City, Area 6, Site 1.
Figure 2.10 Refraction seismic layout, Cedar City, Area 6, Site 2.
Figure 2.11 Location of Site 1, Beaver, Area 7. Areas of quartz monzonite are outlined.
Figure 2.12 Location of Site 1 and general geology of Pedernal Hills, Area 8.
Figure 2.13 Location of Site 1 and general geology of Mockingbird Gap, White Sands, Area 9.
CHAPTER 3
SUMMARY AND CONCLUSIONS

Tables 2.1 and 2.2 summarize observations in the 9 areas and 33 specific sites evaluated for this study. It is concluded that The Three Peaks quartz monzonite intrusive in the Cedar City area meets project criteria best of those evaluated. The geometry of the terrain, the shallow overburden, the moderately high seismic velocities obtained, the apparent soundness and moderate jointing of much of the exposed rock, and the fact that the land is under Federal or State ownership are points favoring choice of this area as a site for the project. The proximity of the area to Cedar City, on the other hand, may pose problems from the standpoint of an adequate buffer zone.

Site 1 in China Lake Area 1A met most of the criteria, but the area of exposed or shallow surface rock was fairly small and, more important, scheduling of the experiment would have conflicted with operations of the Naval Weapons Center.

Sites 11 and 13 in the Fort Irwin area were considered for further investigation, but poor accessibility of the former site and insufficient buffer zone and low velocities at the latter discouraged more extended evaluation.

Further investigation of the Cima Dome area may have resulted in location of a suitable site. However, problems of land ownership,
project support, and insufficient buffer zone discouraged additional investigation.
A.1 REFRACtion Seismic INVESTIGATIONS

The refraction seismic investigations were conducted using a portable seismograph unit consisting of 12 velocity-type geophones and a recording unit equipped with a camera providing a permanent record on film. Detonation of explosives provided the energy source.

The seismic lines ranged in length from 325 to 875 feet. The lengths of the lines were normally controlled by the area and terrain features of the site investigated but were always of sufficient length to provide adequate coverage. In addition to the longer lines, numerous surveys were performed at selected locations, with the geophones spaced at intervals of 10 feet (or less for short distances) to give a more accurate indication of overburden depth, particularly where overburden appeared to be rather shallow.

The procedure employed to shoot a 325-foot line consisted of laying out the geophones at 25-foot intervals and detonating an explosive charge 25 feet from the geophone at either end, so that the forward and reverse traverses were shot consecutively. (A traverse for the purposes of this report is considered to be a line shot in one direction only.) To shoot the 600-foot line, four explosive charges were used, two at each end of the line. The geophones were laid out in a 300-foot spread in 25-foot intervals, and a charge was
fired at each end of the 600-foot line. The geophones were transferred to cover the remaining 300 feet of line, with the geophone at the 300-foot location, which was used for correlation purposes, left undisturbed. After the geophones had been transferred, another charge was fired at each end of the 600-foot line. When the above shot plan had been completed, the result was 600-foot forward and reverse traverses. In shooting the 875-foot line, an additional dynamite charge was utilized on each end of the 875-foot line and the geophones were transferred an additional time.

A.2 SEISMIC DATA REDUCTION METHOD

Data obtained from refraction seismic tests consist basically of time required for a compression wave to travel from a seismic source or shot point to successive points of measurement. Data are plotted in graphic form as travel time from the seismic source to each geophone versus the respective distances of the geophones from the source. The inverse slopes of the lines drawn to connect the plotted points indicate the velocity of the compression wave through each subsurface medium encountered. A change in the slope of the line indicates that the wave has passed through an interface between two subsurface layers having different velocities, and the inverse slope of the changed line indicates the velocity of the second material encountered. The depth at which the first interface occurs
below the surface can be calculated by means of the following equation:

\[ D_1 = \frac{X_1}{2} \sqrt{\frac{v_{c2}^2 - v_{c1}^2}{v_{c2}^2 + v_{c1}^2}} \]  

(A.1)

where

\[ D_1 = \text{depth from surface to first interface, } L \]
\[ X_1 = \text{distance from seismic source to point at which first change in inverse slope occurs, } L \]
\[ v_{c1} = \text{compression wave velocity in first layer, } LT^{-1} \]
\[ v_{c2} = \text{compression wave velocity in second layer, } LT^{-1} \]

If a second interface is detected, its depth can be calculated from the following equation:

\[ D_2 = \frac{5}{6} D_1 + \frac{X_2}{2} \sqrt{\frac{v_{c3}^2 - v_{c2}^2}{v_{c3}^2 + v_{c2}^2}} \]  

(A.2)

where

\[ D_2 = \text{depth from surface to second interface, } L \]
\[ X_2 = \text{distance from seismic source to point at which second change in inverse slope occurs, } L \]
\[ v_{c3} = \text{compression wave velocity in third layer, } LT^{-1} \]

If a third interface is encountered, the following equation is used to compute its depth:

\[ D_3 = \frac{1}{6} D_1 + \frac{3}{4} D_2 + \frac{X_3}{2} \sqrt{\frac{v_{c4}^2 - v_{c3}^2}{v_{c4}^2 + v_{c3}^2}} \]  

(A.3)
where

\[ D_3 = \text{depth from surface to third interface, } L \]
\[ X_3 = \text{distance from seismic source to point at which third change in inverse slope occurs, } L \]
\[ v_{c4} = \text{compression wave velocity in fourth layer, } LT^{-1} \]

A more advanced interpretation was made in computing the location and extent of irregularities that occurred in the subsurface rock. The method employed, described in Reference 16, utilizes the time arrivals from the forward and reverse traverses. The delay times (that part of time arrivals due to overburden) for the forward and reverse profiles were adjusted for the best correlation, and a datum depth was established from the computed depth at one of the shot points. An average velocity for the overburden was utilized in computing a depth difference with reference to the datum depth to give the correct depth at each geophone location. These points were plotted at their respective locations, and a curve or line was drawn through the points to form a subsurface profile.
APPENDIX B

TIME VERSUS DISTANCE TRAVERSES AND

SUBSURFACE PROFILES FROM SEISMIC INVESTIGATIONS
Figure B.1 Time versus distance; Traverses S-1 and S-2, Site 1, Wilson Canyon, Area 1A, China Lake, California.
Figure B.2  Time versus distance; Traverse S-2s, Site 1, Wilson Canyon, Area 1A, China Lake, California.
Figure B.3 Time versus distance; Traverses S-3 and S-4, Site 1, Wilson Canyon, Area 1A, China Lake, California.
Figure B.4 Time versus distance; Traverses S-3e and S-4e, Site 1, Wilson Canyon, Area 1A, China Lake, California.
Figure B.5 Time versus distance; Traverses S-5 and S-6, Site 1, Wilson Canyon, Area 1A, China Lake, California.
Figure B.6 Approximate subsurface profiles of Traverses S-1, S-2, and S-2s, Site 1, Wilson Canyon, Area 1A, China Lake, California.
Figure B.7 Approximate subsurface profiles of Traverses S-3, S-4, S-3e, S-4e, S-5, and S-6, Site 1, Wilson Canyon, Area 1A, China Lake, California.
Figure B.8 Time versus distance; Traverses S-1 and S-2, Site 7, Area 1B, China Lake, California.
Figure B.9  Time versus distance; Traverses S-3 and S-4, Site 7, Area 1B, China Lake, California.
Figure B.10 Approximate subsurface profiles of Traverses S-1 and S-2, Site 7, Area 1B, China Lake, California.
Figure B.11 Approximate subsurface profiles of Traverses S-3 and S-4, Site 7, Area 1B, China Lake, California.
Figure B12 Time versus distance; Traverses S-1 and S-2, Site 1, Area 2, Fort Irwin, California
Figure B.13  Approximate subsurface profiles of Traverses S-1 and S-2, Site 1, Area 2, Fort Irwin, California.
Figure B.14  Time versus distance; Traverses S-1 and S-2, Site 11, Area 2, Fort Irwin, California.
Figure B.15 Approximate subsurface profiles of Traverses S-1 and S-2, Site 11, Area 2, Fort Irwin, California.
Figure B.16 Time versus distance; Traverses S-1 and S-2, Site 13, Area 2, Fort Irwin, California.
Figure B.17 Approximate subsurface profiles of Traverses S-1 and S-2, Site 13, Area 2, Fort Irwin, California.
Figure B.18  Time versus distance; Traverse S-1, Site 14, Area 2, Fort Irwin, California.
Figure B.19 Approximate subsurface profiles of Traverse S-1, Site 14, Area 2, Fort Irwin, California.
Figure B.20 Time versus distance; Traverses S-1 and S-2, Site 1, Area 3, Cima Dome, California.
Figure B.21  Approximate subsurface profiles of Traverses S-1 and S-2, Site 1, Area 3, Cima Dome, California.
Figure B.22 Time versus distance; Traverses S-1 and S-2, Site 1, Area 4, Fallon, Nevada.
Figure B.23  Approximate subsurface profile of Traverses S-1 and S-2, Site 1, Area 4, Fallon, Nevada.
Figure B.24  Time versus distance; Traverses S-1 and S-2, Site 3, Area 4, Fallon, Nevada.
Figure B.25 Approximate subsurface profile of Traverses S-1 and S-2, Site 3, Area 4, Fallon, Nevada.
Figure B.26  Time versus distance; Traverses S-1 and S-2, Site 4, Area 4, Fallon, Nevada.
Figure B.27 Approximate subsurface profile of Traverses S-1 and S-2, Site 4, Area 4, Fallon, Nevada.
Figure B.28  Time versus distance; Traverses S-1 and S-2, Site 1, Area 6, Cedar City, Utah.
Figure B.29 Time versus distance; Traverses S-3 and S-4, Site 1, Area 6, Cedar City, Utah.
Figure B.30 Approximate subsurface profile of Traverses S-1 and S-2, Site 1, Area 6, Cedar City, Utah.
Figure B.31  Approximate subsurface profile of Traverses S-3 and S-4, Site 1, Area 6, Cedar City, Utah.
Figure B.32 Time versus distance; Traverses S-1 and S-2, Site 2, Area 6, Cedar City, Utah.
Figure B.33 Time versus distance; Traverses S-3 and S-4, Site 2, Area 6, Cedar City, Utah.
Figure B.34 Time versus distance; Traverses S-5 and S-6, Site 2, Area 6, Cedar City, Utah.
Figure B.35 Approximate subsurface profile of all traverses, Site 2, Area 6, Cedar City, Utah.
Figure B.36 Time versus distance; Traverses S-1 and S-2, Site 1, Area 8, Pedernal Hills, New Mexico.
Figure B.37 Approximate subsurface profile of Traverses S-1 and S-2, Site 1, Area 8, Pedernal Hills, New Mexico.
REFERENCES


2. U. S. Naval Ordnance Test Station; "Geological Investigation of Wilson Mesa, China Lake, California"; Technical Progress Report 162, 1 August 1956; Unclassified.

3. "Geologic Map of California, Death Valley Sheet"; 1965; California Division of Mines, Department of Natural Resources, San Francisco, Calif.; Unclassified.


12. A. E. Granger; "The Iron Province of Southwestern Utah" in
"Geology of Southwestern Utah"; 1963, Pages 146-150; Utah Geological and Mineralogical Survey, Salt Lake City, Utah; Unclassified.


14. "Geologic Map of Southwestern Utah"; 1963; Department of Geology, Brigham Young University, Provo, Utah; Unclassified.


Geological investigations were conducted to locate a site to be used for surface blast experiments in rock for the Mine Shaft Series (formerly Hard Rock). Geologic field reconnaissance and geophysical evaluations of nine areas in the western United States were conducted in conjunction with office studies of available literature and geologic and topographic maps. Where a site appeared promising, a seismic survey was made to determine compressional wave velocities of the rock. The method used in conducting the seismic investigations is discussed in Appendix A. Time versus distance plots and subsurface profiles from seismic investigations are presented in Appendix B. Six possible sites in homogeneous quartz monzonite were finally selected at The Three Peaks Range, near Cedar City, Utah, and recommended for more extensive subsurface investigations.
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