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Cultural Resources Technical Report No. 109
Division of Earth and Ecosystem Sciences
Desert Research Institute
Las Vegas, Nevada

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Prepared for

U.S. Department of Energy
National Nuclear Security Administration
Nevada Field Office, Las Vegas, Nevada
and
U.S. Department of Defense
Defense Threat Reduction Agency
Nevada Test Site Office, Mercury, Nevada

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EXECUTIVE SUMMARY

This report presents a historical evaluation of the U15 Complex on the Nevada National Security Site (NNSS) in southern Nevada. The work was conducted by the Desert Research Institute at the request of the U.S. Department of Energy, National Nuclear Security Administration Nevada Field Office and the U.S. Department of Defense, Defense Threat Reduction Agency. Three underground nuclear tests and two underground nuclear fuel storage experiments were conducted at the complex. The nuclear tests were Hard Hat in 1962, Tiny Tot in 1965, and Pile Driver in 1966. The Hard Hat and Pile Driver nuclear tests involved different types of experiment sections in test drifts at various distances from the explosion in order to determine which sections could best survive in order to design underground command centers. The Tiny Tot nuclear test involved an underground cavity in which the nuclear test was executed. It also provided data in designing underground structures and facilities to withstand a nuclear attack. The underground nuclear fuel storage experiments were Heater Test 1 from 1977 to 1978 and Spent Fuel Test - Climax from 1978 to 1985. Heater Test 1 was used to design the later Spent Fuel Test - Climax experiment. The latter experiment was a model of a larger underground storage facility and primarily involved recording the conditions of the spent fuel and the surrounding granite medium.

Fieldwork was performed intermittently in the summers of 2011 and 2013, totaling 17 days. Access to the underground tunnel complex is sealed and unavailable. Restricted to the surface, four buildings, four structures, and 92 features associated with nuclear testing and fuel storage experiment activities at the U15 Complex have been recorded. Most of these are along the west side of the complex and next to the primary access road and are characteristic of an industrial mining site, albeit one with scientific interests. The geomorphological fieldwork was conducted over three days in the summer of 2011. It was discovered that major modifications to the terrain have resulted from four principal activities. These are road construction and maintenance, mining activities related to development of the tunnel complex, site preparation for activities related to the tests and experiments, and construction of drill pads and retention ponds. Six large trenches for exploring across the Boundary geologic fault are also present.

The U15 Complex, designated historic district 143 and site 26NY15177, is eligible to the National Register of Historic Places under Criteria A, C, and D of 36 CFR Part 60.4. As a historic district and archaeological site eligible to the National Register of Historic Places, the Desert Research Institute recommends that the area defined for the U15 Complex, historic district 143 and site 26NY15117, be left in place in its current condition. The U15 Complex should also be included in the NNSS cultural resources monitoring program and monitored for disturbances or alterations.

ACKNOWLEDGMENTS

This research was conducted for the U.S. Department of Energy, National Nuclear Security Administration Nevada Field Office (NNSA/NFO) and under the direction of Linda Cohn, NNSA/NFO Cultural Resources Manager; and Jeffrey Fraher for the U.S. Department of Defense, Defense Threat Reduction Agency (DTRA). Field work and report preparation were under the supervision of Colleen M. Beck, Desert Research Institute, as project director. The cultural resources fieldwork was conducted by archaeologists Colleen M. Beck, Harold Drollinger, Barbara Holz, Maureen King, Tatiana Menocal, and Carol Shimer, Desert Research Institute, and architectural historian Nancy Goldenberg, Carey and Co., Inc. Architects, San Francisco. Thomas F. Bullard, Desert Research Institute, conducted the geological and geomorphological study.

The Desert Research Institute extends thanks to Laurence Ashbaugh and Wayne Griffin, former members of the DTRA Nevada Operations Office who shared their extensive knowledge of the events and history surrounding the DTRA Underground Nuclear Weapons Effects Test program. Martha DeMarre, National Security Technologies, helped in providing historic documents and photographs on file at the Nuclear Testing Archive, Las Vegas. Loretta Bush at the NNSA/NFO Technical Library, North Las Vegas aided in obtaining key scientific reports for the various nuclear tests. Reports and other documents were also obtained from the Defense Threat Reduction Information Analysis Center at Kirtland Air Force Base, Albuquerque, New Mexico under the direction of managers Dee Hunt and Connie Salus. Troy Leonard, National Security Technologies, provided engineering drawings on file at the Archives and Records Center, Mercury, Nevada. Margaret Townsend provided information in an interview about the geology of the U15 Complex area. A number of archived photographs were made available by Will Tasko and crew at the NNSA/NFO Remote Sensing Laboratory, Nellis Air Force Base, Las Vegas. Special thanks is given to Keith Kolb, Remote Sensing Laboratory, for photographing the site during this study and recording video interviews with Laurence Ashbaugh, Wayne Griffin, and Bill Flangas. Bill Flangas, who was directly involved in the construction at the U15 Complex as Mine Superintendent and Department Manager for Reynolds Electrical and Engineering Company, Inc., provided copies of documents pertinent to this study from his personal files.

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INTRODUCTION

The U.S. Department of Energy, National Nuclear Security Administration Nevada Field Office (NNSA/NFO) requested the Desert Research Institute conduct a historical evaluation of the U15 Complex located in Areas 8 and 15 of the Nevada National Security Site (NNSS), Nye County, Nevada (Figure 1). The intent of the historical evaluation is in reference to Section 110 of the National Historic Preservation Act of 1966, as amended, and involves the identification and evaluation of historic properties for eligibility to the National Register of Historic Places.

This historical evaluation of the U15 Complex, designated historic district 143 and archaeological site 26NY15117, is the sixth study of an underground nuclear testing tunnel complex at the NNSS. The other five studies are the U12b Tunnel (Jones et al. 2006), the U12e Tunnel (Drollinger et al. 2007), the U12t Tunnel (Drollinger et al. 2009), the U12n Tunnel (Drollinger et al. 2011), and the U16a Tunnel (Jones et al. 2012). Historic themes for these previous studies were nuclear weapons testing and national defense. The NNSS, formerly the Nevada Test Site, was the continental site where the nuclear weapons developed by the United States were actually tested. The U15 Complex, at the north edge of the NNSS, was in operation from 1959 to 1967 by the Defense Atomic Support Agency, a predecessor agency of the Defense Threat Reduction Agency (DTRA), for the Hard Hat, Tiny Tot, and Pile Driver underground nuclear weapons tests. The objective of these tests was to monitor the response of ground shock and various structure types to a nuclear explosion in order to design and construct underground facilities, such as command centers, that would be impervious to a direct nuclear attack. Subsequent to these nuclear weapons tests, the complex was used for underground nuclear fuel storage tests by the Lawrence Livermore National Laboratory for the U.S. Department of Energy from 1978 to 1985. No other major projects have since been conducted at the site.

Based on this historical evaluation, the U15 Complex, historic district 143 and archaeological site 26NY15177, meets Criteria A, C, and D of 36 CFR Part 60.4 for eligibility to the National Register of Historic Places. It does not meet Criterion B, an association with an important person in history. It is eligible under Criterion A because of its historic and scientific significance at the NNSS and its role in national defense as an underground nuclear test site during the Cold War between the United States and the former Soviet Union. The underground spent nuclear fuel storage experiment contributed to the national defense of the nation by proving that spent nuclear fuel could be safely stored in a secure environment underground. It is eligible under Criterion C because of specialized engineering techniques and designs in carrying out underground nuclear tests and scientific experiments. It is eligible under Criterion D because the association of cultural material at the site can provide important information about activities conducted at the complex. The U15 Complex also conveys aspects of integrity for eligibility to the National Register of Historic Places. Therefore, the U15 Complex is recommended to be maintained in situ with no modification and to be included in the NNSS cultural resources monitoring program and monitored for disturbances or alterations.

The following sections of this report are the setting and previous investigations, research design and methods, a historic context for nuclear testing at the NNSS, geology and geomorphology of the complex, summaries of the tests and experiments conducted at the complex and description of the cultural resources, and an overall summary and National Register eligibility evaluation.

SETTING AND PREVIOUS INVESTIGATIONS

The NNSS lies within the southern portion of the Great Basin, characterized by high mountain ranges interspersed by valleys and bolsons (Dohrenwend 1987), and is approximately 105 km (65 miles) northwest of Las Vegas, Nevada by way of U.S. Highway 95. The main entrance and the base camp of Mercury are located toward its southeast corner. The U15 Complex is at the northern extent of the NNSS and is reached from Mercury by initially traveling north on the Mercury Highway for approximately 53 km (33 miles) through Frenchman Flat, past the Area 6 Control Point, and to the B-J Wye intersection in the northern part of Yucca Flat. Turning east at the Wye, the route travels another 7.2 km (4.5 miles) to the 10-2 Road turnoff to the north, and then for another 4.2 km (2.6 miles) to the southwest corner of the complex. The total distance from Mercury base camp to the U15 Complex is approximately 64 km (40 miles).

The U15 Complex is at the north end of Yucca Flat (Figure 2), along the south flank of the Belted Range, and at the base of Oak Spring Butte. Oak Spring Butte, directly north, rises to an elevation of 2,123 m (6,965 ft), while Quartzite Ridge to the west reaches an elevation of 2,168 m (7,114 ft). Rhyolite Hills to the east is at a high elevation of 1,698 m (5,570 ft) and the Smoky Hills reaching an elevation of 1,614 m (5,294 ft) is to the southwest. Major drainages are Oak Spring Wash to the west and Butte Wash to the east. Elevations in the project area range from 1,579 m (5,180 ft) along the north edge to 1,481 m (4,860 ft) along the south edge. Aspect is toward the southeast.

Climate is characterized by limited precipitation, low humidity, and extreme daily temperature ranges. Generally, the lower elevations have dry, hot summers and mild winters, while the higher elevations have increased precipitation and lower temperatures. Most of the precipitation is in the form of snow and winter rainstorms, with an occasional storm during the fall and spring. Rainstorms do occur in the summer, but are rare. Permanent natural water sources for the region are springs and seeps. The nearest natural water sources are Oak Spring 2.2 km (1.4 miles) to the northwest at the head of the Oak Spring Wash, an unnamed spring about 200 m (656 ft) northwest of Oak Spring, and Tub Spring 1.1 km (0.7 mile) to the northeast at the head of Butte Wash.

The U15 Complex is also at the northern edge of a vegetation transitional zone between the Great Basin Desert to the north and the Mojave Desert to the south. The plant association is a blackbrush (*Coleogyne ramosissima*) and Nevada jointfir (*Ephedra nevadensis*) shrubland (Ostler et al. 2000; Wills and Ostler 2001). Blackbrush is dominant, comprising over 50 percent of the shrubs. Nevada jointfir constitutes 10 percent. Other less frequent plants include white burrobush (*Hymenoclea salsola*), Anderson's wolfberry (*Lycium andersonii*), green rabbitbrush (*Chrysothamnus viscidiflorus*), spiny hopsage (*Grayia spinosa*), banana yucca (*Yucca baccata*), Mormon tea (*Ephedra viridis*), Joshua tree (*Yucca brevifolia*), cholla cactus (*Opuntia echinocarpa*), prickly pear cactus (*Opuntia erinacea*), and Mojave yucca (*Yucca schidigera*).

Nearly 80 percent of the fauna consists of insects, and of these, most are ants, termites, and beetles (Castetter and Hill 1979; Greger 1994; Medica 1990; O'Farrell and Emery 1976). The more noticeable fauna found near the U15 Complex are coyote (*Canis latrans*), badger (*Taxidea taxus*), kit fox (*Vulpes macrotis*), mule deer (*Odocoileus hemionus*), raven (*Corvus corax*), red-tailed hawk (*Buteo jamaicensis*), chukar (*Alectoris chukar*), quail (*Callipepla gambelii*), jay (*Aphelocoma coerulescens*), golden eagle (*Aquila chrysaetos*), mice (*Perognathus parvus*), kangaroo rat

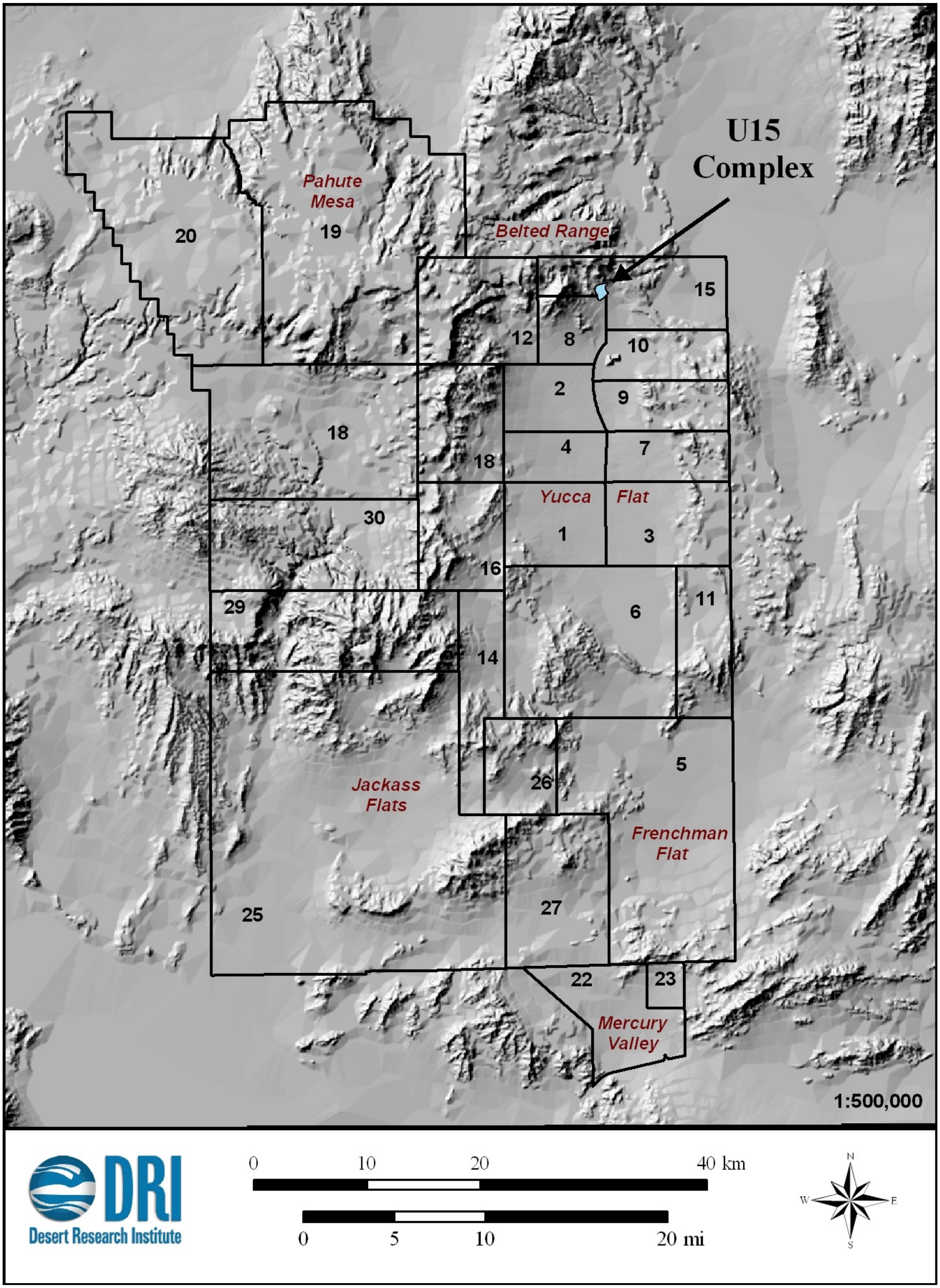

Figure 1. Location of the U15 Complex on the Nevada National Security Site.

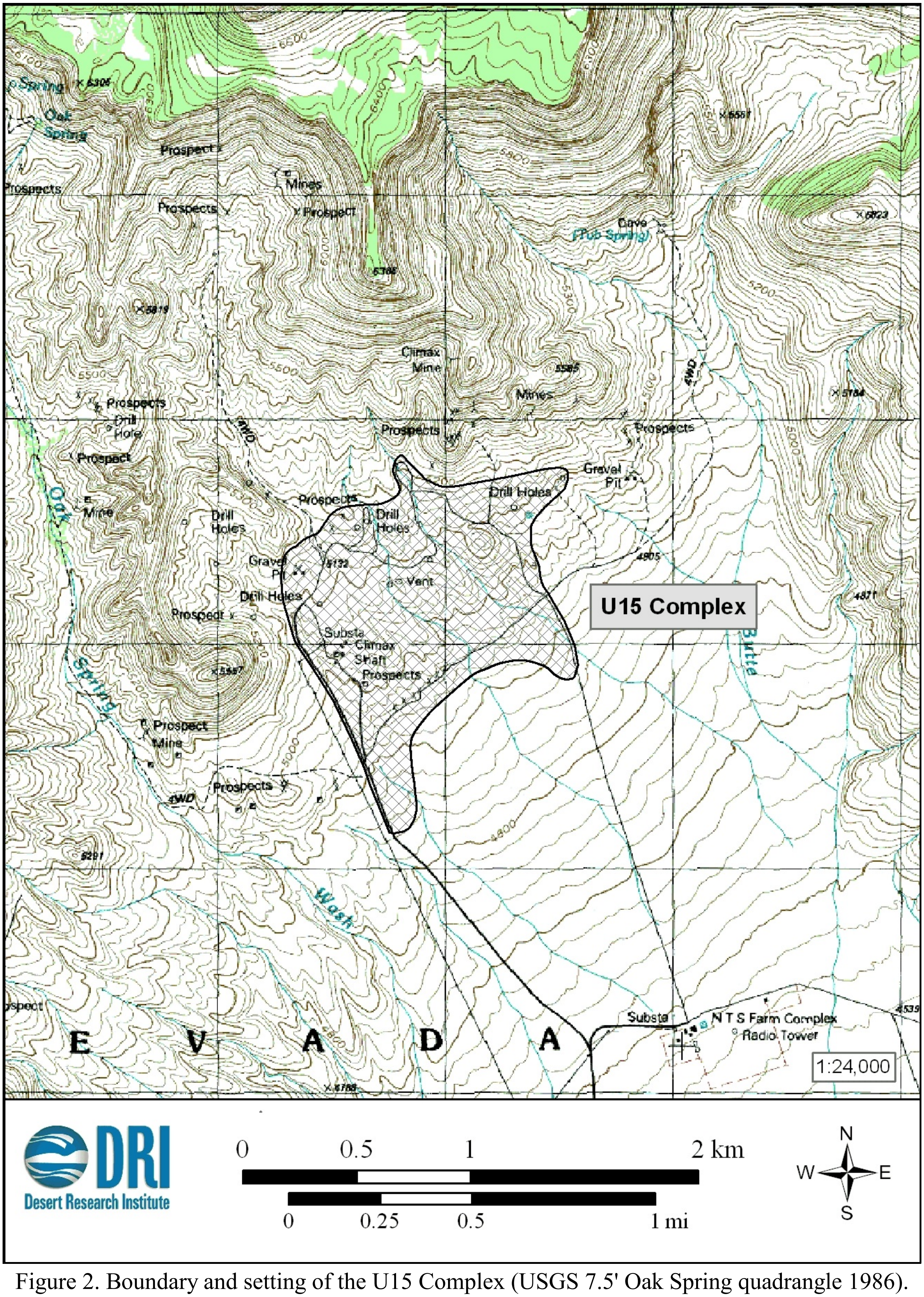

Figure 2. Boundary and setting of the U15 Complex (USGS 7.5' Oak Spring quadrangle 1986).

(*Dipodomys microps*, *Dipodomys ordii*), squirrel (*Ammospermophilus leucurus*, *Spermophilus townsendii*, *Spermophilus variegatus*), jackrabbit (*Lepus californicus*), cottontail (*Sylvilagus audubonii*, *Sylvilagus nuttallii*), lizard (*Sceloporus graciousus*, *Sceloporus occidentalis*, *Eumeces skiltonianus*), and snake (*Chionactis occipitalis*, *Pituophis melanoleucus*, *Crotalus mitchellii*, *Crotalus lutosus*, *Crotalus stephensi*). Other large animals known to occur in the region are mountain lion (*Felis concolor*), pronghorn antelope (*Antilocapra americana*), and bighorn sheep (*Ovis canadensis*).

Previous Cultural Resources Investigations

Previous cultural resources investigations in and within at least 1.6 km (1 mile) of the U15 Complex include 16 reports, with 23 archaeological sites recorded and 15 of them determined eligible to the National Register of Historic Places (Table 1; Figures 3 and 4). Three of the previous investigations consisted of seismograph studies within the U15 Complex (Jones and Drollinger 1992a, 1992b, 1992c). Most of the archaeological sites are prehistoric lithic artifact scatters or small localities (n=18), dating from the early to late Holocene periods. The prehistory is characterized by hunter and gatherer groups with changing settlement and subsistence patterns through time as a result of adaptive strategies to acquire the necessary natural resources from the surrounding environment (cf. Steward 1938). This lifestyle is viewed as a response to the availability of food and other resources at different times and places and in varying amounts over the year and between years. Resulting mobility over the landscape tended to follow this pattern of available resources.

Four previously recorded sites are associated with mining in the historic Oak Spring mining district that was centered around Oak Spring Butte. The district dates to the late nineteenth and early twentieth centuries. Documents at the Recorder's Office in Tonopah show the first claims were by Antonio Aguayo and W.S. Bennett in 1886. Most of the activity, however, is from the early twentieth century and coincides with the Tonopah-Goldfield-Rhyolite mining boom around 1905 and later (Ball 1907:128-130; Lincoln 1923:179; Quade and Tingley 1984; Stager and Tingley 1988:144-148). The main objectives of the early mining efforts were gold and silver, with a somewhat lesser emphasis on copper, tungsten, mercury, and lead. In 1937, the Climax group discovered a source of tungsten. Subsequent nearby mining activities to the Climax claims included the Indian Trail claim, the Crystal tungsten claims, and the Garnetyte Load claim (Kral 1951:139-140; Stager and Tingley 1988:145). Ore was processed in a nearby mill that was removed before World War II. The area was closed toward the end of 1941 by the Federal government with the founding of the Tonopah Bombing and Gunnery Range (Kral 1951:140; Quade and Tingley 1984:15). The last known mining operation was the Climax claims in 1957 involving a co-use agreement between the Climax Tungsten Corporation and the Atomic Energy Commission who then had control of the area for nuclear testing (Quade and Tingley 1984:15).

The 12 hectare (30 acre) Environmental Protection Agency farm, with a small herd of Holstein cows, was an experimental dairy program researching air-borne radionuclides in the soil-forage-cow-milk food chain (Goldenberg et al. 1994). The farm, located 1.5 kilometers (0.9 mile) southeast of the U15 Complex, had irrigated crop land, an irrigation reservoir, and a Grade A dairy operation. The farm started in 1964 and was decommissioned in 1981.

Table 1. Results of Previous Cultural Resources Investigations.

REPORT	AUTHOR	SITES	TYPE	NRHP ELIGIBLE
SR011183-1	Clerico 1983	None		
SR012583-1	Reno 1983	26NY3121	Lithic Artifact Scatter	Yes
Technical Report 35	Reno and Pippin 1985	26NY3121	Quarry	Yes
SR050785-1	Henton 1985	26NY3121	Quarry	Yes
SR062492-1	Jones and Drollinger 1992a	26NY8054	Lithic Artifact Locality	No
		26NY8055	Lithic Artifact Scatter	Yes
SR062592-1	Jones and Drollinger 1992b	26NY8058	Lithic Artifact Scatter	Yes
SR062592-2	Jones and Drollinger 1992c	26NY8056	Lithic Artifact Scatter	No
		26NY8057	Lithic Artifact Scatter	No
SR090893-1	Goldenberg et al. 1994	26NY8441	EPA Farm	Yes
SR061394-2	Winslow 1994	None		
Technical Report 90	DuBarton and Drollinger 1996	26NY1989	Tub Spring	Yes
		26NY8820	Rockshelter	Yes
		26NY8821	Rockshelter	Yes
		26NY8822	Rockshelter	Yes
SR081396-1	Drollinger and Edwards 1996	26NY10123	Historic Camp	Yes
HABS NV-28	Johnson and Goldenberg 1998	26NY8441	EPA Farm	Yes
SR012302-1	Jones 2002	26NY11673	Temporary Camp	Yes
Technical Report 100	Drollinger 2003	26NY8806	Bower Cabin	Yes
SR052510-1	Drollinger 2011	26NY14162	Lithic Scatter	Yes
		26NY14163	Historic Camp	Yes
		26NY14164	Lithic Artifact Locality	No
		26NY14165	Lithic Artifact Locality	No
		26NY14166	Lithic Artifact Locality	No
		26NY14167	Historic Debris	Yes
		26NY14168	Lithic Artifact Locality	No
		26NY14169	Lithic Artifact Locality	No
		26NY14170	Lithic/Historic Locality	No
SR083111-1	Holz 2012	None		
SR091311-1	DeMaio and Holz 2012	26NY14162	Lithic Artifact Scatter	Yes
		26NY14163	Historic Camp	Yes

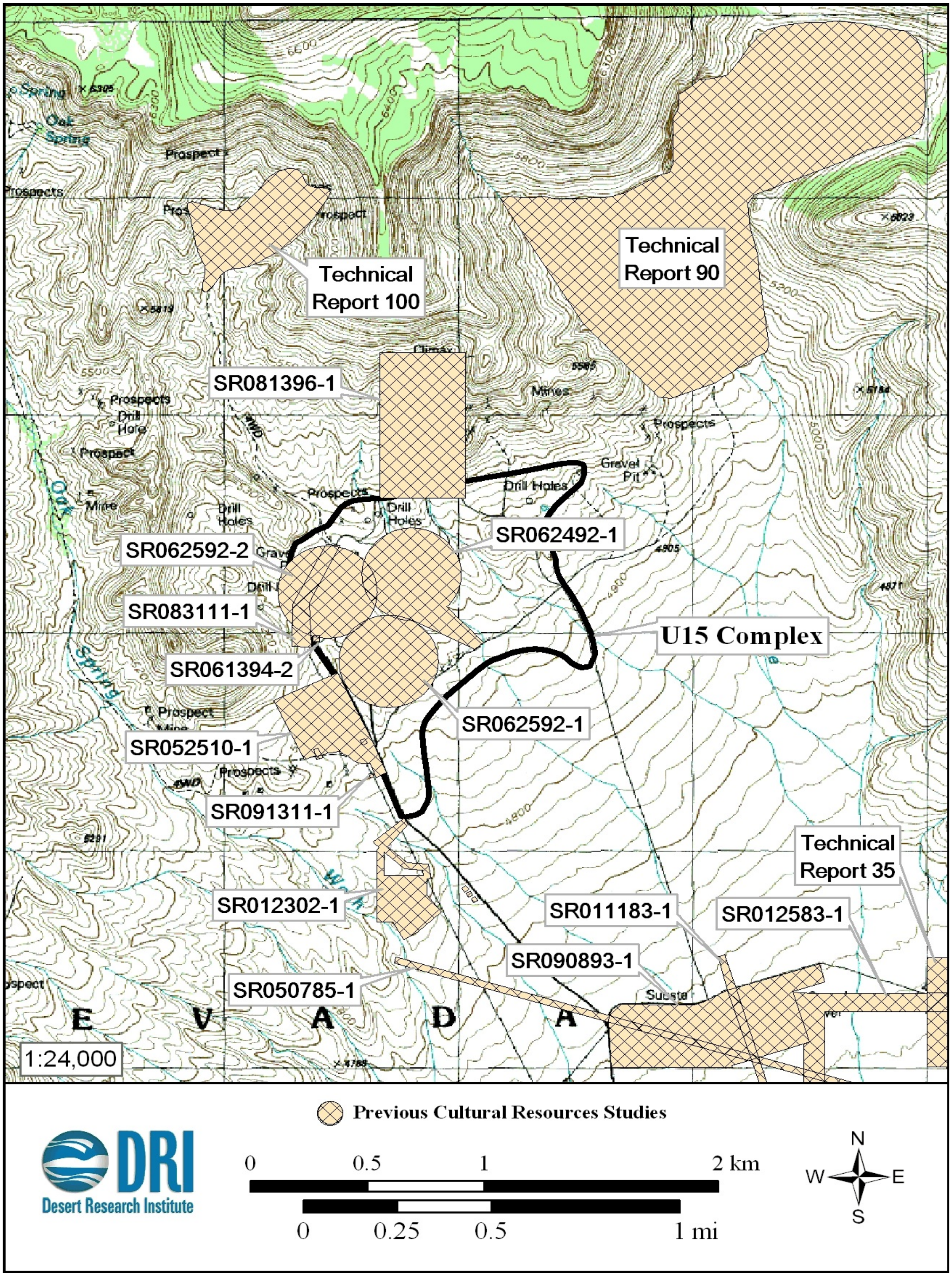

Figure 3. Previous cultural resources investigations within at least 1.6 km (1 mile) of the U15 Complex (USGS 7.5' Oak Spring quadrangle 1986).

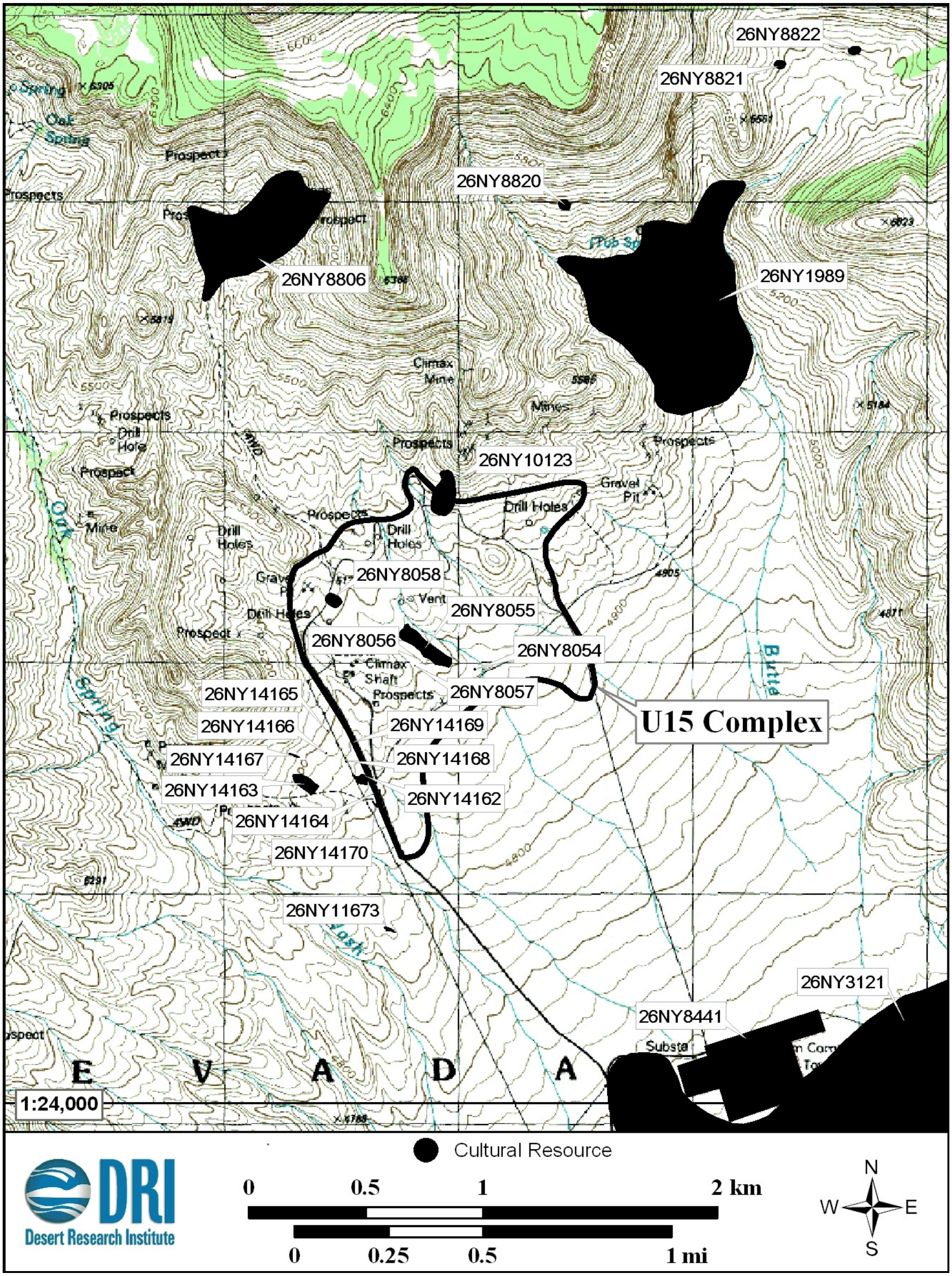

Figure 4. Previously recorded cultural resources within at least 1.6 km (1 mile) of the U15 Complex (USGS 7.5' Oak Spring quadrangle 1986).

RESEARCH DESIGN AND METHODS

Nuclear testing is a major and important theme in the history of Nevada and the nation and played a vital role in the national defense of the United States during the Cold War (Tlachac 1991a, 1991b). Most of the developments and experiments in nuclear weapons were tested at the NNSS, both above and below ground. This includes the physical effects from such tests on various weapon systems and on structures that were constructed above and below ground. Documentation of the cultural remains and history of nuclear testing at the U15 Complex is the primary research goal for this historical evaluation. The research design to address this goal consisted of archival document research and the field recording of the geology, geomorphology, and extant buildings, structures, and features at the complex. The archival research had a major emphasis on obtaining documents in order to describe the history and setting of the complex. This information was also used to evaluate the historic significance and exceptional importance of the complex for determining its eligibility to the National Register of Historic Places. Information obtained was based solely on available unclassified or declassified records. These include documents and photographs from the NNSA/NFO Nuclear Testing Archive, Las Vegas; the NNSA/NFO Technical Library, North Las Vegas; the NNSA/NFO Remote Sensing Laboratory, Las Vegas; the Archives and Records Center, Mercury, Nevada; and the Defense Threat Reduction Information Analysis Center at Kirtland Air Force Base, Albuquerque, New Mexico. All photographs and drawings in this report have been approved for public release.

Other studies of cultural resources on the NNSS with similar historic themes are the Area 2 Equipment Support Yard (Johnson 1994), the Japanese Village (Johnson and Edwards 1996), Camp Desert Rock (Edwards 1997), the Apple-2 historic district in Yucca Flat (Johnson and Edwards 2000), the Frenchman Flat historic district (Johnson et al. 2000), the Yucca Lake historic district (Jones et al. 2005), underground nuclear test locations in Frenchman Flat (Jones and Drollinger 2001), bunkers used in atmospheric nuclear tests (Edwards and Johnson 1995; Johnson 2002; Jones 2003, 2004), benches for viewing atmospheric nuclear tests (Jones 2005), buildings in the Area 6 control point area (Drollinger et al. 2003), the Super Kukla facility (Drollinger et al. 2000; Drollinger and Goldenberg 2004), the Pluto Control Facility historic district (Drollinger et al. 2005), the U12b Tunnel (Jones et al. 2006), the U12e Tunnel (Drollinger et al. 2007), the U12t Tunnel (Drollinger et al. 2009), the U12n Tunnel (Drollinger et al. 2011), and the U16a Tunnel (Jones et al. 2012).

Cultural resources determined eligible to the National Register of Historic Places from the above studies include the structures in the Frenchman Flat and Yucca Lake historic districts, houses in the Apple-2 historic district, the Japanese Village, the atmospheric testing bunkers, the viewing benches, buildings in the Area 6 control point, the Super Kukla facility, the Pluto Control facility, and the U12b, U12e, U12t, U12n, and U16a Tunnels. Sedan Crater, a Plowshare nuclear experiment conducted in 1962, is listed on the National Register of Historic Places. All of these historic properties date to the Cold War era following World War II and are representative of the various nuclear testing activities carried out at the NNSS during this period.

Procedures to document the physical setting and description of the U15 Complex consisted of site visits, photographs, mapping of the geology and geomorphology, and mapping and description of extant buildings, structures, and features. Boundaries for the U15 Complex were based on field recordings and surrounding cultural features. Total area for the U15 Complex is 113 hectares (279 acres) and spans 1,100 m (3,609 ft) east-west and 1,150 m (3,773 ft) north-south.

The purpose of the geological and geomorphological study was to document changes in the landscape as a result of site preparation and surface disturbances related to underground testing activities at the U15 Complex. This work was conducted by geomorphologist Dr. Thomas F. Bullard, Desert Research Institute, Reno. Research for this particular study includes bedrock geology, Quaternary geology, and geomorphology. In the U15 Complex area are the U15a/e shaft area and tailings pile, various exploratory and test drill holes, staging areas and trailer pads, roads, quarries, retention ponds, and exploratory fault trenches. Field reconnaissance and recording of anthropogenic influenced geomorphic change was conducted August 29-31, 2011. Surficial geologic deposits were the primary units mapped, although some small areas of bedrock were also included. Surface disturbances include construction of roads, parking and staging areas, building and drilling pads, a large tailings pile, and drainage control structures such as earthen berms and retention ponds. Field mapping developed a reconnaissance level map of the surficial and bedrock geology and the various types of surface disturbance. Contacts were marked on copies of enlarged orthophotographs while in the field and were transferred to digital format. No digging or detailed field descriptions of bedrock or soils were undertaken during this study.

Fieldwork for the historic landscape of the U15 Complex consisted of 10 intermittent days from June to July 2011 and seven intermittent days from May to August, 2013. The fieldwork was restricted to the main setting of the U15 Complex (existing buildings and structures) and the surrounding drill holes, trailer parks, and surface features. Posted radiation and contaminated areas were not entered. This work was conducted by archaeologists Colleen Beck, Harold Drollinger, Barbara A. Holz, Maureen King, Carol Shimer, and Tatiana Minocal, Desert Research Institute, Las Vegas and architectural historian Nancy Goldenberg, Carey and Co., Inc. Architects, San Francisco. Four buildings, four structures, and 92 cultural features were recorded. During this project, and following the guidelines of the State Historic Preservation Office, a building was defined as a resource that shelters some form of human activity, while a structure was a constructed resource, such as a mining hoist, having a purpose other than to provide shelter. The U15 Complex historic district, resource number D143, consists of the four buildings, four structures, and archaeological site 26NY15177. Archaeological site 26NY15177 was defined by the location of features on the landscape. No intensive survey or artifact inventories were conducted. Overall dimensions, UTM coordinates with handheld GPS units, and digital, color, and black-and-white photographs were taken of the buildings, structures, and features. The digital and print photographs and the print negatives are on file at the NNSA/NFO curation facility, Frank H. Rogers Building, Desert Research Institute, Las Vegas.

HISTORIC CONTEXT

The NNSS had an important role in the United States nuclear testing program during the Cold War with the former Soviet Union. A result of this confrontation was an ever-escalating arms race for nuclear weapon superiority (Anders 1978:4; Loeber 2002:80; Ogle 1985:20). This led to numerous nuclear detonations worldwide in the atmosphere, outer space, underwater, and underground by the United States and other foreign nuclear powers. The U.S. Department of Energy and the U.S. Department of Defense conducted these tests for the United States. The NNSS, located within the continental United States, was where most of these tests occurred and included both atmospheric and underground tests.

U.S. Department of Energy

Shortly after World War II, the Atomic Energy Commission, now the U.S. Department of Energy (DOE), was established when President Harry Truman signed the Atomic Energy Act of 1946. The purpose of the act was to address government control of fissionable material, nuclear experiments for military applications, and regulations pertaining to the release of scientific and other related data. The function of the Atomic Energy Commission was to maintain civilian government control of the research, development, and production of atomic weapons for the military (Anders 1978:2). Nuclear weapons research was conducted in New Mexico at the Los Alamos Scientific Laboratory, now the Los Alamos National Laboratory. Established in 1943, it was part of the Manhattan Engineer District. Development and production of the weapons took place at Sandia Laboratory, now the Sandia National Laboratories, in New Mexico; the Y-12 Plant in Oak Ridge, Tennessee; at Hanford, Washington; and the Rock Island Arsenal in Illinois (Anders 1978:3; Brady et al.1989:18-19; Stapp 1997). Following the first nuclear detonation by the former Soviet Union in 1949 (Anders 1978:4; Ogle 1985:20), increased efforts for research and production were implemented in the United States. A second nuclear weapons research laboratory was established in 1952 at Livermore, California (Brady et al.1989:18). It became the Lawrence Livermore National Laboratory in 1982 (DOE 1997:203). Other facilities added to the nuclear weapons industry in the 1950s included manufacturing plants at Rocky Flats near Golden, Colorado; the Kansas City Plant in Missouri; the Burlington Army Ordnance Plant in Iowa; the Pinellas Plant in Largo, Florida; Mound Laboratory in Miamsburg, Ohio; and the Pantex Plant near Amarillo, Texas (Anders 1978:4; DOE 1997:27).

The United States and the former Soviet Union ceased nuclear testing in 1958 by self-imposed moratoriums at the urging of internal and external forces (Ogle 1985:30-31), but by 1961 both superpowers were again conducting nuclear tests. After ratification of the Limited Test Ban Treaty by the United States, the former Soviet Union, and Great Britain in 1963, all nuclear tests were underground (Friesen 1995:6). According to the treaty, no tests could be conducted in the atmosphere, outer space, or underwater. Furthermore, certain safeguards for the United States were established in order for the U.S. Senate to ratify the treaty (DTRA 2002:246). These safeguards were an intensive underground testing program, maintenance of the weapons laboratories, the ability to resume atmospheric testing on short notice, and improvements in verifying compliance to the treaty. In 1974, the United States and the former Soviet Union agreed to the Threshold Test Ban Treaty and, in 1976, to the Peaceful Nuclear Explosions Treaty in order to restrict nuclear test explosions to a defined test site and to yields no greater than 150 kilotons. A second self-imposed moratorium on nuclear testing by the United States was established in 1992, and in 1996, the United States signed the Comprehensive Test Ban Treaty banning all nuclear tests. This latter treaty, however, has yet to be ratified by the U.S. Senate.

U.S. Department of Defense

The U.S. Department of Defense, with the establishment of the Armed Forces Special Weapons Project (AFSWP) in 1947, had a continuing role post-World War II in the testing of nuclear weapons at the Pacific Proving Grounds and later at the Nevada Test Site, now the NNSS (DTRA 2002). This group evolved over the years through reorganization and mission change into the Defense Atomic Support Agency (DASA) from 1959 to 1971, the Defense Nuclear Agency (DNA) from 1971 to 1996, the Defense Special Weapons Agency (DSWA) from 1996 to 1998, and as the Defense Threat Reduction Agency (DTRA) since 1998. General L.R. Groves, who was instrumental in developing the first nuclear weapon during the Manhattan Project and in keeping the military active in the nuclear weapons industry after the war, was appointed chief of AFSWP in early 1947 (DTRA 2002:35). The primary mission was to train military personnel in the assembly, storage, and firing of the atomic weapon, tasks previously conducted primarily by civilian scientists.

By 1949, when AFSWP was set up and operating, it was assigned the tasks of studying the effects of nuclear weapons on targets underwater, underground, and in the atmosphere and for radiological warfare (DTRA 2002:71-72). More tasks soon followed as the agency and the nuclear weapons industry as a whole became more adept. For example, the agency began to provide specialized training and technical support, coordinated storage and oversight of the ever-expanding nuclear weapons stockpile, and became more involved in the planning and operation of the weapons tests (DTRA 2002:80, 104). Most importantly, for the first time an agency of the U.S. Department of Defense participated in the development of the nuclear weapons and associated systems. DASA became the new name for the organization in 1959, and with the change, the added responsibility for the supervision of weapons effects tests for all the military branches (DTRA 2002:149). The agency also served as an integral information source in Cold War strategy for the United States.

Significant changes occurred in the agency during the 1960s. The number and diversity of nuclear weapons, including the associated delivery and defense systems increased dramatically in response to the high state of nuclear readiness in Cold War policy (DTRA 2002:173). DASA had to modify the weapons effects tests and management of the weapons stockpile accordingly. It also meant changes or upgrades in scientific and technical staff within the organization to increase research and development. At the same time, as the role and prominence of the agency changed, control of the agency was placed directly under the civilian Secretary of Defense rather than the joint chiefs of the military services. In addition, because of current situations and readiness for immediate response in case of attack, custody of the nuclear weapons stockpile was formally transferred from the Atomic Energy Commission to the U.S. Department of Defense (DTRA 2002:178). It was agreed that the Atomic Energy Commission would be responsible for weapons development, quality assurance of the weapons stockpile, effects tests on warhead components, and management of the NNSS; while the U.S. Department of Defense through DASA would provide testing facilities, certain hardware for diagnostics and data recording, field support, and funding (Brady et al. 1989:9; DTRA 2002:180). Both agencies would still be able to conduct nuclear tests, with devices supplied by either the Livermore or Los Alamos national laboratories through the Atomic Energy Commission, and both would do research in detecting nuclear tests by other nations.

A major difference in research objectives also occurred between the Atomic Energy Commission and DASA (DTRA 2002:189). DASA began to emphasize research on the actual use and effects of the nuclear weapon by the military. This emphasis contrasted with the research interests and desires of the weapon developers for the Atomic Energy Commission, whose main focus was on developing the weapon and not how it was going to be used. Because of limits imposed on testing in 1963, three methods of nuclear weapons effects tests were implemented by the defense agency (DTRA 2002:191). The first was improvements in underground testing techniques, particularly for containment; the second was the use of high explosives rather than nuclear explosives for some of the effects tests; and the third was the use of simulators, such as reactors, in some of the effects tests. The new effects testing methods, however, could not replicate all the effects from an actual nuclear explosion. It was found that nearly all the military systems when fully assembled and interacting together failed initially during a nuclear weapons effects test (Ristvet et al. 2007). Nuclear testing was still considered necessary for assessing the different types of weapon systems and structures. Nuclear testing was also deemed necessary for testing the reliability of the weapons stockpile (DTRA 2002:250).

In the late 1970s and early 1980s, DNA had an important role in the buildup of the military and national defense of the United States (DTRA 2002:259). The central theme of this role was survivability from a nuclear weapons attack, particularly the improvement and hardening of the various military weapons systems against such an attack. Efforts were also made to improve and harden communication systems, airplanes, airplane components, missiles, missile components, and underground bunkers. These efforts often used high explosive tests in order to simulate open air reactions or blast effects to the materials and structures as in an actual attack. Earlier weapons effects data from atmospheric nuclear tests at the NNSS were used to bolster these efforts. The nuclear tests at the U15 Complex also contributed to this research.

Nevada National Security Site

During the late 1940s, a search was conducted to establish a nuclear test site in the continental United States, remote from the populace and near the research laboratories. The main reasons for this were security, shorter travel times, and economic costs in the transportation of people and equipment (Lay 1950; Ogle 1985:44; Tlachac 1991a). At the time, nuclear testing was conducted at the Proving Grounds in the Pacific Ocean and was expensive in both cost and time. Security at the Pacific locale became a major concern due to the situation developing in Korea (DTRA 2002:77). Four places in the United States were seriously considered for a continental testing ground: Camp Lejeune in North Carolina, Dugway Proving Ground in Utah, White Sands Proving Ground in New Mexico, and the Las Vegas Bombing and Gunnery Range in southern Nevada (Lay 1950). The ideal location, in addition to the attributes described above, was to have favorable and predictable weather and terrain conditions to be able to test year round, be under federal control, and have an infrastructure already in place (Lay 1950; Tlachac 1991a). The bombing and gunnery range in southern Nevada was the place chosen that best met the conditions for the continental test site.

The first nuclear weapon test, Able of Operation Ranger, was carried out in Frenchman Flat on January 27, 1951 (Ogle 1985:43-44; Titus 1986:58). Construction of the facilities for the Nevada Proving Grounds, as it was originally designated, began soon afterwards. The first land withdrawal by the Atomic Energy Commission establishing the official nuclear weapons testing ground in the continental United States was February 12, 1952 under Public Land Order 805. After a series of name changes, it became the Nevada Test Site on the last day of 1954. Additional land parcels were then obtained under public orders and memorandum of agreements. The Nevada Test Site became the NNSS in 2010. Currently, the NNSS encompasses an area of approximately 3,522 square kilometers (1,360 square miles or 870,397 acres), and spans approximately 89 kilometers (55 miles) north-south and 50 kilometers (30 miles) east-west.

When the Atomic Energy Commission began to develop the NNSS in the early 1950s, the existing infrastructure in the area, such as roads and buildings, was used to support nuclear weapon testing activities. This infrastructure was the result of the Las Vegas Bombing and Gunnery Range activities as well as the earlier historic use of the region back into the late 1800s for mining and ranching. When the NNSS began, the roads were unpaved and diesel-powered generators were used for electricity. A main road from just south of Mercury extended northward and was intersected by other roads. Only fragments of this existing road system have been found in archival records. Nuclear testing was initially conducted in Frenchman Flat, but in 1952 testing moved north to Yucca Flat with primary access along the main road, now designated as Mercury Highway. Two electric lines came into the test site in the middle 1950s, one from the west and one from the south. Over the next decade, the road system was expanded and the electrical system upgraded to replace the steam plant in Mercury and the generators used throughout the test site. Most of the present infrastructure of the NNSS had been established by the middle 1960s. On the NNSS today there are 480 kilometers (300 miles) of paved roads, 805 kilometers (500 miles) of powerlines, three public water systems, three runways, and two helipads.

A total of 928 atmospheric and underground nuclear tests have been conducted at the NNSS, with 120 performed in the 1950s and 808 after 1961 (DOE/NV 2000; Friesen 1995:6, 10). Atmospheric tests number 100, and most were conducted on Frenchman Flat or Yucca Flat. Three atmospheric nuclear tests were conducted in the upper Fortymile Canyon area. Most of the underground nuclear tests were either in vertical shafts on Pahute Mesa and Yucca and Frenchman Flats or in horizontal tunnels mined into the sides of Aqueduct and Rainier Mesas. Some underground tests were on Buckboard Mesa and Dome and Shoshone Mountains. Three underground nuclear tests were conducted at the U15 Complex at the north end of Yucca Flat. In 1992, the Hunters Trophy test, conducted in the U12n Tunnel in Rainier Mesa, was the last nuclear weapons effects test at the NNSS (DTRA 2002:296).

Atmospheric Nuclear Testing

In the 1950s, the nuclear devices were initially dropped from airplanes, but due to efforts for greater monitoring and a general lack of control on air drops, the devices were placed near the ground, on top of towers, and eventually elevated by balloons to the desired height. Also at this time in the Pacific arena, high altitude tests of large yield were being performed, mostly by balloon, a few on rockets into outer space, and some on barges and underwater (Ogle 1985:49-50). Main objectives of the testing were for monitoring, measuring, perfecting techniques, and technological improvements of the nuclear weapons (Ogle 1985:84-85). Other objectives included physical effects (DTRA 2002:106). Some of the earliest physical effects experiments were on naval ships, while later experiments were carried out on airplanes, tanks, jeeps, automobiles, clothing, docks, different types of houses, underground structures, and radio and radar transmissions. At the NNSS, various structure and building designs were for civil defense, such as underground shelters, domed subterranean structures, concrete and brick buildings, residential houses, a metal bridge, and a bank vault. In some cases, U.S. Army personnel participated in the tests in order to prepare for nuclear warfare. Camp Desert Rock, located at the south edge of the NNSS, was created to house military and other personnel involved in the nuclear tests as participants or as observers (DTRA 2002:80, 85; Edwards 1997).

Underground Nuclear Testing

The concept of the underground nuclear test was not acted upon until the late 1950s when containment of the nuclear explosions became a major issue (Carothers 1995:16, 20; Johnson et al. 1959:2; Malik et al 1981:12; Byron Ristvet, personal communication 2006). Radioactive fallout was a safety and health concern for both the workers doing the tests and for the public at large. Following the signing of the Limited Test Band Treaty in 1963, all nuclear tests were designed to be contained underground except for four Plowshare cratering experiments (Schoengold et al. 1996:2).

Initially, underground testing posed a new engineering challenge and learning experience and not all tests were able to be contained right away. After a number of underground nuclear tests had been completed, it was determined that radioactive material from nuclear tests could be satisfactorily contained with proper depths of burial, stemming of the drill hole or tunnel, blocking seeps around cables and pipes, and understanding the surrounding geology for possible cracks or other weaknesses (Malik et al 1981:12-15).The first underground nuclear test in a tunnel, code named Saturn, was a safety experiment and took place at the U12c Tunnel in August 1957 (DOE/NV 2000:8). The Saturn test had zero yield. The Rainier nuclear weapons-related test with a yield of 1.7 kilotons was conducted in the U12b Tunnel a month later and was the first contained underground nuclear detonation in the world (Carothers 1995:31; DOE/NV 2000:10; Jones et al. 2006).

DTRA and the national research laboratories began studies in the mid 1950s on the development of underground complexes to meet their testing needs. Most of the underground nuclear tests at the NNSS have been for either weapons development or for weapons effects (DOE/NV 2000). A few tests had other purposes, such as safety experiments, industrial engineering for the Plowshare program, and seismic monitoring. Weapons development tests evaluated the performance of the nuclear device itself and were usually placed in vertical shafts; whereas, weapons effects tests evaluated the effects on critical components of missiles and warheads, and sometimes entire systems, and were usually conducted in horizontal tunnels deep below ground (Brady et al. 1989:2; Wolff 1984). Generally, two to four years went into the planning, preparation, construction, and post-test analyses of a single underground nuclear weapons effects test.

Another type of effects study was first started by the U.S. Army Corps of Engineers in the Underground Explosion Test program from 1948 through 1952 (MacDonald 1970:4). In this program the Corps of Engineers conducted high explosive tests of various magnitudes in unlined underground tunnels of various diameters in rock in different areas of the United States to study the damage resulting from the explosions. In 1957, the Rainier nuclear test on the NNSS mentioned above was also in an unlined tunnel (MacDonald 1970:5). Following the Rainier nuclear test, four more nuclear tests in tunnels were conducted in 1958, but this time the tunnels were lined with horseshoe-shaped metal sets and wood lagging. Damage to the tunnels of these four tests, Blanca, Evans, Logan, and Tamalpais, was not as pronounced and indicated that more substantial tunnel support could be obtained that would protect and thereby preserve the tunnel by lessening the effect of the explosion. This lead to further interest and development in having certain structures underground, particularly major command and control centers, that would be invulnerable to nuclear attack.

U15 Complex

Three underground nuclear tests and two underground spent nuclear fuel storage projects were conducted at the U15 Complex. Two of the nuclear tests, Hard Hat in 1962 and Piledriver in 1966, assessed the response of various kinds of underground structures to nuclear explosions as part of a program to design and develop certain facilities underground. The third nuclear test, Tiny Tot, in 1965, was an underground nuclear cratering and ground shock experiment. The Hard Hat test was conducted under Operation Nougat and was 5.7 kilotons in yield (DOE/NV 2000:19). Pile Driver was conducted under Operation Flintlock and had a yield of 62 kilotons (DOE/NV 2000:43). The Tiny Tot test was conducted under Operation Whetstone and the yield was less than 20 kilotons (DOE/NV 2000:39). The spent nuclear fuel storage projects began in 1976 and ended in 1985. The purpose of the projects was to demonstrate the feasibility of deep underground storage of spent fuel from commercial nuclear reactors in a granite or hard rock medium (Patrick 1986:1).

GEOLOGY AND GEOMORPHOLOGY

Most of the U15 Complex is situated on alluvial fan and pediment surfaces (Figures 2 and 5). With the exception of exploratory drill holes UE15m1, U15m3, and U15m3-1 located on the steep lower slopes of Oak Spring Butte, the U15 Complex is situated on southeast sloping pediment and alluvial fan surfaces. The principal access road leading to the site follows the alluvial fan surface from Yucca Flat. The road parallels and crosses an unnamed wash that heads on Paleozoic rocks, which outcrop in a low north-trending ridge east of Oak Spring Wash north and west of the main areas. The wash borders the large muckpile at the complex, which has partially filled the adjacent stream valley.

Drainages in the U15 Complex area typically are short and steep, or long with relatively low gradients. Drainage is mostly parallel. Streams flowing across the pediment surfaces and those associated with alluvial fans flow southeast toward Yucca Flat and have gradients of three to five percent. Gradients tend to steepen where they cross the trace of the Boundary fault. The south facing slopes of Oak Spring Butte are dissected by numerous short, steep, drainages. Most small surface drainages on the dissected pediment adjacent to the U15a/e shaft area have been disrupted by mining and site preparation activities as well as drainage control attempts. This is notable in the area between the U15a/e shaft area and drill hole U15 GZ #14 located about 1.3 km (0.7 miles) northeast.

In general, the soils of the NNSS are similar to those of surrounding areas and include Aridisols and Entisols. The degree of soil development reflects age, and the soil types and textures reflect their genesis. Entisols generally form on colluvium on steep mountain slopes and on fluvial deposits in stream valleys along active washes; Entisols have very little soil development and primarily consist of very thin A horizons and slightly weathered parent materials. Aridisols in the area commonly have strongly developed profiles reflective of greater length of time for soil development and tend to be found on stable alluvial fans and stream terraces.

In the U15 Complex area, patches of older hillslope soils formed on colluvium derived from Paleozoic carbonate and Tertiary volcanic rocks have well developed B horizons. These soils typically contain thick accumulations of calcium carbonate that coats stones, fills interstitial pore spaces in the B horizon, and forms a relatively impervious horizon. Along the Boundary fault, exploratory fault trenches expose extremely well-developed soils having reddened Bt horizons and strong accumulations of calcium carbonate. Elsewhere, hillslope soils are thin and weakly developed, minimally developed on tailings slopes, and weak to undeveloped along the wash at the base of the muckpile and on low terraces along larger drainages.

Four soil series were described in 1966 for the Area 15 area and included the Banded, Butte, Twin Peaks, and Thirsty series (Leavitt and Mason 1971). All series with the exception of Banded are classified as Typic Torrifluvents, which are characterized as young, coarse loamy, mixed, calcareous soils formed on fluvial and alluvial fan deposits. The Banded series is classified as Typic Durorthids, which are sandy, mixed, calcareous soils having a calcium carbonate- and silica-cemented C horizon. The Twin Peaks soil contains a buried soil with a reddened, well-developed, calcium-carbonate rich B horizon.

Figure 5. Overview and generalized geology of the U15 Complex area.

Geology of the U15 Complex Area

A number of geologic mapping efforts and compilations have been made in the area of the Climax stock intrusive area (Figures 6 and 7), including Barnes et al. (1963), Rogers and Nobel (1969), Frizzell and Shulters (1990), Swadley and Hoover (1990), and Slate et al. (2000). The geology of the U15 Complex area is described (Barnes et al. 1963; Frizzell and Shulters 1990; Slate et al. 2000) as consisting of Paleozoic (Ordovician) limestones, dolomite, and metasediments; a Mesozoic (Cretaceous) granodiorite and quartz monzonite stock intrusion; a complex sequence of Tertiary bedded volcanic tuffs; and Quaternary alluvial deposits (Figure 8). Paleozoic rocks consist of sedimentary rocks of the Ordovician Pogonip Group (Op). Tertiary rock units are represented by Miocene volcanic rocks that include older tuffs, tuffs, ash-fall tuff, and basalt of the Belted Range Tuff, (Frizzell and Shulters 1990; Slate et al. 2000). The Quaternary is represented by alluvial fans and pediments in the immediate U15 Complex area (Swadley and Hoover 1990).

Faults

Trenching studies were carried out in the 1970s and 1980s on several faults near and crossing the U15 Complex area (Figures 5-7) for purposes of defining the boundaries of the Climax stock intrusion and to assess the geologic materials response to nuclear testing. The U.S. Geological Survey excavated five bulldozer trenches: three trenches were placed across the north trending Tippinip fault along Oak Butte Wash west of the U15 Complex area, one trench across the Boundary fault southeast of U15 area and near the junction with the Yucca fault, and across bedrock contacts between the Climax stock and Paleozoic rocks in the west central part of the U15 area to define the nature of the contact (Figure 6). The Boundary fault, which had been previously explored with trenches by the U.S. Geological Survey in 1972 (2 trenches) and in 1980 by the U.S. Geological Survey and Lawrence Livermore National Laboratory (4 trenches), were reexamined by Orkild et al. (1983). Based on ages from laminar calcium carbonate exposed in soils (Szabo et al. 1981) and age estimates using fault scarp-slope techniques (Wallace 1977), the Boundary fault is thought to have formed in the latest Pleistocene (Orkild et al. 1983). The U.S. Geological Survey active fault database includes the Boundary and Yucca faults as being active faults having low slip rates (less than 0.2 mm per year) and last rupturing in the latest Pleistocene or Holocene (Anderson 1998a, 1998b). During this current study, fault scarp heights were measured using a hand level and found to be approximately 15 m (49 ft).

Surficial Geologic Units

The deposits of these units consist of alluvium, colluvium, and landslide deposits (Figure 9). They are considered to be Holocene, and likely late Holocene because of the weak to absent soil morphology indicative of appreciable soil development. The steep hillslope environment of the area also contributes to the absence of well-developed soils on the upper slopes because of mixing of the soil caused by mass wasting processes.

<u>Quaternary Alluvium (Qa)</u>. Quaternary alluvium is mapped along ephemeral stream channels and constitutes about 22 hectares (54 acres) or 10 percent of the mapped surficial geologic deposits. It consists of thin deposits of unconsolidated silt, sand, and gravel transported and deposited during

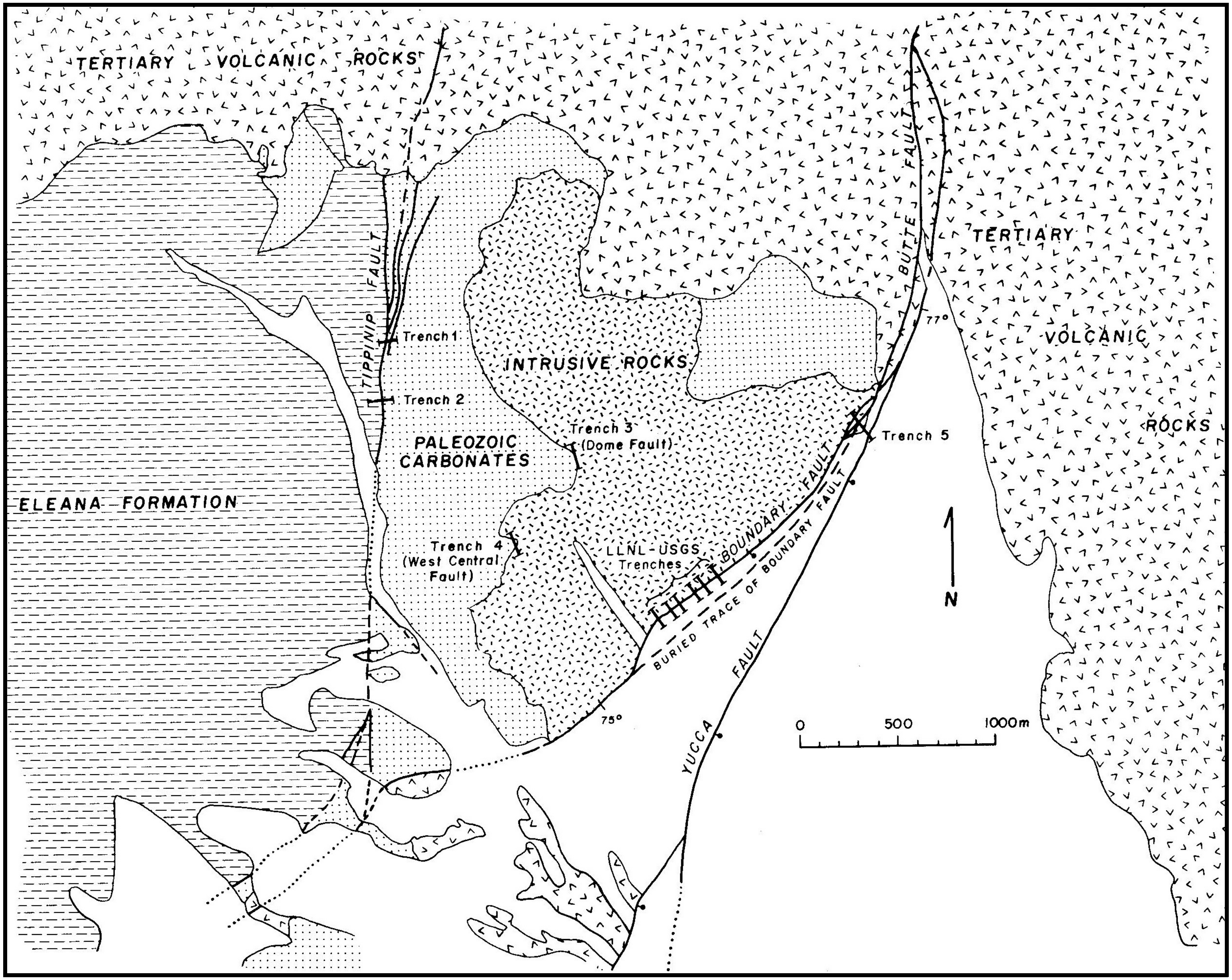

Figure 6. Geologic map of the U15 Complex area and Climax stock intrusion.

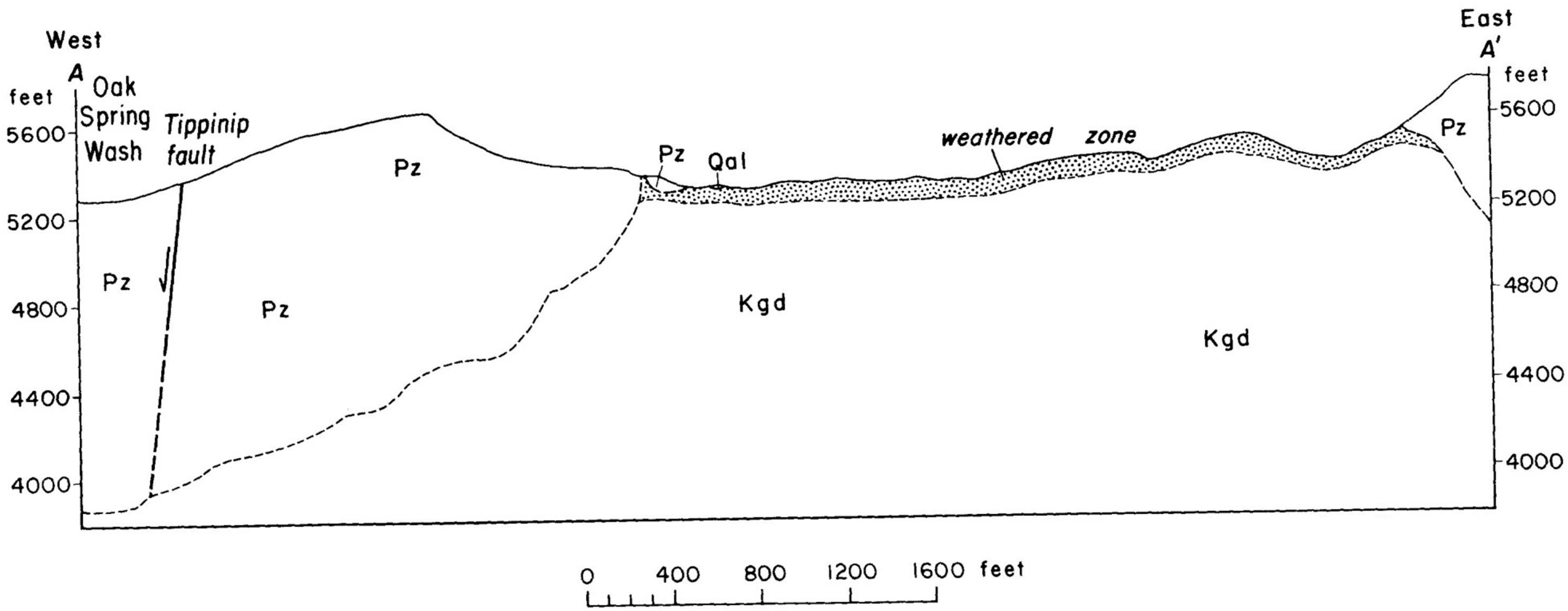

Figure 7. Generalized east-west section through the Climax Stock (Orkild et al. 1983).

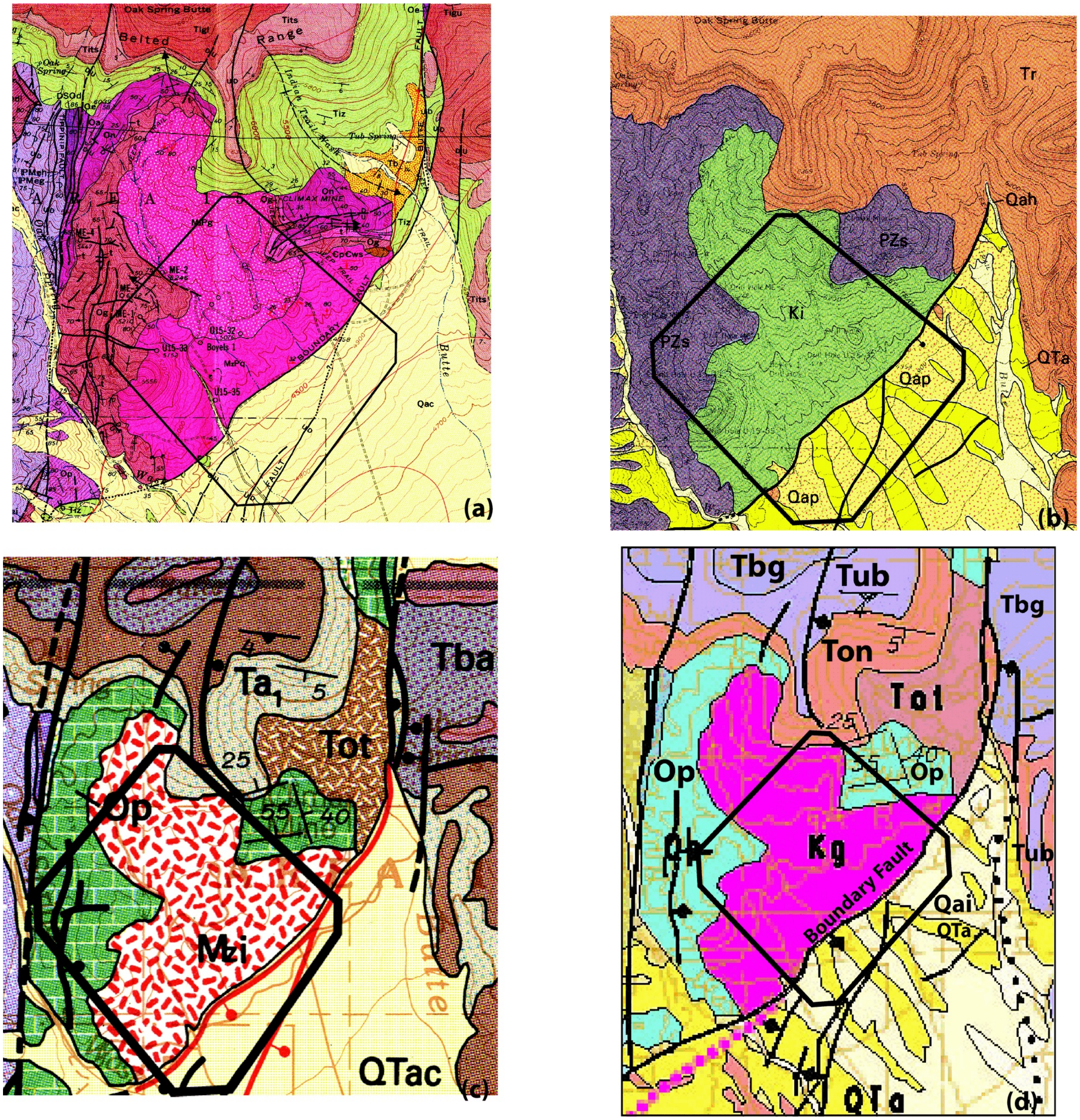

Figure 8. Portions of geologic maps for the U15 Complex area: (a) 1:24,000 scale geologic map by Barnes et al. (1963); (b) 1:48,000 scale surficial geologic map of Swadley and Hoover (1990); (c) 1:100,000 scale geologic map of Frizzell and Shulters (1990); (d) 1:120,000 scale geologic map of Slate et al (2000).

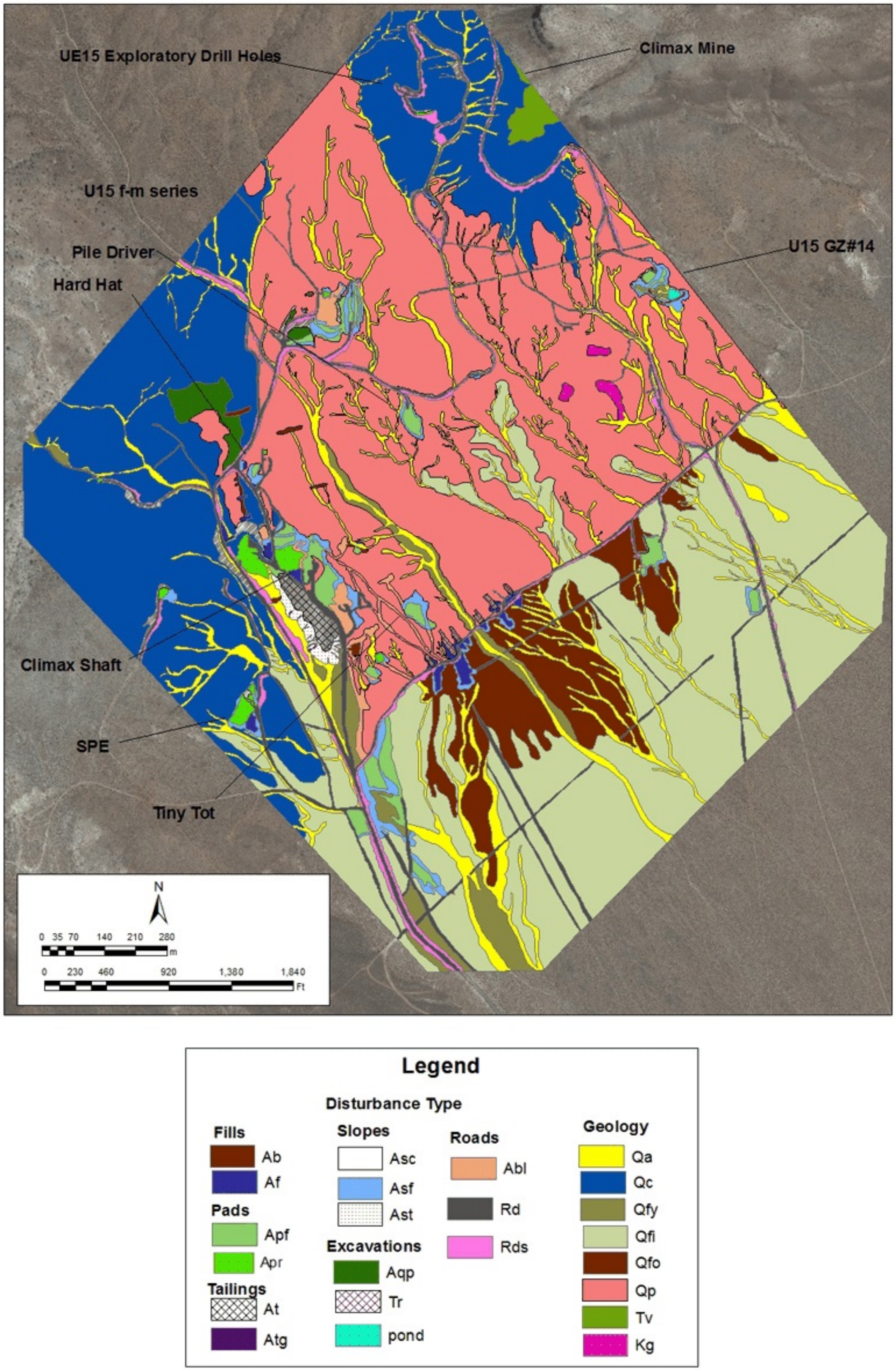

Figure 9. U15 Complex area showing bedrock outcrop, surficial deposits, and areas disturbed during development and testing activities.

rain events and snow melt of magnitudes sufficient to generate runoff. Quaternary alluvium is derived from erosion of hillslopes, tailings piles, and channel margins.

Quaternary Alluvial Fans (Qfy, Qfi, Qfo). Alluvial fans are prominent in the area south of the Boundary fault (Figures 5 and 9). Based on surface morphology, tonal qualities, and landscape position it was possible to differentiate three alluvial fan units and assign relative ages. A few exposures of the different fan units supports the relative chronology based on surface characteristics and soil morphology.

Young Alluvial Fans (Qfy). These young fans (Figure 10) are comprised of unconsolidated, poorly to moderately sorted, intermixed and interbedded gravel, sand, and silt. The young alluvial fans retain prominent evidence of original depositional topography (bar and swale topography) and can include fluvial, colluvial, and eolian components. These fan surfaces lack a desert pavement and desert varnish development. There is little to no soil development, typically consisting of a very thin A horizon and an unweathered C horizon. Young alluvial fans are Holocene age.

Intermediate Age Alluvial Fans (Qfi). The intermediate age fans (Figure 10) are comprised of weakly consolidated, poorly to moderately sorted, intermixed and interbedded gravel, sand, and silt representing fluvial, colluvial, and eolian components. Intermediate age fans are inset into older alluvial fans (Qfo) and pediment surfaces (Qp). These alluvial fans retain muted evidence of original depositional topography (bar and swale topography), including debris flow deposits. In general, the surface is planar and has a moderately packed to densely packed desert pavement with moderately- to well-varnished clasts. Soil development ranges from profiles with a pinkish-brown cambic B horizon and stage I-II carbonate horizon to profiles having pinkish-brown argillic B horizons and 1 m- thick stage III-IV carbonate horizons. Intermediate age alluvial fans are late Pleistocene to early Holocene age.

Older Alluvial Fans (Qfo). Older alluvial fan remnants are comprised of consolidated to cemented, poorly to moderately sorted, intermixed and interbedded gravel, sand, and silt representing fluvial, colluvial, and eolian components. Evidence of original depositional topography (bar and swale topography) and debris flow deposits is weak to absent. In general, the surface is planar and has a moderately- to densely-packed desert pavement and variable but strong desert varnish on clasts. The surfaces are typically eroded and dissected by drainages originating on the fan surface. Soils found on older fans have up to 2 m (6.6 ft) thick stage III-IV carbonate horizons; argillic horizons, if present, are reddened, have strong morphology, and generally post-date erosion. Older alluvial fans are Pleistocene age.

Quaternary Pediment Surface (Qp). Pediment surfaces (Figure 10) are erosional surfaces formed on the Mesozoic granodiorite and quartz monzonite of the Climax stock intrusion. Surface deposits are thin and generally consist of gravel and weathered granitic rocks. Soils are thin and range from weak to strongly developed. The pediment surfaces are dissected and form broad interfluves commonly referred to as ballena topography.

Quaternary Colluvium (Qc). Quaternary colluvium (Figures 6 and 11) is mapped throughout the area and consists of a very thin veneer, generally 0.5 m (1.6 ft) or less of silt, sand, gravel, angular cobbles, and angular boulders derived from Tertiary volcanic rocks in the Belted Range and a variety

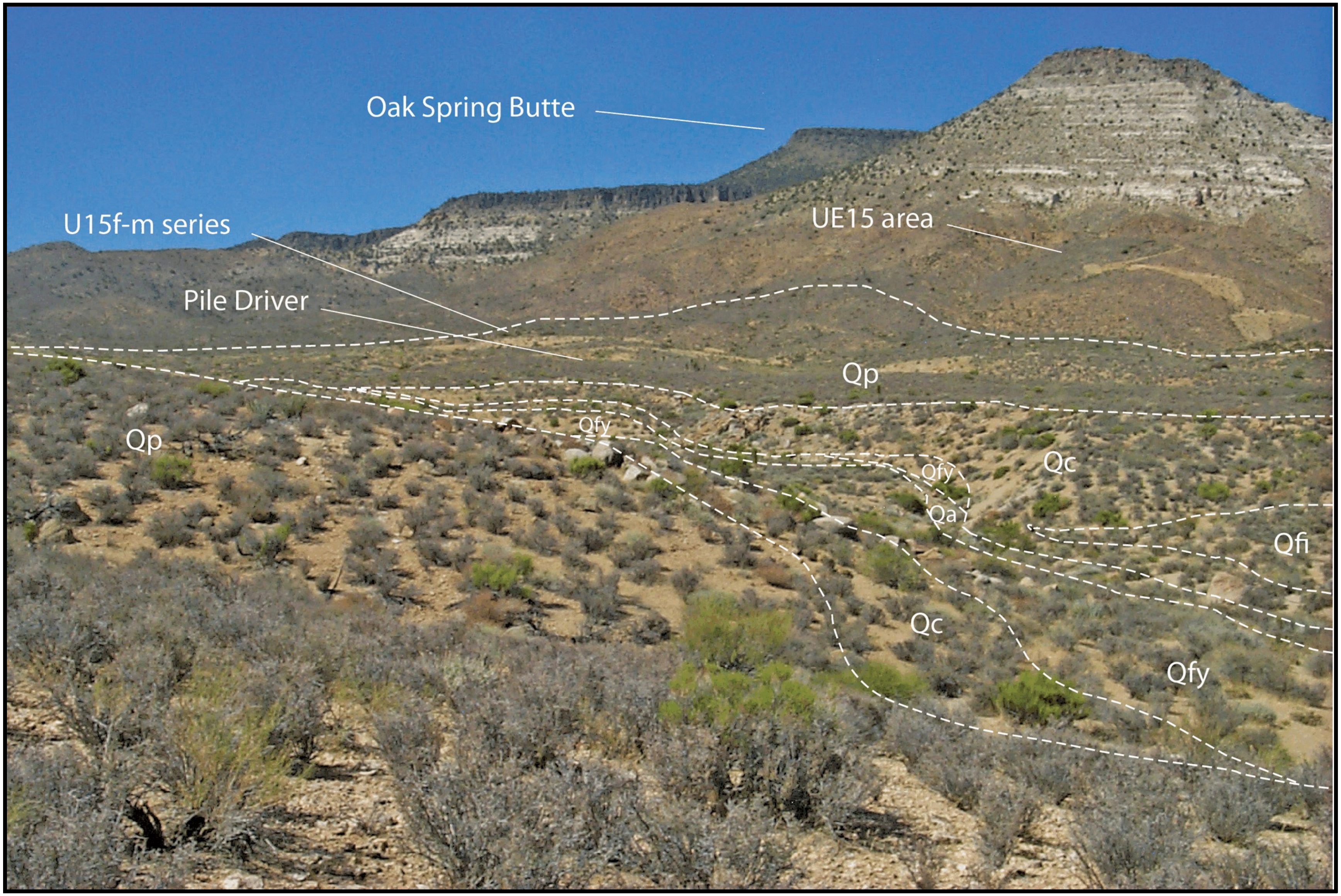

Figure 10. View of incised pediment (Qp) in the vicinity of the Pile Driver test site. Active alluvium (Qa) is present in the incised valley along with small remnants of young (Qfy) and intermediate (Qfi) age alluvial fans. Surface disturbance associated with the UE15 exploratory drill hole sites at the base of Oak Spring Butte and the cut-and-fill pads at the U15f-m site are conspicuous.

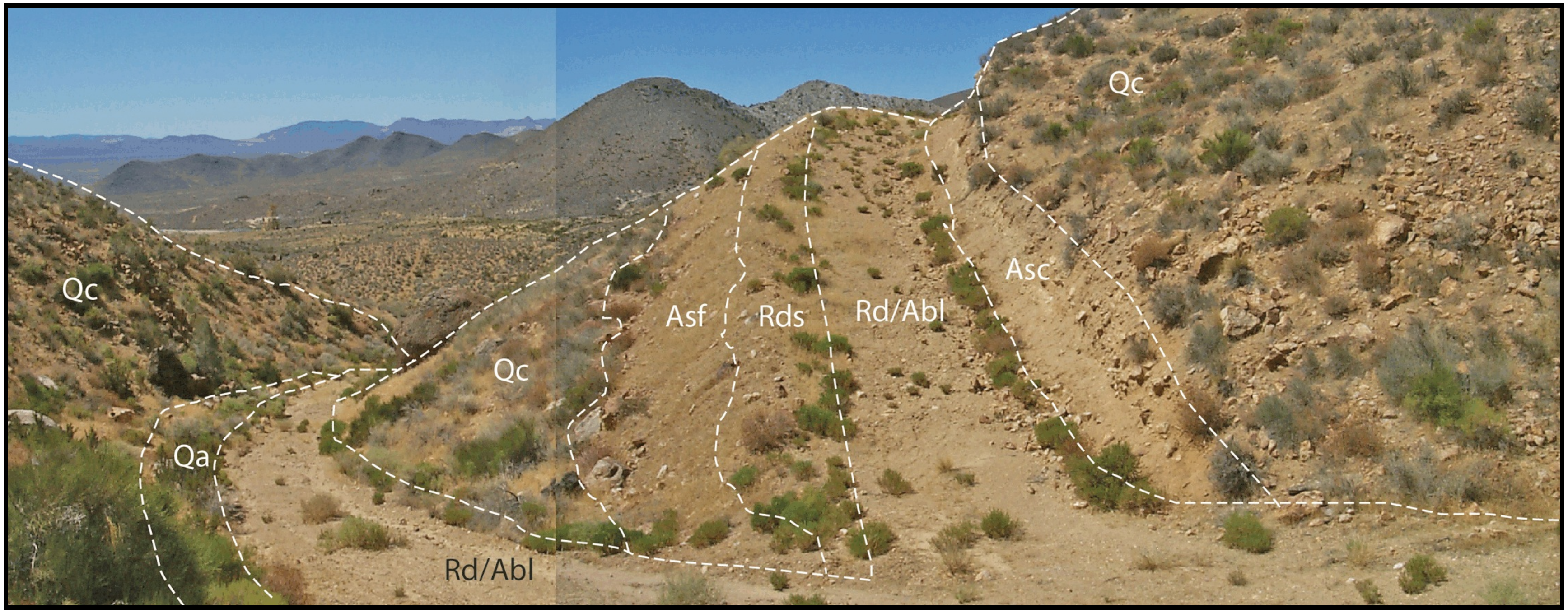

Figure 11. View of the access road (Rd/Abl) to the UE15 drill pads, cut slopes (Asc), fill slopes (Afs), road side-cast (Rds), active alluvium (Qa), and Quaternary colluvium (Qc). Access road is on bedrock and thin veneer of alluvium from runoff. Small vegetated prism of colluvium is present at the base of the cut slope.

of carbonate rocks derived from the Pogonip Group west of the shaft area. All grain sizes can be derived from the mechanical and chemical weathering of bedrock units in the area; however, the local presence of a thin, silt-rich soil crust indicates that an eolian component is probably present in the colluvium. Colluvium covers about 51.2 hectares (126.5 acres) and represents about 23 percent of the mapped area of surficial geology.

Older Geologic Units

Geologic units represented in the U15 area include Paleozoic sedimentary rock (Op) exposed on the western edge of the study area in the vicinity of the Source Physics Project (SPE) and in the vicinity of the Climax Mine site, Tertiary volcanic rocks in the extreme northeast part of the area on the slopes below Oak Spring Butte, and granodiorite and quartz monzonite associated with the Climax stock throughout most of the area. The mapped bedrock covers about less than one percent of the study area; however, much of the areas mapped as colluvium could have easily been included as bedrock.

Geomorphology of the U15 Complex Area

Area for the geomorphology field study is about 252 hectares (622 acres) and extends about 150 m (492 ft) west of the main area and about 800 m (2,625 ft) to the east along the access road parallel to the Boundary fault. The study area also includes part of the access road to the historic Climax mine site. Topographic relief across much of the study area is less than 20 m (66 ft). In the northeast part of the study area the relief is about 60 to 80 m (197 to 262 ft) and about 150 m (492 ft) on the carbonate ridge on the west side. The main paved access road from Yucca Flat is situated on an alluvial fan surface and parallels one of the many streams associated with active alluvial fans.

Principal geomorphic components include narrow ephemeral stream valleys, dissected broad erosional (pediment) surfaces, alluvial fan surfaces, bedrock ridges and outcrops, steep rocky hillslopes, and prominent resistant bedrock ledges. Hillslopes commonly have a thin mantle of sandy and silty colluvium and large angular boulders shed from local bedrock exposures. Resistant bedrock ledges are bare of vegetation, but it is common to find sparsely vegetated colluvial wedges at the foot of ledges and cut slopes. Ephemeral stream valleys are generally less than 20 m (66 ft) wide and in places only as wide as the channel that occupies them. Stream valleys typically are vegetated with grasses and low woody shrubs.

Dominant geomorphic processes are slow to rapid mass wasting on the slopes of Oak Spring Butte and Quartzite Ridge, fluvial erosion and deposition, and eolian deposition. Rill and gully erosion of the artificial fill and muckpile occurs during rainstorms and snowmelt. Fluvial processes occur primarily as overland flow on road surfaces and steep slopes on tailings and as channelized flow. Channelized flow occurs as rivulets on hillslopes, road cuts, and roads; rills and small gullies on roads, ditches, and tailings; and as channels and tributaries of the main drainage systems. Eolian processes have minor areal extent and are primarily related to dust emissions from roads and disturbed areas.

Two principal types of mass wasting processes are creep and rock fall. Creep, the imperceptible downslope movement of the surficial mantle, occurs on most colluvium mantled hillslopes, fill slopes, cut slopes, and tailing piles. Rock falls and rock slides appear to originate on the upper slopes and from the densely welded tuff of the Indian Trail Formation along the rim of Oak Spring Butte and from carbonate rocks of the Ordovician Pogonip Group at the Climax mine site. Very small, localized slope failures are associated with some artificial cut slopes as evidenced by small (less than 200 m sq [2,153 ft sq] and a volume of 5 to 10 cubic m [177 to 353 cubic ft]) debris cones and fans that spill onto the floodplain adjacent to the tailings area.

Historic Deposits and Modifications to the Landscape

Modifications to the landscape during and since testing were mapped (Figure 6). Mapping units consist of the types and extent of historic surface modification that likely occurred during and after development of the U15 Complex area, including road and infrastructure construction (Tables 2 and 3). These modifications include the following historical deposits and disturbances (map unit symbol provided):

1) Artificial fill used as berms (Ab) for drainage control and artificial fill (Af);
2) Construction pads built on fill (Apf) and on bedrock or pediment surfaces (Apr);
3) Mine waste rock (muck, tailings, At) used as fill (Af) and erosion and gullying of the muckpile (Atg);
4) Slopes formed during road construction are characterized as either cut slopes (Asc) or fill slopes (Asf), and slopes on muckpiles (Ast);
5) Excavations include quarries and miscellaneous pits (Aqp), fault exploration trenches (Tr) and retention ponds (Ap);
6) Road related disturbances including pads, bladed paths or roads (Abl), roads (Rd), and material cast to the side of the road during construction (Rds).

Artificial Fill

Artificial fill is derived from muckpiles, quarries and borrow pits, cut slopes, and even import from off site. Typically, fill is used to construct berms, pads, and roads.

<u>Berm (Ab)</u>. Artificial berms cover about 0.4 hectares (0.9 acres) and represent 1.3 percent of the disturbed area. Artificial berms are linear piles of poorly compacted fill material that have been emplaced as drainage control structures. Most of the drainages in the U15 Complex area have one or more drainage control structures crossing the ephemeral stream channels.

<u>Fill (Af)</u>. Anthropogenic fill deposits cover about 0.9 hectares (2.2 acres) and represent 3.1 percent of the disturbed ground. Many of the flat areas of artificial fill are vegetated with grasses and low shrubs. Fill is commonly emplaced simply by dumping muck and/or quarried material into topographic lows and continuing to dump until the fill is built to a desired level, or by the same process but engineered by careful selection of material size and composition, adequate mixing, and compaction in designed layers, or lifts. For building and major highway construction, engineered fill is normally required. It is not known if the artificial fill in staging areas in the U15 Complex area was engineered or simply dumped on the existing surface. Because there is no obvious cracking of concrete pads, or displacements of the fills after nearly 60 years, it is likely that some form of compaction was used. The composition of the fill indicates that the source of fill material was in

Table 2. Historic Surface Modifications in the U15 Complex Area.

Map Symbol	Map Unit	Description
Artificial Fill		
Ab	Berm	Simple fill pile, commonly placed for drainage control (e.g., check dam)
Af	Fill	Mechanically placed fill derived primarily from tunnel development or quarries
Constructed Pads		
Apf	Constructed pads – fill	Construction and drill pads formed on artificial fill material
Apr	Constructed pads – rock	Construction and drill pads formed on rock
Muckpile/Tailings		
At	Mine muck and tailings	Mine waste (muck) dumped in valleys and on hill slopes
Atg	Gullied muckpile	Muckpile/tailings slopes with defined gully networks and rills
Slopes		
Asc	Cut slopes	Slopes cut in bedrock or colluvium during road construction
Asf	Fill slopes	Slopes formed on fill placed during road and drill pad constructions
Ast	Muckpile slopes	Slopes formed on muckpiles
Excavations		
Aqp	Pit	Quarry or borrow pit, drilling mud pit
Tr	Trench	Exploratory bulldozer trenches across Boundary fault
Ap	Pond	Shallow holding ponds to capture surface runoff and capture sediment
Road Related		
Abl	Bladed	Ground disturbed by simple grading with road grader or bulldozer
Rd	Road	Principal access roads in U15 area
Rds	Road side-cast	Material pushed onto slopes during road grading and fill emplacement
Geology		
Qa	Alluvium	Late Holocene alluvium associated with ephemeral stream channels
Qc	Colluvium	Late Holocene mantle of bedrock derived colluvium, eolian dust, and weathered bedrock on slopes.
Qfy	Young alluvial fan	Holocene alluvial fans; irregular surface, no desert pavement or varnished clasts, weak soil development.
Qfi	Intermediate age alluvial fan	Early Holocene and Pleistocene alluvial fans; muted depositional topography; moderate to strong desert pavement and varnished clasts; soils with reddened calcic Bw horizons and Bt horizons with stage III+ carbonate accumulations.
Qfo	Older alluvial fan	Pleistocene alluvial fan remnants; variable desert pavement and clast varnish; remnant soils consist of thick stage III-IV calcic and petrocalcic horizons; red, argillic B horizons are post-erosion of older soil.
Qp	Pediment surface	Beveled bedrock surface, broad to rounded ridges (ballena); remnants of soils usually consist of fractured petrocalcic horizon material; in places no soil has developed; mantled by granitic grus in many places.
Tv	Tertiary volcanics	Volcanic rocks (air fall and ash-flow tuffs, welded tuffs, basalt, rhyolite of the Belted Range Group (Slate et al., 2000)
Kg	Cretaceous granitics	Granodiorite and quartz monzonite stocks (Climax stock) (Slate et al., 2000)

Table 3. Relative Areas of Disturbance.

Anthropogenic Disturbances (comprise 11% of map area)					Percentage of Disturbed Area
Map Unit	**Description**	**m^2**	**Hectares**	**Acres**	
Artificial Fill					
Ab	Berm	3,740	0.4	0.9	1.3
Af	Fill	8,778	0.9	2.2	3.1
Constructed Pads					
Apf	Pad – fill	31,383	3.1	7.8	11.2
Apr	Pad – rock	9,874	1.0	2.4	3.5
Muckpile/Tailings					
At	Muckpile/Tailings	7,634	0.8	1.9	2.7
Atg	Gullied muckpile	527	0.1	0.1	0.2
Slopes					
Asc	Cut slope	15,342	1.5	3.8	5.5
Asf	Fill slope	32,017	3.2	7.9	11.4
Ast	Muckpile/tailings slope	5,646	0.6	1.4	2.0
Excavations					
Aqp	Pit	14,372	1.4	3.6	5.1
Tr	Trench	2,478	0.2	0.6	0.9
Ap	Pond	511	0.1	0.1	0.2
Road Related					
Abl	Bladed ground	17,775	1.8	4.4	6.3
Rd	Road	85,513	8.6	21.1	30.4
Rds	Road side cast	45,866	4.6	11.3	16.3
	Totals	281,456	28.1	69.5	100.0

Bedrock and Surficial Geologic Units (comprise 89% of map area)					Percentage of Bedrock & Surficial Deposit Area
Map Unit	**Description**	**m^2**	**Hectares**	**Acres**	
Qa	Alluvium	217,285	21.7	53.7	9.7
Qc	Colluvium	512,004	51.2	126.5	22.9
Qfy	Fan – young	4,7970	4.8	11.9	2.1
Qfi	Fan – intermediate age	584,388	58.4	144.4	26.1
Qfo	Fan – old	132,068	13.2	32.6	5.9
Qp	Pediment	728,906	72.9	180.1	32.6
Tv	Tertiary – volcanics	9,065	0.9	2.2	0.4
Kg	Cretaceous granite	4,234	0.4	1.0	0.2
	Totals	2,235,920	251.7	622.0	100.0

large part from quarried material, especially in areas more distant from the mine shaft, although around the mine shaft area it appears that a mix of mined and native material was used.

Constructed Pads

A variety of pads were constructed for the siting of buildings, drilling pads, or miscellaneous equipment yards. Pads were constructed on fill as well as on bladed bedrock or pediment surfaces.

Constructed Pads on Fill (Apf). Building and drilling pads on fill material comprise about 3.1 hectares (7.8 acres) and represent 11 percent of the mapped disturbed area. The constructed pads on fill are made of leveled and compacted fill material and were sites for drilling equipment, drill holes, instrumentation, small buildings, and trailer parks. In many cases the thin surficial deposits of pediment surfaces were removed and a thin fill was placed over the bedrock or pediment. In other cases, the fill was added above existing surficial geologic deposits. In the UE15 exploratory drill hole sites the slope colluvium was cut to bedrock and fill placed over bedrock to create a smooth level surface.

Constructed Pads on Rock (Apr). Building and drilling pads on leveled rock surfaces comprise about 1 hectare (2.4 acres) and represent 3.5 percent of the mapped disturbed area. The constructed pads on rock were placed on top of bladed weathered granite or very thin pediment deposits that were leveled; these appear to have been sites for non-critical equipment storage areas and mining equipment sites. The pads on leveled rock surfaces are most prevalent in the area around the Hard Hat and Tiny Tot tests and around the U15a/e shaft area.

Muckpile/Tailings

The muckpile is a prominent feature formed from mined waste rock. Construction of muckpiles generally impacts drainages as well as flora and fauna. Long-term erosion of muckpiles can have impacts well into the future.

Muckpile/Tailings (At). The muckpile at the U15 Complex consists of waste rock (muck) mined during tunnel construction and post-event re-entry of underground workings. In typical mining operations, as mining progresses, the muck removed following drilling and blasting is dumped at or near the mine shaft. As more and more material is removed, a broad area is built up to accommodate other project-related infrastructure, such as buildings, equipment yards, or staging areas. As the muckpile expands vertically and horizontally, muck may travel down slope until the angle of repose is attained (Figures 9, 12-13). There is no doubt that during initial underground development a certain volume of material was dumped directly onto the slope adjacent to the shaft areas. Muck from underground mining activity covers about 7,600 square meters surface area and comprise about 2.7 percent of the mapped disturbed area. The existing prism of muck is more than 250 m long, about 150 m wide. Borehole data through the tailings indicate that the thickness of the tailings range from about 3 m at the northern end to about 10 m at the southern end of the pile (Figure 14). The muckpiles are estimated to contain approximately 122,600 cubic meters (160,333 cubic yards) (Defense Threat Reduction Agency 2007).

Figure 12. View northeast of the muckpile (At). Shown are rilled and gullied muckpile (Atg) on the muckpile slopes (Ast). Also visible are roads (Rd) and road side-cast (Rds).

Figure 13. Alluvial valley partially filled with the muckpile (At and Ast) on the left and road side-cast (Rds) on the right. Also visible is active alluvium (Qa) and a prominent berm (Ab) placed across the stream to control runoff.

Rilled and Gullied Muckpile/Tailings (Atg). The muckpile is subjected to rilling and gullying on the relatively unvegetated slopes (Figures 12 and 13). These rilled deposits are characterized by dendritic networks of rills, parallel rills, and shallow gullies of less than 1 m (3.3 ft) deep. Approximately 527 sq m (5,673 sq m) of unvegetated tailings are covered with visible gullies. This area represents less than 0.5 percent of the muckpile slopes.

Gullies are prominent sites of intense vertical and lateral erosion of the muckpile. The gullied tailings occur on unvegetated portions of the muckpile slope and may be several meters wide. The expansion of individual gullies commonly occurs by fluvial erosional processes, but localized slope failure of banks, localized debris flow, and sapping processes also occur. In some locations the gullies have expanded into dendritic drainage patterns that extend to the top of the muckpile slope. The major gullies are associated with poorly controlled surface drainage in the broad, relatively level areas formerly used as staging areas and equipment storage. The rills and gullies have supplied, and are capable of supplying, substantial volumes of fine-grained sediment to the stream system adjacent to the muckpile.

Slopes

In addition to natural slopes, there are numerous example of slopes formed during construction activities. These include slopes formed by muckpiles. More pervasive are slopes associated with cut and fill features, such as building pads, benched pads, and roads.

Cut slope (Asc). Cut slopes are formed principally during road construction and maintenance activities, and during excavations and preparations for pads, pits, and buildings (Figures 11 and 15). Cut slopes are commonly associated with small colluvial wedges of loose rock and soil shed from bedrock or fill cut slopes. Cut slopes are associated with access road preparation and are particularly notable on steep slopes. In general, large volumes of friable bedrock and colluvium may be removed depending on road alignment. Road cuts may be many meters tall where road alignment and topography require significant excavation into a hillslope but generally the cut slopes are less than 2 m (6.6 ft) tall. The material excavated from cut slopes is commonly used in road and pad construction activities, especially to fill minor topographic lows, increase the width of road or pad, or raise the road bed or pad elevation. As a pad or roadbed is constructed, material is bladed to the edges of the road or pad and commonly spills onto adjacent hillslopes. In the U15 Complex area, cut slopes occupy about 1.5 hectares (3.8 acres) and comprise 5.5 percent of the mapped disturbed surface area. Cut slopes in colluvium tend to shed sediment into roadside ditches or onto the pad where it can restrict drainage and can result in gullies forming on road surfaces.

Fill slope (Asf). Fill slopes cover approximately 3.2 hectares (7.9 acres) and comprise 11.4 percent of the disturbed area. Fill slopes, other than fill slopes formed on the U15a/e muckpile, are found along the edges of fill prisms, construction pads built on fill, trailer park pads, stream crossings, and portions of road beds (Figure 16). Fill slopes are often prone to rilling and gullying, which can inundate adjacent native terrain with sediment.

Muckpile/Tailings slopes (Ast). The slopes formed on the U15a/e muckpile cover an area of about 0.6 hectares (1.4 acres) and comprise 2 percent of the disturbance area. The muckpile has filled a portion of a main tributary and part of the valley of the trunk stream system. Much of the native

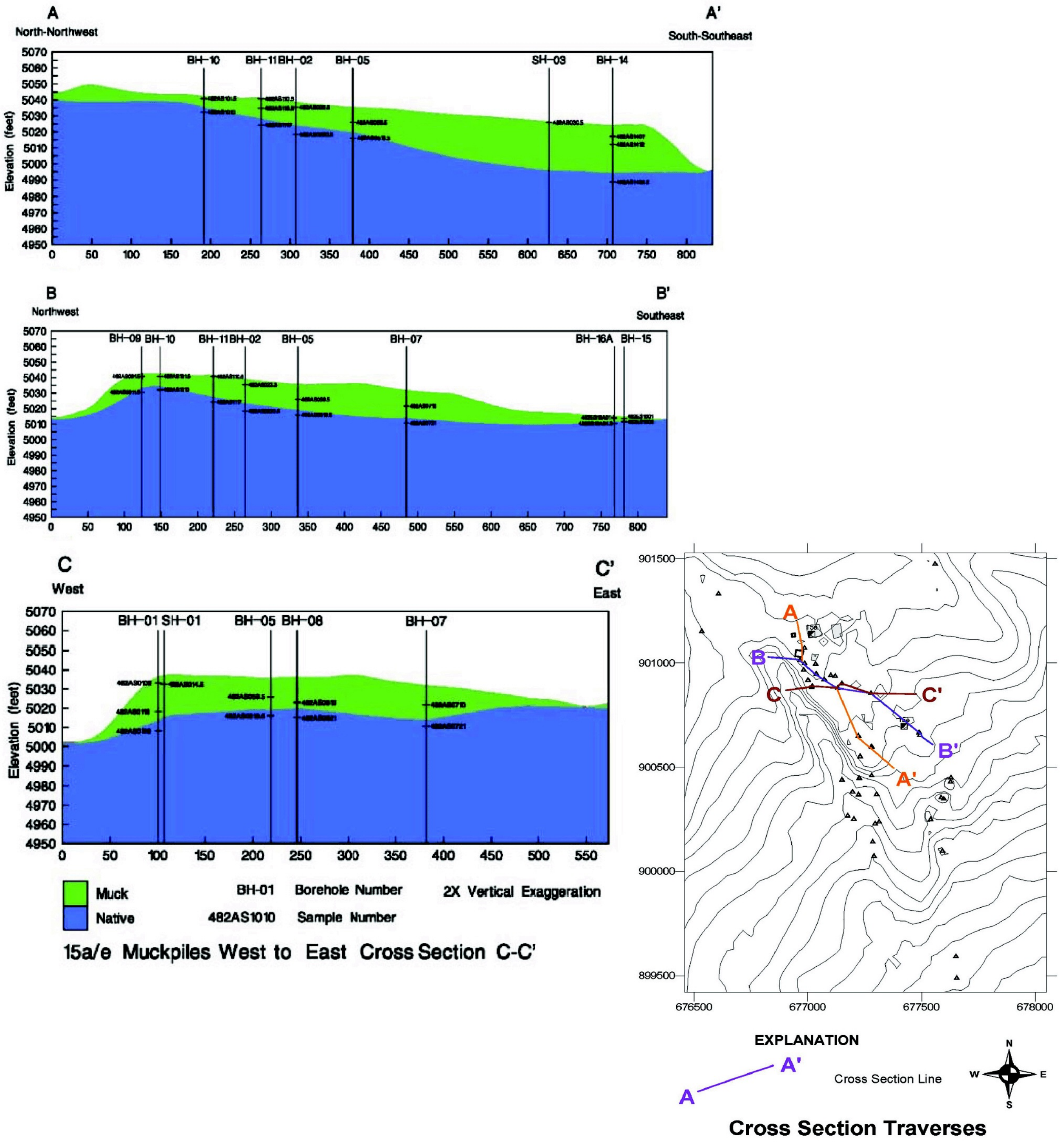

Figure 14. Cross sections through the muckpiles (Defense Threat Reduction Agency 2007).

Figure 15. Constructed pad (Apf) and fill slopes (Asf) near the Pile Driver test (top); and fill pads and benches cut in fill (Apf) and pediment surface (Apr) in the U15f-m series area (bottom).

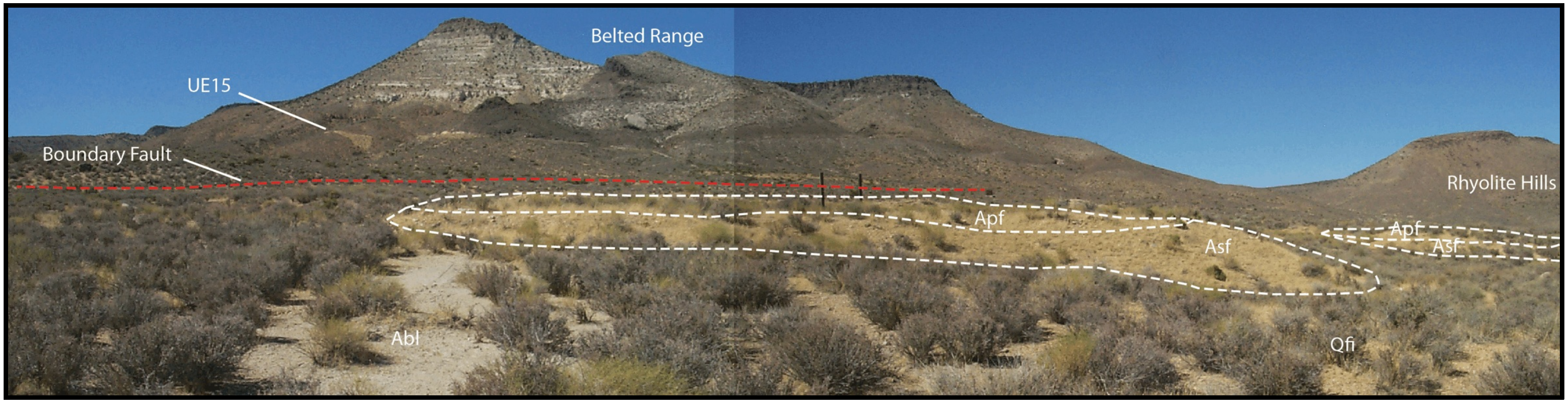

Figure 16. Examples of fill slopes (Asf) along the edges of fill pads (Apf) south of the Boundary fault (red dashed line).

vegetation has been destroyed and little vegetation other than grasses and sparse sage and rabbit brush has established in the intervening decades since the last mining activities were undertaken. Small rill networks have developed on the slopes and provide an effective transport linkage between potentially hazardous tailings and the downstream geomorphic and hydrologic systems (see Defense Threat Reduction Agency, 2007). Several large gully systems have formed resulting in the introduction of substantial volumes of sediment onto the lower slopes and into the stream system (Figures 12 and 13).

Excavations

Excavations in the U15 Complex area include quarries and borrow pits, trenches, and ponds. Some ponds may be excavated, whereas others are formed by simply blocking a drainage with a berm of fill.

Pit (Aqp). Borrow pits and quarries present in the U15 Complex area are associated with drilling mud pits, small borrow areas, and larger quarries for construction fill materials (Figure 17). This unit covers 1.4 hectares (3.6 acres) and comprises 5.5 percent of the mapped disturbed area. The largest borrow pit is located north of U15e. The ground surface within or adjacent to pits and quarries is typically irregular, drainage lines have been disrupted, and berms were placed as surface runoff control structures along drainages.

Trench (Tr). The trace of the Boundary fault (Figures 5, 6, 8, 9, 16), which lies to the south of the main area is expressed by a scarp that was measured to be about 15 m (49 ft) high. In 1972, the U.S, Geological Survey excavated two bulldozer pits across the Boundary fault to characterize the geometry and to gain additional knowledge regarding the boundary of the Climax stock. Four additional trenches were excavated by Lawrence Livermore National Laboratory in 1980 and subsequently were reexamined by Orkild et al. (1983). These trenches range from 20 to 40 m (66 to 131 ft) long, 8 to 15 m (26 to 49 ft) wide, and 3 to 5 m (10 to 16 ft) deep (Figure 18). The fault places pediment surfaces formed on the granodiorite and quartz monzonite rocks of the Climax stock intrusive against alluvial fan deposits that have a very thick petrocalcic horizon that forms a resistant ledge in the exposed trench walls. The unconsolidated nature of the deposits exposed in the trench walls and sloughing of surface deposits into the trench has resulted in the partial filling of the trenches. Excavated material from the trenches was pushed into large piles on the south end of the trenches (Figures 18 and 19).

Artificial pond (Ap). Retention ponds were constructed for the purpose of capturing water and sediment runoff from the tailings slopes, test areas, and drill holes. One of the more prominently visible ponds is on the eastern edge of the U15 Complex area near drill hole U15 GZ#14. The pond is situated below a series of benched cut and fills benches (Figure 20). A constructed berm at the south end captures runoff from the GZ#14 area and an adjacent stream. Small alluvial fan-like lobes of sediment are clearly visible on the most upstream part of the pond.

Figure 17. Quarry and borrow pit (Aqp) north of U15a area. Cut slopes (Asc) in Paleozoic bedrock (Op) and colluvium are visible. Prominent berm (Ab) has been pushed into place on borrow pit floor to control runoff.

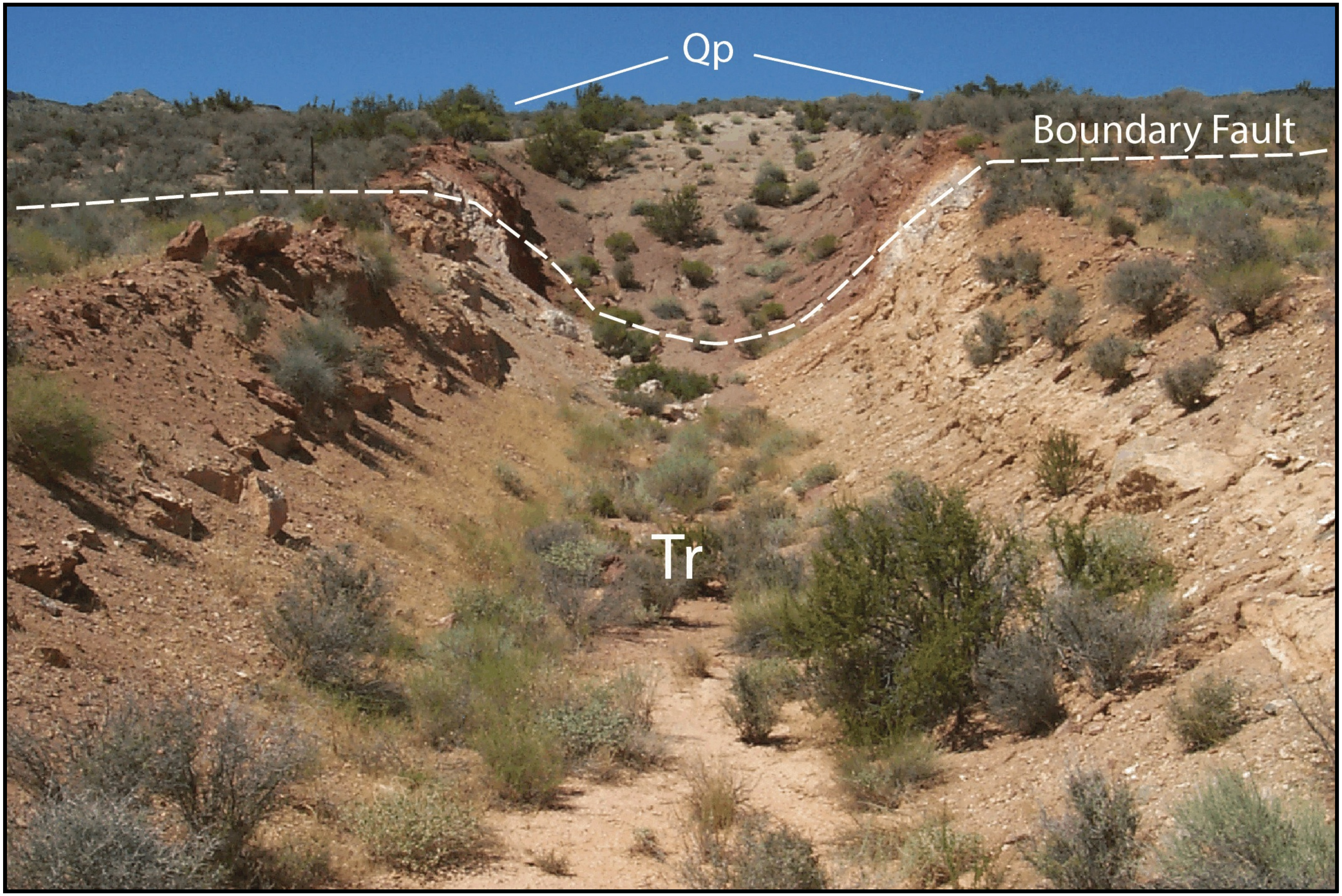

Figure 18. View north of bulldozer trench excavated across the Boundary fault. Trench (Tr) shows contact of old alluvial fan remnants with altered quartz monzonite in the fault zone, remnants of pediment (Qp) and partially filled trench from colluvium derived from trench walls and pediment and fan surfaces.

Figure 19. View south toward Yucca Flat of bulldozer trench excavated across the Boundary fault. Trench shows the resistant ledge formed of calcium carbonate, partially filled trench floor, and spoil pile (Af) derived from trench excavation.

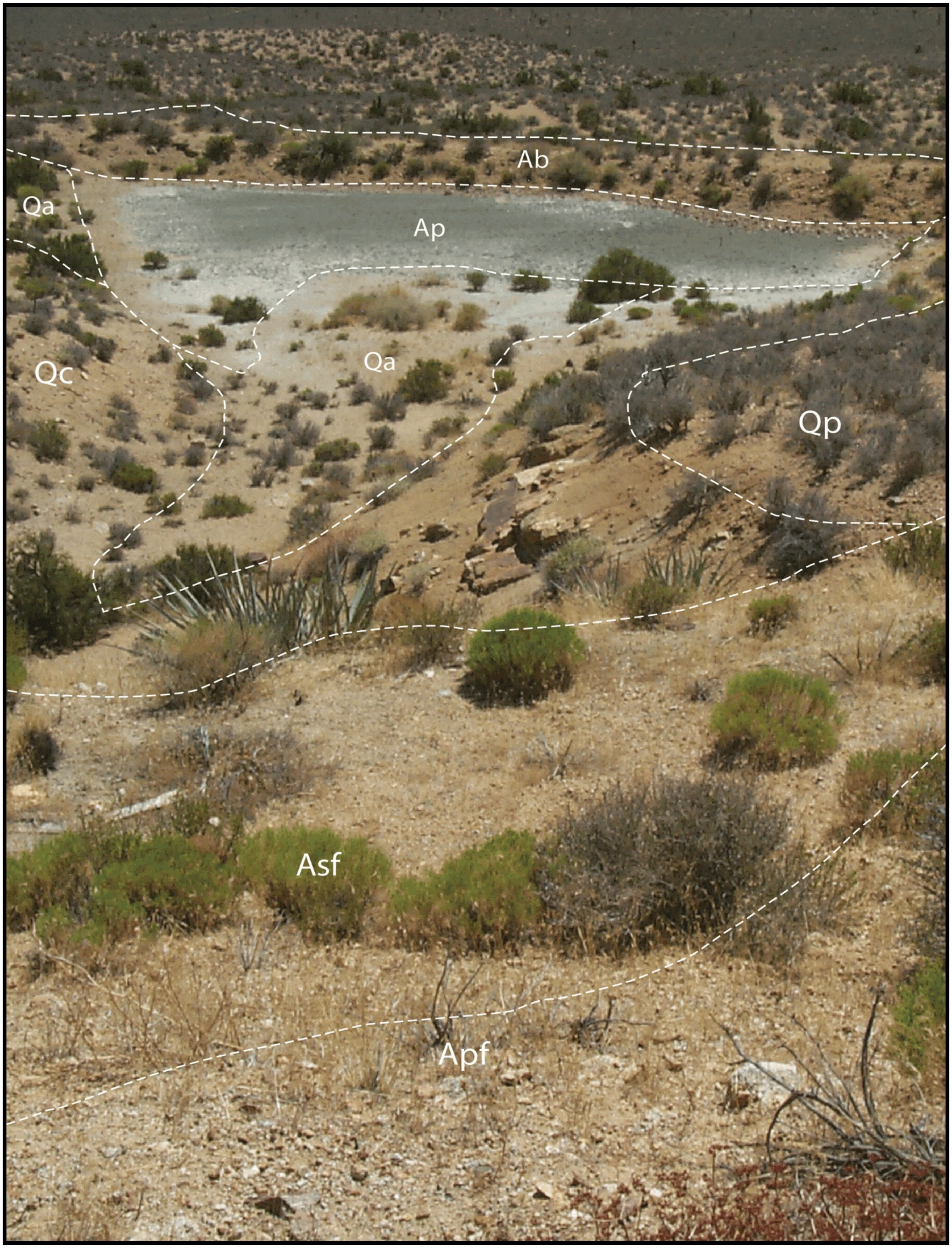

Figure 20. View of retention pond (Ap) at the U15 GZ#14 drill hole. An artificial berm (Ab) was placed across the drainage to control sediment runoff. Present are several cut and fill pads (Apf), fill slopes (Asf), remnants of the pediment surface (Qp), colluvium (Qc), and active alluvium (Qa).

Road Related

Road related disturbances include the roadbed itself and displaced material associated with road building and maintenance. Blading with graders and bulldozers to form temporary access roads for installation of utilities was common throughout the U15 Complex area.

Bladed (Abl). Bladed ground covers about 1.8 hectares (4.4 acres) and comprises 6.3 percent of the mapped disturbed area. Bladed ground is typically related to temporary roads (Figure 11), cleared areas for utility lines, margins of quarries, or areas cleared of the surficial mantle of weathered bedrock and leveled for a variety of purposes that include equipment yards, equipment storage sites, and staging and parking areas.

Road (Rd). This is the principal access to the U15 Complex (Figures 5 and 12). Numerous small utility line roads and defunct roads branching from the main road are still visible; however, they are generally impassable or overgrown with woody shrubs. The principal roadbed leading to the U15 Complex has remnants of pavement or macadam surface. The road is crowned or sloped to provide some degree of control for surface runoff to roadside ditches. The network of roads throughout the U15 Complex is extensive, despite the relatively small area of study. Road area covers 8.6 hectares (21.1 acres) and comprises 30.4 percent of the mapped disturbed area. Most of the roads that traverse the area between U15a/e, U15f-m, UE15 exploratory holes, the U15 GZ#14 area, and the road parallel to the Boundary fault cross ephemeral streams and result in the disruption of surface drainage. In addition to blocking or altering the channel characteristics of the streams, road surfaces contribute to increased surface runoff and water and sediment discharge to streams and alluvial fan surfaces during high intensity and/or duration precipitation events.

Road Side-cast (Rds). Road side-cast consists of road bed material that is graded from the road as part of the roadbed leveling and smoothing process (Figures 11-13, 15). Road side-cast commonly forms small berms along the edges of the road and is often pushed beyond the road edge onto steep slopes where it may be transported long distances down slope. The slope angle, material consistency, and amount of material govern the distance of down slope movement and subsequent impact on the slope system. For the purposes of this report, the road side-cast also includes fill material that is draped over slopes as a result of the process of creating fill areas such as road turnouts and staging areas. In the U15 area, road side-cast covers about 4.6 hectares (11.3 acres) and represents 16.3 percent of the disturbed area. Road side-cast is most notable on the steep slopes leading to the UE15 exploratory drill holes west of the historic Climax mine and on the mine access road (Figure 11). In this area the slope adjacent to the road is very steep and a large amount of material was displaced during the cutting and filling when extending the road to exploratory drill pads and during drill pad preparation. The greatest impact from the perspective of modification to the landscape is confined to a few meters from the road bed. An indirect consequence of road side-cast is the disruption to the drainage function of roadside ditches and without proper maintenance roadside drainage can flow onto the road surface and cause severe erosion of the roadbed.

DESCRIPTION OF THE U15 COMPLEX

The U15 Complex is characteristic of an industrial mining site, with access shafts, head frames, hoist houses, and other support infrastructure. What is different from a typical mining site is that, beginning in 1959 and ending in 1985, three underground nuclear tests and two underground nuclear spent fuel storage projects were conducted at the U15 Complex. Along the west side of the complex where most of the activity took place are two access shafts, a device emplacement shaft, a canister access hole, and associated buildings, structures, and features (Figures 21-23). Surrounding this main area are drill holes and pads, instrument trailer parks, exploratory geological trenches, and quarries. The U15 Complex is approximately 1,100 m (3,609 ft) east-west and 1,150 m (3,773 ft) north-south. It encompasses 113 hectares (279 acres). The west edge is defined by the paved road into the complex, the northwest corner by a large gravel pit, the north boundary by drill holes and gravel roads, the northeast and southeast corners by drill holes, and the southern boundary by trailer parks and trench features. UTM coordinates (NAD 27, Zone 11) roughly defining the limits of the complex are provided below.

Northwest corner	E 583292	N 4120370
Northeast corner	E 584544	N 4120770
Southeast corner	E 584578	N 4119842
Southwest corner	E 583785	N 4119145

Access into the complex is the 10-2 Road from the Circle Road connected to Mercury Highway. Just before the paved portion of the 10-2 Road ends at a gravel road, it branches to the right into the main area and onto an upper terrace created by the muck pile. At this point the yellow hoist mechanisms and other associated buildings and structures are clearly visible. Access to the outlying cultural features is by a series of intertwining gravel roads. The basic road system in this area was in place prior to the establishment of the NNSS and once served the Oak Spring mining community during the early part of the twentieth century (Ball 1907; Long 1950). This basic road system has since been expanded and improved as needed, e.g., the current 10-2 Road and connecting roads that lead to the site from Mercury are now widened and paved. Permanent and temporary gravel roads were also made within the U15 Complex to reach certain localities. Most of the roads, particularly the temporary ones, at the U15 Complex are now abandoned and not maintained. No major projects have been conducted at the complex since the spent fuel experiments.

Drill holes associated with the U15 Complex are listed in Table 4. This table includes access and device emplacement shafts, sample recovery, instrument, exploratory, and postshot holes (Bennett 1991; Orkild et al. 1983). Some additional holes are plotted in Figure 24. A relatively large number of different size drill holes, ranging from 7.6 cm (3 inches) to 28 cm (11 inches) in diameter for the exploratory and instrument holes to 1.2 m (4 ft) in diameter for the canister access hole, are reported in various references for the complex. The exact number of holes is unknown, especially the instrument holes, and many cannot be relocated or it cannot be determined if they were actually started or completed (Traynor 1999). Some are masked by later activities. Drill holes listed in Table 4 and found during this cultural resources study are described in the features section below.

Large exploratory trenches in the southern part of the complex and along a gravel road were part of the studies to map the Boundary geological fault. Two initial exploratory trenches were by the U.S.

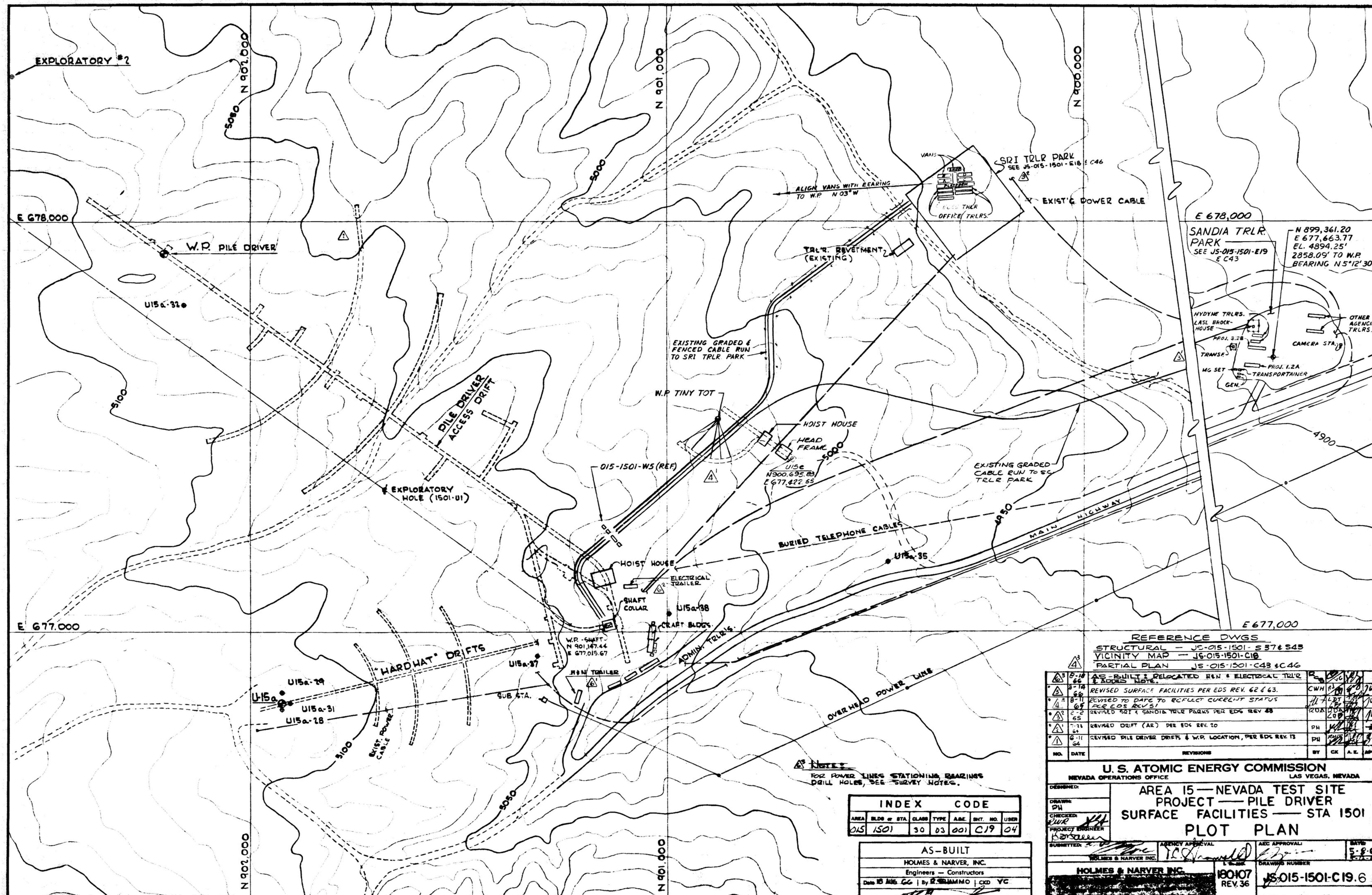

Figure 21. Surface facilities and underground nuclear tests for the U15 Complex (drawing JS 015 1501 C19.6, dated 1964, on file at the Archives and Records Center, Mercury, Nevada).

Figure 22. Aerial view northwest of the U15 Complex in 1964. Shown are the head frames and hoist houses for the Tiny Tot access shaft to the lower left and the Pile Driver access shaft to the upper right (REECo photograph 2017-9, dated 1964, on file at the Nuclear Testing Archive, Las Vegas).

Figure 23. Aerial view south of the U15 Complex in 1980 during the Spent Fuel Test - Climax experiment. Shown are the head frames and hoist houses for the main access shaft in the middle and the canister access hole to the lower right (photograph CL7, dated 1980, on file at the Remote Sensing Laboratory, Las Vegas).

Table 4. U15 Drill Holes, UTM Coordinates, Depth, Size, and Date.*

1	Marble Exploratory #1	E 583,158	N 4,120,112	115 m (377 ft)	7.6 cm (3 inches)	1959
2	Marble Exploratory #2	E 583,142	N 4,120,710	60 m (197 ft)	6.1 cm (2.4 inches)	1959
3	Marble Exploratory #3	E 583,000	N 4,120,352	298 m (978 ft)	7.6 cm (2.98 inches)	1959
4	Marble Exploratory #4	E 582,860	N 4,120,536	362 m (1,188 ft)	15.2 cm (6 inches)	1959
5	U15a Device Emplacement Shaft	E 583,453	N 4,120,183	294 m (963 ft)	111.8 cm (44 inches)	1960
6	U15a #28 Rad Chem	E 583,448	N 4,120,189	289 m (949 ft)	15.6 cm (6.125 inches)	1960
7	U15a #31 Granite Hole	E 583,453	N 4,120,184	366 m (1,200 ft)	7.6 cm (3 inches)	1959
8	U15a #32 Instrument	E 583,748	N 4,120,262	277 m (908 ft)	22.9 cm (9 inches)	1962
9	U15a #33 Instrument	E 584,072	N 4,120,119	301 m (987 ft)	22.9 cm (9 inches)	1962
10	U15a #34 Instrument	E 583,537	N 4,120,482	301 m (987 ft)	22.9 cm (9 inches)	1962
11	U15a #35 Instrument	E 583,562	N 4,119,746	251 m (822 ft)	15.9 cm (6.25 inches)	1962
12	U15a #37 Instrument	E 583,489	N 4,120,002	508 m (1,667 ft)	22.9 cm (9 inches)	1962
13	U15a #38-1 (Suspended)	E 583,523	N 4,119,905	118 m (386 ft)	15.9 cm (6.25 inches)	1960
14	U15a #38-2 Instrument	E 583,523	N 4,119,905	610 m (2,001 ft)	15.9 cm (6.25 inches)	1962
15	U15a Postshot #1	E 583,453	N 4,120,183	294 m (963 ft)	111.8 cm (44 inches)	1962
16	U15a Postshot #28S	E 583,449	N 4,120,186	310 m (1,016 ft)	15.9 cm (6.25 inches)	1962
17	U15a Postshot #29-1	E 583,460	N 4,120,189	221 m (724 ft)	15.9 cm (6.25 inches)	1962
18	U15a Postshot #29S	E 583,456	N 4,120,202	123 m (402 ft)	7.6 cm (3 inches)	1962
19	U15.00/15.01 Access Shaft	E 583,512	N 4,119,950	444 m (1,456 ft)	2.7 x 3.7 m (9 x 12 ft)	1964
20	U15b	E 583,616	N 4,120,535	403 m (1,323 ft)	31 cm (12.25 inches)	1961
21	U15b Ground Zero Exploratory	E 583,637	N 4,120,537	549 m (1,800 ft)	15.6 cm (6.125 inches)	1960
22	U15b Exploratory #1	E 583,822	N 4,120,786	549 m (1,800 ft)	15.6 cm (6.125 inches)	1960
23	U15b Exploratory #2	E 583,917	N 4,120,387	549 m (1,800 ft)	15.6 cm (6.125 inches)	1960
24	U15 Ground Zero Instrument	E 583,788	N 4,120,275	370 m (1,213 ft)	22.9 cm (9 inches)	1965
25	U15 Ground Zero #14	E 584,302	N 4,120,601	1,088 m (3,571 ft)	28 cm (11 inches)	1965
26	U15 Ground Zero #15	E 584,514	N 4,120,735	14 m (46 ft)	38 cm (15 inches)	1964
27	U15 Ground Zero #15S	E 584,514	N 4,120,735	12 m (41 ft)	44.5 cm (17.5 inches)	1964
28	U15 Ground Zero #15S2	E 584,513	N 4,120,735	473 m (1,553 ft)	28 cm (11 inches)	1965
29	U15 Ground Zero #24	E 584,326	N 4,119,993	439 m (1,439 ft)	22.9 cm (9 inches)	1965

Continued

Table 4. U15 Drill Holes, UTM Coordinates, Depth, Size, and Date (continued).

30	U15 Ground Zero #25	E 584,549	N 4,119,874	465 m (1,525 ft)	22.9 cm (9 inches)	1964
31	U15e Access Shaft	E 583,636	N 4,119,815	118 m (387 ft)	2 x 3.4 m (6.67 x 11 ft)	1964
32	UE15e Exploratory	E 583,206	N 4,119,901	183 m (600 ft)	7.6 cm (2.98 inches)	1964
33	U15e #1	E 583,664	N 4,119,870	99 m (325.5 ft)	15.6 cm (6.125 inches)	1965
34	U15e Postshot #1 Vertical	E 583,667	N 4,119,867	98 m (322 ft)	27 cm (10.625 inches)	1965
35	UE15f	E 583,783	N 4,119,882	199 m (653 ft)	7.6 cm (2.98 inches)	1964
36	UE15g	E 583,715	N 4,119,911	200 m (655 ft)	7.6 cm (2.98 inches)	1964
37	UE15h	E 583,715	N 4,119,935	185 m (606 ft)	7.6 cm (2.98 inches)	1964
38	U15.01 Postshot #1 Vertical	E 583,788	N 4,120,275	200 m (655 ft)	25 cm (9.875 inches)	1967
39	UE15i	E 590,587	N 4,120,305	120 m (394 ft)	25 cm (9.875 inches)	1969
40	UE15j	E 592,299	N 4,117,407	380 m (1,248 ft)	31 cm (12.25 inches)	1969
41	UE15j #1	E 592,299	N 4,117,346	381 m (1,250 ft)	~ 10 cm (4 inches)	1970
42	UE15j A-5	E 592,016	N 4,117,300	227 m (745 ft)	17 cm (6.75 inches)	1969
43	UE15j C-5	E 592,156	N 4,117,354	102 m (336 ft)	17 cm (6.75 inches)	1969
45	UE15j D-1	E 592,337	N 4,117,097	152 m (498 ft)	17 cm (6.75 inches)	1969
46	UE15j D-9	E 592,119	N 4,117,680	137 m (450 ft)	17 cm (6.75 inches)	1969
47	UE15j E-5	E 592,357	N 4,117,431	4.6 m (15 ft)	17 cm (6.75 inches)	1969
48	UE15j F-5	E 592,342	N 4,117,426	7.6 m (25 ft)	17 cm (6.75 inches)	1969
49	UE15j G-2	E 592,524	N 4,117,250	8.5 m (28 ft)	17 cm (6.75 inches)	1969
50	UE15j I-5	E 592,584	N 4,117,518	119 m (389 ft)	17 cm (6.75 inches)	1969
51	UE15j K-5	E 592,725	N 4,117,572	229 m (750 ft)	17 cm (6.75 inches)	1969
52	U15k Test Hole	E 583,644	N 4,120,544	261 m (857 ft)	22.2 cm (8.75 inches)	1980
53	U15.01 Canister Access Hole	E 583,404	N 4,119,990	418 m (1,370 ft)	122 cm (48 inches)	1978
54	U15.01 Radiological Drill Hole #1	E 583,504	N 4,119,950	46 m (150 ft)	22.2 cm (8.75 inches)	1988
55	U15.01 Radiological Drill Hole #2	E 583,506	N 4119,952	46 m (150 ft)	22.2 cm (8.75 inches)	1988
56	U15.01 Radiological Test Hole	E 583,502	N 4,119,943	6 m (20 ft)	44.5 cm (17.5 inches)	1988
57	U15.01 Radiological Test Hole #1	E 583,502	N 4,119,943	61 m (200 ft)	31 cm (12.25 inches)	1988
58	U15.01 Radiological Test Hole #2	E 583,502	N 4,119,943	8 m (25 ft)	44.5 cm (17.5 inches)	1988
59	USGS Hole #36	E 583,736	N 4,120,081	62 m (204 ft)	15.6 cm (6.125 inches)	

* Data obtained from Bennett (1991); UTM coordinates are NAD27 and Zone 11.

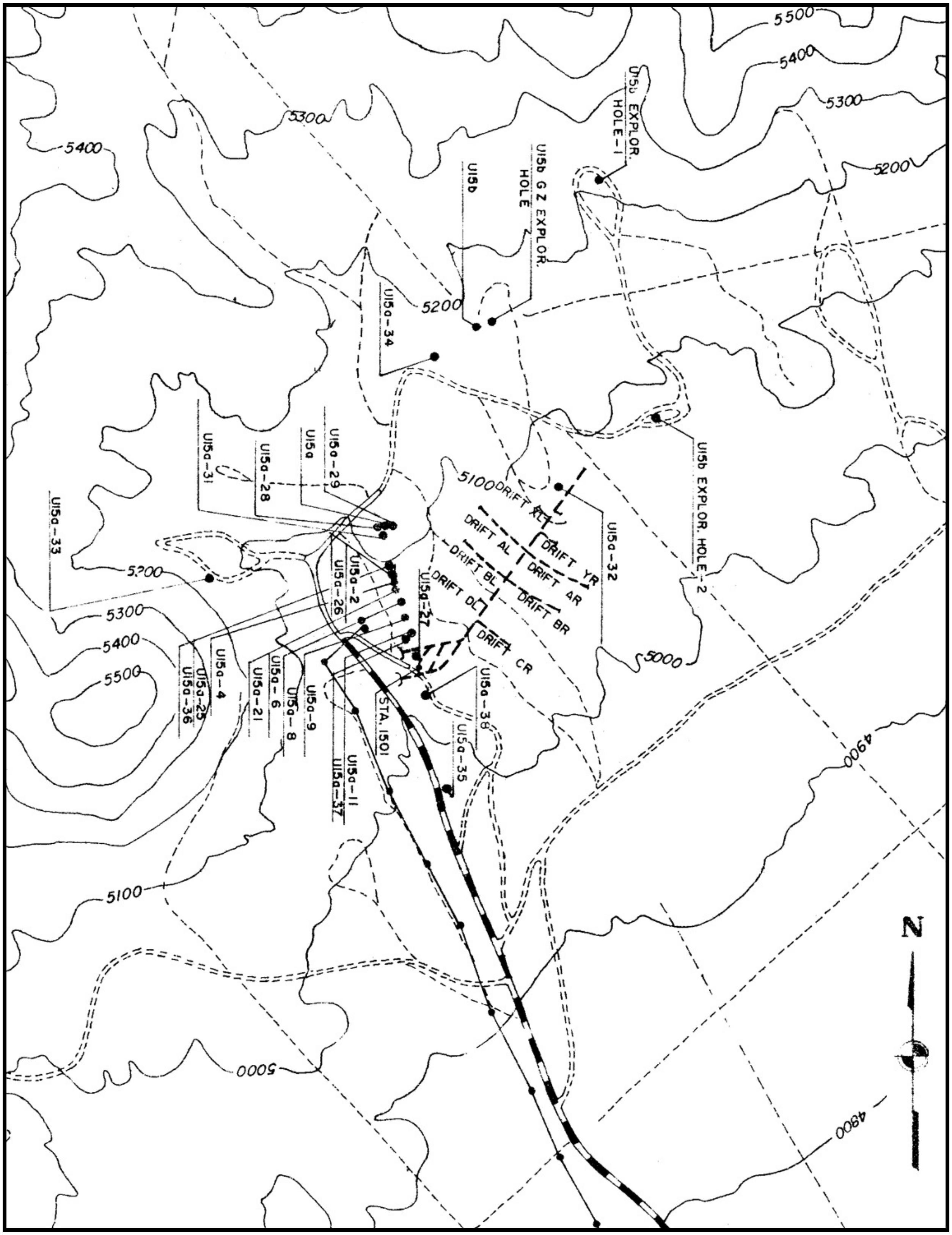

Figure 24. Drill holes at the U15 Complex (modified from drawing 895 670, dated 1968, on file at the Archives and Records Center, Mercury, Nevada).

Geological Survey in 1973 and another four were made by the Lawrence Livermore National Laboratory in 1980 (Orkild et al. 1983:17). The trenches were excavated with a bulldozer. As part of a study in 1983 to advance the understanding of other geological faults in the area for a proposed nuclear seismic test codenamed Midnight Blue, the U.S. Geological Survey excavated two exploratory trenches in the northwest corner, one in the southeast corner, and two in the middle of the complex (Orkild et al. 1983:9). These trenches served to further map the Tippinip, Boundary, Yucca, and Butte faults and were not located during this investigation.

Regarding the underground access shafts and drifts, at the bottom of the access shafts a series of drifts were excavated to meet the designs of the tests and experiments. Mining techniques consisted of drilling and blasting with dynamite. As the work progressed the resulting rock rubble was hoisted to the surface where it was deposited adjacent to the access shafts and formed a substantial muck or tailings pile (see Figure 12). All construction material and equipment had to be transported underground via the access shafts. In addition, workers had to be transported in and out of the underground facilities each day. Key to these everyday operations were the hoist houses located near the access shafts where cables stretched from hoists inside to head frames positioned over the shafts and attached to elevators for lowering and raising materials and workers.

U15 Complex Nuclear Tests

The three nuclear weapon effects tests conducted at the U15 complex are Hard Hat in 1962, Tiny Tot in 1965, and Pile Driver in 1966. All three tests were conducted underground, with one in a vertical shaft from the surface, a second in an excavated cavity at the end of an underground drift, and the third in a vertical subshaft from an underground drift. The purpose of the Hard Hat and Pile Driver tests was to assay different hardened underground structures against a nuclear explosion. The Tiny Tot nuclear test was an underground cratering and ground shock experiment.

Hard Hat

The Hard Hat underground nuclear weapons effects test took place on February 15, 1962 when the nuclear device was detonated in the U15a shaft at a depth of 287 m (943 ft) below the surface (Brady et al. 1984:75). Yield of the test was 5.7 kilotons (DOE/NV 2000). The nuclear device was supplied by the Los Alamos National Laboratory. The purpose of the test was to determine the effects of a nuclear explosion on various types of underground tunnel liners (DASA 1964:131; McCool 1962; Polatty and McDonald 1963:9; Reeves 1963:73; Swift 1962a:7). Information obtained from the Hard Hat test could then be used in designing underground facilities to withstand a nuclear attack (MacDonald 1970:1).

In April 1959, during the moratorium between the United States and the former Soviet Union, Holmes and Narver, Inc., submitted a proposal to the former Atomic Energy Commission for a study on tunnel liners as part of the Gnome Project in the Plowshare program (DASA 1964:131; Holmes et al. 1963:24; see Swift 1962a:7). This proposal was similar to one submitted to DTRA by the University of Illinois. Eventually, both proposals were combined into Project 29, Structural Response Program of the Lollipop Program. The Lollipop Program, a nuclear test in granite with a yield of about five kilotons, was being developed by the Lawrence Radiation Laboratory, now the Lawrence Livermore National Laboratory, as part of the Seismic Improvement Program, the predecessor of the Vela Uniform Program. Construction at the NNSS for Project 29 of the Lollipop Program began in November 1959. The work was suspended in October 1960, however, due to the lack of satisfactory packing material for tunnel liners. In June 1961, DTRA became the sole sponsor and the test, now with an emphasis as a structural effects experiment, was renamed to Hard Hat. The moratorium ended on August 30, 1961 when the former Soviet Union formally announced their return to nuclear testing (Ogle 1985:240). The first series of nuclear tests at the NNSS after the moratorium began in September 1961 under Operation Nougat and included the Hard Hat test. Work at the Hard Hat test site resumed in October 1961 (DASA 1964:131).

The Vela Uniform Program, a seismic detection program, remained as part of the Hard Hat test. Prior to the Hard Hat test, the only full-scale deep underground nuclear tests were in volcanic tuff in Rainier Mesa (Swift 1962b:2). Hard Hat, conducted in granite, provided an opportunity in the seismic studies for detecting underground nuclear explosions in a hard rock medium (McLamore and Forbes 1964:13; Perret 1963; Swift 1962b:2; Swift and Eisler 1965). Seismic measurements during the test were taken from the surface, from inside the tunnel, and from drill holes originating at the surface and from inside the tunnel. Six surface drill holes were at various distances from the nuclear explosion and at different depths (Swift 1962b:5-8). The instrumentation plan for taking the measurements was developed by the University of Illinois with the help of the Stanford Research Institute and Holmes and Narver, Inc. The U.S. Army Engineer Waterways Experiment Station was responsible for grouting the instrument holes (Polatty and McDonald 1963). In addition, a 2,400 pound high explosive was to be detonated at the surface five minutes after the nuclear detonation in order to compare the different signals between a nuclear and non-nuclear explosion (Betts 1962). The high explosive failed to detonate at the designated time, but was detonated three hours later. Small high explosive charges and a dropped 600 pound weight were employed prior to the Hard Hat test to obtain readings on compression and shear waves (McLamore and Forbes 1964:22).

The Hard Hat underground complex consisted of a shaft from the surface in which the nuclear device was emplaced, an underground tunnel, a second shaft from the surface to access the tunnel, and three side drifts (A, B, and C) extending horizontally outward on both sides of the underground tunnel for the structures experiments (Figure 25). The device emplacement shaft, designated U15a, was not connected underground to the access shaft, designated Station 1500, or to the tunnel. Because planning and construction of the shafts and tunnel began during the moratorium, the test complex was almost finished when the work was suspended in 1960, leaving to be completed only a room at the forward face of the tunnel, the experiment sections, and installation of instrumentation (DASA 1964:58). In the three side drifts, 27 experiment sections had been constructed, 16 liners were installed, and drilling of instrumentation holes was started (Reeves 1963:73). Construction of the remaining experiment sections and liners began in November 1961 by Reynolds Electrical and Engineering Company, Inc., and was completed in January 1962. A total of 43 experiment sections were constructed for the Hard Hat test.

Drilling for the device emplacement shaft, U15a, was started on September 23, 1959 and was completed on April 5, 1960 (Bennet 1991). The borehole was 963 ft in depth, 44 inches in diameter, and had a casing diameter of 36 inches the entire depth. The access shaft, Station 1500, was 244 m (800 ft) southeast of the U15a emplacement shaft (Brady et al. 1984:75). It was 239 m (785 ft) deep to the invert or floor of the Hard Hat access drift. Mining of the access shaft was started in November 1959 using conventional shaft sinking techniques with jack hammers (Holmes et al. 1963:109). The

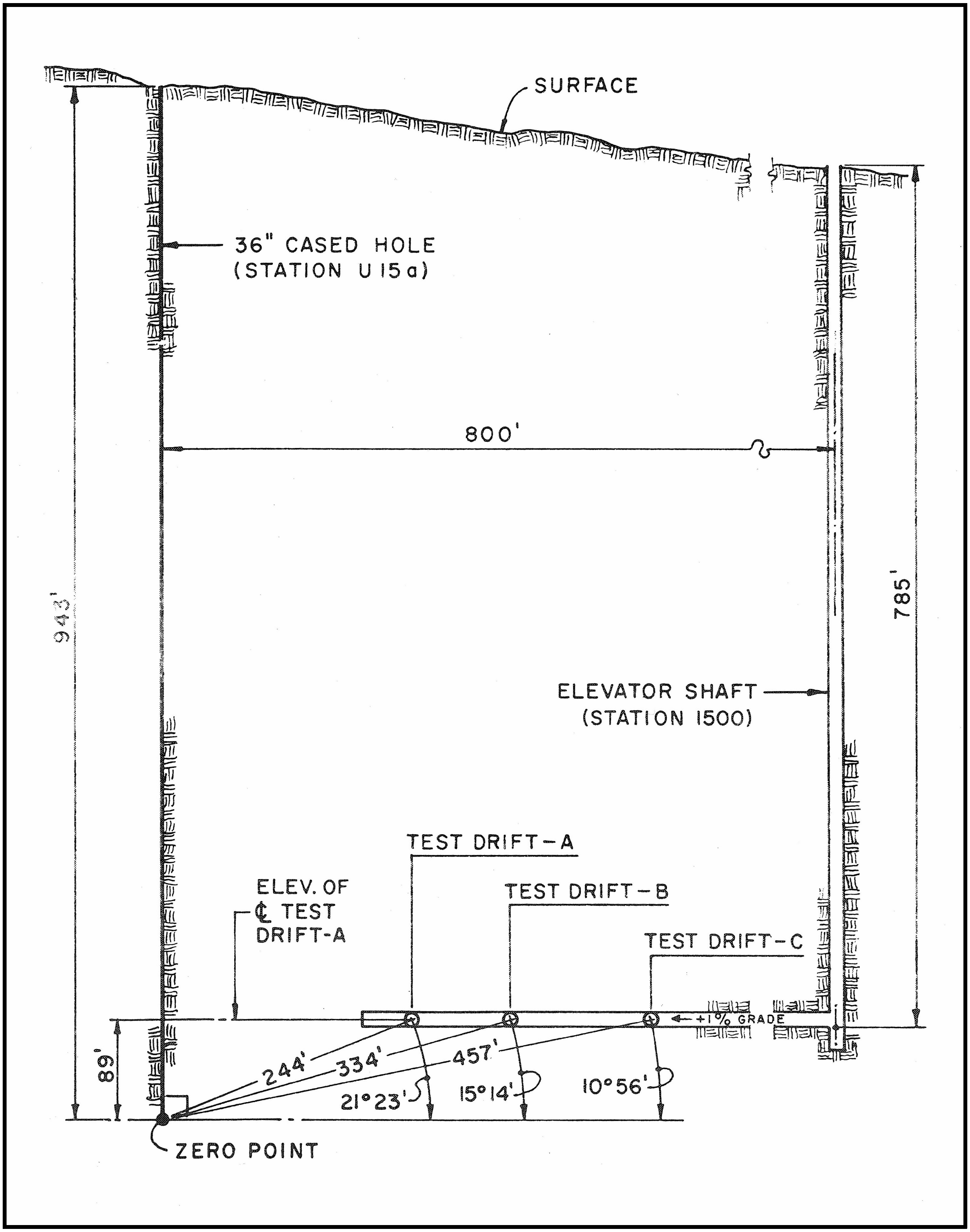

Figure 25. Profile of the subsurface layout for the Hard Hat nuclear test (Holmes et al. 1963:95).

muck was removed to the surface by a Cryderman shaft-mucking machine into a 2.1 cubic meters (75 cubic ft) capacity self-dumping skip. The shaft lining, along with the hoist manway and utility compartments, was installed as excavation proceeded (Figure 26). The access shaft was completed in February 1960 and mining of the Hard Hat access tunnel and side drifts was started (Holmes et al. 1963:110). Mining equipment for the tunnel and side drifts included Jackleg rock drills, Eimco Model 630 mucking machines, and scootcretes for hauling the muck to the access shaft. No back or roof supports were used while mining the access and test drifts. The access drift was 188 m (616 ft) long and had a one percent upward slope toward the working point where the device was to be detonated. Elevation of the tunnel was approximately 90 ft above the working point to eliminate any obstructions between the experiment drifts and the working point. That is, one drift did not block the next one from the force of the detonation. Rough excavation of the experiment drifts was completed in May 1960 and the surrounding rock was smoothed to the desired dimensions by removing projections and filling in areas with gunite (Holmes et al. 1963:112).

Three symmetrical, arc-shaped drifts, containing 43 individual structure experiment sections (Figure 27), were excavated at different elevations and perpendicular to the underground access tunnel and to the anticipated blast wave (Lewis 1973:3). The drifts were located in three zones of anticipated damage, designated as heavy, intermediate, and light, based on their distance from the working point (Holmes et al. 1963:49). The first drift, Drift A, was located as to cause total collapse of the experiment sections, while the last drift, Drift C, was located so it would only have some slight distortion, and the middle drift, Drift B, was located just past the midway point between Drifts A and C. The structure experiments ranged from unlined openings to large concrete tunnel liners (Figure 28). Identical structure experiment types (e.g., tunnel liners) were placed in the three drifts in order to determine degrees of damage for each experiment type in relation to the distance from the working point. In addition, different experiment types were placed in the same drift in order to compare the degree of damage between the different types when they were at equal distances from the working point. Drift A had 10 experiment sections with 5 on each side of the access tunnel, Drift B had 18 with 9 on each side of the access tunnel, and Drift C had 15 with 7 on the right side of the access tunnel and 8 on the left side.

The 43 structure experiment sections, illustrated in Figures 29-32, were of five general types (Holmes et al. 1963:52): 1) unlined square or circular without reinforcement, 2) square or circular and reinforced with rockbolts and wire mesh, 3) circular with a rigid liner of reinforced concrete, a flexible liner (corrugated steel liner plate), or a rigid-flexible liner with rigid steel rings and flexible wood lagging, 4) conventional horseshoe-shaped steel sets with wood lagging, and 5) circular reinforced concrete liners cast against rock. All experiment sections were approximately 4.6 m (15 ft) in length and spaced 0.6 m (2 ft) apart (Holmes et al. 1963:53). The experiment sections with larger diameters that required greater excavation were placed nearer the access tunnel. Two types of backpacking materials - polyurethane foam and volcanic cinders - were used for 30 circular experiment sections (Holmes et al. 1963:57). The backpacking material was placed in the void between the sections and the surrounding rock. The other 13 experiment sections did not have backpacking material and included unlined sections, some of the circular-shaped and square-shaped sections, and the steel sets. The steel sets were the same as the ones used for support in the tunnel tests in Rainier Mesa and were included in the Hard Hat test in order to compare damage effects between the granite and volcanic tuff geologic mediums (Holmes et al. 1963:63).

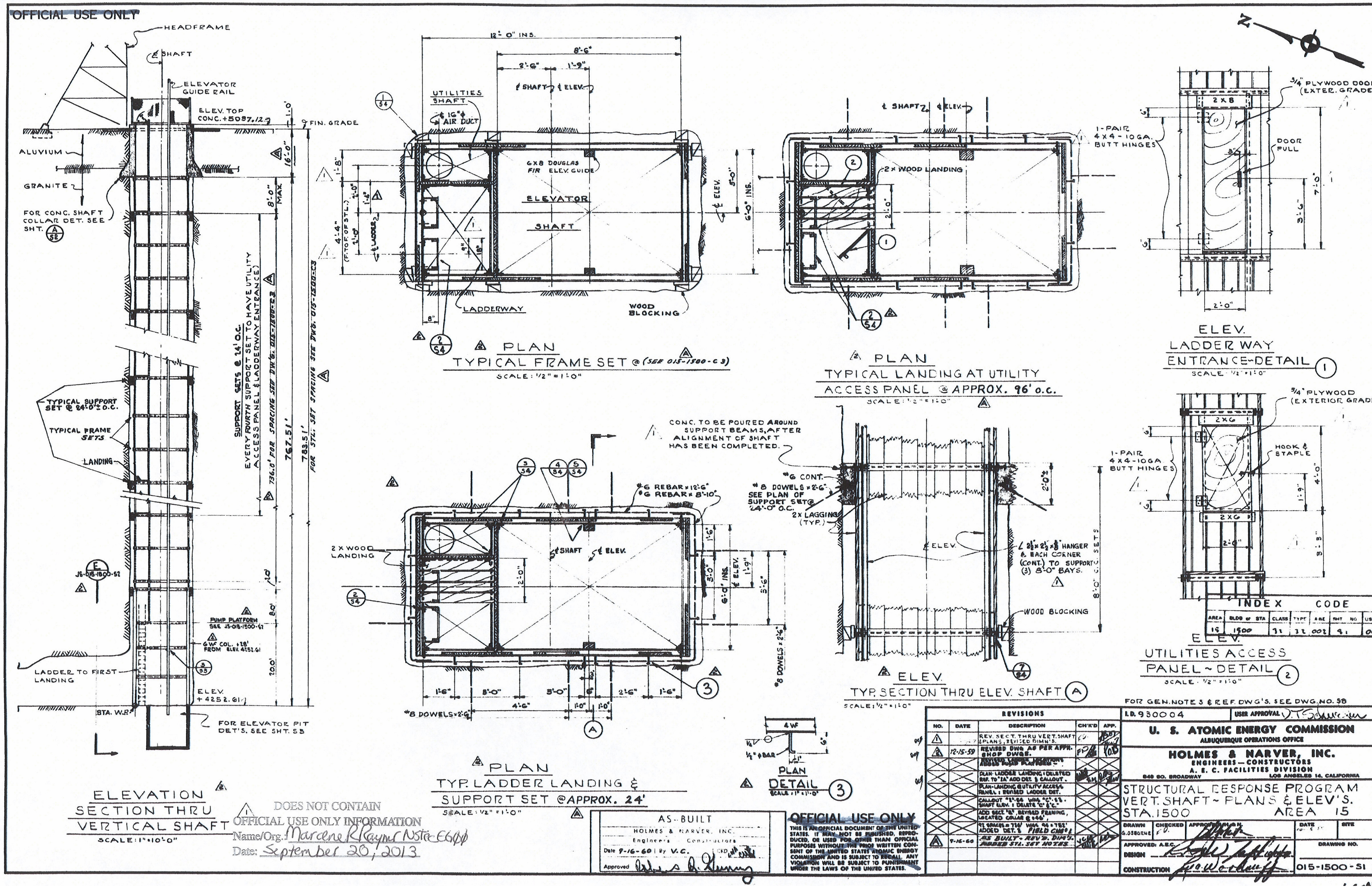

Figure 26. Plan and section of the access shaft for the Hard Hat nuclear test (drawing 015 1500 S1, dated 1959, on file at the Archives and Records Center, Mercury, Nevada).

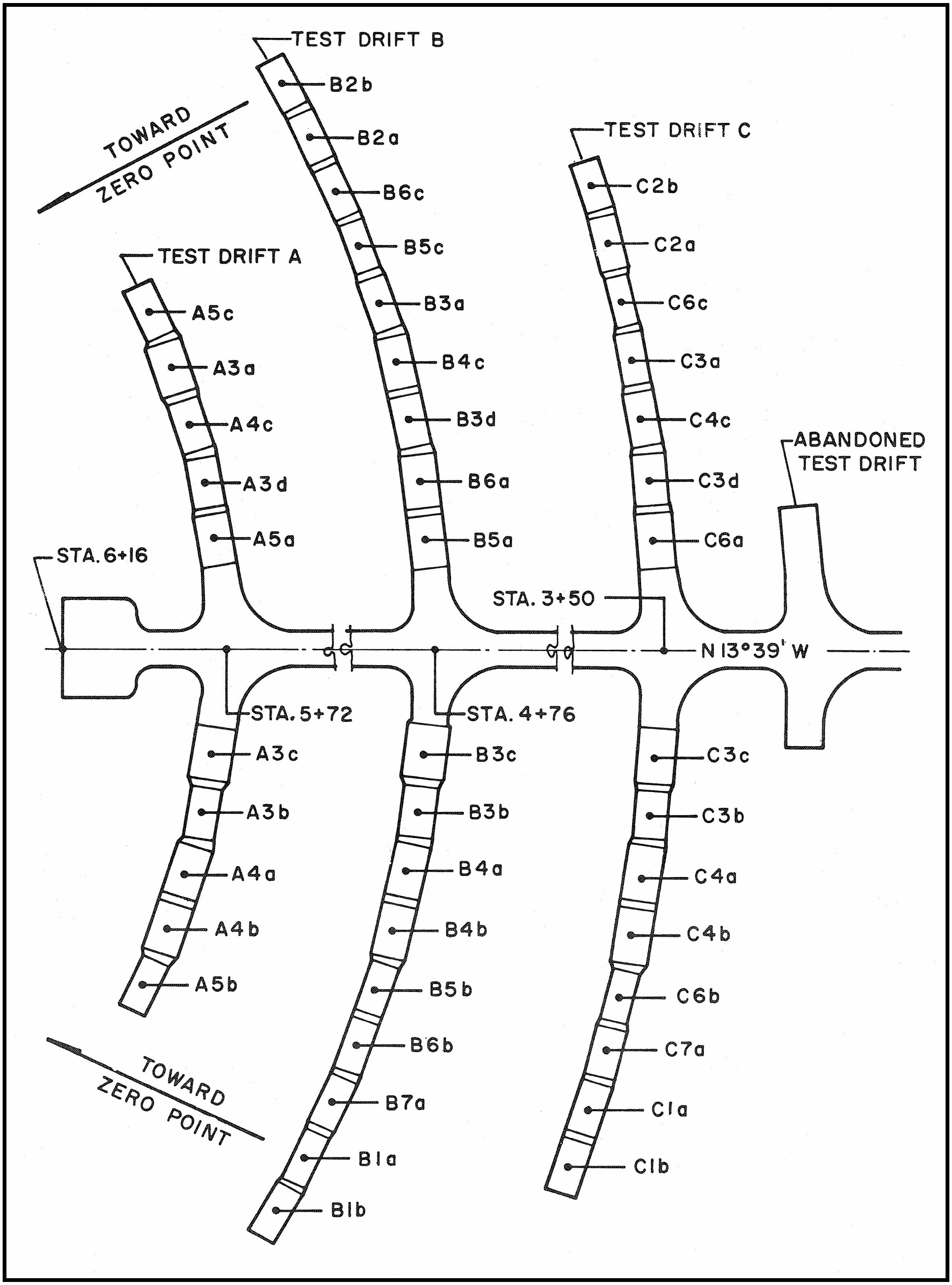

Figure 27. Plan of test drifts and experiment sections for the Hard Hat nuclear test (Holmes et al. 1963:104).

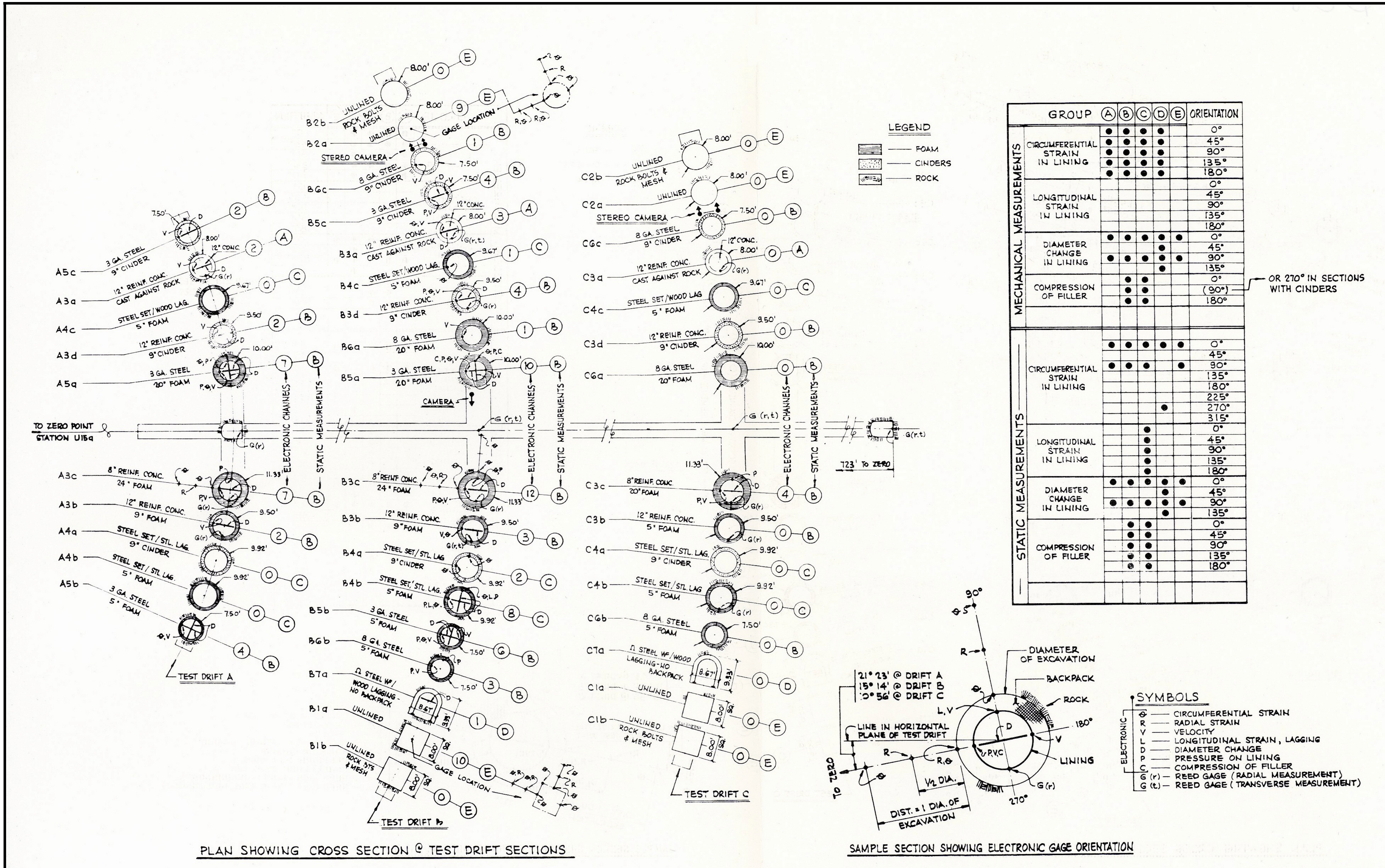

Figure 28. Instrumentation plan and cross section of the test drifts and tunnel liners for the Hard Hat nuclear test (Holmes et al. 1963:161-162).

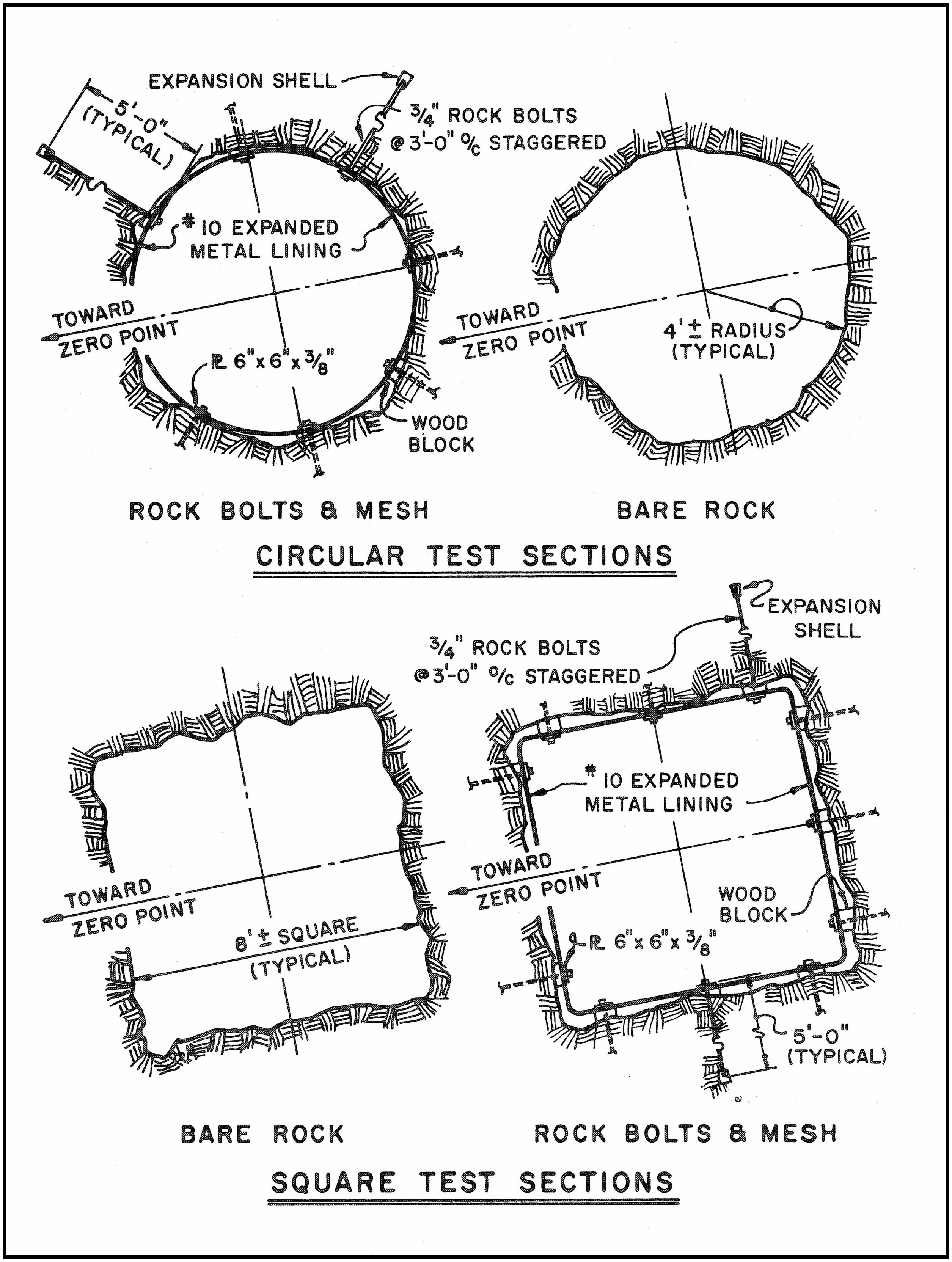

Figure 29. Examples of circular and square metal-lined and unlined experiment sections for the Hard Hat nuclear test (Holmes et al. 1963:93).

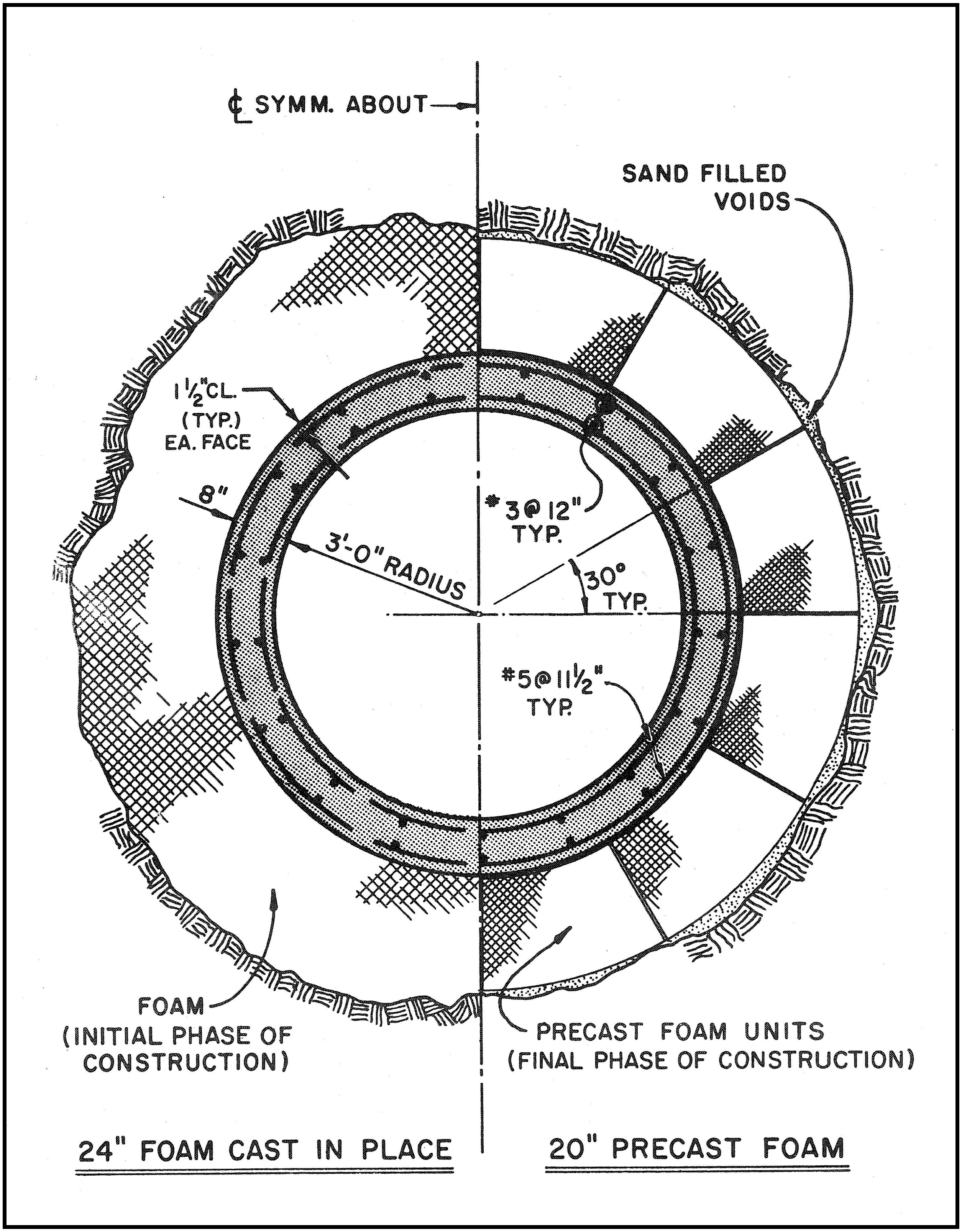

Figure 30. Examples of reinforced rigid concrete experiment sections for the Hard Hat nuclear test (Holmes et al 1963:98).

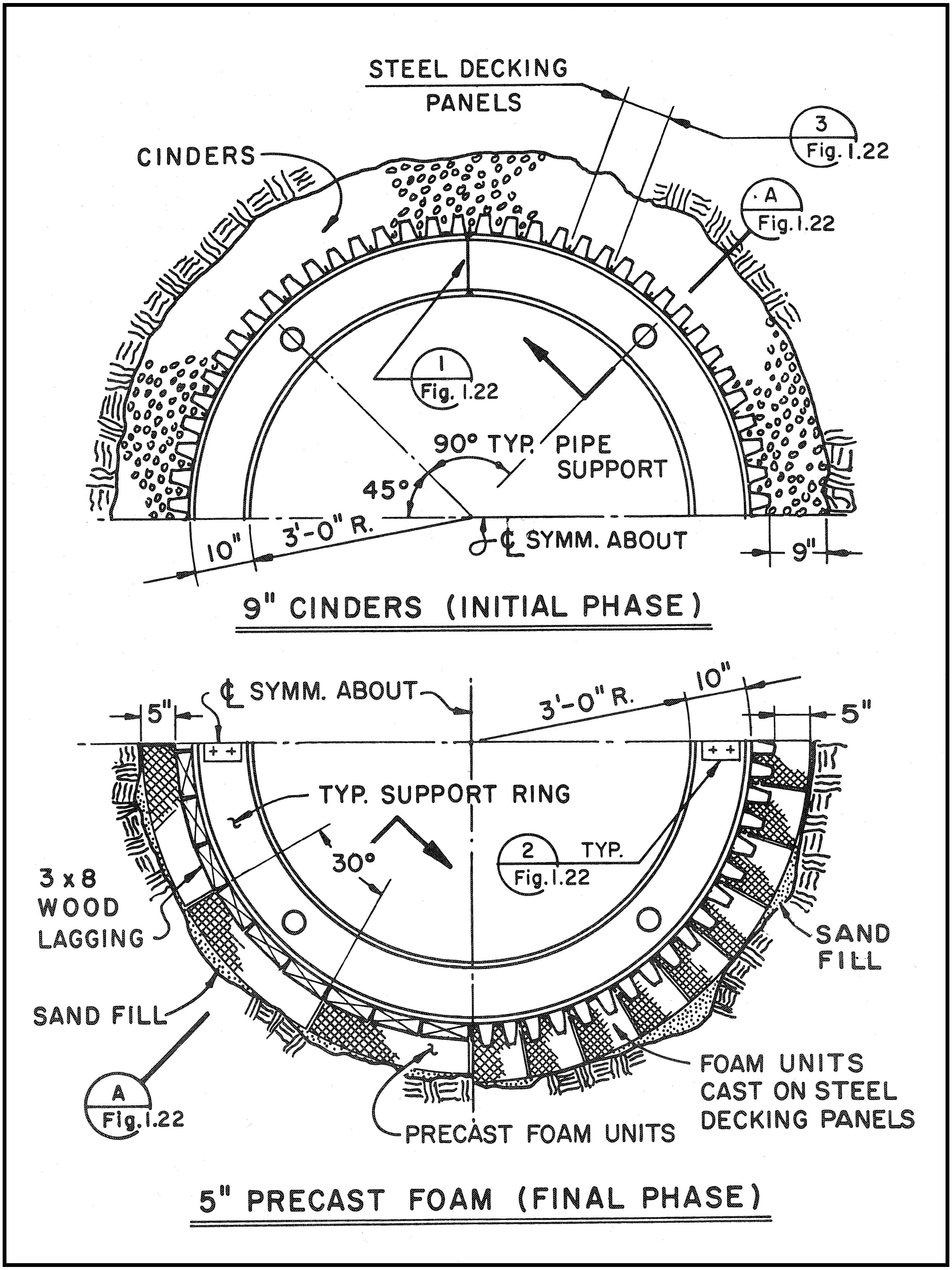

Figure 31. Examples of flexible and rigid-flexible concrete experiment sections for the Hard Hat nuclear test (Holmes et al. 1963:101).

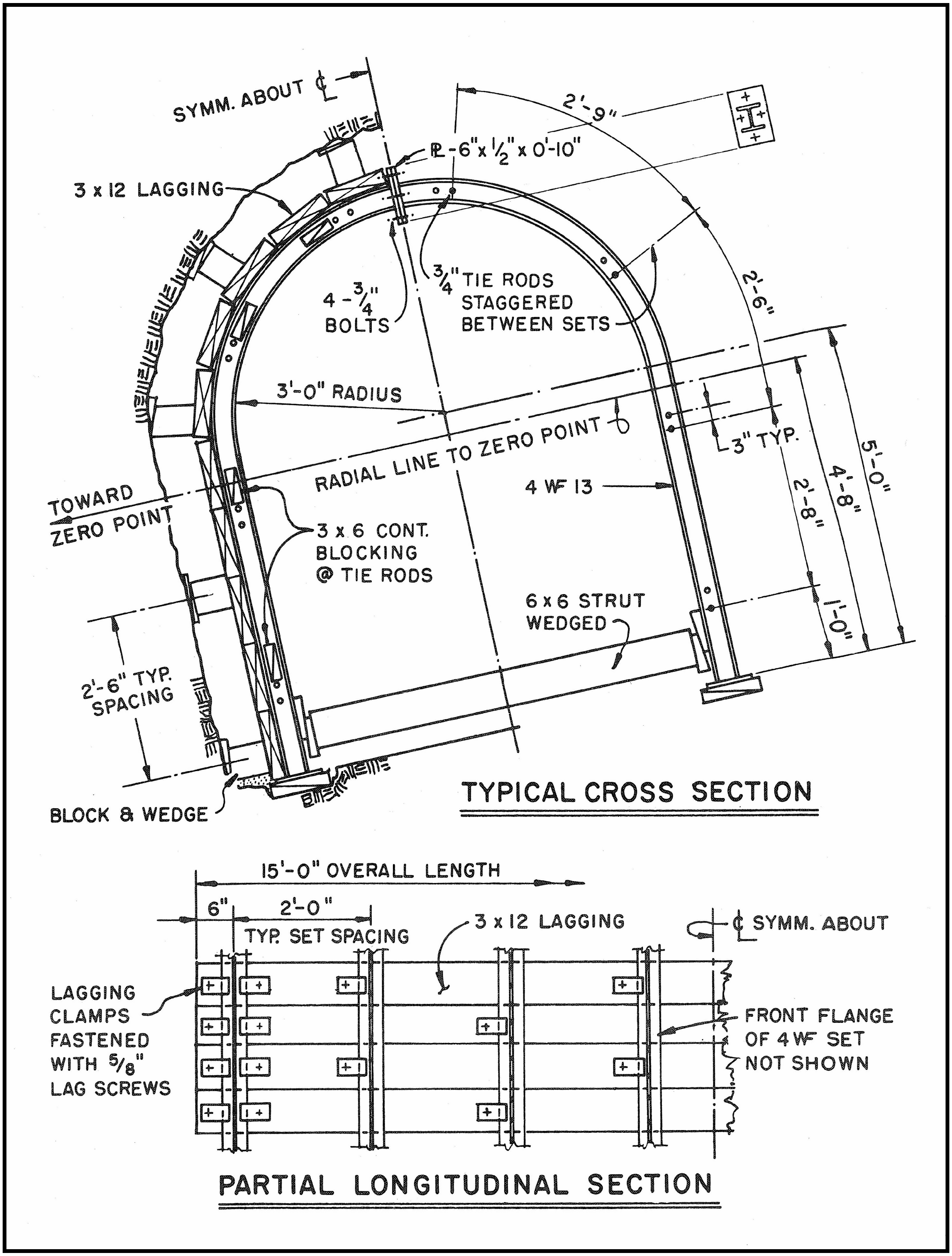

Figure 32. Example of experiment section with horseshoe-shaped steel sets and wood lagging for the Hard Hat nuclear test (Holmes et al. 1963:103).

Installation of the backpacking material was conducted after each experiment section was completed. The reddish-brown, volcanic cinder material ranged in size from 0.6 to 1.9 cm (1/4 to 3/4 inches) and was obtained from a cinder cone 113 km (70 miles) north of the NNSS (Holmes et al. 1963:65). The cinder material was blown into place through several holes in the end bulkheads of 10 tunnel liners by a concrete pumping machine (Holmes et al. 1963:118). A similar procedure did not work satisfactorily for two private contractors trying to fill the void between the liner and the surrounding rock with polyurethane material. One of the problems was that the polyurethane material was too fluid and tended to flow out of the access holes before it could set up (Holmes et al. 1963:120). Only 4 out of 20 tunnel liners to be backed with polyurethane were completed when the test operation was suspended in 1960. In August 1961, a third contractor, a plastic foam manufacturer, was given the task. Through experiments at the manufacturer's business, the best method conceived was to construct the liners in stages from the invert up and pour the polyurethane into wood forms behind the liners for each successive stage (Holmes et al. 1963:121). This method was seen as inefficient, however, and involved different crafts working at the same time in tight places in the test drifts. A decision was made to use precast polyurethane foam in the remaining 16 tunnel liners and trim the surrounding rock behind the liners to the right dimensions (Holmes et al. 1963:122).

Stemming in the tunnel for the test consisted of two sand plugs and one 75 psi blast door (Holmes et al. 1963:128). The sand plugs were 9 m (30 ft) in length and centered at 133 m (435 ft) and 161 m (527 ft) into the tunnel. The blast door was located 11 m (37 ft) into the tunnel. Air sampling pipes for reentry were placed through the sand bag plugs and the blast door (Brady et al. 1984:80). Flexible 2 inch (5 cm) diameter hoses were placed in Drifts B and C to attach compressed air lines and remove gases before reentry into the drifts. At the surface, the headframe, hoist, and ventilation blower were removed prior to the test.

The Hard Hat nuclear test was executed on February 15, 1962 at 10:00 in the morning and was successfully contained within the cavity (Brady et al. 1984:75; Holmes et al. 1963:175). Immediately after detonation, telemetry units in Drift B and at 142 m (465 ft) into the access tunnel failed, but other units indicated radiation levels were at normal background levels at around 0.05 milliroengten per hour (mR/h) at the surface and underground (Brady et al. 1984:84). The telemetry units were secured 6.5 hours after detonation. Initial reentry survey teams were dispatched to the Hard Hat test area two hours after detonation. No elevated radiation or toxic and explosive gas levels were detected at the surface. Approximately five hours after detonation, a forward control point was established about 61 m (200 ft) from the U15a shaft, with radiation safety personnel to monitor surface recovery efforts around the shaft for the next few hours (Brady et al. 1984:85). At eight hours after detonation, all surface data recovery efforts were finished and all personnel were cleared of the site to a security checkpoint located 213 m (700 ft) south of the shaft. At 9.5 hours after detonation another survey for radiation and toxic and explosive gases was made. No toxic or explosive gases were detected, but an elevated radiation level of 18 mR/h was detected at the U15a shaft.

Approximately 11 hours after detonation the cavity collapsed and radioactive materials were released to the atmosphere (Betts 1962; Placak.1962:2). Noise from the collapse was heard at the security checkpoint and it was moved 61 m (200 ft) further away as a precaution (Brady et al. 1984:85). Radiation levels at the surface above the detonation point reached 100 mR/h about an hour after the cavity collapsed and after another three hours were 500 mR/h (Betts 1962). Radiation levels were 500 mR/h at the bottom of the access shaft as well, while inside the gas seal door the readings reached 10 roengten per hour (R/h) (DASA 1964:58). After 72 hours, radiation levels at the surface had receded to 0.1 mR/h or about twice that of normal background levels. Radiation levels inside the gas seal door returned to normal in about a week. No elevated radiation levels were detected offsite due to the release dispersing to safe levels soon after it entered the atmosphere (Placak.1962:2). Subsequent investigations determined that the cavity extended 86 m (281 ft) above the working point and had a radius of about 19.8 m (65 ft), with fractures extending outward horizontally at least 55 m (180 ft) from the centerline (AEC 1965:163).

On February 17, two days after detonation or D+2, restoration of the surface facilities began in preparation for reentry to the tunnel by way of the main access shaft (Holmes et al. 1963:175; Reeves 1963:73). On February 23, two men on the reentry team descended to the bottom of the shaft in a small free-swinging cage. The objective was to assess damage to the shaft and facilities and to obtain readings on explosive and toxic gases and on radiation levels. The access shaft was found to be damaged at all depths, but the upper portion had suffered the greatest damage. Many of the shaft-bearing metal sets were distorted and connecting bolts were sheared, which caused permanent misalignment of the shaft (Holmes et al. 1963:177). As a consequence, the distance between the elevator guides had to be reduced from 1.6 m (62 inches) to 1.3 m (50 inches), which in turn caused a reduction in the size of the elevator cage. Rehabilitation of the shaft began on February 28 and was finished on March 9; whereupon, the next day, on March 10, reentry to the tunnel began by opening the blast door (Holmes et al. 1963:176). The tunnel was completely blocked by rockfall at 84 m (275 ft), from 88 m (290 ft) to 104 m (340 ft), and from 122 m (400 ft) onward (Figure 33). Rehabilitation of the tunnel began on March 12 by removal of the rockfall and sand plugs and repairing utilities and the rail line. Broken rock in the tunnel back or ceiling was supported with steel sets and wood lagging (Brady et al. 1984:95).

Reentry and documentation of damage in the experiment drifts began on April 16 and finished on June 2, 1962 (Holmes et al. 1963:179). Photographs were taken, instrument gauges recovered, conditions of the experiment sections recorded, bulkheads removed, and debris was removed from within the tunnel liners. In Drift C, furthest from the working point, 14 experiment sections were inspected, with one section too heavily damaged to access. All sections with liners survived the explosion and those with backpacking were in better condition than those without it (Holmes et al. 1963:181; McCool 1962:4). In Drift B, 13 experiment sections were accessible and five were too heavily damaged to access. All of the sections were damaged and debris had to be removed from inside the tunnel liners of those that were accessed and inspected (Holmes et al. 1963:198). Experiment sections without tunnel liners completely collapsed and a reentry drift was mined around them to access the sections further down the B Drift (Figure 34). In Drift A, the closest to the working point, only three experiment sections were inspected because of heavy damage to the drift (Holmes et al. 1963:215). These three sections were the closest to the access tunnel and were able to be viewed because of tunnel cleanup. Two of these sections were completely collapsed and the third was only open at the top, which enabled viewing of the adjoining section. An assumption based on these findings was that the remaining experiment sections were collapsed as well and no attempt was made to access them. On June 6, 1962, mining equipment was removed from the tunnel and, on June 8, to end operations, the access shaft was secured with a bulkhead at the surface.

Generally, the physical results of the Hard Hat test were as expected; but the amount of electronic data did not attain the levels anticipated due to excessive damage in the experiment drifts,

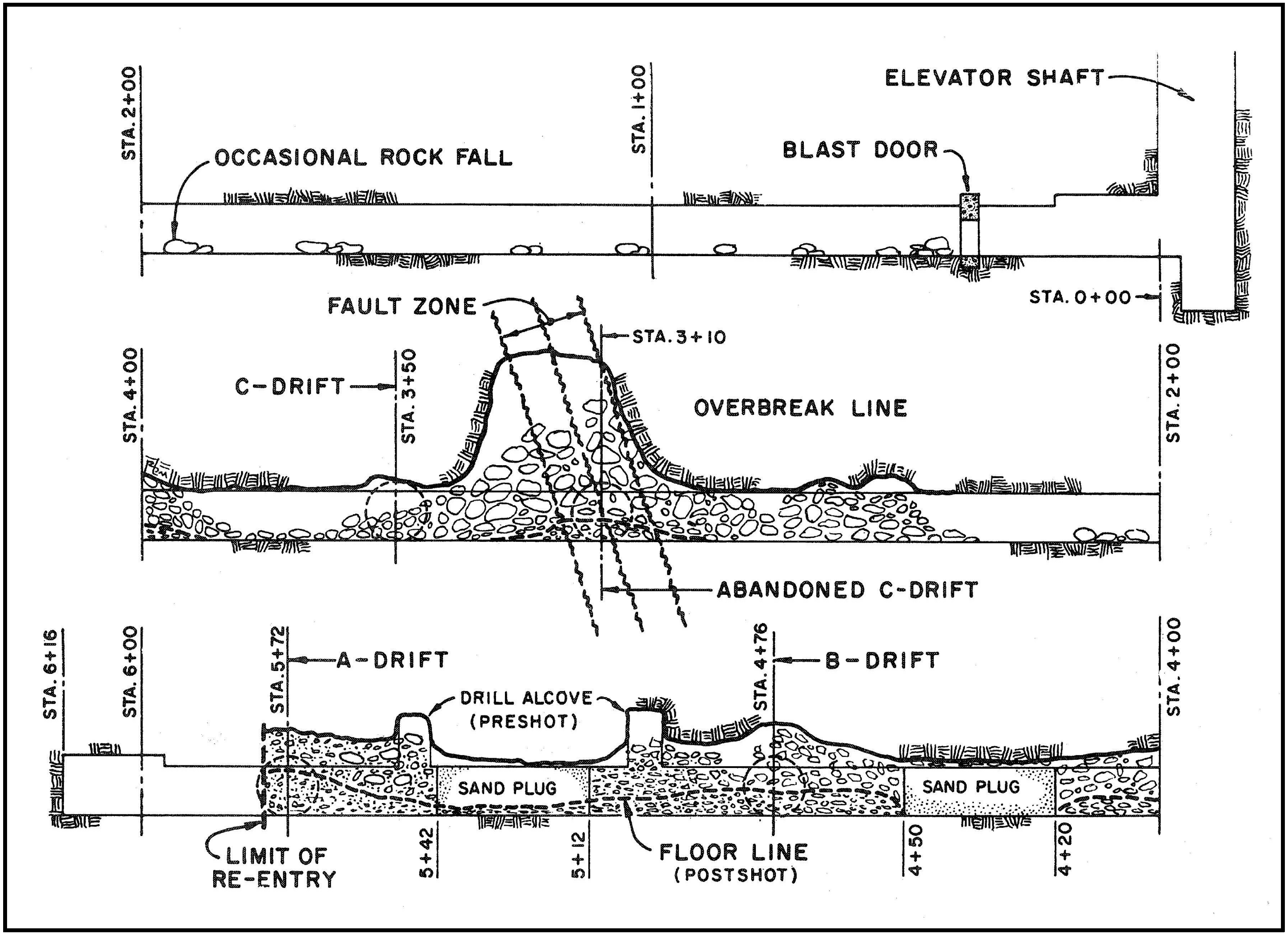

Figure 33. Post test profile of damage to tunnel from the Hard Hat nuclear test (Holmes et al. 1963:245).

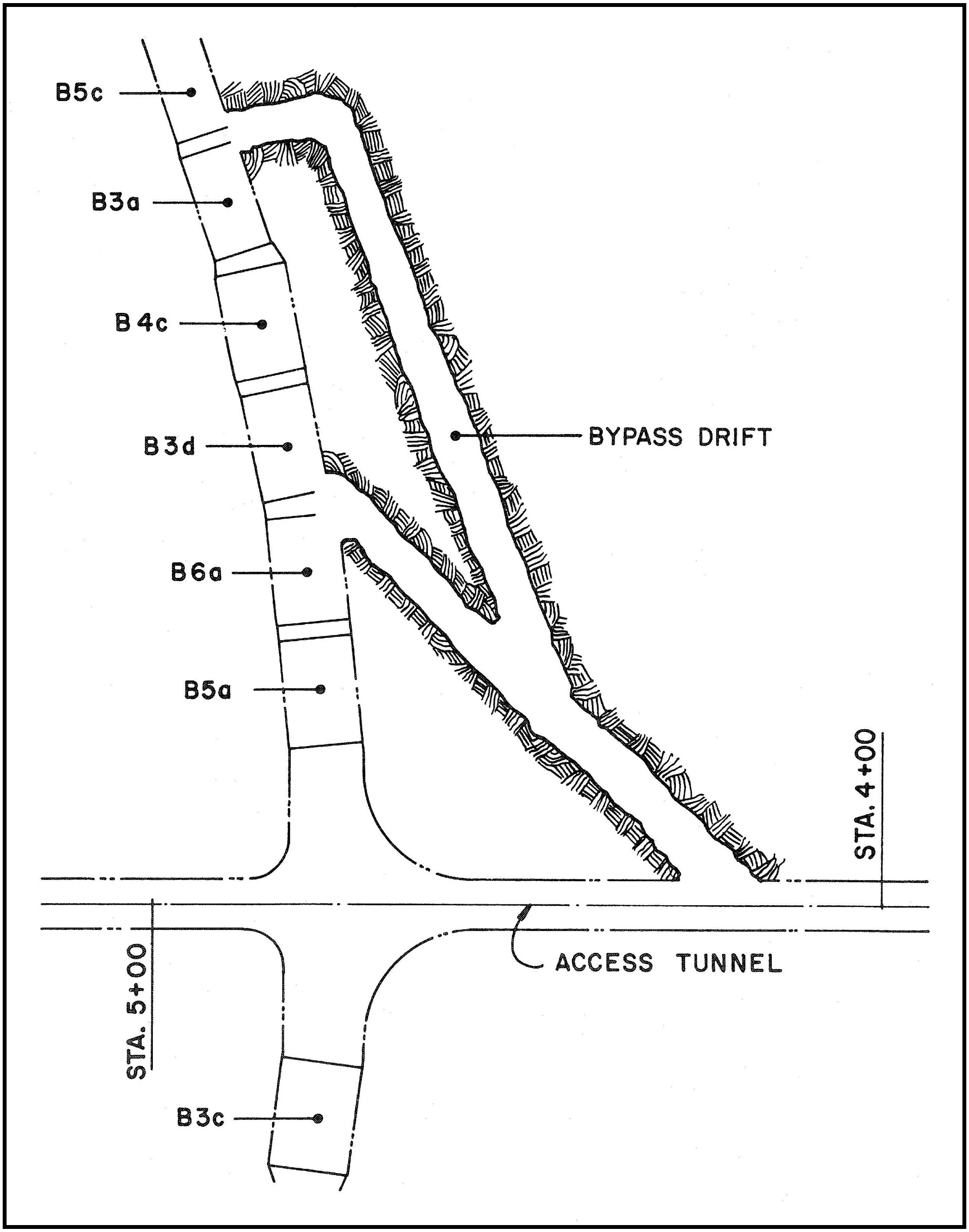

Figure 34. Reentry drift for the B Drift experiment sections in the Hard Hat nuclear test (Holmes et al. 1963:271).

particularly to Drift B where over 70 percent of the gauges were installed (Holmes et al. 1963:347, 397). Causes attributed to the excessive damage included the yield of the detonation, the slant angles between the working point and the test drifts were less than originally planned, and the surrounding rock was not as competent as assumed during the design of the test. However, physical inspection of the experiment sections and the tunnel did provide useful data in regard to the overall test (Holmes et al. 1963:385-386). For example, locating the three experiment drifts in the three different zones of damage did provide the anticipated results, with the closest drift to the working point receiving the greatest damage and the one furthest away the least damage. This allowed for comparison of liner type performance as well as backpacking material between the drifts. All experiment sections in the A and B drifts, except for B3c in the B drift, were destroyed (Burgess 2003). In the C drift, all unlined sections were destroyed, the steel sets with wood lagging were severely damaged, and sections cast in concrete against the surrounding rock were damaged. All backpacked sections had little damage. The experiment section with the least amount of damage was the reinforced concrete liner with thick foam backpacking (Burgess 2003; Holmes et al. 1963:397). In the tunnel, the two sand bag plugs reduced the amount of rock breakage (Holmes et al. 1963:398).

Post test drilling from the surface into the cavity to obtain core samples began on February 16, 1962 (Brady et al. 1984:91). Eventually, three drill rigs were setup around the U15a shaft to drill into the cavity. On February 24, the first drill rig reached the cavity boundary and began drilling through the cavity rubble. Drilling through the rubble was problematic, due to voids in the rubble, lost mud circulation in the drill hole, collapse of side holes, and stuck or lost drill stems and bits. A core sample toward the bottom of the cavity at a depth of 300 m (985 ft) was finally taken on May 5. Another sample was obtained at a depth of 304.5 m (999 ft). The surface drilling operation ended on May 8, 1962.

In December 1962, as shown in Figure 35, efforts were undertaken to mine and drill into the cavity by extending the Hard Hat access drift forward (Brady et al. 1984:97). The objective of the mining was to reach the working point and gather rubble fragments for analysis and size distribution. Drilling objectives were to determine cavity size and outline and to obtain mineral samples. The edge of the cavity was encountered on January 7, 1963, and radiation levels near the mined face of the tunnel ranged from 1 to 5 mR/h. Labor problems interrupted the work until February 14. When mining resumed, radiation levels had slowly increased at the face, ranging from 6 to 9 mR/h, and workers were required to wear protective clothing (Brady et al. 1984:98). Mining of the tunnel was halted on March 6 to excavate a drill alcove off to the side of the tunnel at 183 m (600 ft) from the access shaft and the first of two horizontal drill rigs was in place by March 19. By April 30, the access tunnel had reached its maximum length of 270 m (885 ft), over and past the Hard Hat working point at 244 m (800 ft). A crosscut drift was mined at 230 m (755 ft) to obtain rock samples. Radiation levels at this point were the greatest encountered, reaching an average of 30 mR/h, with the highest at 60 mR/h (Brady et al. 1984:99). Both the mining and drilling operations ended on May 17, 1963.

Tiny Tot

The Tiny Tot nuclear weapons effects test was executed on June 17, 1965, at U15e in an underground hemispherical cavity (Brady et al. 1984:215). Lawrence Livermore National Laboratory provided the nuclear device and the yield was less than 20 kilotons (DOE/NV 2000). Depth of the

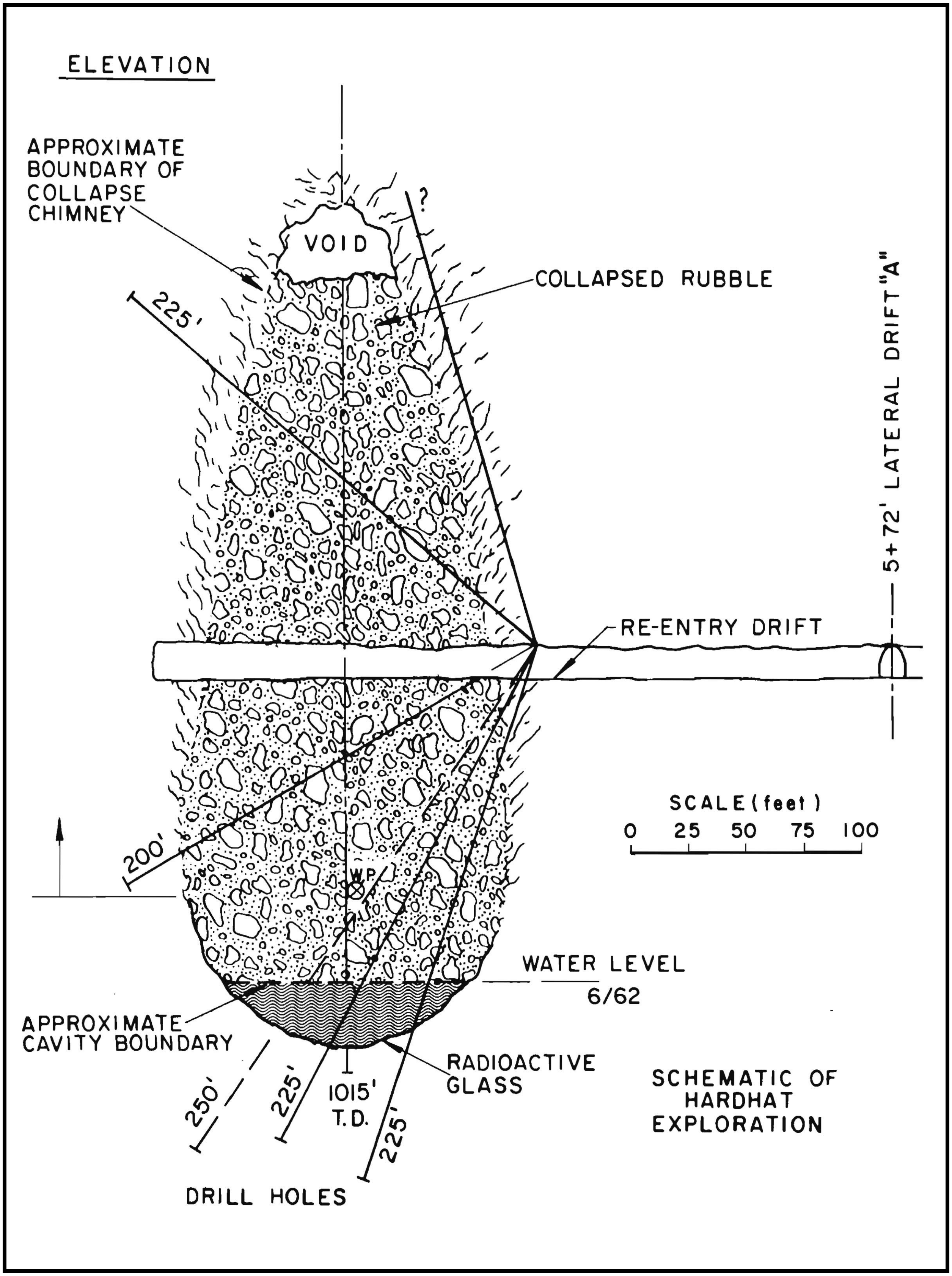

Figure 35. Schematic profile of the Hard Hat post test reentry (Document 99978, on file at the Nuclear Testing Archive, Las Vegas).

device below ground surface was 110.9 m (363.7 ft) in a quartz monzonite geologic formation (AEC/NV 1966). It was the last nuclear test in the Operation Whetstone test series and was the first underground nuclear cratering experiment conducted at the NNSS (DOE/NV 2000; Merritt 1969:14). Tiny Tot was also part of the Ferris Wheel (subsequently Discus Wheel) test series sponsored by DTRA to investigate ground shock and cratering (Merritt 1969:11). The objective of the Ferris Wheel series was to provide data in designing underground structures and facilities, e.g., command centers, against a nuclear attack consisting of surface or near-surface detonations (Merritt 1969:13; Prickett 1965). As part of this series, the Tiny Tot nuclear test contributed data on ground shock from surface detonations and cratering on dry, hard rock as opposed to other medium such as alluvium. After detonation, some radioactive gases leaked to the surface by way of instrument cables and the access drift, but the gases were not detected beyond the boundaries of the NNSS.

Basic underground configuration of the Tiny Tot test consisted of an access shaft, a near vertical hemispherical cavity, an access drift between the shaft and cavity, and an instrument drift off the access drift and partially around the cavity (Figures 36 and 37). The access shaft was started on August 27, 1964 and was completed by October 27, 1964 (Merritt 1969:18). It measured 2 m (6 ft 8 inches) by 3.4 m (11 ft 2 inches), 117.8 m (386 ft 7 inches) deep to the access drift invert, and another 8 m (27 ft) below the invert for a well. The access drift was started on October 27, 1964 and, when completed, was 61 m (200 ft) long from the center of the access shaft to the centerline of the cavity. It slanted downward toward the cavity at a 0.5 degree slope. The access drift was 3 m (10 ft) high and wide for most of the distance except for the first 15 m (50 ft) near the shaft where it was of various heights and widths to accommodate people and material into and out of the drift. The working point and device location was 8.9 m (28.5 ft) left of the centerline for the access drift and 10.7 m (35 ft) above the invert or floor of the drift. The horizontal instrument drift, branching off in an arc to the left of the access drift, was 76 m (250 ft) long and 3 m (10 ft) high and wide. It circled a quarter way around the cavity on a 30.5 m (100 ft) radius. Instruments in the drift were connected to the cavity by five main drill holes at different angles from the working point (Merritt 1969:22). Four of the holes were drilled from the working point because of the preciseness needed for some of the gauges to be near the nuclear device (Merritt 1969:23). Stemming for the test consisted of two reinforced-concrete plugs in the access drift on either side of the instrument drift and 15 m (50 ft) of alluvial sand in the bottom of the access shaft.

Mining of the cavity began on January 2, 1965 and was completed by April 20, 1965. The shape and orientation of the nearly vertical cavity was based on a number of factors, including ease of construction due to shorter roof spans, less cost in construction and post test recording, simplified installation of instruments and post test reentry, and to take advantage of natural joint planes in the geologic formation for the face to be as smooth or flat as possible (Merritt 1969:15). The flat face of the hemispherical cavity was on a 16 degree vertical angle to follow a natural fracture plane in the geologic formation (Figures 38 and 39). The radius of the cavity from the working point varied from 10.7 m (35 ft) to 13.7 m (45 ft) to create a prolate effect where the polar axis is greater than the equatorial diameter. According to Merritt (1969:14), this prolate spheroid shape directed air shocks away from the working point. Total distance across the face of the cavity on the short or equatorial axis was 21 m (70 ft) and was 24 m (80 ft) on the long or polar axis. The "height" or distance directly outward from the working point on the centerline of the cavity was 13.7 m (45 ft). The orientation of the cavity allowed crater ejecta to fall downward and clear of the resulting crater in the middle of the vertical face so it would not have to be cleaned out after the detonation (Merritt

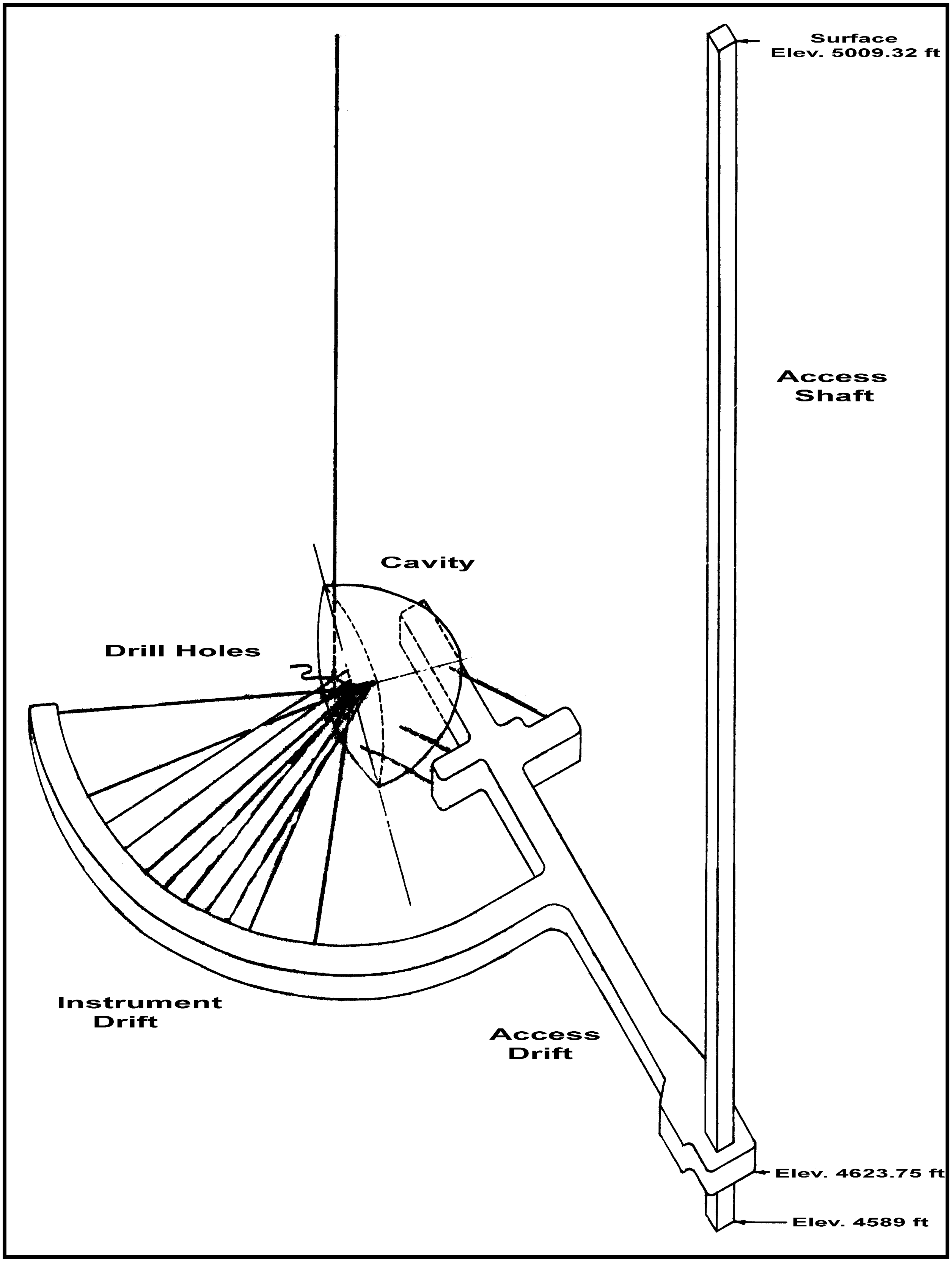

Figure 36. Schematic of the Tiny Tot nuclear test (modified from drawing MER M2.76.B, on file at the Archives and Records Center, Mercury, Nevada).

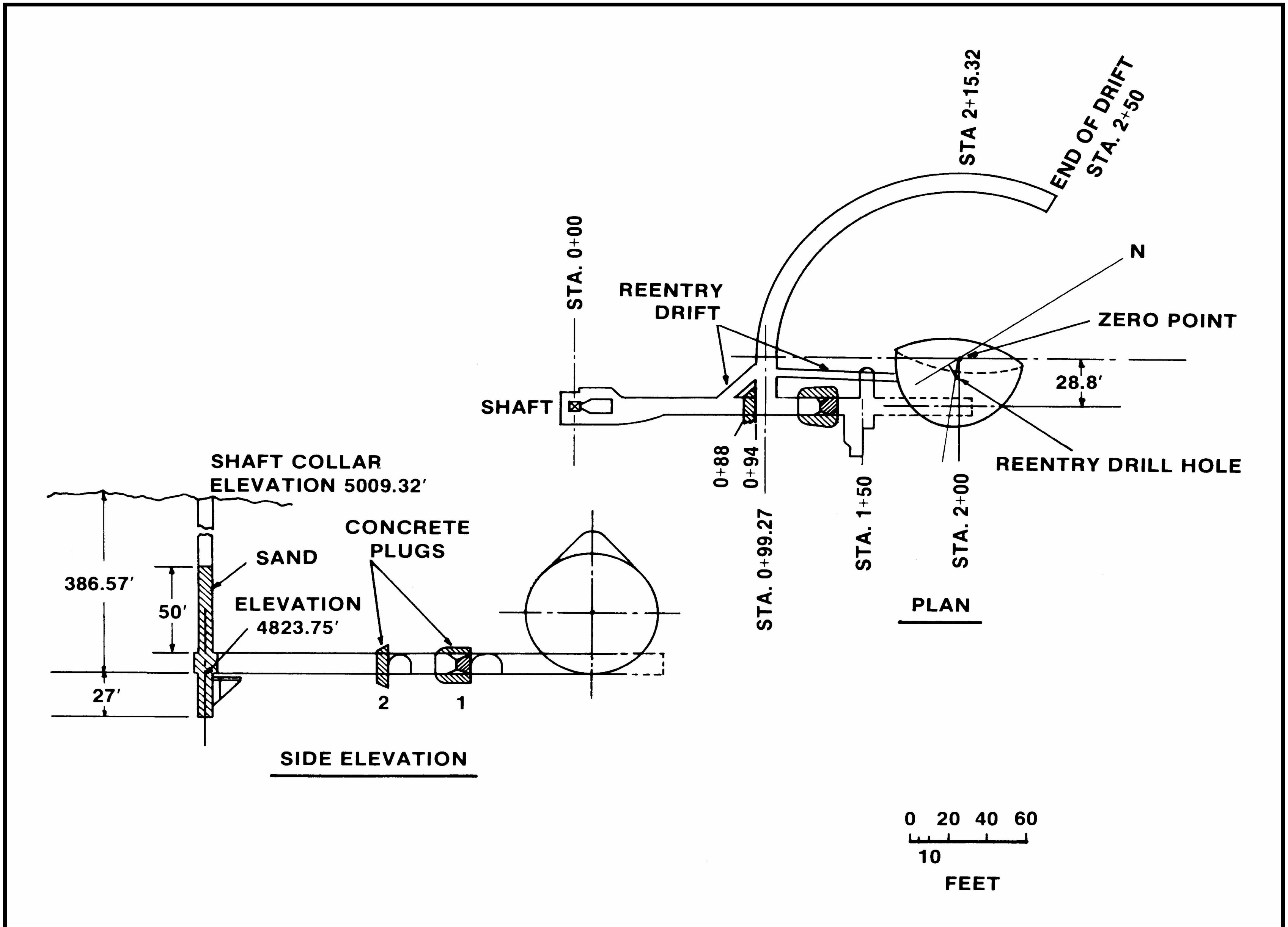

Figure 37. Plan and elevation of the Tiny Tot nuclear test (Brady et al. 1984:216).

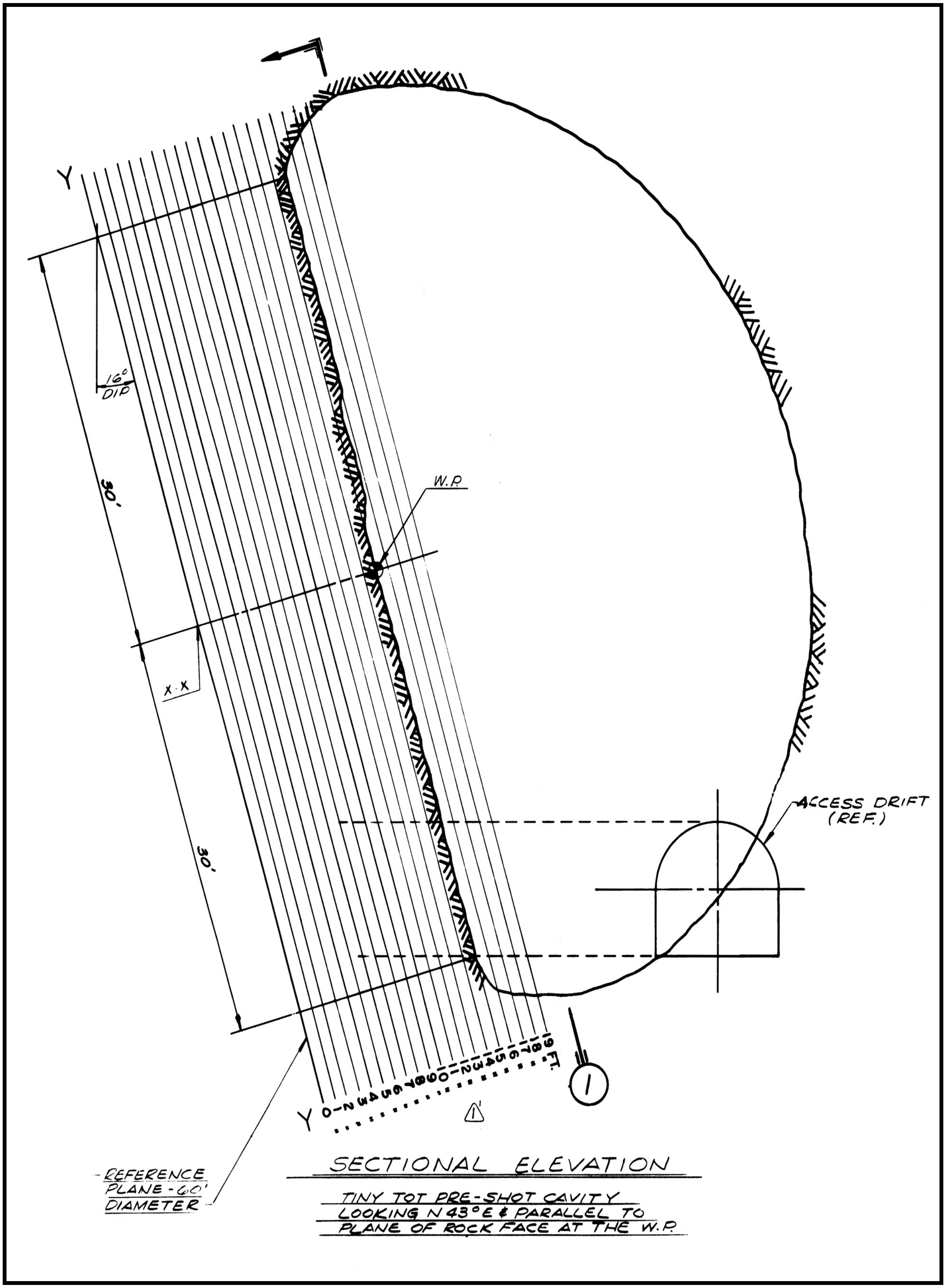

Figure 38. Profile of the cavity for the Tiny Tot nuclear test (modified from drawing JS 015 U15E C2.1, on file at the Archives and Records Center, Mercury, Nevada).

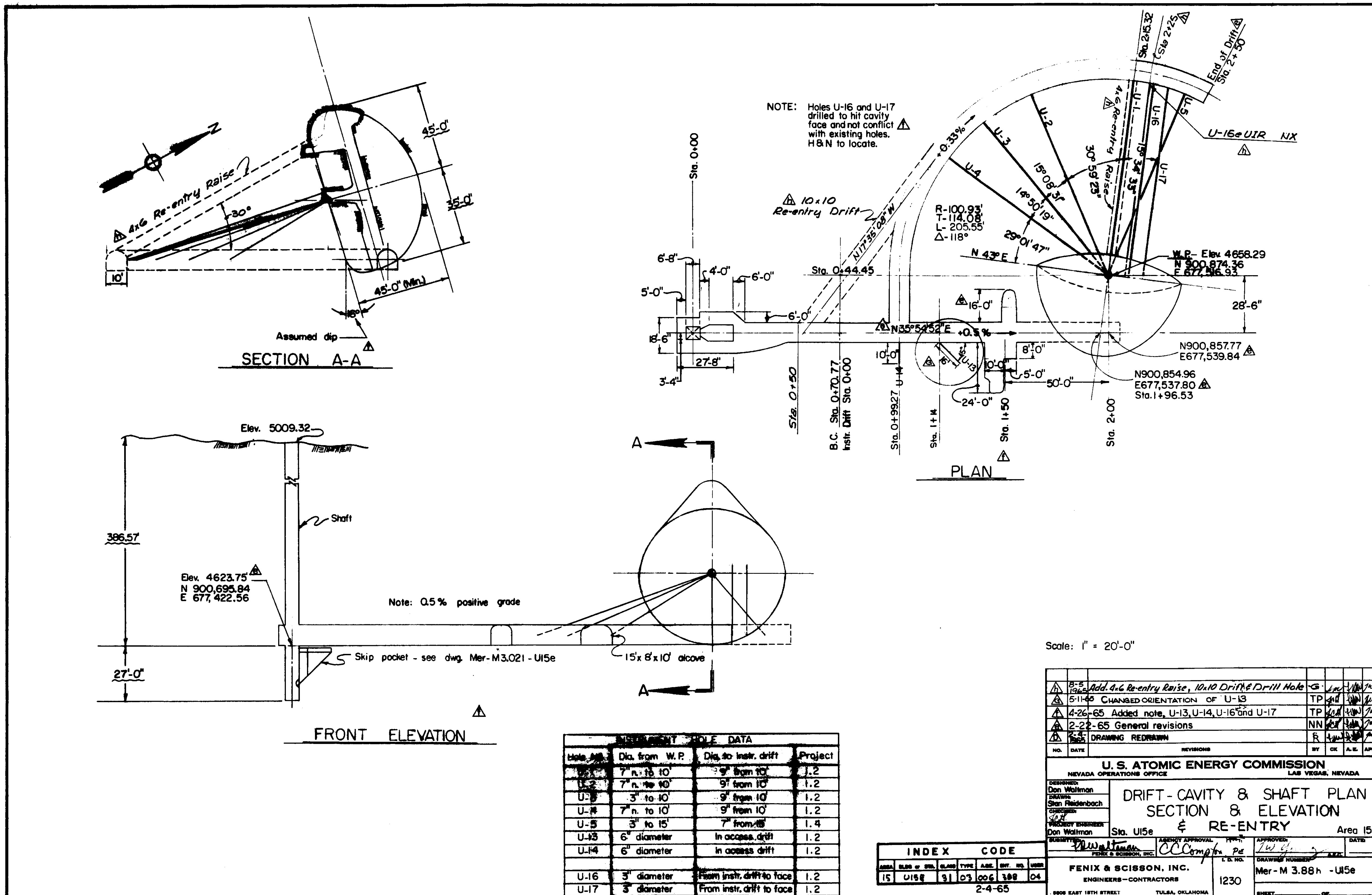

Figure 39. Plan and elevation of the Tiny Tot nuclear test (drawing Mer M 3.88h U15e, dated 1965, on file at the Archives and Records Center, Mercury, Nevada).

1969:15). It was understood before the test that the cavity would be greatly contaminated with radioactive material and having the crater already empty would shorten the time and exposure inside the cavity for post test survey and recording. The size of the cavity was large enough to determine direct and secondary ground shocks and to meet the elastic properties of the surrounding rock. Approximately 30,000 rock bolts were installed in the cavity. Rock bolts 9.1 m (30 ft) in length and fully grouted were used for the dome of the cavity (Clayton 1967a; Merritt 1969:24). Rock bolts 4.9 m (16 ft) long were utilized on the cavity face. The rock bolts were arranged on a grid pattern, spaced 1.8 m (6 ft) apart. No rock bolts were placed within 1.2 m (4 ft) of the working point. Wire mesh, consisting of chain link fencing, covered the entire cavity interior except around the working point.

Remote air monitoring stations were established in the instrument and main access drifts, in the U15e shaft, at the surface above the working point, at the trailer parks, and at specified intervals on the surface around the test location (Brady et al. 1984:217). Readouts from the stations were sent to the forward control point, where the test group director for DTRA was positioned (Brady et al. 1984:218). The results were plotted at the forward control point and at the main control point in Area 6. Sandia Corporation was responsible for the timing and firing systems and EG&G, Inc., personnel armed and fired the nuclear device. All non-essential personnel were removed from the controlled area surrounding the test four hours before the planned detonation and all non-authorized personnel left the controlled area three hours before the detonation (Brady et al. 1984:220). Permission from the test manager to arm the device was received just less than three hours before detonation and the final weather briefing was conducted two hours before detonation. Test countdowns on the NNSS radio nets began 30 minutes before detonation.

The Tiny Tot test was executed at 10:00 on the morning of June 17, 1965. Minutes afterward, the remote air monitoring stations underground showed high radiation levels, with one station between the two concrete plugs in the access drift reading greater than 1,000 roengten per hour (R/h) for about two hours before starting to recede (Brady et al. 1984:Table 10.1). Radiation levels ranged from 60 to 100 R/h past the second plug after 1.5 hours, and reached 100 R/h past the sand plug after 3.5 hours (Merritt 1969:112). The test manager ordered drilling mud dumped into the access shaft to control the leak. Radiation levels at the underground stations were still relatively high at midnight, with several reading 42 R/h, 30 R/h, and 11 R/h, respectively (Brady et al 1984). All surface monitoring stations read background levels of radiation except for one which had slightly elevated readings of 1 R/h for about 30 minutes before returning to normal. The remote air monitoring stations were secured the next day, on June 18 or D+1, at 8:00 in the morning.

Two radsafe survey teams departed from the forward control point 38 minutes after detonation, with one team going to the U15a shaft area and the other team to the Sandia trailer park, the U15e shaft area, and the surface working point (Brady et al. 1984:226). Other radsafe personnel were standing by if needed at the forward control point. The two survey teams finished their surveys after a couple of hours and returned to the forward control point. Elevated radiation readings were noted in the U15e shaft area, with one reaching 55 mR/h and another 300 mR/h at the U15e shaft collar (Brady et al 1984:Table 10.2). All the other readings were at background or near background levels. Personnel from agencies with experiments in the test were then allowed into the controlled area to retrieve their experiments (Brady et al. 1984:228). These agencies included Ballistics Research Laboratory, Defense Atomic Support Agency, and EG&G, Inc.

Post test drilling began on August 27, 1965, and was completed by September 18. No elevated radiation levels were detected during the drilling (Brady et al. 1984:228). The purpose was to monitor the cavity and determine the degree of damage (Merritt 1969:113).

Post test reentry to the U15e shaft and cavity began on September 2, 1965, almost three months after detonation of the Tiny Tot device (Brady et al. 1984:228). The first task was to clear and repair the shaft, which was accomplished by September 22. Mining out the access drift began on September 24, with an initial objective to reach the blast door and drill a hole in the door to insert a probe through to the instrument drift. A labor dispute, however, postponed the work until November 5 when a reentry drift to bypass the second concrete plug was started from the main access drift to the instrument drift (Brady et al. 1984:229). The reentry drift was finished on November 10, finding little damage to the instrument drift, and on November 24 instruments were recovered from the drift. A second reentry drift bypassed the next concrete plug nearest the cavity. The cavity was reached on November 18. Overall, the cavity was found to be in good condition, with most of the rock bolt plates still in place and tight against the rock (Merritt 1969:114). Most of the netting, however, was dislodged. A trace of alpha radiation was detected in the water in the cavity and the miners working in this area were taken to Building 2 at the main control point in Area 6 for decontamination (Brady et al. 1984:229). Entry into the cavity was made on December 2, 1965, and a radiation level of 700 mR/h was recorded. Gravel was poured into the cavity for a week and then leveled off. The radiation level at this time in the general work area of the cavity was 1 R/h. On December 14, the radiation level had reached 2.5 R/h. Work continued in the cavity until January 14, 1966.

Pile Driver

The Pile Driver underground nuclear weapons effects test was conducted on June 2, 1966, at a depth of 463 m (1,518 ft) below the surface and at the bottom of a subshaft below the main access drift. The nuclear device was furnished by Los Alamos National Laboratory and it had a yield of 62 kilotons (DOE/NV2000). The Pile Driver test was a continuation of studies on the effects of a nuclear weapon on underground structures. The ultimate goal of this structures program was to develop conceptual designs and construction techniques for underground facilities, such as command centers, that would survive large yield nuclear surface detonations. Prior to Pile Driver, previous work on this program at the NNSS included several underground nuclear detonations in volcanic tuff on Rainier Mesa in Area 12 in 1957 and the nearby Hard Hat test in 1962 in granite (Figure 40). The Shoal nuclear test in 1963 in northern Nevada, sponsored by the Department of Defense, was also in granite and part of the Vela Uniform program. Primary objectives of the Pile Driver test were to verify and improve on the concepts and construction techniques tested and formulated during the Hard Hat nuclear test, determine the response of different types and sizes of structures at various distances from the detonation, and to measure the free field, wave, and stress effects from the explosion (Distefano et al. 1970:11-12; MacDonald 1970; Merritt and Palaniswamy 1973). Most Pile Driver experiments were designed specifically to test and expand on the results from the Hard Hat test. That is, the Hard Hat results indicated that backpacked experiment sections had less damage than other types of sections and the experiment section with the least amount of damage was the reinforced concrete liner with thick foam backpacking (Lewis 1973:5). What was to be resolved in the Pile Driver test were the limits of underground concrete liners and different backpacking material to withstand a nuclear explosion. Other experiment sections in the Pile Driver test involved new or

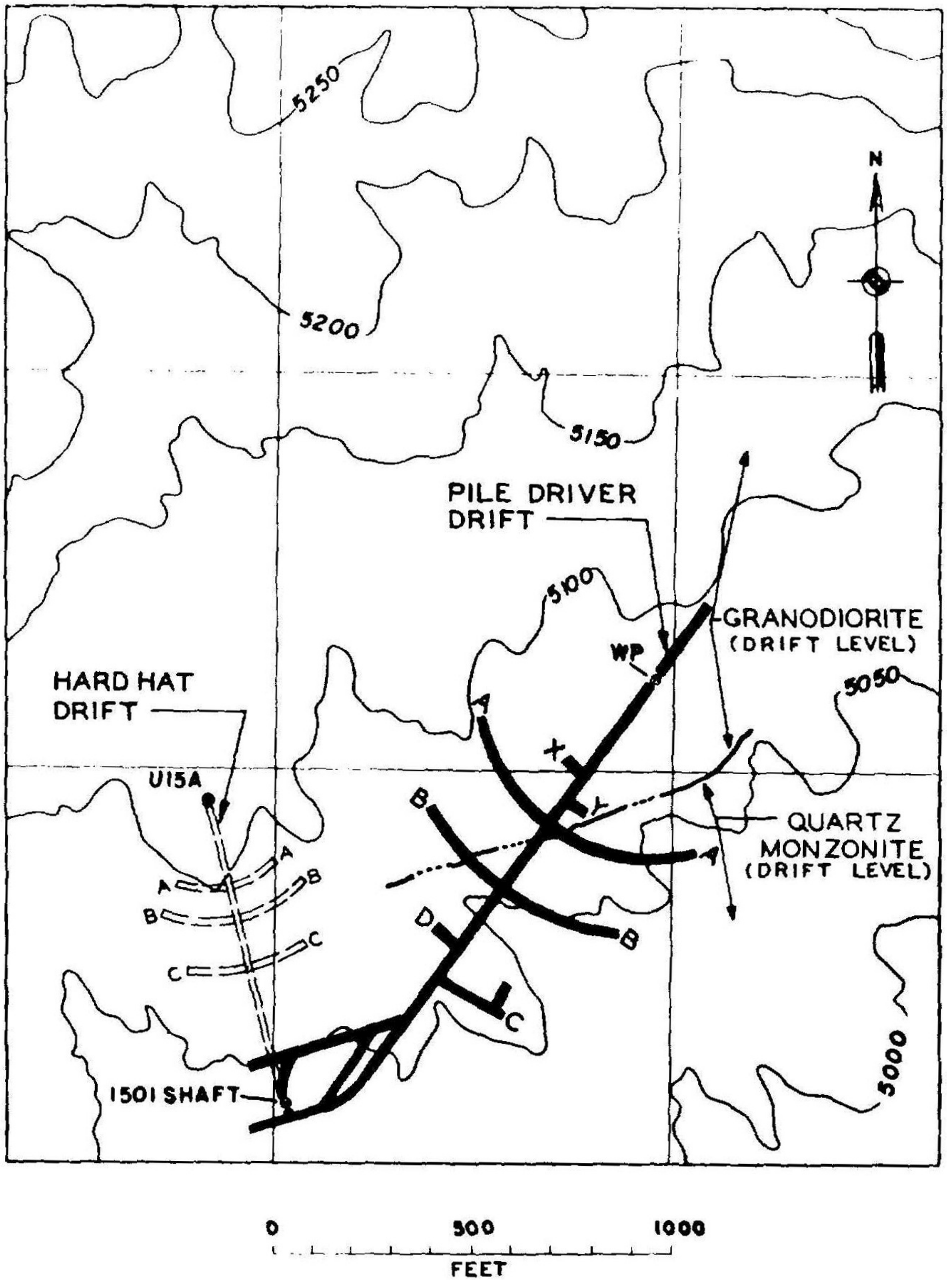

Figure 40. Location of the Pile Driver and Hard Hat nuclear tests to one another and the granitic geologic formations (Distefano et al. 1969:57).

modified structure designs and configurations, such as sandwich, composite, and rock bolt and wire mesh experiment sections and capsule and tunnel intersection configurations.

The Pile Driver underground complex, excavated in granite, consisted of an access shaft from the surface to the working level of the main access drift, the main access drift, six experiment structures drifts, a supply drift, a shop drift, an explosives drift, a tail drift, alcoves, and a subshaft toward the far end of the main access drift for emplacing the nuclear device (Figures 41 and 42). Construction of the underground complex took three years and during the greatest work load involved 442 personnel in three work shifts (Clayton 1967b). Mining was by the drill-and-blast technique with a jumbo drill. Drill holes were typically spaced 30.5 cm (12 inches) to 46 cm (18 inches) apart, 12 m (40 ft) deep, and loaded full length with an explosive of Trim-Tex dynamite (Distefano et al. 1969:78). Approximately 30,582 cubic meters (40,000 cubic yards) of granite were removed (Clayton 1967b). The list of construction material for the tunnel included 18,800 rock bolts, 15,291 cubic meters (20,000 cubic yards) of concrete, 461 cubic meters (603 cubic yards) of polyurethane foam, 307 cubic meters (402 cubic yards) of crushed cinders, 495 cubic meters (647 cubic yards) of cellular concrete, 2,400 plywood panels for forms, 29 corrugated steel experiment sections with 2,400 bolts, and 29,000 sand bags and 7,416 cubic meters (9,700 cubic yards) of sand for stemming. A larger head frame and faster hoist, a permanent power source, and a new ventilation system were also added at the surface.

Rehabilitation of the Hard Hat access shaft, Station 1500, began in May 1963 and was re-designated the U15.01 or Station 1501 access shaft for the Pile Driver test. Initially, this rehabilitation work entailed fixing the metal sets and wood lagging and removal of loose rock (Clayton 1967b; Distefano et al. 1970:103). Beginning in July 1963, the access shaft was extended another 239 m (785 ft) deeper to a final depth of 444 m (1,456 ft) at a rate of 2.9 m (9.56 ft) per day. The upper Hard Hat section of the access shaft had 108 steel sets on 2.4 m (8 ft) centers and lined with 2-x-12 wood lagging, while the lower Pile Driver section had 95 steel sets on 2.1 m (7 ft) centers and lined with 3-x-12 wood lagging (AEC/NV 1967). A muck pocket at the bottom of the access shaft for temporary muck storage and a loading chute was excavated to a 27 m (90 ft) depth below the level of the main access drift (Figure 43). Muck from mining the drifts was loaded into rail cars and dumped into the muck pocket for delivery to the surface. A pit was mined below the railroad track to facilitate the unloading of muck cars. The pit was mined straight down for 7.2 m (23.5 ft) where it then sloped at 50 degrees for another 7.5 m (24.75 ft) to intersect with the south side of the muck pocket. When not in use the pit was secured with a steel cover to allow personnel traffic between the access shaft and the drifts.

Mining of the main access drift commenced in February 1964 (Distefano et al. 1970:104). The access drift was horseshoe-shaped and 3 m (10 ft) high and wide and about 427 m (1,400 ft) below the surface. Rock bolts of 3.7 m (12 ft), 4.3 m (14 ft), and 5.5 m (18 ft) lengths on 0.9 m (3 ft) to 1.1 m (3.5 ft) centers were utilized for reinforcement in planned sections that would be greater than 4.9 m (16 ft) in diameter (Distefano et al. 1970:109). The start of the main access drift was 7.3 m (24 ft) from the centerline for the access shaft and at the intersection of the access, supply, and tail drifts (Figures 44 and 45). The access drift began in an easterly direction for a short distance and then turned to a more northeast direction. The access drift was level for the first 125 m (411 ft), increased to a 0.05 percent grade to the 298 m (976 ft) mark, and then leveled off to the end. At 508 m (1,666 ft) into the access drift, near the original location for the working point, mining of the drift was

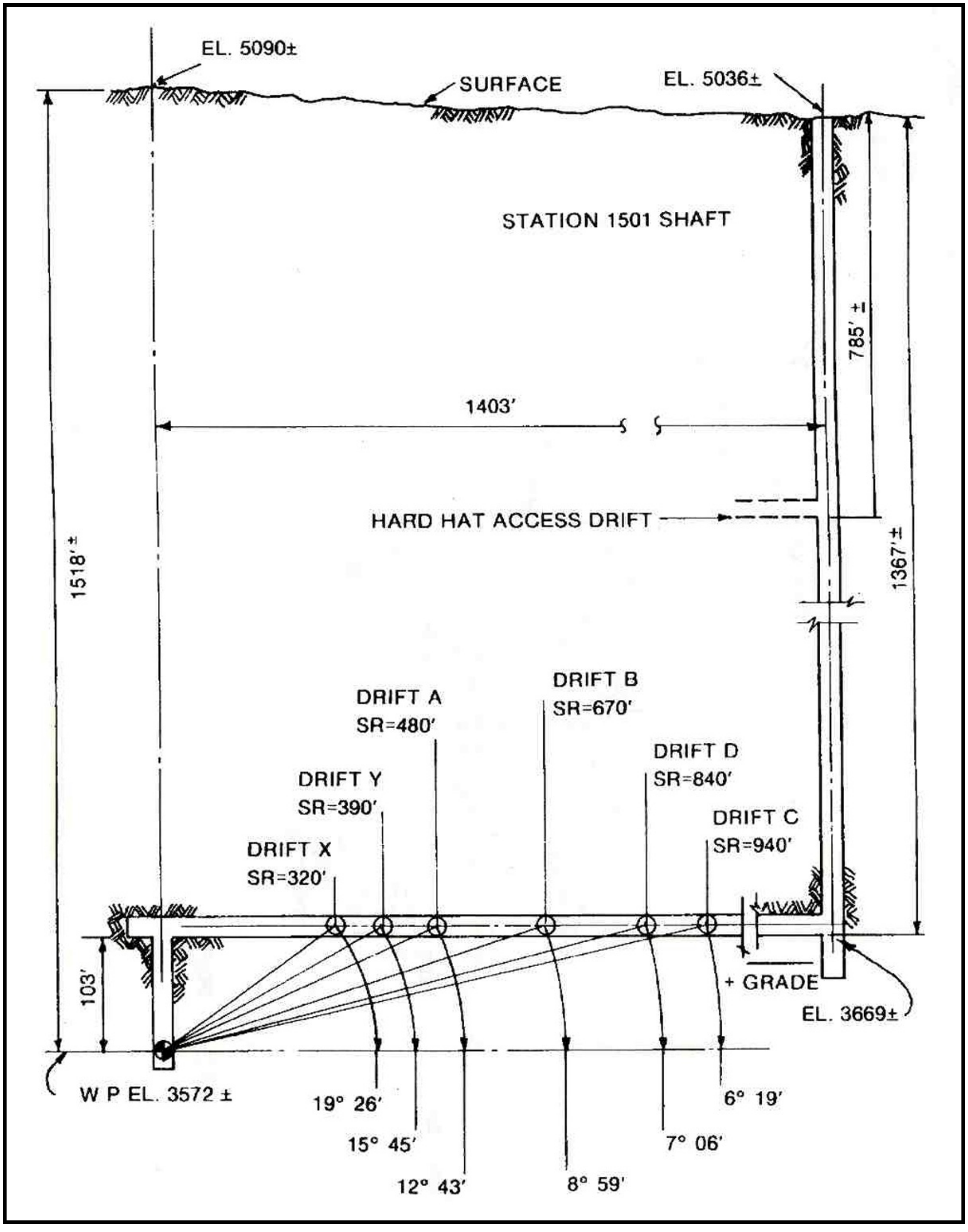

Figure 41. Profile of the subsurface layout for the Pile Driver nuclear test (Horton et al. 1984:129).

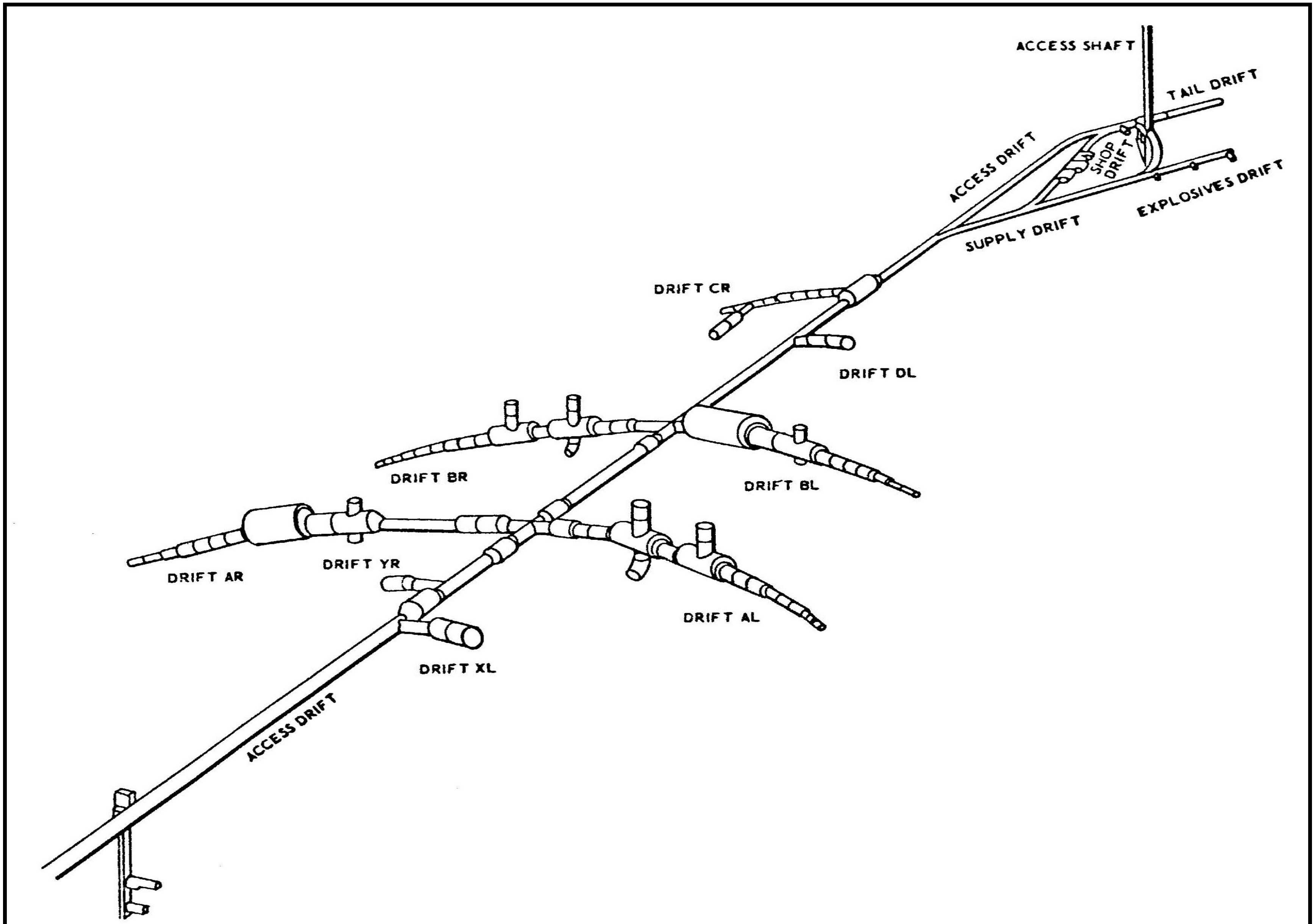

Figure 42. Schematic of the Pile Driver nuclear test underground drift system and experiment sections (Merritt and Palaniswany 1973).

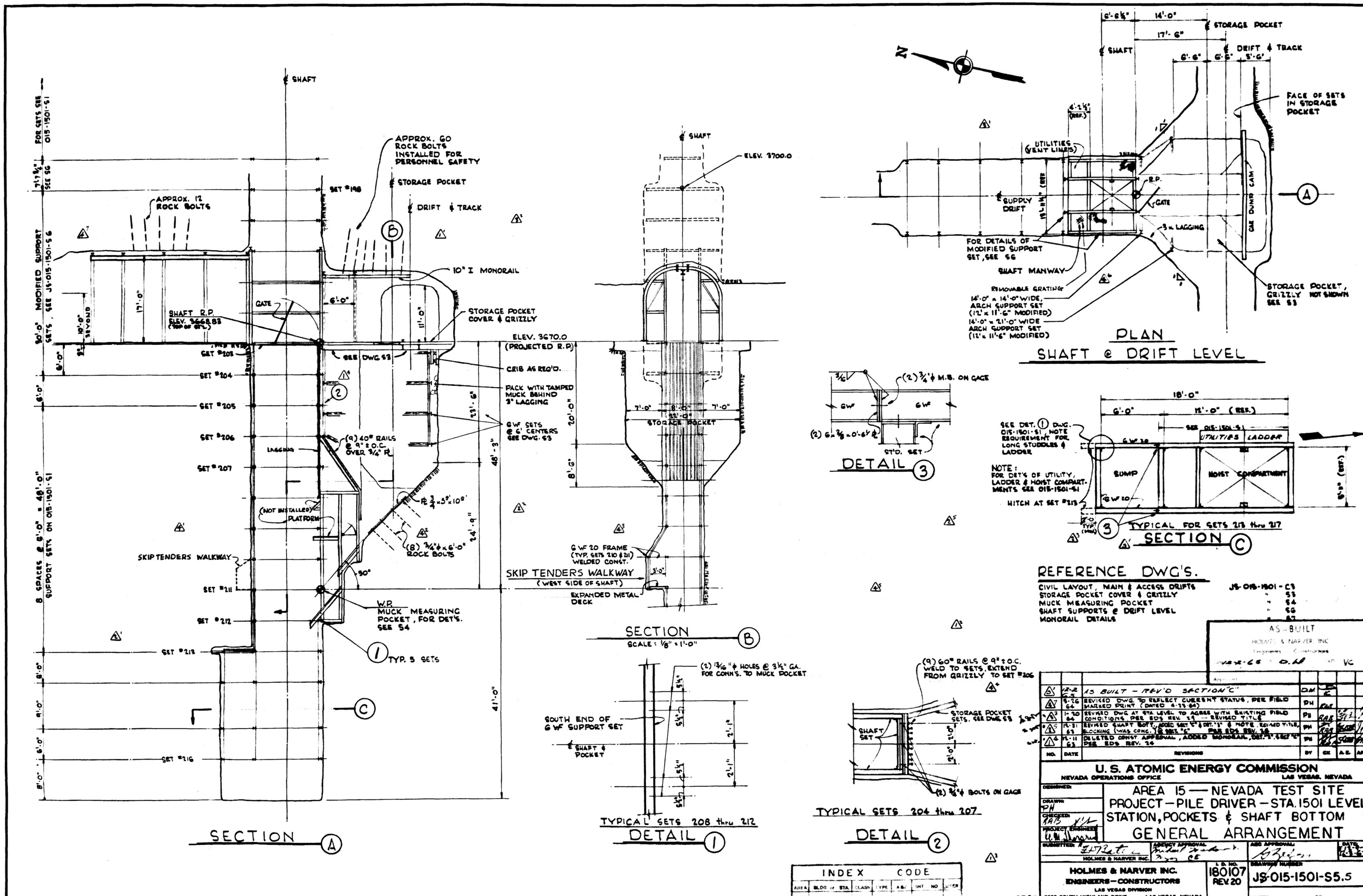

Figure 43. Profile of muck pocket at the bottom of the access drift for the Pile Driver nuclear test (drawing JS 015 1501 S5.5, dated 1963, on file at the Archives and Records, Mercury, Nevada).

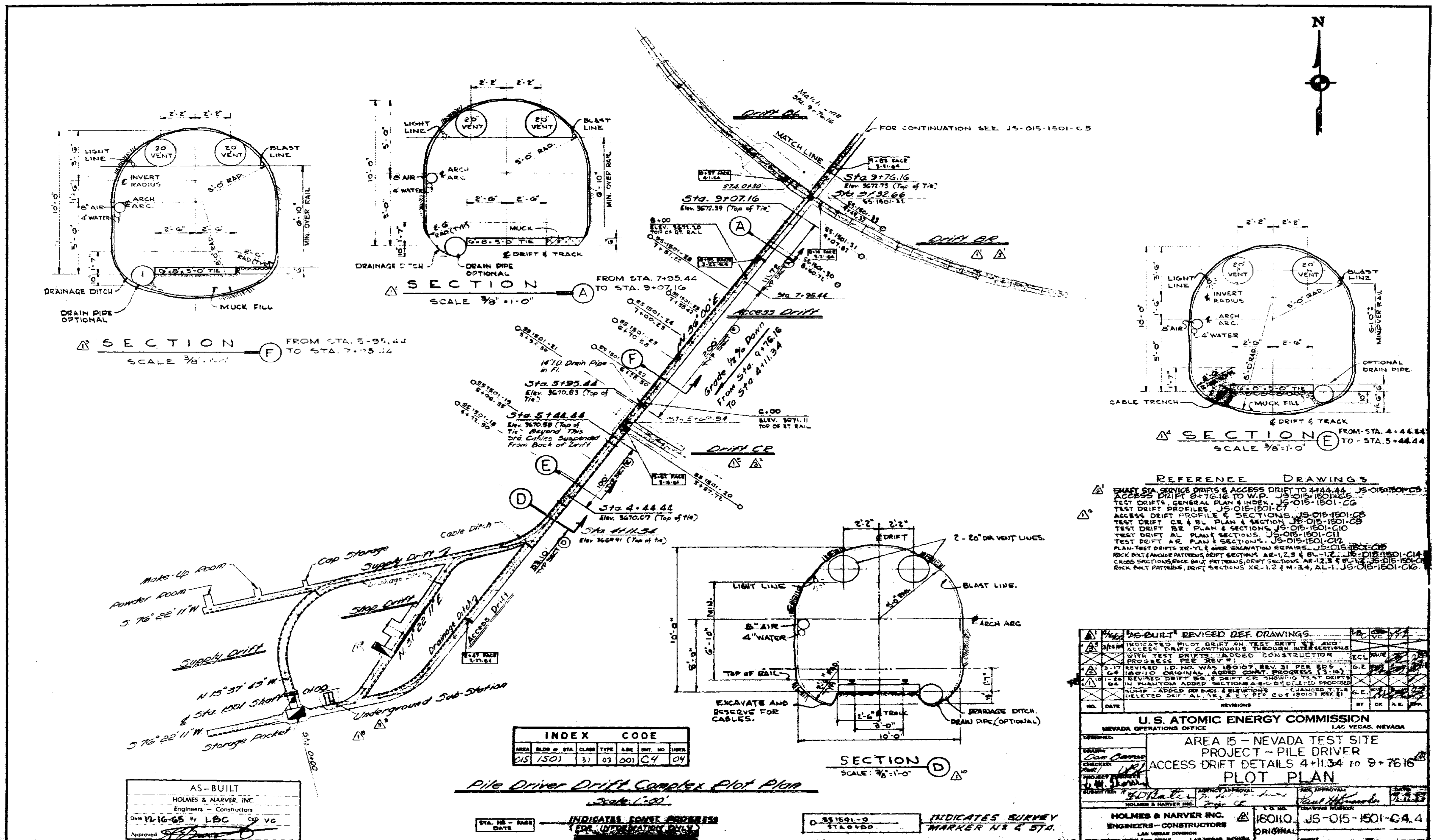

Figure 44. Plot plan and sections of the Pile Driver access drift (drawing JS 015 1501 C4.4, dated 1965, on file at the Archives and Records Center, Mercury, Nevada).

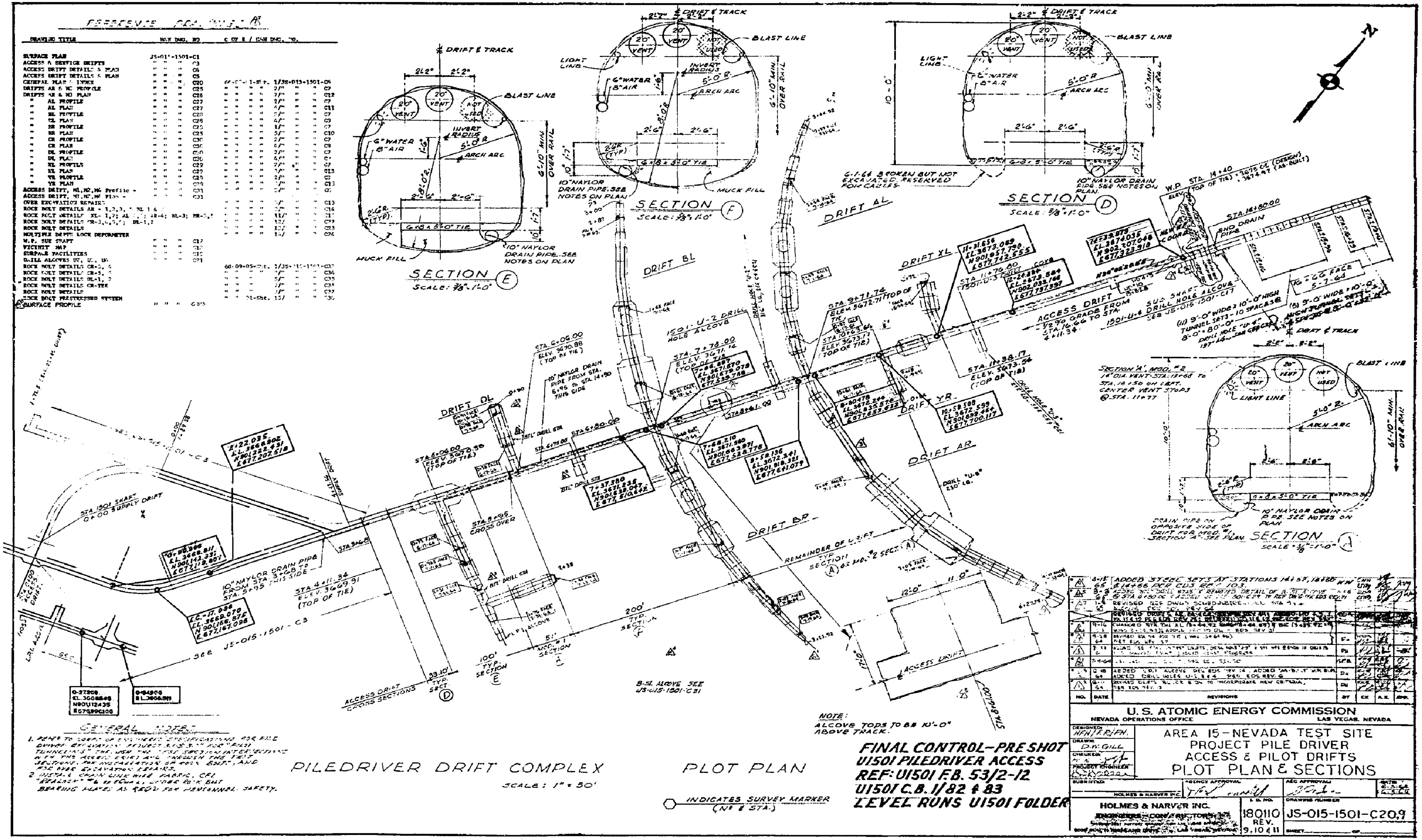

Figure 45. Plot plan and sections of the Pile Driver nuclear test (drawing JS 015 1501 C20.9, dated 1965, on file at the Archives and Records Center, Mercury, Nevada).

halted in June 1964 due to the presence of excessive ground water (Distefano et al. 1970:105). The ground water indicated a connection to the surface whereby radioactive material from the test could vent along the same path upward to the surface (Distefano et al. 1970:112).

As a consequence of ground water at the original location, the working point was moved back to the 439 m (1,440 ft) mark in the main access drift and beginning in July 1964 a vertical subshaft was mined down to the working point (Distefano et al. 1970:108). The working point where the device would be detonated was 31.4 m (103 ft) below the main access drift. The subshaft started from a small alcove, 3 m (10 ft) long, 1.4 m (4.5 ft) wide, and 2.1 m (7 ft) high, off the right side of the access drift. The subshaft measured 2.1 m (7 ft) by 1.4 m (4.5 ft). A 9 m (30 ft) raise was excavated above the subshaft in order to fit in a head frame to facilitate mining to the lower depths. The subshaft reached a depth of 32.8 m (107.5 ft). A small alcove, 2.4 m (8 ft) by 1.5 m (5 ft), to contain the nuclear device was mined off the subshaft to the working point (Distefano et al. 1970:109). The working point was sited directly below the center line of the access drift and 1.38 m (4.5 ft) above the bottom of the subshaft. At a depth of 24 m (80 ft), an alcove, 3.0 m (10 ft) long, 1.5 m (5 ft) wide, and 2.1 m (7 ft) high, for a hydrodynamic yield experiment was mined off the subshaft and over the working point alcove. Construction of the subshaft area was completed in December 1964.

Shop, supply, explosive storage, and tail drifts and a power transformer alcove to support the forward operations were located near the access shaft and mined at the same time as the main access drift (Distefano et al. 1970:103). The tail drift, 32 m (105 ft) long, was at the end of the main access drift and to the right of the access shaft. The supply drift extended from the rear of the access shaft, curved around to intersect with the explosive storage drift, and continued until it intersected the main access drift at about the 122 m (400 ft) mark. The explosive storage drift had several small alcoves which included a powder storage room, a make up room, and a cap storage room. A mechanics shop alcove was mined off the left side of the supply drift. Lawrence Livermore National Laboratory had a small alcove off the right side of the tail drift and another on the left side of the main access drift between the supply and shop drifts.

Six structure experiment drifts, X, Y, A, B, C, and D, of different lengths and diameters from 2.1 m (7 ft) to 13.4 m (44 ft) were mined on arcs of a circle centered 31 m (103 ft) above the working point (Figure 42). Due to the working point being moved approximately 60 m (200 ft) shorter, the B and C experiment drifts had to be relocated (Distefano et al. 1970:113). Drift C was moved 43 m (140 ft) closer to the new working point to comply with the design of the test and the B drift location was adjusted to maintain the geometric mean distance between the drifts. Drift A was located where most experiment sections were expected to completely fail and suffer severe damage (Distefano et al. 1970:25). Experiment sections in the B drift, located midway, were expected to survive with moderate to minor damage. The six drifts were placed at angles from the working point at distances of 96 m (320 ft), 119 m (390 ft), 146 m (480 ft), 204 m (670 ft), 287 m (940 ft), and 256 m (840 ft), respectively (Distefano, et al. 1969:15; Distefano et al. 1970:15). Two of the experiment structures were located in the access drift at distances of 107 m (350 ft) and 137 m (450 ft) from the working point and two rock bolted sections in the C drift faced the working point head on at a distance of 258 m (846 ft). Most of the experiment drifts were first mined with a pilot drift in a horseshoe shape that was 3 m (10 ft) high and wide and enlarged later to full size when the rock structure was deemed fit by the geologists and engineers (Distefano et al. 1970:106). The size of the pilot drift was reduced for those sections less than three meters in size. Mining of the pilot drifts started in June 1964 and finished in August 1964, with final excavation to full size of all experiment drifts completed by March 1965 (Distefano et al. 1970:106, 108).

The structure experiment drifts had designations of R for the right side and L for the left when looking toward the working point. The XL drift had 2 structures, YR had 1, AR had 12, AL had 18, BR had 17, BL had 10, CR had 9, DL had 2, and the access drift (M) had 2 (Table 5). The design of the A, B, and C drift structure experiment sections were similar to those tested on the Hard Hat test. Although most structure experiment sections were aligned on a perpendicular axis to the explosion, as in the previous Hard Hat test, some of the Pile Driver sections were placed in various positions including end on to the explosion (Distefano et al. 1970:16). The Pile Driver test had a total of 73 individual structure experiment sections, almost double that of the Hard Hat test, with 71 located in the six experiment drifts and two in the main access drift (Distefano et al. 1970:15).

Table 5. Pile Driver Test Drifts and Section Types (Distefano et al. 1970:47).

	Test Drift									
Section Type	XL	YR	AR	AL	BR	BL	CR	DL	M	Total
Concrete	-	1	4	7	7	4	2	-	1	26
Steel	-	-	4	7	7	4	-	-	-	22
Intersection	-	-	1	2	2	1	-	-	-	6
Sandwich	2	-	2	1	-	-	-	-	1	6
Composite	-	-	1	-	-	1	1	-	-	3
Capsule	-	-	-	1	1	-	-	-	-	2
Rock Bolt	-	-	-	-	-	-	5	2	-	7
Unlined	-	-	-	-	-	-	1	-	-	1
Total	2	1	12	18	17	10	9	2	2	73

Construction of the structure experiment sections began in January 1965 and finished a year later in January 1966 (Distefano et al. 1970:120). When the experiment drifts were completed, the section at the furthest end of the experiment drift was constructed first and then each successive section until the access drift was reached. Those sections deemed most likely to survive tended to be placed closest to the access drift for easier access during reentry. Basic design for the experiment sections was a 2.1 m (7 ft) inside diameter, a 15 cm (6 inch) thick concrete structural lining, and 1.2 m (4 ft) of backpacking material (Distefano et al. 1970:24). The surrounding rock was mined to a 4.9 m (16 ft) diameter. The internal diameter for other experiment sections varied from 0.9 m (3 ft) to 6.1 m (20 ft), with the smallest sections located the furthest from the access drift and the larger ones nearest the access drift (Distefano et al. 1970:27; Merritt and Palaniswamy 1973). The length of each section was 2.5 times that of its internal diameter (Distefano et al. 1970:28). Of the 73 experiment sections, 65 were lined in some manner with reinforced concrete or corrugated steel, one was unlined, and seven were lined with rock bolts and chain link wire mesh. The types of sections are presented in Table 5, and consist of concrete, corrugated steel, intersections, sandwich, composite, capsule, rock-bolted, and unlined. Most sections were located in the A drift (n= 30) and B drift (n= 27).

Concrete experiment sections with cellular concrete backpacking varied in size and makeup (Distefano et al. 1970:122). They had different diameters, thicknesses, and thickness of backpacking (Figures 46-47). Inner and outer wood forms, designed by William Shutte, a private engineering consultant (Clayton 1967b), were used to pour the reinforced concrete section when there was adequate space between the surrounding rock and the section. Backpacking was added later (Methods A, B, and C in Figure 48). If not enough space was available, then the cellular concrete backpacking material was placed against the surrounding rock first and only the inner wood form was used. The backpacking material constituted the outer form in this case. Reinforcement consisted of two layers of steel rebar and once the forms were set the concrete was poured in one continuous operation. Wood bulkheads covered the ends of the sections to hold the concrete within the forms. A completed concrete section is shown in Figure 49. The batch plant for the concrete was located on the surface about 0.4 km (0.25 mile) from the access shaft (Distefano et al. 1970:116). The concrete was mixed in concrete trucks with a capacity of seven cubic yards and was transported to the access shaft where it was dumped into a three cubic yard bucket that was lowered to the underground complex (Figure 50). At the main access drift level the concrete was put into a cylindrical agitator rail car and moved down the access drift to a pumping machine (Figure 51). The pumping machine was positioned at the intersection of the access drift and an experiment drift. The concrete was then pumped into a wooden form for an experiment section. Extreme compressive strength of the concrete experiment sections ranged from 3,320 to 6,800 psi on the day of the test. (Distefano et al. 1970:57). The expected average was about 4,500 psi.

Corrugated steel liners were manufactured by the Republic Steel Corporation in Canton, Ohio (Distefano et al. 1970:121). They were used to determine if steel liners would buckle under the strain from the explosion and whether they would provide adequate support to the backpacking material (Distefano et al. 1970:39). The steel liner consisted of two types: single or double thickness (Figure 52). The double thickness type was either nested and comprised of two corrugated steel plates laminated together or honeycombed and comprised of two corrugated steel plates with facing corrugations. Small steel liners with 0.9 or 1.2 m (3 or 4 ft) diameters were hauled down the access shaft and into the experiment drifts completely assembled, while the larger ones with 2.1 m (7 ft) diameters were transported disassembled to fit into the access shaft and assembled in the experiment drifts (Distefano et al. 1970:122). After assembly the liner was held in place with supports from the surrounding bulkheads or on hangers. Backpacking material was then placed in one or more lifts around the steel liner (Method A in Figure 48).

Four cross and two tee intersection experiment sections (Figures 53-54), representing corridor intersections, were placed in the A and B experiment drifts (Distefano et al. 1970:123). The main component of these sections was parallel to the experiment drift and extensions from the main component were perpendicular. Interior diameter was 3.6 m (12 ft) for the main component and 2.1 m (7 ft) for the extensions. Two of the cross intersections had 3.7 m (12 ft) long capsules with domed ends connected to the lower extensions and oriented 45 degrees from the explosion (Distefano et al. 1970:17, 124). The main component, lower extension, and capsules were constructed in place along with backpacking material. The upper extensions of all four cross intersections were precast, lifted into place, and backpacking added. Nylon fiber reinforcement was added to the concrete for the upper extensions.

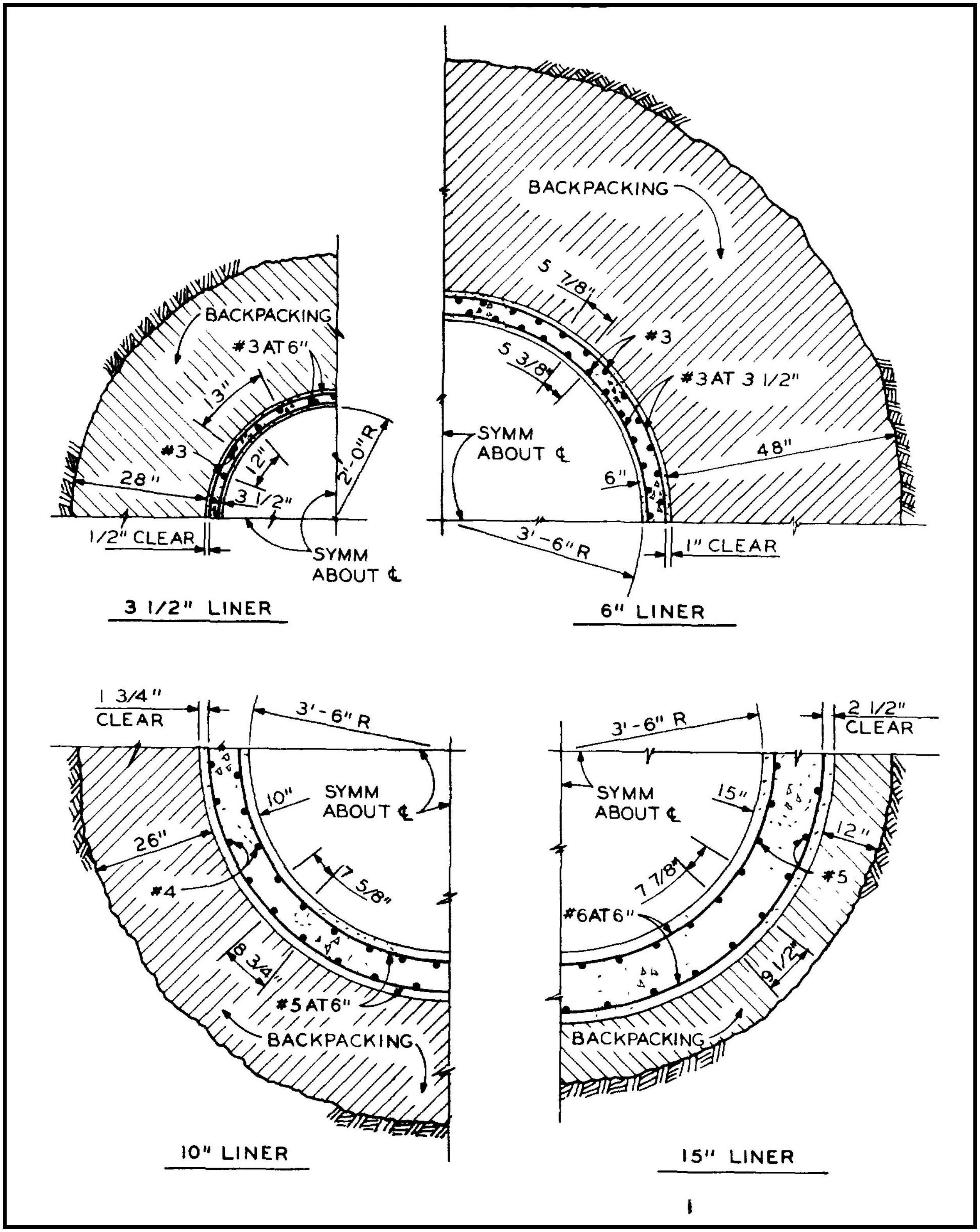

Figure 46. Examples of 3.5, 6, 10, and 15 inch thick concrete experiment sections for the Pile Driver nuclear test (Distefano et al. 1970:95).

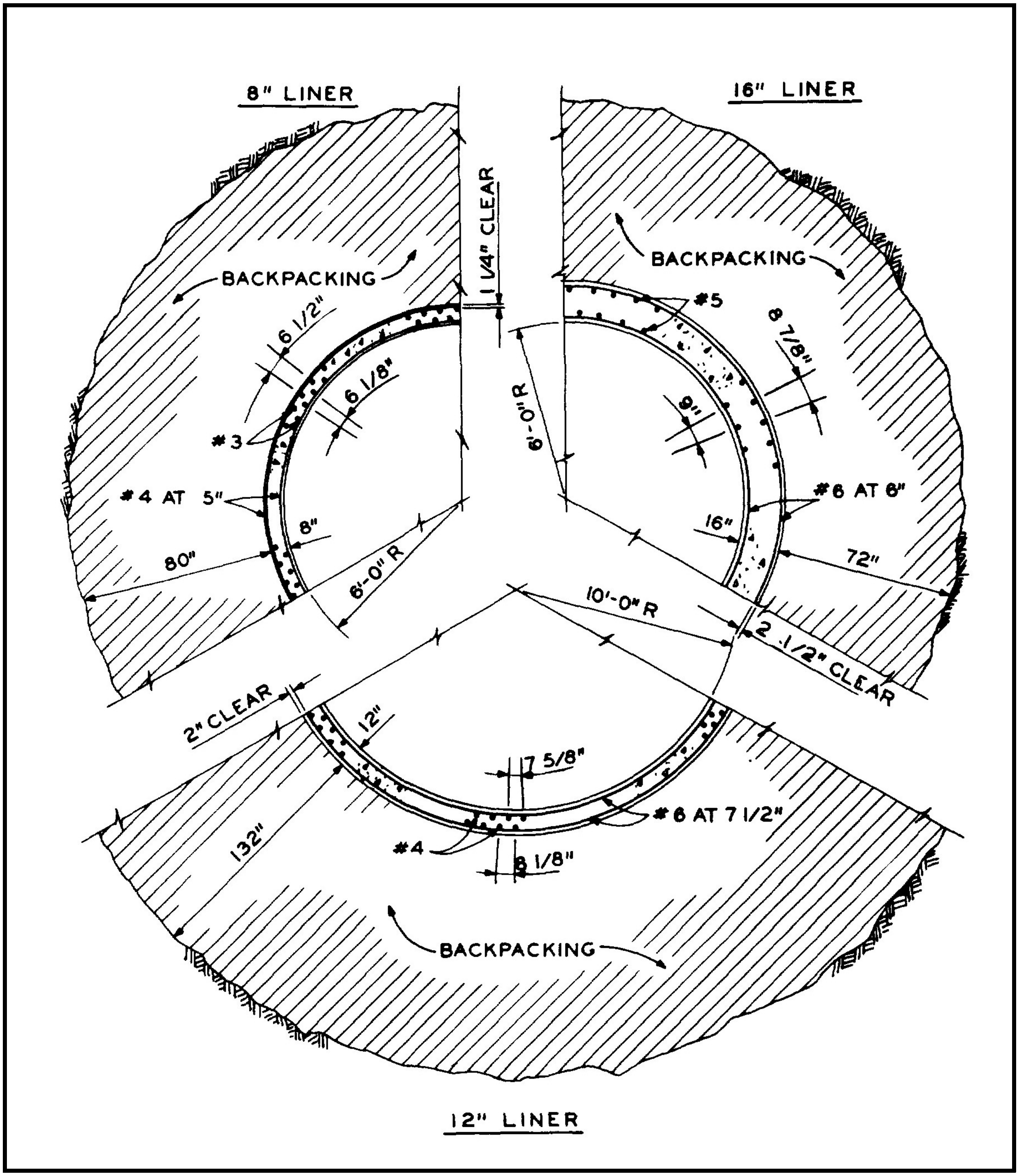

Figure 47. Examples of 8, 12, and 16 inch thick concrete experiment sections for the Pile Driver nuclear test (Distefano et al. 1970:96).

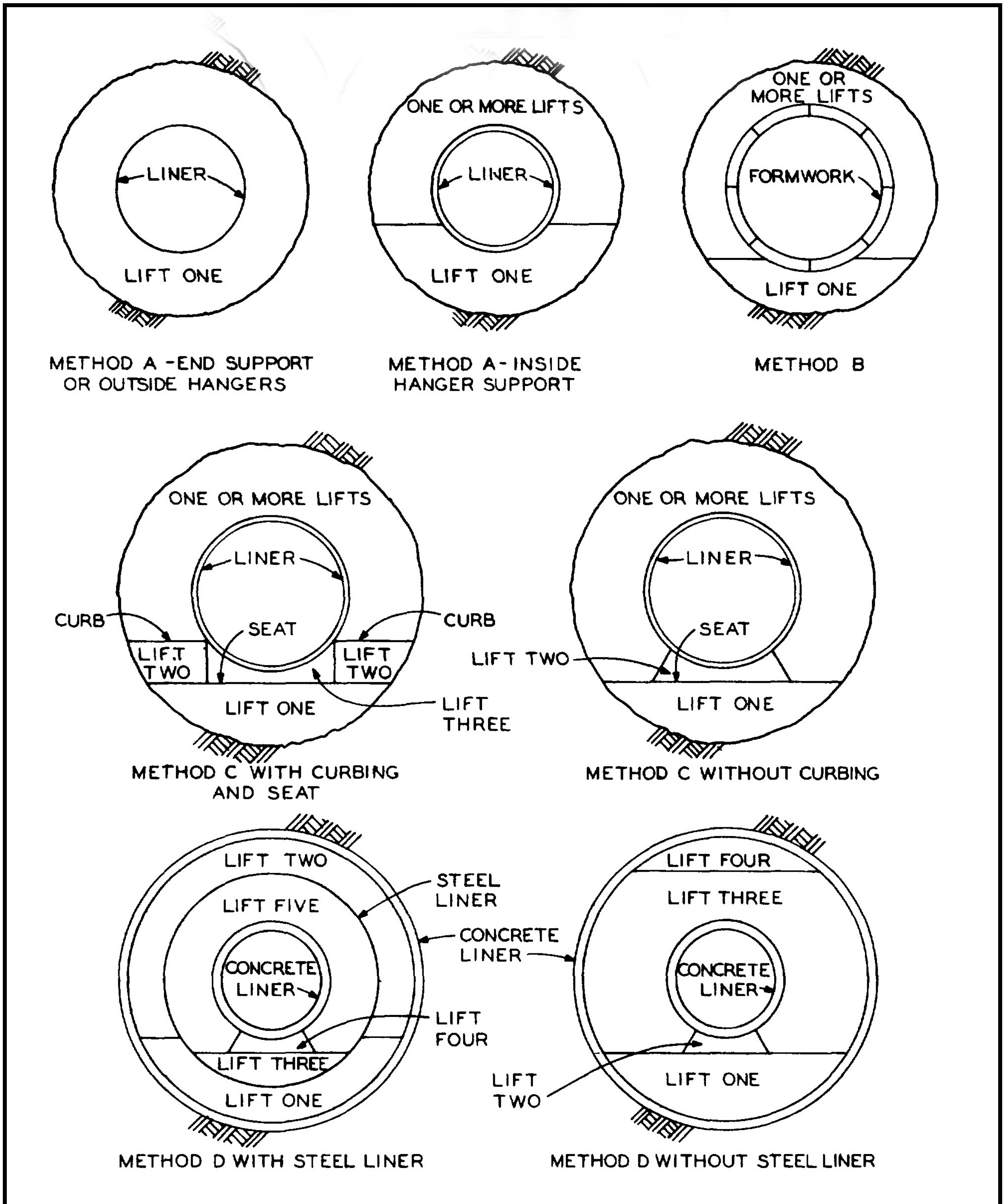

Figure 48. Configurations of backpacking construction for the Pile Driver nuclear test (Distefano et al. 1970:152).

Figure 49. View of concrete experiment section and work station in the Pile Driver nuclear test (REECo photograph 3041-2, dated 1965, on file at the Nuclear Testing Archive, Las Vegas).