UCRL-ID-104560
PATC-IR 89-04

An Engineering Geologic Evaluation of the PSA Flight 1771 Crash Site Near Paso Robles, California

October 1, 1989

D. W. Carpenter, J. C. Chen, G. S. Holman

Prepared for
U. S. Nuclear Regulatory Commission

This work was supported by the United States Nuclear Regulatory Commission under a Memorandum of Understanding with the United States Department of Energy.

PATC-IR 89-04

An Engineering Geologic Evaluation of the PSA Flight 1771 Crash Site Near Paso Robles, California

October 1, 1989

D. W. Carpenter, J. C. Chen, G. S. Holman

Prepared for
U. S. Nuclear Regulatory Commission

EXECUTIVE SUMMARY

At approximately 1615 PST on December 7, 1987, Pacific Southwest Airlines (PSA) Flight 1771 with 43 passengers and crew, crashed with great force on a hillside about 19 km (12 miles) southwest of the City of Paso Robles, California. The velocity of the aircraft at impact is estimated at 282 m/s (925 ft/s). The aircraft, a British Aerospace 146-200, and its contents broke into small pieces upon impact.

The U. S. Nuclear Regulatory Commission (NRC) has chosen the PSA Flight 1771 crash as a worst case crash against which proposed air transport containers for the shipment of plutonium nuclear fuel may be tested pursuant to Section 5062 of Public Law 100-203.

This report presents the results of an engineering geologic study of the PSA Flight 1771 crash site. The study included geologic reconnaissance and mapping and subsurface exploration by five Nx-cored drill holes and four backhoe test pits. Geophysical and earth penetrator studies were also performed at the site. Relevant engineering geologic aspects of these investigations are discussed in this report.

The PSA Flight 1771 crash site is underlain by steeply dipping, thinly interbedded marine sandstones and shales of the late Mesozoic Toro Formation. These rocks have been intensely deformed as a result of recurring tectonic activity that has affected the region surrounding the crash site. A branch of the Oceanic Fault Zone, a portion of the inactive Sur-Nacimiento Fault System, passes about 90 m (300 ft) northeast of the crash site.

A clayey silt colluvial soil cover, generally about 150 mm (0.5 ft) thick, covers the immediate vicinity of the aircraft impact point. The colluvial soil cover thickens gradually downslope toward the southeast.

Past tectonic deformation has resulted in intense fracturing and shearing of rocks in the study area. Rock Quality Designation values for rocks at the site average less than 30% indicating poor to very poor rock in a geotechnical sense. Intense weathering has affected the near surface portions of the rock mass beneath the study area and immediately beneath the colluvial cover, the rocks are characteristically decomposed to materials with the geotechnical properties of dense soils.

Earth penetrator tests were performed at a location centered approximately 30 m (100 ft) southeast of the aircraft impact point. Geology at the test location is similar to that at the impact point. The penetrator testing yielded an S-number of 2.5±0.5 for the weathered rock zone beneath the site, a value observed previously in intensely weathered to decomposed rocks.

Geophysical studies indicate the presence of a two-layer system beneath the crash site. Comparison of geophysical studies with other information indicates that the first layer, with shear and compressional wave velocities of 610 and 1220 m/s (2000 and 4000 ft/s) respectively, corresponds roughly to the zone of decomposed and intensely weathered rock. The second layer, with shear and compressional wave velocities of 950 and 1645 m/s (3120 and 5400 ft/s), corresponds to less weathered to unweathered rocks present at greater depths.

The effects of the PSA Flight 1771 crash upon the site itself appear largely limited to the excavation of a crater approximately 3.5 m deep by 6 m wide by 12 m long (11.5 ft x 20 ft x 40 ft) and the expulsion of about 175 Mg (195 tons) of pulverized weathered rock and soil from the crater. Other effects, if any, were trivial, Pulverized rock and soil were expelled from the crater preferentially toward the southwest, the direction of flight. Dispersal appears to have been chiefly influenced by the force of the impact and the prevailing wind.

Geotechnical properties of the crash site are intermediate between rock and alluvial deposits. Dry, cemented alluvial deposits present at a number of localities in the arid interior southwest of the United States would probably provide geotechnically similar targets for package proof testing. Harder sites would be provided by rock exposures or by areas underlain by thin soils and lightly to moderately weathered igneous, metamorphic or well-indurated sedimentary rocks.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

The work described in this report was funded by the Transportation Branch within the Office of Nuclear Materials Safety and Safeguards of the U.S. Nuclear Regulatory Commission (NRC). Dr. John Cook was the NRC Project Monitor for this investigation.

The authors wish to express their sincere appreciation to the members of the Wilbur W. Hartzell family, on whose ranch the PSA Flight 1771 accident occurred. The Hartzell family not only allowed us access to their property, but also provided substantial material assistance that contributed greatly to the success of our field operations. We would particularly like to thank Mr. Hartzell for his willingness to become an active participant in our investigation, and for his assistance in contacting various local government officials. Tim Hartzell made shop facilities available on several occasions when they were needed, and aided with communications between the field and LLNL. Jim Hartzell constructed access trails prior to our operations and provided capable earth moving services as required during the course of our work.

The investigation discussed in this report was a multi-disciplinary effort drawing on the technical and administrative talents of many individuals. We would particularly like to acknowledge the contributions of the following participants.

- Keith Graham of the LLNL Laboratory Counsel's Office, and Martin Tangeman of Sinsheimer, Schiebelhut and Baggett (San Luis Obispo, California), who developed the necessary Right-of-Entry Agreements under which we performed our field operations.
- Matt Westervelt and Mark Clark of P.C. Exploration (Roseville, California), who performed the actual exploratory drilling of the accident site.
- Casey Endacott of Endacott and Associates (Pasadena, California), who performed the shear wave investigation of the accident site.
- Clement Lee of Aelytek, Inc. (Sunnyvale, California), who made the topographical survey and aerial photographs of the accident site.
- C. Wayne Young and his team from Sandia National Laboratories (Albuquerque, New Mexico), who conducted the earth penetrator testing, as well as Mark Eli of the LLNL Nuclear Systems Safety Program, who assisted us with field operations during the earth penetrator testing.

- Don Emerson of the LLNL Earth Sciences Department, and Carl Walter of the LLNL Nuclear Systems Safety Program, who each provided valuable technical and administrative reviews of this report.

- Jim Caywood and his team from the LLNL Technical Information Department, who generated a comprehensive motion picture record of our field operations.

- Jackie McBride of LLNL Public Information Department, who provided still photography of our field operations.

- Paul Conners of the LLNL Public Information Department, who served as public information officer for this project.

We would also like to thank Sheriff Edward Williams of San Luis Obispo County and the members of his staff for sharing with us important information about the Flight 1771 accident and for arranging, through the Sheriff's Aero Squadron, helicopter services for our film crew.

Priscilla Proctor of the LLNL Technical Information Department prepared the figures and test pit logs included in the report. Ken Toney of Brown and Caidwell, Inc. Walnut Creek, California, input field data and prepared the detailed logs of the five exploratory holes drilled during the our investigation. Sherry Miron and Karen Gutierrez of the LLNL Earth Sciences Department typed the original report, and Lisa Hensel and Renee Pletcher of the LLNL Nuclear Systems Program provided final revised manuscript.

1. INTRODUCTION

At 15:30 PST on December 7, 1987, Pacific Southwest Airlines (PSA) Flight 1771, with 43 passengers and crew, departed from Los Angeles, California bound for San Francisco, California. At approximately 16:15 PST, probably as the result of a criminal act, the British Aerospace 146-200 employed for PSA Flight 1771 crashed with great force into a hillside about 19 km (12 miles) southwest of Paso Robles, California (Fig. 1). The aircraft broke into small pieces upon impact and its contents were widely scattered. There were no survivors. The appearance of the crash site shortly after the accident is shown in Fig. 2.

The purpose of this report is to present the results of an engineering geologic study of the crash site and its environs. This study was undertaken by Lawrence Livermore National Laboratory (LLNL) at the request of the U. S. Nuclear Regulatory Commission (NRC) in order to assist the NRC in its response to Section 5062 of Public Law 100-203.

Section 5062 is concerned with air shipments of plutonium (Pu) from one foreign nation to another through U.S. airspace. It applies specifically to the packages or containers in which the Pu is shipped, requiring that they be certified by the NRC as safe for the purpose and that they must be able to survive the worst aircraft accident that might occur while in transit without releasing significant quantities of their Pu contents.

The law sets forth general requirements for certifying a shipping package as safe including a drop test of the package and a crash test of the cargo aircraft, or equivalent, with test packages aboard. The crash test can be waived if other tests used to develop the package can be shown to produce at least as severe an environment for the test packages.

The NRC has determined that, because of flight conditions believed to have been existing at impact, the PSA Flight 1771 crash represents a worst case crash as required by Section 5062 (Ref. 1). In order to assure adequacy of testing, the geotechnical characteristics of the aircraft crash site must be similar or more resistant to impact than the site where PSA Flight 1771 crashed (see Ref. 2). The investigation reported herein was undertaken to determine the engineering geology of the crash site and to obtain samples for rock and soil testing in order to further other geotechnical studies of the site. These investigations were necessary in order to geotechnically characterize the crash site so that the applicant for U.S. NRC safety certification of the package can be able to determine whether its proposed test site(s) is adequate under the test criteria (Ref. 2). A detailed description of the field investigation is provided as part of this report.

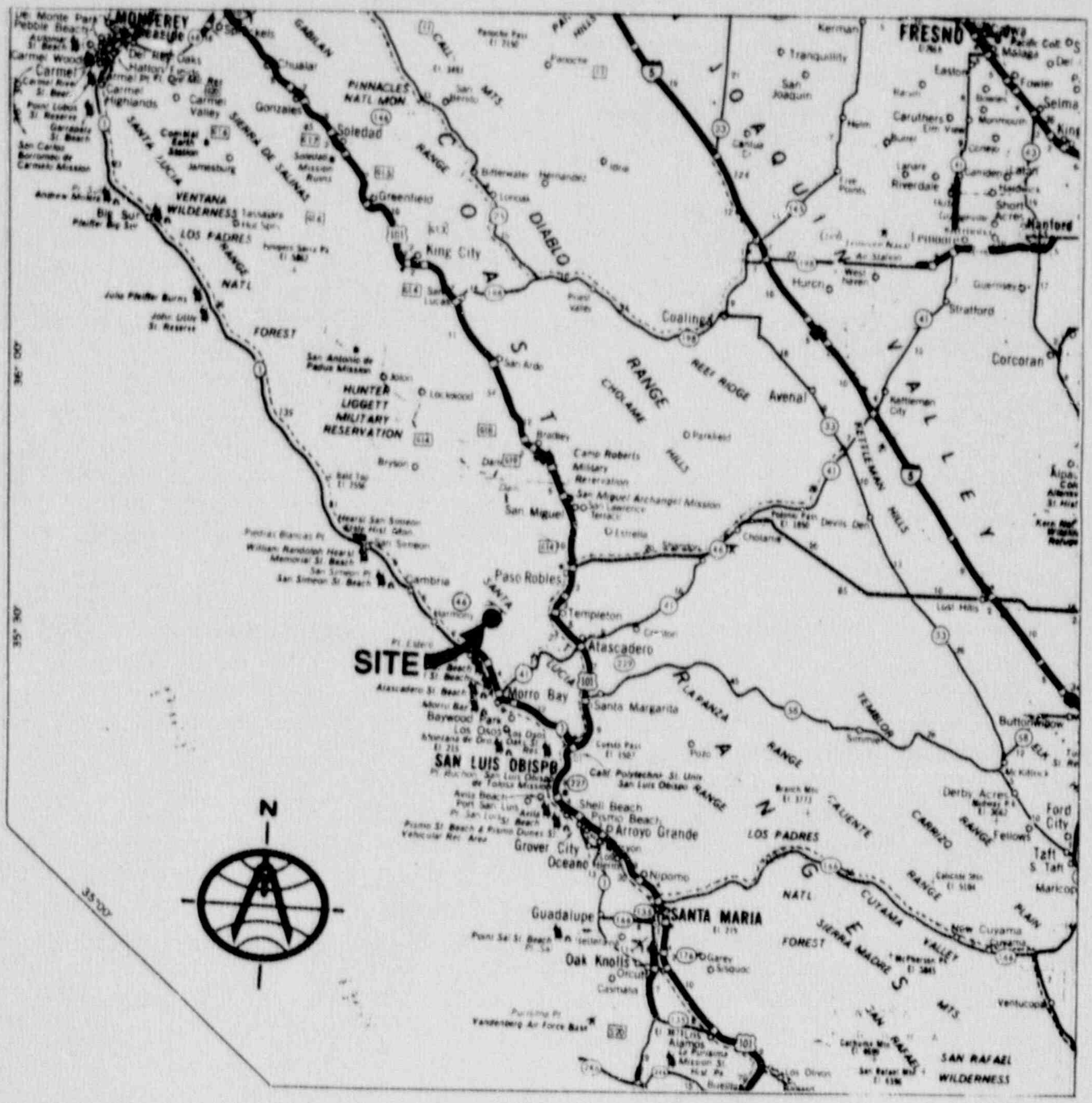


Fig. 1. Location Map, PSA Flight 1771 Crash Site.

Fig. 2. Photograph of PSA Flight 1771 Crash Site.

2. SITE LOCATION AND PHYSICAL DESCRIPTION

The PSA Flight 1771 impact point is located near the top of an east-facing hillside at approximate elevation 403 m (1322 ft) above mean sea level. Most of the crash site slopes steeply; slope gradients vary from about 20 to 40 percent in the vicinity of the impact point. Figure 3 is a topographic map of the site prepared by photogrammetric means.

As stated above, the crash site is located approximately 19 km (12 miles) southwest of the city of Paso Robles, California. The location is southwest of Old Creek Road on private lands of the Santa Rita Ranch (Hartzell Ranches, Inc.).

The crash occurred at the edge of a wooded area. According to the land owners, the aircraft destroyed approximately six oak trees during impact. However, most of the area involved was grass-covered.

3. GEOLOGIC SETTING

3.1 Regional Geology

The PSA Flight 1771 crash site is located in the southern Coastal Ranges physiographic subprovince of central California. This subprovince includes a number of individual mountain ranges and large structural valleys that do not coincide with the distribution of older rocks and structures exposed in the region (Ref. 3).

The crash site is located within the Sur-Obispo Belt of the southern Coastal Ranges. Within the Sur-Obispo Belt, Jurassic and Cretaceous metamorphic rocks of the Franciscan assemblage are structurally overlain by marine sedimentary rocks of similar ages known as the Great Valley Sequence. Younger strata of Tertiary and Quaternary age locally cover the older rocks. The entire sequence has undergone repeated periods of deformation and may have been affected by large lateral movements (Ref. 3 and Ref. 4).

Figure 4 is a geologic map of the area surrounding the PSA Flight 1771 crash site. As shown in Fig. 4, the crash site and near vicinity are underlain by marine sedimentary rocks of the late Mesozoic Toro Formation (Ref. 5). These rocks are a portion of the Great Valley Sequence. Franciscan melange, chert and serpentine are exposed northeast of the crash site (Fig. 4). These rocks are separated from the marine sedimentary rocks present in the vicinity of the crash site by a branch of the Oceanic Fault zone (Ref. 5) which in turn is a portion of the regional Sur-Nacimiento Fault system (Ref. 3). The Sur-Nacimiento Fault system was an important tectonic feature during the late Mesozoic and early Cenozoic eras of earth history but has not been active in geologically recent times (Ref. 6).

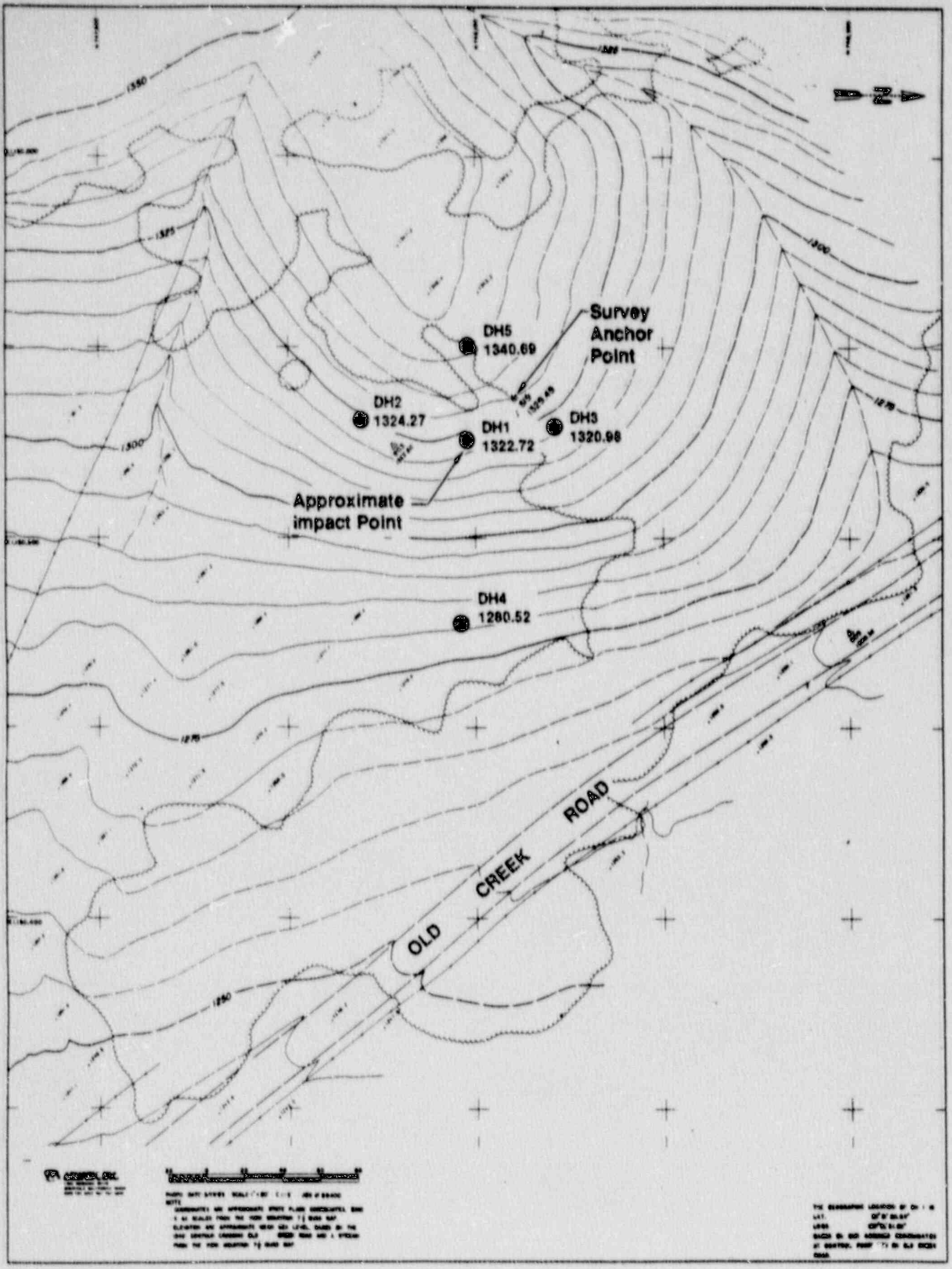


Fig. 3. Site topography and drill hole locations, PSA Flight 1771 crash site.

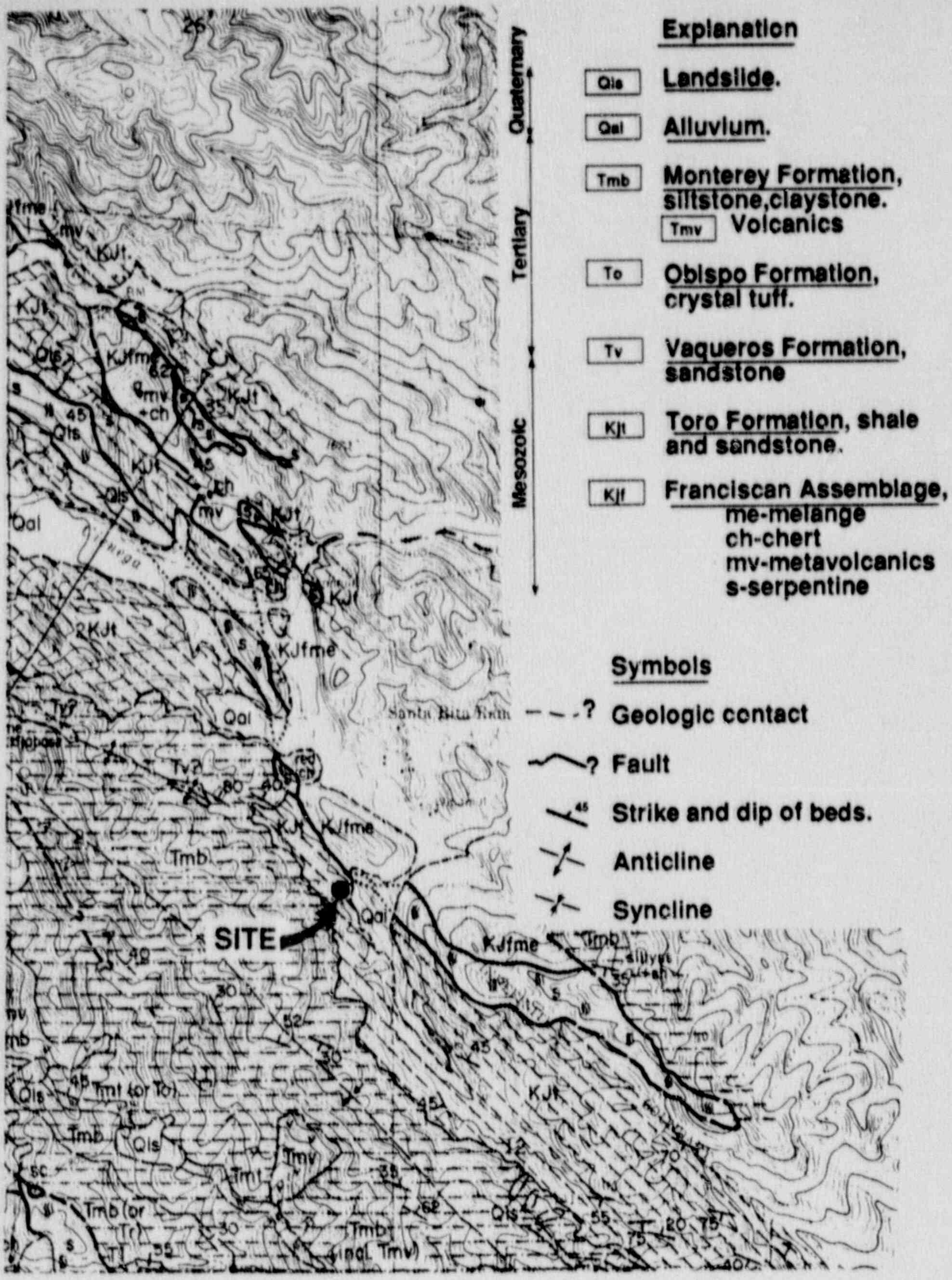
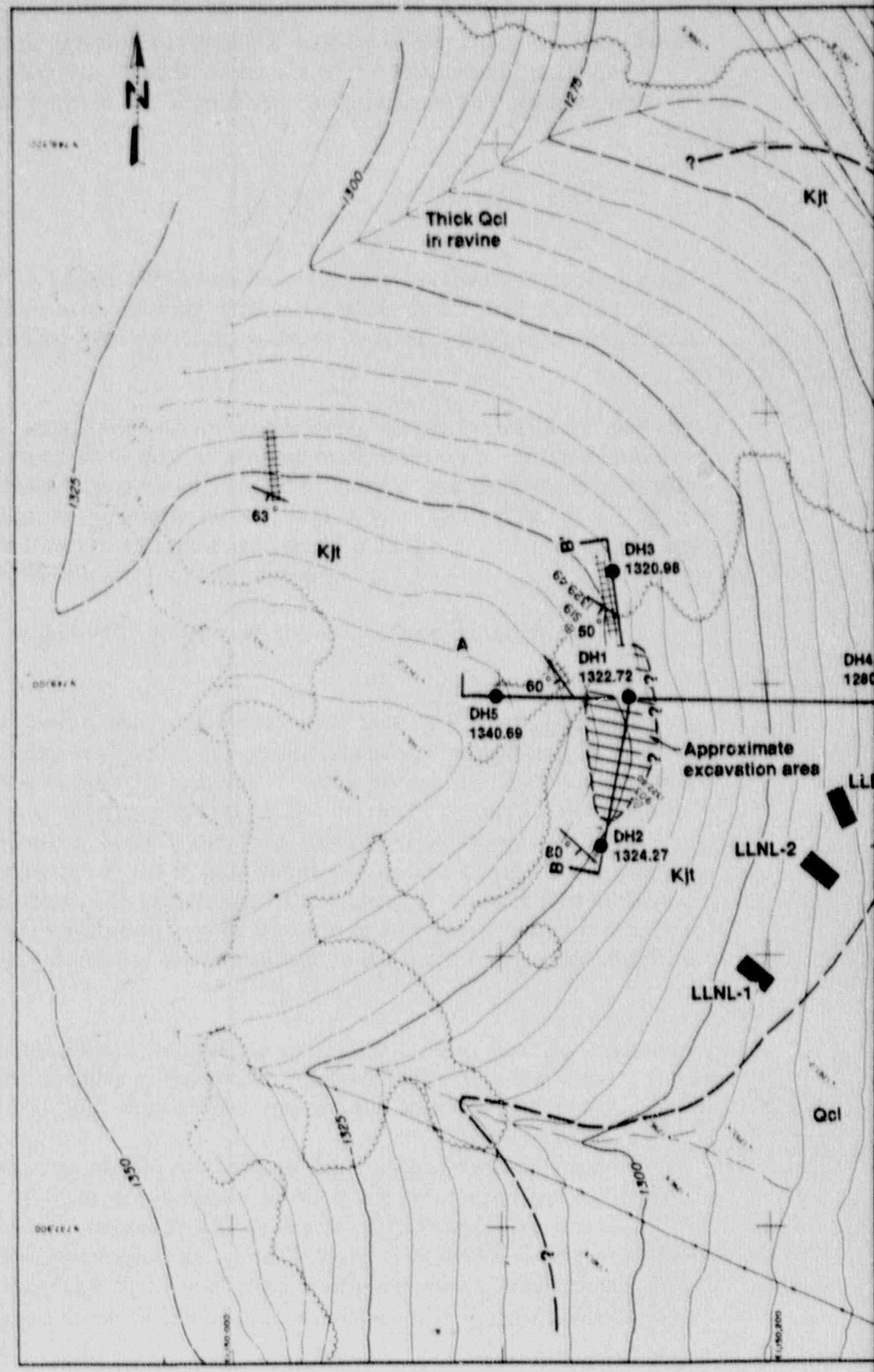


Fig. 4. Regional geologic map, PSA Flight 1771 crash site, adapted from Hall, 1974.


N
1275
?
Kjt
1300
Thick Qcl in ravine
1325
63°
Kjt
B'
DH3
1320.98
50
A
DH1
1322.72
DH4
128
60°
DH5
1340.69
Approximate excavation area
LL
LLNL-2
80°
B
DH2
1324.27
Kjt
LLNL-1
Qcl
1325
1350
1300
?

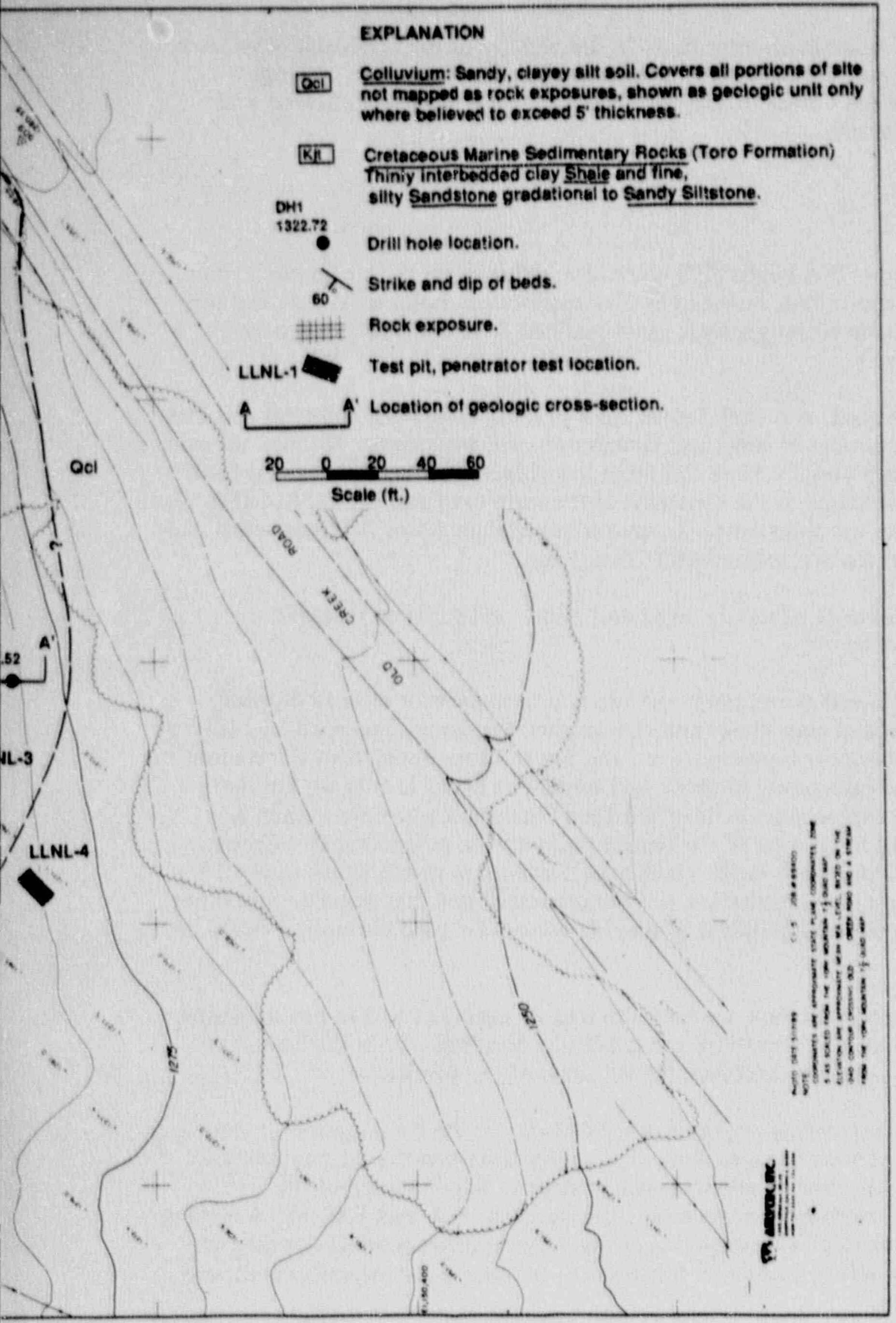


Fig. 5. Geologic Map of PSA Flight 1771 Crash Site.

SI
APERTURE
CARD

Also Available On
Aperture Card

As a result of past tectonic activity, rocks in the vicinity of the crash site have been intensely fractured and sheared. Matrix materials of the Franciscan melange sequence and some shale beds of the Toro Formation are intensely sheared and penetratively deformed.

4. SITE GEOLOGY

Surface geology of the PSA Flight 1771 crash site is shown on the site geologic map, Fig. 5. Subsurface conditions, revealed by five exploratory holes drilled at and near the crash site, are inferred on geologic cross-sections A-A' and B-B', shown as Fig. 6 and Fig. 7, respectively.

The crash site is covered with dark brown, root-bearing clayey silt colluvial soil that contains variable amounts of sand and weathered rock fragments. Known colluvial thicknesses vary from about 0.15 m (0.5 ft) in the vicinity of the impact point itself to about 1 m (3 ft) downslope to the southeast in the vicinity of test pit LLNL-1 (Fig. 5). Colluvial thicknesses are inferred to increase to more than 1.6 m (5 ft) eastward and southeastward from the site toward Old Creek Road.

The colluvial soil cover is generally loose and shows evidence of surficial downslope movement.

Beneath the colluvial soil cover, the crash site is underlain by a steeply dipping sequence of interbedded clay shales and fine-grained sandstones mapped by Hall (1974) as the late Mesozoic (upper Jurassic and lower Cretaceous) Toro Formation. Lenses of very hard calcareous siltstone and sandstone occur locally within these rocks. Prior to site exploration, beds of the Toro Formation were exposed in a portion of a fire trail northwest of the impact point and in cuts along Old Creek Road northeast and southeast of the crash site. Excavation of access trails to drill hole locations during site exploration and excavation of test pits at earth penetrator test locations also created additional exposures where the Toro Formation could be studied.

Beds within the Toro Formation are typically 6 to 75 mm (1/4 to 3 in.) in thickness. As shown in Fig. 5, in the vicinity of the crash site, bedding within the Toro Formation strikes northwest and dips 50°-80° toward the southwest.

A well-developed weathering profile has formed on the Toro Formation at the crash site. The rocks vary from decomposed to intensely weathered immediately beneath the colluvial cover to unweathered at depth. Subdivisions of the weathering profile are shown on geologic cross sections A-A' and B-B' (Fig. 6 and Fig. 7, respectively). Qualitative descriptions of the varying degrees of weathering are provided in the following section of this report concerning site investigations and engineering geology.

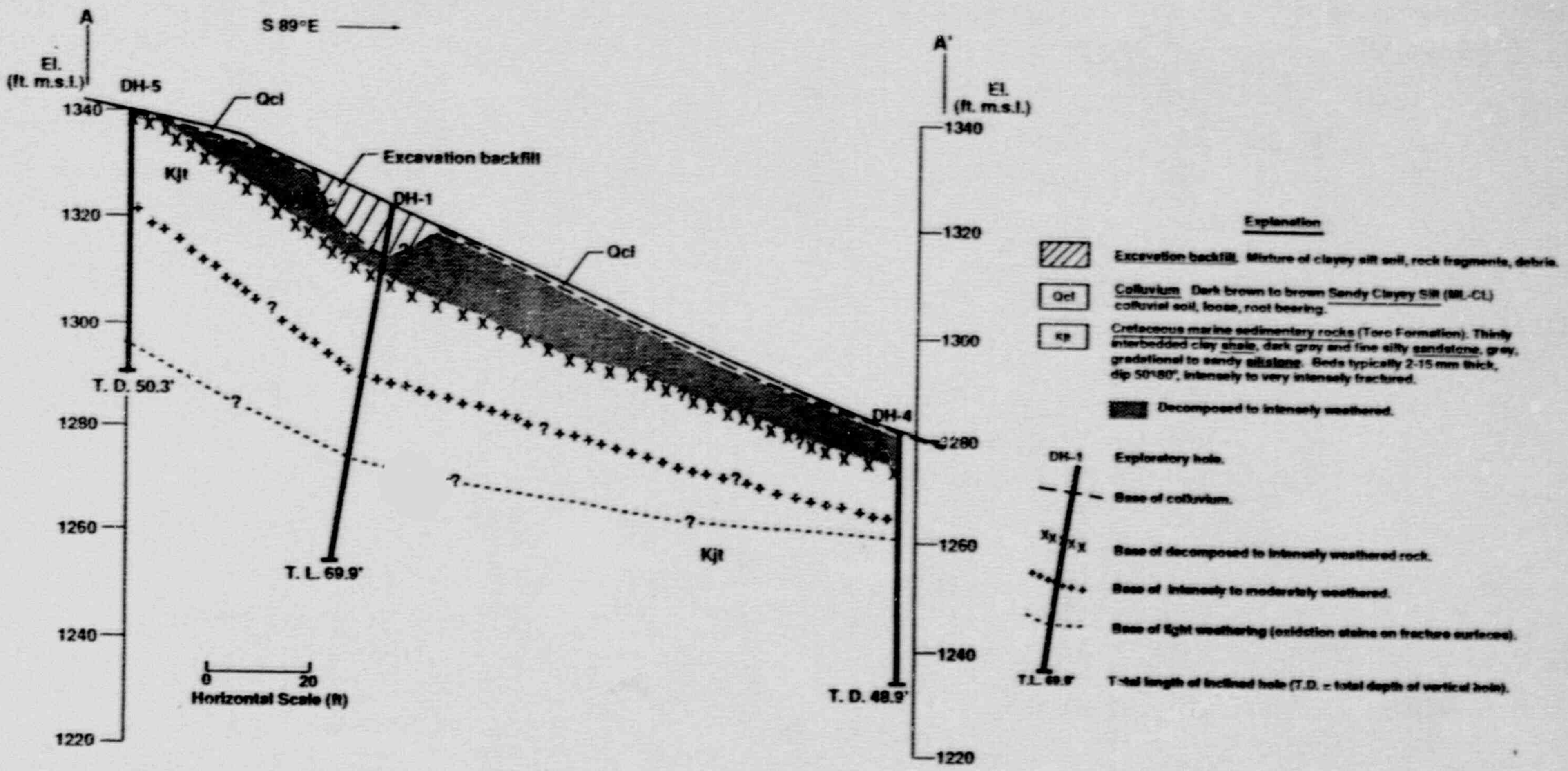


Fig. 6. Geologic Cross-Section A-A'.

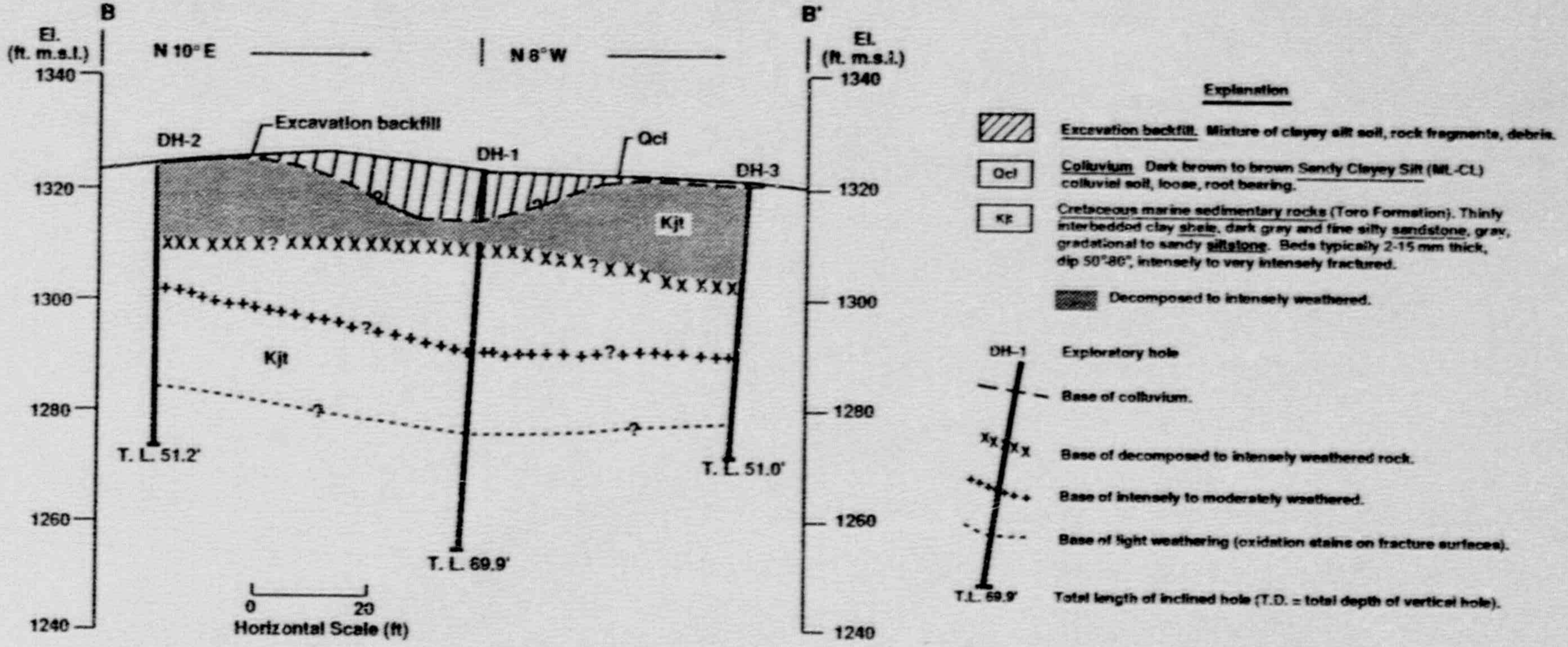


Fig. 7. Geologic Cross-Section B-B'.

The PSA Flight 1771 impact point is approximately 90 m (300 ft) southwest of a branch of the Oceanic Fault zone, a portion of the inactive Sur-Nacimiento Fault system (Ref. 5 and Ref. 6).

As a result of past tectonic activity, the beds of the Toro Formation have been intensely fractured and sheared. Numerous shear zones are present within the rocks and appear to be products of penetrative deformation of weaker clay shale beds within the Toro Formation. Where observed in test pits southeast of the impact site, the shear zones appear to follow bedding trends. A large shear zone was encountered at depth in DH-1, drilled at the presumed center of impact. The orientation of this shear zone is unknown since it could not be identified with certainty in any other of the drill holes and test pits at the project site.

Sandstone-rich portions of the Toro Formation exposed in the vicinity of the PSA Flight 1771 crash site contain crude joint sets. Two joint sets were observed in test pits LLNL-2 and LLNL-3 (Fig. 5). One set strikes northwest subparallel to bedding and dips northeast at 50°-60° opposite to bedding dips. The second set strikes N 65°-70° E and dips 40°-90° southeast.

Joint sets with similar attitudes were noted in excavations made for drill setups at the locations of exploratory holes DH-2 and DH-3. Some fractures noted in drill cores have attitudes with respect to bedding planes that are consistent with the attitudes of joints observed in exposures.

Joint spacings are variable but are mostly in the range of 25-150 mm (1 to 6 inches).

In thinner bedded shale-sandstone sequences, joints become indistinct and very closely spaced and a random-appearing fracture pattern is visible. In clay-shale rich rocks, very intense crushing and shearing is predominant and reflects the penetrative deformation that has affect these strata (Ref. 6).

5. SITE INVESTIGATION

5.1 Exploratory Program

As a part of the site characterization study, a field exploratory program was conducted at the PSA Flight 1771 crash site.

An initial reconnaissance of the crash site was made on February 7, 1989. Following the reconnaissance, a site characterization program was developed. The site characterization program as initially envisioned consisted of geologic mapping, drilling of five Nx-sized (48 mm) (1 7/8 inches) exploratory core holes, collection of soil and rock samples from these holes and geophysical studies. Later, the opportunity arose to perform earth penetrator tests at the site to evaluate the response of in-situ materials to high velocity impacts and this study was added to the field investigation.

Geologic, geophysical and drilling investigations were conducted during the period March 21 through April 12, 1989. The earth penetrator study was conducted during the period May 22 through May 24, 1989. Four test pits were excavated as part of the earth penetrator study. Geologic logs were prepared for these test pits.

Field geologic studies were conducted by LLNL staff personnel. Earth penetrator testing was performed by members of the Sandia National Laboratory, Albuquerque staff under subcontract to LLNL. Geophysical studies were conducted by Endacott and Associates, Inc., Pasadena, California. Their report appears as Appendix A to this report.

Drilling support was provided by P.C. Exploration, Inc., Roseville, California. Bulldozer and backhoe services required in support of the drilling and earth penetrator studies were provided by Hartzell Ranches, Inc. through a subcontract to P.C. Exploration, Inc.

5.2 Drilling and Sampling

Five exploratory holes were drilled as part of the site characterization study. Drill hole DH-1 was located in the center of the impact area as nearly as this could be determined(a) and was inclined 10° from vertical into the slope face in order to obtain samples oriented roughly parallel to the direction of presumed impact. Drill holes DH-2 and DH-3 were also inclined 10° from vertical into the slope face and were located roughly along contour from DH-1 but outside the impact area in order to provide characterization data on undisturbed site materials.

Drill hole DH-4, a vertical hole, was located at the toe of the hillside east of the impact point. This hole was drilled to provide geologic information for site characterization. It also served to demonstrate the geologic similarity of the toe of the hillside, accessible to the earth penetrator equipment, to the impact point thereby assuring that geotechnical conditions at the sites of the earth penetrator tests are representative of the impact area.

(a) The crater backfill area shown in Figure 5 is larger than the actual impact crater itself. In order to restore the hillside following the crash, Hartzell Ranches, Inc. overexcavated the crater area and used the excavation to bury some aircraft parts and other debris from the crash.

Drill hole DH-5, also a vertical hole, was drilled at the top of the hill about 50 feet west of the impact point. This hole also provided geologic information for site characterization. Following drilling, DH-5 was completed for geophysical logging. Completion procedures were the following:

1. The hole was enlarged to 4-inch dia. using a reaming bit.
2. Two inch dia. blank schedule 40 PVC pipe was installed in the hole.
3. The annulus between the pipe and the hole wall was filled with a fine to medium grained sand mixture in order to provide seismic coupling between the pipe and hole wall.

Drill hole locations are shown in Fig. 3 and Fig. 5. Table 1 presents summary data for each of the five holes drilled. Detailed logs are included in Appendix B of this report. Following completion of the field investigation, the drill holes were sealed with grout and their locations marked with 3-inch dia. steel plates. The pipe in DH-5 was cut off below grade prior to the grouting of that hole.

Following completion of drilling, the drill core was transported to LLNL Site 300 for storage. The core is stored in a weather-tight transportainer located near Site 300, Building 802 and could be retrieved by LLNL personnel if required.

Photographs were taken of the drill core following their delivery to Site 300 by a LLNL Technical Information Department (TID) photographer. Photographs of the core are included in Appendix B along with the drill hole logs. TID personnel extensively photographed drilling and sampling operations as part of a comprehensive photographic record of project activities prepared by them.

A total of 42 sealed soil and rock samples were collected from the five exploratory holes drilled at the PSA Flight 1771 crash site. These samples were transported to LLNL for geomechanical and soils properties testing.

Table 2 provides a listing of the soil and rock samples obtained. Hole numbers, sample designations and types, depths, dates collected and a brief geologic description are provided for each sample. In general, the rock samples collected represented the "best" material available in the drill core. This was because the high degree of fracturing suffered by the Toro Formation resulted in most of the core being recovered as splinters, angular fragments and short core segments. Laboratory testing required specimens at least 75 mm (3 inches) in length and such specimens were not common, especially in sheared zones. Therefore, the geomechanical strength of the rock mass at the crash site may be overestimated based upon the laboratory testing. Also the number of intensely weathered and decomposed rock specimens recovered were limited and as a result only limited data could be obtained concerning the geomechanical properties of materials most affected by the plane crash.

Table 1. Summary Data, Drill Holes, PSA Flight 1771 Crash Site.

Hole Nr.	Length (ft)	Orientation	Summary Log (ft)
DH-1	69.9	80° from horiz. S 87° W	0-9.8' Crater backfill. 9.8-69.9' Interbedded sandstone and shale. 9.8-14.4' Decomposed to intensely weathered. 14.4-33' Moderately weathered, highly sheared. 29-33'. 33-49' Lightly weathered, highly sheared to 34.4'. 49-69.9' Unweathered, mostly highly sheared.
DH-2	51.2	80° from horiz. N 82 ° W	0-0.6' Fill. 0.6-6' Decomposed shale. 6-51.2' Interbedded sandstone and shale. 6-15' Decomposed to intensely weathered. 15-21.7' Moderately weathered. 21.7-39.9' Lightly weathered. 39.9-51.2' Unweathered. 45.8-48.2' Very hard, calcareous sandstone.
DH-3	51.0	80° from horiz. S 70° W	0-0.5' Clayey silt soil. 0.5-51.0' Interbedded sandstone and shale. 0.5-19.8' Decomposed to intensely weathered. 19.8-32' Moderately weathered. 32-43.5' Lightly weathered. 43.5-51.0' Unweathered, highly sheared at 46.9-51.0'.
DH-4	48.9	Vertical	0-0.7' Clayey silt soil. 0.7-15.5' Sandstone, some claystone interbeds. 0.7-8.5' Decomposed to intensely weathered. 8.5-15.5' Lightly to moderately weathered. 15.5-29.9' Sandy Siltstone. 15.5-20.5' Moderately to lightly weathered. 20.5-29.9' Unweathered. 29.9-33.7' Silty Claystone, unweathered. 33.7-48.9' Interbedded sandstone, sandy siltstone, and shale, unweathered, highly sheared at 44.8-46.4'.
DH-5	50.3	Vertical	0-0.5' Sandy silt soil. 0.5-50.3' Interbedded sandstone, siltstone and shale. 0.5-2' Decomposed. 2-18' Moderately weathered. 18-44.5' Lightly weathered. 44.5-50.3' Unweathered.

Table. 2 Soil and Rock Samples, PSA Flight 1771 Site.

Drill Hole	Sample Designation(a)	Depth(ft)	Date	Description
DH-1	#1 (D)	4.9-5.4	3/27/89	Crater backfill
"	#2 (D)	9.9-10.4	3/27/89	Decomposed claystone
"	#3 (Nx)	11.6-11.9	3/28/89	Intensely weathered sandstone
"	#4 (Nx)	14.0-14.4	3/28/89	Moderately weathered sandstone and shale
"	#5 (Nx)	27.0-27.4	3/28/89	Moderately weathered shale and sandstone
"	#6 (Nx)	56±	3/29/89	Unweathered sandstone and shale
"	#7 (Nx)	59.9-60.2	3/29/89	Unweathered sandstone, shale clasts
DH-2	#1 (D)	1.2-1.7	4/3/89	Decomposed shale
"	#2 (D)	5.4-5.9	4/3/89	Decomposed shale
"	#3 (Nx)	11.5-11.9	4/4/89	Intensely weathered sandstone and shale
"	#4 (Nx)	20.1-20.6	4/4/89	Moderately weathered sandstone and shale
"	#5 (Nx)	25.3-25.7	4/4/89	Moderately weathered shale and sandstone
"	#6 (Nx)	31.3-31.6	4/4/89	Lightly weathered sandstone and shale
"	#7 (Nx)	36.5-37.0	4/4/89	Unweathered calcareous sandstone
"	#8 (Nx)	44.4-44.7	4/5/89	Unweathered sandstone and shale
"	#9 (Nx)	47.3-47.7	4/5/89	Unweathered calcareous sandstone
"	#10 (Nx)	48.9-49.2	4/5/89	Unweathered sandstone and shale
DH-3	#1 (D)	0.2-0.7	4/10/89	Sandy silt soil
"	#2 (D)	1.6-2.1	4/20/89	Decomposed shale and sandstone
"	#3 (D)	5.0-5.5	4/10/89	Decomposed shale and sandstone
"	#4 (D)	5.5-6.0	4/10/89	Decomposed shale and sandstone, hard
"	#5 (Nx)	20.4-20.7	4/11/89	Moderately weathered sandstone and shale
"	#6 (Nx)	23.0-23.4	4/11/89	Moderately weathered sandstone and shale
"	#7 (Nx)	35.8-36.2	4/11/89	Lightly weathered sandstone and shale
"	#8 (Nx)	40.0-40.5	4/11/89	Lightly weathered sandstone and shale
"	#9 (Nx)	46.2-46.5	4/12/89	Unweathered sandstone and shale
DH-4	#1 (D)	0.25-0.75	3/21/89	Clayey silt soil
"	#2 (D)	2.25-2.75	3/21/89	Intensely weathered sandstone
"	#3 (D)	5.2-5.7	3/21/89	Intensely weathered claystone
"	#4 (Nx)	21.3-21.6	3/22/89	Unweathered sandy siltstone
"	#5 (Nx)	26.4-26.7	3/22/89	Unweathered sandy siltstone
"	#6 (Nx)	38.3-38.9	3/22/89	Unweathered sandy siltstone and shale
"	#7 (Nx)	46.4-46.8	3/23/89	Unweathered shale and sandstone
DH-5	#1 (D)	0.3-0.8	3/30/89	Sandy silt soil
"	#2 (D)	0.8-1.3	3/30/89	Decomposed sandstone and shale
"	#3 (Nx)	5.7-6.0	3/30/89	Moderately weathered sandstone and shale
"	#4 (Nx)	13.6-14.0	3/30/89	Moderately weathered sandstone and shale
"	#5 (Nx)	19.3-19.8	3/30/89	Lightly weathered sandstone and shale
"	#6 (Nx)	25.2-25.7	3/30/89	Lightly weathered sandstone and shale
"	#7 (Nx)	28.0-28.3	3/30/89	Lightly weathered sandstone and shale
"	#8 (Nx)	34.7-35.1	3/30/89	Lightly weathered sandstone and shale
"	#9 (Nx)	44.1-44.4	3/31/89	Lightly weathered sandstone and shale

---

(a) D = 1 1/2" drive sample in brass liner
Nx - Nx drill core (approx. 1 7/8" dia.)

Therefore, during field operations in May, 1989, a number of additional samples of weathered rocks were collected from excavations and exposures at the crash site. Criteria for these samples were that they possessed a minimum dimension of 75 mm (3 inches) and were visibly intact. Several of these samples proved to include incipient fractures along which they deteriorated and broke as a result of handling and transit. However, a number of samples were successfully delivered to the laboratory where samples for testing were extracted using a coring device.

The results of the laboratory tests on these specimens will be preferentially used to establish the constitutive models of the soil and rock at the crash site.

The results of the laboratory testing and geomechanical analysis are presented in by Blair et al (Ref. 7).

5.3 Rock Quality Designation (RQD)

The Rock Quality Designation (RQD) was proposed by Deere (see Ref. 9) as an empirical measure of the degree of fracturing in a rock mass and therefore as an approximation of its gross strength and behavior during tunneling and in large excavations. The RQD value is determined by a modified core logging procedure in which the lengths of all intact pieces of core 100 mm (4 inches) or longer in length are added up and recorded as the modified core recovery. The modified core recovery divided by the total length of the core run, multiplied by 100 is the value of RQD in percent. As an example:

Core run (R) = 3.0 ft = 36 in.
Cores ≥ 4 in. (MR) = 4 in. + 8 in. + 6 in. + = 18 in.

$$\text{RQD} = \frac{\text{MR}}{\text{R}} \times 100 = \frac{18}{36} \times 100 = 50\%. \qquad (1)$$

RQD values for three geotechnical zones established at the PSA Flight 1771 site are given in Table 3. These zones and their average RQD values are:

1. Zone 1 - Decomposed to Intensely Weathered Rock: This material has been thoroughly oxidized and weakened and in part, particularly near the ground surface, has been altered to a dense soil. However, relict bedding and jointing are visible and bedding dips can occasionally be determined. These materials were generally investigated by a combination of drive sampling and rotary wash boring since they were too severely weathered to core effectively. Seven core runs were made, mostly in intensely weathered rocks. The average RQD for Zone 1 is 8% (Table 3).

2. Zone 2 - Moderately Weathered Rock: This material is rock that has been physically affected by oxidation, hydration etc. Sandstone beds are typically oxidized throughout. Shale beds may show partial weathering or appear

as unweathered except for heavy oxidation along fractures. The average RQD for Zone 2 is 17% (e.g. very poor rock) (Table 3). The spread in measured RQD values is 0-47%, with a number of runs having a zero RQD value.

3. Zone 3 - Lightly Weathered to Unweathered Rock: Weathering effects in this zone are limited to oxidation stains on fracture surfaces. These stains decline in frequency with depth and eventually disappear. The average RQD for Zone 3 is 23% (e.g. poor rock) (Table 3). The range in RQD values is 0-81%. The RQD values for Zone 3 are slightly biased by the data from DH-1 which encountered a major shear zone at depth. The average RQD for Zone 3 in DH-1 is 4% and a number of zero values were recorded. However, if RQD values from DH-1 are excluded, the average RQD for the crash site is 29%, a minor improvement.

The inferred distributions of these zones in the subsurface are shown in geologic cross-sections A-A' and B-B' (Fig. 6 and Fig. 7 respectively).

It should be noted that RQD values for core obtained from DH-5, located on a hilltop west of the impact point, average higher than those for core obtained from the other holes drilled during the investigation. This suggests that the rock mass properties of the DH-5 area are better than average for the crash site as a whole. If so, the geophysical measurements made by Endacott and Associates, using DH-5 may have yielded seismic velocities that are on the high side relative to the crash site as a whole.

5.4 Earth Penetrator Testing

During the period May 22 to 24, 1989 personnel from Sandia National Laboratory, Albuquerque performed four earth penetrator tests in an area centered approximately 33 m (100 ft) southeast of the PSA Flight 1771 impact point. The four test locations are at the sites of test pits LLNL-1 through LLNL-4 (Fig. 5). These test pits were excavated to recover the penetrator and to obtain geologic information on the materials penetrated. Logs of the four test pits are included in Appendix B.

The area where the tests were performed is geologically similar to the impact point. Testing closer to the impact point was prevented by the steepness of the hillside which posed insurmountable access problems for the heavy penetrator equipment that is mounted on a 50-ft-long semitrailer.

As it was, it proved necessary to make shallow bulldozer excavations at the test locations in order to facilitate setup of the penetrator equipment. Technically, these were advantageous since they permitted the tests to be performed either on weathered rock (Tests LLNL-2 and LLNL-3) or on colluvial thicknesses similar to those believed to have been present at the impact point (Tests LLNL-1 and LLNL-4).

Table 3. RQD Values for Defined Geotechnical Zones, PSA Flight 1771 Crash Site.

Hole Nr.	Zone 1 Dec-Int. Wea.	Zone 2 Int.-Mod. Wea.	Zone 3 Light-Unwea.
DH-1	(15)(b) (1)(c)	0-46(a) (14)(b) (6)(c)	0-29(a) (4)(b) (12)(c)
DH-2	0-10(a) (5)(b) (2)(c)	8-14(a) (11)(b) (3)(c)	0-62(a) (24)(b) (9)(c)
DH-3	0-8(a) (7)(b) (4)(c)	11-33(a) (22)(b) (4)(c)	0-56(a) (24)(b) (7)(c)
DH-4	—	0-22(a) (7)(b) (3)(c)	0-39(a) (16)(b) (10)(c)
DH-5	—	14-47(a) (28)(b) (5)(c)	20-81(a) (49)(b) (11)(c)
<u>Cumulative</u>	0-15(a) (8)(b) (7)(c)	0-47(a) (17)(b) (21)(c)	0-81(a) (23)(b) (49)(c)

(a) Range of RQD values (in percent).
(b) Average value (in percent).
(c) Number of runs in zone.

The penetrability (S-number) is a constant based on soil and rock properties averaged over the penetration distance of a special instrumented projectile (penetrator). The penetrability constant was introduced by Young (see Ref. 10) as a measure of earth penetration. Using an experimental data base, Young (Ref. 11) developed empirical equations to calculate the penetration depth in earth materials and to estimate the average and peak axial deceleration of the penetrator.

Calculations showing derivation of S-numbers from field data are presented in Walter, et al 1989 and Young, 1989 (see Ref. 2 and Ref. 8). Field data for the tests are presented in Table 4. The average S-number derived from the penetrator tests is 2.5 ± 0.5, consistent with the intensely weathered rocks present at the test locations.

For reference, qualitative descriptions of soil/rock materials and corresponding S-numbers are given in Table 5, modified from Young, 1988.

The data summarized in Table 5 illustrates the importance of fractures as well as weathering in controlling penetration depths in rock. Fracture effects were evident especially for tests LLNL-2 and LLNL-3 during which the penetrator impacted directly on weathered rock. Small, elongated craters were formed during both of these tests and examination of the craters prior to penetrator recovery revealed that their shapes were influenced by the attitudes of bedding and joint planes. Rock fragments formed by penetrator impacts were frequently bounded by bedding and joint planes. The craters were elongated toward the northwest. This was subparallel to bedding (Fig. 5) but also in the plane of penetrator entry and it appears that the latter was the principal element controlling crater orientation.

5.5 Geophysical Studies

Endacott and Associates, Pasadena, California, performed geophysical studies at the PSA Flight 1771 crash site. These studies were performed on April 3, 1989.

Investigations consisted of a downhole shear wave velocity survey conducted in DH-5 located about 50 feet west of the crash site and two seismic refraction profiles oriented along the alignments of geologic cross-sections A-A' and B-B' (Fig. 6 and Fig. 7, respectively).

Details concerning test methods and results are presented in the report by Endacott and Associates reproduced as Appendix A to this report. Table 6 (from Endacott and Associates, 1989) summarizes the velocity data obtained.

Table 4. Field Data, Earth Penetrator Tests, PSA Flight 1771 Crash Site.

Test Nr.	Firing Angle	Firing Pressure (psi)	Exit Velocity (fps)	Penetration(a) Depth (ft)	Summary Log(b) (ft)
LLNL-1	75° from horiz.	1700	650	5.7	0-2 ± Silty clay colluvium.
	Bearing N 55° W				2-3 ± Claystone, blocky, intensely weathered.
					3-6 ± Claystone, hard, blocky, moderately weathered.
LLNL-2	57° from horiz.	2800	800	7.1	0-0.5 ± Fill.
	Bearing N 55° W				0.5-3.5 ± Interbedded shale and sandstone, intensely weathered, sheared.
					3.5-6 ± Interbedded shale and sandstone, hard, moderately weathered
LLNL-3	75° from horiz. Bearing N 26° W	3328	near 900	8.3	0-8 ± Interbedded shale and sandstone, intensely weathered with moderately weathered lenses.
LLNL-4	73° from horiz.	3485	> 900	12.2	0-4 ± Clayey silt, colluvium.
	Bearing N 24° W				4-11 ± Interbedded shale and sandstone, decomposed to intensely weathered, locally sheared. 11' ± wet.

(a) Distance from ground surface to tip of penetrator measured along penetrator pathway.

(b) Average depths below ground surface, for details see logs.

Table 5. Qualitative Descriptions of Soil/Rock Materials and Corresponding S-numbers (Young, 1988, Modified).

S-Number	Description
0.5 - 1.4	Hard rock with crack spacing of 0.2 to 1.2 m (the S-number varies inversely with crack spacing). This is the effect of cracks and fissures, independent of the weathering effects.
1 - 2.5	Weathered rock, but still a "rock". To some extent, weathering will result in lowering the unconfined strength and increase the bulk porosity. Weathering may also drastically increase the size of the cracks or fissures, resulting in hard blocks of rock, with several centimeters of a soil-like material between the blocks. Weathering may be very superficial, but typically may extend over 10 m below the rock surface. Bedrock at depth may or may not be weathered, depending on when the soil cover was laid down relative to when weathering occurred.
2.5 - 5	Technically weathered rock, but has the appearance and feel of soil. It can usually be dug with a shovel and has a porosity similar to that of soil.
2 - 4	Dense, dry, cemented sand (such as the hard layers in the dry lake playas at the Tonopah Test Range). Dry caliche. Massive gypsite and selenite deposits (White Sand Missile Range, WSMR).
4 - 6	Sandy gravel, no cementation.
6 - 9	Moderately dense to loose sand (> 80% sand), no cementation, water content not important.

Table 6. Velocity Table, PSA Flight 1771 Crash Site.

	Wave Velocity			
Seismic Layer	Shear Wave Velocity		Compressional Wave Velocity	
	Depth Feet	Vel Ft/Sec	Depth Feet	Vel Ft/Sec
1	0-14	2000	0-17	4000
2	14-50	3120	17-50	5400

A comparison of the geophysical data obtained by Endacott and Associates with geologic information obtained during other phases of site characterization, indicates that seismic layer 1 corresponds roughly to the zone of intense weathering and decomposition beneath the study area. Seismic layer 2 corresponds roughly to the less weathered to unweathered rocks present at greater depths beneath the area. Examination of the seismic data led Endacott and Associates to conclude that the impact crater was not symmetrical along the slope face with respect to exploratory drill hole DH-1. The indicated asymmetry is shown on geologic cross-section B-B' (Fig. 7) which is oriented along the slope face at the same location as seismic profile S-2 in which the asymmetry predominantly appears. The indicated asymmetry is also shown in Endacott and Associates Inc. (1989) Fig. 9 (see Appendix A).

6. DISCUSSION - EFFECTS OF CRASH ON SITE

PSA Flight 1771 impacted at the crash site with great force. The aircraft velocity at impact has been estimated at 282 m/s (925 ft/s) (Ref. 2) and the aircraft broke into small pieces upon impact. Based upon a photograph taken shortly after the disaster (Fig. 2), the aircraft upon crash excavated a crater with maximum dimensions about 3.5 m deep by 6 m wide by 12 m long (11.5 ft x 20 ft x 40 ft) (Ref. 2). The volume of material displaced is estimated at 74 m^3 (2600 ft^3) with corresponding mass of about 175 Mg (195 tons) (Ibid).

Materials expelled from the crater consisted largely of decomposed and intensely weathered sandstone and shale bedrock. Minor amounts of colluvial soil and vegetation were also involved.

Based upon photographs taken shortly after the crash, excavated materials appear to have been preferentially dispersed as dust toward the west and southwest. This was the direction that the aircraft was traveling at the time of impact (S 50° W) (Ref. 2). Reports also indicate that the prevailing wind was from the northeast at the time of the crash and the wind speed and direction would also have favored dust dispersal to the southwest, downwind.

Other effects of the crash upon geologic materials beneath the site appear minor. A sample of decomposed rock obtained at 10 feet in DH-1, directly beneath the crater backfill, appears to have been slightly densified based upon an elevated blow count relative to similar materials sampled in DH-2, DH-3 and DH-4 and its physical appearance. However, no deeper effects could be discerned.

As discussed previously, DH-1 penetrated a highly sheared zone at depth and the average RQD for this hole is lower than for the other holes drilled during the investigation. However, this increased degree of fracturing does not appear to be the result of rock damage resulting from the PSA Flight 1771 crash.

RQD values for near-surface rocks penetrated by DH-1 (geotechnical zones 1 and 2) do not materially differ from those obtained for geotechnical zones 1 and 2 in the other holes drilled during the project (see Table 3). It seems reasonable to presume that had the PSA Flight 1771 crash caused shearing of moderately weathered to unweathered rocks at depths of 30 feet and greater, the more weathered rocks between the bottom of the crater and the sheared strata would have been severely affected.

Jet fuel stains were noted along a fracture at a depth of about 21 feet in core recovered from DH-1. This is believed to reflect the local availability of jet fuel rather than an increase in openness of fractures as a result of the crash. This belief is supported by the observation that fluid losses were experienced during the drilling of all of the core holes completed as part of the site investigation. Fluid losses were greater in the upper portions of the core holes than at depth in most cases and fluid losses similar to those in DH-1 were experienced while drilling the upper portions of DH-2 and 3, located in similarly weathered and fractured rocks but outside the crater area.

7. SUMMARY AND CONCLUSIONS

The PSA Flight 1771 crash site is underlain at shallow depth by thinly interbedded sandstones and shales of the late Mesozoic Toro Formation. These rocks have been intensely deformed as a result of recurring tectonic activity following their deposition and have also undergone intense chemical weathering. As a result, these rocks are "poor" to "very poor" in a geotechnical sense. Average RQD values even for unweathered rocks are less than 30% and earth penetrator testing yielded an S-number of 2.5 ± 0.5, typical for highly weathered and fractured rocks.

The principal geotechnical effects of the PSA Flight 1771 crash on the impact area itself appear to have been limited to the excavation of a crater about 3.5 m deep by 6 m wide by 12 m long (11.5 x 20 x 40 ft) and the expulsion of about 175 Mg (195 tons) of pulverized weathered rock and some soil from the crater. The expelled material was dispersed toward the southwest, the direction of flight at impact, by the force of the impact and the prevailing wind. Any other effects, if present, of the crash upon the impact site, appear trivial.

The geotechnical properties of the crash site are intermediate between rock and alluvial deposits. The S-number obtained at the site is similar to that observed in dry, cemented alluvial deposits present at a number of locations in the arid interior southwest of the United States. Harder sites would generally be provided by areas of rock exposures and by areas underlain, beneath a thin soil cover, by lightly to moderately weathered igneous, metamorphic or well-indurated sedimentary rocks.

Therefore, from an engineering geologic perspective, it should not be difficult to locate a suitable site in which to conduct further proof tests as required by Section 5062 of Public Law 100-203.

8. REFERENCES

1. U. S. Nuclear Regulatory Commission, 1988, Selection of a Worst Actual Aircraft Accident for Murkowski Amendment Implementation (Public Law 100-203), U. S. NRC Internal Memorandum SECY-88-344, p. 5.

2. Walter, C. E., Van Sant, J. H. and Chou, C. K., 1989, Draft Criteria for Package Drop and Aircraft Crash Tests - An Interim Report, University of California, Lawrence Livermore National Laboratory, UCID-21697, p. 50.

3. Page, B. M., 1981, "The Southern Coast Ranges" in The Geotectonic Development of California, W. G. Ernst, Ed., Prentice-Hall Inc., Englewood Cliffs, N. J. p. 329-417.

4. Dickinson, W. R., 1983, Cretaceous Sinistral Slip along Nacimiento Fault in Coastal, California, Bull. Amer. Assn. Petroleum Geologists, 167, No. 4, p. 624-645.

5. Hall, C. A., 1974, Geologic Map of the Cambria Region, San Luis Obispo County, California, U. S. Geological Survey, Washington, D.C., Miscellaneous Field Studies Map MF-599.

6. Hart, E. W., 1989, personal communication.

7. Blair, S. C., Chen, J. C., Ralph, W. R., and Ruddle, D. V., 1989, Mechanical Properties of Rocks from PSA 1771 Crash Site, Lawrence Livermore National Laboratory, PATC-IR 89-05.

8. Young, C. W., Sandia National Laboratory, Albuquerque, New Mexico, letter to J. C. Chen, June 16, 1989.

9. Deere, D. V., 1963, Technical Description of Rock Cores for Engineering Purposes, Rock Mechanics and Engineering Geology, Journal of International Society of Rock Mechanics (Springer-Verlag, Vienna), Vol. 1, p. 16.

10. Young, C. W., 1967, The Development of Empirical Equation for Predicting Depth of an Earth-Penetrating Projectile, Sandia National Laboratories, Albuquerque, NM, SC-DR-67-60.

11. Young, C. W., 1969, Depth Prediction for Earth-Penetrating Projectiles, Journal of Soil Mechanics and Foundations Division, Proc. Am. Civil Engineers, p. 803.

12. Young, C. W., 1988, Equations for Predicting Earth Penetration by Projectiles: An Update, Sandia National Laboratories Report SAND88-0013, Advanced Projects Division II, Sandia National Laboratories, Albuquerque, NM.

13. Endacott and Associates, Inc., 1989, Shear Wave Investigation, PSA Crash Site, Paso Robles, California, Consultant's Report, Endacott and Associates, Pasadena, CA, p. 3.

APPENDIX A

GEOPHYSICAL STUDIES

ENDACOTT AND ASSOCIATES

SHEAR WAVE INVESTIGATION
PSA Crash Site
Paso Robles, California

INTRODUCTION

Shear wave studies were conducted at the PSA crash site near Paso Robles, California.

The primary purpose of the survey was to determine the seismic properties of the soil and rock material underlying the site and to evaluate their material properties. The second purpose was to profile the impact crater using seismic refraction methods.

A seismic downhole survey was used to determine shear wave velocities at intervals in the upper 50 feet of earth materials. The survey made use of existing boring drilled at the site adjacent to the impact crater. The survey was conducted on April 3, 1989 by Endacott & Associates.

The location of the seismic lines surveyed was made in the field by David Carpenter of the Lawrence Livermore National Laboratory. See Fig. A-1 for the reference location of these lines. The lines were placed on the slope and cross-slope over the impact crater of the crash site. The down-slope line S-1 was also used for the surface shear wave study.

The location of the boring used for this investigation is on the geotechnical site plan. The survey was conducted in a 590 foot vertical boring cased with two inch diameter plastic pipe.

PROCEDURES

Downhole:
Shear (S) waves were generated using a 12 pound sledge hammer striking horizontally on the sides of the skid mounted drill rig coupled to the surface by the weight of the drill. To aid in the detection of shear waves on the seismic records the polarity of sides of the drill skids. Compressional (P) waves were generated by striking the top of the skid with the hammer.

A downhole seismometer with three mutually perpendicular ground-motion sensitive transducers was placed in the boring. This geophone was secured at prescribed depths by inflating a bladder.

A composite seismogram was recorded at each depth for the two horizontal reversed events and the one vertical event. A solid state accelerometer mounted on the hammer provided the exact zero time impulse. The seismic waves were recorded by a Geometric ES 1210 F seismograph. This device can be used to enhance or "build-up" the signal from several impacts to assure good data quality. Data is displayed visually and printed on a paper record.

Recording stations were at five foot intervals in the hole. The deepest recording was made at 50 feet.

The recorded seismograms for each five foot interval were picked and timed for both the P and S waves. Times were plotted versus depth as shown in Fig. A-2. Also shown on Fig. A-2 is a plot of interval velocity calculated for a ten foot interval and plotted at the midpoint of the interval. The purpose of this plot, also shown in Fig. A-2, is to show the variation of seismic velocities with depth and to determine the average wave velocities of the soil and rock layers.

Examination of the interval velocity plot of the data shows that the upper layer does not have a constant velocity but rather shows a zone with increasing velocities to a depth between fifteen and twenty feet where the velocities appear to be more constant for the bedrock material. For modeling purposes we have assumed a two layer case shown in Fig. A-2 (top) and tabulated below.

VELOCITY TABLE

	Shear Wave Velocity		Compressional Wave Velocity	
Layer	Depth Feet	Vel fps	Depth Feet	Vel fps
1	0-14	2000	0-17	4000
2	14-50	3120	17-50	5400

Surface:
Both a standard reverse profiling and shear wave profiles were conducted at the site. The standard reverse profiling requires that both ends of the geophone spread be "shot" (generation of a seismic event either by shooting explosives or by successive impacts of a sledge hammer) in order to determine the true velocity of the subsurface materials. Several methods of depth calculations can be used to find the depth of the velocity layers.

A geometric ES 1210 F signal enhancement digital memory seismic system was used to record the impact events. This system records twelve traces of seismic arrival times for a single impact event. A twelve station cable is used to connect the station geophones to the seismograph. The station interval used for these surveys was equally spaced at ten feet (spread). Every other geophone was replaced with a horizontal phone for the surface shear wave detection.

Seismograms for the reverse compressional wave profiles (S-1P and S-2P) were generated for multiple impacts located at each end and in line offset from each end of the spread. Seismograms for the shear wave profile (S-1S) were generated for multiple impacts on opposite ends of the drill skids on one end and a confined railroad tie located at the opposite end of the spread.

Each seismogram was inspected and first arrival (compressional wave) and/or reversed waves (shear wave) were picked and timed. These times were then tabulated and plotted on a time vs. distance graph. See the top of Fig. A-4., Fig. A-6 and Fig. A-8 for the TD plots for lines S-1P, S-1S, and S-2P. From these plots the seismic velocity for each layer can be determined and the depth calculated.

All of the calculation schemes used to calculate seismic depth profiles are based on Snell's Law and assume that the seismic velocity of these layers increases with depth. The two most commonly used formulae are the critical distance and the intercept time. Endacott & Associates uses a variation of the time intercept method(1) where the delay time under each geophone station is found by subtracting the delay time of the shot from the intercept time.

DISCUSSION OF RESULTS

Examination of the profiles would indicate that the shape of the impact crater in the S-1 direction is not symmetrical about the referenced boring DH-1. The crater appears to have been cut laterally into the hillside showing a thickness of about fifteen feet of low velocity (1300 fps) in the fill overlying an intermediate velocity material (3076 fps) reaching a maximum depth of nineteen feet to the undisturbed high velocity (9300 fps) material "bedrock" at about station 0+42 on line S-1P

The shear wave profile for line S-1S shows a ten foot thickness of low velocity (600 fps) overlying an intermediate velocity layer (2000 fps) of disturbed or weathered rock reaching a maximum depth to high velocity (5400 fps) "bedrock" at about twelve feet in depth at station 0+42 on the line.

Inspection of the cross slope profile (Line S-2P) shows that the crater is nearly symmetrical near the referenced boring with nine feet of low velocity (1300 fps) material overlying an intermediate (2730 fps) velocity material which extends to depth interpreted to be undisturbed bedrock.

CONCLUSIONS

There are two sources of error which would account for the minor disagreement in the profiles both in material velocity and depths. The first is "picking error" where

---

(1) Barry, K.M., 1967. Delay time and it's application to refraction

the pick of the first arrival could be miss picked by one milli-second. A one milli-second error would translate to about two feet difference in total bedrock depth.

The second source of error would be unaccounted for lateral changes in the velocity of the near surface materials. This would be true in the area of backfill where the velocity of the compacted fill (1100 fps) is slightly less than the velocity of the natural material (1300 fps). This difference of 200 fps would translate into about one-half of a foot error in calculating the maximum depth to the disturbed rock.

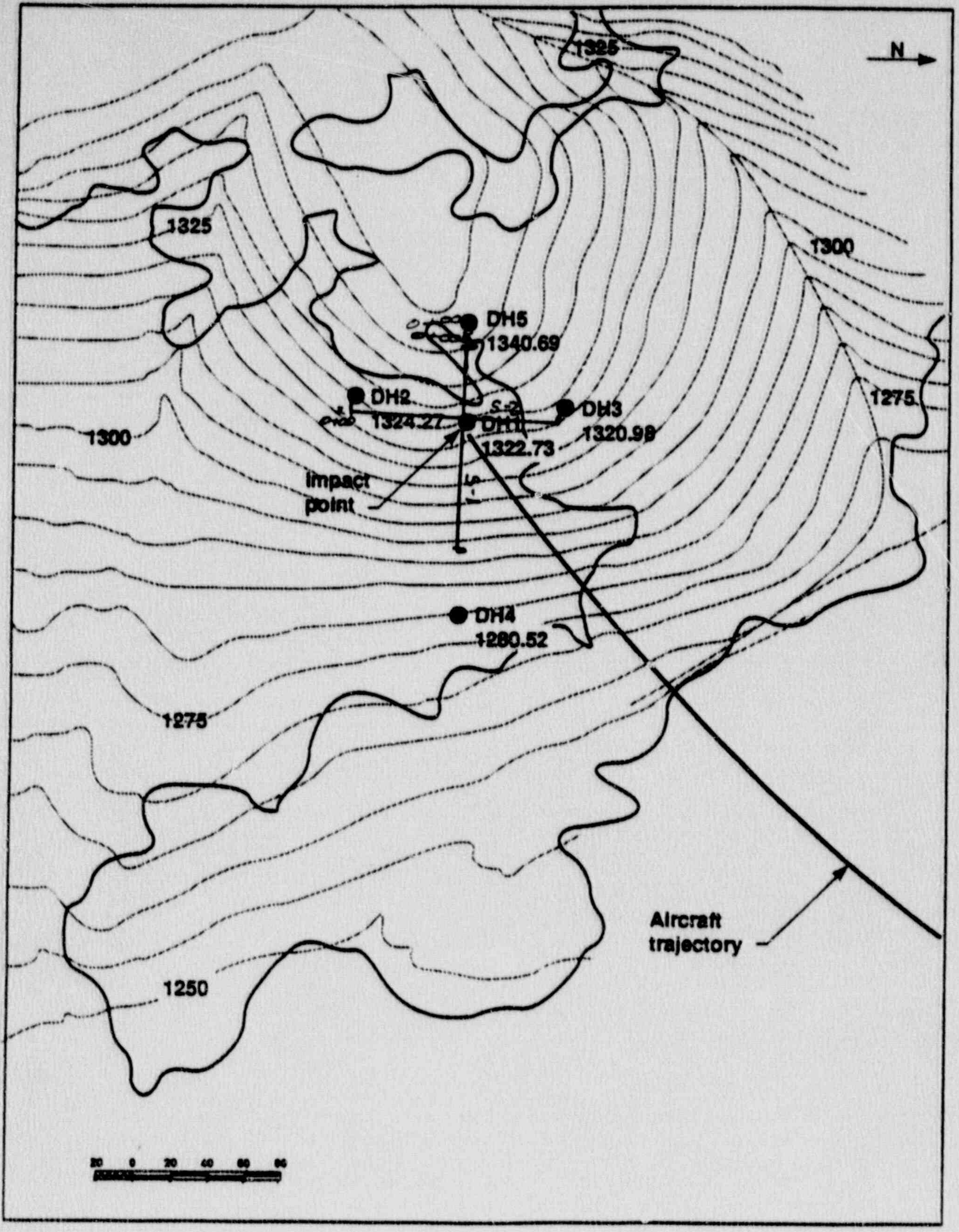


Fig. A-1. Location of seismic lines S1 and S2, PSA Flight 1771 crash site.

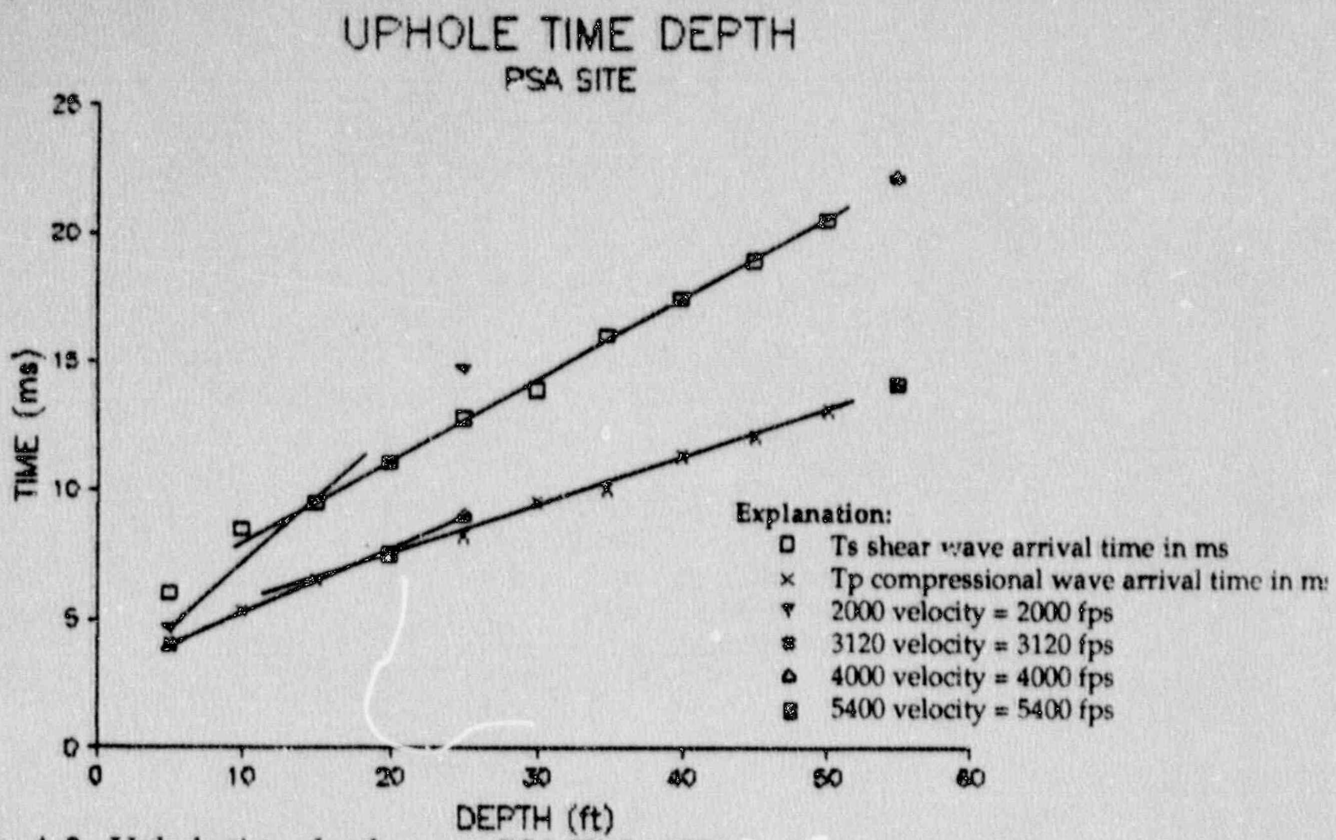


Fig. A-2. Uphole time depth curve, PSA Flight 1771 crash site.

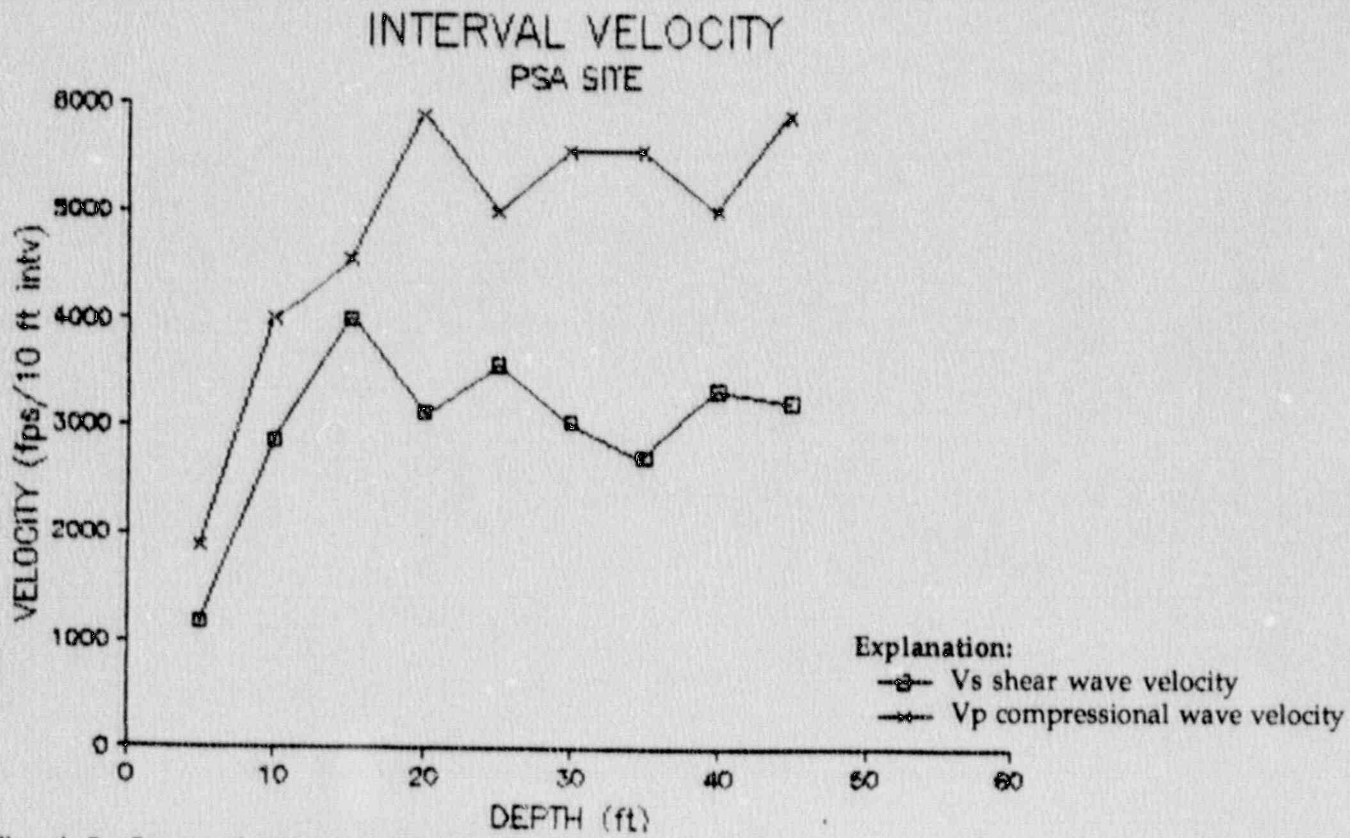
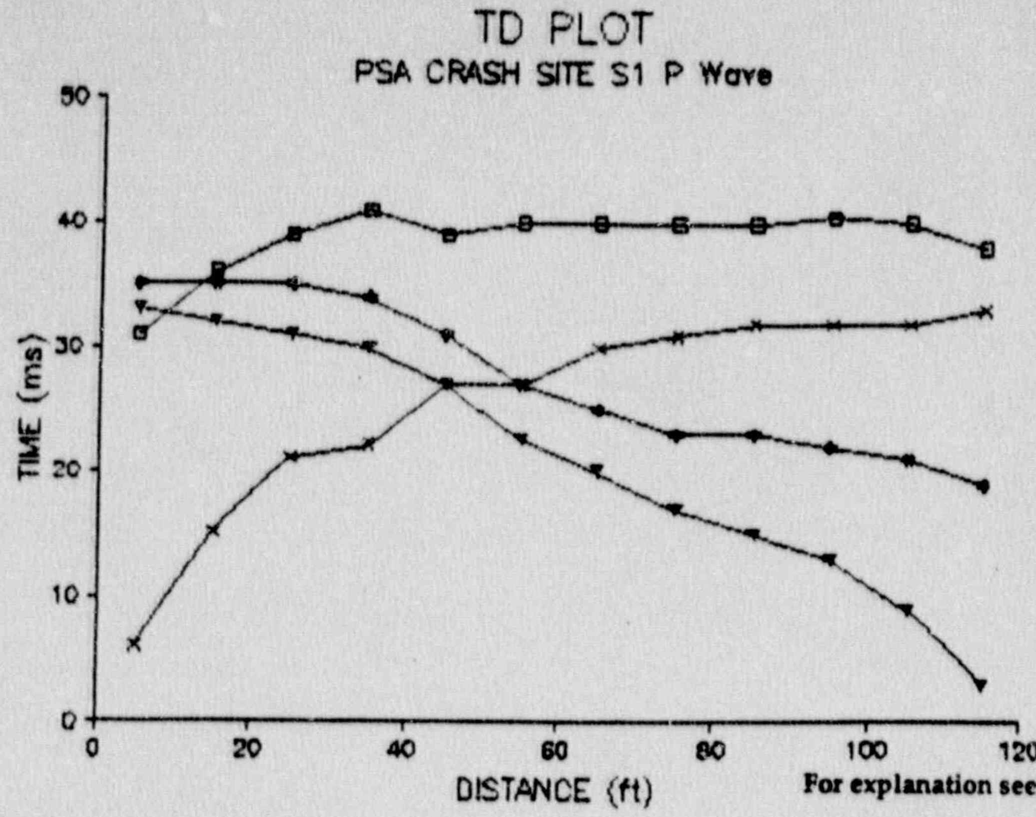
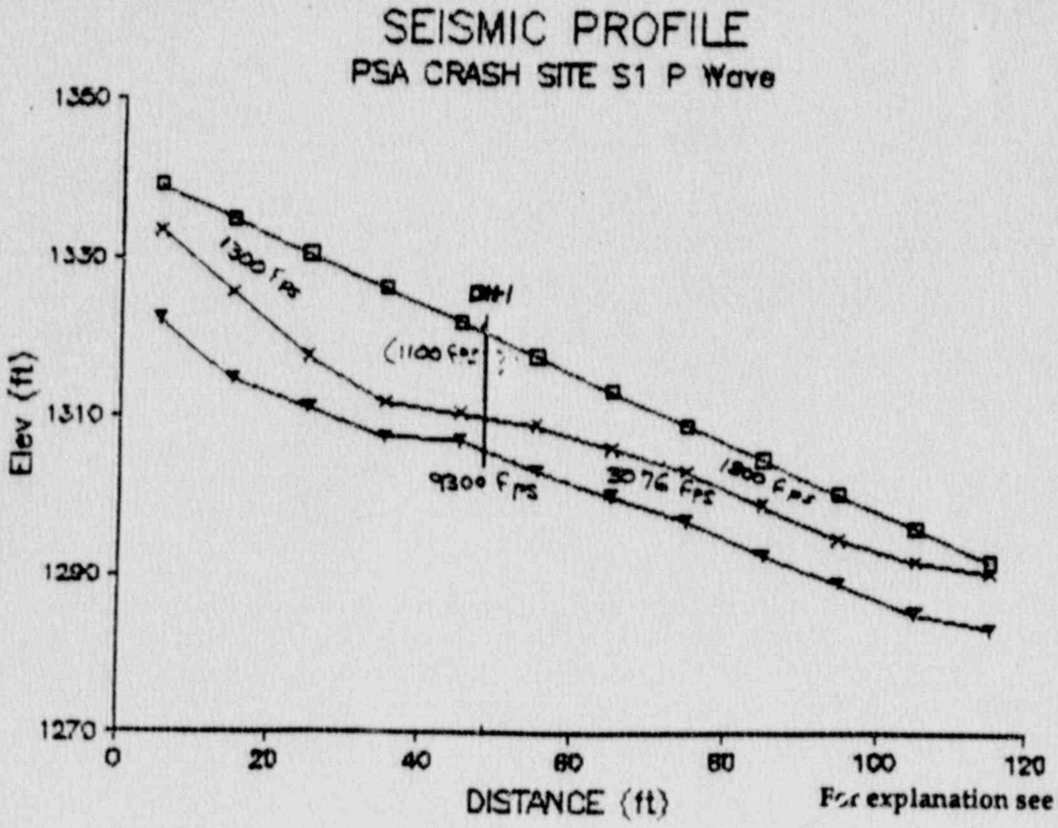


Fig. A-3. Internal velocity, PSA Flight 1771 crash site.



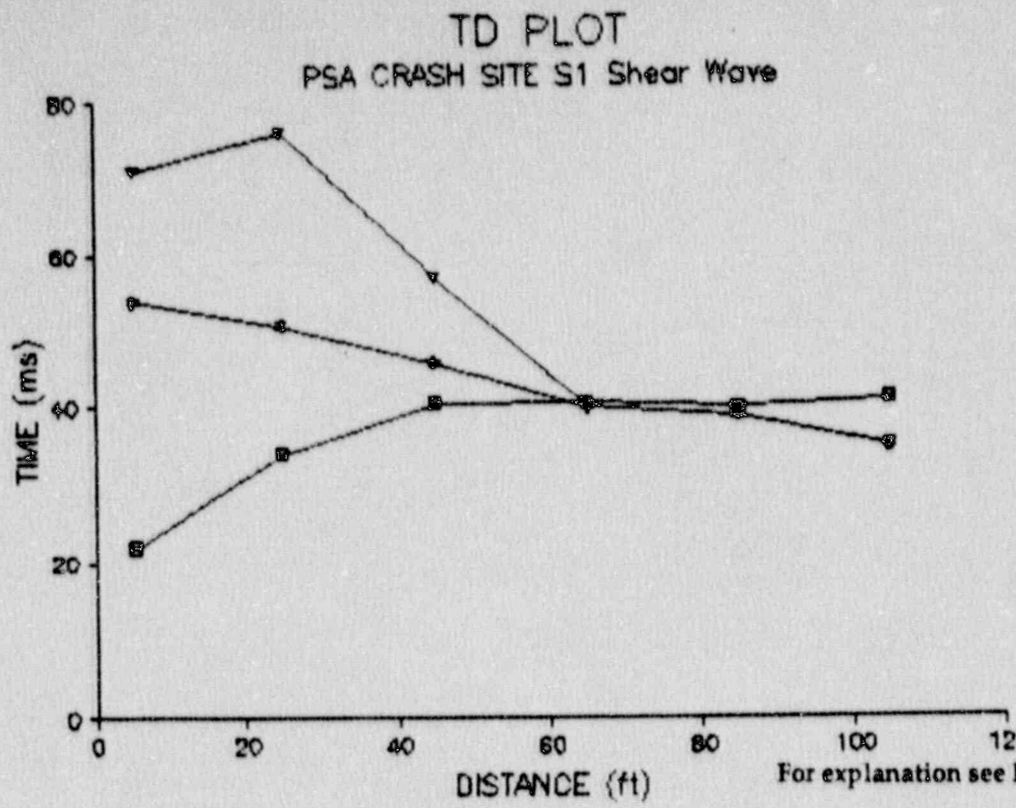
For explanation see Fig. A-2

Fig. A-4. Time-distance plot, compressional wave velocities, seismic line S1, PSA Flight 1771 crash site.



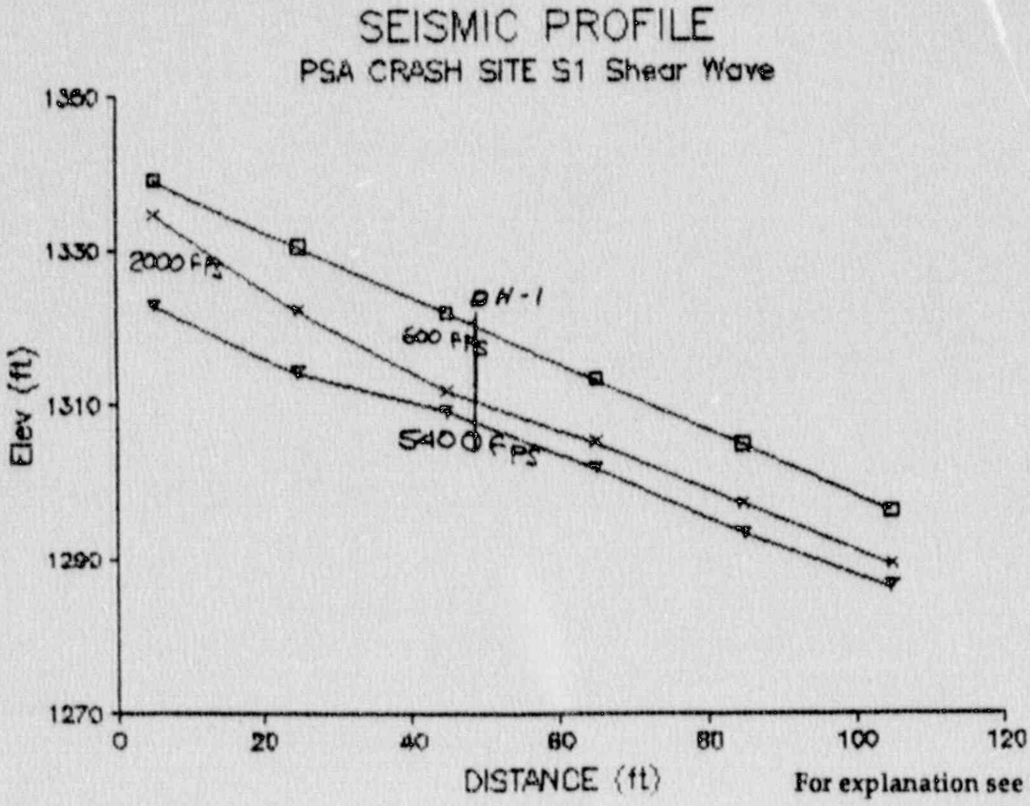
For explanation see Fig. A-2

Fig. A-5. Profile of compressional wave velocities, seismic line S1, PSA Flight 1771 crash site.



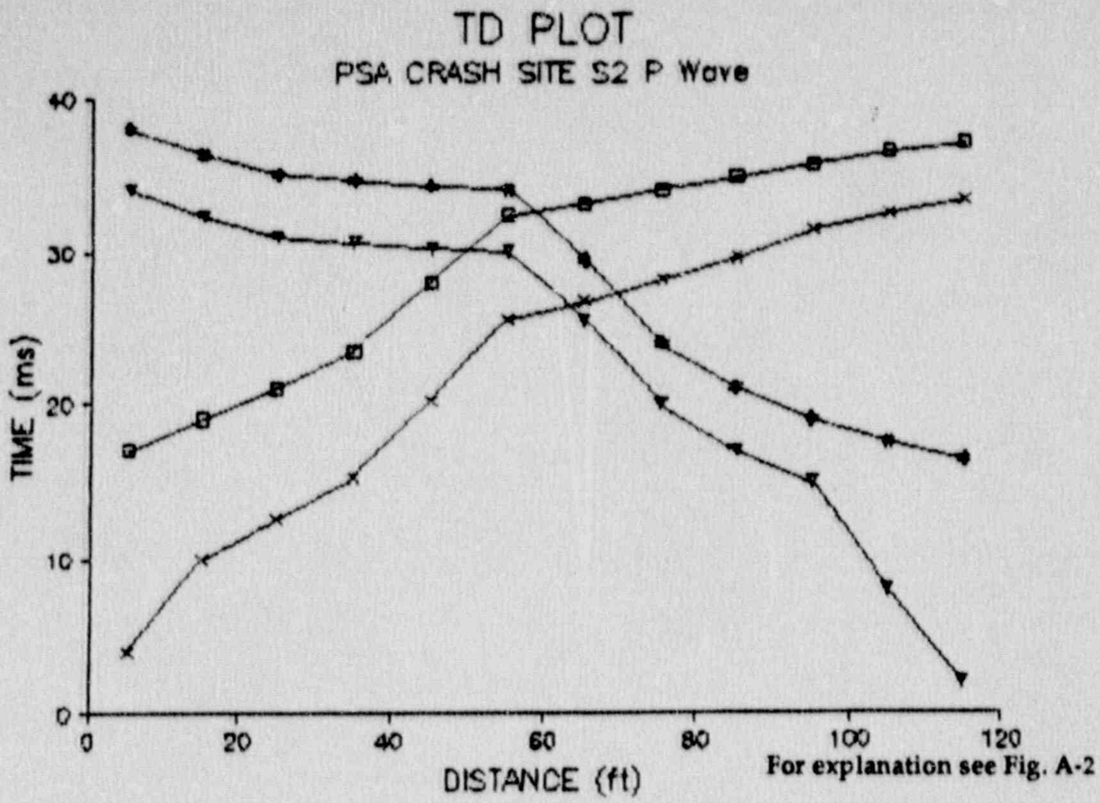
For explanation see Fig. A-2

Fig. A-6. Time-distance plot, shear wave velocities, seismic line S1, PSA Flight 1771 crash site.



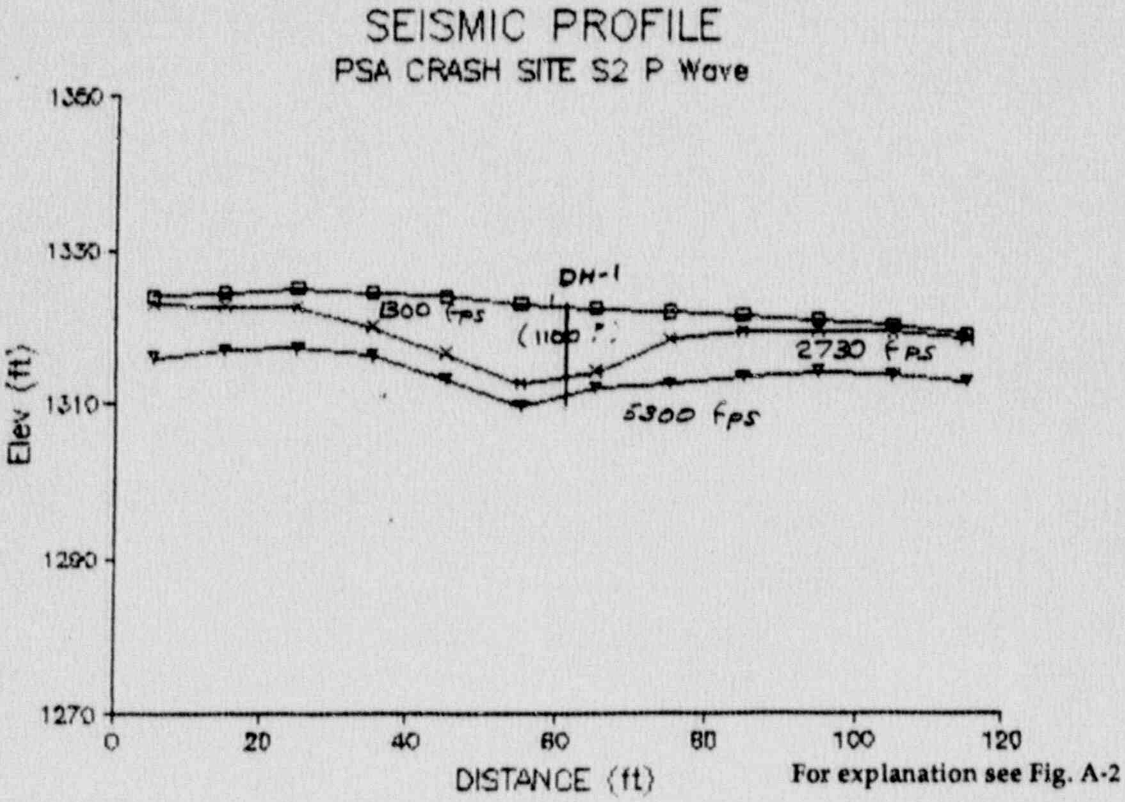
For explanation see Fig. A-2

Fig. A-7. Profile of shear wave velocities, seismic line S1, PSA Flight 1771 crash site.



For explanation see Fig. A-2

Fig. A-8. Time-distance plot, compressional wave velocities, seismic line S2, PSA Flight 1771 crash site.



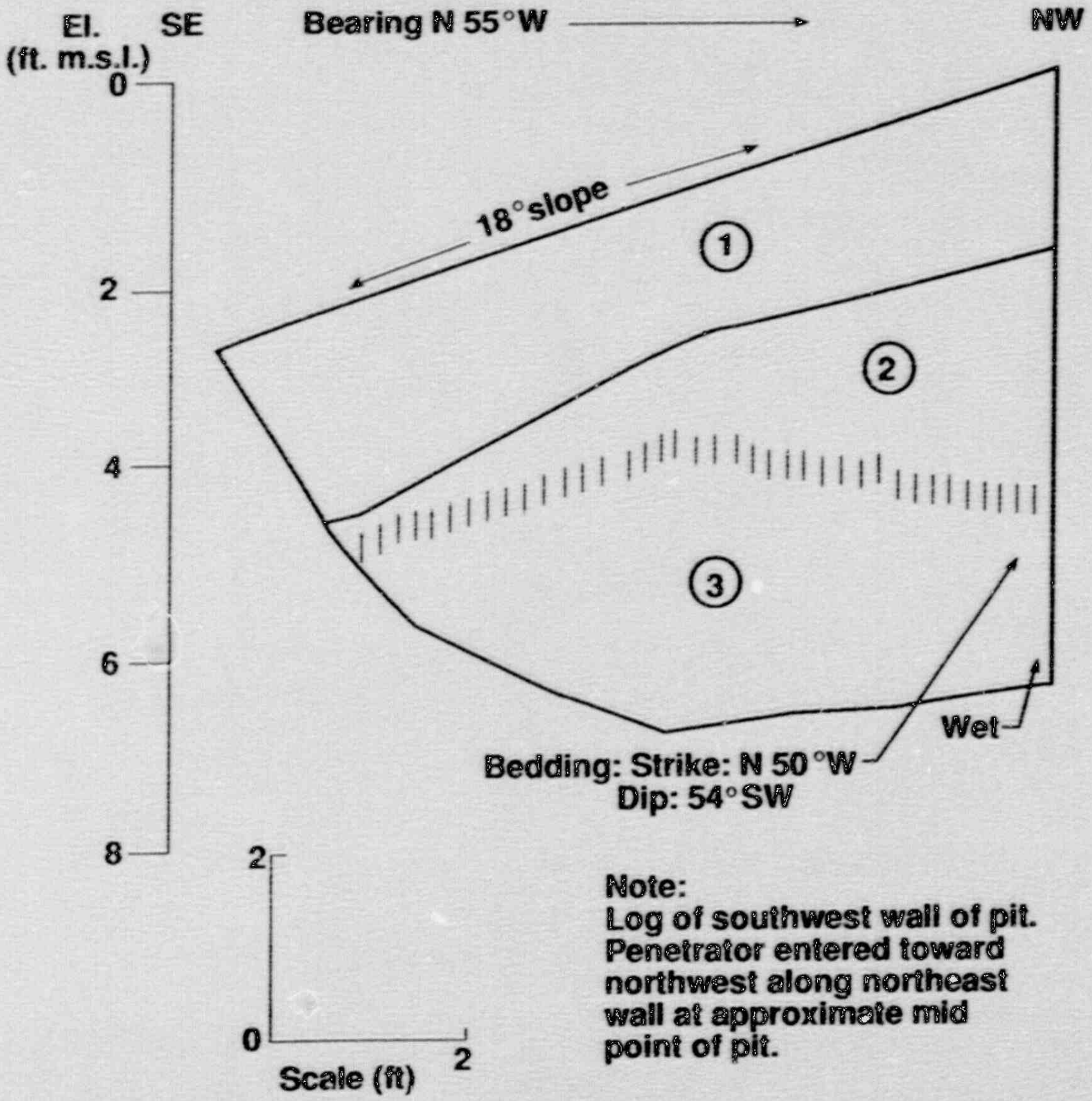
For explanation see Fig. A-2

ig. A-9. Profile of compressional wave velocities, seismic line S2, PSA Flight 1771 crash site.

APPENDIX B

LOGS OF TEST PITS AND DRILL HOLES

PHOTOGRAPHS OF DRILL CORE



Location

N: 747,995
E:1,150,197
El. 1293

Explanation

① Silty Clay (CL): Low to moderate plasticity, hard, red brown,dry to damp. Colluvium.

② Claystone: Blocky, intensely weathered, plastic, greenish gray with abundant black, Mn oxide stains. Very intensely fractured, locally crushed to clay. Moist soil on fracture surfaces.

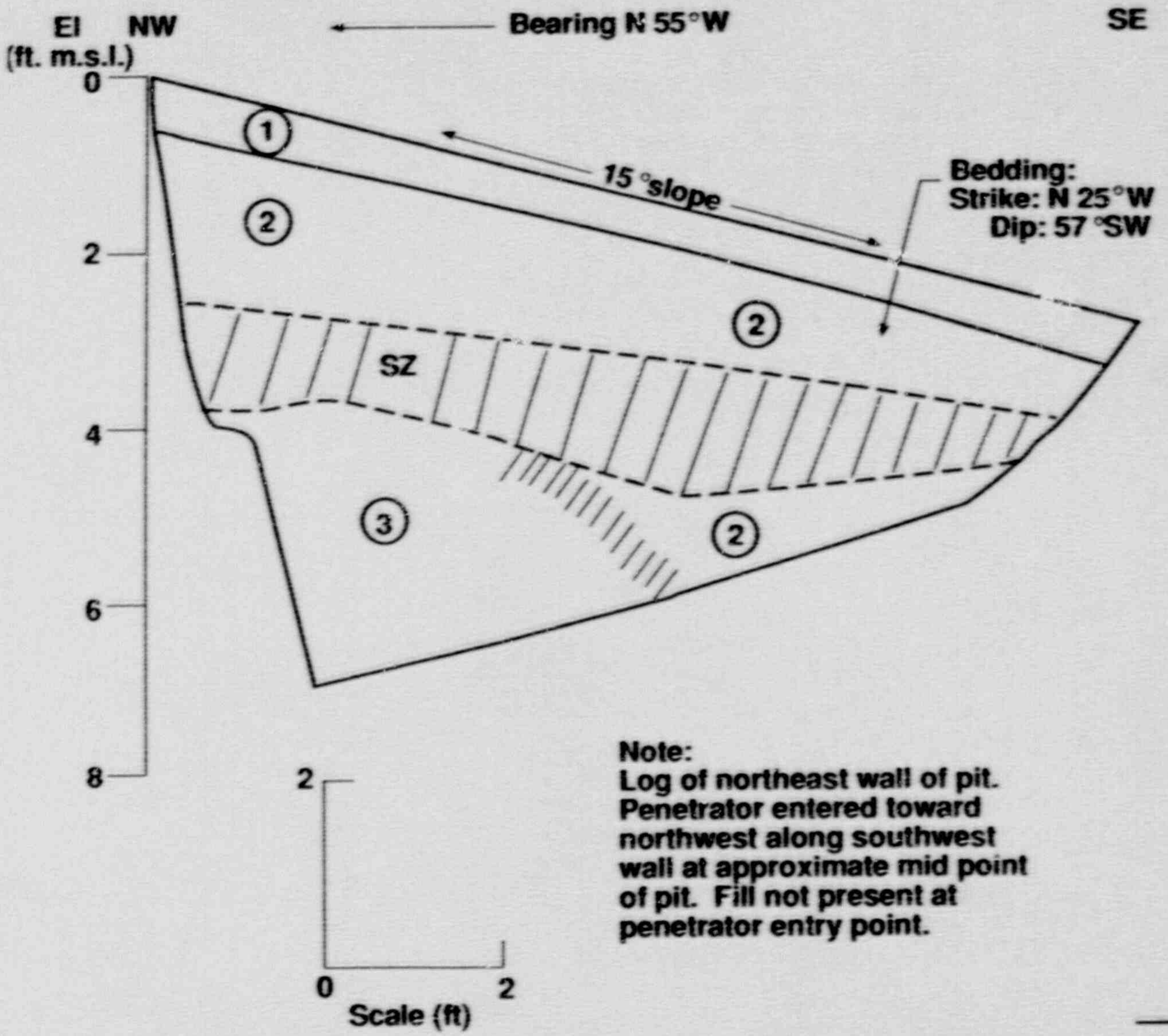
③ Claystone: Blocky, moderately weathered, hard. Gray with abundant black Mn oxide stains on fractures, some clay. Intensely fractured parallel and normal to bedding.

— Sharp contact

||||| Gradational contact

Note:
Log of southwest wall of pit. Penetrator entered toward northwest along northeast wall at approximate mid point of pit.

Log of test pit LLNL-1



Note:
Log of northeast wall of pit. Penetrator entered toward northwest along southwest wall at approximate mid point of pit. Fill not present at penetrator entry point.

Location:
N:748,029
E:1,150,223
El: 1287

Explanation

① Mixture of rock fragments and silty clay soil. Fill.

② Interbedded Shale and Sandstone. Intensely weathered, fragments crush in hands. Shale dominant, olive brown with abundant Mn oxide stains. Sandstone very fine grained, silty, present as thin interbeds weathered to dense silty sand, brown.

③ Interbedded Shale and Sandstone. Moderately weathered. Shale dominant, hard, greenish gray to gray with abundant Fe & Mn oxide stains. Sandstone oxidized throughout, brown.

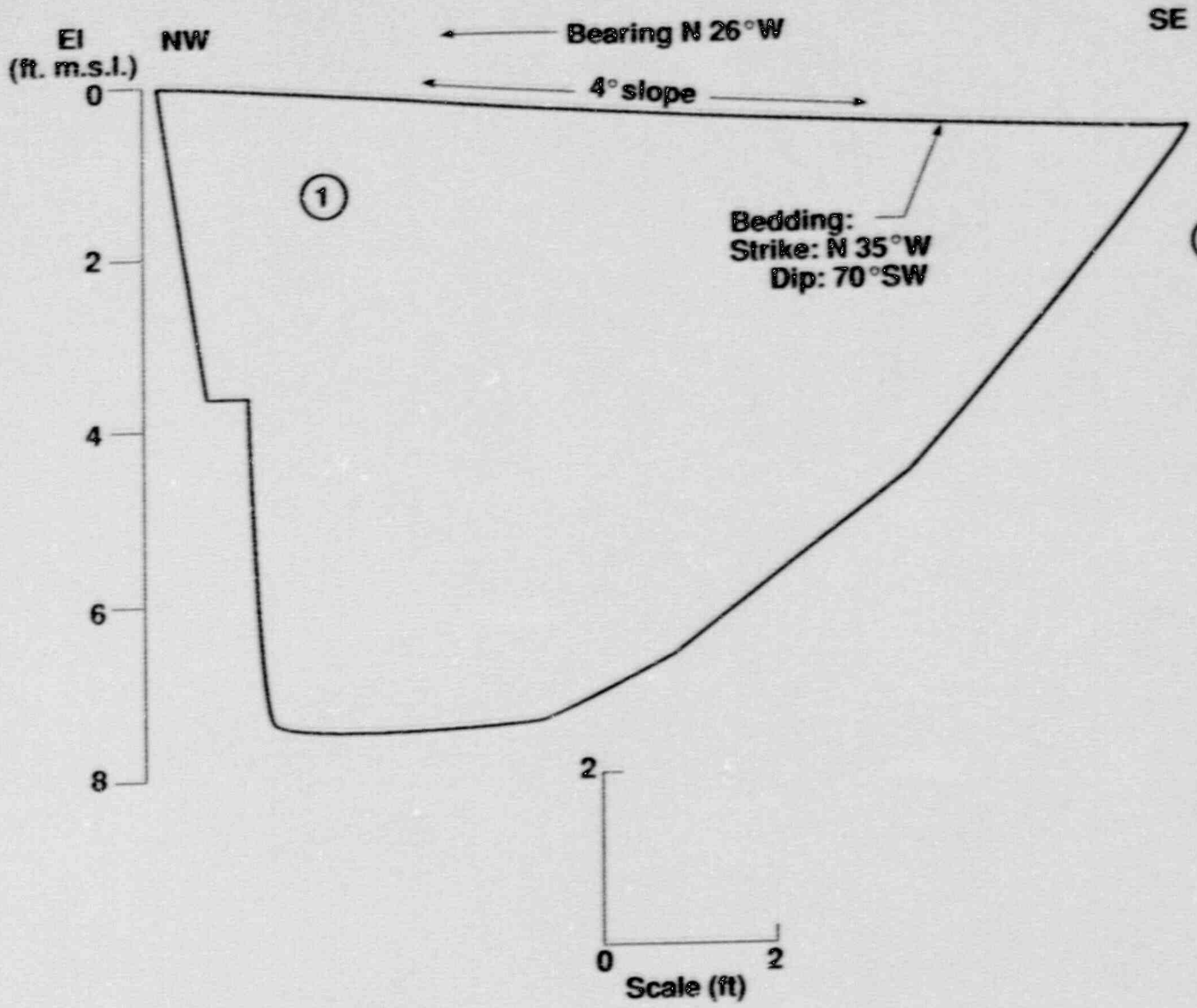
SZ Shear zone: Dark brown, moist sandy clay along near-vertical fracture. Several similar fractures, 1"-3" wide visible on NW face of pit.

—— Sharp contact

- - - Approximate contact

///// Gradational contact

Log of test pit LLNL-2.



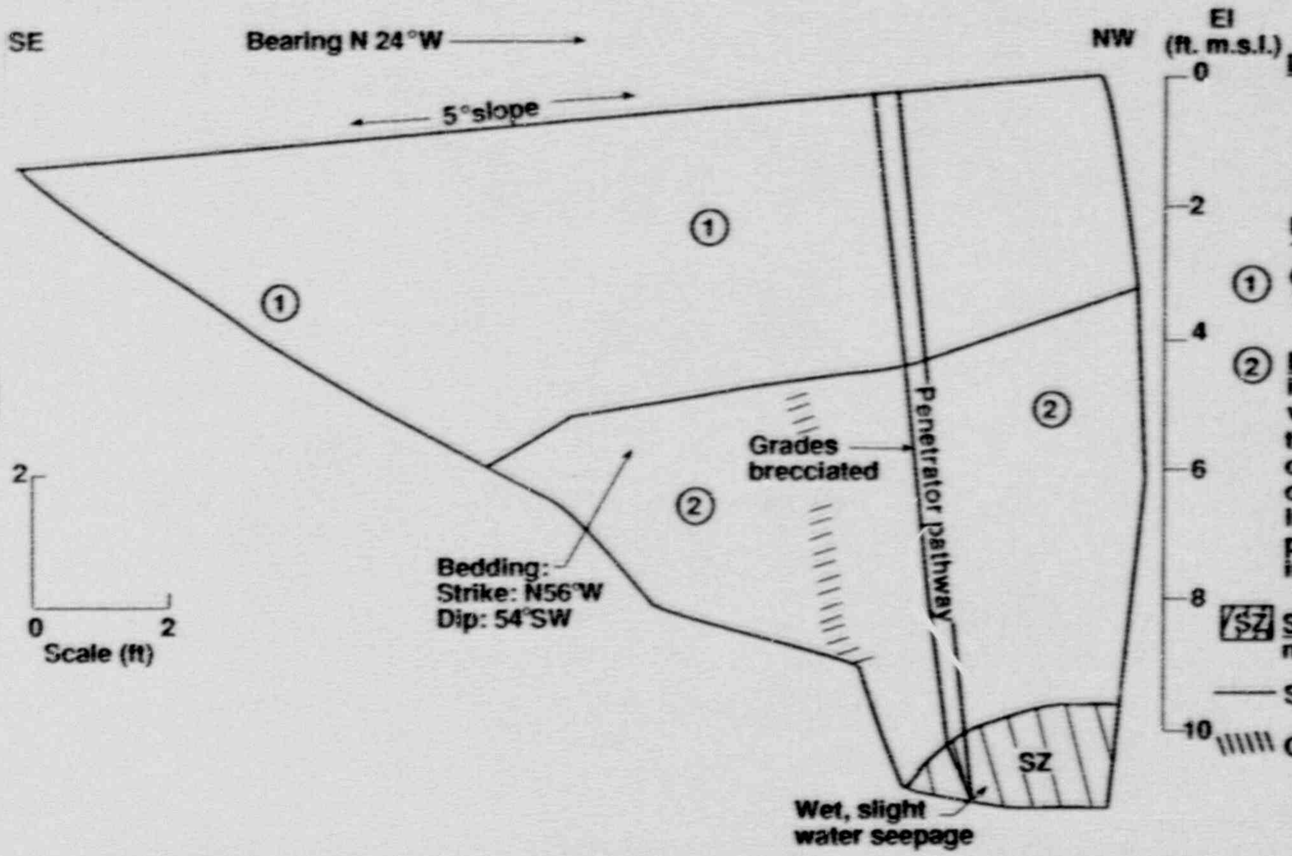
Location:
N:748,050
E:1,150,226
El.1287

Explanation:

① **Interbedded Shale andSandstone:** Intensely weathered with some moderately weathered lenses on NW wall of pit. Shale dominant, gray brown to greenish gray, abundant Fe & Mn oxide stains on fractures along which rock breaks easily. Sandstone beds to 1/2" thick, very fine grained, silty, oxidized brown throughout. Some soil on fracture surfaces.

Note:
Log of northeast wall of pit. Penetrator entered toward northwest along southwest wall at approximate mid point of pit.

Log of test pit LLNL-3.



Location:
N: 748,019
E: 1,150,052
El: 1281

Explanation

① Clayey Silt (ML-CL), very slight plasticity, brown, dry, roots to 1' depth. Colluvium.

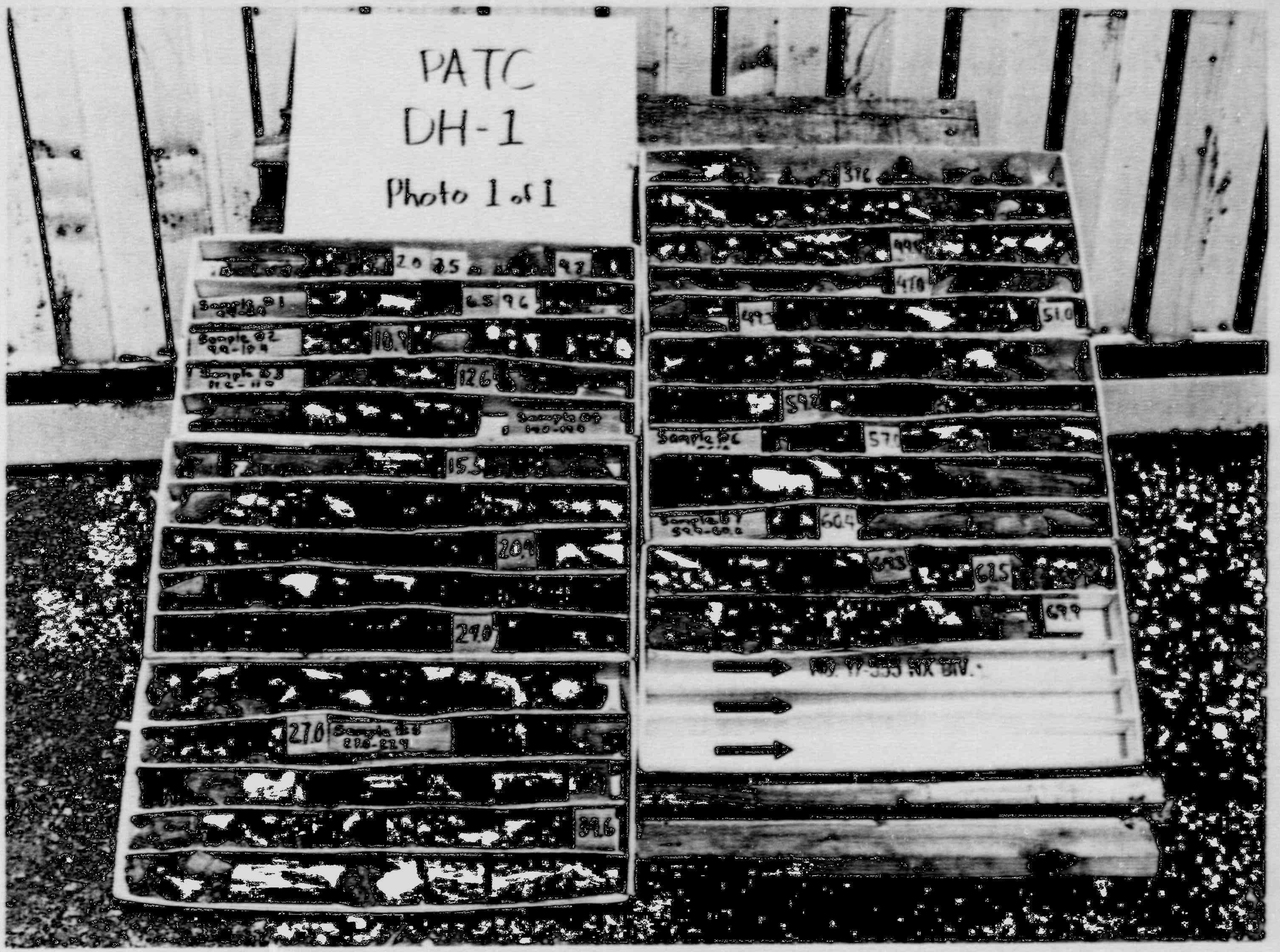
② Interbedded Shale and Sandstone. Decomposed to intensely weathered. Shale dominant, varies from veryhard silty clay (CL) to rock oxidized brown throughout and easily broken in hands along Mn oxide stained fractures. Sandstone as thin beds oxidized to brown silty sand (SM). Intensely fractured to brecciated, in northwestern portion of pit grades to mixture of rock fragments in clay matrix.

▨ SZ Shear Zone: Blue gray, moist to wet clay along near-vertical fracture.

— Sharp contact

\\\\\\ Gradational contact

Log of test pit LLNL-4.


PATC
DH-1
Photo 1 of 1
2.0
3.5
9.7
6.5
9.6
10.9
12.6
15.5
20.9
29.0
27.0
51.0
57.0
60.4
69.9

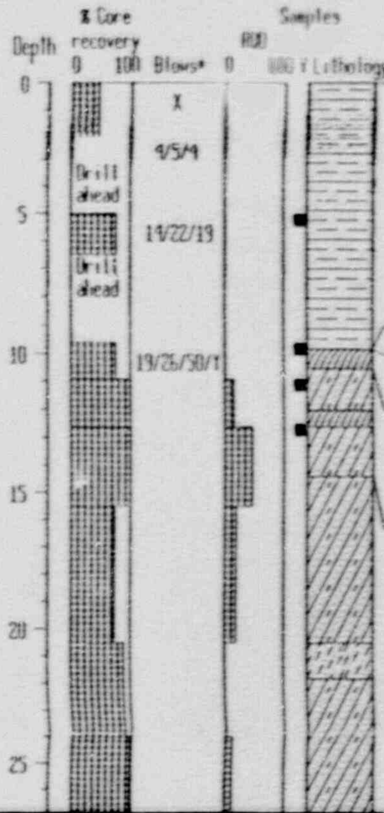
LOG EXPLORATORY HOLE DH-1

Location: Near center of impact site
Coordinates: N 740,[illegible]95.01
E 1,150,140.45
Ground Elevation: 1322.72 feet
Geophysical Logging: None
Hole Orientation: 80° from horizontal, bearing S87°W
Dates Drilled: 3/27 to 3/29/89

Drilling: W. Weisberell, P. C. Exploration, Inc., Roseville, CA
Drill Rig: Longyear 34
Drilling Method: Rotary wash and drive sampling, 0-10.9'
NX continuous wireline coring, recirculated water, 10.9-69.9'
Geologic Logging: D. W. Carpenter, LLNL

INDEX TO SYMBOLS

■ SAMPLES
▭ SHEAR ZONE
▭ MODERATELY FRACTURED
▭ FRACTURED
▨ INTENSELY FRACTURED
▩ VERY INTENSELY FRACTURED
▭ MOSTLY MODERATELY FRACTURED
▭ MOSTLY FRACTURED
▨ MOSTLY INTENSELY FRACTURED
▩ MOSTLY VERY INTENSELY FRACTURED



Lithologic descriptions and/or remarks

(0-9.8) FILL, CLAYEY SILT, (ML-CL), soil mixed with rock fragments, brown, moist, soft
0-5 Contains wood and metallic debris

5-9.8 Predominantly rock fragments in soil matrix, no debris noted

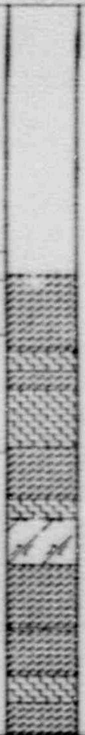
(9.8-69.9) JURASSIC-CRETACEOUS MARINE SEDIMENTARY ROCKS

(9.8-10.5) CLAYSTONE, decomposed to very hard lean clay (CL), brown with orange Fe-oxide stains, varibly dry to moist, appears compacted

(10.5-14.4) Interbedded SILTY SANDSTONE and CLAYEY SHALE, bedding inclined 70°-80°. Estimate 70% very fine to fine grained silty sandstone, brown with orange Fe-oxide stains, moderately hard, intensely weathered. Estimate 30% clayey shale gray-brown to gray with Fe-oxide stains, moderately hard
12.0-12.6 Predominantly clayey shale

(14.4-33) Interbedded CLAYEY SHALE and SILTY SANDSTONE, beds 1/16" to 1" thick, inclined 70°-75°. 50-70% clayey shale, gray with Fe-oxide stains on fractures, moderately hard, lightly weathered. 30-50% very fine grained silty sandstone, gray-brown with Fe-oxide stains, hard, moderately weathered.
18.0-18.7 Very lightly weathered.
20.5-21.8 Predominately sandy siltstone, mottled blue-gray and brown

Fractures



Fracture log

0-9.8 Not applicable, fill material.

9.8-14 Mostly very intensely fractured, recovered as fragments and short cores, Fe- and Mn-oxide stained fractures inclined 20°-40° and 60°-80°

12.6-13.3 Intensely fractured

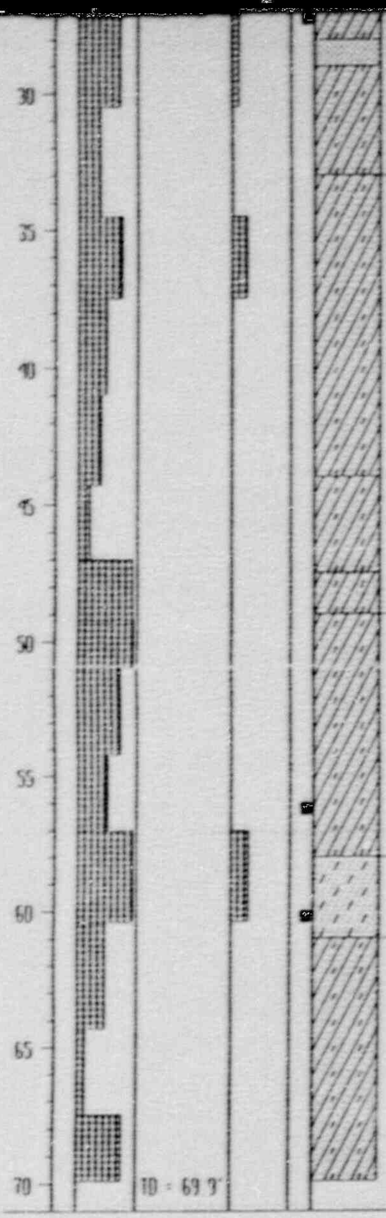
14.0-16.1 Intensely fractured, fractures spaced 0.1' to 0.5', inclined 20° and 45°-70°, partly healed by carbonate, Fe- and Mn-oxide and clay

16.1-24.2 Mostly very intensely fractured, recovered mainly as small fragments. Fe- and Mn-oxide stained fractures inclined 15°-30°, 45°-60°, and 70°-90°.
18.0-18.7 Intensely fractured.
18.7-20.4 Shear zone, angular fragments mixed with clay.

22.7-22.8 Shear zone, light brown clay bonding fragments and on fractures inclined 30°

24.2-25.5 Intensely fractured, core broken on Fe- and Mn-oxide stained fractures inclined 20°, 45-60°, and 75°

25.5-29 Mostly very intensely fractured, recovered as fragments, Fe- and



28-29 Sandstone, mottled brown and gray, fine to medium grained, moderately weathered.
29-33 Mottled gray and brown with Fe-oxide stains on fractures, moderately to intensely weathered in shear zone.

(33-49) Interbedded SILTY SANDSTONE and CLAYEY SHALE, beds 1/8" to 1/2" thick, locally disrupted to nodules and trains of shale rip-up clasts, inclined 70°-85°, lightly weathered, Fe-oxide stains on fracture surfaces. Estimate 50% very fine grained silty sandstone, gray, hard. Estimate 50% clayey shale, dark gray, hard.

44-47.5 Quartz veins in sandstone beds.

(49-58) Interbedded SILTY SANDSTONE and CLAYEY SHALE, beds 1/8" to 3" thick, inclined 55-65°, scattered quartz-pyrite veinlets, unweathered. 50-60% fine grained silty sandstone, gray, hard, some shale rip-up clasts. 40-50% clayey shale, dark gray, hard.
49.3-49.7 Core healed by 2" thick quartz vein containing shale fragments, inclined 70-85°.

(58-61) SILTY SANDSTONE, very fine to medium grained, gray, hard, unweathered, abundant black shale lenses and clast trains inclined 60°-90°.

(61-69.9 Interbedded CLAYEY SHALE and SILTY SANDSTONE, highly sheared, bedding disrupted, contact at top inclined 70°, unweathered. Predominantly clayey shale, dark gray, moderately hard. Thin interbeds and nodules of gray very fine grained silty sandstone.

Notes:
- * Per 6" interval
- X Drove easily, blows not recorded, no tubes in sampler
- Y 50 blows for 4" advance
- Z About 50% water and mud loss, 10.5-27' interval

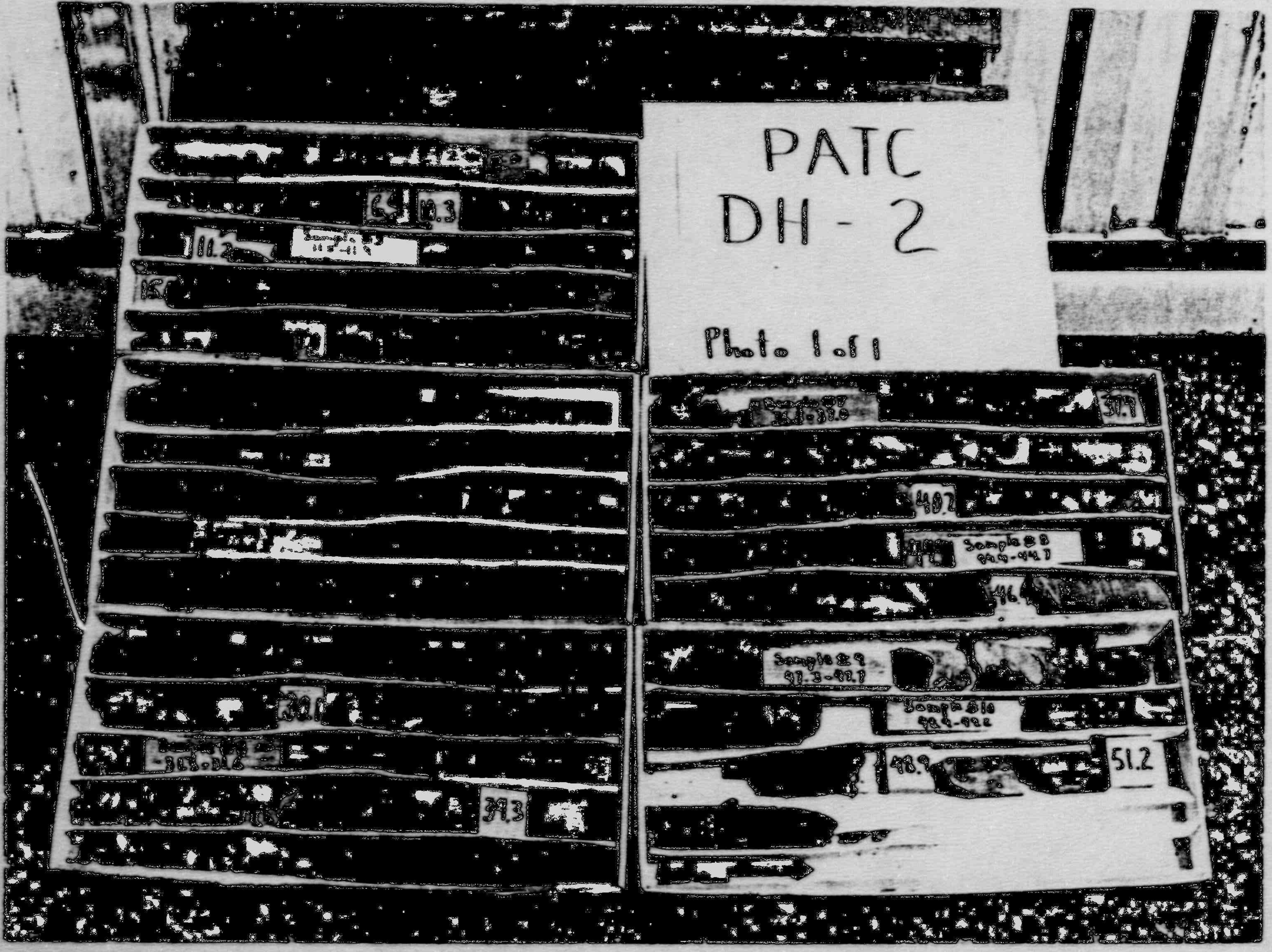
Fe-oxide stained fractures inclined 20-45° and 70-90°, local partial healing.
26.8-27.0 Shear zone, inclined 70°, fragments bonded by clay.
27.0-27.5 Intensely fractured.
29.0-34.4 Shear zone, rock crushed, bedding disrupted, recovered as angular rock fragments in matrix of gray and brown mottled plastic clay. Fracture at top inclined 70°, heavy Fe-oxide stains, fracture at base inclined 30°. Core loss zone.
34.4-36.2 Mostly intensely fractured, Fe-oxide stained fractures spaced mostly 0.2'-0.6', inclined 15°-45°, 50°-60°, and 75°.
36.2-49.0 Very intensely fractured, recovered as fragments and splintered cores broken along variably Fe-oxide stained fractures inclined 20°-40°, 60°-90° (normal to bedding), and 75° (parallel to bedding). Traces of carbonate and pyrite on less stained fractures, some gray clay coatings.

49.0-51.0 Shear zone, crushed to small fragments, some clay, fractures inclined 60°-90°. Fe-oxide stained fracture at 49.0 feet, unstained below, trace of pyrite.
51.0-59.2 Very intensely fractured, shear zones, core crushed to splinters along fractures inclined 35°, 60°-90° (normal to bedding), and 55°-65° (parallel to bedding), faint slickensides, clay, quartz, and pyrite on some fractures, local partial healing. Some core losses.
53-54.2 Shear zone, gray clay and sand bearing small, angular shale fragments, fracture at top inclined 70°.
57.3-57.5 Shear zone.

58.9-59.2 Shear zone.
59.2-61.3 Intensely fractured, recovered as short cores and fragments along intersecting fractures inclined 30°-45°, 80° (normal to bedding), and 80° (parallel to bedding).
61.3-67.5 Shear zone, recovered mostly as small angular fragments in dark silty clay matrix, fractures inclined 20° and 60°-90°. Core and water losses, hole binding on drill rods.

67.5-69.9 Very intensely fractured, fractures spaced about 1" apart, inclined 45° and 60°-70°.
69.2-69.8 Shear zone, recovered angular shale fragments in matrix of dense silty clay.

9010050099-02


PATC
DH - 2
Photo 1 of 1
10.3
11.2
15
37.9
40.2
Sample #8
46
Sample #9
Sample #10
48.9
51.2
30.1
39.3

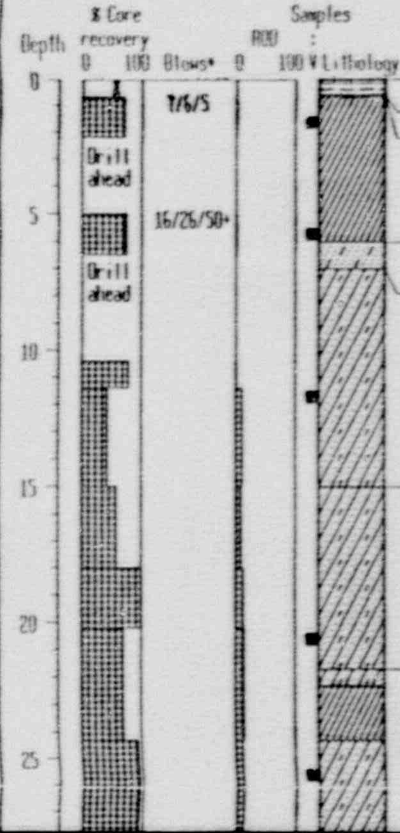
LOG EXPLORATORY HOLE DH-2

Location: South of impact site
Coordinates: N: 748,039.66
E: 1,150,137.36
Ground Elevation: 1324.47 'eet
Geophysical Logging: None
Hole Orientation: 80° fr m horizontal; bearing N82°W
Dates Drilled: 4/3 to 4/ 5/89

Drilling: M. Westerveit, P. C. Exploration, Inc., Roseville, CA
Drill Rig: Longyear 34
Drilling Method: Rotary wash and drive sampling, 0-10.3'
NX continuous wireline coring, recirculated water, 10.3-51.2'
Geologic Logging: D. W. Carpenter, LLNL

INDEX TO SYMBOLS

■ SAMPLES
▨ MODERATELY FRAC URED
▨ MOSTLY MODERATELY FRACTURED
▨ FRACTURED
▨ MOSTLY FRACTURED
▨ INTENSELY FRACTURED
▨ MOSTLY INTENSELY FRACTURED
▨ SHEAR ZONE
▨ VERY INTENSELY FRACTURED
▨ MOSTLY VERY INTENSELY FRACTURED



Lithologic descriptions and/or remarks

(0-0.6) FILL: SILTY CLAY, (CL), and rock fragments, brown

(0.6-51.2) JURASSIC-CRETACEOUS MARINE SEDIMENTARY ROCKS

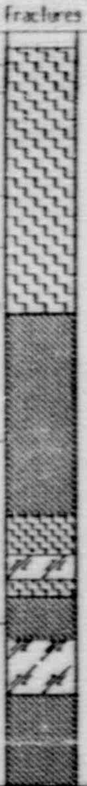
(0.6-6) SHALE, decomposed to stiff SANDY CLAY, (CL), light to dark brown, dry to moist, trace of roots

(6-7) SILTY SANDSTONE, decomposed to very dense, fine grained SILTY SAND, (SM), orange-brown, damp

(7-15) Interbedded SILTY SANDSTONE and CLAYEY SHALE, beds laminae to 1/2" thick, inclined 80°. Intensely weathere' 60-80% very fine to fine grained silty sandstone, moderately hard with softened intervals, orange-brown. 20-40% clayey shale, moderately hard, olive. Abundant Fe- and Mn-oxide stains on fractures.

(15-21.7) Interbedded SILTY SANDSTONE and CLAYEY SHALE, beds laminae to 1/2" thick, inclined 50-80°, wavy, some bedding disrupted to lenses and shale fragment trains. Moderately weathered. Estimate 50% very fine to fine grained silty sandstone, hard, orange to gray-brown. Estimate 50% clayey shale, moderately hard, olive to gray with brown stains. Fe- and Mn-oxide stains on fractures, brown clay coatings.

(21.7-39.9) Interbedded SILTY SANDSTONE and CLAYEY SHALE, beds laminae to 1" thick, inclined 55°-70°, wavy. Lightly weathered becoming very lightly weathered below 29.2'. 40-75% very fine to fine grained silty sandstone, hard, gray. 25-60% clayey shale, hard, dark gray. Fe- and Mn-oxide stains on fractures, decreasing stains with depth, local carbonate veinlets, traces of pyrite below 29.2'.
22.3-24.3 Predominantly Shale

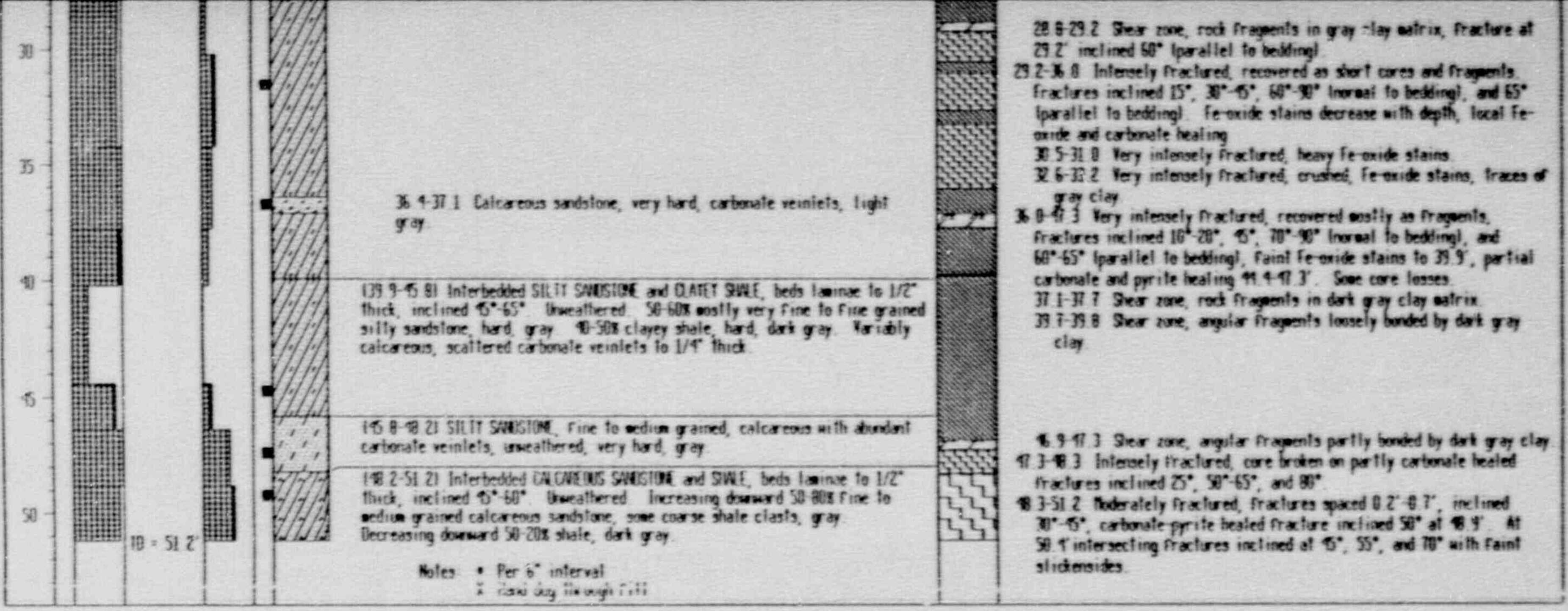


Fracture log

0-0.6 Not applicable.
0.6-10.3 Mn-oxide stained fractures visible in samples.

10.3-17.7 Very intensely fractured, recovered mostly as fragments and splintered cores, scattered intact cores. Fe- and Mn-oxide stained fractures inclined 35°-60° and 70°-90°, clay coatings and soft zones. Some healed fractures. Core loss zone.

17.7-20.7 Intensely fractured, fractures Fe- and Mn-oxide stained, clay traces, inclined 20°-30°, 70°-90° (normal to bedding), and 70° (parallel to bedding). Healed fractures 19.8-20.7'.
19.2-20.1 Shear zone, core crushed to fragments along intersecting 30° and 60°-70° fractures, up to 1/2" brown clay filling fractures.
20.7-29.2 Very intensely fractured, recovered as fragments and splinters. Fe- and Mn-oxide stained fractures inclined 20°-45°, 70°-90° (normal to bedding), and 60°-70° (parallel to bedding), partial carbonate and Fe-oxide healing 24.3-25.3' and 28.2-28.8'.
22.3-24.3 Shear zone, shale fragments in dark gray, stiff silty clay matrix.



36.4-37.1 Calcareous sandstone, very hard, carbonate veinlets, light gray.

(39.9-45.8) Interbedded SILTY SANDSTONE and CLAYEY SHALE, beds laminae to 1/2" thick, inclined 45°-65°. Unweathered. 50-60% mostly very fine to fine grained silty sandstone, hard, gray. 40-50% clayey shale, hard, dark gray. Variably calcareous, scattered carbonate veinlets to 1/4" thick.

(45.8-48.2) SILTY SANDSTONE, fine to medium grained, calcareous with abundant carbonate veinlets, unweathered, very hard, gray.

(48.2-51.2) Interbedded CALCAREOUS SANDSTONE and SHALE, beds laminae to 1/2" thick, inclined 45°-60°. Unweathered. Increasing downward 50-80% fine to medium grained calcareous sandstone, some coarse shale clasts, gray. Decreasing downward 50-20% shale, dark gray.

Notes: • Per 6" interval
x Hand dug through fill

28.8-29.2 Shear zone, rock fragments in gray clay matrix, fracture at 29.2' inclined 60° (parallel to bedding).

29.2-36.0 Intensely fractured, recovered as short cores and fragments. Fractures inclined 15°, 30°-45°, 60°-90° (normal to bedding), and 65° (parallel to bedding). Fe-oxide stains decrease with depth, local Fe-oxide and carbonate healing.
  30.5-31.0 Very intensely fractured, heavy Fe-oxide stains.
  32.6-33.2 Very intensely fractured, crushed, Fe-oxide stains, traces of gray clay.

36.0-47.3 Very intensely fractured, recovered mostly as fragments. Fractures inclined 10°-20°, 45°, 70°-90° (normal to bedding), and 60°-65° (parallel to bedding). Faint Fe-oxide stains to 39.9', partial carbonate and pyrite healing 44.4-47.3'. Some core losses.
  37.1-37.7 Shear zone, rock fragments in dark gray clay matrix.
  39.7-39.8 Shear zone, angular fragments loosely bonded by dark gray clay.

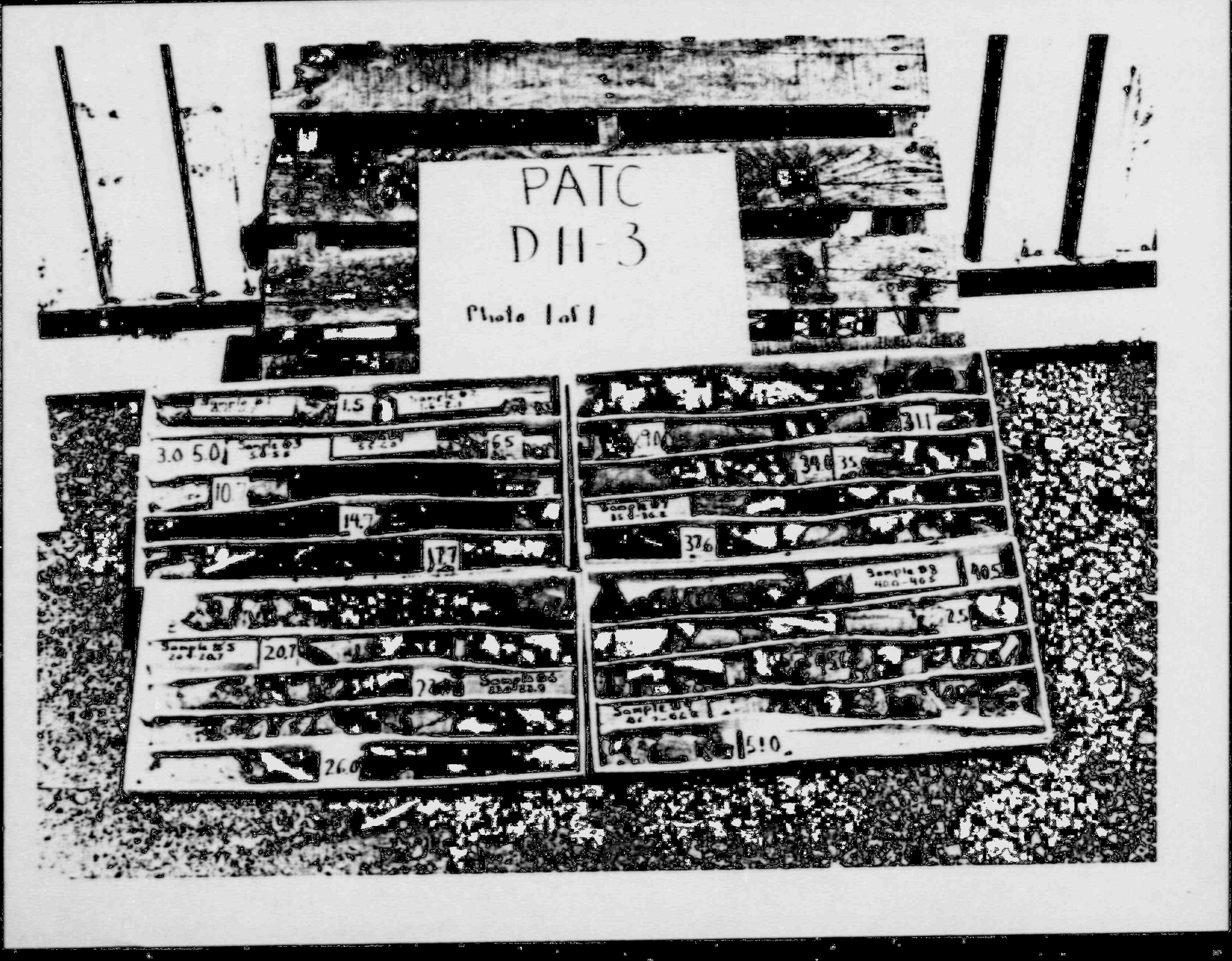
  46.9-47.3 Shear zone, angular fragments partly bonded by dark gray clay.

47.3-48.3 Intensely fractured, core broken on partly carbonate healed fractures inclined 25°, 50°-65°, and 80°.

48.3-51.2 Moderately fractured, fractures spaced 0.2'-0.7', inclined 30°-45°, carbonate-pyrite healed fracture inclined 50° at 48.9'. At 50.4' intersecting fractures inclined at 45°, 55°, and 70° with faint slickensides.

9010050099 -03

SI
APERTURE
CARD
Also Available On
Aperture Card


PATC
DH-3
Photo 1 of 1
1.5
3.0
5.0
6.5
10
14.7
17.7
20.7
26.0
31.1
34.0
35
37.6
40.5
51.0
Sample #8
40.0-40.5

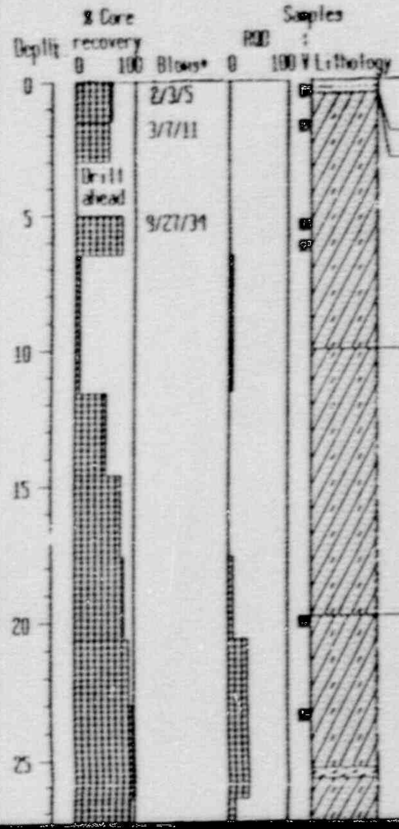
LOG: EXPLORATORY HOLE DH-3

Location: North of impact site
Coordinates: N: 748,142.21
E: 1,150,141.76
Ground Elevation: 1320.90 feet
Geophysical Logging: None
Hole Orientation: 80° from horizontal; bearing S70°W
Dates Drilled: 4/10 to 4/12/89

Drilling: M. Westervelt, P. C. Exploration, Inc., Roseville, CA
Drill Rig: Longyear 34
Drilling Method: Rotary wash and drive sampling, 0-6.5'
NX continuous wireline coring, recirculated water, 6.5-51.0'
Geologic Logging: D. W. Carpenter, LLNL

INDEX TO SYMBOLS

- ■ SAMPLES
- ▨ MODERATELY FRACTURED
- ▨ MOSTLY MODERATELY FRACTURED
- ▨ FRACTURED
- ▨ MOSTLY FRACTURED
- ▨ INTENSELY FRACTURED
- ▨ MOSTLY INTENSELY FRACTURED
- ▨ SHEAR ZONE
- ▨ VERY INTENSELY FRACTURED
- ▨ MOSTLY VERY INTENSELY FRACTURED



Lithologic descriptions and/or remarks

(0-0.5) COLLUVIUM: SANDY SILT, (ML-SM), estimate 50% slightly plastic fines, 30% sand, 20% rock fragments, dark brown, dry, contains roots.

(0.5-51.0) JURASSIC-CRETACEOUS MARINE SEDIMENTARY ROCKS

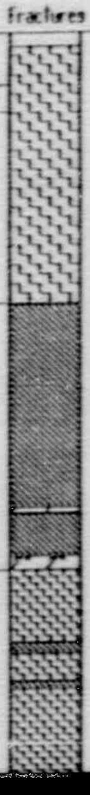
(0.5-10) Interbedded CLAYEY SHALE and SILTY SANDSTONE, clayey shale predominant, decomposes to damp, moderately plastic lean clay (CL), and silty clay (CL-ML), brown. Silty sandstone in thin, steeply inclined beds, decomposed to silty sand (SM), orange-brown.

0.5-1.5 Contains roots.

(10-13.8) Interbedded CLAYEY SHALE and SILTY SANDSTONE, beds laminae to 3" thick, inclined 45°-80°, locally disrupted. 50-60% clayey shale, intensely weathered, oxidized, breaks down to lean clay (CL) with difficulty, mottled brown and olive. 40-50% very fine to fine grained silty sandstone, intensely weathered, oxidized, friable, orange-brown.

(19.8-32) Interbedded SILTY SANDSTONE and CLAYEY SHALE, beds laminae to 3" thick, inclined 50°-80°, wavy, locally disrupted. 50-60% very fine to fine grained silty sandstone, moderately weathered, oxidized, moderately hard, gray-brown. 40-50% clayey shale, moderately weathered, gray to olive-gray, abundant Fe- and Mn-oxide stains on fractures.

25.3-25.7 Calcareous sandstone, poorly sorted, blue-gray, Fe-oxide stains on fractures.

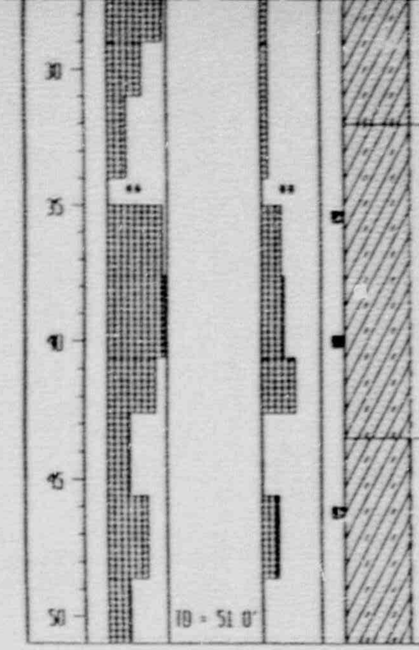


Fracture log

0-0.5 Not applicable.
0.5-10 Fractures visible in decomposed rock, Fe- and Mn-oxide stains, inclined 45° and parallel to bedding.

10-13.8 Very intensely fractured, rock broken to splinters and split cores along heavily Fe- and Mn-oxide stained fractures inclined 20°, 45°-60°, and 70°-90°, decomposed veinlets 14.5-17.5'.

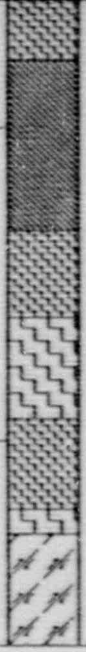
17.5-17.7 Shear zone, rock crushed to small fragments loosely bonded by brown clay.
19.3-19.8 Shear zone, parallel bedding, shale fragments loosely bonded by orange-brown clay.
19.8-29.5 Intensely fractured, recovered as short cores and fragments broken on heavily Fe- and Mn-oxide stained fractures inclined 20°-45°, 50°-60° (parallel to bedding), and 70°-90° (normal to bedding). Some brown clay and weathered carbonate on fracture surfaces.
22.4-22.8 Very intensely fractured.
22.8-24.1 Very intensely fractured.



(32-43.5) Interbedded CLAYEY SHALE and SILTY SANDSTONE, beds laminae to 1" thick, inclined 60°-85°, wavy. 50-75% clayey shale, hard, dark gray. 25-50% very fine to fine grained silty sandstone, hard, gray, some carbonate veinlets. Lightly weathered, Fe-oxide stains on fractures, decreasing stains with depth.

(43.5-51.0) Interbedded SILTY SANDSTONE and CLAYEY SHALE, beds laminae to 1" thick, inclined 55°-80°, occasional carbonate veinlets. 50% very fine grained silty sandstone, hard, gray. 50% clayey shale, hard, dark gray, unweathered.

Notes
- * Per 6" interval
- ** Core barrel mislatch



29.5-35.8 Very intensely fractured, recovered as fragments. Visible fractures heavily Fe- and Mn-oxide stained, inclined 30° and 60°-70° (parallel and normal to bedding). Core loss zone, possibly sheared.

35.8-39.0 Intensely fractured, recovered as short cores and fragments broken on Fe-oxide stained fractures inclined 45° and 70°-90° (parallel and normal to bedding). Some gray and orange-brown stained clay on fracture surfaces.

39.0-42.7 Moderately fractured, recovered mainly as cores broken on fractures inclined 30°-45°, 60° (normal to bedding), and 80° (parallel to bedding), slight Fe-oxide staining on some fractures, partial carbonate healing.

42.7-46.0 Intensely fractured, recovered as short cores and fragments, fractures inclined 25°, 55°, and 80° (normal to bedding), slight Fe-oxide stains 42.7-43.5'.
At 43.5', 1/2" thick Fe-oxide stained carbonate veinlet inclined 60°.

46.0-46.9 Moderately fractured, mechanically broken.

46.9-51.0 Shear zone, partial carbonate healing, recovered as fragments, some gray clay. Visible fractures inclined 30-45° and 70°-85°, bedding disrupted. Core loss zone.


PATC
DH-4
Photo 1 of 1
1.75
3.50
8.5
10.0
15.0
17.0
20.0
22.0
25.0
27.0
30.0
35.0
37.4
43.9
45.9
48.9

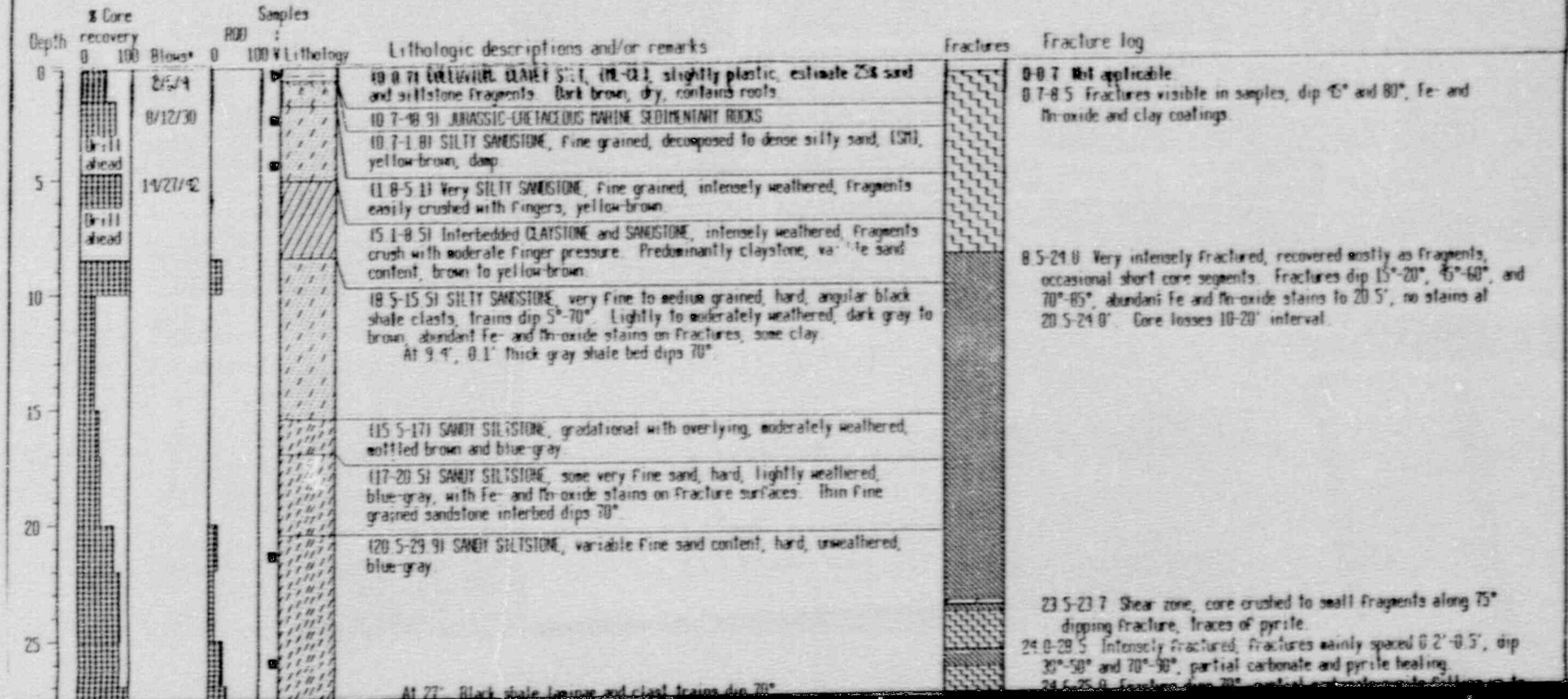
LOG EXPLORATORY HOLE DH-4

Location: Base of slope, east of impact site.
Coordinates: N: 748,092.89
E: 1,150,246.95
Ground Elevation: 1280.53 feet
Geophysical Logging: None
Hole Orientation: Vertical
Dates Drilled: 3/21 to 3/23/89

Drilling: M. Westervelt, P. C. Exploration, Inc., Roseville, CA
Drill Rig: Longyear 34
Drilling Method: Rotary wash and drive sampling, 0-8.5'
NX continuous wireline coring, recirculated water, 8.5-48.9'
Geologic Logging: D. W. Carpenter, LLNL

INDEX TO SYMBOLS

- ■ SAMPLES
- ▨ MODERATELY FRACTURED
- ▨ MOSTLY MODERATELY FRACTURED
- ▨ FRACTURED
- ▨ MOSTLY FRACTURED
- ▨ INTENSELY FRACTURED
- ▨ MOSTLY INTENSELY FRACTURED
- ▨ SHEAR ZONE
- ▨ VERY INTENSELY FRACTURED
- ▨ MOSTLY VERY INTENSELY FRACTURED



Lithologic descriptions and/or remarks

(0-0.7) COLLUVIUM, CLAYEY SILT, (ML-CL), slightly plastic, estimate 25% sand and siltstone fragments. Dark brown, dry, contains roots.

(0.7-48.9) JURASSIC-CRETACEOUS MARINE SEDIMENTARY ROCKS

(0.7-1.8) SILTY SANDSTONE, fine grained, decomposed to dense silty sand, (SM), yellow-brown, damp.

(1.8-5.1) Very SILTY SANDSTONE, fine grained, intensely weathered, fragments easily crushed with fingers, yellow-brown.

(5.1-8.5) Interbedded CLAYSTONE and SANDSTONE, intensely weathered, fragments crush with moderate finger pressure. Predominantly claystone, variable sand content, brown to yellow-brown.

(8.5-15.5) SILTY SANDSTONE, very fine to medium grained, hard, angular black shale clasts, trains dip 5°-70°. Lightly to moderately weathered, dark gray to brown, abundant Fe- and Mn-oxide stains on fractures, some clay.
At 9.4', 0.1' thick gray shale bed dips 70°.

(15.5-17) SANDY SILTSTONE, gradational with overlying, moderately weathered, mottled brown and blue-gray.

(17-20.5) SANDY SILTSTONE, some very fine sand, hard, lightly weathered, blue-gray, with Fe- and Mn-oxide stains on fracture surfaces. Thin fine grained sandstone interbed dips 70°.

(20.5-29.9) SANDY SILTSTONE, variable fine sand content, hard, unweathered, blue-gray.

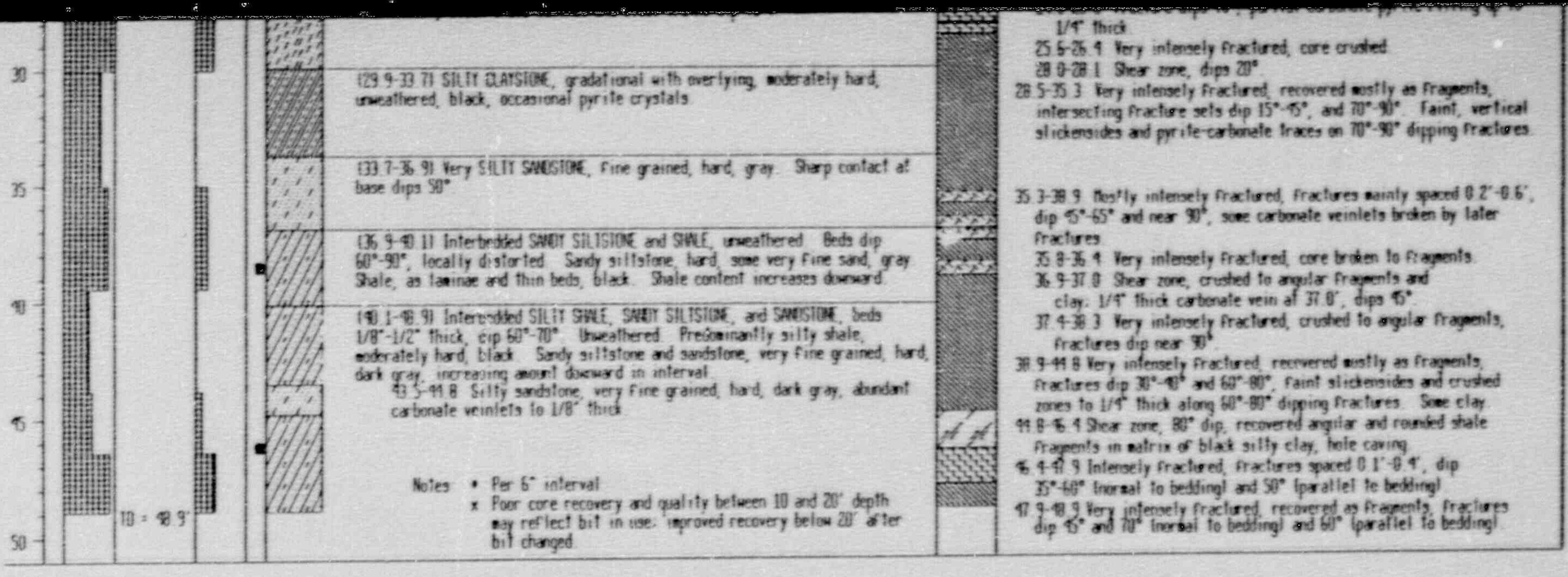
At 27' Black shale laminae and clast trains dip 70°.

Fracture log

0-0.7 Not applicable.
0.7-8.5 Fractures visible in samples, dip 45° and 80°, Fe- and Mn-oxide and clay coatings.

8.5-24.0 Very intensely fractured, recovered mostly as fragments, occasional short core segments. Fractures dip 15°-20°, 45°-60°, and 70°-85°, abundant Fe and Mn-oxide stains to 20.5', no stains at 20.5-24.0'. Core losses 10-20' interval.

23.5-23.7 Shear zone, core crushed to small fragments along 75° dipping fracture, traces of pyrite.
24.0-29.5 Intensely fractured, fractures mainly spaced 0.2'-0.5', dip 30°-50° and 70°-90°, partial carbonate and pyrite healing.
24.6-25.0 Fractures dip 70°, [illegible]



(29.9-33.7) SILTY CLAYSTONE, gradational with overlying, moderately hard, unweathered, black, occasional pyrite crystals.

(33.7-36.9) Very SILTY SANDSTONE, fine grained, hard, gray. Sharp contact at base dips 50°.

(36.9-40.1) Interbedded SANDY SILTSTONE and SHALE, unweathered. Beds dip 60°-90°, locally distorted. Sandy siltstone, hard, some very fine sand, gray. Shale, as laminae and thin beds, black. Shale content increases downward.

(40.1-48.9) Interbedded SILTY SHALE, SANDY SILTSTONE, and SANDSTONE, beds 1/8"-1/2" thick, dip 60°-70°. Unweathered. Predominantly silty shale, moderately hard, black. Sandy siltstone and sandstone, very fine grained, hard, dark gray, increasing amount downward in interval.

43.5-44.8 Silty sandstone, very fine grained, hard, dark gray, abundant carbonate veinlets to 1/8" thick.

Notes:
- • Per 6" interval
- x Poor core recovery and quality between 10 and 20' depth may reflect bit in use; improved recovery below 20' after bit changed.

1/4" thick.

25.6-26.4 Very intensely fractured, core crushed.

28.0-28.1 Shear zone, dips 20°.

28.5-35.3 Very intensely fractured, recovered mostly as fragments, intersecting fracture sets dip 15°-45°, and 70°-90°. Faint, vertical slickensides and pyrite-carbonate traces on 70°-90° dipping fractures.

35.3-38.9 Mostly intensely fractured, fractures mainly spaced 0.2'-0.6', dip 45°-65° and near 90°, some carbonate veinlets broken by later fractures.

35.8-36.4 Very intensely fractured, core broken to fragments.

36.9-37.0 Shear zone, crushed to angular fragments and clay. 1/4" thick carbonate vein at 37.0', dips 45°.

37.4-38.3 Very intensely fractured, crushed to angular fragments, fractures dip near 90°.

38.9-44.8 Very intensely fractured, recovered mostly as fragments, fractures dip 30°-40° and 60°-80°, faint slickensides and crushed zones to 1/4" thick along 60°-80° dipping fractures. Some clay.

44.8-46.4 Shear zone, 80° dip, recovered angular and rounded shale fragments in matrix of black silty clay, hole caving.

46.4-47.9 Intensely fractured, fractures spaced 0.1'-0.4', dip 35°-60° (normal to bedding) and 50° (parallel to bedding).

47.9-48.9 Very intensely fractured, recovered as fragments, fractures dip 45° and 70° (normal to bedding) and 60° (parallel to bedding).

9010050099-05

SI
APERTURE
CARD

Also Available On
Aperture Card


PATC
DH-5
Photo 1 of 1
6.8
5.0
Sample 07
28.0-28.3
28.7
31.7
35.5
38.8
41.4
44.7
47.5
48.8
50.3

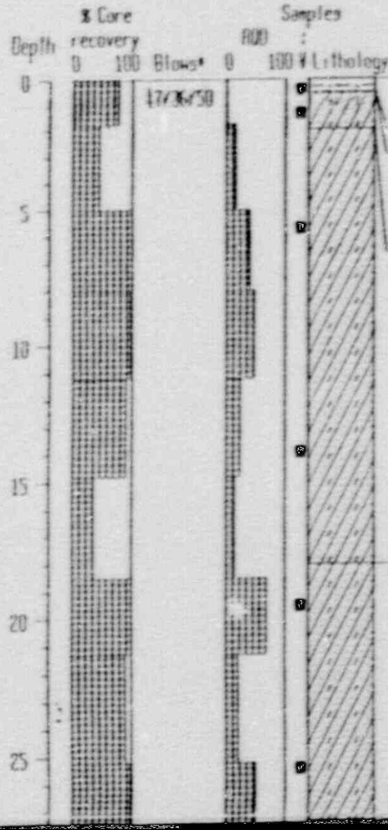
LOG EXPLORATORY HOLE DH-5

Location: Hilltop, west of impact site
Coordinates: N: 748,096.20
E: 1,150,099.56
Ground Elevation: 1340.69 feet
Geophysical Logging: Endacott and Associates, Pasadena, Ca
Hole Orientation: Vertical
Dates Drilled: 3/30 to 3/31/89

Drilling: M. Westervelt, P. C. Exploration, Inc., Roseville, CA
Drill Rig: Longyear 34
Drilling Method: Drive sampling, 0-1.8'
NX continuous wireline coring, recirculated water, 1.8-50.3'
4" tricone bit, recirculated water, ream, 0-50'
Install 2" blank PVC pipe to 50' for geophysical logging
Geologic Logging: D. W. Carpenter, LLNL

INDEX TO SYMBOLS

- ■ SAMPLES
- ▨ MODERATELY FRACTURED
- ▨ MOSTLY MODERATELY FRACTURED
- ▨ FRACTURED
- ▨ MOSTLY FRACTURED
- ▨ INTENSELY FRACTURED
- ▨ MOSTLY INTENSELY FRACTURED
- ▨ SHEAR ZONE
- ▩ VERY INTENSELY FRACTURED
- ▩ MOSTLY VERY INTENSELY FRACTURED



Lithologic descriptions and/or remarks

(0-0.5) COLLUVIUM, SANDY SILT, (ML), slightly plastic, abundant shale fragments. Dark brown, damp, contains roots.

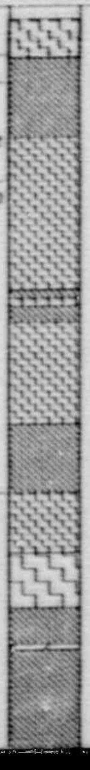
(0.5-50.3) JURASSIC-CRETACEOUS MARINE SEDIMENTARY ROCKS

(0.5-2.0) Interbedded SILTY SANDSTONE and CLAYEY SHALE, beds 1/8"-1/4" thick, dip 60°. Silty sandstone predominant, decomposed to silty sand, (SM), orange-brown. Clayey shale decomposed to hard lean clay, (CL), brown. Mn-oxide stains on bedding planes.

(2.0-18.0) Interbedded SILTY SANDSTONE and CLAYEY SHALE, beds 1/8"-1" thick, dip 55°-60°. Moderately weathered. Estimate 60% very fine to fine grained, occasionally medium grained, silty sandstone, hard, oxidized, yellow to gray-brown. Estimate 40% clayey shale, hard, dark gray. Fe- and Mn-oxide stains and traces of clay on fracture surfaces.

14-15 Lightly weathered.

(18-27.4) Interbedded SILTY SANDSTONE and CLAYEY SHALE, beds 1/4" to 1" thick, dip 50°-60°. Lightly weathered. 60-70% very fine to fine grained, occasionally medium grained, silty sandstone, very hard, gray to blue-gray. 30-40% clayey shale, hard, dark gray. Fe- and Mn-oxide stains and traces of clay on fracture surfaces.



Fracture log

0-0.5 Not applicable

0.5-2 Mn-oxide stained bedding plane fractures visible in decomposed rock.

2-5 Very intensely fractured, Fe- and Mn-oxide coated fractures dip 60° (parallel to bedding) and 30° (normal to bedding).

5-15.5 Intensely fractured, recovered as short cores and fragments broken on Fe- and Mn-oxide stained fractures with opposed 30°, 50°, and 80° dips. Some partly healed fractures.

10.6-10.9 Very intensely fractured, intensely weathered to decomposed to damp, brown clay. Visible fractures dip 15°, 35°, and 90°.

11.2-11.8 Very intensely fractured, broken to splinters along fractures with 15°-30° and 65°-90° dips.

15.5-18 Very intensely fractured, recovered as fragments, some brown clay gouge, Fe- and Mn-oxide stained fractures dip 30° and 60°-70°. Core loss zone.

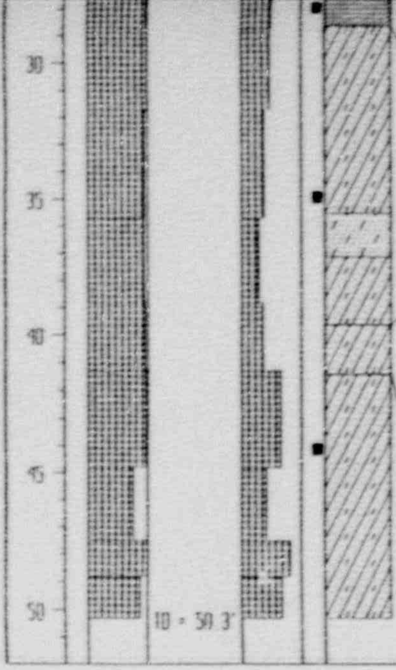
18-20.2 Intensely fractured, recovered as short cores and fragments broken on Fe- and Mn-oxide stained fractures dipping 20° and 70° (normal to bedding) and 60° (parallel to bedding). Some healed fractures.

20.2-22.2 Moderately fractured, many healed fractures and quartz veinlets. Open Fe-oxide stained fractures dip 15°-20° and 65°.

22.2-27.4 Very intensely fractured, recovered as fragments and splintered core broken on Fe- and Mn-oxide stained fractures, some clay coated, dip 10°-20°, 45°-60°, and 70°-90°.

23.5-23.7 Shear zone, crushed to angular fragments and clay.

24.9-25.9 Zone of variably healed fractures.



(27.4-28.6) CALCAREOUS SILTSTONE, lightly weathered, some very fine sand, very hard. Blue-gray with Fe-oxide stains on fractures.

(28.6-39.6) Interbedded SILTY SANDSTONE and CLAYEY SHALE, beds 1/8"-1" thick, dip 60°-75°, wavy. Lightly weathered. Estimate 60% very fine to fine grained silty sandstone, very hard, gray. Estimate 40% clayey shale, hard, dark gray. Fe-oxide stains on fractures.

35.5-37.1 Silty sandstone, fine grained, scattered shale clasts and laminations.

(39.6-41.4) Interbedded CLAYEY SHALE, SILTSTONE, and SANDSTONE, beds dip 65°. Lightly weathered. Estimate 60% clayey shale, hard, black. Estimate 40% very hard siltstone and very fine grained sandstone laminations, gray. Fe-oxide stains on fracture surfaces.

(41.4-50.3) Interbedded SILTY SANDSTONE and CLAYEY SHALE, beds 1/8"-1" thick, dip 60°-70°, wavy. Estimate 60% very fine to fine grained silty sandstone, very hard, gray. Estimate 40% clayey shale, hard, dark gray.
41.4-44.5 Very lightly weathered. Fe-oxide stains on some fractures.
44.5-50.3 Unweathered. No oxidation visible.

Notes: • Per 6" interval
Hole completed for geophysical logging. Reamed to 4" diameter 0-50.0'. Installed 2" blank PVC pipe to 50' depth. Filled space between pipe and hole wall with graded sand mixture.

27.4-35.5 Mostly moderately fractured, fractures mostly spaced 0.2'-0.7', Fe-oxide stains and some carbonate coatings, dip 20°-45° and 60°-80°.
29.1-29.9 Very intensely fractured.

31.7-33.1 Intensely fractured, core broken on Fe-oxide stained fractures with 35°-45°, 50°-60°, and 70° dips.

35.5-37.2 Intensely fractured, recovered as cores broken on Fe-oxide stained fractures with 45°, 60°, and 70°-80° dips.

37.2-41.9 Very intensely fractured, recovered as fragments, some orange clay, visible fractures dip as 35.5'-37.2' interval.
39.3-40.4 Variably intensely fractured to sheared, core broken on Fe-oxide stained fractures with 45°-50° and 70°-90° dips; crushed zones with gray brown clay gouge.

41.9-50.1 Mostly moderately fractured, fractures mostly spaced 0.3'-1.0', some mechanical breaks. Fe-oxide stains to 44.5', carbonate and pyrite on some fractures. Dips 30°-45°, 70°-90° (normal to bedding), and 60°-65° (parallel to bedding).

47.5-47.8 Very intensely fractured, core splintered on intersecting fractures with 50° and 80° dips.

50.1-50.3 Shear zone, recovered gray clay gouge, fracture at 50.1' dips 40°.