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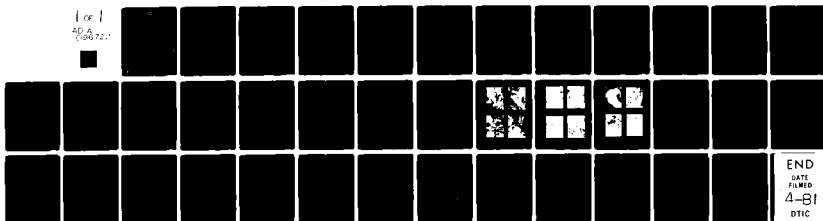
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## EFFECT OF SHOCK LOADING ON ROCK PROPERTIES AND IN SITU STATES

Terra Tek, Inc.  
420 Wakara Way  
Salt Lake City, Utah 84108

1 June 1980

Topical Report for Period 7 September 1978—1 June 1980

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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br><br>In situ characteristics of geological materials are a function of the mineral and chemical composition, physical properties such as porosity and moisture content, and in situ stress state. The material characteristics or behavior can be altered by changes in the above mentioned parameters or by changing the stress history of the material. Very little is known, however, about the latter and especially shock wave induced stress changes. The Nevada Test Site nuclear test program presented an opportunity to study the changes |                                      |                                                                                         |

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20. ABSTRACT (Continued)

in ash-fall tuff material resulting from shock waves ranging in magnitude from approximately 100 MPa to 1000 MPa.

Comparisons are made of the geology, physical and mechanical properties, geophysical properties, and geomechanical properties of the tuff media, before and after a nuclear event. The results indicate changes in the physical and mechanical properties (i.e. stress-volume response, shear strengths, ultrasonic velocities), geophysical properties (seismic velocities) and geomechanical properties (*in situ* stresses). Little change was noticeable in the geology except for some indication of horizontal movement in small, tight discontinuous fractures.

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## PREFACE

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The USGS program was coordinated through the Special Projects Branch in Denver, Colorado with Ms. S. Steele and Mr. D. Townsend (Fenix and Scisson) responsible for the geology, Mr. R. Carroll responsible for the geophysics, and Mr. B. Ellis responsible for the geomechanics.

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## INTRODUCTION

Rock material characteristics and behavior can be altered by pressure, temperature, chemistry, and changes in microstructure, saturation, porosity, etc. Of interest are alterations resulting from man induced activities such as mining, oil and gas retrieval and shock induced stress waves. The Nevada Test Site nuclear test program has presented an opportunity to study changes in ash-fall tuff material resulting from the latter -- shock waves.

Planning an underground nuclear event requires information on select geologic locations on a detailed scale not typically required in other geologic related activities. Because of new nuclear test configurations, a recent detailed review has been conducted on materials both before and after the rock material had been subjected to significant stress waves and displacements from a nuclear event. That is, the Dining Car nuclear event media had been thoroughly characterized preshot and was subsequently characterized postshot in preparation for another nearby nuclear event, the U12e.20.

This report summarizes the examination of changes in geologic structures such as faults, joints, etc., physical properties (density, moisture content, gas filled porosity and shear strength), geophysical properties (seismic velocity) and geomechanical properties (*in situ* stress) as a function of the shock wave intensity (i.e. peak radial stress), which varied from about 100 MPa to 1000 MPa.

The information obtained and compiled is a joint effort of several agencies. The Defense Nuclear Agency Field Command Office was responsible

for overall control of the site characterization program with Mr. J. W. LaComb directing the activities. The United States Geological Survey, Special Projects Branch (Denver), obtained the geological, geophysical and geomechanical data while Terra Tek, Inc. (Salt Lake City) supplied the physical properties data.

The data and discussions will be presented in individual sections on geology, physical properties, geophysical properties and geomechanical properties followed by overall conclusions.

## SECTION I

### GEOLOGY

The Dining Car nuclear test area is located in an ash-fall tuff approximately 400 meters below the surface and approximately 200 meters above the Paleozoic rocks in the Rainier Mesa at the Nevada Test Site, see Figure 1. The water table is approximately 1000 meters below the surface. The overburden consists of a cap rock (150 meters thick) and approximately 250 meters of ash-flow and ash-fall tuff with the ash-flow tuff overlying the ash-fall tuff. The Dining Car area and U12e.20 area (media characterized for a nuclear event after the Dining Car event) consist of a thick-bedded to massive zeolitized calkalkaline and peralkaline ash-fall tuff with minor amounts of reworked calkalkaline ash-fall tuff.

The Dining Car complex and associated drill holes are shown in Figure 2. Post-Dining Car drifts (re-entry drifts and U12e.20 drifts) and drill holes are shown in Figure 3; dashed lines indicate pre-Dining Car configuration. Figure 4 shows the peak radial stresses due to the Dining Car event.

*Effects of the Dining Car Event:* The Dining Car re-entry drifts and U12e.20 drifts provided an opportunity to observe changes in the pre-Dining Car geology. No bedding plane shifts or fault movements were noted. However, it must be pointed out that the Dining Car site was not structurally complex and, therefore, no faults were encountered that were mapped pre-Dining Car. Small, tight and discontinuous fractures are present in the U12e.20 drifts and some show evidence of horizontal movement. Even though

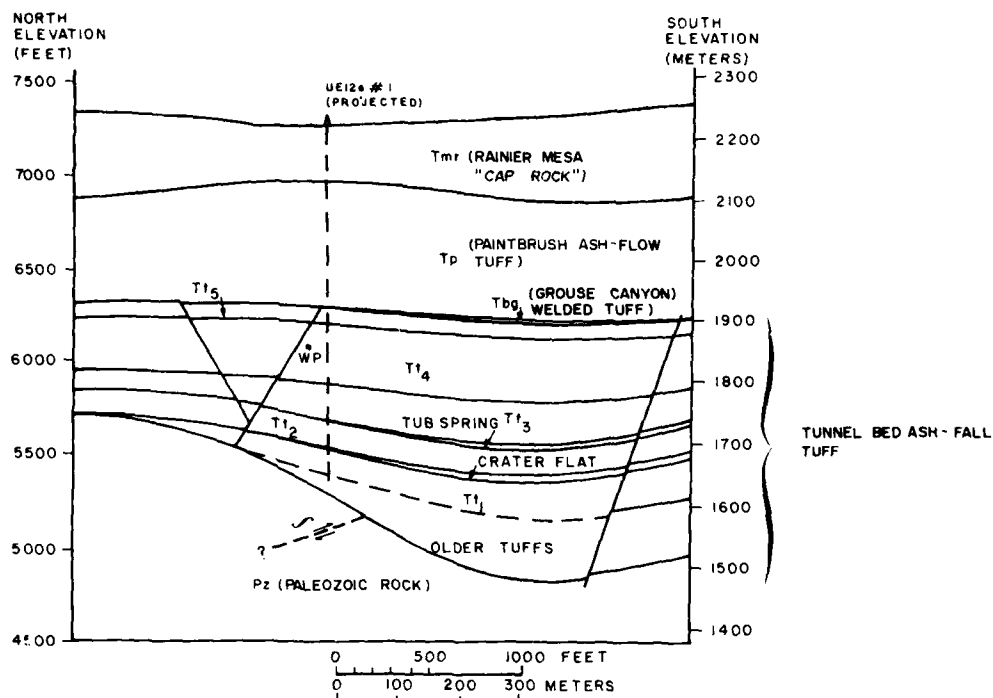


Figure 1a. Approximate north-south cross-section of the Dining Car site.

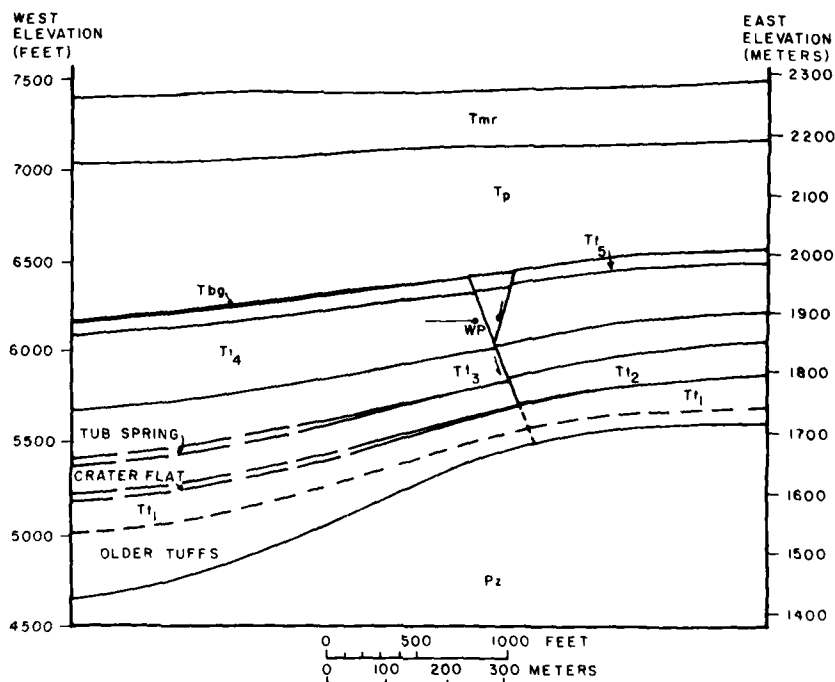


Figure 1b. Approximate west-east cross-section of the Dining Car site.



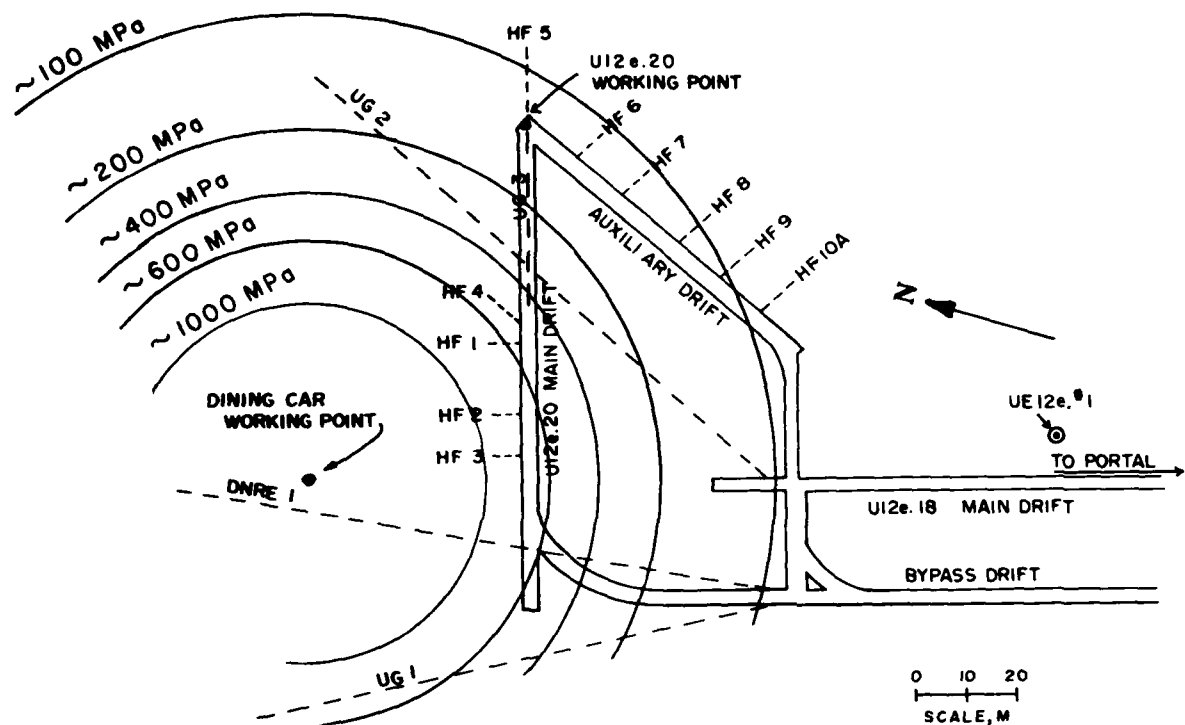


Figure 4. Plan view showing the previous Dining Car location and approximate peak radial stresses, the U12e.20 tunnels, and selected drill holes.

these features were not mapped pre-Dining Car, they are believed to be shock induced.

Mining observations nearest to the Dining Car site (50-60 meters), in a peak stress range of several hundred megapascals, indicate the material to be easily excavated with a tendency to bind together after cutting (i.e. clogging the Alpine Miner). As the mining continued away from the Dining Car site, the rock became more competent and the tendency to slab increased.

## SECTION II

### PHYSICAL AND MECHANICAL LABORATORY PROPERTIES

The U12e.20 event at the Nevada Test Site required, as for past events, material characterization and hence a material model, for predicting stemming and containment. However, the event configuration was unusual in that the working point and drifts were within 90 meters of a previous event (Dining Car). The U12e.20 material characterization was therefore conducted with consideration given to this unusual condition.

Material properties were determined on core samples taken prior to the Dining Car event from a vertical drill hole located approximately 100 meters southwest of the working point and three drill holes in the horizontal plane of the working point. Post-Dining Car core samples (i.e. U12e.20 samples) were from several drill holes located in the horizontal plane of the U12e.20 main and auxiliary drifts.

Tests were conducted on core samples from the following drill holes:

|                                           |   |                                   |
|-------------------------------------------|---|-----------------------------------|
| UE12e#1 (vertical from Mesa top)          | } | Pre-Dining Car<br>(see Figure 2)  |
| U12e.14 UG#10                             |   |                                   |
| U12e.15 UG#2                              |   |                                   |
| U12e.18 GZ#1                              |   |                                   |
| U12e.18 DNRE#1                            | } | Post-Dining Car<br>(see Figure 4) |
| U12e.20 UG#1, 2, 3                        |   |                                   |
| U12e.20 HF#1, 2, 3, 4, 5, 6, 7, 8, 9, 10A |   |                                   |

Material characterization was accomplished by determination of mechanical properties (i.e., a combination of uniaxial strain and triaxial compression tests) and measurement of physical properties and ultrasonic



longitudinal and shear wave velocities. Select core samples were also subjected to scanning electron microscopy. The above material properties are summarized in individual tables in the appendix.

*Effects of the Dining Car Event:* Interest in the effects of nuclear shock loading on tuff material led to comparison of preshot and postshot\* Dining Car data. The effects were first observed in a re-entry drill hole and in other site investigation holes from which the uniaxial strain tests produced lower stress differences for given confining pressures\*\*. This lower stress difference becomes immediately apparent when preshot and postshot data are plotted together as shown in Figure 5. Uniaxial strain volume change curves also showed a marked difference between preshot and postshot tuffs. When test results are plotted on an expanded scale, postshot tuffs have a significantly larger "foot" than do preshot tuffs, as shown in Figure 6. Strangely enough, however, the postshot tuffs produced lower uniaxial strain permanent volume compactions than did the preshot (the unloading curves are not shown but the data is listed in Tables A1-A7).

It was reasoned that the differences might be explained by the presence of numerous microcracks in the postshot tuff<sup>1</sup>, which reopen on unloading. The preshot tuff's permanent volume compactions are primarily due to air filled pore porosity. Thus, the relative small "foot" associated with the usual permanent volume compaction of 1 to 2% by volume. The

---

\* The "postshot" data is generally a combination of tuff which was subjected to a peak radial stress of from 100 MPa to 1000 MPa.

\*\* Uniaxial strain tests to 400 MPa confining pressure are conducted to simulate the one-directional stress waves from the nuclear event in addition to providing indicators of material shear strength (i.e. stress-stress response) and gas-filled void content (i.e. stress-strain response).

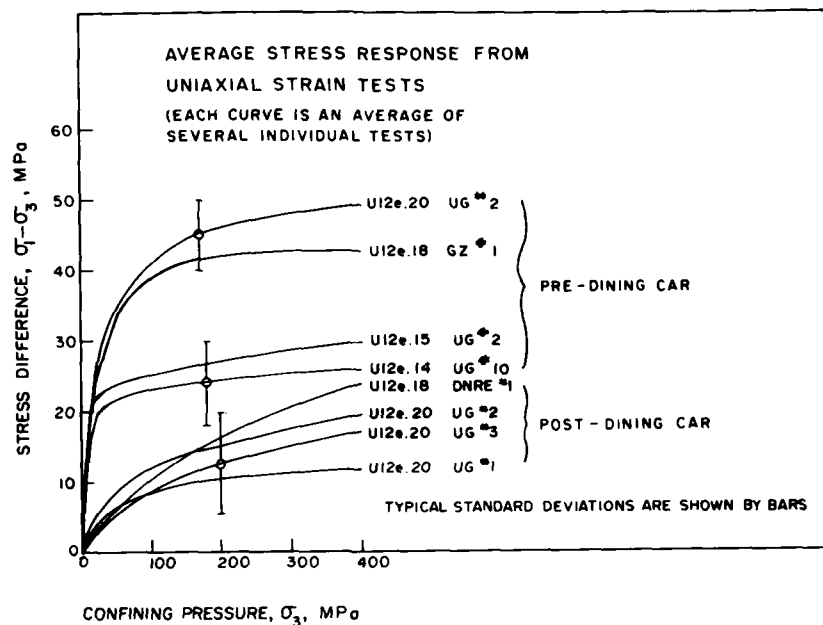


Figure 5. Comparison of preshot and postshot Dining Car uniaxial strain tests -- stress difference versus confining pressure.

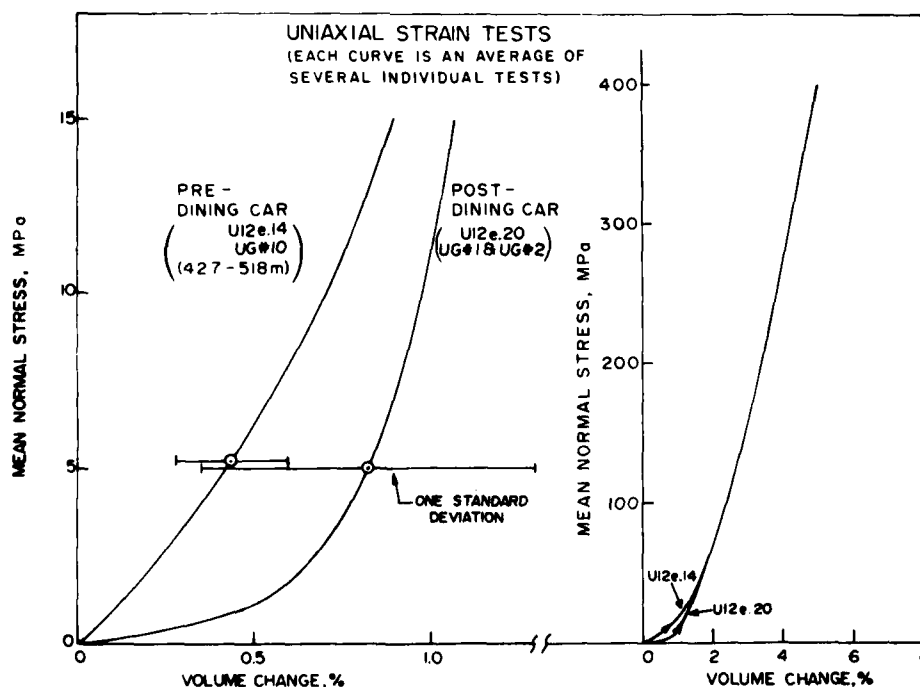


Figure 6. Comparison of preshot and postshot Dining Car uniaxial strain tests -- mean normal stress versus volume change.

apparent air void content of the postshot tuff, on the other hand, is thought to be due to shock-induced microcracks which have been "opened" when relieved of overburden stress and are closed easily at low stresses -- reference the "foot" on the postshot samples. The postshot samples either contain very little, if any, of the original air-filled pore porosity or the existing pores have been filled with water. This latter possibility has been suggested by data on the preshot and postshot Ming Blade tuff<sup>2</sup> and is also reflected in the data contained herein, see Table 1. The bed 4J\* numbers represent the average properties of that rock unit throughout the Area 12 tunnel complex. Bed 4J shows identical porosities and moisture contents to that of the pre-Dining Car media (also 4J) but both have noticeably lower porosities and moisture contents than the postshot media.

To address these gas-filled void changes, select postshot samples were hydrostatically loaded to estimated overburden stresses followed by

TABLE 1\*\*  
Average Select Properties of Preshot Dining Car  
and U12e.20 Media

|                              | Density, gm/cc |      |       | Porosity<br>% | Moisture<br>Content<br>% |
|------------------------------|----------------|------|-------|---------------|--------------------------|
|                              | As-Received    | Dry  | Grain |               |                          |
| Dining Car                   | 1.93           | 1.59 | 2.44  | 35            | 18                       |
| (4J)                         | 1.96           | 1.63 | 2.47  | 35            | 18                       |
| Post Dining Car<br>(U12e.20) | 1.90           | 1.51 | 2.52  | 40            | 20.3                     |

\* An individual sub-unit within the Tt4 unit shown in Figure 1.

\*\* Compiled by Mr. J. W. LaComb, DNA, Mercury, Nevada.

uniaxial strain loading. It was observed that the foot was virtually eliminated and measured permanent compaction from the uniaxial strain portion of the test was reduced substantially (Tables A6 and A7). Typical tests are shown in Figure 7. This observation suggested that microcracks do apparently close when overburden stresses are applied. Similar tests were conducted on a few preshot tuff samples to determine if the initial hydrostatic compression would eliminate any permanent compaction. The data, however, was not sufficient to draw any conclusions. Further tests comparing preshot and postshot tuff are needed to answer these questions of overburden stress and microcrack effect on material properties.

To investigate microcrack presence, several preshot and postshot tuff samples were subjected to microscopic examination using a scanning electron microscope. Preshot tuff samples were thoroughly examined and

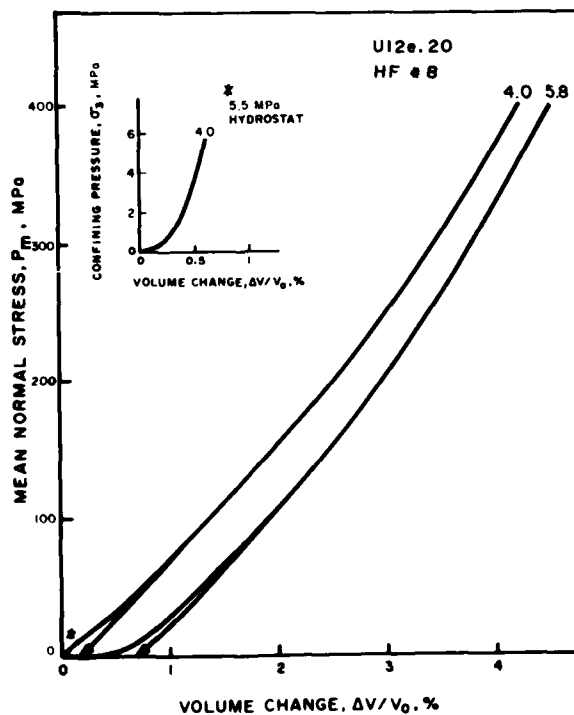


Figure 7. Typical uniaxial strain and hydrostatic compression/uniaxial strain tests on Hybla Gold tuff.

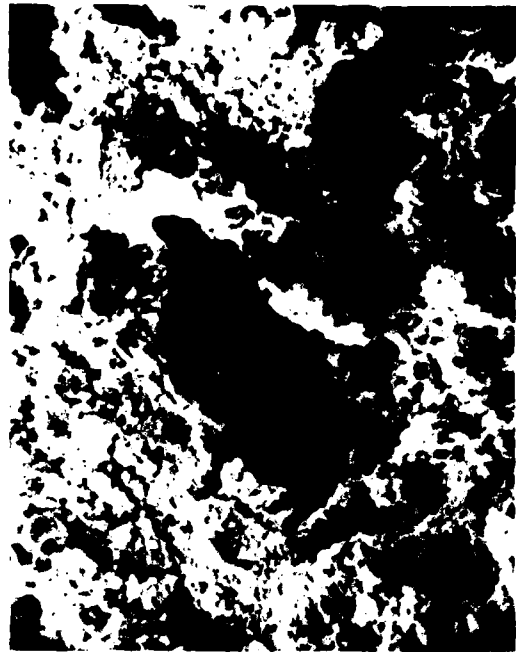
few microcracks were observed. Pore structure appeared undamaged and the zeolite web-like structures often found in the pores were still intact. Representative preshot photographs are shown in Figure 8. Postshot tuff samples were examined equally thoroughly and a large number of microcracks were present in all cases, see Figure 9. The zeolite webbing was partially broken down in some cases and cleavage planes were occasionally present. An examination was also made of preshot tuff subjected to a 400 MPa uniaxial strain test. Figure 10 shows photographs of post uniaxial strain tuff. There is some indications of damage although not as obvious as in the post-shot material.

So far, changes in physical properties and the existence of microcracks have been documented. Their effect on the gas-filled void content has also been discussed and partially verified. The mechanisms behind the changes in the shear stress response are at this time mostly speculation, although supportive test data are available.

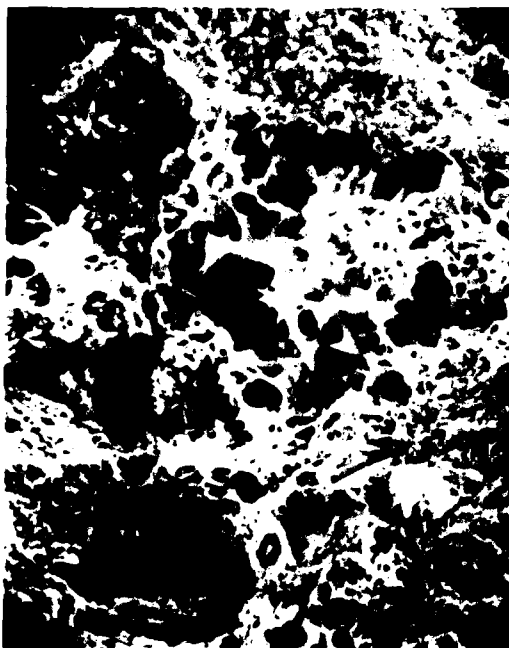
The lower stress-stress response during the uniaxial strain tests, Figure 5, could be a result of both the microcracks and the physical properties changes. Tests have been conducted in which samples were subjected to two cycles of uniaxial strain loading to roughly simulate fractured postshot samples<sup>3</sup>. Many of the samples produced a lower stress-stress curve on the second cycle. There is evidence, therefore, that the existence of microcracks can lessen the shear stress capacity of the material. Likewise, a material with high porosity, high moisture content (i.e. simulating postshot material), and, hence, a lower effective stress, will also exhibit lower shear stresses.



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|———| 50 Microns

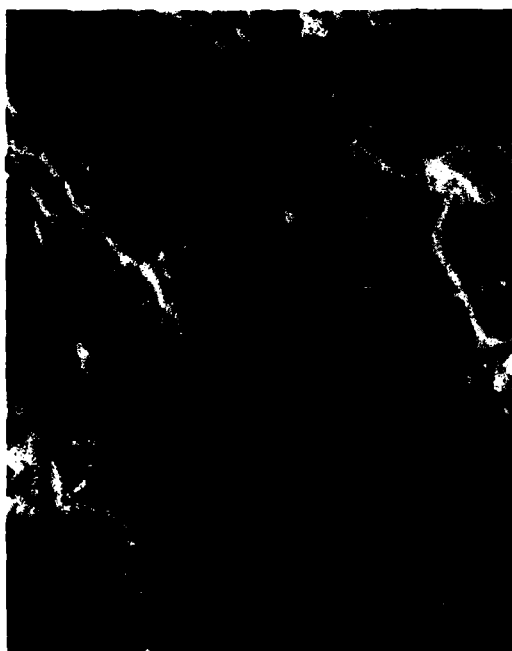


|———| 50 Microns



|———| 25 Microns

Figure 8. ESM photographs of virgin ash-fall tuff from Hybla Gold Site.



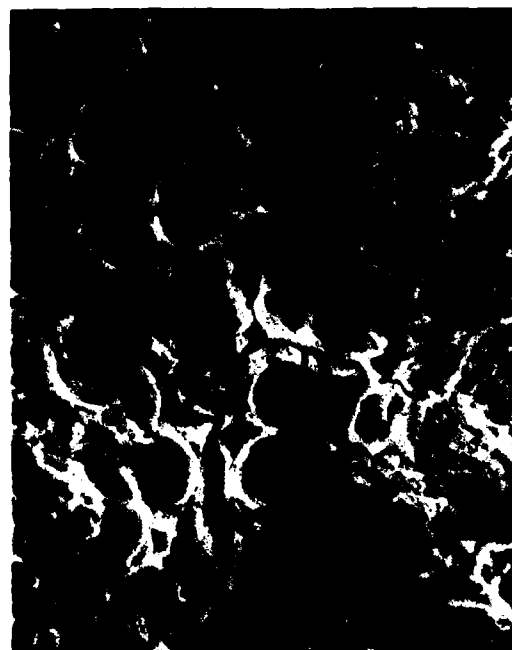
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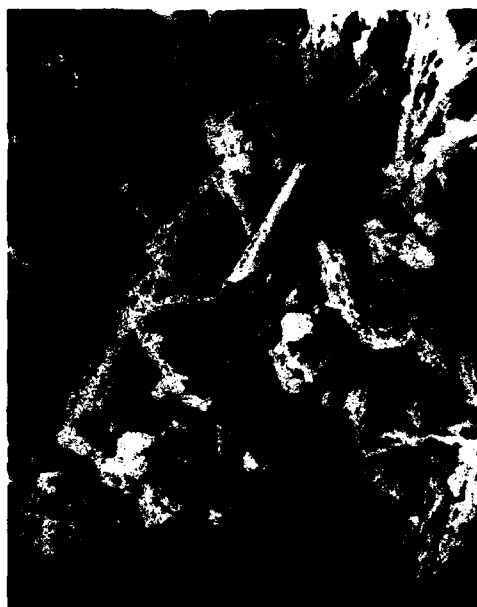


25 Microns

Figure 9. ESM photographs of ash-fall tuff subjected to shock wave from the Dining Car nuclear explosion.



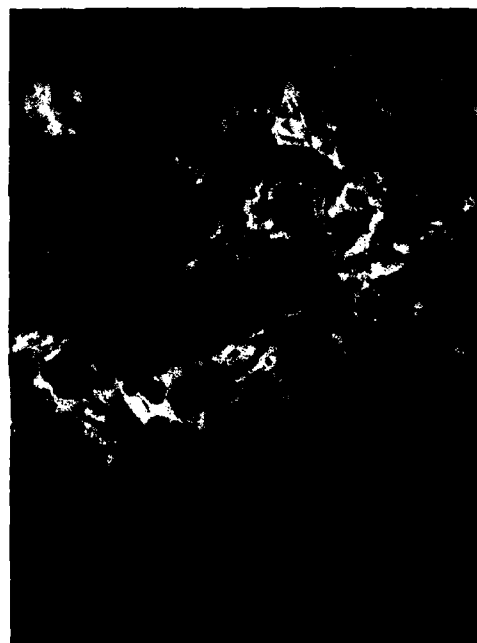
12.5 Microns



50 Microns



25 Microns



50 Microns

Figure 10. ESM photographs of ash-fall tuff subjected to 400 MPa uniaxial strain test.



The ultrasonic p- and s-wave velocities conducted at room conditions show several regions of low velocities (not seen pre-Dining Car), see appendix. The decreases were as much as 30 to 50 percent in select areas. This decrease in ultrasonic velocities could also be a result of both the microcracks and the physical properties changes. Test results generated at Terra Tek show ultrasonic longitudinal (p-wave) velocity decreases of up to 25 percent as a result of fracturing by uniaxial compression loading and direct shearing<sup>4</sup>. With regard to the physical properties changes (primarily the increase in porosity and moisture content) Figure 11 shows p-wave plotted versus moisture content for random tunnel bed tuff samples. Although there is considerable scatter, the data does suggest lower p-wave velocities with higher water contents.

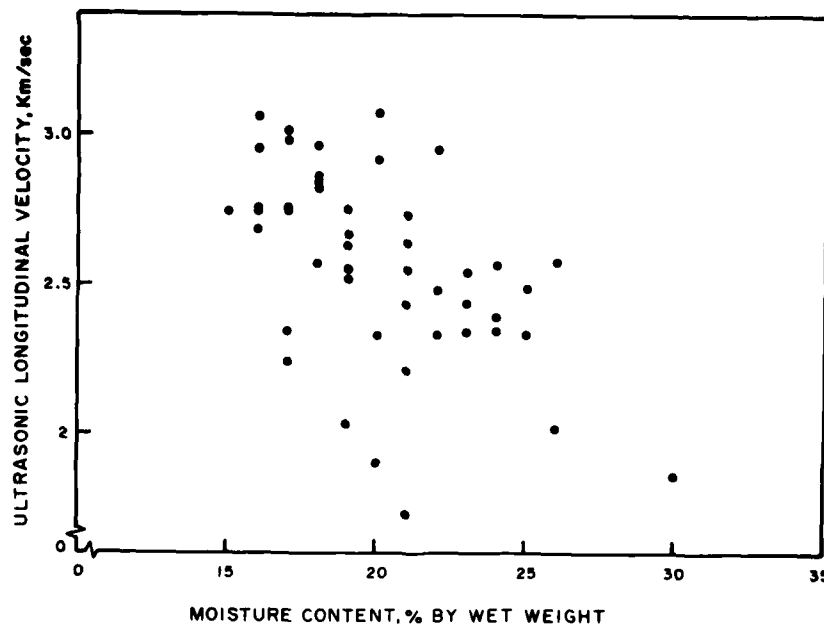


Figure 11. Ultrasonic p-wave velocity versus moisture content for random Area 12 tunnel bed tuffs.

### SECTION III

#### GEOPHYSICAL PROPERTIES

Seismic velocities were measured for the Dining Car event and they varied from 2400 to 2500 meters per second, which is typical of the bed 4 tuff.

*Effects of the Dining Car Event:* The seismic velocities measured after the Dining Car event (Figure 12) indicate changes due to the shock loading. Within the "chimney" region (i.e. disjointed) the velocities are, as expected, only about 1500 meters/second (M/S) (the "chimney" region is shown in Figure 3 by the dashed circle around the Dining Car working point). From the "chimney" region out to a radial distance of about 65 meters (i.e. a peak radial stress of about 300 MPa) the velocities ranged from about 2100 M/S to 2200 M/S. The reduction in this region is probably due to the small, tight, discontinuous fractures and faults present as well as possible microfracturing\*. As mentioned in the laboratory test program (Section II), the ultrasonic velocities on core samples from this same region substantiated the decrease in velocity.

At a range of 80 to 90 meters (a radial stress of 100 to 200 MPa), the longitudinal seismic velocities were comparable to the pre-Dining Car values. In this same region, however, shear seismic velocities were still noticeably lower than preshot values. A possible explanation is that the microcracks which exist postshot have a more pronounced affect on the shear wave velocity than on the longitudinal wave velocity.

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\* See Section II.

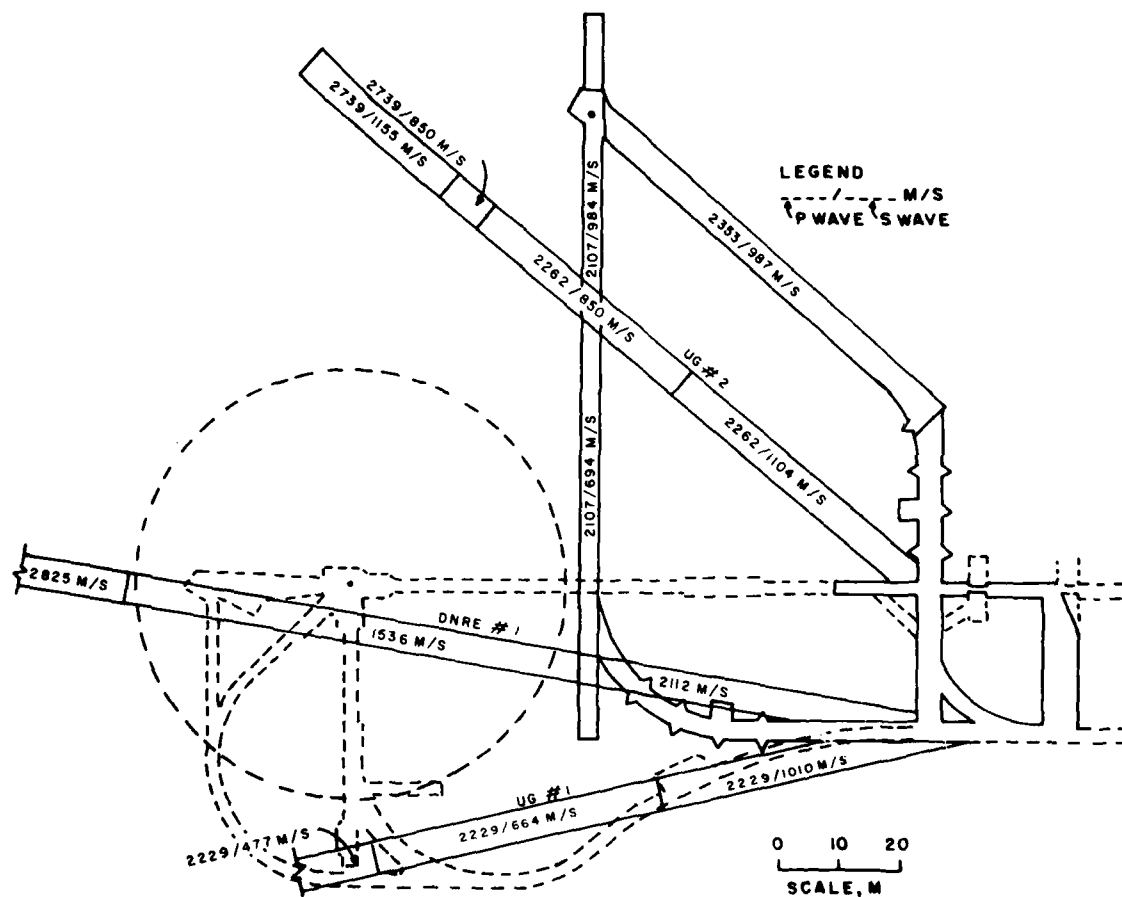


Figure 12. Plan view of the U12e.20 complex showing longitudinal and shear wave velocities.

## SECTION IV

### GEOMECHANICAL PROPERTIES

Since the *in situ* stress is an important parameter in determining the potential for a particular site to contain a nuclear event, considerable effort was spent in obtaining the stresses, via the overcore technique and hydraulic fracturing. The Dining Car region indicated, via hydraulic fracturing, a minimum *in situ* stress of about 3.8 MPa and via the overcore technique, approximately 2.8 MPa.

Results of the overcore data are preliminary since the technique requires use of a Young's modulus and there are uncertainties in integrating the laboratory measured moduli with the overcore data.

Minimum *in situ* stress via overcoring in another "e" tunnel location (several hundred meters south of the U12e.20 site) was about 3.4 MPa. An average or typical value for minimum *in situ* stress in the subject area would be between 3.0 and 3.5 MPa.

*Effects of the Dining Car Event:* In anticipation of the U12e.20 event (i.e. post-Dining Car), over forty hydraulic fracture tests and several overcore experiments were performed. Figure 13 shows the apparent minimum *in situ* stresses as a function of distance from the Dining Car event and peak radial stress. Near the Dining Car chimney, stresses had decreased to about 1.2 MPa. There appears to be "higher than normal" stresses near the U12e.20 location but further data are necessary to address this phenomena. The results indicate that the Dining Car stress wave did not have an apparent affect on the *in situ* stress field (at least

minimum) at a peak stress less than about 100 MPa (i.e. a range of about 85 meters). However, affects are apparent as the peak stress increases to 1000-2000 MPa.

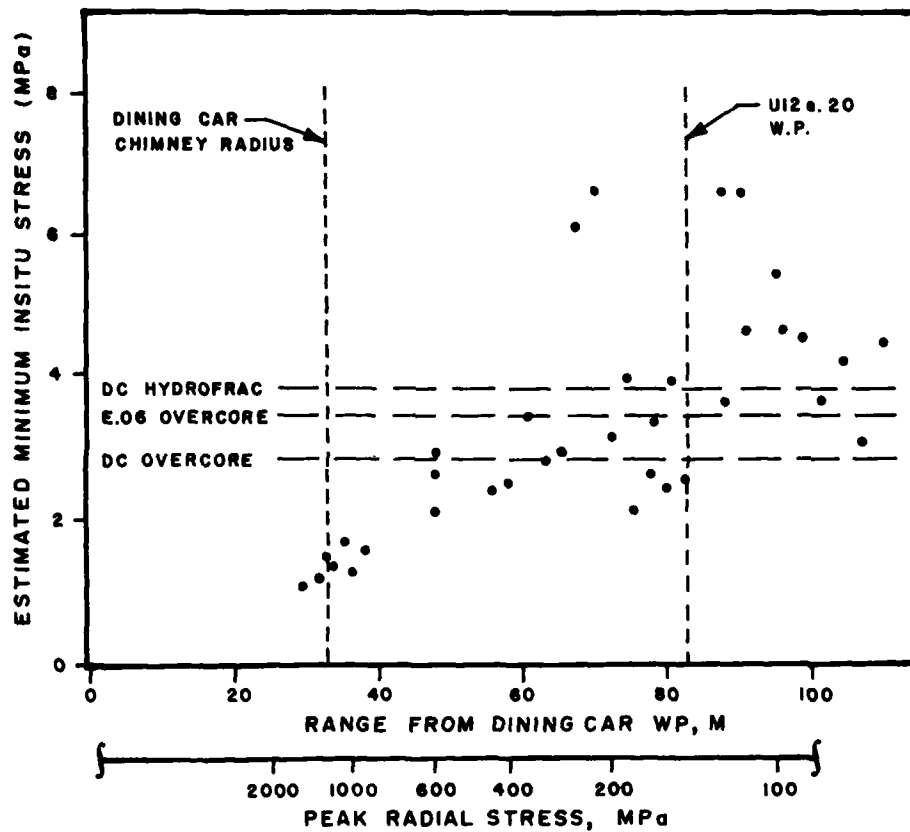


Figure 13. Minimum *in situ* stresses as a function of distance from the Dining Car event and peak radial stresses.

## CONCLUSIONS

The Dining Car event provided an opportunity to study the changes in rock material (tuff) subjected to shock waves. In this case, the range of peak radial stress was from 1000 to 100 MPa.

Geology: There was no evidence of bedding plane shifts or fault movement. There were, however, few faults mapped pre-Dining Car. The post-Dining Car media does contain small, tight and discontinuous fractures and faults, some of which showed evidence of horizontal movement. These features are believed to be shock induced.

The ease of excavation in the tuff which had been subjected to a stress of several hundred megapascals (i.e. 500-700 MPa), as compared to preshot mining, suggests changes such as a decrease in the shear strength of the material.

Material Properties: Of significance were:

- 1) changes in the characteristics of volume strain and permanent volume compaction during uniaxial strain tests,
- 2) an apparent decrease in the shear stress capacity during uniaxial strain loading, and
- 3) a decrease in the ultrasonic p- and s-wave velocities.

Further examination produced evidence that densities, porosities, and moisture contents had increased, suggesting fluid migration into existing or induced cracks and pores. Also, subsequent electron scanning microscope pictures showed numerous microcracks in the postshot material.

The mechanical properties changes (numbers 1 through 3 above) appear to be explainable via the changes in the physical characteristics.

In most cases, data are presented to verify the proposed relationships between the changes.

Geophysics: The seismic velocities decreased from the pre-Dining Car values (2500-2600 M/S) to about 1500 M/S through the Dining Car "chimney". The tuff which had been subjected to several hundred megapascals peak stress (~400 to 800 MPa) showed a decrease of 10 to 20 percent -- from 2500 M/S to ~2100 M/S. Outside of a stress of about 200 MPa, there was little apparent change in the longitudinal seismic velocities. The shear wave velocities, however, were affected more noticeably even beyond the 100 MPa stress level.

Geomechanics: There were no apparent changes in the *in situ* stress field outside of about 100 MPa peak radial stress. As the peak stresses increased to 1000 MPa, however, the apparent minimum *in situ* stress decreased to about 1.2 MPa, as compared to a pre-Dining Car stress of 3-3.5 MPa. These measurements were obtained via a combination of hydraulic fracturing and overcoring.

In summary, the *in situ* stress state and material properties were affected noticeably when subjected to peak radial stresses greater than 100 MPa. There are likely some changes at lower stresses but their magnitudes were not quantified for this application.

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4. Lingle, R., R. S. Rosso, and L. M. Buchholdt, "An Investigation to Determine the Effect of Fracture on the Ultrasonic Velocities in Ash-Fall Tuff," Terra Tek Report TR 75-20, DNA Contract No. 001-75-C-0260, May 1975.



APPENDIX  
PRE-DINING CAR DATA

UE12e#1  
U12e.14 UG#10  
U12e.15 UG#2  
U12e.18 GZ#1

TABLE A1

Physical Properties, Uniaxial Strain Measured Permanent Compaction, and  
Ultrasonic Longitudinal and Shear Wave Velocities of  
UE12e#1 Tuffs

| DRILL HOLE<br>FOOTAGE<br>( M ) | DENSITY (grn/cc) |      |       | WATER<br>BY WET<br>WEIGHT<br>(%) | POROSITY<br>(%) | SATURATION<br>(%) | CALC.<br>AIR<br>VOIDS<br>(%) | MEAS.<br>PERMANENT<br>COMP.<br>(%) | VELOCITY<br>( km/sec ) |       |
|--------------------------------|------------------|------|-------|----------------------------------|-----------------|-------------------|------------------------------|------------------------------------|------------------------|-------|
|                                | AS-<br>RECEIVED  | DRY  | GRAIN |                                  |                 |                   |                              |                                    | LONG                   | SHEAR |
| UE12e.#1                       | Meas.            | Cal. | Meas. | Meas.                            | Cal.            | Cal.              | Cal.                         | Meas.                              | Meas.                  | Meas. |
| 345.6                          | 1.80             | 1.38 | 2.42  | 23                               | 43              | 97                | 0.9                          | 1.8                                | 2.50                   | 1.23  |
| 349.3                          | 1.85             | 1.54 | 2.42  | 17                               | 36              | 86                | 5.5                          | 2.0                                | 2.99                   | 1.69  |
| 353.0                          | 1.84             | 1.47 | 2.42  | 20                               | 39              | 94                | 2.3                          | 3.1                                | 2.46                   | 1.28  |
| 357.2                          | 1.79             | 1.41 | 2.42  | 21                               | 42              | 90                | 3.7                          | 1.0                                | 2.44                   | 1.25  |
| 360.3                          | 1.88             | 1.53 | 2.47  | 18                               | 38              | 90                | 2.9                          | 3.0                                | 2.66                   | 1.37  |
| 364.2                          | 2.06             | 1.83 | 2.44  | 11                               | 25              | 91                | 1.9                          | 1.1                                | 3.08                   | 1.47  |
| 368.5                          | 1.94             | 1.59 | 2.45  | 18                               | 35              | 99                | 0.1                          | 0.7                                | 3.15                   | 1.62  |
| 371.9                          | 1.94             | 1.61 | 2.45  | 17                               | 34              | 96                | 1.3                          | 1.3                                | 2.93                   | 1.50  |
| 376.1                          | 1.88             | 1.51 | 2.47  | 20                               | 39              | 96                | 1.9                          | 1.5                                | 2.57                   | 1.24  |
| 379.8                          | 1.88             | 1.55 | 2.37  | 18                               | 34              | 97                | 1.6                          | 2.1                                | 2.89                   | 1.58  |
| 383.7                          | 1.80             | 1.46 | 2.44  | 19                               | 40              | 85                | 6.2                          | 3.2                                | 2.62                   | 1.05  |
| 387.4                          | 1.93             | 1.56 | 2.58  | 19                               | 39              | 93                | 2.5                          | 1.7                                | 2.47                   | 1.09  |
| 391.4                          | 1.94             | 1.59 | 2.53  | 18                               | 37              | 94                | 2.1                          | 1.7                                | 3.01                   | 1.40  |
| 395.0                          | 1.99             | 1.65 | 2.58  | 17                               | 36              | 94                | 2.0                          | 2.7                                | 2.50                   | 1.11  |
| 398.7                          | 1.82             | 1.44 | 2.42  | 21                               | 40              | 94                | 2.5                          | 2.2                                | 2.67                   | 1.51  |
| 402.3                          | 1.81             | 1.41 | 2.43  | 22                               | 42              | 95                | 2.0                          | 3.4                                | 2.54                   | 1.18  |
| 406.3                          | 1.85             | 1.46 | 2.44  | 21                               | 40              | 97                | 1.2                          | 1.4                                | 2.75                   | 1.43  |
| 410.0                          | 1.80             | 1.42 | 2.43  | 21                               | 41              | 91                | 3.6                          | 2.3                                | 2.41                   | 1.18  |
| 413.9                          | 1.81             | 1.45 | 2.47  | 20                               | 41              | 87                | 5.3                          | 3.1                                | 2.17                   | 1.03  |
| 417.9                          | 1.85             | 1.46 | 2.49  | 21                               | 42              | 94                | 2.4                          | 2.4                                | 2.18                   | 1.10  |
| 421.8                          | 1.81             | 1.42 | 2.45  | 22                               | 42              | 94                | 1.6                          | 1.0                                | 2.48                   | 1.06  |

TABLE A2

Physical Properties, Uniaxial Strain Measured Permanent Compaction, and  
Ultrasonic Longitudinal and Shear Wave Velocities of  
U12e.14 UG#10 Tuffs

| DRILL HOLE<br>FOOTAGE<br>(M) | DENSITY (gm/cc) |      |       | WATER<br>BY WET<br>WEIGHT<br>(%) | POROSITY<br>(%) | SATURATION<br>(%) | CALC.<br>AIR<br>VOIDS<br>(%) | MEAS.<br>PERMANENT<br>COMP.<br>(%) | VELOCITY<br>(km/sec) |       |
|------------------------------|-----------------|------|-------|----------------------------------|-----------------|-------------------|------------------------------|------------------------------------|----------------------|-------|
|                              | AS-<br>RECEIVED | DRY  | GRAIN |                                  |                 |                   |                              |                                    | LONG                 | SHEAR |
| U12e.14<br>UG#10             | Meas.           | Cal. | Meas. | Meas.                            | Cal.            | Cal.              | Cal.                         | Meas.                              | Meas.                | Meas. |
| 198.1                        | 1.89            | 1.47 | 2.43  | 22                               | 39              | -100              | -0                           | 0.4                                | 2.95                 | 1.47  |
| 212.8                        | 1.87            | 1.51 | 2.44  | 19                               | 38              | 94                | 2.1                          | 1.3                                | 2.67                 | 1.32  |
| 227.7                        | 2.07            | 1.71 | 2.55  | 17                               | 33              | -100              | -0                           | 0.6                                | 2.76                 | 1.41  |
| 243.2                        | 1.97            | 1.59 | 2.51  | 19                               | 36              | -100              | -0                           | 1.4                                | 2.52                 | 1.07  |
| 258.5                        | 1.83            | 1.40 | 2.42  | 23                               | 42              | -100              | -0                           | 1.0                                | 2.44                 | 1.12  |
| 274.6                        | 1.94            | 1.61 | 2.49  | 17                               | 35              | 93                | 2.3                          | 0.9                                | 3.01                 | 1.31  |
| 289.9                        | 1.93            | 1.56 | 2.45  | 19                               | 36              | -100              | -0                           | 1.4                                | 2.75                 | 1.36  |
| 306.6                        | 2.00            | 1.64 | 2.42  | 18                               | 32              | -100              | -0                           | 1.3                                | 2.84                 | 1.40  |
| 320.3                        | 1.92            | 1.57 | 2.32  | 18                               | 32              | -100              | -0                           | 0.8                                | 2.96                 | 1.61  |
| 325.2                        |                 |      |       |                                  |                 |                   |                              | 2.4                                |                      |       |
| 327.4                        | 1.83            | 1.41 | 2.38  | 23                               | 41              | -100              | -0                           | 4.4                                | 2.45                 | 1.06  |
| 329.2                        |                 |      |       |                                  |                 |                   |                              | 2.2                                |                      |       |
| 335.0                        | 1.90            | 1.54 | 2.42  | 19                               | 36              | 99                | 0.3                          | 1.1                                | 2.63                 | 1.15  |
| 342.9                        | 2.05            | 1.81 | 2.40  | 12                               | 25              | 99                | 0.7                          | 0.9                                | 3.67                 | 2.14  |
| 350.5                        | 1.93            | 1.58 | 2.42  | 18                               | 35              | -100              | -0                           | 1.1                                | 2.86                 | 1.70  |
| 358.8                        | 1.84            | 1.49 | 2.46  | 19                               | 39              | 89                | 4.4                          | 1.5                                | 2.57                 | 1.15  |
| 365.2                        | 1.81            | 1.37 | 2.42  | 24                               | 43              | -100              | -0                           | 2.5                                | 2.34                 | 1.01  |
| 372.8                        | 1.90            | 1.50 | 2.45  | 21                               | 39              | -100              | -0                           | 1.0                                | 2.55                 | 1.20  |
| 381.0                        | 1.85            | 1.44 | 2.49  | 22                               | 42              | 97                | 1.2                          | 1.2                                | 2.33                 | 0.84  |
| 388.3                        | 1.88            | 1.52 | 2.52  | 19                               | 40              | 90                | 3.7                          | 0.8                                | 2.55                 | 1.19  |
| 395.9                        | 1.85            | 1.44 | 2.47  | 22                               | 42              | 98                | 0.7                          | 1.3                                | 2.34                 | 1.01  |
| 403.3                        | 1.86            | 1.46 | 2.48  | 21                               | 41              | 96                | 1.0                          | 1.9                                | 2.43                 | 1.12  |
| 405.7                        | 1.77            | 1.35 | 2.43  | 24                               | 45              | 96                | 2.0                          | 1.2                                | 2.39                 | 0.99  |
| 412.7                        | 1.98            | 1.65 | 2.50  | 17                               | 34              | 99                | 0.4                          | 0.8                                | 2.75                 | 1.36  |
| 420.3                        | 1.91            | 1.57 | 2.42  | 18                               | 35              | 97                | 1.0                          | 1.1                                | 2.65                 | 1.13  |
| 427.9                        | 2.01            | 1.68 | 2.49  | 16                               | 32              | 99                | 0.3                          | 0.6                                | 2.76                 | 1.31  |
| 435.0                        | 2.00            | 1.68 | 2.58  | 16                               | 34              | 95                | 1.7                          | 1.3                                | 3.06                 | 1.36  |
| 443.2                        | 2.02            | 1.70 | 2.51  | 16                               | 32              | 99                | 0.3                          | 1.2                                | 2.95                 | 1.36  |
| 446.5                        | 2.01            | 1.65 | 2.51  | 18                               | 34              | -100              | -0                           | 1.5                                |                      |       |
| 450.8                        | 1.91            | 1.60 | 2.46  | 16                               | 35              | 87                | 4.4                          | 2.9                                | 2.74                 | 1.36  |
| 455.1                        | 2.05            | 1.72 | 2.54  | 16                               | 32              | -100              | -0                           | 1.1                                |                      |       |
| 458.4                        | 2.00            | 1.68 | 2.50  | 16                               | 33              | 98                | 0.8                          | 0.9                                | 2.68                 | 1.18  |
| 465.7                        | 1.94            | 1.59 | 2.49  | 18                               | 36              | 97                | 1.0                          | 1.1                                | 2.69                 | 1.25  |
| 474.3                        | 1.77            | 1.33 | 2.45  | 25                               | 46              | 97                | 1.4                          | 1.8                                | 2.33                 | 1.03  |
| 482.0                        | 1.83            | 1.44 | 2.41  | 21                               | 40              | 97                | 1.3                          | 2.7                                | 2.73                 | 1.26  |
| 489.2                        | 1.81            | 1.39 | 2.48  | 23                               | 44              | 95                | 2.2                          | 1.9                                | 2.54                 | 1.12  |
| 496.5                        | 1.89            | 1.53 | 2.39  | 19                               | 36              | 100               | 0.1                          | 1.0                                |                      |       |
| 501.4                        | 1.96            | 1.64 | 2.43  | 16                               | 33              | 99                | 0.4                          | 0.9                                |                      |       |
| 508.1                        | 1.87            | 1.54 | 2.38  | 18                               | 35              | 95                | 1.7                          | 0.7                                | 2.82                 | 1.37  |
| 517.6                        | 1.89            | 1.53 | 2.45  | 19                               | 37              | 96                | 1.4                          | 1.3                                | 2.52                 | 1.17  |

TABLE A3

Physical Properties, Uniaxial Strain Measured Permanent Compaction, and  
Ultrasonic Longitudinal and Shear Wave Velocities of  
U12e.15 UG#2 Tuffs

| DRILL HOLE<br>FOOTAGE<br>(M) | DENSITY (gm/cc) |      |       | WATER<br>BY WET<br>WEIGHT<br>(%) | POROSITY<br>(%) | SATURATION<br>(%) | CALC.<br>AIR<br>VOIDS<br>(%) | MEAS.<br>PERMANENT<br>COMP.<br>(%) | VELOCITY<br>(km/sec) |       |
|------------------------------|-----------------|------|-------|----------------------------------|-----------------|-------------------|------------------------------|------------------------------------|----------------------|-------|
|                              | AS-<br>RECEIVED | DRY  | GRAIN |                                  |                 |                   |                              |                                    | LONG                 | SHEAR |
| U12e.15<br>UG#2              | Meas.           | Cal. | Meas. | Meas.                            | Cal.            | Cal.              | Cal.                         | Meas.                              | Meas.                | Meas. |
| 631.9                        | 1.93            | 1.53 |       | 21                               |                 |                   |                              | 1.6                                |                      |       |
| 647.4                        | 2.01            | 1.67 |       | 17                               |                 |                   |                              | 1.2                                |                      |       |
| 663.6                        | 1.91            | 1.55 |       | 19                               |                 |                   |                              | 1.0                                |                      |       |
| 677.9                        | 2.02            | 1.73 |       | 14                               |                 |                   |                              | 0.6                                |                      |       |
| 693.1                        | 1.80            | 1.37 |       | 24                               |                 |                   |                              | 1.8                                |                      |       |
| 708.1                        | 1.90            | 1.53 |       | 19                               |                 |                   |                              | 2.0                                |                      |       |
| 723.6                        | 1.91            | 1.52 |       | 20                               |                 |                   |                              | 0.9                                |                      |       |
| 737.3                        | 1.96            | 1.63 | 2.48  | 17                               | 34              | 97                | 1.3                          | 1.9                                |                      |       |
| 751.3                        | 2.01            | 1.69 | 2.50  | 16                               | 32              | 99                | 0.4                          | 1.5                                |                      |       |
| 755.3                        | 1.99            | 1.69 | 2.43  | 15                               | 30              | 98                | 0.5                          | 2.2                                |                      |       |

TABLE A4

Physical Properties, Uniaxial Strain Measured Permanent Compaction, and  
Ultrasonic Longitudinal and Shear Wave Velocities of  
U12e.18 GZ#1 Tuffs

| DRILL HOLE<br>FOOTAGE<br>(M) | DENSITY (gm/cc) |      |       | WATER<br>BY WET<br>WEIGHT<br>(%) | POROSITY<br>(%) | SATURATION<br>(%) | CALC.<br>AIR<br>VOIDS<br>(%) | MEAS.<br>PERMANENT<br>COMP.<br>(%) | VELOCITY<br>(km/sec) |       |
|------------------------------|-----------------|------|-------|----------------------------------|-----------------|-------------------|------------------------------|------------------------------------|----------------------|-------|
|                              | AS-<br>RECEIVED | DRY  | GRAIN |                                  |                 |                   |                              |                                    | LONG                 | SHEAR |
| U12e.18<br>GZ#1              | Meas.           | Cal. | Meas. | Meas.                            | Cal.            | Cal.              | Cal.                         | Meas.                              | Meas.                | Meas. |
| 2.7                          | 2.02            | 1.72 | 2.50  | 15                               | 31              | 97                | 1.1                          | 0.7                                | 3.30                 | 1.80  |
| 7.3                          | 1.85            | 1.44 | 2.47  | 22                               | 42              | 99                | 0.5                          | 1.7                                | 2.64                 | 1.23  |
| 8.8                          | 1.85            | 1.44 | 2.44  | 22                               | 41              | 99                | 0.4                          | 3.9                                | 2.63                 | 1.25  |
| 10.7                         | 1.84            | 1.43 | 2.48  | 23                               | 42              | 98                | 1.0                          | 3.0                                |                      |       |
| 14.6                         | 2.00            | 1.72 | 2.44  | 14                               | 30              | 94                | 1.8                          | 0.6                                | 3.36                 | 1.87  |
| 18.6                         | 1.84            | 1.46 | 2.49  | 21                               | 41              | 92                | 3.3                          | 1.2                                | 2.64                 | 1.30  |
| 21.3                         | 1.84            | 1.45 | 2.45  | 22                               | 41              | 97                | 1.4                          | 2.3                                | 2.57                 | 1.30  |
| 21.9                         | 1.81            | 1.37 | 2.47  | 25                               | 45              | 99                | 0.3                          | 2.1                                | 2.49                 | 1.08  |
| 24.7                         | 1.87            | 1.52 | 2.46  | 19                               | 38              | 92                | 3.2                          | 2.1                                | 3.46                 | 1.75  |

# POST-DINING CAR DATA

U12e.18 DNRE#1  
 U12e.20 UG#1, 2, 3  
 U12e.20 HF#1-10A

TABLE A5

Physical Properties, Uniaxial Strain Measured Permanent Compaction, and  
 Ultrasonic Longitudinal and Shear Wave Velocities of  
 U12e.18 DNRE#1 Tuff

| DRILL HOLE<br>FOOTAGE<br>(M) | DENSITY (gm/cc) |      |       | WATER<br>BY WET<br>WEIGHT<br>(%) | POROSITY<br>(%) | SATURATION<br>(%) | CALC.<br>AIR<br>VOIDS<br>(%) | MEAS.<br>PERMANENT<br>COMP.<br>(%) | VELOCITY<br>(km/sec) |       |
|------------------------------|-----------------|------|-------|----------------------------------|-----------------|-------------------|------------------------------|------------------------------------|----------------------|-------|
|                              | AS-<br>RECEIVED | DRY  | GRAIN |                                  |                 |                   |                              |                                    | LONG                 | SHEAR |
| U12e.18<br>DNRE#1            | Meas.           | Cal. | Meas. | Meas.                            | Cal.            | Cal.              | Cal.                         | Meas.                              | Meas.                | Meas. |
| 12.2                         | 1.97            | 1.64 | 2.52  | 16.7                             | 34.9            | 94.3              | 2.0                          | 1.0                                | 2.72                 | 1.29  |
| 21.0                         | 1.80            | 1.40 | 2.49  | 22.5                             | 44.0            | 92.1              | 3.5                          | 2.4                                | 2.24                 | 1.13  |
| 24.7                         | 1.87            | 1.49 | 2.44  | 20.1                             | 38.9            | 96.7              | 1.3                          | 0.8                                | 2.38                 | 1.19  |
| 30.8                         | 1.89            | 1.53 | 2.51  | 19.2                             | 39.2            | 92.7              | 2.9                          | 1.1                                | 2.67                 | 1.41  |
| 37.2                         | 1.89            | 1.52 | 2.50  | 19.6                             | 39.3            | 94.2              | 2.3                          | 1.0                                | 2.11                 | 1.43  |
| 44.5                         | 1.79            | 1.40 | 2.47  | 22.0                             | 43.5            | 90.6              | 4.1                          | 2.7                                | 1.70                 | --    |
| 51.5                         | 1.77            | 1.33 | 2.47  | 24.6                             | 46.0            | 94.7              | 2.4                          | 1.2                                | --                   | --    |

TABLE A6

Physical Properties, Uniaxial Strain Measured Permanent Compaction, and  
Ultrasonic Longitudinal and Shear Wave Velocities of  
U12e.20 UG#1,2,&3 Tuffs

| DRILL HOLE<br>FOOTAGE<br>(M) | DENSITY (gm/cc) |      |       | WATER<br>BY WET<br>WEIGHT<br>(%) | POROSITY<br>(%) | SATURATION<br>(%) | CALC.<br>AIR<br>VOIDS<br>(%) | MEAS.**<br>PERMANENT<br>COMP.<br>(%) | VELOCITY<br>(km/sec) |       |
|------------------------------|-----------------|------|-------|----------------------------------|-----------------|-------------------|------------------------------|--------------------------------------|----------------------|-------|
|                              | AS-<br>RECEIVED | DRY  | GRAIN |                                  |                 |                   |                              |                                      | LONG                 | SHEAR |
| U12e.20<br>UG#1              | Meas.           | Cal. | Meas. | Meas.                            | Cal.            | Cal.              | Cal.                         | Meas.                                | Meas.                | Meas. |
| 10.7                         | 1.89            | 1.56 | 2.53  | 18.1                             | 38.5            | 89.3              | 4.1                          | 0.9                                  | 2.24                 | 0.95  |
| 20.7                         | 2.08            | 1.82 | 2.47  | 12.3                             | 26.0            | 98.3              | 0.4                          | 0.5                                  | 3.37                 | 1.82  |
| 27.7 m.s.*                   | 1.98            | 1.65 | 2.54  | 16.8                             | 35.0            | 94.9              | 1.8                          | ---                                  | ---                  | ---   |
| 29.9                         | 1.77            | 1.29 | 2.63  | 27.1                             | 50.9            | 94.3              | 2.9                          | 1.7                                  | 2.42                 | 1.20  |
| 35.1                         | 1.78            | 1.32 | 2.66  | 26.1                             | 50.5            | 91.8              | 4.1                          | 1.9                                  | 2.44                 | 1.40  |
| 42.4                         | 1.74            | 1.31 | 2.53  | 24.6                             | 48.0            | 88.9              | 5.3                          | 1.9                                  | 1.91                 | 0.93  |
| 48.8 m.s.*                   | 1.80            | 1.38 | 2.49  | 23.3                             | 44.5            | 94.2              | 2.6                          | ---                                  | ---                  | ---   |
| 57.0 m.s.*                   | 1.74            | 1.30 | 2.51  | 25.4                             | 48.3            | 91.5              | 4.1                          | ---                                  | ---                  | ---   |
| 61.3                         | 1.83            | 1.42 | 2.54  | 22.6                             | 44.2            | 93.7              | 2.8                          | 0.1                                  | 1.91                 | 0.73  |
| 69.5                         | 1.94            | 1.60 | 2.48  | 17.7                             | 35.6            | 96.4              | 1.3                          | 1.1                                  | 2.28                 | 1.24  |
| U12e.20<br>UG#2              |                 |      |       |                                  |                 |                   |                              |                                      |                      |       |
| 6.4                          | 1.95            | 1.62 | 2.48  | 17.0                             | 34.7            | 95.5              | 1.6                          | ---                                  | 3.18                 | 1.87  |
| 14.0                         | 1.89            | 1.56 | 2.46  | 17.4                             | 36.5            | 90.0              | 3.7                          | 1.0                                  | 2.44                 | 1.18  |
| 21.0                         | 1.95            | 1.59 | 2.49  | 18.3                             | 36.0            | 99.1              | 0.3                          | 0.4                                  | 2.87                 | 1.39  |
| 29.9                         | 1.98            | 1.66 | 2.51  | 16.2                             | 33.9            | 94.8              | 1.8                          | 0.4                                  | 2.98                 | 1.40  |
| 37.5                         | 1.82            | 1.38 | 2.50  | 24.0                             | 44.6            | 97.7              | 1.1                          | 0.6                                  | 2.35                 | 0.99  |
| 45.7                         | 1.88            | 1.48 | 2.50  | 21.1                             | 40.6            | 97.4              | 1.0                          | 1.1                                  | 2.25                 | 1.15  |
| 53.0                         | 1.89            | 1.48 | 2.53  | 21.8                             | 41.6            | 99.0              | 0.4                          | 0.3                                  | 2.47                 | 1.37  |
| 61.0                         | 1.92            | 1.53 | 2.52  | 20.1                             | 39.2            | 98.8              | 0.5                          | 0.6                                  | 2.08                 | 1.13  |
| 68.6                         | 1.91            | 1.50 | 2.55  | 21.6                             | 41.3            | 100.0             | 0                            | 0.4                                  | 2.21                 | 1.20  |
| 75.9                         | 1.88            | 1.49 | 2.50  | 20.9                             | 40.5            | 96.9              | 1.3                          | 0.7                                  | 2.19                 | 1.10  |
| 82.9                         | 1.99            | 1.65 | 2.60  | 16.9                             | 36.4            | 92.3              | 2.8                          | 0.7                                  | 2.43                 | 1.12  |
| 91.4                         | 1.92            | 1.55 | 2.53  | 19.4                             | 38.8            | 95.8              | 1.6                          | 1.2                                  | 2.29                 | 1.15  |
| 106.7                        | 1.88            | 1.49 | 2.49  | 20.6                             | 40.1            | 96.8              | 1.3                          | 1.6                                  | 2.43                 | 1.40  |
| 114.0                        | 1.95            | 1.57 | 2.55  | 19.4                             | 38.4            | 98.7              | 0.5                          | 0.3                                  | 2.30                 | 1.12  |
| 121.3                        | 1.88            | 1.48 | 2.47  | 21.0                             | 39.9            | 99.0              | 0.4                          | 0.2                                  | 2.51                 | 1.30  |
| U12e.20<br>UG#3              |                 |      |       |                                  |                 |                   |                              | HYD/1-D                              |                      |       |
| 0.6                          | 1.92            | 1.55 | 2.56  | 19.1                             | 39.3            | 93.2              | 2.6                          | 0.8                                  | 2.62                 | 1.36  |
| 1.5                          | 1.93            | 1.55 | 2.57  | 19.6                             | 39.6            | 95.4              | 1.8                          | 0.8/0.2                              | 2.39                 | 1.27  |
| 3.4                          | 1.89            | 1.50 | 2.54  | 20.4                             | 40.8            | 94.6              | 2.2                          | 0.1                                  | 2.22                 | 1.49  |
| 5.5                          | 1.86            | 1.45 | 2.56  | 22.0                             | 43.3            | 94.4              | 2.4                          | 0.6/0.1                              | 2.32                 | 1.30  |
| 7.3                          | 1.88            | 1.49 | 2.55  | 20.8                             | 41.6            | 94.0              | 2.5                          | 0.7                                  | 2.30                 | 1.52  |
| 9.1                          | 1.89            | 1.49 | 2.53  | 21.2                             | 41.1            | 97.4              | 1.1                          | 0.4/0.8                              | 2.04                 | 1.16  |
| 10.7                         | 1.93            | 1.56 | 2.54  | 19.1                             | 38.6            | 95.7              | 1.7                          | 0.5                                  | 2.30                 | 1.48  |
| 11.9                         | 1.93            | 1.55 | 2.55  | 19.6                             | 39.1            | 96.6              | 1.3                          | 0.3/0.3                              | 2.26                 | 1.35  |
| 13.1                         | 1.91            | 1.52 | 2.51  | 20.5                             | 39.5            | 99.1              | 0.3                          | 0.2                                  | 2.50                 | 1.37  |
| 14.9                         | 1.93            | 1.57 | 2.56  | 18.8                             | 38.8            | 93.6              | 2.5                          | 1.3/0.2                              | 2.22                 | 1.34  |
| 16.5                         | 1.90            | 1.52 | 2.52  | 20.2                             | 39.9            | 96.3              | 1.4                          | 0.1                                  | 2.82                 | 1.21  |
| 18.3                         | 1.98            | 1.62 | 2.57  | 18.3                             | 37.1            | 97.8              | 0.8                          | 0.5/0.2                              | 2.53                 | 1.51  |
| 19.5                         | 1.95            | 1.58 | 2.49  | 18.8                             | 36.4            | 100.0             | 0                            | 1.8                                  | 3.07                 | 1.49  |
| 21.0                         | 1.93            | 1.56 | 2.54  | 19.4                             | 38.8            | 96.6              | 1.3                          | 0.7/0.1                              | 2.33                 | 1.48  |
| 22.6                         | 1.95            | 1.59 | 2.49  | 18.6                             | 36.2            | 100.0             | 0                            | 0.5                                  | 2.51                 | 1.46  |
| 24.1                         | 1.93            | 1.56 | 2.53  | 19.3                             | 38.4            | 96.9              | 1.2                          | 0.8/0.1                              | 2.65                 | 1.54  |
| 25.6                         | 1.88            | 1.48 | 2.51  | 21.2                             | 41.0            | 97.3              | 1.1                          | 0.3                                  | 2.86                 | 1.29  |
| 27.1                         | 1.65            | 1.45 | 2.52  | 21.4                             | 42.3            | 93.6              | 2.7                          | 1.3/0.1                              | 2.53                 | 1.38  |
| 29.0                         | 1.89            | 1.51 | 2.46  | 20.2                             | 38.7            | 98.7              | 0.5                          | 0.5                                  | 2.53                 | 1.41  |
| 30.2                         | 1.89            | 1.52 | 2.56  | 19.8                             | 40.8            | 91.7              | 3.4                          | 0.9/0.1                              | 2.31                 | 1.27  |
| 32.3                         | 1.91            | 1.55 | 2.48  | 19.1                             | 37.7            | 96.8              | 1.2                          | 0.6                                  | 2.51                 | 1.28  |
| 33.2                         | 1.73            | 1.27 | 2.42  | 26.8                             | 47.7            | 97.3              | 1.3                          | 0.7/0.1                              | 2.19                 | 1.27  |
| 34.4                         | 1.74            | 1.30 | 2.42  | 25.5                             | 46.3            | 95.8              | 2.3                          | 0.6                                  | 2.67                 | 1.36  |
| 36.0                         | 1.95            | 1.59 | 2.48  | 18.5                             | 35.9            | 100.0             | 0                            | 0.7                                  | 2.91                 | 1.46  |
| 36.9                         | 1.94            | 1.59 | 2.57  | 17.8                             | 38.1            | 90.6              | 3.1                          | 0.4/0.1                              | 2.39                 | 1.43  |

\* Moisture sample (i.e. the amount or condition of material limited the test program to measurement of only "physical properties").

\*\* The double figures in the "measured permanent compaction" column reflect the volume compactions resulting from hydrostatic compression followed by uniaxial strain loading. See Section II for further details.

TABLE A7

Physical Properties, Uniaxial Strain Measured Permanent Compaction, and  
Ultrasonic Longitudinal and Shear Wave Velocities of  
U12e.20 HF#1-10A Tuffs

| DRILL HOLE<br>FOOTAGE<br>(M) | DENSITY (gm/cc) |      |       | WATER<br>BY WET<br>WEIGHT<br>(%) | POROSITY<br>(%) | SATURATION<br>(%) | CALC.<br>AIR<br>VOIDS<br>(%) | MEAS.<br>PERMANENT<br>COMP.<br>(%) | VELOCITY<br>(km/sec) |       |
|------------------------------|-----------------|------|-------|----------------------------------|-----------------|-------------------|------------------------------|------------------------------------|----------------------|-------|
|                              | AS-<br>RECEIVED | DRY  | GRAIN |                                  |                 |                   |                              |                                    | LONG                 | SHEAR |
| U12e.20<br>HF#1              | Meas.           | Cal. | Meas. | Meas.                            | Cal.            | Cal.              | Cal.                         | Meas.                              | Meas.                | Meas. |
| 1.8                          | 1.89            | 1.50 | 2.52  | 20.7                             | 40.5            | 96.5              | 1.4                          | 0.9/-0.1                           | 2.14                 | 1.26  |
| 4.9                          | 1.88            | 1.49 | 2.50  | 20.5                             | 40.2            | 95.8              | 1.7                          | M.S.                               | M.S.                 | M.S.  |
| U12e.20<br>HF#2              |                 |      |       |                                  |                 |                   |                              |                                    |                      |       |
| 3.0                          | 1.80            | 1.39 | 2.47  | 3.0                              | 43.7            | 94.7              | 2.7                          | 0.8/-0.1                           | 1.93                 | 1.07  |
| U12e.20<br>HF#3              |                 |      |       |                                  |                 |                   |                              |                                    |                      |       |
| 1.5                          | 1.79            | 1.35 | 2.49  | 24.6                             | 45.8            | 96.1              | 1.8                          | 0.3/0.4                            | 1.80                 | 1.20  |
| U12e.20<br>HF#4              |                 |      |       |                                  |                 |                   |                              |                                    |                      |       |
| 0.3                          | 1.94            | 1.57 | 2.55  | 19.1                             | 38.4            | 96.4              | 1.4                          | 0.8/0.4                            | 2.16                 | 1.26  |
| 2.7                          | 1.96            | 1.60 | 2.55  | 18.4                             | 37.3            | 96.7              | 1.4                          | 0.9/-0.1                           | 1.98                 | 1.12  |
| 6.4                          | 1.87            | 1.45 | 2.49  | 22.4                             | 41.7            | 100.0             | 0                            | 0.5                                | 2.13                 | 1.12  |
| 7.6                          | 1.89            | 1.49 | 2.52  | 20.9                             | 40.7            | 97.1              | 1.2                          | 0.7                                | 1.76                 | 0.82  |
| U12e.20<br>HF#5              |                 |      |       |                                  |                 |                   |                              |                                    |                      |       |
| 0.3                          | 1.94            | 1.59 | 2.54  | 17.9                             | 37.3            | 93.2              | 2.6                          | 0.6                                | 2.50                 | 1.33  |
| 1.5                          | 1.93            | 1.57 | 2.49  | 18.5                             | 36.8            | 96.8              | 1.2                          | 0.7/-0.1                           | 2.48                 | 1.33  |
| 2.7                          | 1.90            | 1.52 | 2.50  | 19.8                             | 39.0            | 96.3              | 1.4                          | 0.5                                | 2.42                 | 1.35  |
| 4.6                          | 1.90            | 1.52 | 2.50  | 20.1                             | 39.3            | 97.3              | 1.1                          | 0.8/-0.1                           | 2.57                 | 1.36  |
| 6.7                          | 1.92            | 1.54 | 2.51  | 19.6                             | 38.5            | 97.8              | 0.8                          | 1.2                                | 2.72                 | 1.45  |
| 8.5                          | 1.92            | 1.56 | 2.51  | 18.6                             | 37.7            | 94.7              | 2.0                          | 0.7/0.6                            | 2.73                 | 1.36  |
| 9.8                          | 1.79            | 1.39 | 2.44  | 22.4                             | 43.1            | 93.1              | 3.0                          | 1.1                                | 2.62                 | 1.50  |
| 11.3                         | 1.74            | 1.31 | 2.46  | 24.9                             | 46.8            | 92.6              | 3.5                          | 1.0/-0.1                           | 2.18                 | 1.23  |
| 12.5                         | 1.97            | 1.63 | 2.48  | 17.3                             | 34.4            | 99.4              | 0.2                          | 0.5                                | 2.83                 | 1.59  |
| 13.4                         | 1.92            | 1.54 | 2.46  | 19.6                             | 37.3            | 100.0             | 0                            | 0.6/-0.1                           | 2.57                 | 1.38  |
| 14.9                         | 2.03            | 1.71 | 2.55  | 15.9                             | 33.1            | 97.7              | 0.8                          | 0.4                                | 2.60                 | 1.17  |
| 16.8                         | 1.99            | 1.67 | 2.46  | 16.2                             | 32.2            | 100.0             | 0                            | 0.3/-0.1                           | 2.56                 | 1.19  |
| 18.0                         | 2.06            | 1.75 | 2.57  | 15.2                             | 32.0            | 97.8              | 0.7                          | 0.4                                | 2.66                 | 1.19  |
| 20.1                         | 2.03            | 1.71 | 2.60  | 16.0                             | 34.4            | 94.4              | 1.9                          | 0.7/0.1                            | 2.31                 | 1.04  |
| 21.0                         | 1.99            | 1.66 | 2.54  | 16.5                             | 34.6            | 94.9              | 1.7                          | 0.7                                | 2.23                 | 1.05  |
| U12e.20<br>HF#6              |                 |      |       |                                  |                 |                   |                              |                                    |                      |       |
| 1.8                          | 1.82            | 1.40 | 2.49  | 22.9                             | 43.7            | 95.5              | 2.0                          | 0.8/0                              | 2.06                 | 1.10  |
| 4.9                          | 1.87            | 1.51 | 2.46  | 19.4                             | 38.7            | 93.7              | 2.4                          | 0.4                                | 2.12                 | 1.41  |
| U12e.20<br>HF#7              |                 |      |       |                                  |                 |                   |                              |                                    |                      |       |
| 1.2                          | 1.94            | 1.59 | 2.53  | 18.3                             | 38.0            | 93.8              | 1.4                          | 0.4/0                              | 2.52                 | 1.50  |
| 3.4                          | 1.87            | 1.48 | 2.49  | 20.9                             | 40.6            | 96.1              | 1.6                          | 0.7                                | 2.98                 | 1.41  |
| 5.2                          | 1.91            | 1.55 | 2.52  | 19.0                             | 38.6            | 93.9              | 2.4                          | 0.5/0                              | 2.03                 | 1.34  |
| U12e.20<br>HF#8              |                 |      |       |                                  |                 |                   |                              |                                    |                      |       |
| 1.5                          | 1.96            | 1.62 | 2.42  | 17.2                             | 32.9            | 100.0             | 0                            | 1.0                                | 2.69                 | 1.70  |
| 4.0                          | 1.95            | 1.59 | 2.57  | 18.5                             | 38.2            | 94.7              | 2.0                          | 0.7/0.2                            | 2.24                 | 1.78  |
| 5.8                          | 1.96            | 1.60 | 2.54  | 18.2                             | 36.9            | 96.9              | 1.2                          | 0.7                                | 2.59                 | 1.14  |
| U12e.20<br>HF#9              |                 |      |       |                                  |                 |                   |                              |                                    |                      |       |
| 1.2                          | 1.85            | 1.44 | 2.52  | 22.3                             | 43.0            | 96.0              | 1.8                          | 0.7/0.5                            | 2.35                 | 1.47  |
| 3.4                          | 1.85            | 1.44 | 2.50  | 22.4                             | 42.6            | 97.3              | 1.1                          | 0.9                                | 2.42                 | 1.35  |
| 5.5                          | 1.87            | 1.46 | 2.55  | 21.6                             | 42.5            | 95.1              | 2.1                          | 1.1/0.1                            | 2.61                 | 1.25  |
| U12e.20<br>HF#10a            |                 |      |       |                                  |                 |                   |                              |                                    |                      |       |
| 1.8                          | 2.00            | 1.67 | 2.46  | 16.3                             | 32.0            | 109.0             | 0                            | 0.5                                | 3.06                 | 1.75  |
| 4.0                          | 1.94            | 1.56 | 2.52  | 19.4                             | 37.9            | 99.0              | 0.4                          | 0.9/0.4                            | 2.31                 | 1.40  |
| 6.1                          | 1.89            | 1.53 | 2.45  | 18.9                             | 37.4            | 95.4              | 1.7                          | 1.5                                | 2.73                 | 1.58  |

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