University of Nevada, Reno

Evaluation of Failure Mechanics of the Malpais Landslide, Eureka County, Nevada

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Geological Engineering

By

Coralie P. Wilhite

Robert J. Watters/Thesis Advisor

May, 2009

University of Nevada, Reno
Statewide • Worldwide

THE GRADUATE SCHOOL

We recommend that the thesis
prepared under our supervision by

CORALIE P. WILHITE

entitled

Evaluation of Failure Mechanics of the Malpais Landslide, Eureka County, Nevada

be accepted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

Robert J. Watters, Ph.D., Advisor

James R. Carr, Ph.D., Committee Member

Alan R. Wallace, Ph.D., Graduate School Representative

Marsha H. Read, Ph. D., Associate Dean, Graduate School

May, 2009

Abstract

Investigations of the Holocene Malpais landslide, located on the northeastern end of the Shoshone Mountains in north-central Nevada, show that very weakly clay-cemented Tertiary fluviolacustrine sedimentary rocks controlled the failure. The sedimentary rocks overlie competent deep-ocean Paleozoic basement rocks and underlie Miocene dacite flow units. The landslide, which originated at a local high point along the fault-controlled Malpais Rim, flowed north into Whirlwind Valley. It has a surface area of ~2.2 km^2 and volume of ~0.032 km^3. The landslide mass is composed of the Tertiary sedimentary and volcanic rocks. The only Paleozoic rocks in the landslide are remobilized clasts in the Miocene sedimentary rocks, thus the slide apparently did not cut into the Paleozoic basement itself.

Field and laboratory testing show that the sedimentary rocks are extremely weak, and that the dacite has high intact rock strength, but also has pervasive columnar joints. Modeling results suggest that the initial landslide originated in the weak sedimentary rocks and followed the joints in the dacite to the surface. The over-steepened rear scarp subsequently failed in a retrogressive manner, allowing rock falls, topples, intact block rotations, and slides to occur. Continued retrogressive failure and scarp formation progressed farther up slope until the overall slope equilibrated at the present head-scarp location near the crest of the Malpais Rim.

Possible failure triggering mechanisms include an increase in the water table level and/or seismic loading, given the proximity to the Malpais and other faults that have documented Holocene movement. The Malpais landslide failure depended on the

presence of very weak lacustrine sedimentary units, and similar weak units are present at other landslides in the region. Those units may have been contributing factors, along with the destabilizing influence of water pressure and seismic loading, in the formation of those landslides.

Acknowledgements

To my parents and brothers: thank you for supporting my dreams and for always making the outdoors a priority. To Erik: thank you for your support, proofreading, and editing. To Logan: thank you for being awesome. To Bob Watters, Alan Wallace, and Jim Carr: thank you for your time and guidance. To Stephanie Watts: thank you for your help and answering my many questions. To Steve Wesnousky: thank you for the aerial photographs. To the University of Nevada, Reno: thank you for the facilities and transportation. To Chris Sladek: thank you for the use of your GPS device. Finally, to my fellow students: thank you for your friendship and help throughout this project and my time at UNR.

Table of Contents

List of Tables

List of Figures

Chapter I: Introduction

The Malpais Landslide study area is located along the Malpais Rim in northern Eureka County, Nevada, approximately 33 km (20.5 mi) east-southeast of Battle Mountain. This area is within the Basin and Range Province of North America and is structurally controlled by normal faulting (Figure 1). The Malpais Rim is an approximately N65W-trending arm of the Northern Shoshone Range and was formed by approximately 300 m (984 ft) of offset along the Malpais Fault with respect to the valley floor in the study area (Figure 2). A large Holocene (?) landslide (the Malpais Landslide) originated at a local high point along the Malpais Rim and flowed north into Whirlwind Valley.

Figure 1: Basin and Range Province of North America (USGS, 2004).

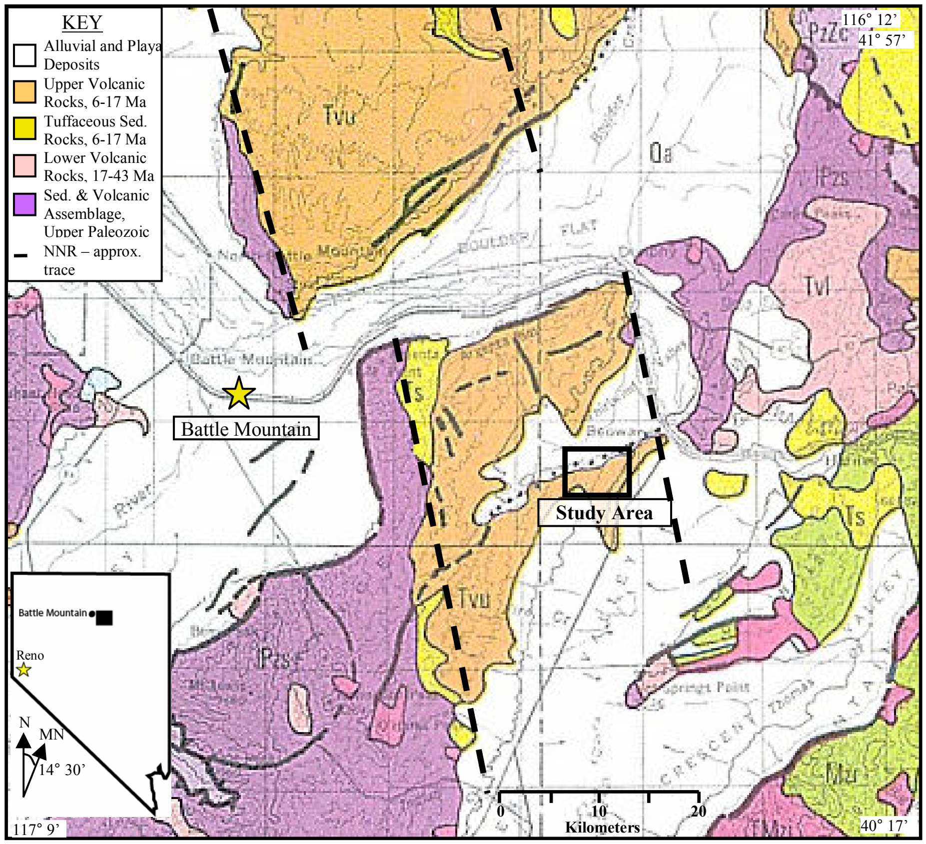


Figure 2: Location map of the Malpais Landslide study area. NNR is the northern Nevada rift. Base map from Stewart and Carlson 1977.

This landslide is well defined and can be easily viewed in aerial photographs and on topographic maps. It is approximately 2.2 km^2 in size with an approximate failure volume of 0.035 km^3. The toe of the landslide is composed mainly of the early Eocene to middle Miocene sedimentary rock and forms a low angle (8 degree) slope. The low angle suggests a) that the sediments were partially saturated at the time of failure and b) that the rock has a very low strength. The head of the landslide is composed mainly of the Miocene dacite in the form of large blocks and hills. Inspection of the landslide mass and head scarp indicates that the dacite failed in the form of rock falls, topples, block rotations, and slides. These failures occurred along pervasive columnar jointing (discontinuities) in the dacite.

Three and a half kilometers west of the Malpais Landslide is the Beowawe Geothermal Field, which includes geysers, hot springs, and hydrothermal deposits. Steam rises from several of the geysers, but the majority of the activity ceased with the opening of a geothermal plant in 1985. The geothermal activity has caused hydrothermal alteration of some of the local rocks and produced siliceous sinter deposits in the vicinity of the geysers, and to a lesser extent, mineral alteration and iron staining. An open-pit barite mine located 2 km (1.2 mi) east of the landslide provides good exposure of late Eocene to middle Miocene sedimentary rocks (the weakest unit involved in the landslide) overlying the Paleozoic sedimentary rock. Miocene dacite overlies the early Eocene to middle Miocene sediments and forms the cap rock of the Malpais Rim. The Humboldt River is located 6 km (3.7 mi) east of the landslide.

The purpose of this study is to determine the most likely cause of the landslide; the possible failure triggering mechanisms include an increase in the water table and/or seismic loading. The following steps were performed to establish the most likely cause of failure:

- Mapping of geologic units, structures, and landslide extent within the study area.
- Collecting discontinuity data.
- Assessing the paleo-seismicity.
- Determining the material properties of each unit involved in the landslide.
- Establishing likely failure modes and slope failure scenarios.

Chapter II: Geologic Framework

Geologic Setting

The Malpais Landslide is located on the northeast end of the Shoshone Range, along the Malpais Rim in northeastern Nevada. The formation of this region began with late Proterozoic rifting, which created deep crustal breaks (John et al., 2000). During the Paleozoic, shallow and deep ocean sediments were deposited and then offset by east-directed compression, which created the Roberts Mountain Thrust (John et al., 2000). Finally, in the middle Miocene the area began to rift again in response to the regional west-directed extension and, in part, the emergence of the Yellowstone hotspot. Extension in a more northwesterly direction has continued to the present (Zoback et al., 1994, John et al., 2000, and Dickinson, 2006). These events have created an interlayered sequence of sedimentary and volcanic units that are cut by both north-northwest- and east-northeast-striking normal faults.

The Yellowstone hotspot first emerged on the Nevada – Oregon border north-northwest of the study area. A positive aeromagnetic anomaly extending south-southeast of the hotspot was termed the northern Nevada rift (NNR) by Zoback and Thompson (1978) (Figure 2). This 500 km(311 mi)-long rift is believed to have formed at about 17 Ma (Zoback et al., 1994 and John et al., 2003) and is defined by north-northwest trending normal faults and dikes. Zoback and Thompson (1978) found this period of rifting to mark the beginning of spreading of the northern Basin and Range Province. John et al. (2000) and Watt et al. (2007) found that the NNR formed along reactivated Proterozoic structural breaks. Zoback et al. (1994) showed that it formed as a result of the Miocene regional stress state of N65-70E related to the then-active subduction zone to the west. This rifting caused magma intrusion and volcanic deposition to occur between 16.5 and 15 Ma along the NNR and on the Columbia River Plateau (Zoback et al., 1994, and John et al., 2000). At approximately 10 to 6 Ma the regional stress state rotated approximately 45 degrees clockwise, to the now current stress direction of N60-70W (Zoback 1994 quoting Zoback, 1989). This rotation occurred in response to the formation of the San Andreas Fault as the boundary between the North American and Pacific Plates changed from subduction to oblique-slip (Zoback et al., 1994).

Several faults are located in and around the study area (Figure 3). The Dunphy Pass Fault, which is located just west of the landslide formed in response to the middle Miocene stress state (Watt et al., 2007). The Malpais Fault formed after the stress state changed in the late Miocene (Struhsacker 1980, and Watt et al., 2007). Recharge for the Beowawe Geothermal Field is believed to take place along these faults (Tilden et al., 2005, and Watt et al., 2007). The geothermal field is located approximately 3.5 km (2.2 mi) west of the study area along the Malpais Fault. It is believed to have deep reservoirs in the carbonate rocks of the lower Roberts Mountain Thrust (John et al., 2003 and Watt et al., 2007) and shallower reservoirs in the upper Roberts Mountain Thrust and Miocene volcanic rocks (Struhsacker, 1980).

Hydrothermal alteration associated with the Beowawe Geothermal Field is visible throughout the area. Massive siliceous sinter deposits are present around the geysers with lesser alteration in the surrounding area, most noticeable as red, orange, and pink coloration. Smectitic clays were found on the surface at the barite mine and may represent hydrothermal alteration of the unit; though this may also be from diagenetic alteration of ash within the unit. Also, some alteration of phynocrysts within the porphyritic units was observed. In general, this hydrothermal alteration may have reduced the strength of the units, but alteration is not extensive in the vicinity of the landslide and is likely not a large factor in the cause failure.

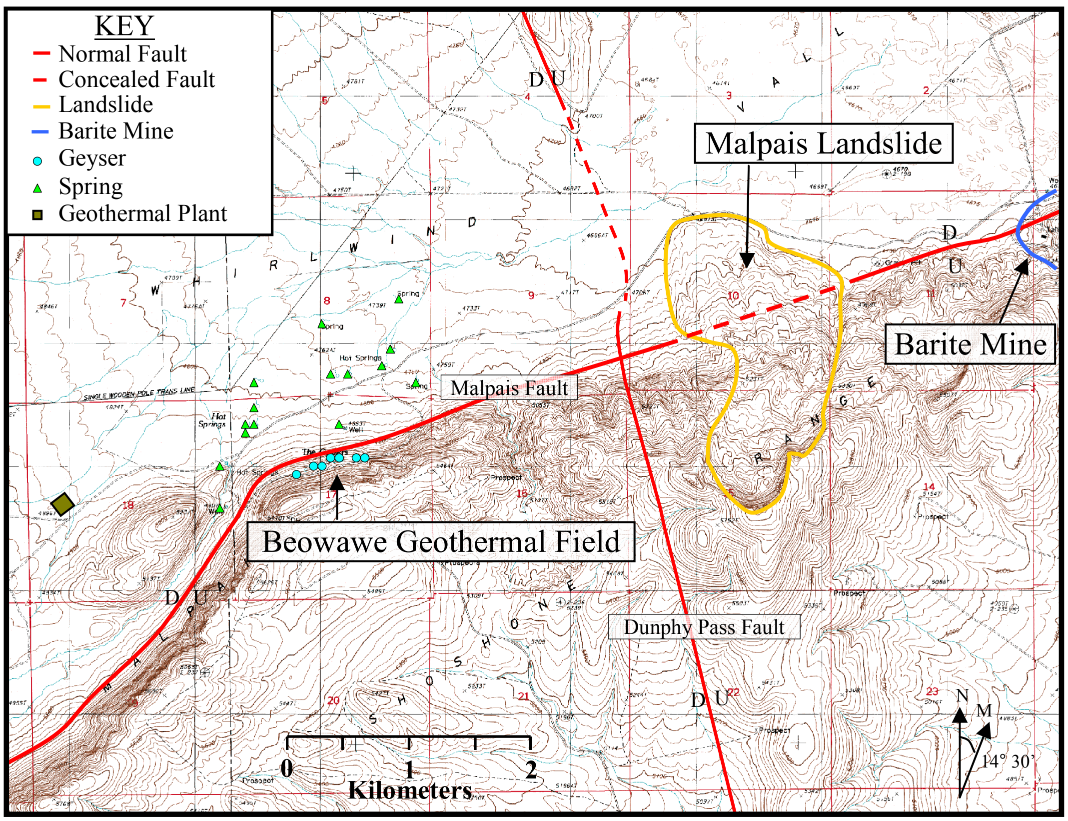


Figure 3: Location of major faults, the Beowawe Geothermal Field, and the barite mine with respect to the Malpais Landslide.

Geologic units in the area are of sedimentary and volcanic origin. The basement rock is composed of deep-ocean Paleozoic sediments (the Valmy Formation) which form the upper plate of the Roberts Mountain Thrust (Watt et al., 2007). Late Eocene to middle Miocene sedimentary rocks unconformably overlie the Valmy Formation. They are composed of tuffaceous, lacustrine, fluvial, and ash layers. Middle Miocene volcanics deposited during the formation of the NNR overlie the sedimentary deposits. These volcanics were found to be greater than 65 m (213 ft) thick approximately 1 km (0.6 mi) east of the landslide (John et al., 2000).

Tectonic Setting and Seismicity

The Basin and Range Province is defined by approximately north-trending, fault-bounded, mountains and valleys that formed in response to extension that began about 10 Ma. In central Nevada, more recent activity along these structures formed in response to an extensional rate of 1 mm per year for the past 60 thousand years (Koehler, 2009). This slip rate corresponds to magnitude 5.5-9 earthquakes occurring approximately every 100-12,500 years (Figure 4a) (Slemmons, 1982). Within the study area the Malpais Fault has uplifted the Malpais Rim approximately 300 m (984 ft) with respect to the valley floor and likely represents the cumulative offset which has occurred over several million years. The landslide lies across, and does not appear to be offset by, the Malpais Fault, suggesting that the landslide is younger than the last major fault offset. A study by Wesenousky et al. (2005) found that the last offset occurred 7450 ± 112 cal years before present. Several other normal faults, which have offset and caused repeating of layers, are also present. Most faults are approximately east-striking, though the older north-striking Dunphy Pass Fault passes just west of the landslide. Another north-striking fault forms the landslide’s western release plane, and may be a splay of the Dunphy Pass Fault. The region has potential for a peak ground acceleration of 0.2g, with a 2% probability of exceedance in 50 years (USGS, 2008) (Figure 4b). Longer time periods typically result in higher peak ground accelerations, but 0.2g was sufficient for this study.

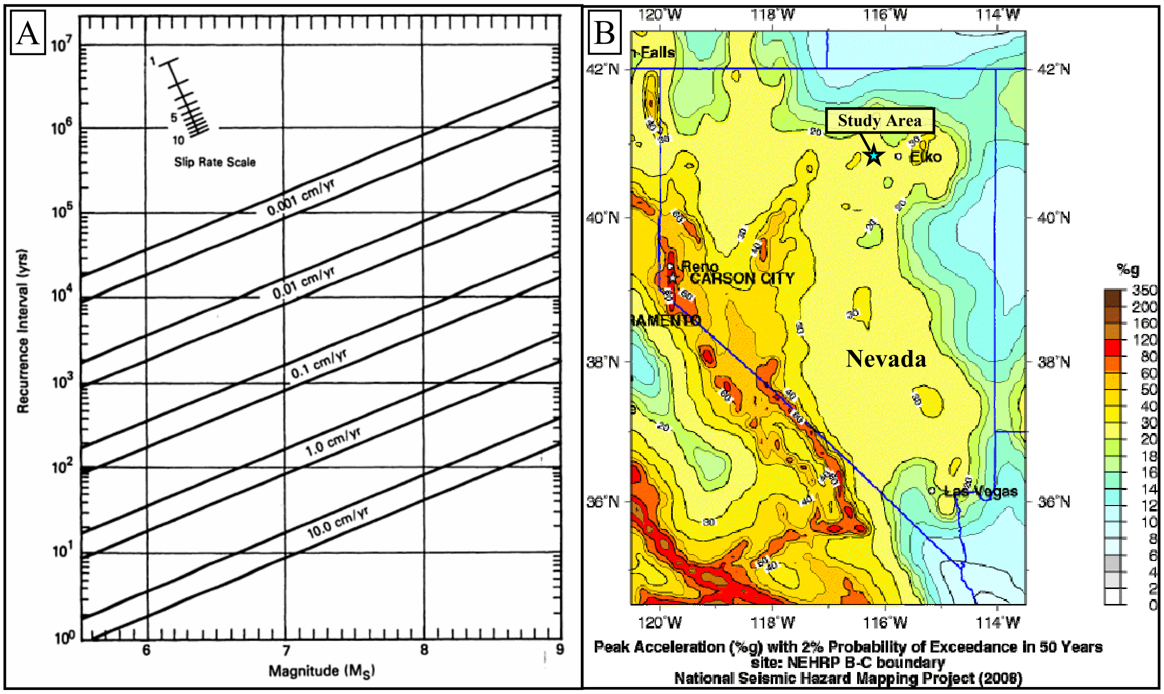


Figure 4: A – The slip rate of 1 mm per year in Central Nevada corresponds to a magnitude 5.5-9 earthquake occurring every 100-12,500 years (Slemmons, 1982). B – Seismicity of the study area and region (USGS, 2008).

Climate

Current climate data for the study area was found through The Western Regional Climate Center, Beowawe Station, which has a 114-year record. This record shows the area to be semi-arid to arid with an average maximum temperature of 18.5 °C (65.3 °F) and an average minimum temperature of -0.5 °C (31.1 °F). Average annual rainfall for the region is 192.5 mm (7.58 in) and average annual snowfall is 431.8 mm (17.0 in). Vegetation consists mainly of sagebrush and grasses. A study by Mifflin and Wheat

(1979) of the late Pleistocene climate found that an average decrease in temperature of 2.8 °C (a decrease of 5 °F) would produce an average precipitation increase of 68% of today's average and would produce the pluvial lakes of the late Pleistocene. Mapping of the Pleistocene lakes performed by Mifflin and Wheat does not show any lakes in the area around the landslide, though mapping by Reheis (1999) shows a "possible additional area of pre-late Pleistocene lakes" reaching about 10 km (6.2 mi) into Whirlwind Valley. No shorelines or lake deposits are visible today.

Chapter III: Investigation Methods

Geologic Mapping

The study area was mapped in 2008 using the USGS 1:24000-scale topographic map. Geologic mapping was completed using field observation, aerial photography, and was augmented by mapping published by Struhsacker (1980) and John et al. (2000). Mapping focused on factors relevant to slope stability and included bedrock, colluvium, and alluvium contacts; landslide topography and deposits; and bedding, faulting, and jointing (Figure 5). The six units mapped include Paleozoic deep ocean sedimentary rocks (Valmy Formation) (Pz), Tertiary sedimentary rocks (Ts), Tertiary dacite flow units (Td), Quaternary alluvial deposits (Qal), Quaternary colluvial deposits (Qc), and Quaternary landslide deposits (Qls). A small talus slope of Tertiary hornblende andesite (Tha) was mapped on the western edge of the landslide and is shown in purple on figure 5. This unit is discontinuous and is contained within Ts. Four east-striking normal faults, one north-striking fault, and pervasive columnar jointing of Td were also identified in the study area.

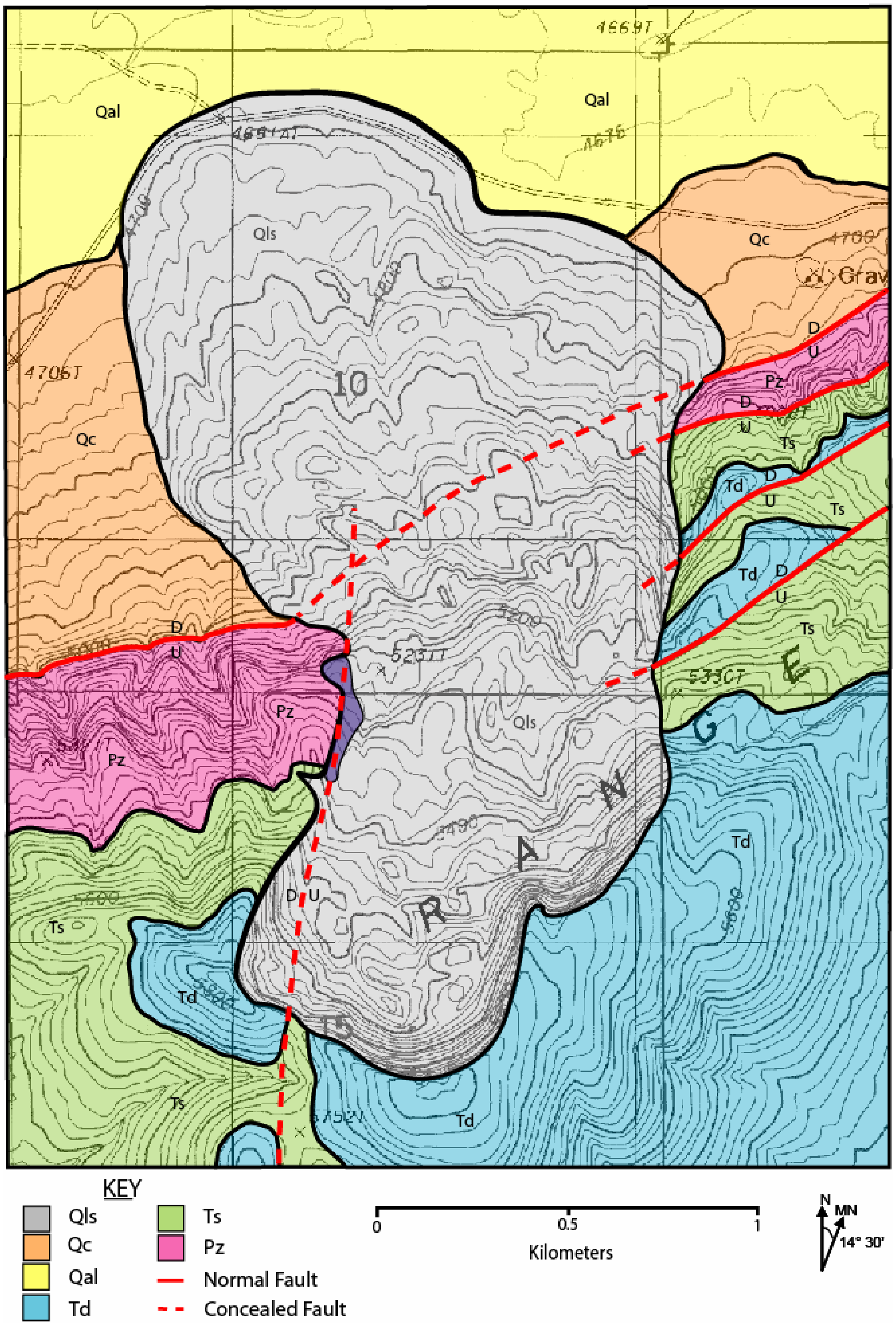


Figure 5: Geologic map of the Malpais Landslide, Eureka County, Nevada. Pz – Paleozoic Valmy Formation, Ts – Tertiary sedimentary rocks, Td – Tertiary dacite, Qal – Quaternary alluvium, Qc – Quaternary colluvium, Qls – Quaternary landslide, purple region represents the Tha talus slope. Mapping was completed using field observations and aerial photography, and augmented by mapping published by Struhsacker (1980) and John et al. (2000).

Laboratory Analysis

Rock and soil samples were obtained from the landslide and a nearby barite mine (Figure 3). Pz and Td were sampled at outcrops adjacent to the landslide, along the head scarp, and from the landslide surface. Ts samples were collected from the east wall of the barite mine as no outcrops and very little intact material exist on the landslide surface; however, some field point load testing of Ts was performed on samples collected from the landslide surface. The barite mine enabled access to approximately the lower half of the sedimentary section. The sedimentary rocks were divided into four sub-units based on appearance, grain size, and mineralogy. These sub-units were termed Ts(a), Ts(b), Ts(c), and Ts(d) in ascending (younger) order (Figure 6) and are described in detail in the lithology section below. Ts(a) was not sampled, as intact samples could not be gathered. Laboratory analysis included point load, specific gravity, slake durability, particle-size distribution, direct shear, and Atterburg Limits tests. Laboratory testing was performed following relevant ASTM Standards and Bowles (1992).

Point load testing was performed following ASTM D 5731 – 95 (2005). Laboratory point load testing of material from Ts(b), Ts(c), and Ts(d) was performed using a Roctest Telemac and Engerpac Saf-T-Lite machine. Material from Pz, Ts, and Td was point load tested in the field using an Engineering Laboratory Equipment Limited point load machine. The resulting point load values were divided by the square of the sample diameter and multiplied by a correction factor (dependent on the sample diameter) to obtain the corrected point load index (Is). Finally, the Is was multiplied by a correlation factor (C) to obtain the unconfined compressive strength (UCS) of each sample. A C of 24 was used for the stronger rock units (Pz and Td) (ASTM D 5731 – 95, 2005 and Bowden et al., 1998) and a C of 10 was used for the weaker rock unit (Ts) (Bowman and Watters, 2007). The results are discussed in Chapter IV and in Appendix B.

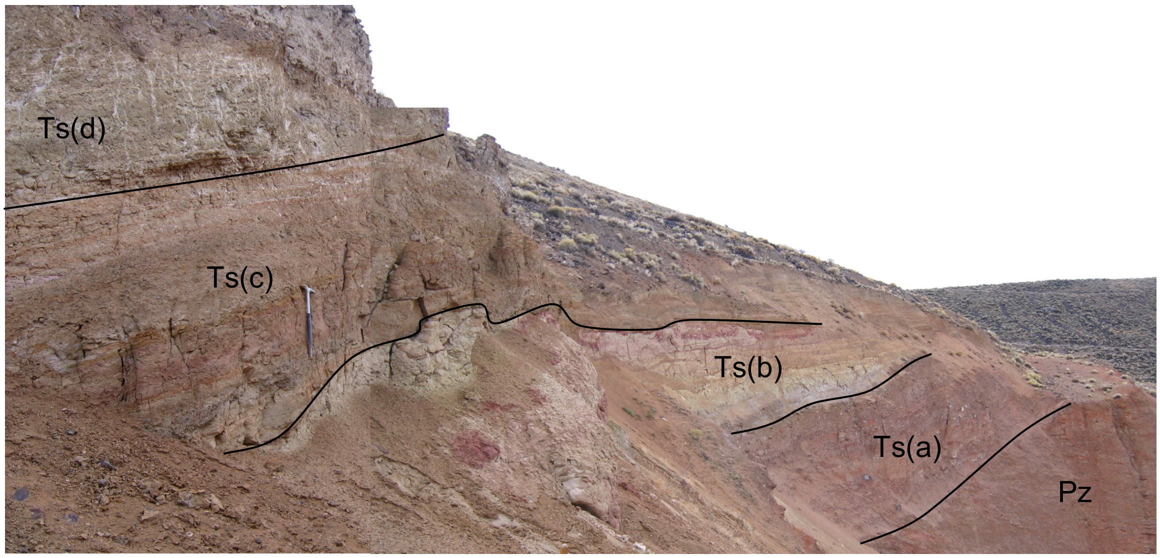


Figure 6: East wall of the Barite Mine showing the lower half of the Tertiary sedimentary section (Ts) with sub-units Ts(a), Ts(b), Ts(c), and Ts(d) overlying the Paleozoic Valmy Formation (Pz).

Specific gravity testing of each unit was performed following ASTM D 5779 – 95a (2001), except as mentioned below. Three to five tests were run on each unit. Ts(c) had the lowest average specific gravity and Td had the highest (Appendix C). Sample sizes used were smaller than specified in the standard due to limited rock and soil material.

Slake durability testing was performed on an Engineering Laboratory Equipment Limited machine following ASTM D 4644 – 87 (2004), except as mentioned below. Each Ts sub-unit was tested three or four times and Pz and Td were each tested once. Each sample was run for 10 minutes in the slake machine, dried, weighed, run for another

10 minutes, dried, and weighed again. The results are discussed in Chapter IV and in Appendix D. Instead of the specified deionized water, distilled water was used for testing. Ts(b), Ts(c), and Ts(d) each disintegrated within five minutes, leaving only larger sand and gravel. Because of Ts's low strength and tendency to disintegrate when wet, direct shear testing of intact samples could not be performed; therefore material used in the slake testing was oven dried and used for particle-size distribution and direct shear testing.

Particle-size distribution was performed following ASTM D 6913 – 04 (2004). The sieve set was made up of 0.5 inch (12.7 mm), No. 4 (4.75 mm), No. 10 (2 mm), No. 20 (0.84 mm), No. 40 (0.42 mm), No. 80 (0.18 mm), No. 100 (0.15 mm), No. 200 (0.075 mm), and pan (corresponding particle diameters are shown in millimeters). Each sample was placed in a Model B Ro-Tap Testing Sieve Shaker for ten minutes. Materials retained on the No. 40 and smaller sieves were then washed and oven dried. Material percentages were obtained by weighing the material retained on each sieve and dividing by the total sample starting mass. Particle-size distributions were plotted and are shown in Figure 7. Each unit was then named following the unified soil classification system (USCS) following ASTM D 2487 – 66 T (2000). Results are discussed in Chapter IV and in Appendix E.

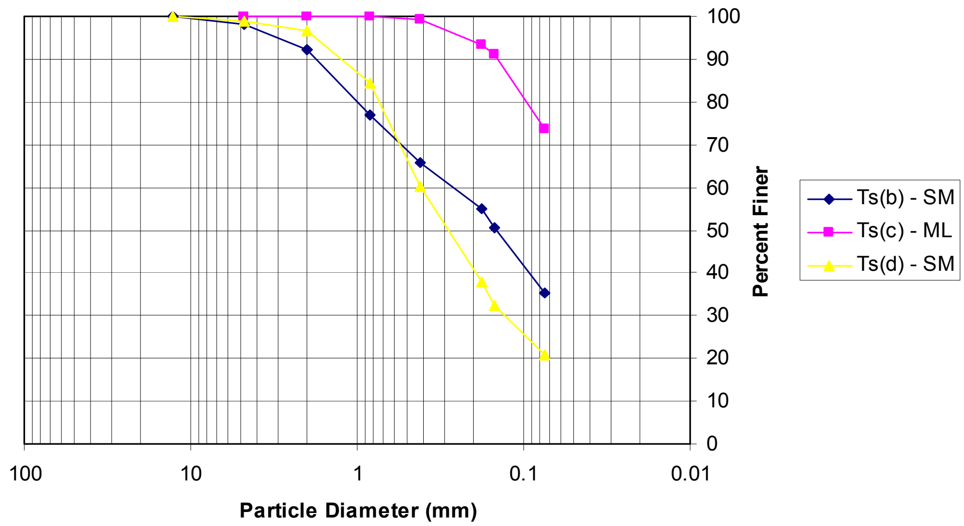


Figure 7: Particle-size distribution curves for the Tertiary sedimentary rocks (semi-log graph). Following the unified soil classification system, Ts(b) is a silty sand (SM), Ts(c) is a silt (ML), and Ts(d) is a silty sand (SM).

Direct shear testing was performed using a GeoTest Instrument Corporation Direct Shear machine as per Bowles (1992). Each of the three Tertiary sedimentary samples were run in dry and saturated step tests. The stresses used in testing correspond to the assumed pre-failure shallow, average, and maximum burial depths of Ts. The shallow burial depth of approximately 40 m (131 ft) corresponds to a normal stress of 0.35 MPa (50.04 psi). The average burial depth of approximately 75 m (246 ft) corresponds to a normal stress of 0.69 MPa (99.93 psi). The maximum burial depth of approximately 150 m (492 ft) corresponds to a normal stress of 1.38 MPa (200.01 psi). The results were plotted as horizontal displacement versus shear stress and normal stress versus shear stress (Mohr-Coulomb failure envelope). The latter plot was used to obtain the material strength properties of cohesion and the angle of internal friction. Figure 8 shows the horizontal displacement versus shear stress and Mohr-Coulomb failure envelope plots for Ts(c) (dry) and represents the typical results of all tests. The results are discussed in Chapter IV and in Appendix F.

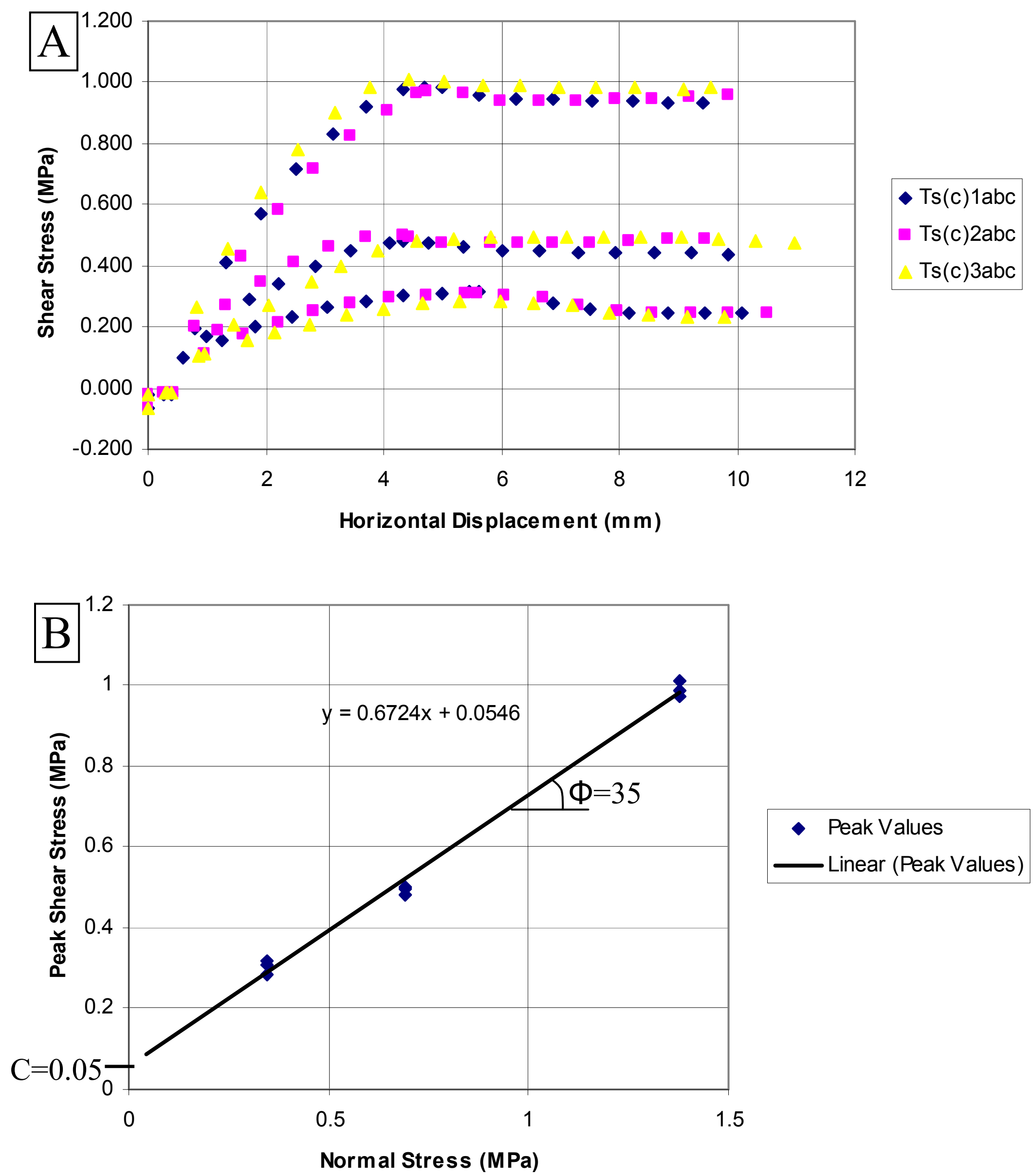


Figure 8: Typical direct shear results. A – Horizontal displacement versus shear stress for Ts(c) dry. B – Mohr-Coulomb Failure envelope showing a cohesion (C) of 0.05 MPa (50 kPa) and an angle of internal friction (Φ) of 35 degrees. See Appendix F for all other graphs.

Atterburg Limits were performed following ASTM D 4318 – 83 (2005) on clay samples gathered from exposures at the barite mine. Liquid limit, plastic limit, and plasticity index results for these samples are discussed Chapter IV.

Chapter IV: Lithologic Descriptions and Rock Mass Characterization

The geology of the study area includes six major units: the Paleozoic Valmy Formation (Pz), a sequence of late Eocene to middle Miocene sedimentary units (Ts), middle Miocene dacite flows (Td), and Quaternary alluvial deposits (Qal), colluvial deposits (Qc), and landslide deposits (Qls) (Figure 5). The materials involved in the landslide were derived from Ts and Td. Sand and gravel sized chips of Pz, which likely came from the basal layer of Ts, were found in the toe of the landslide. All unit descriptions include field observations, classifications, and laboratory testing results. Bedding and joint orientation measurements were plotted on equal area lower hemisphere stereonets (Dips 5.1, 1998-2003).

Rock mass classifications performed include rock mass rating (RMR) and Geologic Strength Index (GSI) following Bieniawski (1989) and Hoek and Brown (1997), respectively. RMR is based on six parameters: 1.the uniaxial compressive strength of the material, 2. the rock quality designation (RQD), 3. the spacing of discontinuities, 4. the condition of discontinuities, 5. the groundwater conditions, and 6. the orientation of the discontinuities. Each of these parameters have a range of values for different materials and conditions (ie. highly fractured versus unfractured). Once values for the six parameters are determined they are summed to a total RMR rating. These totals can range from 0 to 100 and indicated the rock mass strength (Table 1). GSI takes two parameters (surface condition and structure) into account. These parameters are compared on a graph for a total rating ranging from about 0 to 90, with higher values representing stronger rock. Results of the RMR and GSI classifications are presented in each unit description and in Appendix A.

Table 1: Rock mass ratings with corresponding class number and description.

Rating	Class Number	Description
100-81	I	Very good rock
80-61	II	Good rock
60-41	III	Fair Rock
40-21	IV	Poor rock
<21	V	Very poor rock

Paleozoic Valmy Formation

The Paleozoic age Valmy Formation (Pz) crops out as low rolling hills with outcrops 4-10 m (13-33 ft) high along the Malpais Fault scarp. These outcrops are gray and brick red in color. The red coloration is likely hematite and limonite alteration related to hydrothermal activity in the Tertiary and Quaternary (Struhsacker, 1980). This unit is composed of deep-ocean microcrystalline cherts and mudstones forming layers 1-5 cm (0.4-2 in) thick, with scattered barite concentrations. The unit has been highly deformed and displays slight to overturned folding, breaks, and offsets. The variety of deformation along each stratigraphic layer implies that at least some of the deformation occurred prior to lithification. Due to the deformation, bedding orientation measurements may not be exact, but were found have an average dip and dip direction of 38/117 (Figure 9).

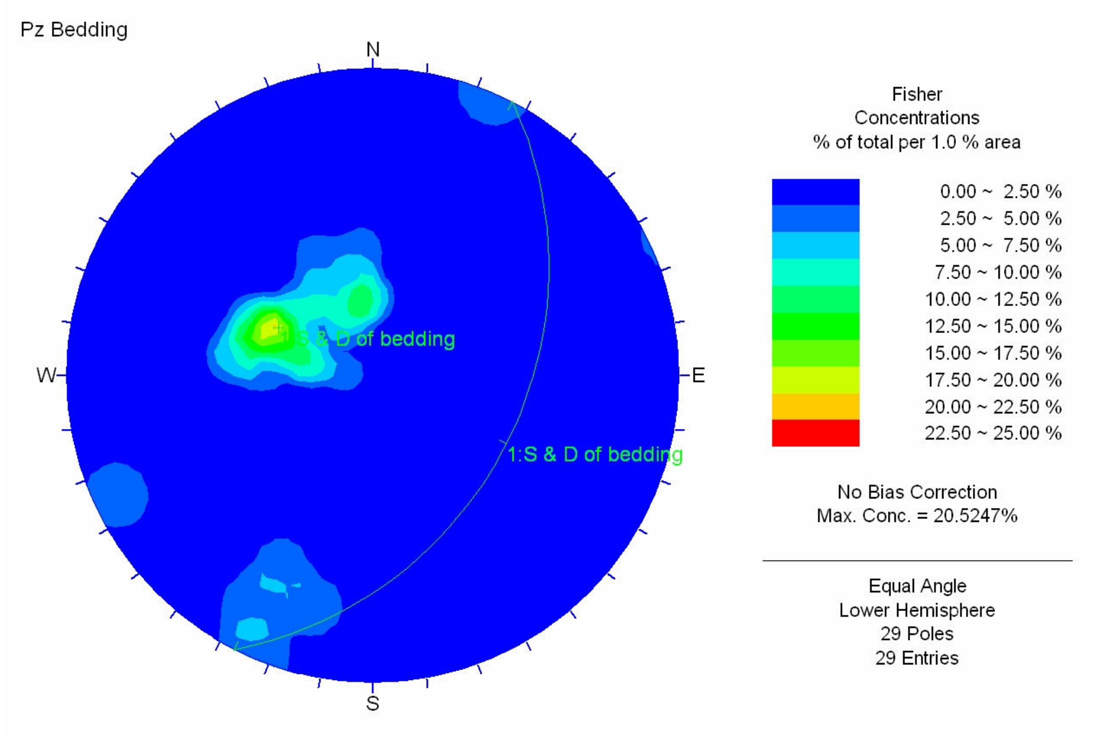


Figure 9: Stereonet showing the bedding dip and dip direction of the Paleozoic Valmy Formation to be 38/117.

To determine the strength of Pz, rock mass ratings were performed on two randomly selected outcrops and laboratory testing was performed on material gathered from outcrops and the landslide surface. The results are summarized in Table 2.

Table 2: Summary of rock mass rating and laboratory testing results for Paleozoic Valmy Formation. See Appendices A, C, and D for complete results.

Unit Pz	Name	Observations	Results
Rock Mass Classification	RMR	see appendix A	79.5 - good rock
	GSI	very blocky and fair to good	50 to 55
Laboratory Testing	Point Load	Average UCS of 34 lump samples	10.33 MPa
	Slake Durability	N/A	98.20%
	Specific Gravity	average of 3 samples	2.48

The high rock mass ratings along with the high point load and slake durability, show that Pz has high intact rock strength. See Appendices A, C, and D for complete results.

Late Eocene to Middle Miocene Sedimentary Rocks

The late Eocene to middle Miocene sedimentary rocks (Ts) lie unconformably on Pz and are composed of tuffaceous, lacustrine, fluvial, ashfall, and conglomerate deposits, with a minor late Eocene andesite flow unit near the base of the section. In outcrop the unit forms low-angle slopes covered with vegetation. Exposures of Ts in the landslide area are limited to animal burrows, talus slopes, and pieces incorporated in the landslide. These poor exposures prevented in situ sampling and bedding orientation measurements from being obtained. The east wall of the barite mine provides good exposure of the lower half of Ts, which is made up of lacustrine, ashfall, conglomerate, and fluvial deposits. Samples were collected and bedding orientation measurements were obtained from this exposure. A stereoplot of the measurements gave an average bedding dip and dip direction of 17/176 (Figure 10). Due to the distance from the landslide and the material's strength, these measurements may not be an accurate representation of the orientation and properties of Ts at the landslide. The upper half of Ts was found to be composed of tuff, andesite, lacustrine, and fluvial deposits, which were visible in animal burrows, talus slopes, and the landside mass. This finding is supported by Struhsacker (1980) and John et al. (2000), who describe the sediments as fine-grained volcaniclastic rocks; rhyolite air-fall, water-lain, and reworked tuffs; and fluvial and lacustrine sandstone. Due to the similarity between the upper and lower half of Ts, average material properties obtained for the lower half of Ts were used for the upper half (discussed below).

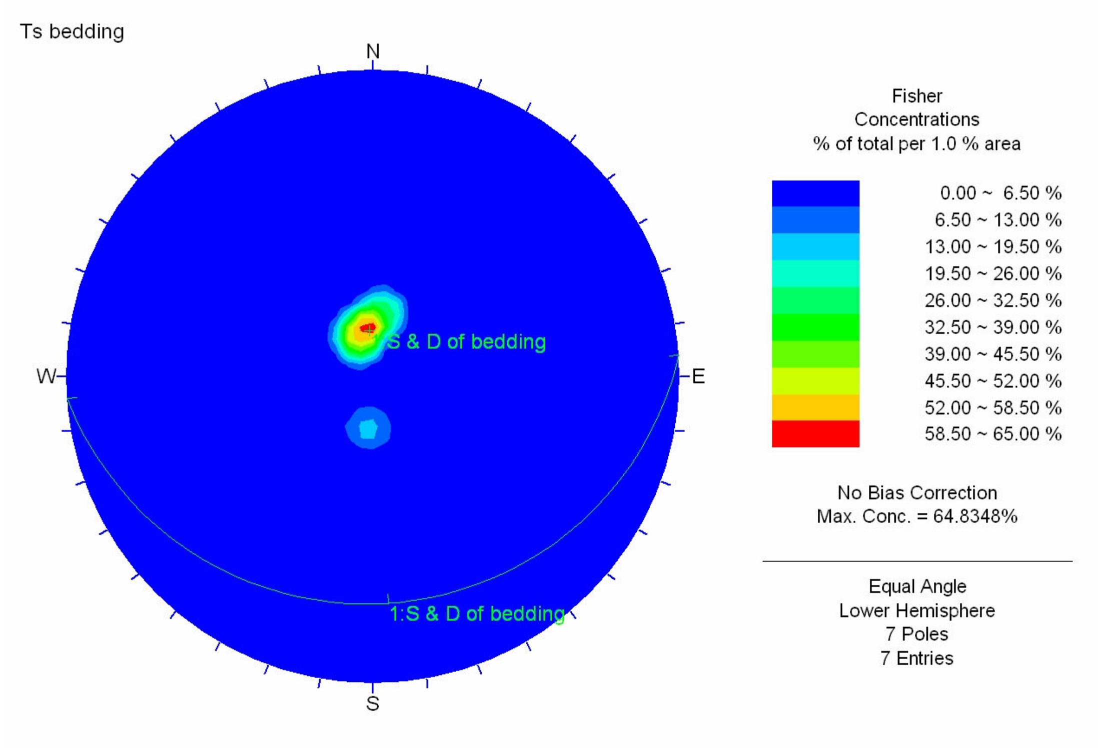


Figure 10: Stereonet showing the bedding dip and dip direction of the Tertiary sedimentary rocks to be 17/176.

To determine the strength of Ts, rock mass ratings and laboratory testing were performed. The mine exposure is composed of silty sand with gravel and boulders. Results are summarized in Table 3. Laboratory point load testing was performed on material gathered at the barite mine. Field point load testing was performed on material gathered from the landslide surface. In-laboratory results are shown below as the material gathered at the barite mine was fresh and more representative of the material incorporated in the landslide. Samples tested in the field likely represent the strongest areas of Ts as they survived the landslide event and subsequent weathering.

Table 3: Summary of rock mass rating and laboratory testing results for the Tertiary sedimentary rocks. See Appendices A, C, and D for complete results.

Unit Ts	Name	Observations	Results
Rock Mass Classification	RMR	see appendix A	39 - poor rock
	GSI	disintegrated and fair	30 to 35
Laboratory Testing	Point Load	average UCS of 96 lump samples	0.828 MPa
	Slake Durability	N/A	5.95%
	Specific Gravity	average of 3 samples	1.81

The poor rock mass ratings along with the low point load strength and slake durability, show that Ts has a very low intact rock strength. The unit appears and feels competent when dry, but once submerged in water the material breaks down within 5 minutes; this is also shown by the low slake durability results. See Appendices A, C, and D for complete results.

The lower half of Ts was divided up into four sub-categories for laboratory testing (Figure 6). Ts(a) is an approximately 6 m(19.7 ft)-thick red-brown colored, matrix-supported conglomerate. It contains subrounded clasts of welded tuff and other volcanics that range in size from sand to 2 m (6.6 ft) in diameter. Due to the clasts sizes Ts(a) is likely a near-source high-energy deposit. Sampling of this unit was not possible, but its matrix was very similar to that of Ts(d); therefore, material strength values obtained for Ts(d) were used for Ts(a). Ts(a) is probably stronger than Ts(d) as a result of higher shear resistance due the presence of larger clasts; thus the use of weaker material properties resulted in more conservative models. Ts(b) is an approximately 5 m (16.4ft)-thick tan to pinkish-red silty sand with 17.3% silt and 1% fine gravel (Appendix E). The sand is made up of ~85% volcanic, ~10% Valmy Formation, and ~5% sedimentary sub-rounded to sub-angular clasts. Ts(c) is an approximately 4 m(13.1 ft)-thick tan silt with sand, containing 26.3% fine to coarse sand (Appendix E). The sand is made up of ~95% volcanic and ~5% Valmy Formation sub-rounded clasts. Ts(d) is an approximately 4 m(13.1 ft)-thick brownish-tan silty sand with 35.7% silt and 1.8% fine gravel (Appendix E). The sand is made up of ~80% Valmy Formation and ~20% volcanic angular to sub-angular clasts. Close-up views of Ts(a), Ts(b), Ts(c), and Ts(d) are shown in Figure 11.

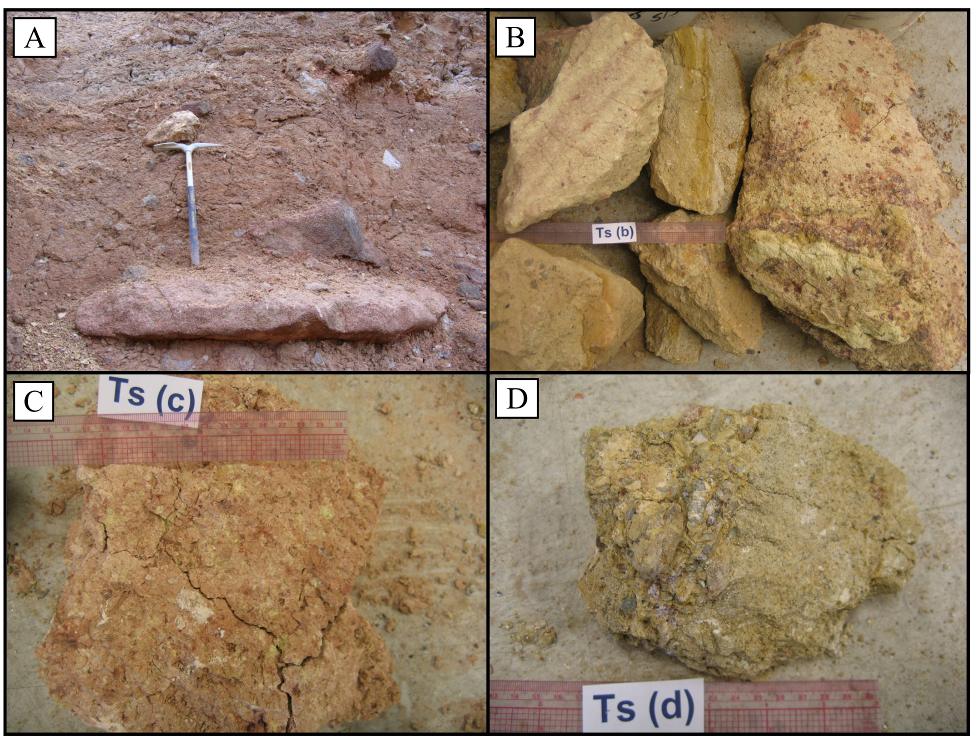


Figure 11: Close-up pictures of the lower half of the Tertiary sedimentary rocks (Ts). A – The typical composition of Ts(a). B – The variation of layers throughout Ts(b), C – The typical appearance of Ts(c), D – A coarse- and finer-grained layer, both typical of Ts(d).

Direct shear testing was performed on Ts(b), Ts(c), and Ts(d) to determine the material strength of each. The average results for shear strength, cohesion (C) and angle of internal friction (Φ) for dry and saturated testing are shown in Table 4. The values for C and Φ were obtained from the Mohr-Coulomb failure envelopes (Appendix F). These results, as well as the slake durability testing, show that Ts(b), Ts(c), and Ts(d) have low dry strengths and even lower saturated strengths. The decrease in strength is caused by decreasing clast sizes as grain to grain bonds are broken and the material becomes finer. Comparing the C and Φ values in tables 4 and 5 shows a drop in both parameters when the material saturated. Saturation causes a drop in C values of up to 20 kPa. More significant is the drop in Φ. Ts(c)'s Φ decreases the most, from 35 to 5 degrees showing that the material is very fine grained and likely has a high clay content. The average material properties of Ts(b), Ts(c), and Ts(d) were used to represent the upper half of Ts (Table 5).

Table 4: Average normal stress, shear stress, cohesion (C), and angle of internal friction (Φ) for Ts(a), Ts(b), and Ts(c). Complete results are in Appendix F.

Unit	Dry					Saturated				
	Equiv. Depth (m)	Normal Stress (kPa)	Shear Stress (kPa)	C (kPa)	Φ	Equiv. Depth (m)	Normal Stress (kPa)	Shear Stress (kPa)	C (kPa)	Φ
Ts(b)	37.7	344.7	349.3	60.0	36.0	37.7	344.7	124.1	60.0	26.0
	75.4	689.5	587.8			75.4	689.5	256.3		
	150.7	1379.0	1146.8			150.7	1379.0	377.5		
Ts(c)	37.7	344.7	303.9	60.0	35.0	37.7	344.7	75.8	50.0	5.0
	75.4	689.5	491.8			75.4	689.5	93.1		
	150.7	1379.0	990.5			150.7	1379.0	152.5		
Ts(d)/ Ts(a)	37.7	344.7	349.3	70.0	38.0	37.7	344.7	141.9	50.0	17.0
	75.4	689.5	587.8			75.4	689.5	281.0		
	150.7	1379.0	1146.8			150.7	1379.0	465.4		

Table 5: Average normal stress, shear stress, cohesion (C), and angle of internal friction (Φ) for the Tertiary sedimentary rocks. Complete results are shown in Appendix F.

Unit	Dry					Saturated				
	Equiv. Depth (m)	Normal Stress (kPa)	Avg. Shear Stress (kPa)	Avg. C (kPa)	Avg. Φ	Equiv. Depth (m)	Normal Stress (kPa)	Avg. Shear Stress (kPa)	Avg. C (kPa)	Avg. Φ
Upper half of Ts	37.7	344.7	320.4	63.3	36.3	37.7	344.7	114.0	53.3	16.0
	75.4	689.5	532.4			75.4	689.5	210.1		
	150.7	1379.0	1053.4			150.7	1379.0	331.8		

The actual strength of the Tertiary sedimentary rock involved in the failure is problematic. Samples were gathered from the barite mine 2 km (1.2 mi) east of the landslide, meaning the obtained strengths may not be representative of the material involved in the landslide. Also, the degree of induration and type of cementation at the landslide may be different (stronger) than at the barite mine. Due to these problems, modeling was performed with the dry material strength values representing the average strength of Ts. Similarly the saturated material strength values were used to represent the low strength boundary.

Two clays were gathered from the surface of Ts at the barite mine. One was yellow-tan with approximately 15% fine- to medium-grained sand and appeared to be derived from Ts(a). It was found to have a liquid limit of 66%, a plastic limit of 40%, and a plasticity index of 26%. The second clay was red with approximately 10% fine-grained sand and appeared to be derived from Ts(b). It was found to have a liquid limit of 76%, a plastic limit of 45%, and a plasticity index of 31%. These results show that both clays are smectitic. They possibly formed within Ts when that unit was altered by hydrothermal activity or during diagenetic alteration of fine-grained ash in the units.

A small talus slope of highly weathered porphyritic biotite-hornblende andesite (Tha) (Struhsacker, 1980) is exposed on the west edge of the landslide (Figure 5). The andesite is discontinuous and outcrops as a portion of the landslide mass; it originated from the lower section of Ts and is only visible at this location. Clasts are gray and weather to red-brown. Hornblende and biotite phenocrysts range from 1-6 mm (0.04-0.24 in) in length. The andesite is composed of approximately 65% groundmass (feldspar and quartz), 20% hornblende, 10% biotite, and 5% olivine. The plagioclase, hornblende, and biotite commonly appear hydrothermally altered to a light green or red-brown color. Point load lump testing of 37 samples gave an average uniaxial compressive strength of 96.4 MPa (13.98 ksi) (Appendix B). Potassium-argon dating by Struhsacker (1980) yielded an age of 38.75 ± 1.3 Ma, which provides an approximate age for Ts as a whole.

Middle Miocene Dacite

The middle Miocene dacite (Td) forms cliffs and the landslide's head scarp, which range from 10-30 m (32.8-98.4 ft) high. In the study area, the unit is made up of six flows, all of which display pervasive columnar jointing (Figure 12). The unit displayed slight magnetism in places; thus the resulting average bedding dip and dip direction of 26/96 could have been affected (Figure 13). Potassium-argon dating by Struhsacker (1980) yielded an age of 16.1 ± 0.6 Ma. The unit is dark gray and weathers to brick red or brown. Each flow is aphanitic and typically grades from non-vesicular at the base to highly vesicular at the top. Many vesicles are elongated, showing either the direction of flow or material degassing, and are commonly filled with clay, calcite, or chalcedony. Blocks of Td incorporated in the landslide display blocky, onion skin, and platy weathering, and form pieces ranging in size from sand to 3 m (9.8 ft) long.

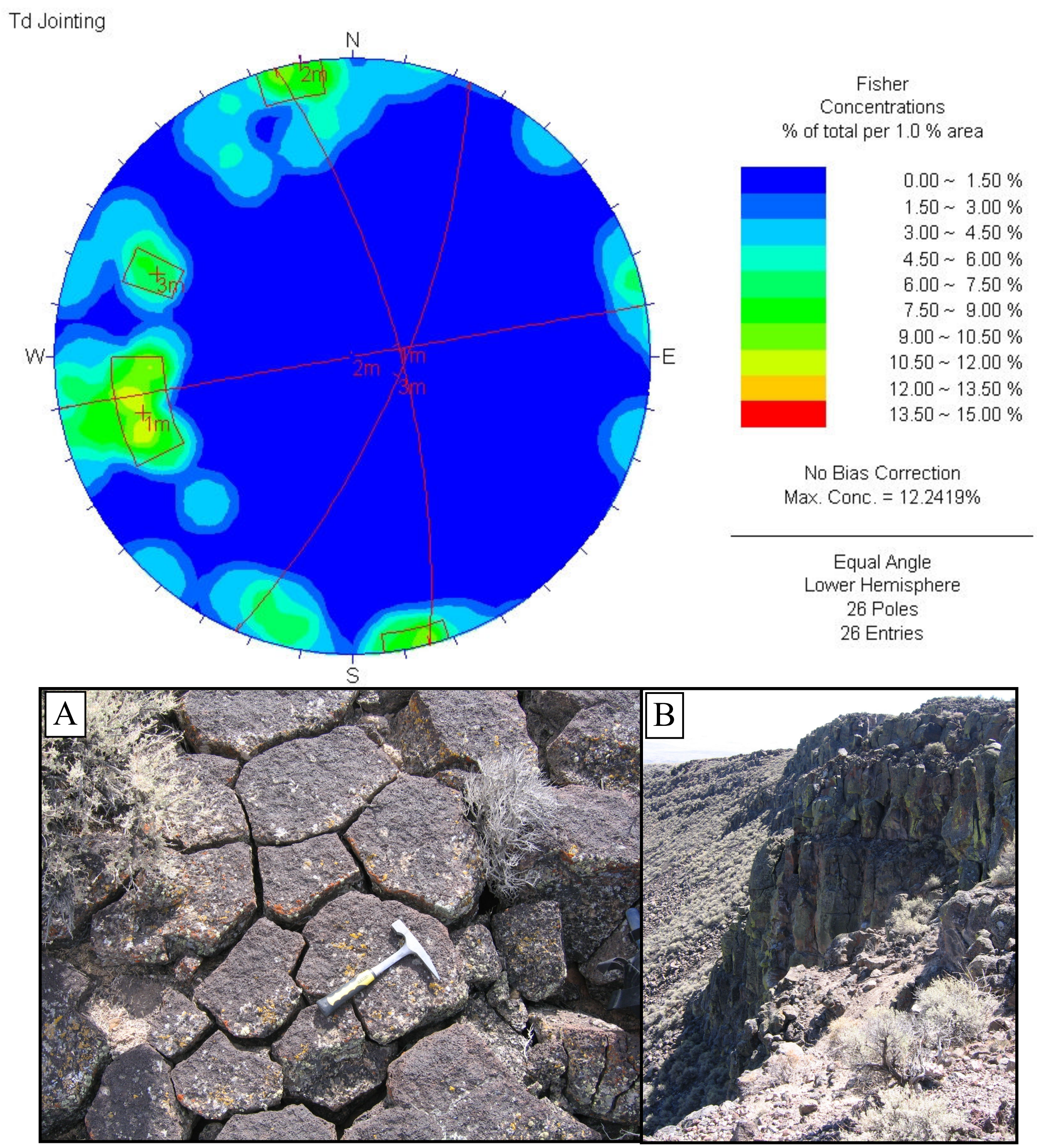


Figure 12: Stereonet depicting the dip and dip direction of columnar jointing within the Tertiary dacite of 71/113, 90/170, and 72/75. A – Columnar jointing tops along the ridge crest. B – Outcrop of columnar-jointed dacite in the head scarp.

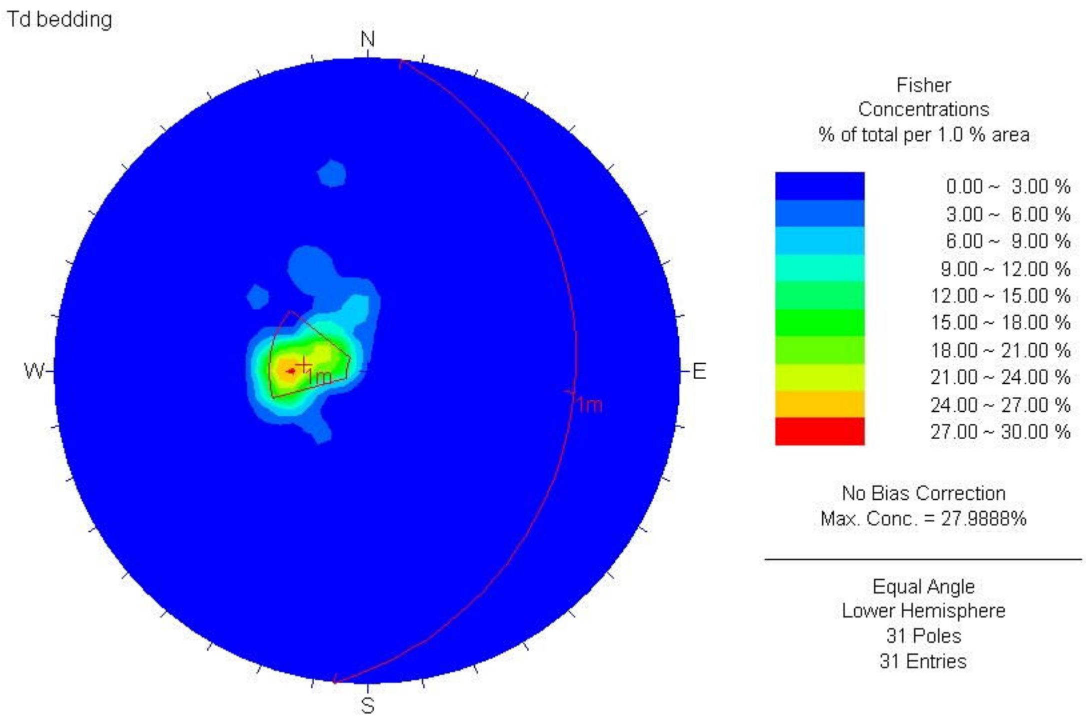


Figure 13: Stereonet showing the bedding dip and dip direction of the dacite to be 26/96.

To determine the strength of Td, rock mass ratings were performed on three randomly selected outcrops, and laboratory testing was performed on material gathered from outcrops and the landslide surface. The results are summarized in Table 6.

Table 6: Summary of rock mass rating and laboratory testing results for the Tertiary dacite. See Appendices A, C, and D for complete results.

Unit Td	Name	Observations	Results
Rock Mass Classification	RMR	see appendix A	77 - good rock
	GSI	very blocky and fair to good	50 to 55
Laboratory Testing	Point Load	average UCS of 21 lump samples	14.48 MPa
	Slake Durability	N/A	99.50%
	Specific Gravity	average of 3 samples	2.54

A comparison of these results to Pz and Ts shows that Td has the highest intact rock strength. Though the intact rock strength is high, the overall strength of the unit is much lower due to the pervasive columnar jointing. See Appendices A, C, and D for complete results.

Chapter V: Landslide Description

The Malpais Landslide failed from a topographic high point on the Malpais Rim (Figure 14) and flowed north into Whirlwind Valley. The landslide averages 0.9 km (0.56 mi) wide and 2.4 km (1.5 mi) long, for an approximate surface area of 2.2 km^2 (0.84 mi^2). Mass-balance calculations were performed by creating a pre-failure cross section of the Malpais Rim at the landslide location (discussed in next section) and comparing it with the post-failure cross section (Figure15) (see Appendix G for additional cross sections). The exact depth of the landslide is unknown as drilling was not performed for this study. Approximate landslide geometry and thickness used for the calculations are shown in Figures 14 and 15. The approximate initial landslide geometry (pre-failure source area) was found to be 0.032 km^3 ($7.7x10^{-3}$ mi^3) with a failure volume of 0.035 km^3 ($8.4x10^{-3}$ mi^3). The larger volume of landslide debris is from bulking of the original rock material during failure. Bulking is caused by increasing material porosity as the material is broken and jumbled. The difference between these calculated volumes is less than the bulking expected in a typical landslide, which is likely the result of the approximations of the landslide dimensions as the landslide depth is not accurately known. Lahars typically increase in volume (bulking) by a factor of 3 to 5 (Wolfe and Pierson, 1995). The volumes calculated here result in a bulking factor of approximately one. This suggests that the Malpais Landslides (which did not fail as a lahar, but likely had a high water content) failure volume may be larger than calculated.

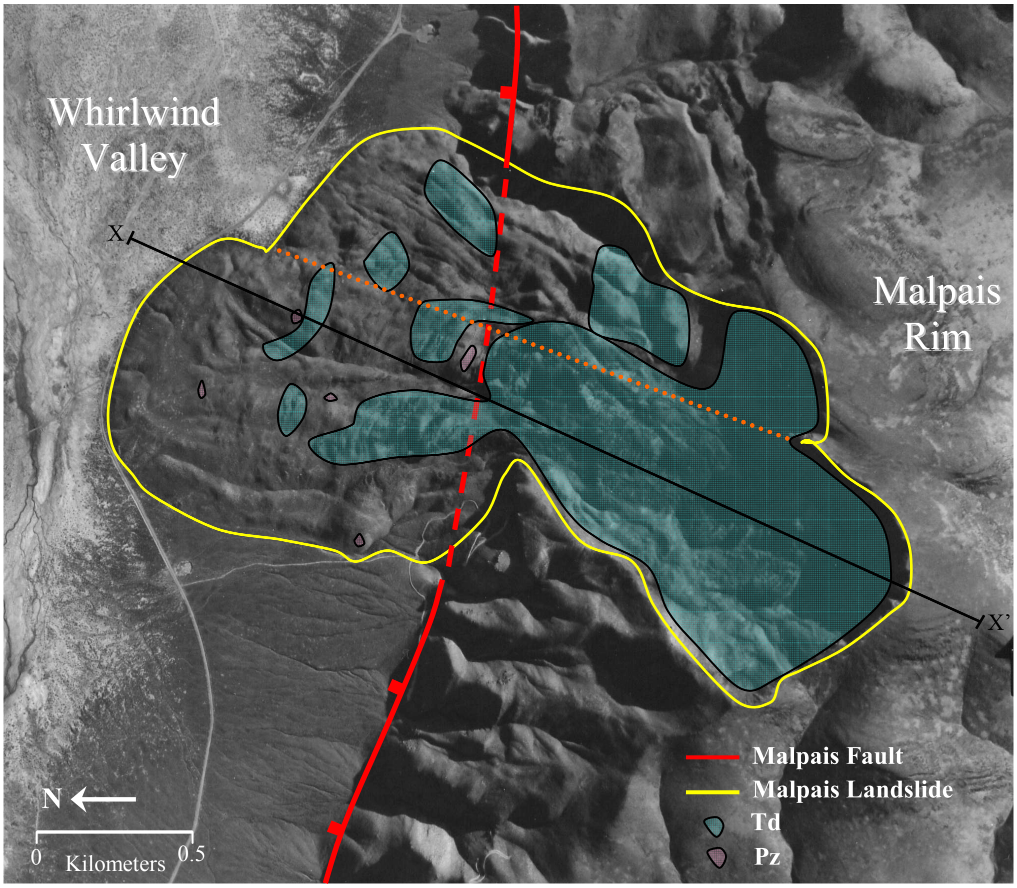


Figure 14: Aerial photograph of the Malpais Landslide study area. Malpais Fault is marked by the red line. Malpais Landslide is outlined in yellow. Distribution of materials within the landslide mass are shown in the shaded regions: blue depicts major Tertiary dacite deposits, pink depicts the Paleozoic sedimentary deposits, and uncolored areas of the landslide represent the Tertiary sedimentary deposits. The orange dotted line represents the divide between the two possible failures. See figure 15 for cross section (X-X').

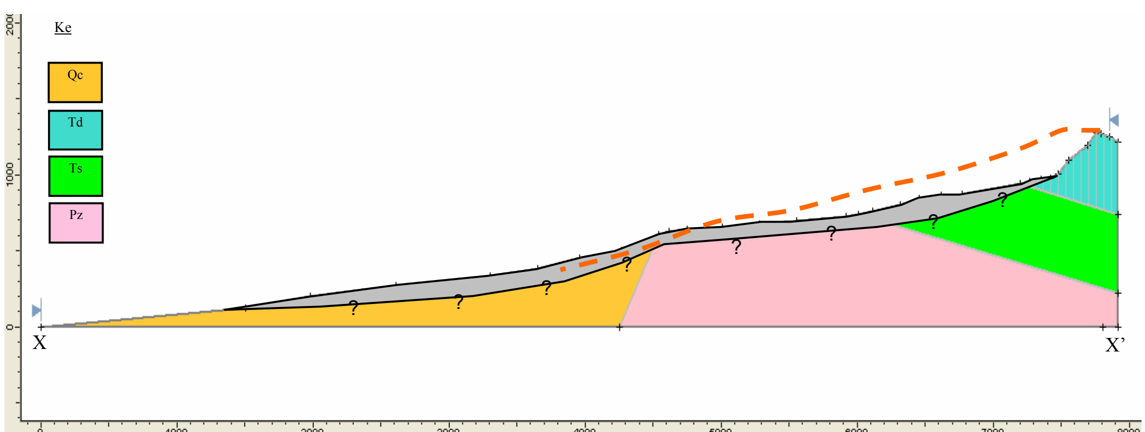


Figure 15: Post-failure cross section with landslide shown in gray. Exact depth of the landslide is unknown as drilling was not performed. Orange line represents the slopes geometry before failure.

The landslide surface is hummocky with incised drainage channels and consists of material from the Tertiary sedimentary rocks (Ts) and Miocene dacites (Td). These units appear approximately in stratigraphic order within the landslide, with Td overlying Ts (Figure 14). The toe of the landslide is composed mainly of Ts, with blocks of Td on the surface. Fragments from Pz were scattered across the western portion of the toe. Those fragments were clasts in the Tertiary sedimentary rocks that were remobilized during failure and were not derived directly from the Paleozoic basement rocks. The head of the landslide is composed mainly of dacite blocks which form hills up to 15 m (49.2 ft) tall (Figure 16). Ts appears as a loose sediments (vs. rock) in the landslide mass and Td appears mainly as broken jumbled blocks ranging in size from sand to 3 m (9.8 ft) long. Near the head of the landslide portions of Td display intact characteristics which are shown in Figure 17. Figure 17a shows the relatively intact, 30 m (98 ft) high, block at the head of the landslide mass. Structural measurements from the block show that it has rotated down slope approximately 30 degrees from the vertical (average dip of the columnar jointing) and dropped down approximately 75 m (246 ft) from the head scarp. The figure also shows the highest point of the landslide mass. Figure 17b shows the linear growth of vegetation in the landslide mass, which is likely occurring along earlier release planes.

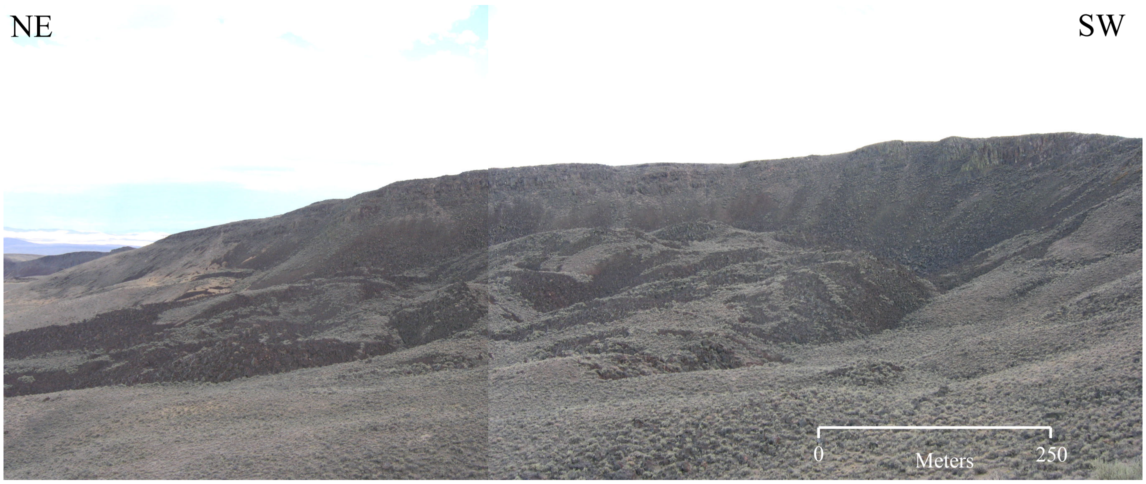


Figure 16: Head of the landslide is composed of dacite blocks.

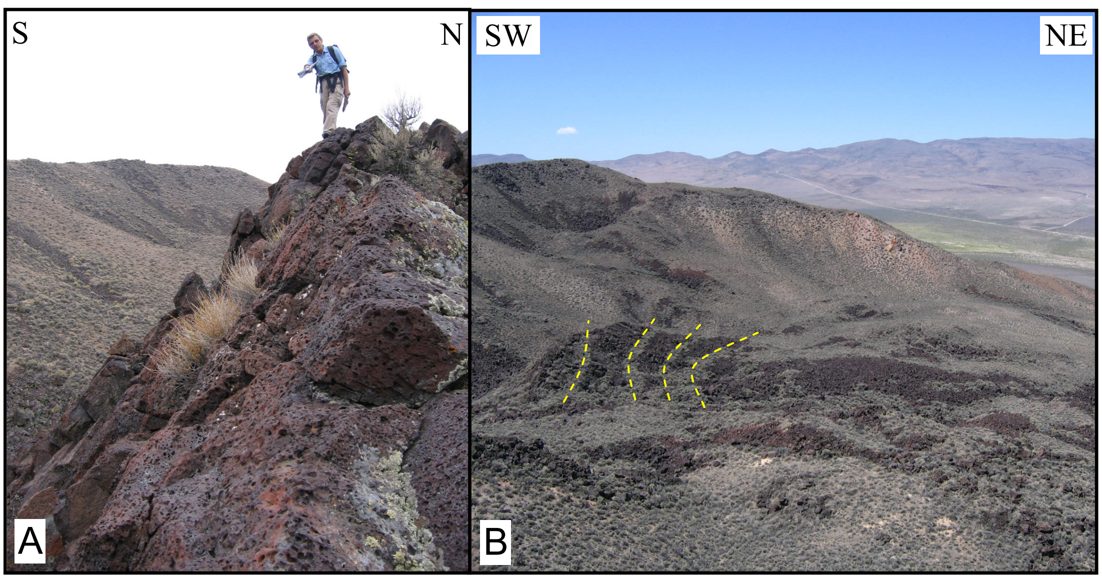


Figure 17: A – Possible release boundary along columnar jointing within the Tertiary dacite which marks the north side of the moat (mentioned below) and is the high point of the landslide mass (1.7 m figure for scale). B – Linear features (marked by yellow lines) showing evidence of multiple release surfaces or block rotations during failure.

A crescent-shaped scarp, approximately 100 m (328.1 ft) high at its highest point, forms the head of the landslide and approximately follows two of the measured columnar jointing strike faces (N23E and N80E) (Figure 12). There is an approximately 240 m

(787.4 ft) wide moat below the head scarp (Figure 18). The western edge of the landslide is stratigraphically intact, with Pz underlying Ts and Td forming the cap rock. The eastern edge of the landslide displays slump blocks, which caused repeating layers of Ts and Td (Figure 5). These repeating layers are underlain by Pz and capped by Td.

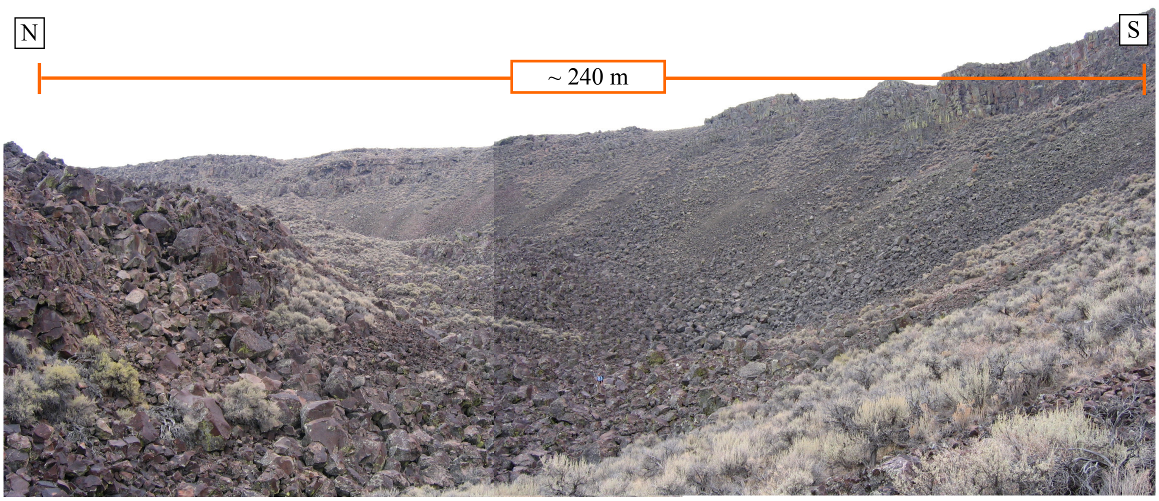


Figure 18: The head scarp and moat.

Several faults are present in the study area. The Malpais Fault, which marks the boundary between the Malpais Rim and Whirlwind Valley, has been locally buried by the landslide. Close inspection of the debris along the fault trace did not reveal evidence of material offset, suggesting that the last fault motion occurred before or coincided with the landslide event. Trench mapping along the Malpais Fault approximately 10 km (6.2 mi) east of the landslide shows that the last fault motion occurred 7450 ± 112 calendar years before present, with a minimum normal offset of approximately 2 m (6.6 ft) (Wesnousky, et al., 2005). No trench mapping across the fault at the landslide was undertaken for that study. Along the eastern margin of the landslide, four subparallel normal faults progressively downdrop the Ts-Td sequence. These faults may be splays of the Malpais Fault given their similar orientation and sense of displacement, or they may be incompletely failed slump blocks that formed as the Malpais Rim was uplifted. Similar faults are exposed west of the landslide (Struhsacker, 1980); the two sets of fault may be continuous beneath the slide if they are tectonic in origin.

Another fault, likely a splay of the Dunphy Pass fault, strikes to the north and is exposed along part of the western boundary of the landslide's release plane (Figure 5). This fault was mapped by observing the change from Td to Ts at the west end of the scarp and by its trace passing through and offsetting material within a spire of Pz along the landslide edge (Figure 19). This spire likely exists due to fluid motion and mineral deposition along the fault, causing a local increase in material strength. The fault cannot be traced beyond this point as it has been buried by, and thus is older than, the landslide.

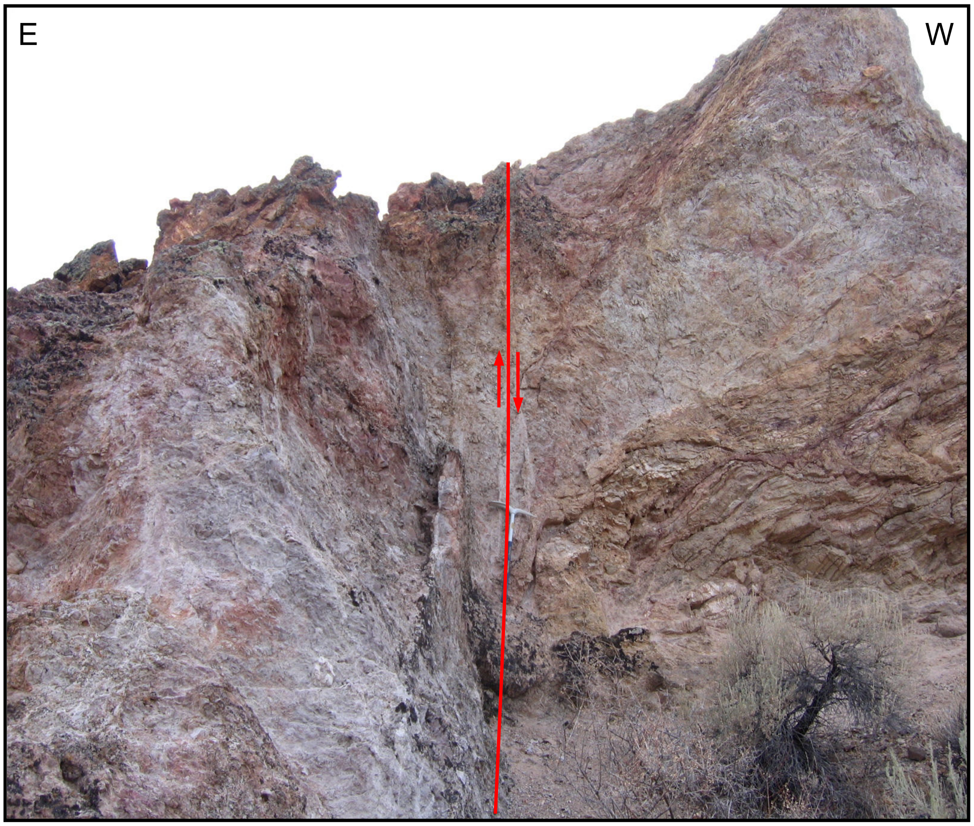


Figure 19: Fault cutting though a spire of the Paleozoic Valmy Formation on the landslide's western release plane.

The landslide has a low surface slope angle of approximately eight degrees, suggesting that significant water was present within Ts at the time of failure. No springs, ponds, or moist ground were observed in the study area. The landslide displays a double-lobe toe and a double-cusped scarp, which suggests that the slope may have failed twice, first on the east and then, on a larger scale, on the west (Figure14). The landslide may have also failed in a retrogressive mode (described in Chapter VI below) similar to the Mt. St. Helens failure in 1980. Though these scenarios are possible, the landslide was treated as one event for the stability analysis.

Other landslides and smaller slump failures are located throughout the region. Mapping by Wallace (1990) in the Jake Creek Mountain Quadrangle, Nevada revealed three large and a few small landslides. These landslides occurred along late Cenozoic escarpments formed by high-angle faulting very similar the Malpais Rim. They occurred in a sequence of relatively weak basaltic andesite overlain by about half a kilometer of competent rhyolite tuff and porphyry. This sequence of weaker material overlain by stronger material is similar to the Malpais study area and the occurrence of these events likely depended on the same triggers (water table location and seismic loading) being studied here.

Chapter VI: Landslide Stability Analysis

The pre-failure slope topography was constructed by extrapolating stable slopes on either side of the landslide to the center along line A-A' (Figure 20 and 21). Figure 22 shows the post-failure cross section created along line B-B'. This cross section shows a steep head scarp and a low-angle (~8 degree) landslide mass. The geometry and thickness of the landslide material shown on the cross section is an approximation as the depth has not been accurately assessed. Mass-balance calculations support the constructed slope geometry as the volume of the initial landslide geometry (pre-failure source area) is smaller than the volume of landslide mass, with approximate values of 0.032 km^3 ($7.7x10^{-3}$ mi^3) and 0.035 km^3 ($8.4x10^{-3}$ mi^3), respectively. Laboratory testing showed that Malpais Rim is made up of a sequence of strong(Pz)-weak(Ts)-strong(Td) units (shown in cross section A-A'). Field work revealed that failure originated within the weakly cemented Ts and propagated upward into Td, but did not extend down into Pz. These strengths, along with the likely destabilizing forces of water table location and seismic loading, were used in the stability analysis.

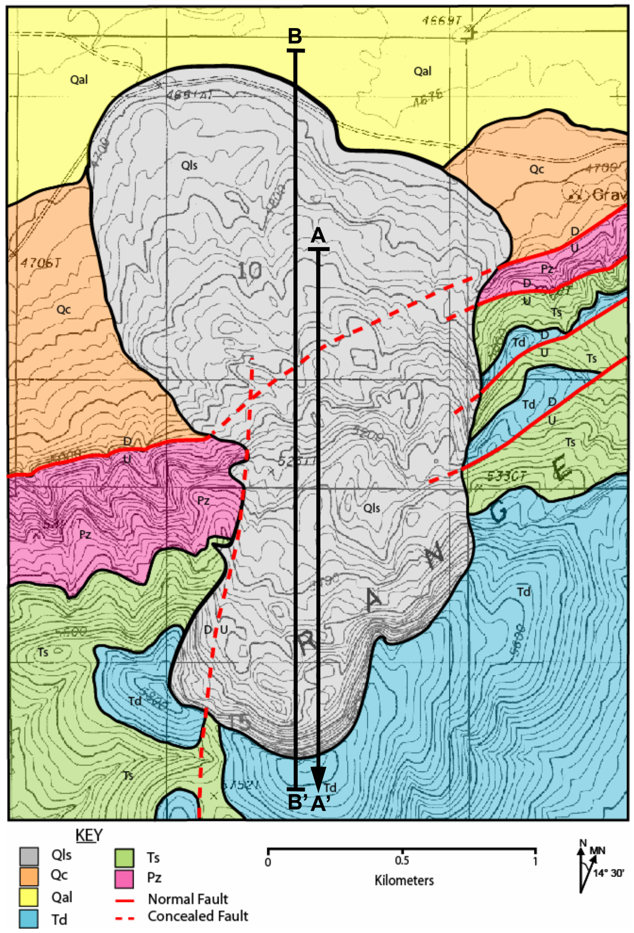


Figure 20: Geologic map of the Malpais Landslide. A-A' shows the location of the constructed slope (pre-failure) cross section. B-B' shows the location of the post-failure cross section.

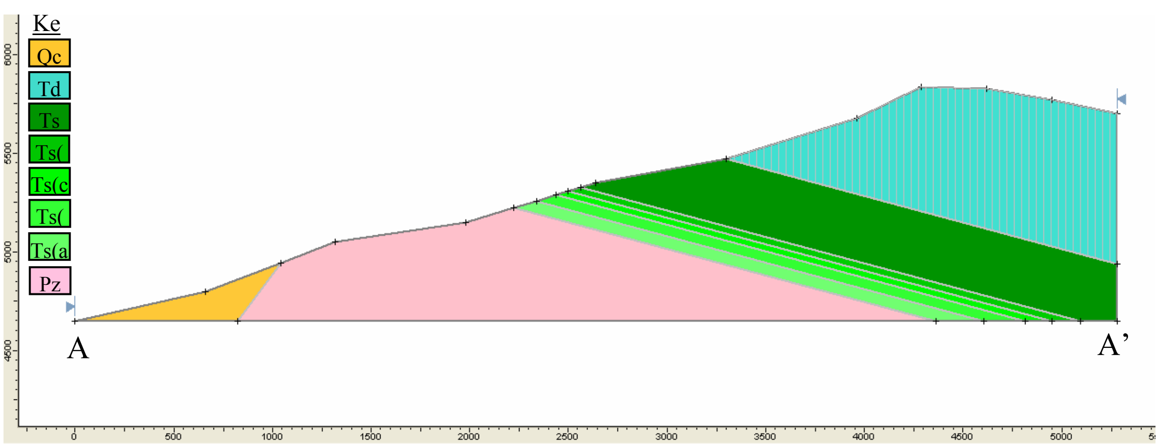


Figure 21: Pre-failure cross section along the center line of the landslide mass (A-A').

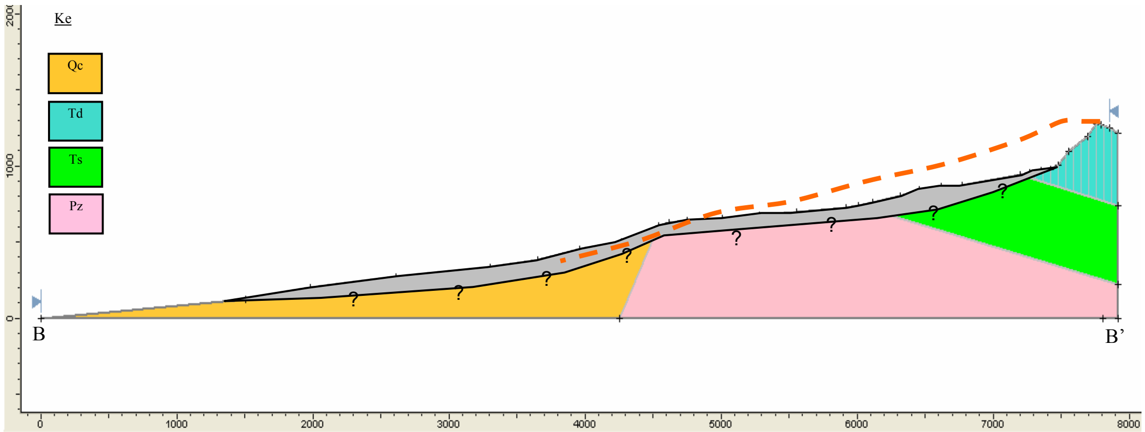


Figure 22: Post-failure cross section along the center line of the landslide mass (B-B'). Landslide mass (shown in gray) is approximated as actual landslide depth has not been accurately assessed. Orange dashed line shows the pre-failure surface geometry.

Stability analyses were performed using Slide 5.0 (1998-2008) a limit equilibrium slope stability program capable of different stability methods. Analyses were run using the Spencer, Bishop Simplified, and Janbu Simplified limit equilibrium methods. Comparing the three methods results in a small difference (up to 0.06) in the calculated factors of safety (FS). Spencer limit equilibrium results are shown below as it was the most comprehensive procedure, employing twenty-five slices, with the normal force acting at the center-base of each slice. The landslide was modeled using the drained-undrained method, which allows cohesion, angle of internal friction, and unit weight to be included for each unit. Cohesion values were varied with depth to a maximum depth of 160 m (524.9 ft). A focus point was added 6 m (19.7 ft) up the slope from the Pz-Ts contact to account for the inclusion of units down to and not including Pz. Tension cracks were added throughout the dacite to represent the pervasive columnar jointing.

Models were created with varying material strengths (Tables 3 and 4), seismic loads, and water table elevations. Peak ground accelerations do not last for more than a moment; consequent standard engineering practice is to use two thirds of the peak (0.2g) for modeling. This fraction (~0.13g) has a 2% probability of exceedance in 50 years (USGS, 2008). Half of the peak is also commonly used for modeling, but since the landslide lies across the Malpais Fault and other faults are located nearby, two thirds of the peak was used to incorporate the possibility of near-field seismic affects. Parameters used and the resulting factors of safety are shown in Table 7. Recall that the saturated material strength values were used to represent the low strength boundary, while the dry material strength values were used to represent the average material strength (discussed in the lithology section). Factors of safety less than one correspond to unstable conditions and indicate failure. The models are shown in Figures 23 through 27.

A circular composite failure surface was chosen to model the weak nature of Ts and to take the tension cracks into account. The resulting models show a failure surface which is circular through Ts and vertical to the surface once it encounters the columnar jointing within Td. It is likely that the landslide failed through Td at a lower point on the slope, producing instability in the jointed dacite and allowing for rock falls, topples, intact block rotations, and slides to occur as the slope was over steepened. These retrogressive failures would have continued up slope until the slope equilibrated at the present head scarp location (marked by the arrow in each model).

Table 7: Summary of model parameters and resulting factors of safety. Recall: saturated material strength values represent the lower strength boundary and dry values represent the average strength of Ts.

Model #	Saturated Material Strength	Water Table Position	Seismic Load	Factor of Safety
1	No	None	None	2.14
2	Yes	None	None	0.96
3	No	None	13%g	1.11
4	No	At the ground surface	None	1.04
5	No	23 m bgs	0.13g	0.98

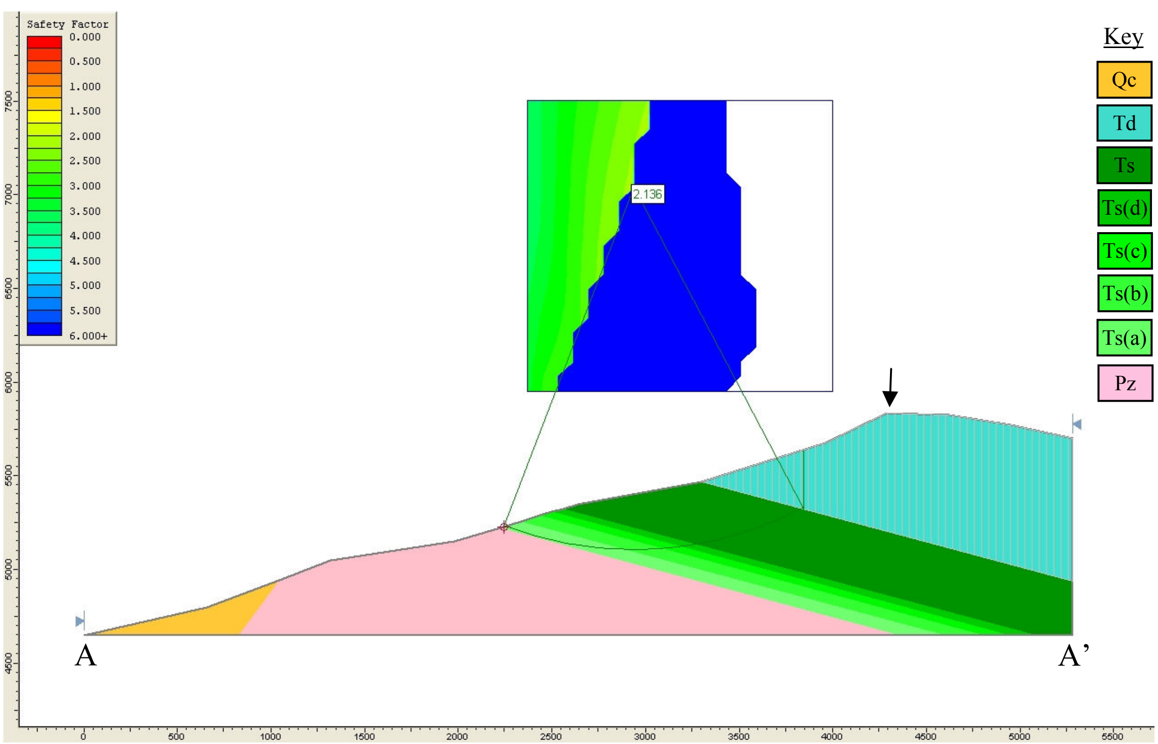


Figure 23: Model 1 – Average (dry) material strength values result in a FS of 2.14. Arrow shows location of actual head scarp.

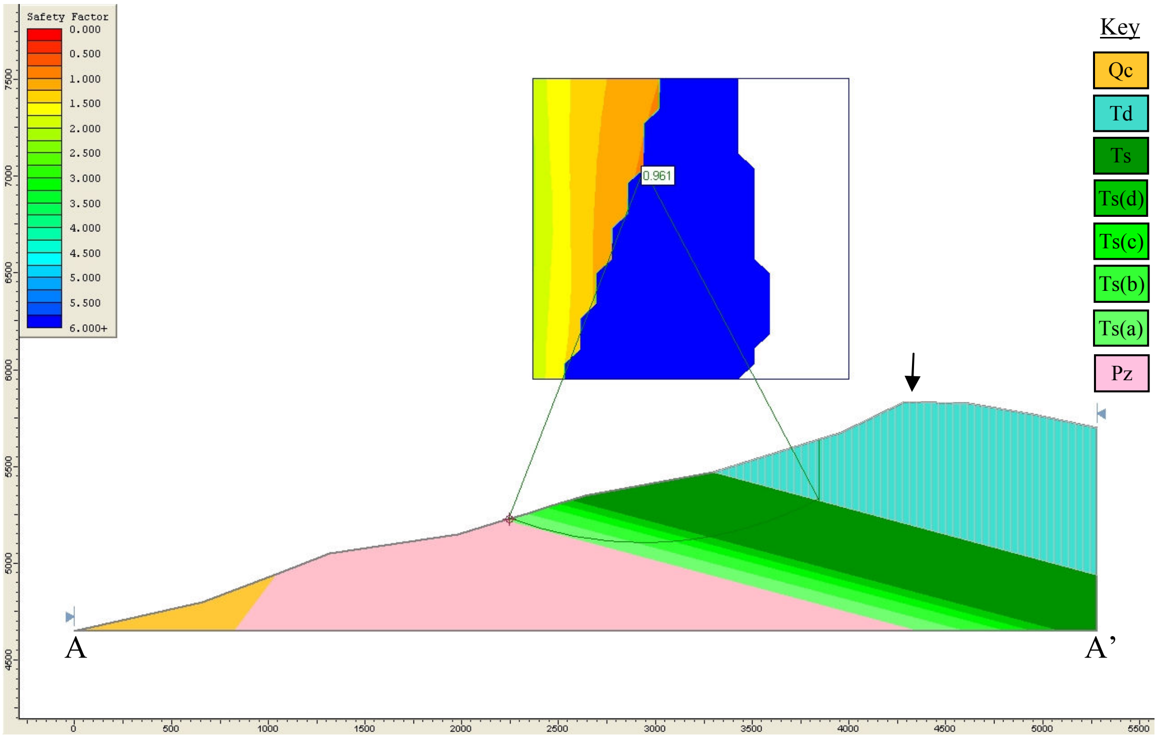


Figure 24: Model 2 – Saturated material strength values result in a FS of 0.96. Arrow shows location of actual head scarp.

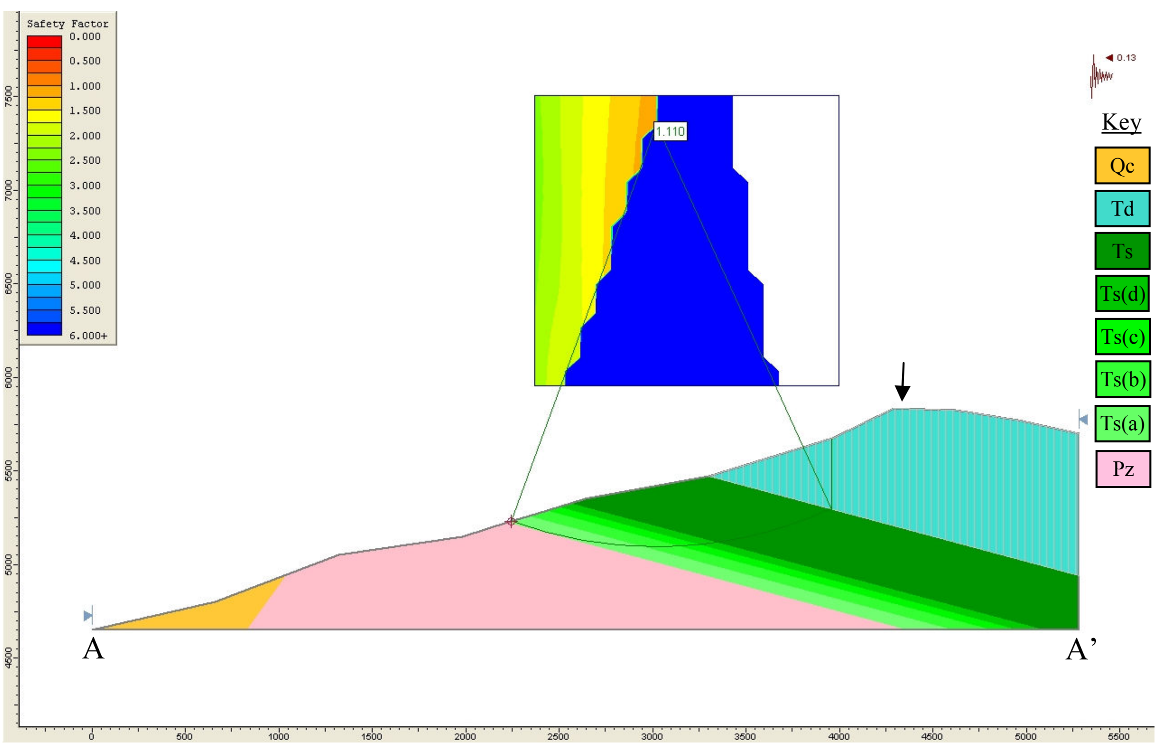


Figure 25: Model 3 – Average (dry) material strength values with a seismic load of 0.13g result in a FS of 1.11. Arrow shows location of actual head scarp.

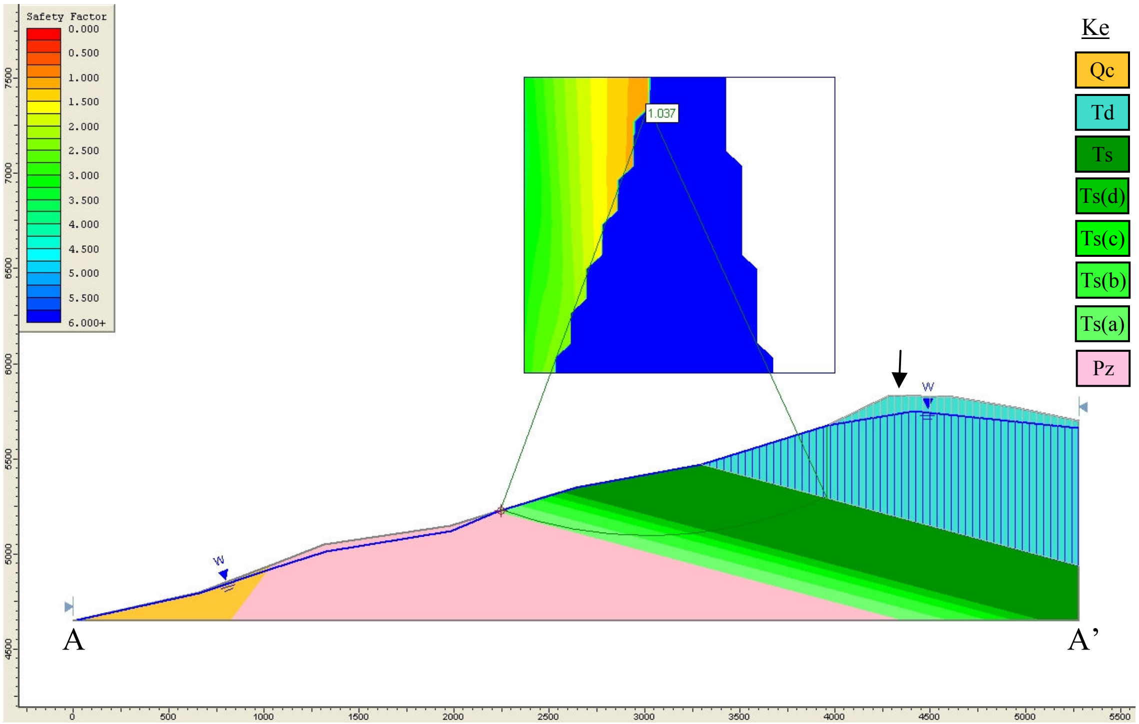


Figure 26: Model 4 – Average (dry) material strength values with the water table (blue line) at the ground surface in the Tertiary sedimentary rock, result in a FS of 1.04. Arrow shows location of actual head scarp.

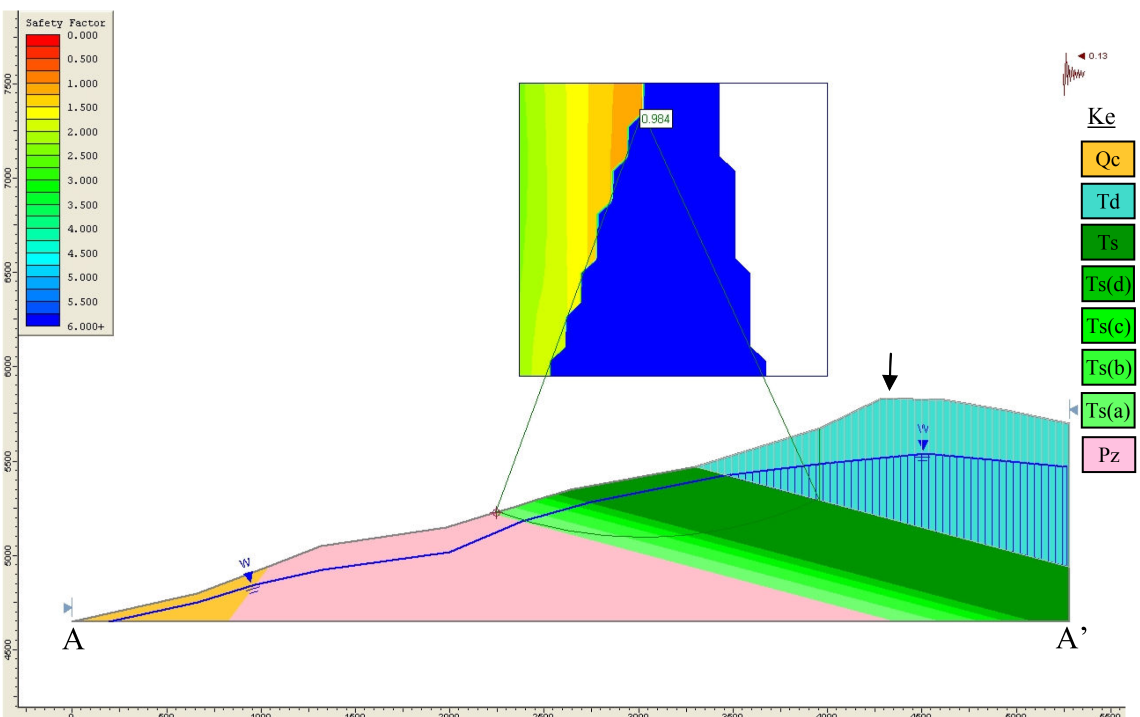


Figure 27: Model 5 – Average (dry) material strength values with a water table depth (blue line) of 23 m in the Tertiary sedimentary rock and a 0.13g seismic load result in a FS of 0.98. Arrow shows location of actual head scarp.

Models 1, 3, and 4 show that the slope is stable as long as the average strength for Ts is used and no seismic load is applied. Model 2 shows that the slope is unstable when the saturated material strength values are used for Ts. Therefore, the most likely failure scenario involves the average (dry) material strength values, a water table, and a seismic load. Model 5 shows that a seismic load of 0.13g and a water table depth of 23 m (75 ft) below ground surface (bgs) in Ts produces failure. Other possibilities of failure using these parameters are a higher water table and a smaller seismic load, a lower water table and a larger seismic load, and a seismic event larger than that calculated for the region. Examples of these scenarios are shown in Figure 28. Figure 28a represents the slope with the average material strength values, a water table of approximately 10 m (32 ft) bgs in Ts, and a seismic load of 0.065g. These changes result in a FS of 0.99. Figure 28b represents the slope with the average material strength values, a seismic load of 0.2g (the peak ground acceleration for the region), and no water table. These changes result in a FS of 0.88.

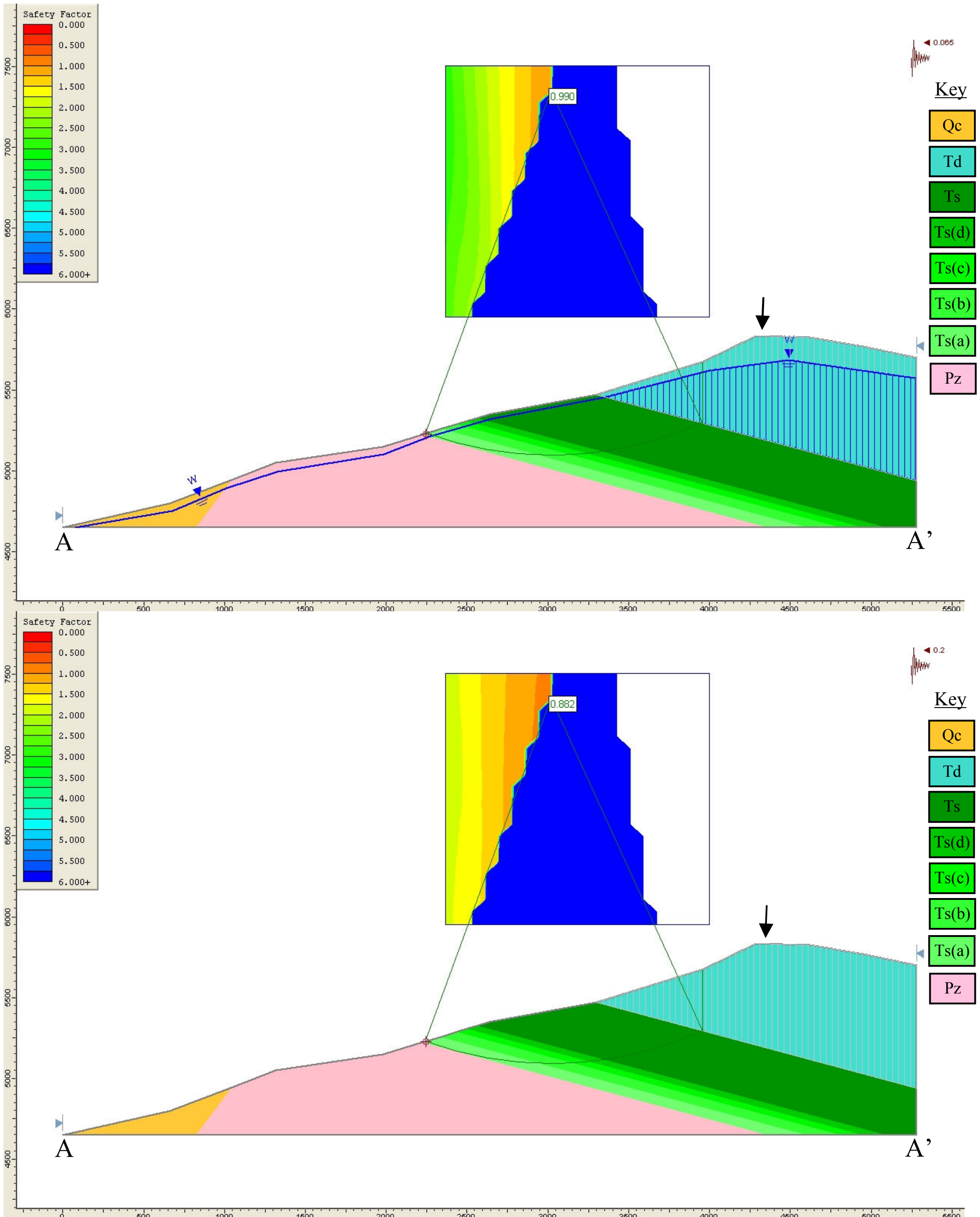


Figure 28: A – Average (dry) material strength values with a water table depth (blue line) of approximately 10 m in the Tertiary sedimentary rock and a seismic load of 0.065g, result in a FS of 0.99. B – Average (dry) material strength values with a seismic load of 0.20g and no water table, result in an unstable slope with a FS of 0.88.

Chapter VII: Conclusions

The Malpais Landslide is located along the northern side of the Malpais Rim, which formed in the late Cenozoic. The landslide has an area of approximately 2.2 km^2 (0.84 mi^2) and a failure volume of 0.035 km^3. The Malpais Fault, which is locally buried by the landslide, marks the boundary between the Malpais Rim and Whirlwind Valley. Seismic hazard mapping performed by the USGS (2008) showed peak ground acceleration for the region to be 0.2g with a 2% probability of exceedance in 50 years. Two thirds of this value (0.13g) was used for the majority of the models. The last motion along the Malpais Fault was found to be 7450 ± 112 calendar years before present (Wesnousky, et al. 2005). No offsets were found within the landslide, suggesting that the landslide occurred contemporaneously with or after the last fault motion, or that the offset was too small to be seen in the landslide debris. The exact age of the landslide is therefore not known; though it is likely Holocene and was mapped as Quaternary for this study, as well as by Stuhsacker (1980) and John et al. (2000).

Through field mapping and investigation, six major lithologic units and five normal faults were defined within the study area. Rock mass classifications and laboratory testing showed that the Tertiary sedimentary rocks (Ts) are the weakest lithology; thus the bottom failure surface likely began within this unit and did not extend into the underlying Paleozoic Valmy Formation. Laboratory direct shear testing of Ts enabled the cohesion and angle of internal friction to be obtained. The strength results were dependent on the degree of saturation. These values were then used to model the landslide, determine the most likely failure mechanism, and the factor of safety at failure.

All units have undergone some hydrothermal alteration. Alteration within Ts would likely produce smectitic clays (though the smectite may also have formed through diagenesis) like those found at the barite mine, further decreasing the strength of Ts. Due to the weakness of Ts, the landslide likely initiated as a shallow circular failure within Ts. Once the failure surface propagated upward into the overlying Td, it followed the pervasive (approximately vertical) columnar jointing in that unit to the surface. All models show that the failure surface daylighted north of the present head scarp, within the area now covered by the landslide. This is a reasonable result as failure at the modeled locations would have produced instability in the dacite, causing the slope to continue to fail in a retrogressive manner as a series of rock falls, topples, intact block rotations, and slides. These failures would have continued up the slope (away from the original head scarp) until equilibrium was re-established and the slope stabilized at the present head scarp location.

Possible failure triggering mechanisms included the presence of a weak unit, an increase in the water table level, and/or seismic loading. Modeling of the reconstructed pre-failure slope established the magnitude and combination of these parameters critical for instability. The slope was found to be stable under average (dry) conditions with no water table or seismic loading (Model 1). The slope was found to be unstable when the saturated material strength values were used for Ts (Model 2). Due to the results of Model 2, it is unnecessary to use saturated material strengths with any other parameters. Modeling with average (dry) material strength values resulted in three other possible failure scenarios. Models 3 and 4 resulted in a stable slope when a ground acceleration of 0.13g or a water table located at the ground surface was applied. Thus, to produce instability, a combination of a water table and seismic loading is required. Model 5 represents a likely failure scenario with the water table located approximately 23 m (75 ft) bgs in Ts and a seismic load of 0.13g (Figure 27). This combination resulted in a FS of 0.98. Figure 28 shows two variations of Model 5 which would also produce failure. Figure 28a represents the slope with the average material strength values, a water table of approximately 10 m (32 ft) bgs in Ts, and a seismic load of 0.065g. Figure 28b represents the slope with the average material strength values, a seismic load of 0.2g and no water table. Therefore, development of the Malpais landslide depended on the presence of a very weak lacustrine sedimentary unit (Ts) along with the destabilizing influence of water pressure and seismic loading.

Several slumps, rockfalls, and landslides are present in the region surrounding the landslide study area and support the potential for future failures. A number of landslides mapped by Wallace (1990) have surrounding stratigraphy which includes a relatively weak unit (like Ts in this study) overlain by stronger units, suggesting that these landslide occurred under the influence of similar destabilizing forces found for the Malpais Landslide. A series of back to back wet seasons which would cause an increase in the water table, a medium to large seismic event, or a combination of both could initiate a future failure. Studies of failed and unfailed ridgelines could be performed to determine the present stability state.

References

ASTM D 2487 – 66 T, 1966 (2000), Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System): ASTM International, West Conshohocken, PA.

ASTM D 4318 – 83, 1983 (2005), Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils: ASTM International, West Conshohocken, PA.

ASTM D 4644 – 87, 1987 (2004), Standard Test Method for Slake Durability of Shales and Similar Weak Rocks: ASTM International, West Conshohocken, PA.

ASTM D 5731 – 95, 1995 (2005), Standard Test Method for Determination of the Point Load Strength Index of Rock: ASTM International, West Conshohocken, PA.

ASTM D 5779 – 95a, 1995 (Reapproved 2001), Standard Test Method for Field Determination of Apparent Specific Gravity of Rock and Manmade Materials for Erosion Control: ASTM International, West Conshohocken, PA.

ASTM D 6913 – 04, 2004, Standard Test Method for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis: ASTM International, West Conshohocken, PA.

Bieniawski, Z.T., 1989, Engineering Rock Mass Classifications. John Wiley and Sons, Inc., p. 51-72.

Bowden, A.J., Lamont-Black, J., and Ullyott, S., 1998, Point load testing of weal rocks with particular reference to chalk: Quarterly Journal Engineering Geology, v. 31, no. 2, p. 95-103.

Bowles, J.E., 1992, Engineering Properties of Soils and Their Measurement: Direct-Shear Test, Test 17, 2nd ed.. Irwin/McGraw-Hill, Inc., p. 201-210.

Bowman, S.D. and Watters, R.J., 2007, Technical Note: A new, highly portable point load test device for extreme field areas: Environmental and Engineering Geoscience, v. 13, no. 1, p. 69-73.

Dickinson, W.R., 2006, Geotectonic evolution of the Great Basin: Geosphere, v. 2, no. 7, p. 353-368.

Dips 5.1, 1998-2003, Rocscience Incorporated, Toronto, Ontario [software package].

Hoek, E. and Brown, E.T., 1997, Practical estimates of rock mass strength: International Journal of Rock Mechanics and Mineral Science, v. 34, no. 8, p. 1165-1186.

John, D.A., Hofstra, A.H., Fleck, R.J., Brummer, J.E., and Saderholm, E.C., 2003, Geologic setting and genesis of the Mule Canyon low-sulfidation epithermal gold-silver deposit, North-Central Nevada: Economic Geology, v. 98, p. 425-463.

John, D.A., Wallace, A.R., Ponce, D.A., Fleck, R.B., and Conrad, J.E., 2000, New perspectives on the geology and origin of the Northern Nevada Rift *in* Cluer, J.K. Price, J.G., Struhsacker, E.M., Hardyman, R.F., and Morris, C.L., ed., Geology and Ore Deposits 2000: The Great Basin and Beyond, Geological Society of Nevada Symposium Proceedings, Reno/Sparks, May 15-18, 2000, P. 127-154.

Koehler, R.D., 2009, Late Pleistocene regional extension rate derived from earthquake geology of late Quaternary faults across Great Basin, Nevada between 38.5° and 40° N latitude, [Ph.D. thesis], University of Nevada Reno, Reno, Nevada.

Mifflin, M.D. and Wheat, M.M., 1979, Pluvial lakes and estimated Pluvial climates of Nevada: Nevada Bureau of Mines and Geology Bulletin 94.

Reheis, M., 1999, Extent of Pleistocene lakes in the western Great Basin: U.S. Geological Survey Miscellaneous Field Studies Map MF-2323, scale 1:800,000.

Slemmons, D.B., 1982, Determination of design earthquake magnitude for microzonation, *in* Proceedings of the Third International Earthquake Microzonation Conference 1: National Science Foundation, Washington, DC, p. 119-130.

Slide 5.0, 1998-2008, Rocscience Incorporated, Toronto, Ontario [software package].

Stewart, J.H. and Carlson, J.E., 1977, Million-scale geologic map of Nevada: Nevada Bureau of Mines and Geology Map 57, scale 1:1,000,000.

Struhsacker, E.M., 1980, The geology of the Beowawe geothermal system, Eureka and Lander Counties, Nevada: University of Utah Research Institute, Earth Science Laboratory Report ESL-37, U.S. Department of Energy 12079-7, p. 78.

Tilden, J.E., Ponce, D. A., Glen, J.M.G., John, D.A., and Person, M.A., 2005, Three-dimensional geologic model of the Beowawe Geothermal Area, North-Central Nevada: Geological Society of America, Abstracts with Programs, v. 31, no. 7, p. 380.

USGS, 2008, Earthquake Hazards Program: Peak acceleration (%g) with 2% probability of exceedance in 50 years site: NEHRP B-C boundary, National Seismic Hazard Mapping Project: Website http://earthquake.usgs.gov/regional/states/nevada/hazards.php, accessed on December 2, 2008.

U.S. Geological Survey, 2004, Geologic provinces of the United States: Basin and Range Province, simple sub-province index map: Website http://geomaps.wr.usgs.gov/parks/province/INDEXbasinRangeSUBS.gif, accessed on March 12, 2009.

Wallace, R.W., 1990, Geologic map of the Jake Creek Mountain quadrangle, Elko County, Nevada: U.S. Geological Survey Map GQ-1672, scale 1:24,000.

Watt, J.T., Glen, J.M.G., John, D.A., and Ponce, D.A., 2007, Three-dimensional geologic model of the Northern Nevada Rift and the Beowawe Geothermal System, North-Central Nevada: Geosphere, v. 3, no. 6, p. 667-682.

Wesnousky, S.G., Barron, D., Briggs, R., Caskey, J., Kumar, S., and Owen, L., 2005, Paleoseismic transect across the northern Great Basin: Journal of Geophysical Research B05408, v. 110.

Western Regional Climate Center, 2009: Website file:///C:/Documents%20and%20Settings/cwilhite/My%20Documents/Malpais%20Slide/Papers/Climate/Beowawe%20Station_files/cliRECtM.htm, accessed January 8, 2009.

Wolf, E.W. and Pierson, T.C., 1995, Volcanic-hazard zonation for Mount St. Helens, Washington: US Geological Survey Open-File Report 95-497.

Zoback, M.L., McKee, E.H., Blakely, R.J., and Thompson, G.A., 1994, The Northern Nevada Rift: Regional tectono-magmatic relations and middle Miocene stress direction: Geological Society of America Bulletin, v. 106, p. 371-382.

Zoback, M.L. and Thompson, G.A., 1978, Basin and Range rifting in northern Nevada: Clues from a mid-Miocene rift and its subsequent offsets: Geology, v. 6, p. 111-116.

Appendix A

Rock Mass Classifications

RMR performed following Engineering Rock Mass Classifications (Bieniawski, 1989)
GSI performed following Practical Estimates of Rock Mass Strength, Table 5 (Hoek & Brown, 1997)

Technician: Coralie Wilhite

Sample Name: **Pz - Valmy Fm.**
Location: 22 - W. of slide GPS: 0538205 4490730
Date: 10 Aug. 2008

Parameter		Value/Description	Rating	Notes
Uniaxial Compressive Strength (Mpa)	128.1 Mpa		12	
RQD %	100%		20	
Spacing of Discontinuities (m)	0.6-2m		13	
Condition of Discontinuities	**Length (m)**	10-20m	1	
	Separation (aperture) (mm)	1-5mm and >5mm	5	
	Roughness	Rough	5	
	Infilling	Soft <5mm	2	
	Weathering	Slight-Mod	4	
Groundwater General Conditions	Dry		15	
		Total Rating	**77**	
		RMR = 77 = Good Rock		

Sample Name: **Pz - Valmy Fm.**
Location: 1 GPS: 0538253 4490743
Date: 10 Aug. 2008

Parameter		Value/Description	Rating	Notes
Uniaxial Compressive Strength (Mpa)	128.1 Mpa		12	
RQD % sum of lenghths >4in divided by total survey length	100%		20	

Spacing of Discontinuities (m)	2.5-10ft or > and <2m		19	
Condition of Discontinuities	**Length (m)**	1-3m	3	
	Separation (aperture) (mm)	1-5mm	1	
	Roughness	Rough	5	
	Infilling	Soft <5mm	2	
	Weathering	Slightly	5	
Groundwater General Conditions	Dry		15	
		Total Rating	**82**	
		RMR = 82 = Very Good Rock		

GSI Rating
50-55, V. blocky and good

Sample Name: **Ts**

Location: Barite Mine E. cliff GPS:

Date: 10 Aug. 2008

Parameter		**Value/Description**	**Rating**	**Notes**
Uniaxial Compressive Strength (Mpa)	1.81 MPa		1	
RQD % sum of lenghths >4in divided by total survey length	~10 %		2	
Spacing of Discontinuities (m)	very close and a lot or approx. 1inch-3ft		6	
Condition of Discontinuities	**Length (m)**	very varied (used 1-3m)	4	
	Separation (aperture) (mm)	1-5mm	1	
	Roughness	rough	5	
	Infilling	sand <5mm	4	
	Weathering	Highly to Decomposed	1	
Groundwater General Conditions	Dry		15	
		Total Rating	**39**	
		RMR = 39 - Poor Rock		

GSI Rating
30-35-disintegrated-fair

Sample Name:	**Td**	
Location:	21 - East head scarp	GPS: 0538792 4490052
Date:	9 Aug. 2008	

Parameter		Value/Description	Rating	Notes
Uniaxial Compressive Strength (Mpa)	152.7 MPa		12	Point Load
RQD % sum of lenghths >4in divided by total survey length	100%		20	
Spacing of Discontinuities (m)	0.6-2m		15	
Condition of Discontinuities	**Length (m)**	3-10m	2	
	Separation (aperture) (mm)	>5mm	0	
	Roughness	Slightly Rough	3	
	Infilling	Hard <5mm-none	5	
	Weathering	Slightly	5	
Groundwater General Conditions	Dry		15	
		Total Rating	**77**	

RMR = 77 = Good Rock

GSI Rating
55-60, very blocky and good

Sample Name:	**Td**	
Location:	19 - East flank of head scarp	GPS: 0538672 4489905
Date:	9 Aug. 2008	

Parameter		Value/Description	Rating	Notes
Uniaxial Compressive Strength (Mpa)	152.7 MPa		12	Point Load
RQD % sum of lenghths >4in divided by total survey length	100%		20	

Spacing of Discontinuities (m)	0.6-2m		15	
Condition of Discontinuities	**Length (m)**	3-10m	2	
	Separation (aperture) (mm)	>5mm	0	
	Roughness	smooth - slight rough	2	
	Infilling	hard<5mm-surface stain	5	
	Weathering	slightly	5	
Groundwater General Conditions	Dry		15	
		Total Rating	**76**	

RMR = 76 = Good Rock

GSI Rating
55-60, blocky to v.blocky and fair-good

Sample Name:	**Td**	
Location:	16 - Head scarp east of saddle	GPS: 0538297 4489703
Date:	9 Aug. 2008	

Parameter		Value/Description	Rating	Notes
Uniaxial Compressive Strength (Mpa)	152.7 Mpa		12	Point Load
RQD % sum of lenghths >4in divided by total survey length	45ft/45ftX100=100%		20	
Spacing of Discontinuities (m)	1-2=5ft, 2-3=7ft, 3-4=10ft, 4-5=1ft 5-6=10ft, 6-7=6ft, 7-8=2ft		17	(0.6-2m >2m)
Condition of Discontinuities	**Length (m)**		1	10-20m
	Separation (aperture) (mm)	1~4cm or 1.5in w/sand 2~12cm or 6in w broken blocks 3~ 5cm or 2in clean (finish)	0	>5mm
	Roughness	Smooth Surface	1	
	Infilling	Surface Staining	6	Mn and Fe
	Weathering	Slightly Weathered	5	

Groundwater General Conditions	Dry	15	
	Total Rating	**77**	

RMR = 77 = Good Rock

GSI Rating
45-50, Very blocky and fair-good

Appendix B

Point Load Testing

Determination of the Point Load Strength Index of Rock (ASTM D 5731 - 05)

KEY: Technician: Coralie Wilhite

D = Diameter
W = Width
LP = Line Pressure
Is(un) = Uncorrected point load index
Is(c) = Corrected point load index
F = Size correction factor
UCS = Uniaxial compressive strength

A correlation factor of 10 was used for the Ts (Bowman and Watters, 2007)

A correlation factor of 24 was used for Pz, Td, and Th (ASTM D 5731-05 and Bowden et al., 1998)

Laboratory Point Load Testing of Ts

Date: 27 Jan. 2009
Location: In lab lump testing
Unit: **Ts(b) S-19-10-08**
Descrip: Pink/tan layers, fine grained, tuff

Point Load											
	D (mm)	W (mm)	LP (MPa)	D (m)	W (m)	Area (m2)	Force (MN)	Is(un) (MPa)	F	Is(c) (MPa)	UCS (MPa)
1	60	68	2.64	0.06	0.068	0.004	0.0025	0.49	1.1	0.54	5.37
2	43	70	1.5	0.043	0.07	0.003	0.0014	0.38	0.9	0.34	3.39
3	63	75	2.47	0.063	0.075	0.005	0.0024	0.39	1.13	0.45	4.46
4	53	70	0.91	0.053	0.07	0.004	0.0009	0.19	1.03	0.19	1.91
5	50	60	1.42	0.05	0.06	0.003	0.0014	0.36	1	0.36	3.57
6	64	50	0.44	0.064	0.05	0.003	0.0004	0.10	1.14	0.12	1.18
7	55	100	2.55	0.055	0.1	0.006	0.0025	0.35	1.05	0.37	3.67
8	49	50	1.28	0.049	0.05	0.002	0.0012	0.39	0.99	0.39	3.90
9	55	43	1.68	0.055	0.043	0.002	0.0016	0.54	1.05	0.56	5.63
10	66	60	1.68	0.066	0.06	0.004	0.0016	0.32	1.16	0.37	3.71
11	70	55	1.14	0.07	0.055	0.004	0.0011	0.22	1.2	0.27	2.68
12	48	60	1.19	0.048	0.06	0.003	0.0011	0.31	0.98	0.31	3.06
13	67	90	3.82	0.067	0.09	0.006	0.0037	0.48	1.17	0.56	5.59

14	63	75	2.49	0.063	0.075	0.005	0.0024	0.40	1.13	0.45	4.49
15	55	55	2.36	0.055	0.055	0.003	0.0023	0.59	1.05	0.62	6.18
16	60	80	1.47	0.06	0.08	0.005	0.0014	0.23	1.1	0.25	2.54
17	53	50	1.58	0.053	0.05	0.003	0.0015	0.45	1.03	0.46	4.64
18	70	90	4.43	0.07	0.09	0.006	0.0043	0.53	1.2	0.64	6.37
19	49	65	1.94	0.049	0.065	0.003	0.0019	0.46	0.99	0.46	4.55
20	54	65	1.8	0.054	0.065	0.004	0.0017	0.39	1.04	0.40	4.03
21	58	55	1.95	0.058	0.055	0.003	0.0019	0.46	1.08	0.50	4.98
22	37	100	2.47	0.037	0.1	0.004	0.0024	0.50	0.83	0.42	4.18
23	61	45	1.91	0.061	0.045	0.003	0.0018	0.53	1.11	0.58	5.83
24	57	50	2.3	0.057	0.05	0.003	0.0022	0.61	1.07	0.65	6.52
25	42	55	1.95	0.042	0.055	0.002	0.0019	0.64	0.92	0.59	5.86
26	64	50	2.3	0.064	0.05	0.003	0.0022	0.54	1.14	0.62	6.18
27	70	70	3.52	0.07	0.07	0.005	0.0034	0.54	1.2	0.65	6.51
28	54	50	1.48	0.054	0.05	0.003	0.0014	0.41	1.04	0.43	4.30
29	75	60	3.3	0.075	0.06	0.005	0.0032	0.55	1.28	0.71	7.08
30	72	50	0.49	0.072	0.05	0.004	0.0005	0.10	1.23	0.13	1.26
31	47	65	0.5	0.047	0.065	0.003	0.0005	0.12	0.97	0.12	1.20
32	66	80	0.39	0.066	0.08	0.005	0.0004	0.06	1.16	0.06	0.65
33	57	65	0.62	0.057	0.065	0.004	0.0006	0.13	1.07	0.14	1.35
34	46	70	1.31	0.046	0.07	0.003	0.0013	0.31	0.96	0.29	2.95
35	64	70	3.22	0.064	0.07	0.004	0.0031	0.54	1.14	0.62	6.18
36	63	55	2.44	0.063	0.055	0.003	0.0023	0.53	1.13	0.60	6.01
37	46	70	1.74	0.046	0.07	0.003	0.0017	0.41	0.96	0.39	3.92
38	66	60	1.79	0.066	0.06	0.004	0.0017	0.34	1.16	0.40	3.96
							Average UCS (MPa) =				**4.21**

Date: 27 Jan. 2009
Location: In lab lump testing
Unit: **Ts(c) S-20-10-08**
Descrip: Pink, tuffaceous, fine grained

Point Load											
	D (mm)	W (mm)	LP (MPa)	D (m)	W (m)	Area (m^2)	Force (MN)	Is(un) (MPa)	F	Is(c) (MPa)	UCS (MPa)
1	55	70	0.19	0.055	0.07	0.004	0.0002	0.037	1.05	0.039	0.39
2	77	80	0.52	0.077	0.08	0.006	0.0005	0.064	1.3	0.083	0.83
3	68	70	0.53	0.068	0.07	0.005	0.0005	0.084	1.18	0.099	0.99
4	70	50	0.36	0.07	0.05	0.004	0.0003	0.078	1.2	0.093	0.93
5	73	70	0.42	0.073	0.07	0.005	0.0004	0.062	1.24	0.077	0.77
6	61	50	0.18	0.061	0.05	0.003	0.0002	0.045	1.11	0.049	0.49
7	68	65	0.48	0.068	0.065	0.004	0.0005	0.082	1.18	0.097	0.97
8	54	85	0.32	0.054	0.085	0.005	0.0003	0.053	1.04	0.055	0.55
9	47	75	0.21	0.047	0.075	0.004	0.0002	0.045	0.97	0.044	0.44
10	46	60	0.23	0.046	0.06	0.003	0.0002	0.063	0.96	0.06	0.60

11	60	95	0.36	0.06	0.095	0.006	0.0003	0.048	1.1	0.052	0.52
12	62	100	0.53	0.062	0.1	0.006	0.0005	0.065	1.12	0.072	0.72
13	46	65	0.35	0.046	0.065	0.003	0.0003	0.088	0.96	0.085	0.85
14	58	95	0.43	0.058	0.095	0.006	0.0004	0.059	1.08	0.064	0.64
15	53	60	0.4	0.053	0.06	0.003	0.0004	0.095	1.03	0.098	0.98
16	59	60	0.19	0.059	0.06	0.004	0.0002	0.041	1.09	0.044	0.44
17	75	100	0.42	0.075	0.1	0.008	0.0004	0.042	1.28	0.054	0.54
18	60	60	0.16	0.06	0.06	0.004	0.0002	0.034	1.1	0.037	0.37
19	66	55	0.21	0.066	0.055	0.004	0.0002	0.044	1.16	0.051	0.51
20	78	90	0.33	0.078	0.09	0.007	0.0003	0.035	1.31	0.046	0.46
21	75	50	0.24	0.075	0.05	0.004	0.0002	0.048	1.28	0.062	0.62
22	60	85	0.11	0.06	0.085	0.005	0.0001	0.016	1.1	0.018	0.18
23	67	55	0.22	0.067	0.055	0.004	0.0002	0.045	1.17	0.053	0.53
24	60	50	0.1	0.06	0.05	0.003	1E-04	0.025	1.1	0.028	0.28
25	76	75	0.57	0.076	0.075	0.006	0.0005	0.075	1.29	0.097	0.97
26	75	50	0.53	0.075	0.05	0.004	0.0005	0.107	1.28	0.137	1.37
27	60	100	0.14	0.06	0.1	0.006	0.0001	0.018	1.1	0.019	0.19
28	60	65	0.13	0.06	0.065	0.004	0.0001	0.025	1.1	0.028	0.28
29	66	80	0.15	0.066	0.08	0.005	0.0001	0.021	1.16	0.025	0.25
30	63	40	0.19	0.063	0.04	0.003	0.0002	0.057	1.13	0.064	0.64
31	74	85	0.16	0.074	0.085	0.006	0.0002	0.019	1.26	0.024	0.24
							Average UCS (MPa) =				**0.598**

Date: 29 Jan. 2009
Location: In lab lump testing
Unit: **Ts(d) S-23-10-08**
Descrip: Tan/light brown fine grained layers and matrix. Some chert/rock fragments

Point Load											
	D (mm)	W (mm)	LP (MPa)	D (m)	W (m)	Area (m^2)	Force (MN)	Is(un) (MPa)	F	Is(c) (MPa)	UCS (MPa)
1	73	50	0.16	0.073	0.05	0.004	0.0002	0.0331	1.24	0.041	0.41
2	67	50	0.23	0.067	0.05	0.003	0.0002	0.0518	1.17	0.061	0.61
3	74	45	0.4	0.074	0.045	0.003	0.0004	0.0907	1.26	0.114	1.14
4	65	90	0.44	0.065	0.09	0.006	0.0004	0.0568	1.15	0.065	0.65
5	55	65	0.24	0.055	0.065	0.004	0.0002	0.0507	1.05	0.053	0.53
6	47	45	0.15	0.047	0.045	0.002	0.0001	0.0535	0.97	0.052	0.52
7	52	60	0.19	0.052	0.06	0.003	0.0002	0.046	1.02	0.047	0.47
8	58	40	0.27	0.058	0.04	0.002	0.0003	0.0878	1.08	0.095	0.95
9	70	75	0.22	0.07	0.075	0.005	0.0002	0.0316	1.2	0.038	0.38
10	67	65	0.45	0.067	0.065	0.004	0.0004	0.078	1.17	0.091	0.91
11	62	70	0.15	0.062	0.07	0.004	0.0001	0.0261	1.12	0.029	0.29
12	66	60	0.4	0.066	0.06	0.004	0.0004	0.0762	1.16	0.088	0.88
13	47	45	0.2	0.047	0.045	0.002	0.0002	0.0714	0.97	0.069	0.69
14	66	50	0.31	0.066	0.05	0.003	0.0003	0.0709	1.16	0.082	0.82

15	60	80	0.25	0.06	0.08	0.005	0.0002	0.0393	1.1	0.043	0.43
16	73	45	0.17	0.073	0.045	0.003	0.0002	0.0391	1.24	0.048	0.48
17	44	45	0.23	0.044	0.045	0.002	0.0002	0.0877	0.94	0.082	0.82
18	65	70	0.33	0.065	0.07	0.005	0.0003	0.0547	1.15	0.063	0.63
19	58	65	0.34	0.058	0.065	0.004	0.0003	0.0681	1.08	0.074	0.74
20	65	100	0.57	0.065	0.1	0.007	0.0005	0.0662	1.15	0.076	0.76
21	56	60	0.29	0.056	0.06	0.003	0.0003	0.0651	1.06	0.069	0.69
22	64	50	0.33	0.064	0.05	0.003	0.0003	0.0778	1.14	0.089	0.89
23	76	80	0.3	0.076	0.08	0.006	0.0003	0.0372	1.29	0.048	0.48
24	64	75	0.28	0.064	0.075	0.005	0.0003	0.044	1.14	0.05	0.50
25	59	80	0.28	0.059	0.08	0.005	0.0003	0.0448	1.09	0.049	0.49
26	71	60	0.12	0.071	0.06	0.004	0.0001	0.0213	1.21	0.026	0.26
27	48	50	0.13	0.048	0.05	0.002	0.0001	0.0409	0.98	0.04	0.40
							Average UCS (MPa) =				**0.624**

Average MPa - Ts(b)	4.21
Average MPa - Ts(c)	0.598
Average MPa - Ts(d)	0.624
Average MPa for Ts	**1.81**

Field Point Load Testing of Pz, Ts, Th, and Td

Date: 10 Aug. 2008
Location: Field lump testing
Unit: **Pz - Valmy Formation**
Descrip: Gray/pink/red, layered chert and mudstone

Point Load										
	D (mm)	LP (PSI)	LP (MPa)	D (m)	D^2 (m^2)	Force (MN)	Is(un) (MPa)	F	Is(c) (MPa)	UCS (MPa)
1	72	670	4.62	0.072	0.005	0.0067	1.29	1.21	1.56	37.33
2	63	1000	6.89	0.063	0.004	0.0099	2.51	1.13	2.83	67.96
3	57	1450	10.00	0.057	0.003	0.0144	4.44	1.07	4.75	113.99
4	48	3300	22.75	0.048	0.002	0.0328	14.25	0.98	13.96	335.07
5	60	2825	19.48	0.06	0.004	0.0281	7.81	1.1	8.59	206.06
6	65	1875	12.93	0.065	0.004	0.0186	4.41	1.15	5.08	121.83
7	43	750	5.17	0.043	0.002	0.0075	4.03	0.93	3.75	90.05
8	71	700	4.83	0.071	0.005	0.007	1.38	1.2	1.66	39.78
9	65	1250	8.62	0.065	0.004	0.0124	2.94	1.15	3.38	81.22
10	56	1450	10.00	0.056	0.003	0.0144	4.60	1.06	4.87	117.00

11	64	1100	7.58	0.064	0.004	0.0109	2.67	1.14	3.05	73.08
12	73	250	1.72	0.073	0.005	0.0025	0.47	1.22	0.57	13.66
13	73	750	5.17	0.073	0.005	0.0075	1.40	1.22	1.71	40.99
14	58	850	5.86	0.058	0.003	0.0085	2.51	1.08	2.71	65.14
15	64	1150	7.93	0.064	0.004	0.0114	2.79	1.14	3.18	76.40
16	75	500	3.45	0.075	0.006	0.005	0.88	1.23	1.09	26.10
17	56	1150	7.93	0.056	0.003	0.0114	3.65	1.06	3.87	92.79
18	43	1250	8.62	0.043	0.002	0.0124	6.72	0.93	6.25	150.08
19	51	1150	7.93	0.051	0.003	0.0114	4.40	1.01	4.44	106.60
20	52	650	4.48	0.052	0.003	0.0065	2.39	1.02	2.44	58.53
21	63	600	4.14	0.063	0.004	0.006	1.50	1.13	1.70	40.78
22	55	1900	13.10	0.055	0.003	0.0189	6.25	1.05	6.56	157.43
23	78	1925	13.27	0.078	0.006	0.0191	3.15	1.26	3.97	95.17
24	50	1300	8.96	0.05	0.003	0.0129	5.17	1	5.17	124.13
25	47	600	4.14	0.047	0.002	0.006	2.70	0.97	2.62	62.89
26	49	1300	8.96	0.049	0.002	0.0129	5.39	0.99	5.33	127.96
27	45	700	4.83	0.045	0.002	0.007	3.44	0.95	3.27	78.39
28	68	1100	7.58	0.068	0.005	0.0109	2.37	1.18	2.79	67.01
29	57	2600	17.93	0.057	0.003	0.0259	7.96	1.07	8.52	204.40
30	57	2275	15.69	0.057	0.003	0.0226	6.96	1.07	7.45	178.85
31	50	3075	21.20	0.05	0.003	0.0306	12.23	1	12.23	293.62
32	50	3850	26.54	0.05	0.003	0.0383	15.32	1	15.32	367.62
33	44	3125	21.55	0.044	0.002	0.0311	16.05	0.94	15.09	362.20
34	45	2500	17.24	0.045	0.002	0.0249	12.28	0.95	11.67	279.97
						Average UCS (MPa) =				**128.1**

Date: 9-10 Aug. 2008
Location: Field lump testing
Unit: **Ts - Tertiary Sediments**
Descrip: Sandstone and conglomerate off slide surface

Point Load										
	D (mm)	LP (PSI)	LP (MPa)	D (m)	D^2 (m^2)	Force (MN)	Is(un) (MPa)	F	Is(c) (MPa)	UCS (MPa)
1	67	450	3.10	0.067	0.004	0.0045	1.00	1.17	1.17	11.67
2	51	1500	10.34	0.051	0.003	0.0149	5.74	1.01	5.79	57.93
3	48	600	4.14	0.048	0.002	0.006	2.59	0.98	2.54	25.38
4	53	500	3.45	0.053	0.003	0.005	1.77	1.03	1.82	18.24
5	50	750	5.17	0.05	0.003	0.0075	2.98	1	2.98	29.84
6	67	450	3.10	0.067	0.004	0.0045	1.00	1.17	1.17	11.67
7	78	500	3.45	0.078	0.006	0.005	0.82	1.26	1.03	10.30
8	72	200	1.38	0.072	0.005	0.002	0.38	1.21	0.46	4.64
9	80	300	2.07	0.08	0.006	0.003	0.47	1.28	0.60	5.97
10	50	550	3.79	0.05	0.003	0.0055	2.19	1	2.19	21.88
11	63	400	2.76	0.063	0.004	0.004	1.00	1.13	1.13	11.33

12	53	380	2.62	0.053	0.003	0.0038	1.35	1.03	1.39	13.86
13	56	660	4.55	0.056	0.003	0.0066	2.09	1.06	2.22	22.19
14	47	240	1.65	0.047	0.002	0.0024	1.08	0.97	1.05	10.48
15	61	400	2.76	0.061	0.004	0.004	1.07	1.11	1.19	11.87
16	51	750	5.17	0.051	0.003	0.0075	2.87	1.01	2.90	28.97
17	49	940	6.48	0.049	0.002	0.0093	3.89	0.99	3.86	38.55
18	41	630	4.34	0.041	0.002	0.0063	3.73	0.91	3.39	33.92
19	45	820	5.65	0.045	0.002	0.0082	4.03	0.95	3.83	38.26
20	48	410	2.83	0.048	0.002	0.0041	1.77	0.98	1.73	17.35
21	43	1600	11.03	0.043	0.002	0.0159	8.61	0.93	8.00	80.04
22	42	860	5.93	0.042	0.002	0.0086	4.85	0.92	4.46	44.61
23	46	200	1.38	0.046	0.002	0.002	0.94	0.96	0.90	9.03
24	42	190	1.31	0.042	0.002	0.0019	1.07	0.92	0.99	9.86
25	43	700	4.83	0.043	0.002	0.007	3.77	0.93	3.50	35.02
26	70	510	3.52	0.07	0.005	0.0051	1.04	1.2	1.24	12.42
27	72	400	2.76	0.072	0.005	0.004	0.77	1.21	0.93	9.29
28	61	440	3.03	0.061	0.004	0.0044	1.18	1.11	1.31	13.06
29	61	700	4.83	0.061	0.004	0.007	1.87	1.11	2.08	20.77
30	80	1160	8.00	0.08	0.006	0.0115	1.80	1.28	2.31	23.08
31	70	680	4.69	0.07	0.005	0.0068	1.38	1.2	1.66	16.56
32	67	690	4.76	0.067	0.004	0.0069	1.53	1.17	1.79	17.89
33	62	250	1.72	0.062	0.004	0.0025	0.65	1.12	0.72	7.25
34	60	340	2.34	0.06	0.004	0.0034	0.94	1.1	1.03	10.33
35	67	710	4.90	0.067	0.004	0.0071	1.57	1.17	1.84	18.41
36	81	360	2.48	0.081	0.007	0.0036	0.55	1.29	0.70	7.04
37	70	630	4.34	0.07	0.005	0.0063	1.28	1.2	1.53	15.35
38	69	420	2.90	0.069	0.005	0.0042	0.88	1.19	1.04	10.44
39	82	500	3.45	0.082	0.007	0.005	0.74	1.3	0.96	9.62
40	55	870	6.00	0.055	0.003	0.0087	2.86	1.05	3.00	30.04
41	57	830	5.72	0.057	0.003	0.0083	2.54	1.07	2.72	27.19
42	68	290	2.00	0.068	0.005	0.0029	0.62	1.18	0.74	7.36
43	60	470	3.24	0.06	0.004	0.0047	1.30	1.1	1.43	14.28
44	50	700	4.83	0.05	0.003	0.007	2.78	1	2.78	27.85
45	57	260	1.79	0.057	0.003	0.0026	0.80	1.07	0.85	8.52
46	65	320	2.21	0.065	0.004	0.0032	0.75	1.15	0.87	8.66
47	62	630	4.34	0.062	0.004	0.0063	1.63	1.12	1.83	18.26
48	72	580	4.00	0.072	0.005	0.0058	1.11	1.21	1.35	13.47
49	69	620	4.27	0.069	0.005	0.0062	1.30	1.19	1.54	15.41
50	79	260	1.79	0.079	0.006	0.0026	0.41	1.27	0.53	5.26
51	78	450	3.10	0.078	0.006	0.0045	0.74	1.26	0.93	9.27
52	52	540	3.72	0.052	0.003	0.0054	1.99	1.02	2.03	20.26
53	46	470	3.24	0.046	0.002	0.0047	2.21	0.96	2.12	21.21
54	42	300	2.07	0.042	0.002	0.003	1.69	0.92	1.56	15.56
55	55	320	2.21	0.055	0.003	0.0032	1.05	1.05	1.10	11.05
									Average UCS (MPa) =	**19.05**

Date: 9 Aug. 2008
Location: Field lump testing
Unit: **Th - Biotite Hornblende Andesite**
Descrip: Gray aphanitic andesite with phenocrysts

Point Load										
	D (mm)	LP (PSI)	LP (MPa)	D (m)	D^2 (m^2)	Force (MN)	Is(un) (MPa)	F	Is(c) (MPa)	UCS (MPa)
1	73	2100	14.48	0.073	0.005	0.021	3.92	1.22	4.78	114.77
2	76	1300	8.96	0.076	0.006	0.013	2.24	1.24	2.78	66.62
3	59	600	4.14	0.059	0.003	0.006	1.71	1.09	1.87	44.85
4	75	600	4.14	0.075	0.006	0.006	1.06	1.25	1.33	31.83
5	56	1450	10.00	0.056	0.003	0.014	4.60	1.06	4.87	117.00
6	59	875	6.03	0.059	0.003	0.009	2.50	1.09	2.73	65.40
7	43	700	4.83	0.043	0.002	0.007	3.77	0.93	3.50	84.05
8	56	750	5.17	0.056	0.003	0.007	2.38	1.06	2.52	60.52
9	60	400	2.76	0.06	0.004	0.004	1.11	1.1	1.22	29.18
10	81	800	5.52	0.081	0.007	0.008	1.21	1.29	1.56	37.55
11	80	2250	15.51	0.08	0.006	0.022	3.50	1.28	4.48	107.42
12	77	1175	8.10	0.077	0.006	0.012	1.97	1.25	2.46	59.13
13	61	1600	11.03	0.061	0.004	0.016	4.28	1.11	4.75	113.94
14	62	400	2.76	0.062	0.004	0.004	1.04	1.12	1.16	27.82
15	65	1900	13.10	0.065	0.004	0.019	4.47	1.15	5.14	123.45
16	55	350	2.41	0.055	0.003	0.003	1.15	1.05	1.21	29.00
17	56	1650	11.38	0.056	0.003	0.016	5.23	1.06	5.55	133.13
18	76	450	3.10	0.076	0.006	0.004	0.77	1.24	0.96	23.06
19	67	2325	16.03	0.067	0.004	0.023	5.15	1.17	6.03	144.66
20	51	1450	10.00	0.051	0.003	0.014	5.54	1.01	5.60	134.41
21	69	2200	15.17	0.069	0.005	0.022	4.60	1.19	5.47	131.26
22	50	1700	11.72	0.05	0.003	0.017	6.76	1	6.76	162.32
23	63	2550	17.58	0.063	0.004	0.025	6.39	1.13	7.22	173.31
24	62	2650	18.27	0.062	0.004	0.026	6.86	1.12	7.68	184.31
25	61	1150	7.93	0.061	0.004	0.011	3.07	1.11	3.41	81.89
26	57	1600	11.03	0.057	0.003	0.016	4.90	1.07	5.24	125.79
27	50	1075	7.41	0.05	0.003	0.011	4.28	1	4.28	102.65
28	52	1675	11.55	0.052	0.003	0.017	6.16	1.02	6.28	150.83
29	63	1600	11.03	0.063	0.004	0.016	4.01	1.13	4.53	108.74
30	52	2300	15.86	0.052	0.003	0.023	8.46	1.02	8.63	207.11
31	43	750	5.17	0.043	0.002	0.007	4.03	0.93	3.75	90.05
32	59	1100	7.58	0.059	0.003	0.011	3.14	1.09	3.43	82.22
33	58	1400	9.65	0.058	0.003	0.014	4.14	1.08	4.47	107.29
34	52	1000	6.89	0.052	0.003	0.010	3.68	1.02	3.75	90.05
35	69	1450	10.00	0.069	0.005	0.014	3.03	1.19	3.60	86.52
36	57	500	3.45	0.057	0.003	0.005	1.53	1.07	1.64	39.31
37	55	1150	7.93	0.055	0.003	0.011	3.78	1.05	3.97	95.29
									Average UCS (MPa) =	**96.4**

Date: 11 Aug. 2008
Location: Field lump testing
Unit: **Td - Tertiary Dacite**
Descrip: Dark gray aphanitic dacite with phenocrysts and vesicles

Point Load										
	D (mm)	LP (PSI)	LP (MPa)	D (m)	D^2 (m^2)	Force (MN)	Is(un) (MPa)	F	Is(c) (MPa)	UCS (MPa)
1	53	3200	22.06	0.053	0.003	0.0318	11.331	1.03	11.67	280.1
2	55	3500	24.13	0.055	0.003	0.0348	11.508	1.05	12.08	290.01
3	50	4250	29.30	0.05	0.003	0.0423	16.909	1	16.91	405.81
4	56	1400	9.65	0.056	0.003	0.0139	4.4403	1.06	4.707	112.96
5	51	800	5.52	0.051	0.003	0.008	3.0592	1.01	3.09	74.156
6	62	1800	12.41	0.062	0.004	0.0179	4.6575	1.12	5.216	125.19
7	52	2125	14.65	0.052	0.003	0.0211	7.8166	1.02	7.973	191.35
8	70	3375	23.27	0.07	0.005	0.0336	6.8508	1.2	8.221	197.3
9	61	3900	26.89	0.061	0.004	0.0388	10.425	1.11	11.57	277.72
10	53	800	5.52	0.053	0.003	0.008	2.8327	1.03	2.918	70.025
11	54	1500	10.34	0.054	0.003	0.0149	5.1165	1.04	5.321	127.71
12	81	1925	13.27	0.081	0.007	0.0191	2.9183	1.29	3.765	90.35
13	56	2800	19.31	0.056	0.003	0.0278	8.8807	1.06	9.414	225.92
14	81	1800	12.41	0.081	0.007	0.0179	2.7288	1.29	3.52	84.483
15	74	2225	15.34	0.074	0.005	0.0221	4.0414	1.22	4.931	118.33
16	79	3775	26.03	0.079	0.006	0.0375	6.0163	1.27	7.641	183.38
17	75	300	2.07	0.075	0.006	0.003	0.5305	1.23	0.652	15.66
18	60	675	4.65	0.06	0.004	0.0067	1.8649	1.1	2.051	49.235
19	65	775	5.34	0.065	0.004	0.0077	1.8245	1.15	2.098	50.356
20	67	500	3.45	0.067	0.004	0.005	1.1079	1.17	1.296	31.109
21	58	2675	18.44	0.058	0.003	0.0266	7.9092	1.08	8.542	205.01
						Average UCS (MPa) =				**152.7**

Appendix C

Specific Gravity

Field Determination of Apparent Specific Gravity of Rock and Manmade Materials for Erosion Control (ASTM D 5779 - 95a (2001))

Summary of Material Specific Gravity								
Sample Description	Name		Specific Gravity	Specific Weight (kN/m^3)	Avg. Specific Gravity	Avg. Spec Weight (kN/m^3)	SW (lbs/ft^3)	Avg. Spec. Weight (lbs/ft^3)
Dacite	Td	Td 1	2.54	24.92	2.54	24.92	81.79	82.50
		Td 2	2.72	26.68			87.58	
		Td 3	2.49	24.43			80.18	
		Td 4	2.41	23.64			77.60	
		Td 5	2.65	26			85.33	
Sedimentary	Ts	Ts(b) 1	2.04	20.01	2.03	19.95	65.69	65.47
		Ts(b) 2	2.11	20.7			67.94	
		Ts(b) 3	1.95	19.13			62.79	
		Ts(c) 1	1.36	13.34	1.38	13.54	43.79	44.44
		Ts(c) 2	1.39	13.64			44.76	
		Ts(c) 3	1.39	13.64			44.76	
		Ts(d) 1	2.04	20.01	2.01	19.75	65.69	64.83
		Ts(d) 2	2.11	20.7			67.94	
		Ts(d) 3	1.89	18.54			60.86	
Bio.-horn. Andesite	Tha	Tha 1	2.45	24.03	2.45	24.03	78.89	78.89
Chert and mudstone	Pz	Pz 1	2.55	25.02	2.48	24.36	82.11	79.96
		Pz 2	2.42	23.74			77.92	
		Pz 3	2.48	24.33			79.86	

Depths and corresponding pressures

Depth (ft)	psi	psf
123.61	50	7200
247.21	100	14400
494.42	200	28800

Ts would have been burried between 0 and ~500 ft. Avg~250ft
AVG specific weight of Ts = 58.25 lbs/ft^3

Exception: Sample weights used were less than specified in the standard due to limited material and lab equipment.

Appendix D

Slake Durability Index

Slake Durability of Shales and Similar Weak Rocks (ASTM D 4644 – 87 (2004))

Technician: Coralie Wilhite

Key:
Type I - Retained specimen remain virtually unchanged
Type II - Retained specimen consist of large and small fragments
Type III - Retained specimen is exclusively small fragments

*all weights are in grams
*run time = 10 minutes at 20 rpm's
*sample pieces should weigh 40-60 g each for a total of 450-550 g.
*use distilled water at room temp (ASTM called for deionized water)

Ts(b)

Date:	9 Jan. 2009	Notes
Sample name:	Ts(b) S-19-10-08	Tuff/sandy/some gravel, tan/red/yellow
Drum Weight (C)	1782.8g	Drum D
Sample Weight	544.8g	
Initial Combined Weight - Dry (B)	2327.0g	
Temp of water 1st run	20 degrees Celsius	
Weight after 1st Drying	1808.9g	Mostly disentegrated within the 1st 5 min.
Temp of water 2nd run	15 degrees Celsius	
Weight after 2nd Drying (Wf)	1796.0g	
Id(2)=[(Wf - C) / (B - C)] X 100	**2.43%**	**Type III**

Date:	29 Jan. 2009	Notes
Sample name:	Ts(b) S-19-10-08	
Drum Weight (C)	1782.8	Drum D
Sample Weight	518.4	
Initial Combined Weight - Dry (B)	2300.8	
Temp of water 1st run	20 degrees Celsius	Disentegrated within 4.5 min. - few clasts left
Weight after 1st Drying	1825.7	
Temp of water 2nd run	17 degrees Celsius	

Weight after 2nd Drying (Wf)	1822.7	
Id(2)=[(Wf - C) / (B - C)] X 100	**7.70%**	**Type III**
Date:	29-Jan-09	Notes
Sample name:	Ts(b) S-19-10-08	
Drum Weight (C)	1782.7	Drum D
Sample Weight	585	
Initial Combined Weight - Dry (B)	2367.2	
Temp of water 1st run	18 degrees Celsius	Disentegrated withing 6 minutes, with a few clasts left (volcanics). Tan water.
Weight after 1st Drying	1807	
Temp of water 2nd run	16 degrees Celsius	
Weight after 2nd Drying (Wf)	1799.2	
Id(2)=[(Wf - C) / (B - C)] X 100	**2.82%**	**Type III**

Ts(c)

Date:	9 Jan. 2009	Notes
Sample name:	Ts(c) S-20-10-08	Tuff/lacustrine/ash, tan/red
Drum Weight (C)	1781.8g	Drum A
Sample Weight	484.1g	
Initial Combined Weight - Dry (B)	2265.4g	
Temp of water 1st run	20 degrees Celsius	
Weight after 1st Drying	1792.7g	Most the sample disentegrated w/in the 1st minute.
Temp of water 2nd run	15 degrees Celsius	
Weight after 2nd Drying (Wf)	1784.0g	
Id(2)=[(Wf - C) / (B - C)] X 100	**0.46%**	**Type III**

Date:	29 Jan. 2009	Notes
Sample name:	Ts(c) S-20-10-08	
Drum Weight (C)	1781.5	
Sample Weight	529.6	
Initial Combined Weight - Dry (B)	2310.6	
Temp of water 1st run	20 degrees Celsius	Desintegrated within 1st minute - few clasts left
Weight after 1st Drying	1794.1	
Temp of water 2nd run	17 degrees Celsius	
Weight after 2nd Drying (Wf)	1789.2	
Id(2)=[(Wf - C) / (B - C)] X 100	**1.46%**	**Type III**

Date:	29 Jan. 2009	Notes
Sample name:	Ts(c) S-20-10-08	
Drum Weight (C)	1738.1	Drum 1
Sample Weight	560.3	
Initial Combined Weight - Dry (B)	2297.3	
Temp of water 1st run	18 degrees celcius	Disentegrated within 1 minute. Lumps were left after the 10 minutes.
Weight after 1st Drying	1831.8	Pink water - takes along time for fines to settle.
Temp of water 2nd run	17 degrees Celcius	
Weight after 2nd Drying (Wf)	1789.4	3 lumps (15, 30, & 40 mm in diam) of fine material were left. Also, some 3-5mm gains.
Id(2)=[(Wf - C) / (B - C)] X 100	**9.17%**	**Type III**

Date:	29 Jan. 2009	Notes
Sample name:	Ts(c) S-20-10-08	
Drum Weight (C)	1781.8	Drum A
Sample Weight	549.4	
Initial Combined Weight - Dry (B)	2330	
Temp of water 1st run	18 degrees celcius	Disentegrated within 1 minute. Lumps were left after the 10 minutes.
Weight after 1st Drying	1834.5	Pink water - takes along time for fines to settle.
Temp of water 2nd run	18 degrees Celcius	
Weight after 2nd Drying (Wf)	1808.4	~ 5 lumps (15-30 mm diam) of fine material were left. Also, a few 2-4mm grains.
Id(2)=[(Wf - C) / (B - C)] X 100	**4.85%**	**Type III**

Ts(d)

Date:	29 Jan. 2009	Notes
Sample name:	Ts(d) S-23-10-09	
Drum Weight (C)	1795.9	Drum B
Sample Weight	512.7	
Initial Combined Weight - Dry (B)	2307.7	
Temp of water 1st run	20 degrees Celcius	Disentegrated within 1st minute - quite a few clasts left.

Weight after 1st Drying	1835.9	
Temp of water 2nd run	18 degrees Celcius	
Weight after 2nd Drying (Wf)	1833	
Id(2)=[(Wf - C) / (B - C)] X 100	**7.25%**	**Type III**

Date:	30 Jan. 2009	Notes
Sample name:	Ts(d)	
Drum Weight (C)	1794.4	Drum B
Sample Weight	544.4	
Initial Combined Weight - Dry (B)	2338.1	
Temp of water 1st run	21 degrees Celcius	Mostly disentegrated within 1st minute. Quite a few large clasts left.
Weight after 1st Drying	1868.3	Tan water - settles pretty fast (1-2 hours)
Temp of water 2nd run	16 degrees Celcius	
Weight after 2nd Drying (Wf)	1865.8	Angular clasts left behind (up to ~40mm)
Id(2)=[(Wf - C) / (B - C)] X 100	**13.13%**	**Type III**

Date:	2 Feb. 2009	Notes
Sample name:	Ts(d) S-23-10-08	
Drum Weight (C)	1794.3	
Sample Weight	514.1	
Initial Combined Weight - Dry (B)	2307.7	
Temp of water 1st run	21 degrees Celcius	Disentegrated w/in 1st minute. Angular clasts left behind (~2-8mm)
Weight after 1st Drying	1848.8	Tan water.
Temp of water 2nd run	16 degrees Celcius	
Weight after 2nd Drying (Wf)	1846.9	
Id(2)=[(Wf - C) / (B - C)] X 100	**10.25%**	**Type III**

Average Slake Durability of Ts	**5.95%**	**Type III**

Pz

Date:	2 Feb. 2009	Notes
Sample name:	Pz	
Drum Weight (C)	1782.6	Drum D
Sample Weight	481.4	
Initial Combined Weight - Dry (B)	2263.1	
Temp of water 1st run	20 degrees Celcius	Turned water pink.
Weight after 1st Drying	2256.6	Some small pieces on base after 10 min.
Temp of water 2nd run	16 degrees Celcius	Water remained pink over night - fines didn't settle.
Weight after 2nd Drying (Wf)	2254.4	
Id(2)=[(Wf - C) / (B - C)] X 100	**98.19%**	**Type I**

Td

Date:	2 Feb. 2009	Notes
Sample name:	Td	
Drum Weight (C)	1738	
Sample Weight	477.9	
Initial Combined Weight - Dry (B)	2215.3	
Temp of water 1st run	20 degrees Celcius	Turned water very light tan.
Weight after 1st Drying	2213.5	Only a few small pieces on base after 10 minutes.
Temp of water 2nd run	16 degrees Celcius	
Weight after 2nd Drying (Wf)	2212.9	
Id(2)=[(Wf - C) / (B - C)] X 100	**99.50%**	**Type I**

Appendix E

Particle-Size Distributions and Classification of Soils

Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis (ASTM D 6913 – 04, 2004)
Classification for Engineering Purposes (ASTM D 2487 – 66 T, (2000))

KEY:

Technician: Coralie Wilhite

Bulk Samples
Oven dried sieve specimen
10 minutes of shaking
Fines were soaked for 10 minutes before washing
Gravel passes a 3 inch sieve and is retained on the No. 4 sieve
Sand passes the No. 4 sieve and is retained on the No. 200 sieve
Silt/Clay pass the No. 200 sieve

Sieve Number	Particle Diameter (mm)
½ inch	12.7
No. 4	4.75
No. 10	2
No. 20	0.84
No. 40	0.42
No. 80	0.18
No. 100	0.15
No. 200	0.075

Sample Name: Ts(b)
Date: 1-3 March 2009
Container Number: Ziplock bag
Mass of container (g): 9.4
Mass of soil + container (g): 568.8
Mass of Dry Soil (g): 559.4

Sieve Number	Mass Retained (g)	Quantity Passing	Percent Retained	Percent Passing	Notes
1/2 inch	0	559.4	0	100	
No. 4	5.9	553.5	1	99	
No. 10	13.9	539.6	2.5	96.5	
No. 20	67	472.6	12	84.5	
No. 40	135.7	336.9	24.3	60.2	
No. 80	125.1	211.8	22.4	37.8	
No. 100	29.5	182.3	5.3	32.5	
No. 200	66.1	116.2	11.8	20.7	

Pan B	96.6	19.6	17.3	3.4	3.4% loss

Summary

% Cobbles: 0

% Gravel: 1

% Sand: 78.3

% Fines: 17.3

USCS: SM - Silty Sand

Sample Name: Ts(c)

Date: 28 Feb - 5 March 2009

Container Number: Bowl

Mass of container (g): 288.3

Mass of soil + container (g): 574.5

Mass of Dry Soil (g): 286.2

Sieve Number	Mass Retained (g)	Quantity Passing	Percent Retained	Percent Passing	Notes
No. 4	0	286.2	0	0	
No. 10	0	286.2	0	0	
No. 20	0.3	285.9	0.1	99.9	
No. 40	2.3	283.6	0.8	99.1	
No. 80	17	266.6	5.9	93.2	
No. 100	6.3	260.3	2.2	91	
No. 200	49.5	210.8	17.3	73.7	
Pan A	201.7	9.1	70.5	3.2	3.2% loss

Summary

% Cobbles: 0

% Gravel: 0

% Sand: 26.3

% Fines: 70.5

USCS: ML - Silt with Sand

Sample Name: Ts(d)

Date: 2-5 March 2009

Container Number: Ziplock bag

Mass of container (g): 9.5

Mass of soil + container (g): 493.3

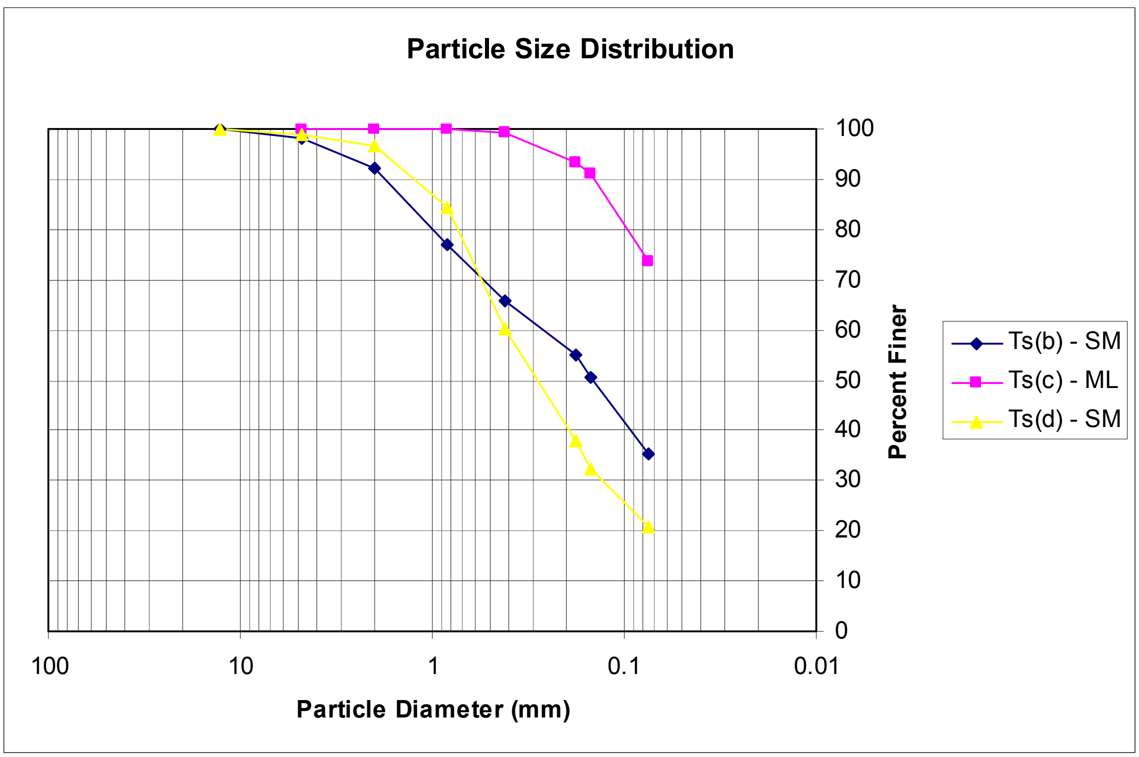
Mass of Dry Soil (g): 483.8

Sieve Number	Mass Retained (g)	Quantity Passing	Percent Retained	Percent Passing	Notes
1/2 inch	0	483.8	0	100	
No. 4	8.6	475.2	1.8	98.2	
No. 10	28.6	446.6	5.9	92.3	

No. 20	74.9	371.7	15.5	76.8	
No. 40	53	318.7	10.9	65.9	
No. 80	52.3	266.4	10.8	55.1	
No. 100	21.6	244.7	4.5	50.6	
No. 200	72.9	171.8	15.1	35.5	
Pan C	172.8	-1	35.7	-0.2	0.2% gain

Summary

% Cobbles:	0
% Gravel:	1.8
% Sand:	62.7
% Fines:	35.7
USCS:	**SM - Silty Sand**



Appendix F

Direct Shear Testing of Ts, Dry and Saturated

Direct-Shear Test, Test 17 (Bowles, 1992)

KEY:

Technician: Coralie Wilhite

Shear Area = 4 sq. in.
Shear Rate = 0.050 in./min.
50 psi = 123.6 ft. = 37.67 m.
100 psi = 247.2 ft. = 75.35 m.
200 psi = 494.4 ft. = 150.69 m.
(yellow highlight) = Max horizontal load
Readings were taken every 30 seconds.

Dry Direct Shear Testing of Ts

Ts(b) Dry Direct Shear Testing

Sample Name: Ts(b) S-19-10-08
Run: 1 Ts(b)1a
Date: 6 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
50	0.345	200	-14	0	0	-3.5	-0.024	Max. taken between 30 second readings
			29	0.018	0.4572	7.25	0.050	
			53	0.043	1.0922	13.25	0.091	
			79	0.064	1.6256	19.75	0.136	
			103	0.089	2.2606	25.75	0.178	
			121	0.113	2.8702	30.25	0.209	
			137	0.137	3.4798	34.25	0.236	
			148	0.162	4.1148	37	0.255	
			160	0.188	4.7752	40	0.276	
			170	0.216	5.4864	42.5	0.293	
			171	0.225	5.715	42.75	0.295	
			167	0.239	6.0706	41.75	0.288	
			159	0.262	6.6548	39.75	0.274	
			156	0.29	7.366	39	0.269	
			155	0.312	7.9248	38.75	0.267	

			162	0.338	8.5852	40.5	0.279	

Vertical displacement (in)= 0.0282

Sample Name: Ts(b) S-19-10-08
Run: 2 Ts(b)1b
Date: 6 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
100	0.689	400	-10	0	0	-2.5	-0.017	Max. taken between 30 second readings
			59	0.022	0.5588	14.75	0.102	
			162	0.054	1.3716	40.5	0.279	
			208	0.074	1.8796	52	0.359	
			240	0.093	2.3622	60	0.414	
			265	0.118	2.9972	66.25	0.457	
			273	0.146	3.7084	68.25	0.471	
			272	0.172	4.3688	68	0.469	
			276	0.198	5.0292	69	0.476	
			276	0.219	5.5626	69	0.476	
			281	0.245	6.223	70.25	0.484	
			285	0.27	6.858	71.25	0.491	
			286	0.296	7.5184	71.5	0.493	
			286	0.322	8.1788	71.5	0.493	
			292	0.344	8.7376	73	0.503	
			293	0.371	9.4234	73.25	0.505	
			293	0.395	10.033	73.25	0.505	
			292	0.42	10.668	73	0.503	
			296	0.435	11.049	74	0.510	
			295	0.446	11.3284	73.75	0.508	
			294	0.47	11.938	73.5	0.507	
			296	0.494	12.5476	74	0.510	

Vertical displacement (in)= 0.0985

Sample Name: Ts(b) S-19-10-08
Run: 3 Ts(b)1c
Date: 6 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
200	1.3789518	800	-10	0	0	-2.5	-0.017	Max. taken between 30 second
			29	0.013	0.3302	7.25	0.050	
			232	0.032	0.8128	58	0.400	
			448	0.078	1.9812	112	0.772	
			524	0.102	2.5908	131	0.903	

			576	0.126	3.2004	144	0.993	readings
			595	0.14	3.556	148.75	1.026	
			594	0.153	3.8862	148.5	1.024	
			579	0.177	4.4958	144.75	0.998	
			571	0.204	5.1816	142.75	0.984	
			573	0.226	5.7404	143.25	0.988	
			573	0.254	6.4516	143.25	0.988	
			570	0.276	7.0104	142.5	0.983	
			570	0.304	7.7216	142.5	0.983	
			573	0.329	8.3566	143.25	0.988	

Vertical displacement (in)= 0.1449

Sample Name: Ts(b) S-19-10-08
Run: 1 Ts(b)2a
Date: 6 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
50	0.344738	200	-9	0	0	-2.25	-0.016	Max. taken between 30 second readings
			64	0.023	0.5842	16	0.110	
			81	0.044	1.1176	20.25	0.140	
			110	0.066	1.6764	27.5	0.190	
			128	0.09	2.286	32	0.221	
			144	0.115	2.921	36	0.248	
			157	0.14	3.556	39.25	0.271	
			164	0.165	4.191	41	0.283	
			168	0.185	4.699	42	0.290	
			166	0.191	4.8514	41.5	0.286	
			161	0.215	5.461	40.25	0.278	
			156	0.241	6.1214	39	0.269	
			152	0.266	6.7564	38	0.262	
			147	0.29	7.366	36.75	0.253	
			144	0.317	8.0518	36	0.248	
			141	0.343	8.7122	35.25	0.243	

Vertical displacement (in)= 0.0334

Sample Name: Ts(b) S-19-10-08
Run: 2 Ts(b)2b
Date: 6 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
100	0.6894759	400	-21	0	0	-5.25	-0.036	Max. taken between 30 second
			-9	0.016	0.4064	-2.25	-0.016	
			52	0.038	0.9652	13	0.090	
			120	0.062	1.5748	30	0.207	
			174	0.092	2.3368	43.5	0.300	

			205	0.112	2.8448	51.25	0.353	readings
			238	0.138	3.5052	59.5	0.410	
			266	0.164	4.1656	66.5	0.459	
			286	0.192	4.8768	71.5	0.493	
			298	0.219	5.5626	74.5	0.514	
			303	0.244	6.1976	75.75	0.522	
			305	0.27	6.858	76.25	0.526	
			311	0.298	7.5692	77.75	0.536	
			313	0.32	8.128	78.25	0.540	
			312	0.326	8.2804	78	0.538	
			312	0.35	8.89	78	0.538	
			308	0.377	9.5758	77	0.531	
			298	0.404	10.2616	74.5	0.514	
			293	0.43	10.922	73.25	0.505	
			292	0.457	11.6078	73	0.503	

Vertical displacement (in)= 0.0959

Sample Name: Ts(b) S-19-10-08
Run: 3 Ts(b)2c
Date: 6 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
200	1.3789518	800	-9	0	0	-2.25	-0.016	Max. taken between 30 second readings
			102	0.016	0.4064	25.5	0.176	
			262	0.038	0.9652	65.5	0.452	
			396	0.073	1.8542	99	0.683	
			417	0.079	2.0066	104.25	0.719	
			509	0.11	2.794	127.25	0.877	
			555	0.135	3.429	138.75	0.957	
			575	0.159	4.0386	143.75	0.991	
			575	0.185	4.699	143.75	0.991	
			574	0.209	5.3086	143.5	0.989	
			580	0.238	6.0452	145	1.000	
			585	0.26	6.604	146.25	1.008	
			590	0.287	7.2898	147.5	1.017	
			599	0.311	7.8994	149.75	1.032	
			603	0.335	8.509	150.75	1.039	
			604	0.345	8.763	151	1.041	
			603	0.361	9.1694	150.75	1.039	
			601	0.384	9.7536	150.25	1.036	
			600	0.41	10.414	150	1.034	
			597	0.436	11.0744	149.25	1.029	
			596	0.46	11.684	149	1.027	
			599	0.488	12.3952	149.75	1.032	
			599	0.498	12.6492	149.75	1.032	

Vertical displacement (in)= 0.1

Sample Name: Ts(b) S-19-10-08
Run: 1 Ts(b)3a
Date: 8 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
50	0.344738	200	-9	0	0	-2.25	-0.016	Max. taken between 30 second readings
			85	0.009	0.2286	21.25	0.147	
			126	0.032	0.8128	31.5	0.217	
			153	0.057	1.4478	38.25	0.264	
			171	0.081	2.0574	42.75	0.295	
			185	0.108	2.7432	46.25	0.319	
			193	0.132	3.3528	48.25	0.333	
			195	0.155	3.937	48.75	0.336	
			197	0.17	4.318	49.25	0.340	
			196	0.18	4.572	49	0.338	
			192	0.206	5.2324	48	0.331	
			185	0.232	5.8928	46.25	0.319	
			175	0.257	6.5278	43.75	0.302	
			167	0.281	7.1374	41.75	0.288	
			159	0.307	7.7978	39.75	0.274	
			156	0.333	8.4582	39	0.269	
			156	0.36	9.144	39	0.269	
			156	0.383	9.7282	39	0.269	

Vertical displacement (in)= 0.0045

Sample Name: Ts(b) S-19-10-08
Run: 2 Ts(b)3b
Date: 8 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
100	0.6894759	400	-10	0	0	-2.5	-0.017	
			-9	0.018	0.4572	-2.25	-0.016	
			114	0.041	1.0414	28.5	0.197	
			162	0.064	1.6256	40.5	0.279	
			204	0.088	2.2352	51	0.352	
			238	0.111	2.8194	59.5	0.410	
			264	0.136	3.4544	66	0.455	
			278	0.162	4.1148	69.5	0.479	
			279	0.187	4.7498	69.75	0.481	
			279	0.212	5.3848	69.75	0.481	
			279	0.238	6.0452	69.75	0.481	
			280	0.263	6.6802	70	0.483	
			281	0.288	7.3152	70.25	0.484	

			284	0.313	7.9502	71	0.490	
			283	0.339	8.6106	70.75	0.488	
			285	0.367	9.3218	71.25	0.491	
			286	0.389	9.8806	71.5	0.493	
			286	0.413	10.4902	71.5	0.493	
			287	0.439	11.1506	71.75	0.495	
			289	0.465	11.811	72.25	0.498	
			292	0.491	12.4714	73	0.503	

Vertical displacement (in)= 0.0395

Sample Name: Ts(b) S-19-10-08

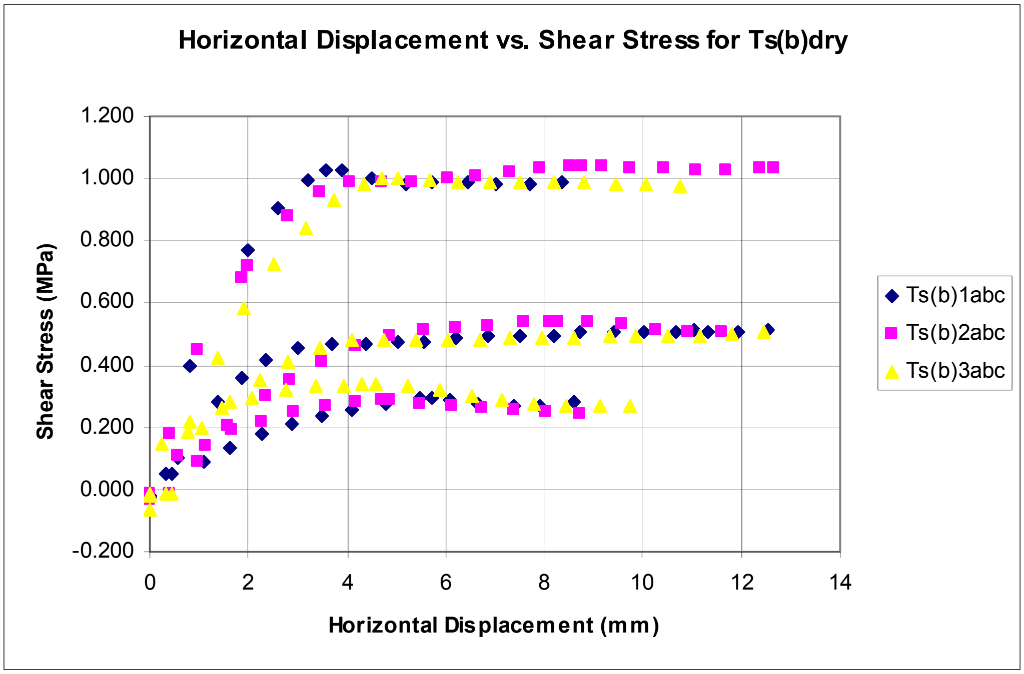
Run: 3 Ts(b)3c

Date: 8 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
200	1.3789518	800	-36	0	0	-9	-0.062	Max. taken between 30 second readings
			-8	0.012	0.3048	-2	-0.014	
			106	0.031	0.7874	26.5	0.183	
			247	0.054	1.3716	61.75	0.426	
			337	0.075	1.905	84.25	0.581	
			420	0.099	2.5146	105	0.724	
			488	0.125	3.175	122	0.841	
			540	0.147	3.7338	135	0.931	
			570	0.171	4.3434	142.5	0.983	
			581	0.185	4.699	145.25	1.001	
			580	0.198	5.0292	145	1.000	
			576	0.223	5.6642	144	0.993	
			573	0.246	6.2484	143.25	0.988	
			572	0.271	6.8834	143	0.986	
			572	0.296	7.5184	143	0.986	
			573	0.322	8.1788	143.25	0.988	
			573	0.347	8.8138	143.25	0.988	
			570	0.372	9.4488	142.5	0.983	
			571	0.397	10.0838	142.75	0.984	
			567	0.423	10.7442	141.75	0.977	

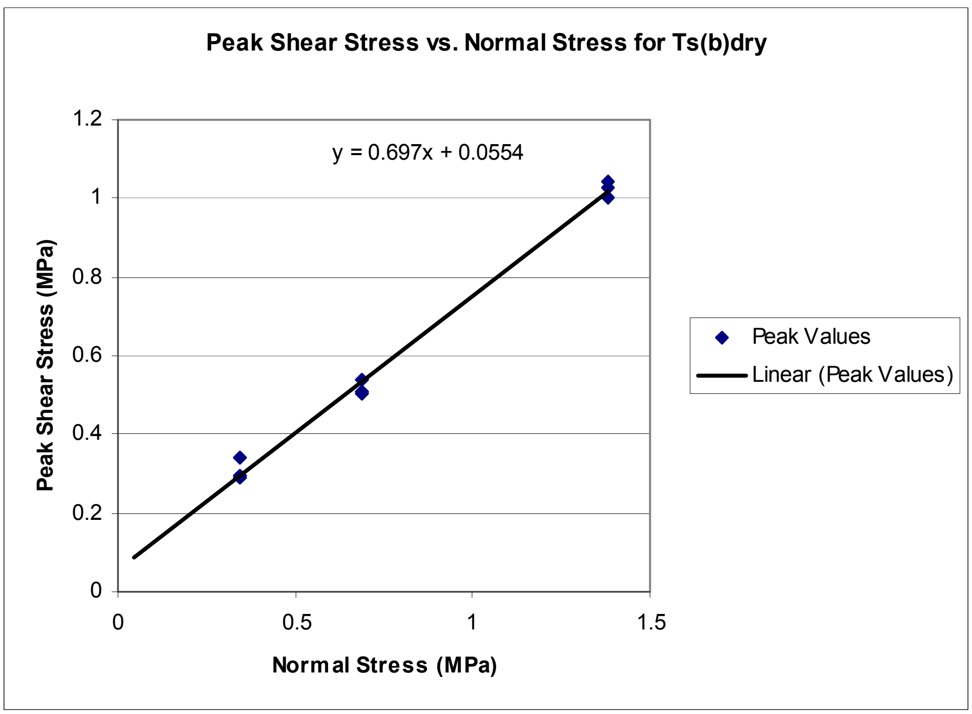
Vertical displacement (in)= 0.0846

Horizontal displacement verses shear stress for Ts(b)dry


Horizontal Displacement vs. Shear Stress for Ts(b)dry
Shear Stress (MPa)
1.200
1.000
0.800
0.600
0.400
0.200
0.000
-0.200
0
2
4
6
8
10
12
14
Horizontal Displacement (mm)
Ts(b)1abc
Ts(b)2abc
Ts(b)3abc

Peak shear stress values for Ts(b)dry at constant normal loads.

Normal Stress (psi)	Shear Stress (psi)	Normal Stress (MPa)	Shear Stress (MPa)	Cohesion (Mpa)	Internal Friction Angle (Φ)	Cohesion (psf)	Max Cohesion (psf)
50	42.75	0.344738	0.294751	0.055	36	1148.6989	21360.006
100	74	0.6894759	0.510212				
200	148.75	1.3789518	1.025595				
50	42	0.344738	0.28958				
100	78.25	0.6894759	0.539515				
200	151	1.3789518	1.041109				
50	49.25	0.344738	0.339567				
100	73	0.6894759	0.503317				
200	145.25	1.3789518	1.001464				



Max shear stress for each test and average of all tests

Normal Stress (psi)	Shear Stress (psi)	Normal Stress (psf)	Shear Stress (psf)	Normal Stress (psi)	Avg. Normal Stress (psf)	Avg. Shear Stress (psf)
50	42.75	231653.16	198063.4	50	231653.2	206943.49
100	74	463306.31	342846.7	100	463306.3	347865.82
200	148.75	926612.62	689168.1	200	926612.6	687237.7
50	42	231653.16	194588.7			
100	78.25	463306.31	362537.2			
200	151	926612.62	699592.5			
50	49.25	231653.16	228178.4			
100	73	463306.31	338213.6			
200	145.25	926612.62	672952.4			

Ts(c) Dry Direct Shear Testing

Sample Name: Ts(c) S-20-10-08
Run: 1 Ts(c)1a
Date: 10 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
50	0.344738	200	-12	0	0	-3	-0.021	Max. taken between 30 second readings Missed the 5 minute reading
			56	0.024	0.6096	14	0.097	
			90	0.049	1.2446	22.5	0.155	
			117	0.072	1.8288	29.25	0.202	
			136	0.096	2.4384	34	0.234	
			153	0.12	3.048	38.25	0.264	
			165	0.146	3.7084	41.25	0.284	
			174	0.171	4.3434	43.5	0.300	
			181	0.197	5.0038	45.25	0.312	
			184	0.215	5.461	46	0.317	
			182	0.221	5.6134	45.5	0.314	
			161	0.271	6.8834	40.25	0.278	
			151	0.296	7.5184	37.75	0.260	
			144	0.321	8.1534	36	0.248	
			142	0.347	8.8138	35.5	0.245	
			142	0.372	9.4488	35.5	0.245	
			142	0.397	10.0838	35.5	0.245	

Vertical displacement (in)= 0.0676

Sample Name: Ts(c) S-20-10-08
Run: 2 Ts(c)1b
Date: 10 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
100	0.6894759	400	-14	0	0	-3.5	-0.024	Max. taken between 30 second readings
			-11	0.016	0.4064	-2.75	-0.019	
			99	0.039	0.9906	24.75	0.171	
			167	0.068	1.7272	41.75	0.288	
			197	0.087	2.2098	49.25	0.340	
			230	0.112	2.8448	57.5	0.396	
			259	0.136	3.4544	64.75	0.446	
			276	0.161	4.0894	69	0.476	
			279	0.17	4.318	69.75	0.481	
			277	0.187	4.7498	69.25	0.477	
			269	0.211	5.3594	67.25	0.464	
			261	0.237	6.0198	65.25	0.450	
			259	0.262	6.6548	64.75	0.446	
			257	0.287	7.2898	64.25	0.443	
			257	0.312	7.9248	64.25	0.443	
			256	0.338	8.5852	64	0.441	
			257	0.363	9.2202	64.25	0.443	
			255	0.388	9.8552	63.75	0.440	

Vertical displacement (in)= 0.1039

Sample Name: Ts(c) S-20-10-08
Run: 3 Ts(c)1c
Date: 10 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
200	1.3789518	800	-39	0	0	-9.75	-0.067	Max. taken between 30 second readings
			-11	0.01	0.254	-2.75	-0.019	
			112	0.031	0.7874	28	0.193	
			238	0.052	1.3208	59.5	0.410	
			330	0.075	1.905	82.5	0.569	
			416	0.099	2.5146	104	0.717	
			482	0.123	3.1242	120.5	0.831	
			534	0.146	3.7084	133.5	0.920	
			567	0.17	4.318	141.75	0.977	
			572	0.185	4.699	143	0.986	
			569	0.196	4.9784	142.25	0.981	
			557	0.221	5.6134	139.25	0.960	
			550	0.246	6.2484	137.5	0.948	
			547	0.271	6.8834	136.75	0.943	
			544	0.297	7.5438	136	0.938	

			543	0.324	8.2296	135.75	0.936	
			541	0.348	8.8392	135.25	0.933	
			541	0.371	9.4234	135.25	0.933	

Vertical displacement (in)= 0.1547

Sample Name: Ts(c) S-20-10-08
Run: 1 Ts(c)2a
Date: 10 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
50	0.344738	200	-11	0	0	-2.75	-0.019	Max. taken between 30 second readings
			65	0.038	0.9652	16.25	0.112	
			100	0.064	1.6256	25	0.172	
			123	0.087	2.2098	30.75	0.212	
			145	0.111	2.8194	36.25	0.250	
			162	0.136	3.4544	40.5	0.279	
			172	0.161	4.0894	43	0.296	
			176	0.186	4.7244	44	0.303	
			178	0.212	5.3848	44.5	0.307	
			180	0.22	5.588	45	0.310	
			177	0.238	6.0452	44.25	0.305	
			173	0.264	6.7056	43.25	0.298	
			156	0.287	7.2898	39	0.269	
			145	0.314	7.9756	36.25	0.250	
			143	0.337	8.5598	35.75	0.246	
			143	0.363	9.2202	35.75	0.246	
			143	0.388	9.8552	35.75	0.246	
			143	0.414	10.5156	35.75	0.246	

Vertical displacement (in)= 0.0709

Sample Name: Ts(c) S-20-10-08
Run: 2 Ts(c)2b
Date: 10 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
100	0.6894759	400	-14	0	0	-3.5	-0.024	Max. taken between 30 second readings
			-10	0.017	0.4318	-2.5	-0.017	
			118	0.047	1.1938	29.5	0.203	
			158	0.063	1.6002	39.5	0.272	
			200	0.087	2.2098	50	0.345	
			238	0.111	2.8194	59.5	0.410	
			268	0.136	3.4544	67	0.462	
			285	0.16	4.064	71.25	0.491	
			290	0.18	4.572	72.5	0.500	
			288	0.186	4.7244	72	0.496	

			277	0.211	5.3594	69.25	0.477	
			275	0.236	5.9944	68.75	0.474	
			274	0.261	6.6294	68.5	0.472	
			275	0.286	7.2644	68.75	0.474	
			277	0.312	7.9248	69.25	0.477	
			280	0.337	8.5598	70	0.483	
			281	0.362	9.1948	70.25	0.484	
			282	0.388	9.8552	70.5	0.486	

Vertical displacement (in)= 0.1127

Sample Name: Ts(c) S-20-10-08
Run: 3 Ts(c)2c
Date: 10 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
200	1.3789518	800	-40	0	0	-10	-0.069	Max. taken between 30 second readings
			-10	0.011	0.2794	-2.5	-0.017	
			111	0.031	0.7874	27.75	0.191	
			250	0.052	1.3208	62.5	0.431	
			339	0.075	1.905	84.75	0.584	
			416	0.098	2.4892	104	0.717	
			478	0.121	3.0734	119.5	0.824	
			528	0.146	3.7084	132	0.910	
			560	0.17	4.318	140	0.965	
			565	0.175	4.445	141.25	0.974	
			560	0.196	4.9784	140	0.965	
			546	0.229	5.8166	136.5	0.941	
			545	0.247	6.2738	136.25	0.939	
			544	0.271	6.8834	136	0.938	
			548	0.296	7.5184	137	0.945	
			550	0.322	8.1788	137.5	0.948	
			553	0.347	8.8138	138.25	0.953	
			557	0.372	9.4488	139.25	0.960	

Vertical displacement (in)= 0.1544

Sample Name: Ts(c) S-20-10-08
Run: 1 Ts(c)3a
Date: 10 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
50	0.344738	200	-11	0	0	-2.75	-0.019	
			-10	0.015	0.381	-2.5	-0.017	
			65	0.038	0.9652	16.25	0.112	
			90	0.066	1.6764	22.5	0.155	
			105	0.084	2.1336	26.25	0.181	

			122	0.108	2.7432	30.5	0.210	
			137	0.133	3.3782	34.25	0.236	
			150	0.158	4.0132	37.5	0.259	
			160	0.183	4.6482	40	0.276	
			165	0.208	5.2832	41.25	0.284	
			163	0.235	5.969	40.75	0.281	
			161	0.258	6.5532	40.25	0.278	
			157	0.284	7.2136	39.25	0.271	
			144	0.309	7.8486	36	0.248	
			137	0.335	8.509	34.25	0.236	
			136	0.36	9.144	34	0.234	
			134	0.385	9.779	33.5	0.231	

Vertical displacement (in)= 0.0529

Sample Name: Ts(c) S-20-10-08
Run: 2 Ts(c)3b
Date: 10 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
100	0.6894759	400	-37	0	0	-9.25	-0.064	
			-9	0.013	0.3302	-2.25	-0.016	
			62	0.034	0.8636	15.5	0.107	
			119	0.057	1.4478	29.75	0.205	
			156	0.081	2.0574	39	0.269	
			202	0.109	2.7686	50.5	0.348	
			230	0.129	3.2766	57.5	0.396	
			260	0.154	3.9116	65	0.448	
			278	0.179	4.5466	69.5	0.479	
			284	0.204	5.1816	71	0.490	
			286	0.229	5.8166	71.5	0.493	
			286	0.258	6.5532	71.5	0.493	
			286	0.28	7.112	71.5	0.493	
			287	0.305	7.747	71.75	0.495	
			286	0.329	8.3566	71.5	0.493	
			285	0.357	9.0678	71.25	0.491	
			282	0.381	9.6774	70.5	0.486	
			280	0.406	10.3124	70	0.483	
			274	0.432	10.9728	68.5	0.472	

Vertical displacement (in)= 0.1026

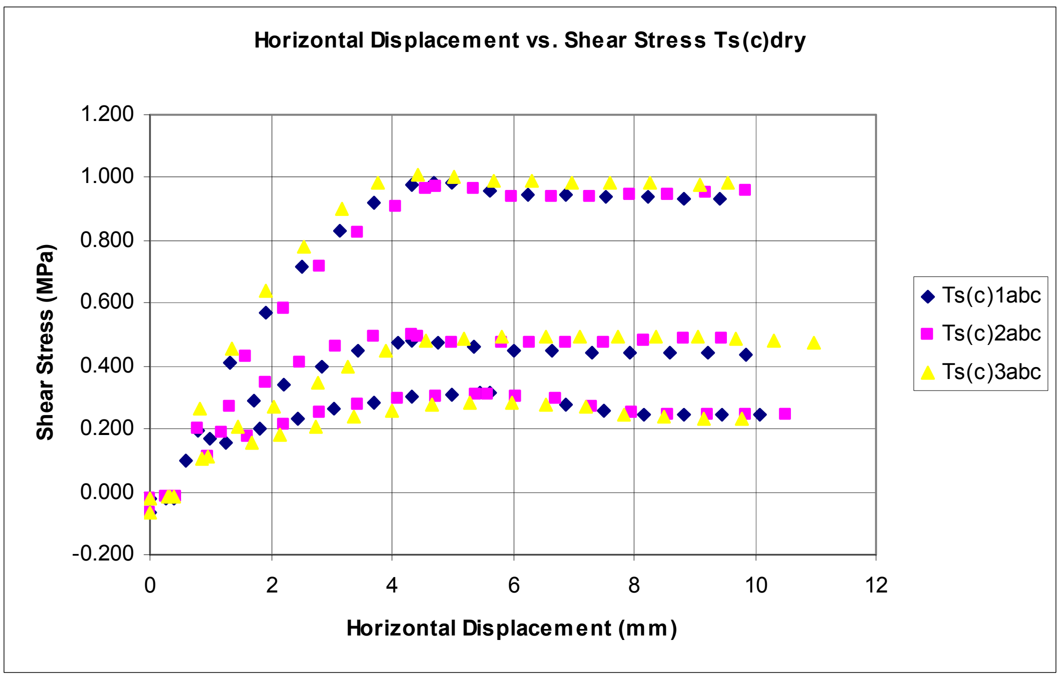
Sample Name: Ts(c) S-20-10-08
Run: 3 Ts(c)3c
Date: 10 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes

200	1.3789518	800	-12	0	0	-3	-0.021
			-10	0.012	0.3048	-2.5	-0.017
			153	0.032	0.8128	38.25	0.264
			264	0.054	1.3716	66	0.455
			370	0.076	1.9304	92.5	0.638
			453	0.1	2.54	113.25	0.781
			523	0.125	3.175	130.75	0.901
			569	0.148	3.7592	142.25	0.981
			587	0.174	4.4196	146.75	1.012
			582	0.198	5.0292	145.5	1.003
			576	0.224	5.6896	144	0.993
			573	0.249	6.3246	143.25	0.988
			571	0.274	6.9596	142.75	0.984
			571	0.299	7.5946	142.75	0.984
			570	0.325	8.255	142.5	0.983
			567	0.358	9.0932	141.75	0.977
			571	0.376	9.5504	142.75	0.984

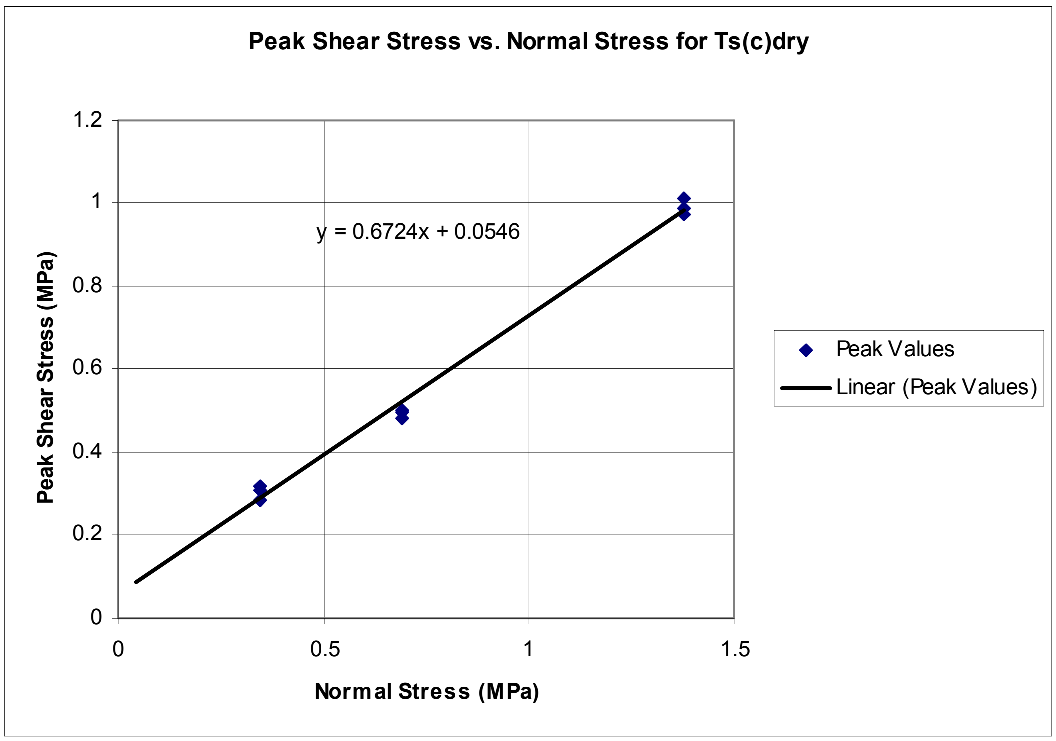
Vertical displacement (in)= 0.1489

Horizontal displacement verses shear stress for Ts(c)dry



Peak shear stress values for Ts(c)dry at constant normal loads.

Normal Stress (psi)	Shear Stress (psi)	Normal Stress (MPa)	Shear Stress (MPa)	Cohesion (Mpa)	Internal Friction Angle (Φ)	Cohesion (psf)	Max Cohesion (psf)
50	46	0.344738	0.317159	0.055	35	1148.6989	20688.005
100	69.75	0.6894759	0.480909				
200	143	1.3789518	0.985951				
50	45	0.344738	0.310264				
100	72.5	0.6894759	0.49987				
200	141.25	1.3789518	0.973885				
50	41.25	0.344738	0.284409				
100	71.75	0.6894759	0.494699				
200	146.75	1.3789518	1.011806				



Max shear stress for each test and average of all tests

Normal Stress (psi)	Shear Stress (psi)	Normal Stress (psf)	Shear Stress (psf)	Normal Stress (psi)	Avg. Normal Stress (psf)	Avg. Shear Stress (psf)
50	46	231653.16	213120.9	50	231653.2	204240.87
100	69.75	463306.31	323156.2	100	463306.3	330491.84
200	143	926612.62	662528	200	926612.6	665616.73
50	45	231653.16	208487.8			
100	72.5	463306.31	335897.1			
200	141.25	926612.62	654420.2			
50	41.25	231653.16	191113.9			
100	71.75	463306.31	332422.3			
200	146.75	926612.62	679902			

Ts(d) Dry Direct Shear Testing

Sample Name: Ts(d) S-23-10-08
Run: 1 Ts(d)1a
Date: 8 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
50	0.344738	200	-16	0	0	-4	-0.028	Max. taken between 30 second readings
			13	0.025	0.635	3.25	0.022	
			83	0.048	1.2192	20.75	0.143	
			117	0.071	1.8034	29.25	0.202	
			145	0.096	2.4384	36.25	0.250	
			170	0.123	3.1242	42.5	0.293	
			186	0.146	3.7084	46.5	0.321	
			195	0.171	4.3434	48.75	0.336	
			199	0.196	4.9784	49.75	0.343	
			200	0.205	5.207	50	0.345	
			198	0.222	5.6388	49.5	0.341	
			188	0.246	6.2484	47	0.324	
			181	0.272	6.9088	45.25	0.312	
			177	0.297	7.5438	44.25	0.305	
			173	0.233	5.9182	43.25	0.298	
			173	0.347	8.8138	43.25	0.298	
			174	0.373	9.4742	43.5	0.300	
			172	0.399	10.1346	43	0.296	

Vertical displacement (in)= 0.0427

Sample Name: Ts(d) S-23-10-08
Run: 2 Ts(d)1b
Date: 8 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
			-46	0	0	-11.5	-0.079	
			-9	0.012	0.3048	-2.25	-0.016	
			59	0.033	0.8382	14.75	0.102	
			135	0.056	1.4224	33.75	0.233	
			187	0.08	2.032	46.75	0.322	
			224	0.104	2.6416	56	0.386	
			256	0.129	3.2766	64	0.441	
			283	0.153	3.8862	70.75	0.488	
			307	0.179	4.5466	76.75	0.529	
100	0.6894759	400	321	0.203	5.1562	80.25	0.553	
			328	0.228	5.7912	82	0.565	
			331	0.253	6.4262	82.75	0.571	
			330	0.278	7.0612	82.5	0.569	
			330	0.303	7.6962	82.5	0.569	
			328	0.329	8.3566	82	0.565	
			333	0.355	9.017	83.25	0.574	
			335	0.379	9.6266	83.75	0.577	
			337	0.406	10.3124	84.25	0.581	
			335	0.428	10.8712	83.75	0.577	

Vertical displacement (in)= 0.0863

Sample Name: Ts(d) S-23-10-08
Run: 3 Ts(d)1c
Date: 8 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
200	1.3789518	800	-65	0	0	-16.25	-0.112	Max. taken between 30 second readings
			-9	0.011	0.2794	-2.25	-0.016	
			80	0.031	0.7874	20	0.138	
			225	0.053	1.3462	56.25	0.388	
			318	0.075	1.905	79.5	0.548	
			388	0.099	2.5146	97	0.669	
			452	0.123	3.1242	113	0.779	
			511	0.146	3.7084	127.75	0.881	
			563	0.171	4.3434	140.75	0.970	
			603	0.195	4.953	150.75	1.039	
			630	0.22	5.588	157.5	1.086	
			650	0.246	6.2484	162.5	1.120	
			658	0.269	6.8326	164.5	1.134	

			667	0.298	7.5692	166.75	1.150	
			671	0.32	8.128	167.75	1.157	
			671	0.344	8.7376	167.75	1.157	
			674	0.37	9.398	168.5	1.162	
			675	0.375	9.525	168.75	1.163	
			670	0.394	10.0076	167.5	1.155	
			667	0.42	10.668	166.75	1.150	
			662	0.445	11.303	165.5	1.141	
			645	0.471	11.9634	161.25	1.112	

Vertical displacement (in)= 0.1317

Sample Name: Ts(d) S-23-10-08
Run: 1 Ts(d)2a
Date: 9 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
50	0.344738	200	-11	0	0	-2.75	-0.019	
			30	0.02	0.508	7.5	0.052	
			80	0.04	1.016	20	0.138	
			118	0.063	1.6002	29.5	0.203	
			148	0.086	2.1844	37	0.255	
			179	0.11	2.794	44.75	0.309	
			199	0.136	3.4544	49.75	0.343	
			206	0.161	4.0894	51.5	0.355	
			203	0.185	4.699	50.75	0.350	
			197	0.21	5.334	49.25	0.340	
			192	0.235	5.969	48	0.331	
			184	0.263	6.6802	46	0.317	
			180	0.286	7.2644	45	0.310	
			179	0.311	7.8994	44.75	0.309	
			178	0.338	8.5852	44.5	0.307	
			177	0.361	9.1694	44.25	0.305	
			175	0.387	9.8298	43.75	0.302	

Vertical displacement (in)= 0.1643

Sample Name: Ts(d) S-23-10-08
Run: 2 Ts(d)2b
Date: 9 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
100	0.6894759	400	-17	0	0	-4.25	-0.029	Max. taken between 30 second readings
			-4	0.021	0.5334	-1	-0.007	
			93	0.041	1.0414	23.25	0.160	
			150	0.064	1.6256	37.5	0.259	
			196	0.088	2.2352	49	0.338	

			233	0.111	2.8194	58.25	0.402	
			266	0.136	3.4544	66.5	0.459	
			297	0.16	4.064	74.25	0.512	
			320	0.185	4.699	80	0.552	
			332	0.21	5.334	83	0.572	
			338	0.238	6.0452	84.5	0.583	
			338	0.26	6.604	84.5	0.583	
			344	0.287	7.2898	86	0.593	
			344	0.311	7.8994	86	0.593	
			346	0.335	8.509	86.5	0.596	
			347	0.35	8.89	86.75	0.598	
			346	0.362	9.1948	86.5	0.596	
			345	0.386	9.8044	86.25	0.595	
			342	0.411	10.4394	85.5	0.590	
			342	0.437	11.0998	85.5	0.590	
			341	0.461	11.7094	85.25	0.588	
			337	0.487	12.3698	84.25	0.581	

Vertical displacement (in)= 0.2044

Sample Name: Ts(d) S-23-10-08
Run: 3 Ts(d)2c
Date: 9 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
200	1.3789518	800	-19	0	0	-4.75	-0.033	Max. taken between 30 second readings
			-10	0.015	0.381	-2.5	-0.017	
			140	0.035	0.889	35	0.241	
			279	0.057	1.4478	69.75	0.481	
			375	0.08	2.032	93.75	0.646	
			454	0.102	2.5908	113.5	0.783	
			520	0.127	3.2258	130	0.896	
			573	0.151	3.8354	143.25	0.988	
			611	0.175	4.445	152.75	1.053	
			637	0.2	5.08	159.25	1.098	
			658	0.225	5.715	164.5	1.134	
			669	0.253	6.4262	167.25	1.153	
			673	0.275	6.985	168.25	1.160	
			675	0.285	7.239	168.75	1.163	
			672	0.3	7.62	168	1.158	
			670	0.325	8.255	167.5	1.155	
			669	0.35	8.89	167.25	1.153	
			669	0.375	9.525	167.25	1.153	
			670	0.401	10.1854	167.5	1.155	
			666	0.425	10.795	166.5	1.148	

Vertical displacement (in)= 0.2457

Sample Name: Ts(d) S-23-10-08
Run: 1 Ts(d)3a
Date: 9 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
50	0.344738	200	-9	0	0	-2.25	-0.016	Max. taken between 30 second readings
			79	0.021	0.5334	19.75	0.136	
			122	0.045	1.143	30.5	0.210	
			155	0.069	1.7526	38.75	0.267	
			183	0.094	2.3876	45.75	0.315	
			199	0.119	3.0226	49.75	0.343	
			202	0.13	3.302	50.5	0.348	
			201	0.143	3.6322	50.25	0.346	
			193	0.168	4.2672	48.25	0.333	
			184	0.194	4.9276	46	0.317	
			179	0.22	5.588	44.75	0.309	
			178	0.245	6.223	44.5	0.307	
			176	0.27	6.858	44	0.303	
			175	0.295	7.493	43.75	0.302	
			174	0.322	8.1788	43.5	0.300	
			175	0.347	8.8138	43.75	0.302	

Vertical displacement (in)= 0.0264

Sample Name: Ts(d) S-23-10-08
Run: 2 Ts(d)3b
Date: 9 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
100	0.6894759	400	-14	0	0	-3.5	-0.024	Max. taken between 30 second readings
			-9	0.018	0.4572	-2.25	-0.016	
			107	0.04	1.016	26.75	0.184	
			175	0.063	1.6002	43.75	0.302	
			226	0.087	2.2098	56.5	0.390	
			272	0.112	2.8448	68	0.469	
			309	0.136	3.4544	77.25	0.533	
			326	0.16	4.064	81.5	0.562	
			326	0.185	4.699	81.5	0.562	
			327	0.211	5.3594	81.75	0.564	
			331	0.237	6.0198	82.75	0.571	
			333	0.261	6.6294	83.25	0.574	
			336	0.286	7.2644	84	0.579	
			338	0.312	7.9248	84.5	0.583	
			339	0.32	8.128	84.75	0.584	
			337	0.336	8.5344	84.25	0.581	
			334	0.361	9.1694	83.5	0.576	

			333	0.387	9.8298	83.25	0.574	
			324	0.412	10.4648	81	0.558	
			318	0.438	11.1252	79.5	0.548	

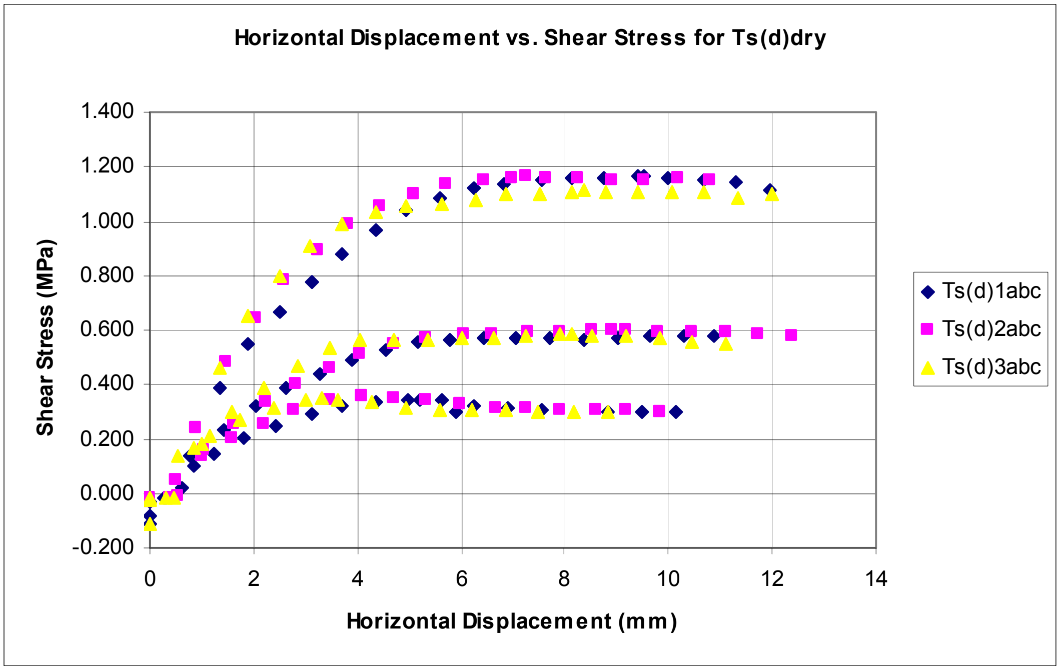
Vertical displacement (in)= 0.0645

Sample Name: Ts(d) S-23-10-08
Run: 3 Ts(d)3c
Date: 9 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
200	1.3789518	800	-63	0	0	-15.75	-0.109	Max. taken between 30 second readings
			-9	0.012	0.3048	-2.25	-0.016	
			95	0.033	0.8382	23.75	0.164	
			269	0.053	1.3462	67.25	0.464	
			378	0.075	1.905	94.5	0.652	
			461	0.098	2.4892	115.25	0.795	
			528	0.122	3.0988	132	0.910	
			573	0.146	3.7084	143.25	0.988	
			600	0.171	4.3434	150	1.034	
			611	0.195	4.953	152.75	1.053	
			618	0.221	5.6134	154.5	1.065	
			625	0.247	6.2738	156.25	1.077	
			636	0.271	6.8834	159	1.096	
			639	0.296	7.5184	159.75	1.101	
			641	0.321	8.1534	160.25	1.105	
			646	0.33	8.382	161.5	1.114	
			643	0.346	8.7884	160.75	1.108	
			644	0.371	9.4234	161	1.110	
			642	0.396	10.0584	160.5	1.107	
			640	0.421	10.6934	160	1.103	
			630	0.446	11.3284	157.5	1.086	
			637	0.472	11.9888	159.25	1.098	

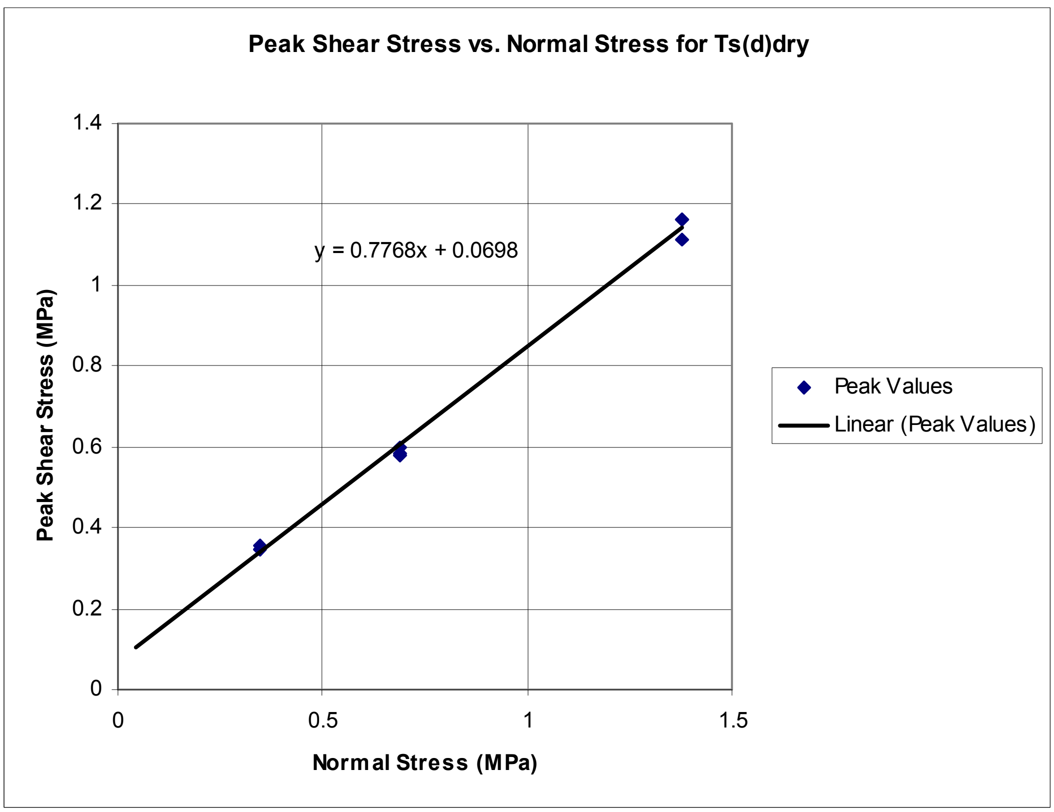
Vertical displacement (in)= 0.1044

Horizontal displacement verses shear stress for Ts(d)dry



Peak shear stress values for Ts(d)dry at constant normal loads.

Normal Stress (psi)	Shear Stress (psi)	Normal Stress (MPa)	Shear Stress (MPa)	Cohesion (Mpa)	Internal Friction Angle (Φ)	Cohesion (psf)	Max Cohesion (psf)
50	50	0.344738	0.344738	0.07	38	1461.9804	23952.006
100	84.25	0.6894759	0.580883				
200	168.75	1.3789518	1.163491				
50	51.5	0.344738	0.35508				
100	86.75	0.6894759	0.59812				
200	168.75	1.3789518	1.163491				
50	50.5	0.344738	0.348185				
100	84.75	0.6894759	0.584331				
200	161.5	1.3789518	1.113504				



Max shear stress for each test and average of all dry strength tests

Normal Stress (psi)	Shear Stress (psi)	Normal Stress (psf)	Shear Stress (psf)	Normal Stress (psi)	Avg. Normal Stress (psf)	Avg. Shear Stress (psf)
50	50	231653.16	231653.2	50	231653.2	234741.86
100	84.25	463306.31	390335.6	100	463306.3	394968.63
200	168.75	926612.62	781829.4	200	926612.6	770632.83
50	51.5	231653.16	238602.8			
100	86.75	463306.31	401918.2			
200	168.75	926612.62	781829.4			
50	50.5	231653.16	233969.7			
100	84.75	463306.31	392652.1			
200	161.5	926612.62	748239.7			

Average dry direct shear results for Ts(a), Ts(b), and Ts(c)

Average Values for each unit and depth				Over all averages for 50, 100, and 200 psi		
Unit	Normal Stress (psi)	Normal Stress (psf)	Shear Stress (psf)	Normal Stress (psi)	Avg. Normal Stress (psf)	Avg. Shear Stress (psf)
Ts(b)	50	231653.16	206943.5	50	231653.2	215308.74
	100	463306.31	347865.8	100	463306.3	357775.43
	200	926612.62	687237.7	200	926612.6	707829.09
Ts(c)	50	231653.16	204240.9			
	100	463306.31	330491.8			
	200	926612.62	665616.7			
Ts(d)	50	231653.16	234741.9			
	100	463306.31	394968.6			
	200	926612.62	770632.8			

Avg Cohesion psf	Average Φ
1253.13	36.33

Saturated Direct Shear Testing of Ts

Ts(b) Saturated Direct Shear Testing

Sample Name: Ts(b) S-19-10-08
Run: 1 Ts(b)w1a
Date: 16 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
50	0.344738	200	-12	0	0	-3	-0.021	Max. taken between 30 second readings
			-4	0.021	0.5334	-1	-0.007	
			58	0.044	1.1176	14.5	0.100	
			61	0.069	1.7526	15.25	0.105	
			67	0.093	2.3622	16.75	0.115	
			70	0.118	2.9972	17.5	0.121	
			72	0.144	3.6576	18	0.124	
			73	0.168	4.2672	18.25	0.126	
			73	0.193	4.9022	18.25	0.126	
			74	0.22	5.588	18.5	0.128	
			74	0.244	6.1976	18.5	0.128	
			75	0.254	6.4516	18.75	0.129	
			74	0.268	6.8072	18.5	0.128	
			74	0.264	6.7056	18.5	0.128	
			73	0.319	8.1026	18.25	0.126	
			74	0.344	8.7376	18.5	0.128	
			74	0.369	9.3726	18.5	0.128	
			75	0.395	10.033	18.75	0.129	

Vertical displacement (in) = 0.1368
Saturation Time = 1 hr. 30 min.

Sample Name: Ts(b) S-19-10-08
Run: 2 Ts(b)w1b
Date: 16 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
100	0.6894759	400	-18	0	0	-4.5	-0.031	
			-11	0.014	0.3556	-2.75	-0.019	
			75	0.04	1.016	18.75	0.129	
			108	0.061	1.5494	27	0.186	
			124	0.084	2.1336	31	0.214	
			134	0.109	2.7686	33.5	0.231	
			143	0.134	3.4036	35.75	0.246	

			147	0.16	4.064	36.75	0.253	
			150	0.185	4.699	37.5	0.259	
			153	0.21	5.334	38.25	0.264	
			152	0.238	6.0452	38	0.262	
			152	0.264	6.7056	38	0.262	
			151	0.285	7.239	37.75	0.260	
			150	0.312	7.9248	37.5	0.259	
			149	0.336	8.5344	37.25	0.257	

Vertical displacement (in) = 0.2356

Saturation Time = 1 hr. 30 min.

Sample Name: Ts(b) S-19-10-08

Run: 3 Ts(b)w1c

Date: 16 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
200	1.3789518	800	-17	0	0	-4.25	-0.029	
			-9	0.013	0.3302	-2.25	-0.016	
			135	0.034	0.8636	33.75	0.233	
			199	0.058	1.4732	49.75	0.343	
			213	0.081	2.0574	53.25	0.367	
			219	0.115	2.921	54.75	0.377	
			221	0.132	3.3528	55.25	0.381	
			221	0.158	4.0132	55.25	0.381	
			223	0.183	4.6482	55.75	0.384	
			225	0.208	5.2832	56.25	0.388	
			226	0.233	5.9182	56.5	0.390	
			224	0.258	6.5532	56	0.386	
			223	0.283	7.1882	55.75	0.384	
			220	0.308	7.8232	55	0.379	
			218	0.334	8.4836	54.5	0.376	

Vertical displacement (in) = 0.3018

Saturation Time = 1 hr. 30 min.

Sample Name: Ts(b) S-19-10-08

Run: 1 Ts(b)w2a

Date: 17 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
50	0.344738	200	-12	0	0	-3	-0.021	Max. taken between 30 second readings
			55	0.014	0.3556	13.75	0.095	
			68	0.038	0.9652	17	0.117	
			70	0.069	1.7526	17.5	0.121	
			73	0.087	2.2098	18.25	0.126	
			74	0.105	2.667	18.5	0.128	

			73	0.113	2.8702	18.25	0.126	
			73	0.137	3.4798	18.25	0.126	
			72	0.163	4.1402	18	0.124	
			71	0.187	4.7498	17.75	0.122	
			70	0.213	5.4102	17.5	0.121	
			69	0.239	6.0706	17.5	0.121	

Vertical displacement (in) = 0.1491

Saturation Time = Overnight 18 hours

Sample Name: Ts(b) S-19-10-08

Run: 2 Ts(b)w2b

Date: 17 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
			-11	0	0	-2.75	-0.019	
			55	0.021	0.5334	13.75	0.095	
			100	0.044	1.1176	25	0.172	
			125	0.072	1.8288	31.25	0.215	
			136	0.093	2.3622	34	0.234	
			142	0.119	3.0226	35.5	0.245	
			145	0.143	3.6322	36.25	0.250	
100	0.6894759	400	145	0.17	4.318	36.25	0.250	
			146	0.199	5.0546	36.5	0.252	
			145	0.219	5.5626	36.25	0.250	
			145	0.245	6.223	36.25	0.250	
			144	0.269	6.8326	36	0.248	
			143	0.295	7.493	35.75	0.246	
			143	0.321	8.1534	35.75	0.246	
			142	0.345	8.763	35.5	0.245	

Vertical displacement (in) = 0.2399

Saturation Time = Overnight 18 hours

Sample Name: Ts(b) S-19-10-08

Run: 3 Ts(b)w2c

Date: 17 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
200	1.3789518	800	-19	0	0	-4.75	-0.033	Max. taken between 30 second readings
			-11	0.01	0.254	-2.75	-0.019	
			95	0.035	0.889	23.75	0.164	
			162	0.055	1.397	40.5	0.279	
			176	0.08	2.032	44	0.303	
			183	0.106	2.6924	45.75	0.315	
			188	0.131	3.3274	47	0.324	
			188	0.156	3.9624	47	0.324	

			191	0.1841	4.67614	47.75	0.329	
			193	0.206	5.2324	48.25	0.333	
			197	0.231	5.8674	49.25	0.340	
			199	0.257	6.5278	49.75	0.343	
			199	0.282	7.1628	49.75	0.343	
			199	0.307	7.7978	49.75	0.343	
			202	0.332	8.4328	50.5	0.348	
			203	0.358	9.0932	50.75	0.350	
			205	0.382	9.7028	51.25	0.353	
			205	0.407	10.3378	51.25	0.353	
			207	0.415	10.541	51.75	0.357	
			205	0.433	10.9982	51.25	0.353	
			205	0.459	11.6586	51.25	0.353	
			204	0.483	12.2682	51	0.352	

Vertical displacement (in) = 0.3029

Saturation Time = Overnight 18 hours

Sample Name: Ts(b) S-19-10-08

Run: 1 Ts(b)w3a

Date: 17 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
50	0.344738	200	-10	0	0	-2.5	-0.017	Max. taken between 30 second readings
			28	0.019	0.4826	7	0.048	
			43	0.043	1.0922	10.75	0.074	
			56	0.068	1.7272	14	0.097	
			62	0.092	2.3368	15.5	0.107	
			64	0.117	2.9718	16	0.110	
			65	0.143	3.6322	16.25	0.112	
			65	0.167	4.2418	16.25	0.112	
			65	0.194	4.9276	16.25	0.112	
			64	0.214	5.4356	16	0.110	
			64	0.243	6.1722	16	0.110	
			63	0.267	6.7818	15.75	0.109	
			65	0.294	7.4676	16.25	0.112	
			67	0.304	7.7216	16.75	0.115	
			66	0.319	8.1026	16.5	0.114	
			65	0.344	8.7376	16.25	0.112	
			64	0.369	9.3726	16	0.110	
			64	0.394	10.0076	16	0.110	

Vertical displacement (in) = 0.2089

Saturation Time = 1 hr. 30 min.

Sample Name: Ts(b) S-19-10-08

Run: 2 Ts(b)w3b

Date: 17 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
100	0.6894759	400	-13	0	0	-3.25	-0.022	
			-8	0.017	0.4318	-2	-0.014	
			81	0.04	1.016	20.25	0.140	
			115	0.063	1.6002	28.75	0.198	
			135	0.09	2.286	33.75	0.233	
			140	0.114	2.8956	35	0.241	
			144	0.139	3.5306	36	0.248	
			145	0.164	4.1656	36.25	0.250	
			145	0.19	4.826	36.25	0.250	
			145	0.215	5.461	36.25	0.250	
			145	0.24	6.096	36.25	0.250	
			145	0.265	6.731	36.25	0.250	
			147	0.29	7.366	36.75	0.253	
			145	0.316	8.0264	36.25	0.250	
			145	0.341	8.6614	36.25	0.250	
			144	0.365	9.271	36	0.248	
			144	0.39	9.906	36	0.248	

Vertical displacement (in) = 0.2941

Saturation Time = 1 hr. 30 min.

Sample Name: Ts(b) S-19-10-08

Run: 3 Ts(b)w3c

Date: 17 Feb. 2009

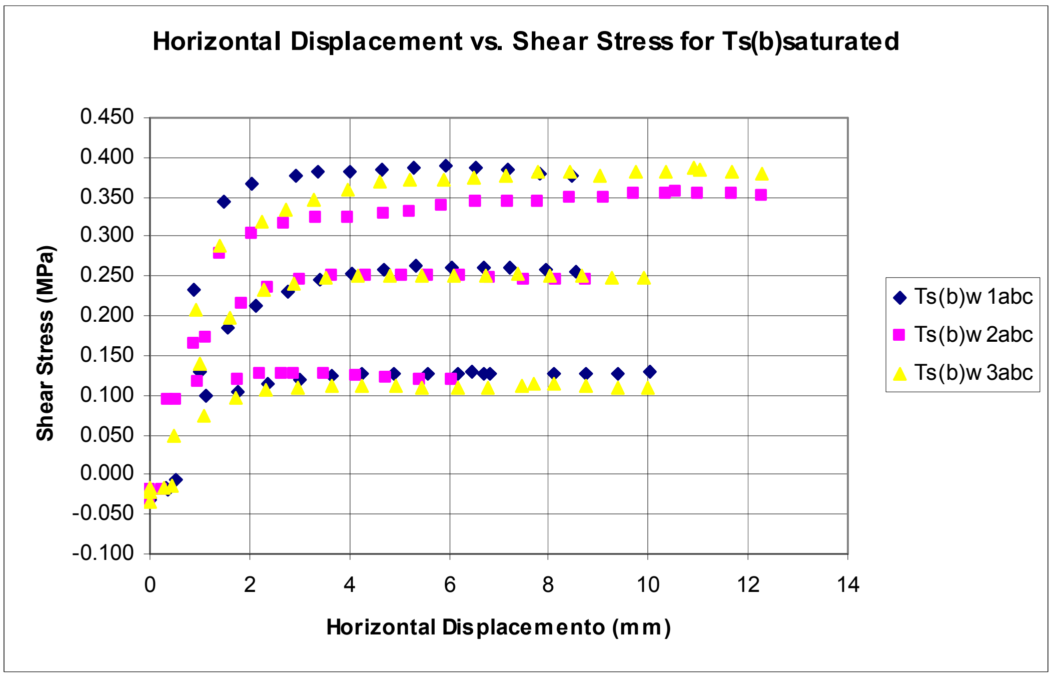
Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
200	1.3789518	800	-20	0	0	-5	-0.034	Max. taken between 30 second readings
			-10	0.011	0.2794	-2.5	-0.017	
			120	0.036	0.9144	30	0.207	
			168	0.056	1.4224	42	0.290	
			185	0.088	2.2352	46.25	0.319	
			194	0.108	2.7432	48.5	0.334	
			201	0.13	3.302	50.25	0.346	
			209	0.157	3.9878	52.25	0.360	
			214	0.181	4.5974	53.5	0.369	
			216	0.206	5.2324	54	0.372	
			215	0.232	5.8928	53.75	0.371	
			217	0.256	6.5024	54.25	0.374	
			219	0.281	7.1374	54.75	0.377	
			221	0.306	7.7724	55.25	0.381	
			221	0.332	8.4328	55.25	0.381	
			219	0.356	9.0424	54.75	0.377	
			221	0.383	9.7282	55.25	0.381	
			221	0.408	10.3632	55.25	0.381	

			224	0.43	10.922	56	0.386	
			223	0.434	11.0236	55.75	0.384	
			221	0.46	11.684	55.25	0.381	
			220	0.484	12.2936	55	0.379	

Vertical displacement (in) = 0.3785

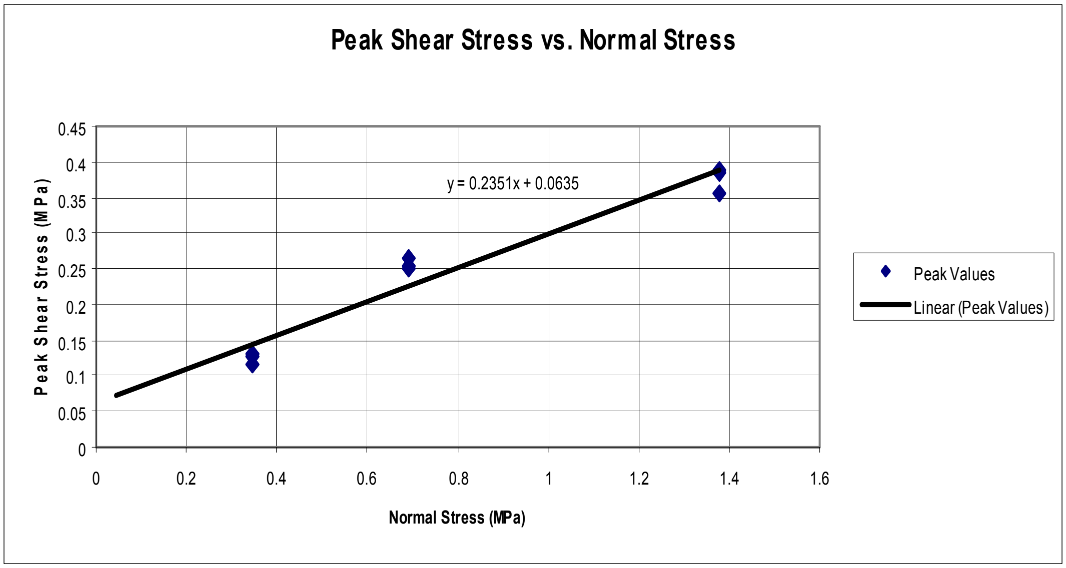
Saturation Time = 1 hr. 30 min.

Horizontal displacement verses shear stress for Ts(b) saturated



Peak shear stress values for Ts(b)saturated at constant normal loads.

Normal Stress (psi)	Shear Stress (psi)	Normal Stress (MPa)	Shear Stress (MPa)	Cohesion (Mpa)	Internal Friction Angle (Φ)	Cohesion (psf)	Max Cohesion (psf)
50	18.75	0.344738	0.129277	0.063	26	1315.7824	8100.0021
100	38.25	0.6894759	0.263725				
200	56.5	1.3789518	0.389554				
50	18.5	0.344738	0.127553				
100	36.5	0.6894759	0.251659				
200	51.75	1.3789518	0.356804				
50	16.75	0.344738	0.115487				
100	36.75	0.6894759	0.253382				
200	56	1.3789518	0.386107				



Max shear stress for each test and average of all saturated tests

Normal Stress (psi)	Shear Stress (psi)	Normal Stress (psf)	Shear Stress (psf)	Normal Stress (psi)	Avg. Normal Stress (psf)	Avg. Shear Stress (psf)
50	18.75	231653.16	86869.93	50	231653.2	83395.136
100	38.25	463306.31	177214.7	100	463306.3	172195.51
200	56.5	926612.62	261768.1	200	926612.6	253660.21
50	18.5	231653.16	85711.67			
100	36.5	463306.31	169106.8			
200	51.75	926612.62	239761			
50	16.75	231653.16	77603.81			
100	36.75	463306.31	170265.1			
200	56	926612.62	259451.5			

Ts(c) Saturated Direct Shear Testing

* Ts(c)w1abc - sample did not fully saturate so data could not be used.

Sample Name: Ts(c) S-20-10-08
Run: 1 Ts(c)w2a
Date: 18 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
50	0.344738	200	-11	0	0	-2.75	-0.019	
			27	0.02	0.508	6.75	0.047	
			38	0.046	1.1684	9.5	0.066	
			42	0.072	1.8288	10.5	0.072	
			44	0.096	2.4384	11	0.076	
			44	0.121	3.0734	11	0.076	
			44	0.147	3.7338	11	0.076	
			43	0.172	4.3688	10.75	0.074	
			43	0.197	5.0038	10.75	0.074	
			42	0.222	5.6388	10.5	0.072	
			42	0.248	6.2992	10.5	0.072	
			41	0.273	6.9342	10.25	0.071	
			41	0.298	7.5692	10.25	0.071	

Vertical displacement (in) = 0.3515
Saturation Time = Overnight 17 hours

Sample Name: Ts(c) S-20-10-08
Run: 2 Ts(c)w2b
Date: 18 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
100	0.6894759	400	-13	0	0	-3.25	-0.022	Max. taken between 30 second readings
			-1	0.02	0.508	-0.25	-0.002	
			33	0.045	1.143	8.25	0.057	
			41	0.071	1.8034	10.25	0.071	
			46	0.095	2.413	11.5	0.079	
			49	0.12	3.048	12.25	0.084	
			52	0.146	3.7084	13	0.090	
			54	0.17	4.318	13.5	0.093	
			55	0.195	4.953	13.75	0.095	
			56	0.22	5.588	14	0.097	
			57	0.246	6.2484	14.25	0.098	
			58	0.272	6.9088	14.5	0.100	
			57	0.298	7.5692	14.25	0.098	

			58	0.321	8.1534	14.5	0.100	
			58	0.346	8.7884	14.5	0.100	
			58	0.372	9.4488	14.5	0.100	
			59	0.38	9.652	14.75	0.102	
			58	0.398	10.1092	14.5	0.100	
			58	0.422	10.7188	14.5	0.100	
			58	0.448	11.3792	14.5	0.100	

Vertical displacement (in) = 0.4089
Saturation Time = Overnight 17 hours

Sample Name: Ts(c) S-20-10-08
Run: 3 Ts(c)w2c
Date: 18 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
200	1.3789518	800	-12	0	0	-3	-0.021	Max. taken between 30 second readings
			-9	0.012	0.3048	-2.25	-0.016	
			32	0.036	0.9144	8	0.055	
			53	0.061	1.5494	13.25	0.091	
			64	0.085	2.159	16	0.110	
			74	0.111	2.8194	18.5	0.128	
			79	0.137	3.4798	19.75	0.136	
			83	0.161	4.0894	20.75	0.143	
			86	0.186	4.7244	21.5	0.148	
			88	0.212	5.3848	22	0.152	
			89	0.24	6.096	22.25	0.153	
			89	0.268	6.8072	22.25	0.153	
			91	0.273	6.9342	22.75	0.157	
			90	0.287	7.2898	22.5	0.155	
			90	0.313	7.9502	22.5	0.155	
			90	0.34	8.636	22.5	0.155	
			89	0.363	9.2202	22.25	0.153	
			90	0.389	9.8806	22.5	0.155	

Vertical displacement (in) = Gage malfunction
Saturation Time = Overnight 17 hours

Sample Name: Ts(c) S-20-10-08
Run: 1 Ts(c)w3a
Date: 18 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
50	0.344738	200	-11	0	0	-2.75	-0.019	Max. taken between 30 second
			3	0.019	0.4826	0.75	0.005	
			47	0.03	0.762	11.75	0.081	
			29	0.044	1.1176	7.25	0.050	

			30	0.07	1.778	7.5	0.052	readings
			33	0.094	2.3876	8.25	0.057	
			35	0.119	3.0226	8.75	0.060	
			36	0.144	3.6576	9	0.062	
			38	0.169	4.2926	9.5	0.066	
			38	0.193	4.9022	9.5	0.066	
			37	0.219	5.5626	9.25	0.064	
			38	0.245	6.223	9.5	0.066	
			37	0.269	6.8326	9.25	0.064	
			39	0.294	7.4676	9.75	0.067	

Vertical displacement (in) = 0.269
Saturation Time = 8 hr. 20 min.

Sample Name: Ts(c) S-20-10-08
Run: 2 Ts(c)w3b
Date: 18 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
100	0.6894759	400	-39	0	0	-9.75	-0.067	Max. taken between 30 second readings
			-10	0.012	0.3048	-2.5	-0.017	
			28	0.036	0.9144	7	0.048	
			32	0.06	1.524	8	0.055	
			34	0.087	2.2098	8.5	0.059	
			40	0.111	2.8194	10	0.069	
			43	0.137	3.4798	10.75	0.074	
			46	0.162	4.1148	11.5	0.079	
			48	0.187	4.7498	12	0.083	
			49	0.211	5.3594	12.25	0.084	
			51	0.24	6.096	12.75	0.088	
			51	0.262	6.6548	12.75	0.088	
			51	0.287	7.2898	12.75	0.088	
			54	0.312	7.9248	13.5	0.093	
			56	0.328	8.3312	14	0.097	
			55	0.338	8.5852	13.75	0.095	
			55	0.365	9.271	13.75	0.095	
			53	0.388	9.8552	13.25	0.091	
			54	0.412	10.4648	13.5	0.093	
			53	0.438	11.1252	13.25	0.091	

Vertical displacement (in) = 0.3322
Saturation Time = 8 hr. 20 min.

Sample Name: Ts(c) S-20-10-08
Run: 2 Ts(c)w3c
Date: 18 Feb. 2009

*Bad data/can't use - sample compressed too far. Was only about 3mm from the porous stone.

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
			-10	0	0	-2.5	-0.017	
			2	0.016	0.4064	0.5	0.003	
			24	0.041	1.0414	6	0.041	
			31	0.066	1.6764	7.75	0.053	
			36	0.091	2.3114	9	0.062	
			40	0.116	2.9464	10	0.069	
			42	0.142	3.6068	10.5	0.072	
200	1.3789518	800	43	0.168	4.2672	10.75	0.074	
			40	0.192	4.8768	10	0.069	
			38	0.219	5.5626	9.5	0.066	
			33	0.244	6.1976	8.25	0.057	
			31	0.268	6.8072	7.75	0.053	
			28	0.294	7.4676	7	0.048	
			25	0.319	8.1026	6.25	0.043	
			22	0.345	8.763	5.5	0.038	

Vertical displacement (in) = 0.679
Saturation Time = 8 hr. 20 min.

* Ts(c)w4abc - sample did not fully saturate so data could not be used.

* Ts(c)w5abc - sample was not quite fully saturate so data could not be used.

Sample Name: Ts(c) S-20-10-08
Run: 1 Ts(c)w6a
Date: 24 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
50	0.344738	200	-16	0	0	-4	-0.028	
			-9	0.013	0.3302	-2.25	-0.016	
			27	0.037	0.9398	6.75	0.047	
			37	0.062	1.5748	9.25	0.064	
			40	0.086	2.1844	10	0.069	
			41	0.111	2.8194	10.25	0.071	
			41	0.136	3.4544	10.25	0.071	
			40	0.161	4.0894	10	0.069	
			40	0.185	4.699	10	0.069	
			40	0.212	5.3848	10	0.069	

			39	0.237	6.0198	9.75	0.067	
			39	0.261	6.6294	9.75	0.067	
			39	0.281	7.1374	9.75	0.067	

Vertical displacement (in) = 0.4305

Saturation Time = Weekend ~65 hrs.

Sample Name: Ts(c) S-20-10-08

Run: 2 Ts(c)w6b

Date: 24 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
-14	-0.096527	400	-14	0	0	-3.5	-0.024	
			-8	0.018	0.4572	-2	-0.014	
			24	0.042	1.0668	6	0.041	
			35	0.067	1.7018	8.75	0.060	
			39	0.091	2.3114	9.75	0.067	
			42	0.116	2.9464	10.5	0.072	
			44	0.142	3.6068	11	0.076	
			45	0.168	4.2672	11.25	0.078	
			46	0.191	4.8514	11.5	0.079	
			46	0.216	5.4864	11.5	0.079	
			47	0.242	6.1468	11.75	0.081	
			47	0.267	6.7818	11.75	0.081	
			47	0.292	7.4168	11.75	0.081	
			47	0.317	8.0518	11.75	0.081	
			47	0.343	8.7122	11.75	0.081	
			47	0.368	9.3472	11.75	0.081	
			47	0.393	9.9822	11.75	0.081	
			46	0.419	10.6426	11.5	0.079	
			47	0.444	11.2776	11.75	0.081	

Vertical displacement (in) = 0.4949

Saturation Time = Weekend ~65 hrs.

Sample Name: Ts(c) S-20-10-08

Run: 3 Ts(c)w6c

Date: 24 Feb. 2009

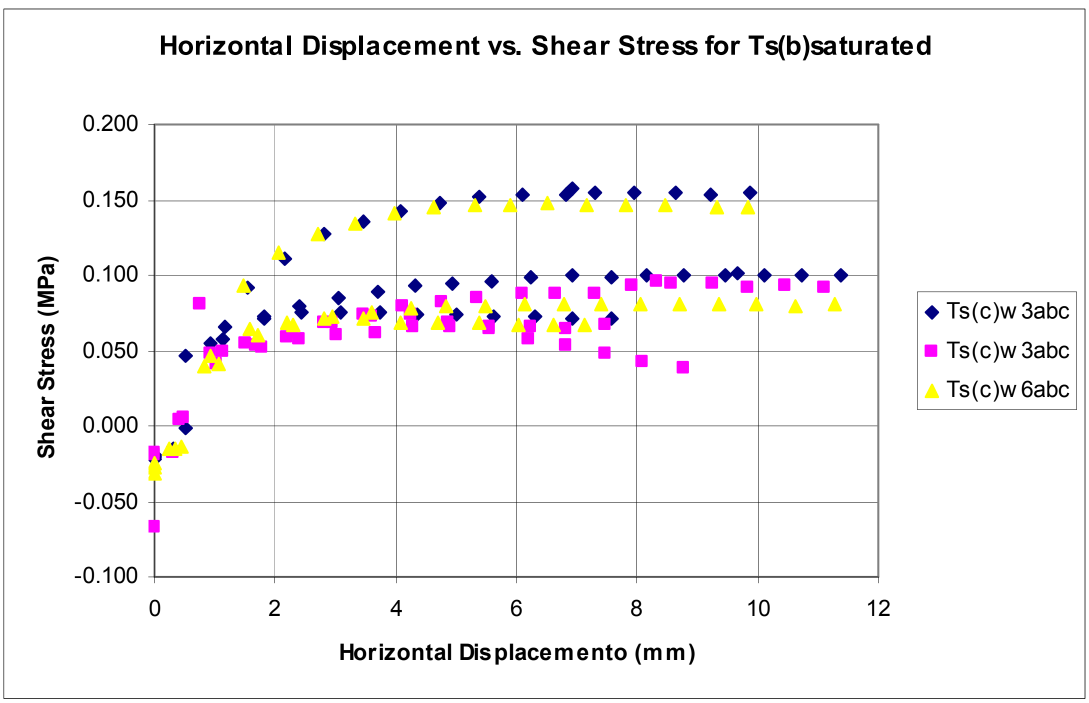
Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
200	1.3789518	800	-18	0	0	-4.5	-0.031	
			-9	0.009	0.2286	-2.25	-0.016	
			23	0.033	0.8382	5.75	0.040	
			54	0.058	1.4732	13.5	0.093	
			67	0.081	2.0574	16.75	0.115	
			74	0.106	2.6924	18.5	0.128	
			78	0.131	3.3274	19.5	0.134	

			82	0.157	3.9878	20.5	0.141	
			84	0.182	4.6228	21	0.145	
			85	0.209	5.3086	21.25	0.147	
			85	0.232	5.8928	21.25	0.147	
			86	0.257	6.5278	21.5	0.148	
			85	0.282	7.1628	21.25	0.147	
			85	0.308	7.8232	21.25	0.147	
			85	0.334	8.4836	21.25	0.147	
			84	0.367	9.3218	21	0.145	
			84	0.387	9.8298	21	0.145	

Vertical displacement (in) = 0.6013

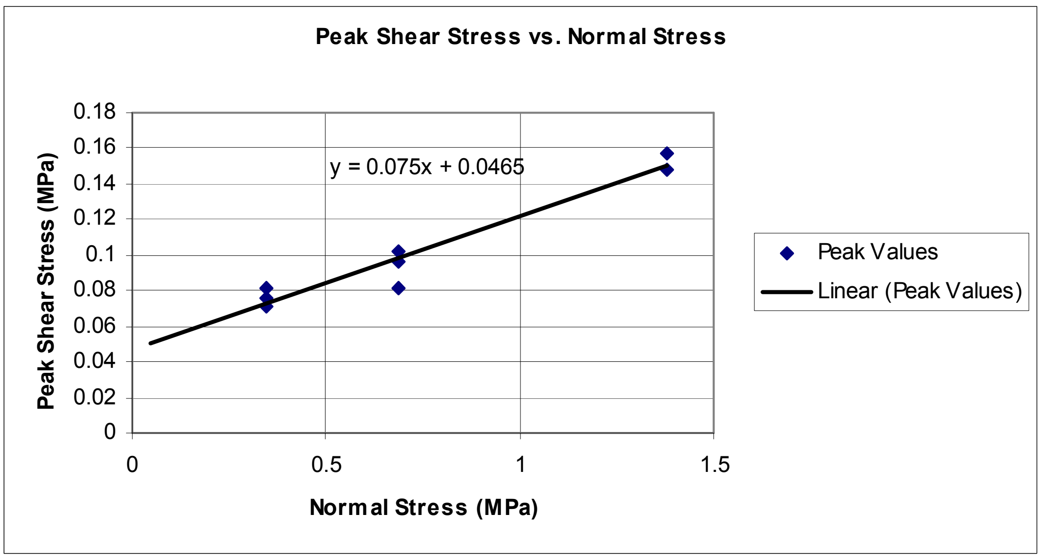
Saturation Time = Weekend ~65 hrs.

Horizontal displacement verses shear stress for Ts(c)saturated



Peak shear stress values for Ts(c)saturated at constant normal loads.

Normal Stress (psi)	Shear Stress (psi)	Normal Stress (MPa)	Shear Stress (MPa)	Cohesion (Mpa)	Internal Friction Angle (Φ)	Cohesion (psf)	Max Cohesion (psf)
50	11	0.344738	0.075842	0.0465	5	971.17269	3186.0008
100	14.75	0.6894759	0.101698				
200	22.75	1.3789518	0.156856				
50	11.75	0.344738	0.081013				
100	14	0.6894759	0.096527				
200		1.3789518	0				
50	10.25	0.344738	0.070671				
100	11.75	0.6894759	0.081013				
200	21.5	1.3789518	0.148237				



Max shear stress for each test and average of all saturated tests

Normal Stress (psi)	Shear Stress (psi)	Normal Stress (psf)	Shear Stress (psf)	Normal Stress (psi)	Avg. Normal Stress (psf)	Avg. Shear Stress (psf)
50	11	231653.16	50963.69	50	231653.2	50963.694
100	14.75	463306.31	68337.68	100	463306.3	62546.352
200	22.75	926612.62	105402.2	200	926612.6	102506.52
50	11.75	231653.16	54438.49			
100	14	463306.31	64862.88			
200		926612.62	0			
50	10.25	231653.16	47488.9			
100	11.75	463306.31	54438.49			
200	21.5	926612.62	99610.86			

Ts(d) Saturated Direct Shear Testing

Sample Name: Ts(d) S-23-10-08
Run: 1 Ts(d)w1a
Date: 24 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
50	0.344738	200	-10	0	0	-2.5	-0.017	Max. taken between 30 second readings
			-7	0.017	0.4318	-1.75	-0.012	
			30	0.042	1.0668	7.5	0.052	
			36	0.07	1.778	9	0.062	
			45	0.091	2.3114	11.25	0.078	
			53	0.116	2.9464	13.25	0.091	
			58	0.141	3.5814	14.5	0.100	
			62	0.166	4.2164	15.5	0.107	
			64	0.19	4.826	16	0.110	
			67	0.216	5.4864	16.75	0.115	
			68	0.241	6.1214	17	0.117	
			70	0.266	6.7564	17.5	0.121	
			76	0.291	7.3914	19	0.131	
			79	0.317	8.0518	19.75	0.136	
			79	0.342	8.6868	19.75	0.136	
			79	0.366	9.2964	19.75	0.136	
			81	0.38	9.652	20.25	0.140	
			80	0.394	10.0076	20	0.138	
			80	0.42	10.668	20	0.138	
			79	0.443	11.2522	19.75	0.136	
			80	0.467	11.8618	20	0.138	
			80	0.493	12.5222	20	0.138	

Vertical displacement (in) = 0.1176
Saturation Time = 3 hrs. 20 min.

Sample Name: Ts(d) S-23-10-08
Run: 2 Ts(d)w1b
Date: 24 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
100	0.6894759	400	-23	0	0	-5.75	-0.040	Max. taken between 30 second readings
			-9	0.024	0.6096	-2.25	-0.016	
			63	0.046	1.1684	15.75	0.109	
			102	0.071	1.8034	25.5	0.176	
			121	0.095	2.413	30.25	0.209	

			131	0.121	3.0734	32.75	0.226	
			140	0.147	3.7338	35	0.241	
			145	0.172	4.3688	36.25	0.250	
			148	0.196	4.9784	37	0.255	
			152	0.228	5.7912	38	0.262	
			154	0.256	6.5024	38.5	0.265	
			153	0.273	6.9342	38.25	0.264	
			160	0.3	7.62	40	0.276	
			163	0.32	8.128	40.75	0.281	
			161	0.327	8.3058	40.25	0.278	
			162	0.354	8.9916	40.5	0.279	
			161	0.375	9.525	40.25	0.278	
			161	0.399	10.1346	40.25	0.278	
			160	0.424	10.7696	40	0.276	
			161	0.452	11.4808	40.25	0.278	

Vertical displacement (in) = gage error

Saturation Time = 3 hrs. 20 min.

Sample Name: Ts(d) S-23-10-08

Run: 3 Ts(d)w1c

Date: 24 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
200	1.3789518	800	-9	0	0	-2.25	-0.016	Max. taken between 30 second readings
			-7	0.017	0.4318	-1.75	-0.012	
			150	0.037	0.9398	37.5	0.259	
			191	0.061	1.5494	47.75	0.329	
			204	0.087	2.2098	51	0.352	
			215	0.111	2.8194	53.75	0.371	
			224	0.138	3.5052	56	0.386	
			233	0.162	4.1148	58.25	0.402	
			234	0.189	4.8006	58.5	0.403	
			240	0.212	5.3848	60	0.414	
			244	0.24	6.096	61	0.421	
			247	0.264	6.7056	61.75	0.426	
			251	0.288	7.3152	62.75	0.433	
			257	0.315	8.001	64.25	0.443	
			255	0.339	8.6106	63.75	0.440	
			258	0.366	9.2964	64.5	0.445	
			261	0.389	9.8806	65.25	0.450	
			263	0.395	10.033	65.75	0.453	
			261	0.415	10.541	65.25	0.450	
			261	0.44	11.176	65.25	0.450	

Vertical displacement (in) = ~0.3

Saturation Time = 3 hrs. 20 min.

* Ts(d)w2abc - sample did not fully saturate so data could not be used.

Sample Name: Ts(d) S-23-10-08
Run: 1 Ts(d)w3a
Date: 25 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
50	0.344738	200	-11	0	0	-2.75	-0.019	Max. taken between 30 second readings
			-11	0.014	0.3556	-2.75	-0.019	
			37	0.035	0.889	9.25	0.064	
			52	0.06	1.524	13	0.090	
			59	0.084	2.1336	14.75	0.102	
			65	0.108	2.7432	16.25	0.112	
			69	0.134	3.4036	17.25	0.119	
			72	0.158	4.0132	18	0.124	
			75	0.183	4.6482	18.75	0.129	
			77	0.209	5.3086	19.25	0.133	
			78	0.234	5.9436	19.5	0.134	
			79	0.259	6.5786	19.75	0.136	
			80	0.284	7.2136	20	0.138	
			80	0.312	7.9248	20	0.138	
			80	0.334	8.4836	20	0.138	
			80	0.359	9.1186	20	0.138	
			82	0.385	9.779	20.5	0.141	
			83	0.392	9.9568	20.75	0.143	
			82	0.41	10.414	20.5	0.141	
			84	0.437	11.0998	21	0.145	
			82	0.462	11.7348	20.5	0.141	
			80	0.486	12.3444	20	0.138	

Vertical displacement (in) = 0.2414
Saturation Time = 4 hrs. 10 min.

Sample Name: Ts(d) S-23-10-08
Run: 2 Ts(d)w3b
Date: 25 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
100	0.6894759	400	-21	0	0	-5.25	-0.036	
			-10	0.013	0.3302	-2.5	-0.017	
			74	0.038	0.9652	18.5	0.128	
			110	0.063	1.6002	27.5	0.190	
			124	0.088	2.2352	31	0.214	
			135	0.113	2.8702	33.75	0.233	
			140	0.138	3.5052	35	0.241	

			145	0.163	4.1402	36.25	0.250	
			149	0.189	4.8006	37.25	0.257	
			154	0.214	5.4356	38.5	0.265	
			157	0.239	6.0706	39.25	0.271	
			157	0.264	6.7056	39.25	0.271	
			160	0.289	7.3406	40	0.276	
			161	0.315	8.001	40.25	0.278	
			164	0.34	8.636	41	0.283	
			165	0.367	9.3218	41.25	0.284	
			163	0.391	9.9314	40.75	0.281	
			164	0.416	10.5664	41	0.283	
			163	0.441	11.2014	40.75	0.281	

Vertical displacement (in) = 0.3132

Saturation Time = 4 hrs. 10 min.

Sample Name: Ts(d) S-23-10-08

Run: 3 Ts(d)w3c

Date: 25 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
200	1.3789518	800	-26	0	0	-6.5	-0.045	Max. taken between 30 second readings
			-10	0.01	0.254	-2.5	-0.017	
			119	0.034	0.8636	29.75	0.205	
			176	0.055	1.397	44	0.303	
			198	0.087	2.2098	49.5	0.341	
			208	0.103	2.6162	52	0.359	
			225	0.128	3.2512	56.25	0.388	
			230	0.154	3.9116	57.5	0.396	
			239	0.179	4.5466	59.75	0.412	
			247	0.205	5.207	61.75	0.426	
			255	0.229	5.8166	63.75	0.440	
			256	0.253	6.4262	64	0.441	
			262	0.28	7.112	65.5	0.452	
			264	0.304	7.7216	66	0.455	
			262	0.329	8.3566	65.5	0.452	
			266	0.355	9.017	66.5	0.459	
			274	0.38	9.652	68.5	0.472	
			277	0.34	8.636	69.25	0.477	
			276	0.41	10.414	69	0.476	
			275	0.43	10.922	68.75	0.474	

Vertical displacement (in) = 0.3625

Saturation Time = 4 hrs. 10 min.

Sample Name: Ts(d) S-23-10-08
Run: 1 Ts(d)w4a
Date: 26 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
50	0.344738	200	-11	0	0	-2.75	-0.019	Max. taken between 30 second readings
			34	0.022	0.5588	8.5	0.059	
			39	0.047	1.1938	9.75	0.067	
			51	0.071	1.8034	12.75	0.088	
			60	0.096	2.4384	15	0.103	
			67	0.121	3.0734	16.75	0.115	
			72	0.146	3.7084	18	0.124	
			73	0.172	4.3688	18.25	0.126	
			74	0.198	5.0292	18.5	0.128	
			74	0.223	5.6642	18.5	0.128	
			74	0.248	6.2992	18.5	0.128	
			76	0.274	6.9596	19	0.131	
			80	0.299	7.5946	20	0.138	
			80	0.324	8.2296	20	0.138	
			81	0.351	8.9154	20.25	0.140	
			83	0.37	9.398	20.75	0.143	
			82	0.376	9.5504	20.5	0.141	
			75	0.4	10.16	18.75	0.129	
			76	0.425	10.795	19	0.131	
			77	0.451	11.4554	19.25	0.133	

Vertical displacement (in) = 0.2063
Saturation Time = Overnight 22 hours

Sample Name: Ts(d) S-23-10-08
Run: 2 Ts(d)w4b
Date: 26 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
100	0.6894759	400	-29	0	0	-7.25	-0.050	
			-10	0.011	0.2794	-2.5	-0.017	
			64	0.033	0.8382	16	0.110	
			110	0.057	1.4478	27.5	0.190	
			129	0.081	2.0574	32.25	0.222	
			140	0.106	2.6924	35	0.241	
			146	0.132	3.3528	36.5	0.252	
			150	0.157	3.9878	37.5	0.259	
			151	0.181	4.5974	37.75	0.260	
			152	0.207	5.2578	38	0.262	
			154	0.232	5.8928	38.5	0.265	
			156	0.257	6.5278	39	0.269	

			155	0.283	7.1882	38.75	0.267	
			159	0.312	7.9248	39.75	0.274	
			160	0.334	8.4836	40	0.276	
			161	0.359	9.1186	40.25	0.278	
			161	0.384	9.7536	40.25	0.278	
			161	0.41	10.414	40.25	0.278	
			158	0.436	11.0744	39.5	0.272	

Vertical displacement (in) = 0.2935

Saturation Time = Overnight 22 hours

Sample Name: Ts(d) S-23-10-08

Run: 3 Ts(d)w4c

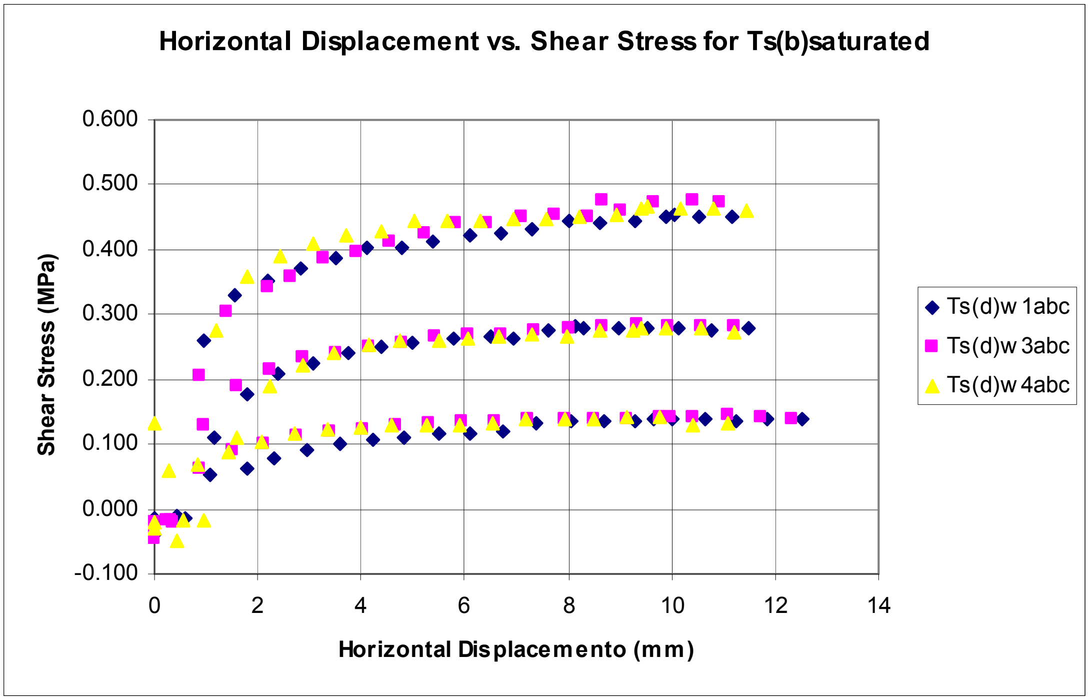
Date: 26 Feb. 2009

Normal Stress (psi)	Normal Stress (Mpa)	Vertical Load (lbs)	Horiz. Load (lbs)	Horiz. Disp. (in)	Horiz. Disp. (mm)	Shear stress (psi)	Shear Stress (Mpa)	Notes
200	1.3789518	800	-18	0	0	-4.5	-0.031	Max. taken between 30 second readings
			-10	0.017	0.4318	-2.5	-0.017	
			160	0.037	0.9398	40	0.276	
			207	0.063	1.6002	51.75	0.357	
			227	0.088	2.2352	56.75	0.391	
			238	0.113	2.8702	59.5	0.410	
			245	0.137	3.4798	61.25	0.422	
			249	0.163	4.1402	62.25	0.429	
			257	0.187	4.7498	64.25	0.443	
			257	0.217	5.5118	64.25	0.443	
			258	0.238	6.0452	64.5	0.445	
			260	0.263	6.6802	65	0.448	
			260	0.288	7.3152	65	0.448	
			261	0.314	7.9756	65.25	0.450	
			264	0.339	8.6106	66	0.455	
			269	0.364	9.2456	67.25	0.464	
			270	0.37	9.398	67.5	0.465	
			269	0.39	9.906	67.25	0.464	
			268	0.416	10.5664	67	0.462	
			266	0.441	11.2014	66.5	0.459	

Vertical displacement (in) = 0.3534

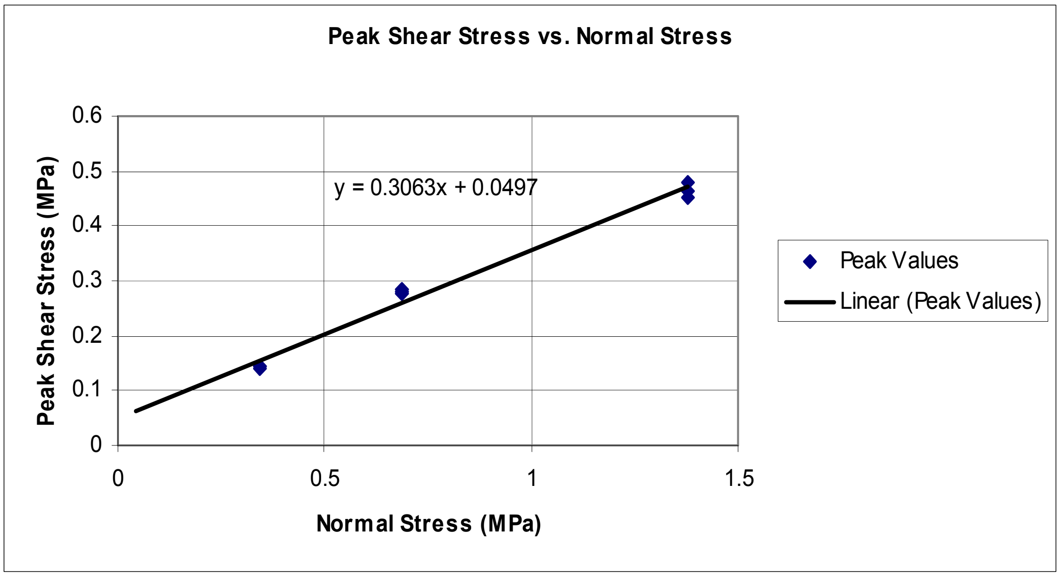
Saturation Time = Overnight 22 hours

Horizontal displacement verses shear stress for Ts(d)saturated



Peak shear stress values for Ts(d)saturated at constant normal loads.

Normal Stress (psi)	Shear Stress (psi)	Normal Stress (MPa)	Shear Stress (MPa)	Cohesion (Mpa)	Internal Friction Angle (Φ)	Cohesion (psf)	Max Cohesion (psf)
50	20.25	0.344738	0.139619	0.0497	17	1038.0061	9720.0025
100	40.75	0.6894759	0.280961				
200	65.75	1.3789518	0.45333				
50	20.75	0.344738	0.143066				
100	41.25	0.6894759	0.284409				
200	69.25	1.3789518	0.477462				
50	20.75	0.344738	0.143066				
100	40.25	0.6894759	0.277514				
200	67.5	1.3789518	0.465396				



Max shear stress for each test and average of all saturated tests

Normal Stress (psi)	Shear Stress (psi)	Normal Stress (psf)	Shear Stress (psf)	Normal Stress (psi)	Avg. Normal Stress (psf)	Avg. Shear Stress (psf)
50	20.25	231653.16	93819.53	50	231653.2	95363.883
100	40.75	463306.31	188797.3	100	463306.3	188797.32
200	65.75	926612.62	304623.9	200	926612.6	312731.76
50	20.75	231653.16	96136.06			
100	41.25	463306.31	191113.9			
200	69.25	926612.62	320839.6			
50	20.75	231653.16	96136.06			
100	40.25	463306.31	186480.8			
200	67.5	926612.62	312731.8			

Average saturated direct shear results for Ts(a), Ts(b), and Ts(c)

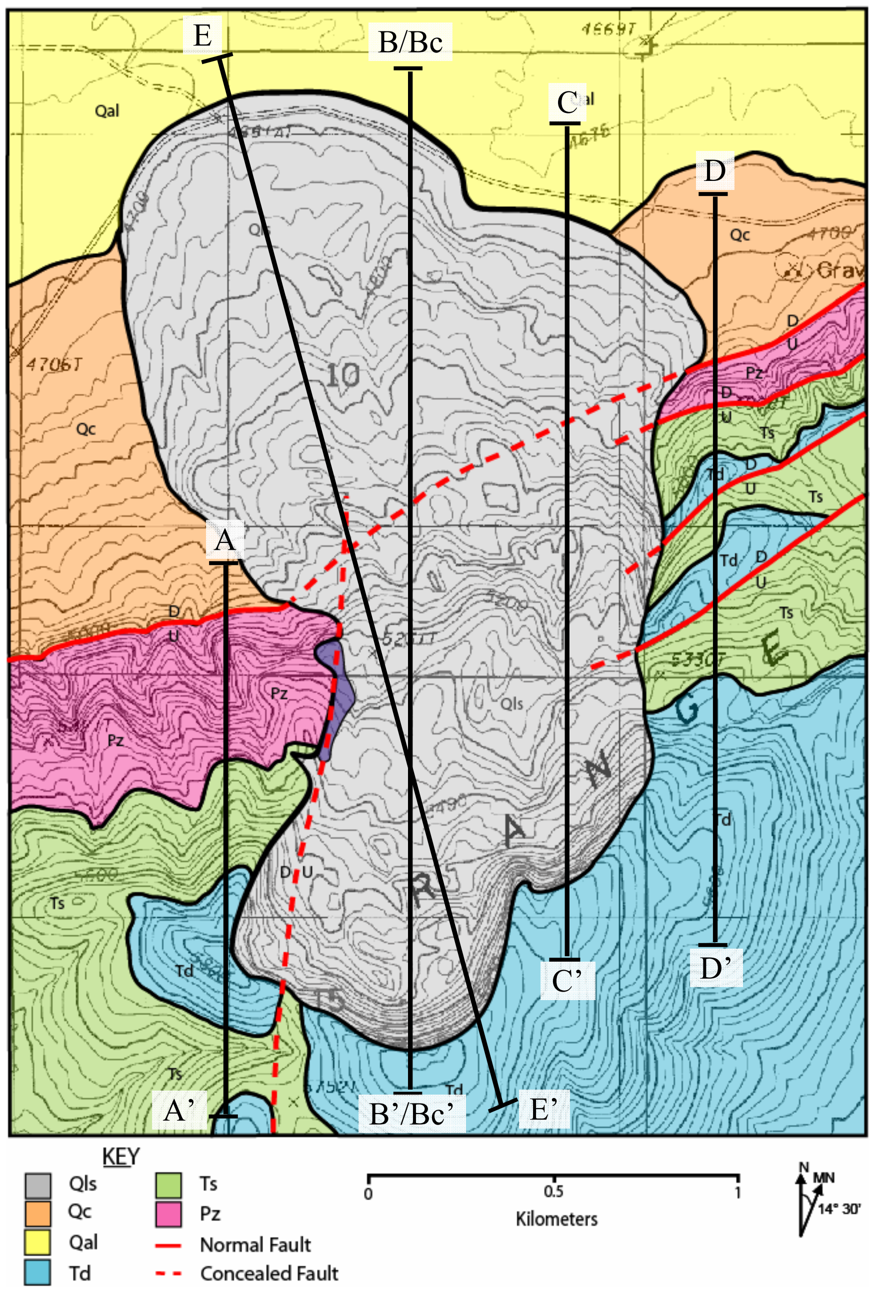
Average Values for each unit and depth				Over all averages for 50, 100, and 200 psi		
Unit	Normal Stress (psi)	Normal Stress (psf)	Shear Stress (psf)	Normal Stress (psi)	Avg. Normal Stress (psf)	Avg. Shear Stress (psf)
Ts(b)	50	231653.16	83395.14	50	231653.2	76574.238
	100	463306.31	172195.5	100	463306.3	141179.73
	200	926612.62	253660.2	200	926612.6	222966.16
Ts(c)	50	231653.16	50963.69			
	100	463306.31	62546.35			
	200	926612.62	102506.5			
Ts(d)	50	231653.16	95363.88			
	100	463306.31	188797.3			
	200	926612.62	312731.8			

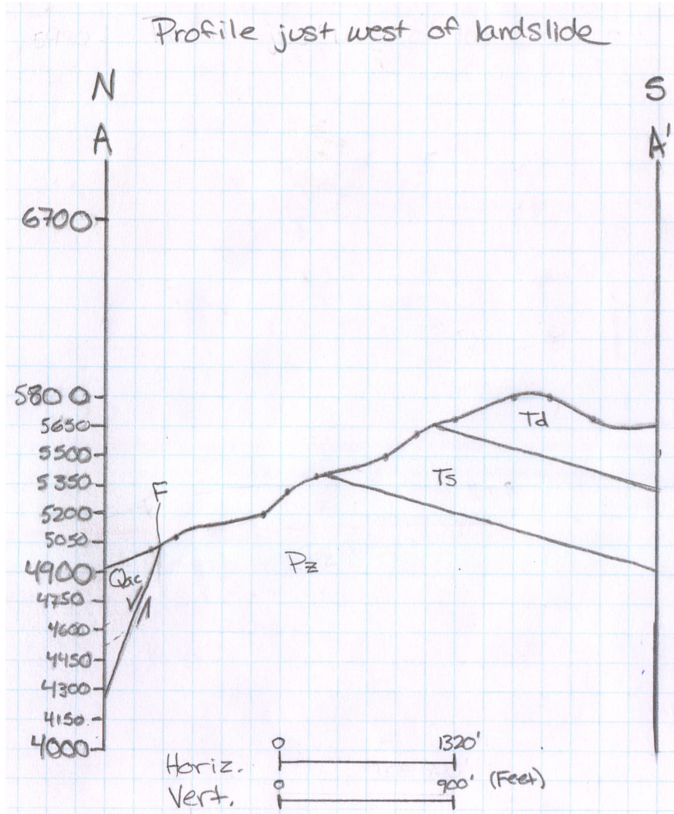
Avg Cohesion psf	Average Φ
1108.32	16.00

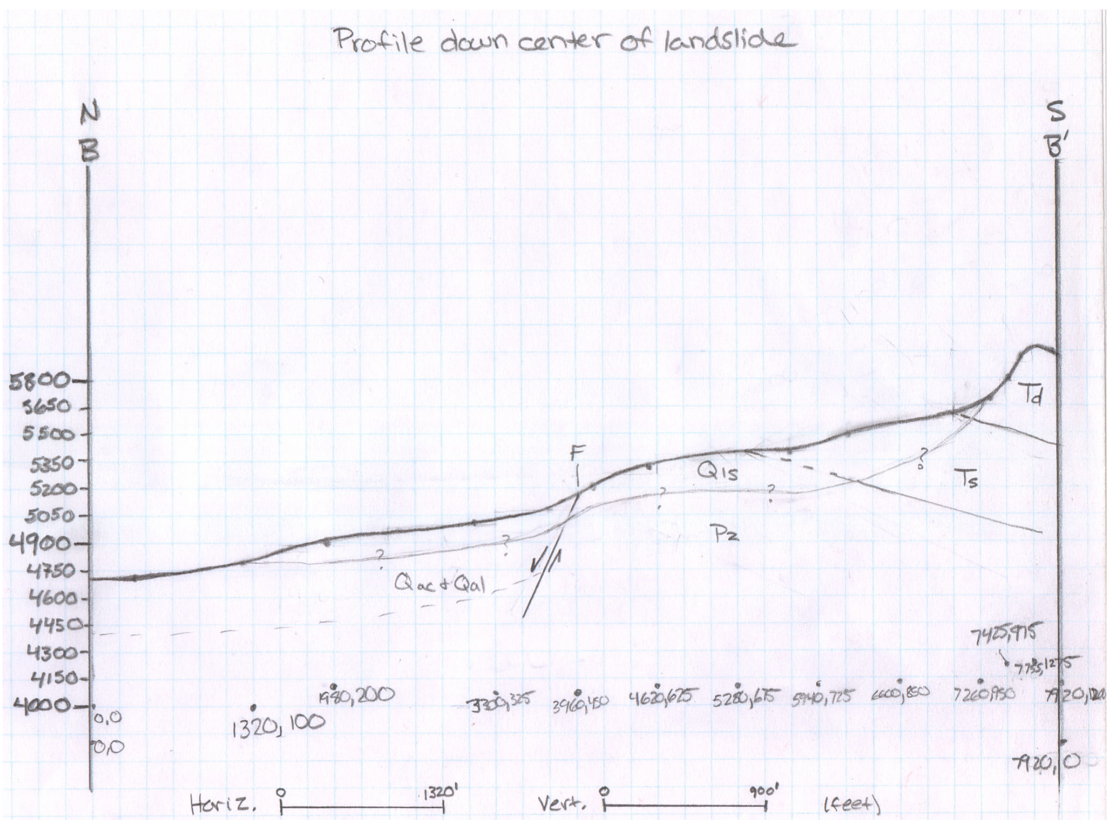
Appendix G

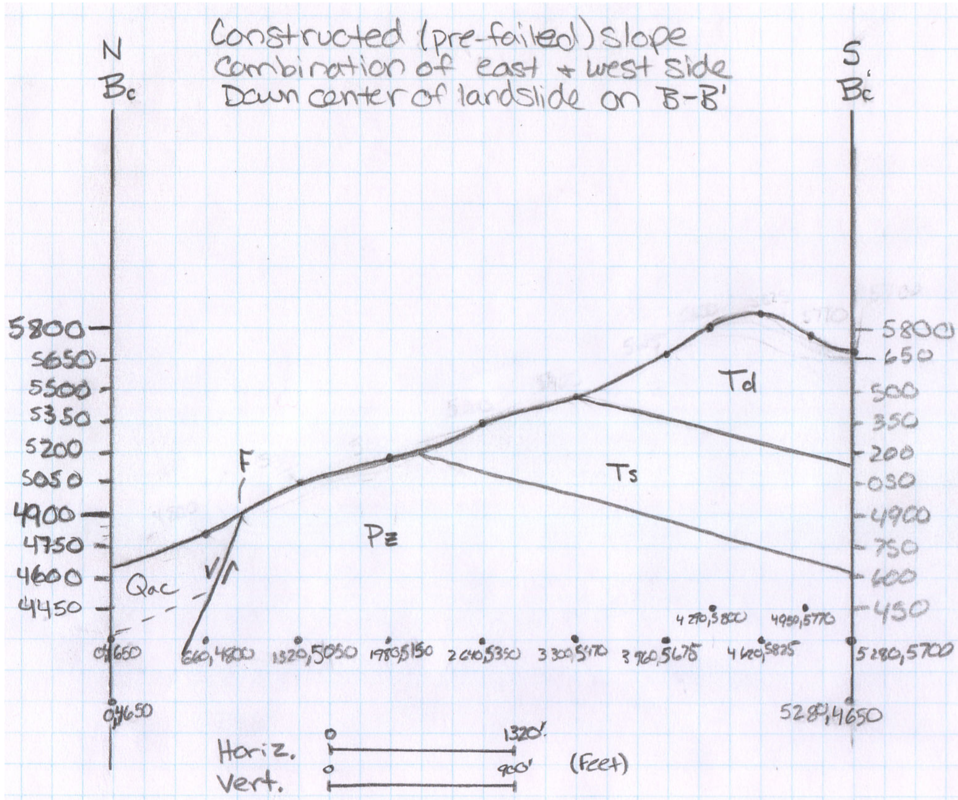
Additional Cross Sections

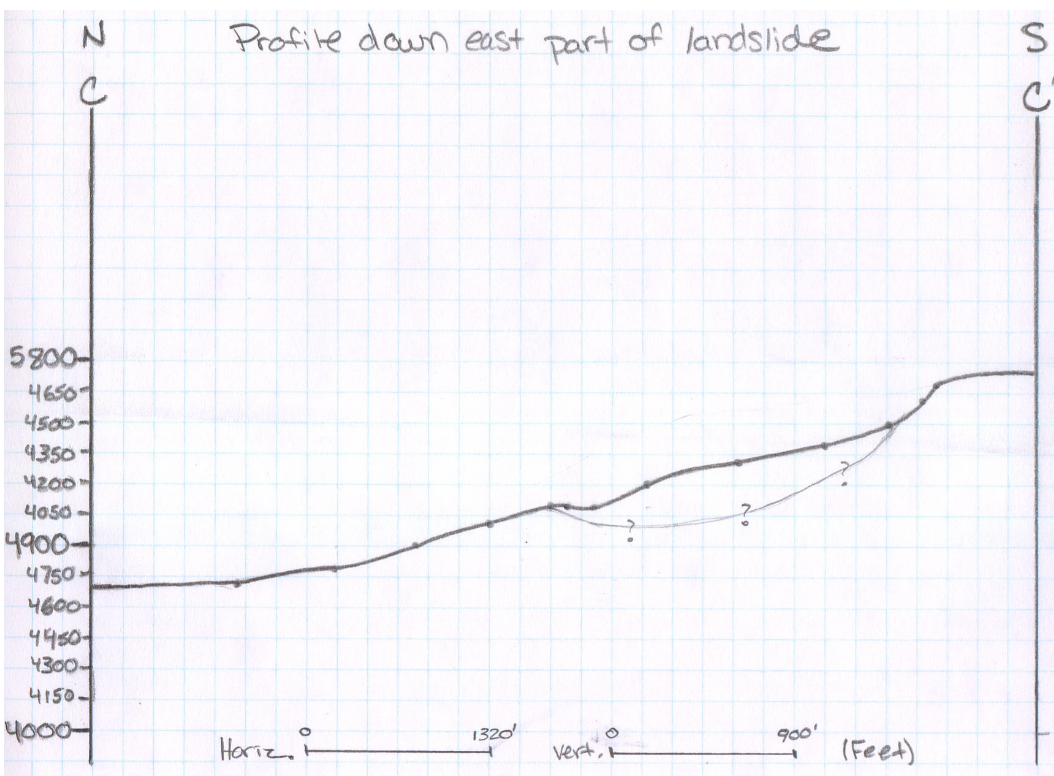
Geologic Map of Malpais Landslide, Eureka County, Nevada

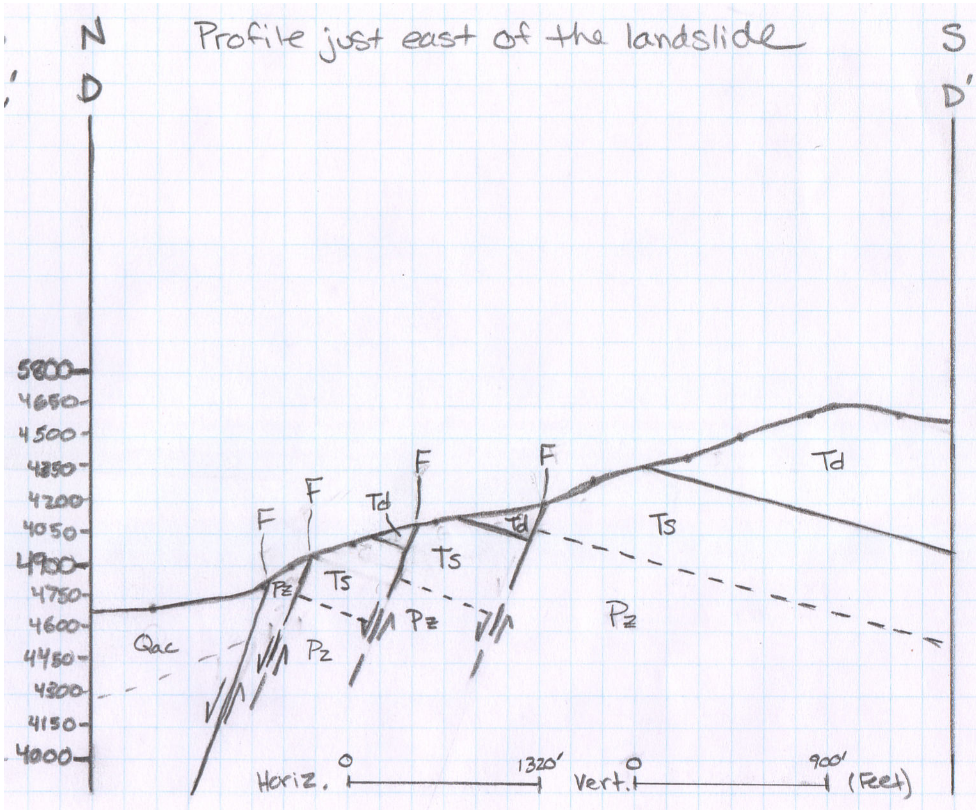



Profile just west of landslide
N
A
S
A'
6700
5800
5650
5500
5350
5200
5050
4900
4750
4600
4450
4300
4150
4000
F
Td
Ts
Pz
Qac
Horiz.
0
1320'
Vert.
0
900'
(Feet)

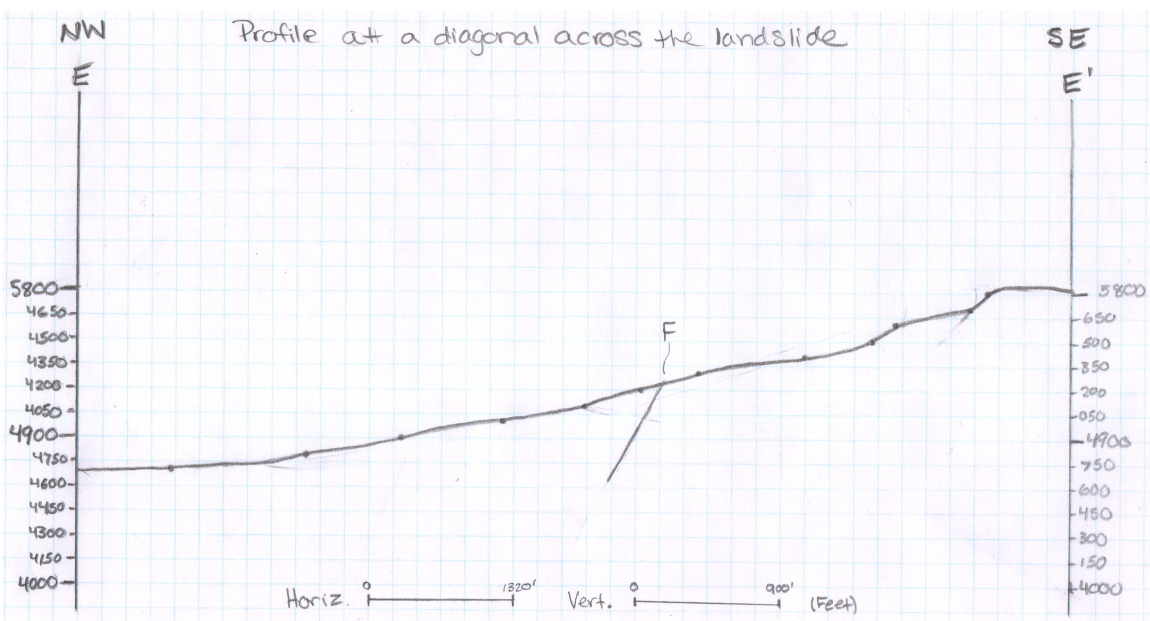

Profile down center of landslide
N
B
S
B'
5800
5650
5500
5350
5200
5050
4900
4750
4600
4450
4300
4150
4000
F
Qls
Td
Ts
Pz
Qac + Qal
0,0
1320, 100
1980, 200
7920, 0
Horiz.
0
1320'
Vert.
0
900'
(feet)


Constructed (pre-failed) slope
Combination of east + west side
Down center of landslide on B-B'
N
Bc
S
Bc
Td
Ts
Pz
F
Qac
Horiz.
Vert.
(Feet)


Profile down east part of landslide
N
C
S
C'
Horiz.
Vert.
(Feet)



N
D
Profile just east of the landslide
S
D'
5800
4650
4500
4350
4200
4050
4900
4750
4600
4450
4300
4150
4000
F
F
F
F
Td
Td
Td
Ts
Ts
Ts
Ts
Pz
Pz
Pz
Pz
Qac
Horiz.
0
1320'
Vert.
0
900'
(Feet)



NW
E
Profile at a diagonal across the landslide
SE
E'
5800
4650
4500
4350
4200
4050
4900
4750
4600
4450
4300
4150
4000
F
5800
650
500
350
200
050
4900
750
600
450
300
150
4000
Horiz.
0
1320'
Vert.
0
900'
(Feet)