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Summary

A series of rock-property measurements was performed on a suite of rhyolitic tuff samples from the area above the Aberdeen Tunnel of Hong Kong. The goal of this study was to determine the mechanical properties of these samples after weathering. This report contains petrographic descriptions, porosity, bulk and grain density, as well as ultrasonic measurements, elastic modulii calculations, and rock-strength determinations. Variations in rock properties are related to alteration and the presence of fractures in the tuff. Granitic rocks located adjacent to the altered tuffs would be better candidates for underground excavations.

Introduction

Four rock samples received from Dr. Kam-Biu Luk (LBNL Physics Division) had previously been collected from the vicinity of the Aberdeen Tunnel on Hong Kong Island. The rock samples were obtained from surface outcrops rather than from the interior of the tunnel (the tunnel is most likely lined with cement, thus precluding sampling). Core plugs measuring 2.54 cm in diameter (1") that were obtained from the hand samples were used for the rock-property measurements (Figure 1).

Figure 1. Core plugs of samples

Petrographic Description

Standard thin sections were prepared for petrographic descriptions. All samples are rhyolitic tuffs that contain broken phenocrysts of quartz and feldspar in a devitrified, microcrystalline groundmass (Table 1). Photomicrographs of the samples are presented in Figure 2. The phenocrysts are typically 0.5–3 mm in size, and constitute around 10% of the rock for samples HK1, 3, and 4. HK2 appears to have a slightly greater abundance of phenocrysts, and also contains small volcanic rock fragments. The groundmass has been variably altered, with clay alteration most abundant in HK1, 3, and 4, while HK2 appears to have been silicified, giving it a purplish-gray hue.

Table 1. Rock descriptions

Sample ID	Rock Type	Collection Location	Petrographic Description
HK1	tuff	Aberdeen Tunnel	Porphyritic devitrified rhyolitic tuff with clay alteration
HK2	tuff	Aberdeen Tunnel	Porphyritic devitrified rhyolitic tuff with lithic fragments, silicified
HK3	tuff	Aberdeen Tunnel	Porphyritic devitrified rhyolitic tuff with clay alteration
HK4	tuff	Aberdeen Tunnel	Porphyritic devitrified rhyolitic tuff with clay alteration

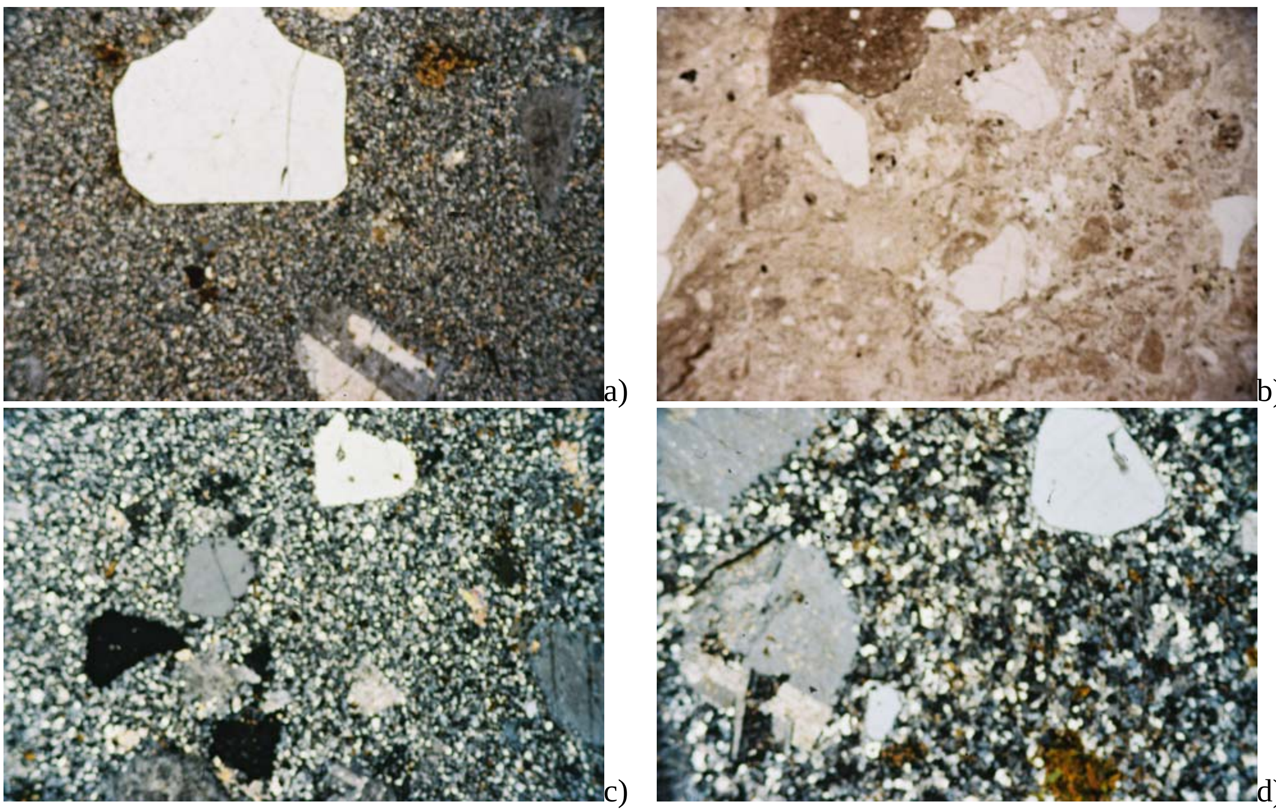


Figure 2 (a-d). Photomicrographs of HK1, 2, 3, and 4. HK1, 3, and 4 taken with crossed nicols, HK2 with plane polarized light. The tuff samples contain phenocrysts of quartz and feldspar in a recrystallized matrix. Width of all images is 4.75 mm.

Porosity, Bulk Density, and Grain Density

Porosity, bulk density, and grain density measurements were made on core-plug samples using a balance, micrometer, and helium porosimeter (Table 2). Grain densities for the tuffs have a narrow range of values, from 2.59 to 2.62 g/cc, while the bulk density values have a wider range of values (2.36 to 2.57 g/cc), reflecting the differences in porosity. The silicified tuff has the smallest porosity value, 1.86%; the other samples range in porosity from 4.58 to 9.55%.

Table 2. Porosity, bulk density, and grain density

Sample ID	**Porosity (%)**	**Bulk Density (g/cc)**	**Grain Density (g/cc)**
HK1	8.86	2.38	2.61
HK2	1.86	2.57	2.62
HK3	9.55	2.36	2.61
HK4	4.58	2.47	2.59

Ultrasonic Measurements and Elastic Moduli Calculations

A series of acoustic (seismic) velocity measurements was conducted on the core plugs using ultrasonic transducers (Table 3). These transducers generated either compressional (P) waves or polarized shear (S) waves with a pulse central frequency of 1 MHz. Assuming that the elastic behavior of the rocks was isotropic, both P- and S-wave velocities were determined from measured wave propagation time along the core axis, and dynamic elastic moduli (Poisson's ratio, Young's modulus and shear modulus) were calculated. The silicified tuff sample (HK2), which has the lowest porosity, has the highest seismic velocity values.

Table 3. Ultrasonic velocities and elastic moduli

Sample ID	**P-wave velocity** (m/s)	**S-wave velocity** (m/s)	**Poisson's ratio**	**Young's Modulus** (GPa)	**Shear Modulus** (GPa)
HK1	3270	2109	0.144	24.4	10.7
HK2	5558	3289	0.231	68.5	27.8
HK3	3238	1997	0.193	22.7	9.5
HK4	4274	2677	0.177	41.9	17.8

Rock-Strength Measurements

Unconfined compressive strength (UCS) tests (Table 4) were performed on core-plug samples using a displacement-controlled loading device (Figure 3). Calibration of the load cell was performed using a dead-weight tester. Teflon discs were inserted on both ends of the core sample to reduce friction between the sample and the load cell. The actual loading rate of the sample was not constant because of the plastic deformation of the Teflon and the compression of the hydraulic fluid. The nonlinearity and hysteresis of the load cell did not significantly affect the unconfined compressive strength measurements.

Table 4. Unconfined compressive strength measurements

Sample ID	**Unconfined Compressive Strength (MPa)**	**Mode of Failure**
HK1	81	Ductile failure (coning along top and bottom of core)
HK2	107	Brittle failure along preexisting silica vein
HK3	38	Ductile failure (coning along top and bottom of core)
HK4	77	Brittle failure along preexisting fracture

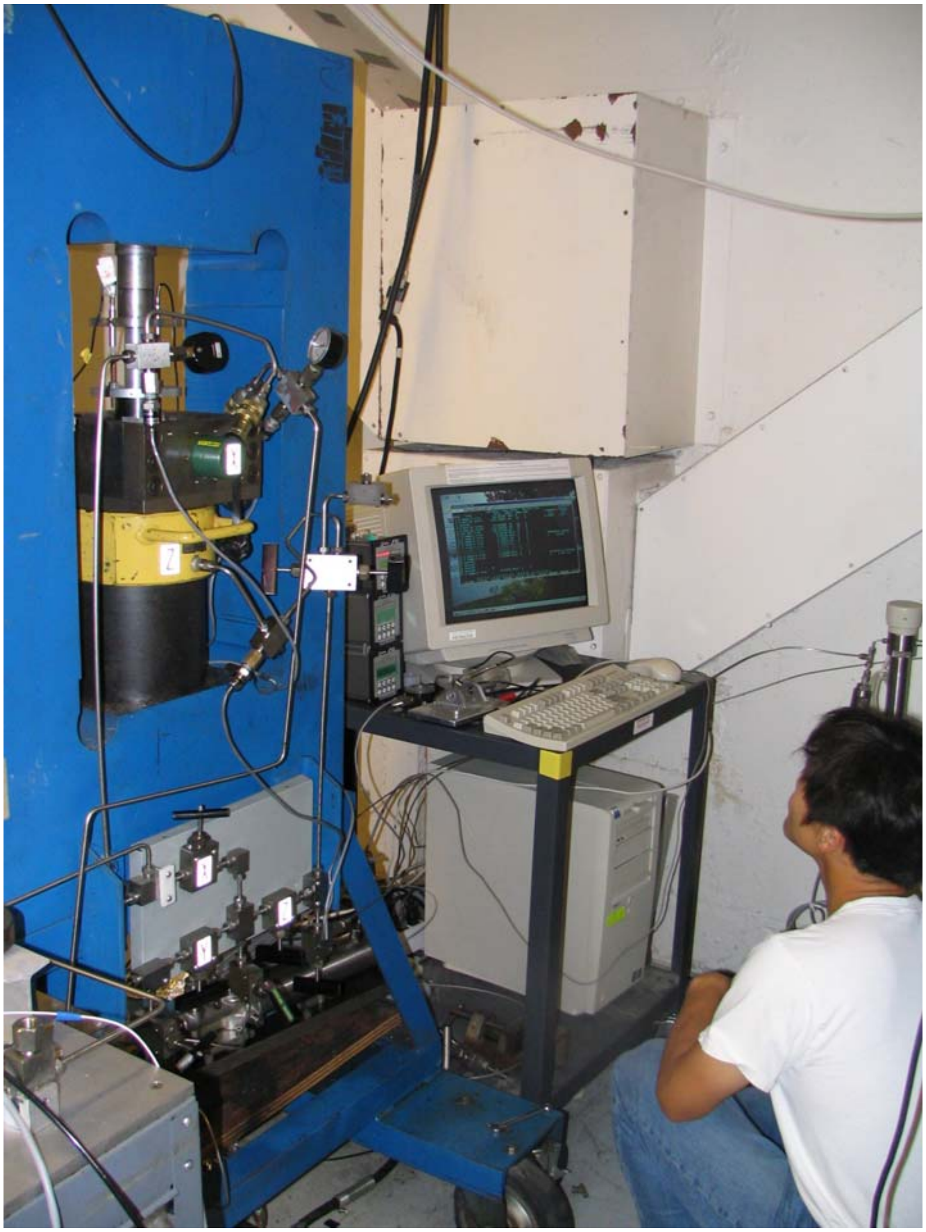
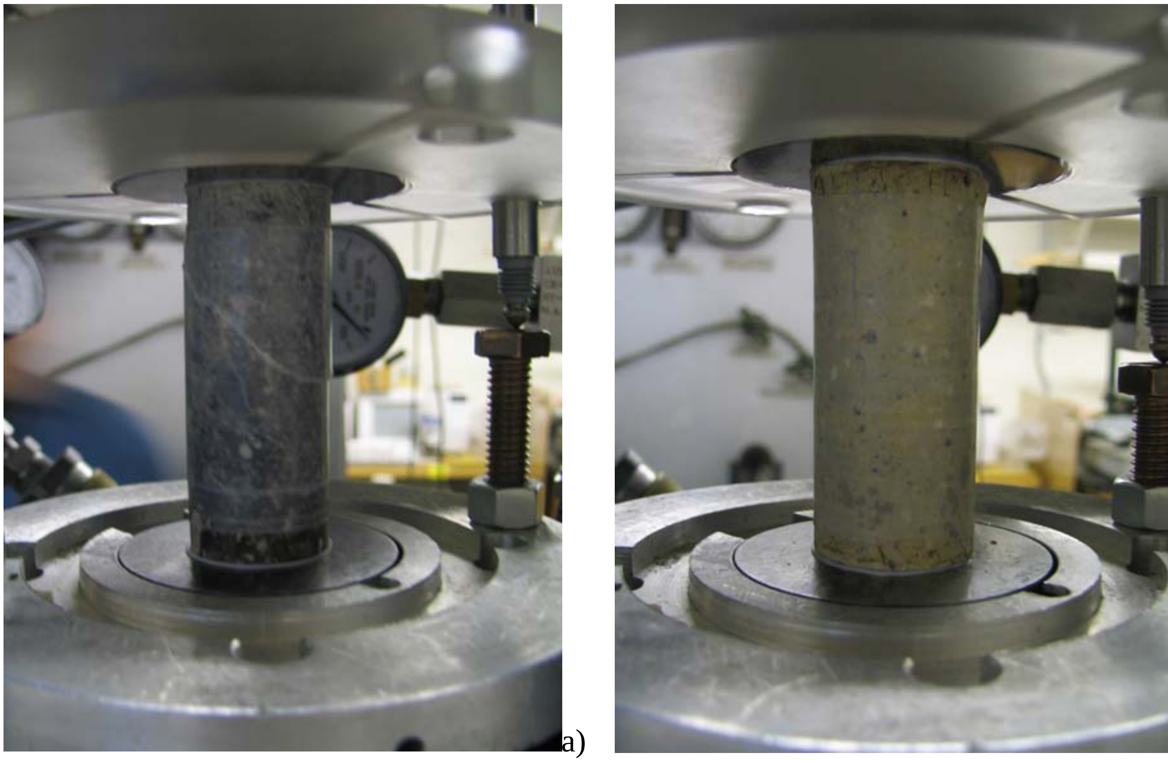


Figure 3. Displacement-controlled loading device for measuring UCS.

The different modes of rock failure are illustrated in Figure 4.



a) b)

Figure 4. Failure modes of Hong Kong tuff samples. HK2 core (a) failed along a preexisting silica vein, while HK3 (b) experienced ductile failure with coning.

Discussion

The two samples (HK1 and HK3) with the highest porosity (9–10%) were also the only tuff samples to have ductile failure. The tuff samples HK2 and HK4, which have reduced porosity (<5 %), experienced brittle failure along preexisting fractures. The tuff samples have undergone varying degrees of alteration, with the silicified (and least porous) sample exhibiting the highest unconfined compressive strength value. The wide range in rock-strength values for the tuff samples suggests that differences in alteration and the presence or absence of preexisting veins and fractures will affect the strength of the rock.

Geologic mapping around the Aberdeen Tunnel (Figure 5) indicates that there are two main rock types present in this area: volcanic tuffs of the Ap Lei Chau Formation (Repulse Bay Volcanic Group) and a series of granitic rocks (GCO, 1986). The tuffs are often altered, with secondary clay minerals such as chlorite, illite, and kaolinite (Duzgoren-Aydin et al., 2002). The combination of steep topography and altered tuffs has resulted in numerous landslides and slope failures (see Qd unit in Figure 5) in the Aberdeen area (Franks et al., 1999; Duzgoren-Aydin et al., 2002). While no granite samples from this area were analyzed, it is likely that the granites are more competent than the altered tuffs, and thus would be a better lithology for tunneling and similar underground excavations.

Figure 5. Geologic map of Aberdeen tunnel area of Hong Kong (GCO, 1986). Geologic units are as follows: JAC–Ap Lei Chau Formation; Qd–Quaternary debris flow deposits;

Qa–Quaternary alluvium; gf–fine grained granite; gfm–fine to medium grained granite; gm–medium grained granite; sqm–medium grained quartz syenite.

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