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Summary
A series of analytical tests was conducted on a suite of granitic rock samples from the Daya Bay region of southeast China. The objective of these analyses was to determine key rock properties that would affect the suitability of this location for the siting of a neutrino oscillation experiment. This report contains the results of chemical analyses, rock property measurements, and a calculation of the mean atomic weight.

Introduction
Four granitic rock samples were received from the Daya Bay region of southeast China for analysis. These samples were obtained from two different rock quarries, the Daya Bay quarry and the Ling Ao quarry (illustrated in Figure 1). The visual characteristics of surface samples are shown in Figure 2 and described in Table 1.

Figure 1. Satellite image showing the locations of Daya Bay and Ling Ao Quarries

Figure 2. Hand specimens and 1-inch core plugs from the Daya Bay and Ling Ao quarries

Table 1. Summary of sample description

Sample	Description
Daya Bay 01	Light colored, medium grained granitic rock
Ling Ao 01	Dark colored, fine grained granitic rock
Ling Ao 02	Light colored, medium grained granitic rock
Ling Ao 03	Light colored, fine grained granitic rock

Rock Composition and Rock Property Measurements

The following tests were conducted on the Daya Bay region rock samples.

Table 2. Measurements performed

Test	Samples analyzed	Analyst
Major and trace element chemistry	All	SGS Minerals, Canada
Gamma spectrometry	Daya Bay 01	Dr. A. Smith, LBNL
Porosity and density	Daya Bay 01	Dr. C.T. Onishi, LBNL
Elastic moduli and rock strength	Daya Bay 01	Dr. C.T. Onishi, Dr. S. Nakagawa, LBNL

In addition, the mean atomic weight of the rock samples was calculated using the results of the major element analysis.

Below are the tabulated results for each of the different test procedures

Major and trace element analyses

The major and trace element compositions of the four rock samples were determined by SGS Minerals using X-Ray Fluorescence Spectrometry (XRF) and Inductively Coupled Plasma-Mass Spectrometry (ICP-MS).

Table 3. Summary of chemical analyses

Major elements							
Oxide	Unit	Detection Limit	Ling Ao 01	Ling Ao 01 (duplicate)	Ling Ao 02	Ling Ao 03	Daya Bay 01
SiO_2	%	0.01	76.49	76.58	74.79	75.57	76.18
Al_2O_3	%	0.01	10.62	10.6	13.59	12.88	12.9
CaO	%	0.01	1.45	1.45	0.31	0.49	0.52
MgO	%	0.01	1.33	1.33	<0.01	0.02	0.03
Na_2O	%	0.01	2.84	2.84	4.7	3.53	3.62
K_2O	%	0.01	2.17	2.18	4.05	4.3	4.74
FeO	%	0.1	3.08	3.08	0.45	0.83	0.77
Fe_2O_3	%	0.01	0.49	0.47	0.38	0.51	0.32
MnO	%	0.01	0.07	0.06	0.07	0.13	0.06
TiO_2	%	0.01	0.5	0.5	0.04	0.04	0.05
P_2O_5	%	0.01	0.11	0.11	<0.01	<0.01	<0.01
LOI	%	0.01	0.55	0.5	0.6	0.45	0.6
H2O+	%	0.1	1.19	1.19	0.71	0.88	0.96
H2O-	%	0.1	<0.1	<0.1	0.11	<0.1	0.1
Sum	%	0.01	100.34	100.39	99.20	99.18	100.25
Trace elements							
Ag	ppm	1	<1	<1	<1	1	<1
As	ppm	30	<30	<30	<30	<30	<30
Ba*	ppm	20	382	381	<20	31	<20
Ba	ppm	0.5	362.6	357.5	9.1	5.6	3.8
Be	ppm	5	<5	<5	6	<5	5
Bi	ppm	0.1	<0.1	0.1	1	8.7	0.1
Cd	ppm	0.2	<0.2	<0.2	<0.2	1.7	<0.2
Ce	ppm	0.1	49.7	53.8	62.7	46.3	41.2
Co	ppm	0.5	10	10.8	<0.5	<0.5	<0.5
Cs	ppm	0.1	8.9	9.4	6.7	18	7.7
Cr	ppm	10	47	48	73	<10	<10
Cu	ppm	5	39	38	<5	45	<5
Dy	ppm	0.05	4.63	4.91	20.7	21.3	11.5
Er	ppm	0.05	2.82	2.89	14.8	14.1	6.9
Eu	ppm	0.05	0.97	1.05	<0.05	<0.05	0.06
Ga	ppm	1	11	12	24	23	17
Gd	ppm	0.05	4.72	4.74	13.4	15.2	9.29
Ge	ppm	1	1	2	4	3	2
Hf	ppm	1	5	5	14	8	4

Ho	ppm	0.05	0.93	0.96	4.34	4.5	2.25
In	ppm	0.2	<0.2	<0.2	<0.2	0.2	<0.2
La	ppm	0.1	23.6	25.8	21.2	16.4	16.8
Li	ppm	10	47	47	33	211	47
Lu	ppm	0.05	0.49	0.51	3.29	2.58	1.17
Mo	ppm	2	<2	<2	3	54	<2
Nb	ppm	1	9	10	54	66	38
Nb*	ppm	2	10	9	65	63	48
Ni	ppm	5	26	26	<5	<5	<5
Nd	ppm	0.1	20.9	22.2	32.3	27.6	22.1
Pb	ppm	5	14	15	43	50	29
Pr	ppm	0.05	5.97	6.44	9.13	6.99	5.79
Rb	ppm	0.2	130.4	138	616.3	799.9	453.3
Rb*	ppm	2	132	132	644	721	458
Sc	ppm	5	10	9	12	9	6
Sm	ppm	0.1	4.5	4.8	13	11.7	7.8
Sn	ppm	1	2	2	10	23	7
Sr	ppm	0.1	73.4	75.7	2.2	9.1	9.6
Sr*	ppm	2	81	81	7	9	10
Ta	ppm	0.5	0.8	0.9	21.5	9.1	3.9
Tb	ppm	0.05	0.74	0.76	2.93	3.05	1.78
Th	ppm	0.1	11.1	12.1	26.7	37.3	28.9
Tl	ppm	0.5	0.7	0.7	2.5	3.2	2
Tm	ppm	0.05	0.38	0.38	2.74	2.25	1.05
U	ppm	0.05	1.9	1.99	22.9	18.7	8.61
V	ppm	5	63	62	<5	<5	<5
W	ppm	1	1	1	10	21	2
Y	ppm	0.5	26.8	27.4	99.5	140.3	65.2
Y*	ppm	2	29	29	124	146	80
Yb	ppm	0.1	3	3.1	21.2	16.2	7.7
Zn	ppm	5	61	62	37	229	20
Zr	ppm	0.5	155.1	145.3	119.2	88.3	65.3
Zr*	ppm	2	179	181	127	96	87

Note: The shaded rows represent main radiogenic elements. Major and selected trace element concentrations (denoted with *) were determined using XRF; all other trace element concentrations were determined using ICP-MS. For several elements (Ba, Nb, Rb, Sr, Y, and Zr), two sets of values are reported, representing results obtained using different analytical techniques (XRF and ICP-MS). LOI represents percent weight loss of sample on ignition.

Gamma Spectrometric Measurements

The Daya Bay 01 sample was analyzed at the Berkeley Low Background Facility (LBF) using Cs-137 gamma-ray sources to identify the level of naturally occurring radioactivity. Radionuclide spectra for the sample were compared to spectra from a number of standard

calibration materials to determine the concentrations of the different radionuclides. First, the intensities for the characteristic peaks of each radionuclide present were determined in the sample. These peak intensities were then translated into absolute elemental abundance or radionuclide activity through comparisons with intensities of the same peaks in the standard calibration samples. Results from gamma-ray spectrometry (Table 4) are within 15% of the more precise analyses of K, Th, and U reported on Table 3.

Table 4. Summary of gamma-ray spectrometry results

Sample	**K_2O** (%)	**Th** (ppm)	**U** (ppm)
Daya Bay 01	4.41	33.0	10.4

Density and Porosity Measurements

The grain density and porosity of the Daya Bay 01 sample were determined by the gas displacement-Boyle's law method using a helium pycnometer. The sample was prepared using a 1-inch (2.54 cm) diameter diamond-coring bit and was oven dried at 90^{o}C for 24 hours. The bulk volume was calculated by using a micrometer to determine the diameter and length of the core plug. The core sample was weighed, thus permitting the calculation of the sample bulk density. Calibration of the pycnometer was performed using inserts of known volume to determine the volume-pressure relationship, which was then used to calculate the grain volume of the sample. The grain density was calculated using the grain volume and sample weight measurements. The porosity was determined by subtracting the measured grain volume from the sample bulk volume. Measurements were repeated to evaluate reproducibility.

Table 5. Summary of porosity and density measurements

Sample	**Porosity** (%)	**Bulk Density** (g/cc)	**Grain Density** (g/cc)
Daya Bay 01	1.33	2.58	2.62

Elastic Moduli and Rock Strength Measurements

Ultrasonic tests and unconfined compressive strength tests were conducted using 1-inch (2.54 cm) diameter cores from the Daya Bay 01 sample, and the results of these tests are summarized in Table 6. The ultrasonic velocity was determined from the wave propagation time along a sample of known length. The wave velocity of a specimen is influenced by material parameters including elastic moduli of mineral grains, density and microstructural features of the rock. The central frequency of the ultrasonic pulses was 1 MHz.

Poisson’s ratio and Young’s modulus were calculated to provide information about the rock mechanical properties. Features such as weathering and fracturing can reduce the velocity and amplitude of measured waves. However, these features may not be fully captured by measurements on hand-sample sized material.

An unconfined compressive strength test was performed using a displacement-controlled loading device. A Teflon film was inserted on both ends of the core sample to reduce the friction between the sample and the load cell. Because of the plastic deformation of the Teflon film, the actual loading rate of the sample was not constant. Calibration of the load cell was performed using a dead-weight tester. The nonlinearity and hysteresis of the load cell did not significantly affect the measurement.

Table 6. Summary of mechanical properties

	Daya Bay 01
S wave velocity (m/s)	1852
P wave velocity (m/s)	2852
Poisson's ratio	0.135
Shear modulus (GPa)	21
Young's modulus (GPa)	48
Unconfined Compressive Strength (MPa)	75 (extensile failure)

Mean Atomic Weight

The mean atomic weights of the rock samples were determined to evaluate the effective shielding potentials of the different granites (higher mean atomic weight provides greater shielding capacity). The values were calculated using the reported compositions for the major rock constituents. First, the compositions for the main oxide components were normalized to totals of 100%. The normalized compositions were then converted from oxides to elemental compositions. Finally, the mean atomic weight for each rock sample (porosity-free) was determined. These values are listed in Table 7.

Table 7. Summary of mean atomic weight

Sample	**Mean Atomic Weight**
Ling Ao 01	23.01
Ling Ao 01 (duplicate)	23.00
Ling Ao 02	22.41
Ling Ao 03	22.60
Daya Bay 01	22.57