TEM-836-C

"GRANITE" EXPLORATION HOLE, AREA 15, NEVADA TEST SITE, NYE COUNTY, NEVADA -- INTERIM REPORT, PART C, PHYSICAL PROPERTIES

By G. A. Izett

Trace Elements Memorandum Report 836-C

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This report is preliminary and has not been edited for conformity with Geological Survey format and nomenclature.

*Prepared on behalf of the U. S. Atomic Energy Commission.

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"GRANITE" EXPLORATION BOREHOLE, AREA 15, NEVADA TEST SITE, NYE COUNTY, NEVADA -- INTERIM REPORT PART C, PHYSICAL PROPERTIES

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ABSTRACT

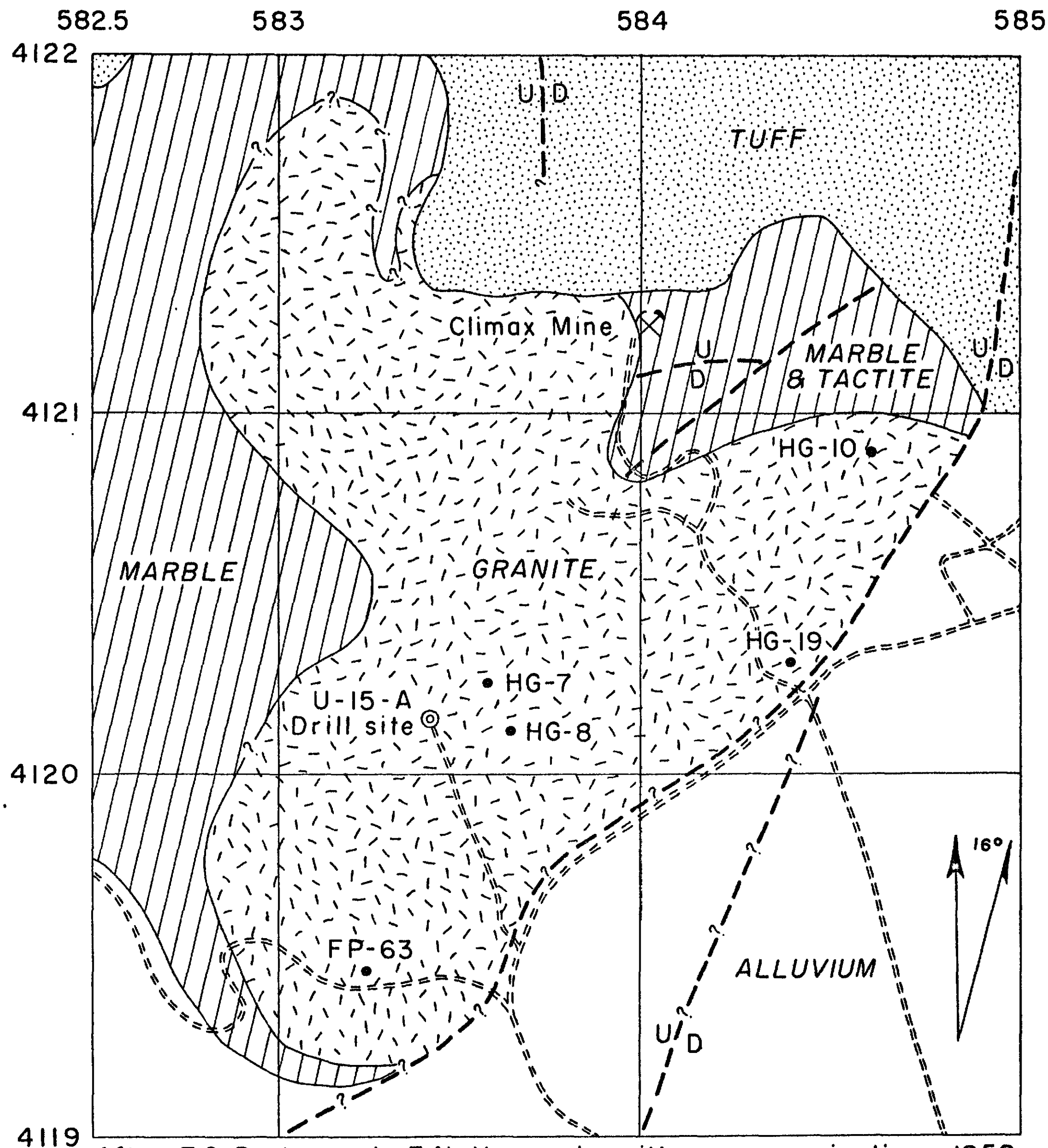
Physical properties measurements including porosity, density, permeability, magnetic susceptibility, and thermal conductivity were made on granite samples from the U-15A "Granite" exploration borehole, Nevada Test Site, Nye County, Nevada. Porosity values range from 0.4 to 4.8 percent, and density values range from 2.56 to 2.69 g/cc (bulk density) and from 2.66 to 2.72 g/cc (grain density). Permeability of fresh rock from the borehole is probably less than 10^{-13} millidarcies. Magnetic susceptibility measurements range from 0.36 to 3.48 x 10^{-3} cgs units, and thermal conductivity values range from 5.6 to 8.1 cgs units.

INTRODUCTION

Physical properties measurements including porosity, density, permeability, magnetic susceptibility, and thermal conductivity were made on granite samples from the U-15A "Granite" exploration borehole in order to define some of the physical characteristics of the granite from the surface to 1200 feet. The U-15A borehole is in the north-central part of the Nevada Test Site, Nye County, Nevada, and the borehole was drilled into a small stock, locally known as the Climax granite, which is intrusive into lower Paleozoic carbonate rocks. The location of the borehole and Climax stock are shown in figure 1.

Although rocks from the Climax stock have been called granite, the composition ranges from quartz monzonite to granodiorite. The term granite will be used in this report to describe samples for which the composition is not accurately known. A more detailed description of the petrography as well as descriptive structural and chemical data have been described in Part A of this report, by Houser and Poole (1959).

The work described in this report was done on behalf of the Albuquerque Operations Office, U. S. Atomic Energy Commission.



After F.G. Poole and F.N. Houser, in written communication, 1959

Note: 4119 etc. are Nevada state coordinates

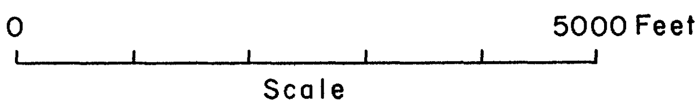


Figure 1.— Map showing location of U-15A bore hole and outcrop samples, Nevada Test Site, Nye County, Nevada

POROSITY AND DENSITY

Porosity, grain density, bulk density, and powder density measurements were made on 26 granite core samples, which were selected randomly from various depths of the U-15A exploration borehole. Similar measurements were made on five weathered outcrop samples in order to compare the porosities and densities of these samples with those of the fresh borehole samples. The locations of the borehole and outcrop samples are shown in figure 1.

Laboratory procedure consisted of drilling 1 inch x 1 inch cylindrical cores from hand samples and heating the cores in an electric oven for 24 hours at 105°C. The dry cores were weighed on an analytical balance to a precision of one milligram and placed in a desiccator. A vacuum was pumped to about 0.1 mm of mercury and deaerated water was introduced into the desiccator at about one atmosphere pressure. After the saturation process, the samples were weighed in air, then weighed while being suspended in water. From these three weights the following parameters were computed:

$$\text{Percent porosity} = \frac{\text{Pore volume}}{\text{Bulk volume}} \times 100 = \frac{M_2 - M_1}{M_2 - M_3} \times 100$$

$$\text{Bulk density (dry)} = \frac{M_1}{M_2 - M_3} \ \text{g/cc}$$

$$\text{Grain density} = \frac{M_1}{M_1 - M_3} \ \text{g/cc}$$

where:
M_1 = dry mass
M_2 = saturated mass
M_3 = suspended mass

Table 1 shows the results of individual porosity and density measurements, and table 2 gives a statistical summary of the data. The sample number is also the depth below the borehole collar. The porosities of most of the core samples from the U-15A borehole range between 0.4 and 0.9 percent, but a few are considerably higher. The average porosity of all samples is about 0.9 percent.

Each porosity value listed in table 1 is a composite figure which represents the sum of intergranular porosity and fracture porosity of the core and an experimental error associated with the process of measurement. The experimental error is probably about 0.3 percent porosity which results from the uncertainty of the saturated weight of the core. The intergranular porosity of most of the fresh core from the borehole is probably small (less than 0.4 percent). A large part of each porosity value represents fracture porosity of the core.

Table 1.--Porosity and density of Climax granite samples from the U-15A borehole, Area 15, Nye County, Nevada

Sample No. (Depth Ft.)	Pct. Porosity	Density, bulk(dry) g/cc	Density, grain g/cc	Density, powder g/cc
63	0.9	2.66	2.69	2.67
144	4.8	2.56	2.68	2.68
160	1.9	2.64	2.69	2.66
165	0.8	2.68	2.70	2.70
236	0.8	2.69	2.72	2.70
277	0.5	2.65	2.66	2.67
321	0.6	2.69	2.71	2.70
374	0.6	2.67	2.69	2.68
400	0.9	2.65	2.67	2.68
414	0.7	2.67	2.69	2.67
478	0.6	2.68	2.70	2.67
500	0.6	2.68	2.69	2.69
555	0.4	2.68	2.69	2.69
600	0.5	2.68	2.70	2.70
693	0.6	2.68	2.69	2.71
700	0.5	2.68	2.70	2.70
739	0.5	2.69	2.70	2.69
800	0.7	2.67	2.69	2.69
812	0.8	2.68	2.70	2.68
833	0.5	2.68	2.69	2.69
854	0.5	2.69	2.69	2.69
900	0.5	2.69	2.71	2.71
930	3.0	2.61	2.69	2.68
1000	0.9	2.68	2.71	2.71
1100	0.5	2.66	2.67	2.70
1200	0.6	2.68	2.69	2.69

Table 2.--Statistical summary of porosity and density of Climax granite samples from the U-15A borehole, Area 15, Nye County, Nevada

Percent porosity:	
Arithmetic mean	0.9
1 standard deviation	± 0.9
2 standard errors of the mean	± 0.3
Number of samples	26
Density, bulk - g/cc:	
Arithmetic mean	2.67
1 standard deviation	± 0.02
2 standard errors of mean	± 0.02
Number of samples	26
Density, grain - g/cc:	
Arithmetic mean	2.69
1 standard deviation	± 0.02
2 standard errors of mean	± 0.02
Number of samples	26
Density, powder - g/cc:	
Arithmetic mean	2.69
1 standard deviation	± 0.01
2 standard errors of mean	± 0.005
Number of samples	26

The samples from 144, 160, and 930 feet have significantly higher porosity than all the other samples from the borehole. These high-porosity samples are from zones of altered rock. The main alteration products seen under the microscope and detected by X-ray diffractometry consist of sericite, chlorite, and epidote. Sample No. 930 is the most highly altered and has the next highest porosity (see table 1). This sample was not fractured, and the increased porosity probably resulted either from volume changes associated with the alteration process, or from intra-granular pore space between the layers of the micaceous minerals formed during alteration.

Average porosity of outcrop samples (table 3) is significantly higher than average porosity for borehole samples. The greater porosity values for the outcrop samples probably results from hairline fractures in the core or from slight volume changes during weathering of the samples. Sample HG-19 is hydrothermally altered and has a relatively high porosity. The high porosity results mainly from the vuggy character of the sample.

Table 3.--Porosity and density of Climax granite

outcrop samples, Area 15, Nye County, Nevada

Sample Number	Pct. Porosity	Density, bulk g/cc	Density, grain g/cc	Density, powder g/cc
FP-62	1.8	2.66	2.71	2.70
FP-63	1.3	2.65	2.70	2.70
HG-19	6.5	2.40	2.57	2.57
HG-7	1.9	2.66	2.71	2.68
HG-8	1.7	2.62	2.66	2.65

Density measurements were made by two methods. Bulk and grain density were determined as part of the water-saturation process, and the data are given in tables 1 and 2. Expressions relating bulk and grain density with dry, saturated, and suspended weights of samples have already been given. Most of the samples from the borehole have bulk densities between 2.66 g per cc and 2.69 g per cc and average about 2.67 g per cc. A few of the samples have significantly lower bulk densities, and are the same samples that have higher-than-average porosities.

Grain-density values of most borehole samples range from 2.66 g per cc to 2.72 g per cc and average about 2.69 g per cc. Grain density was computed from the average modal composition of granite given in table 4, but it was found that the accuracy of most modal analyses of about 1,000 points precludes reliable grain-density estimates from modes.

The only grain-density value which is significantly different from the average density is sample HG-19.

Table 4.--Modal analyses of 17 samples from the U-15A Climax granite exploration borehole, Nevada Test Site, Nye County, Nevada

Mineral (volume percent)	63	160	236	277	321	374	414	477	555	693	739	800	812	833	854	900	1000	Sample No. and depth
Plagioclase feldspar An_{36} 1/	50	48	45	47	54	45	39	37	46	40	43	48	49	41	40	54	46	
Potassium feldspar	27	17	16	17	14	20	26	24	21	19	22	21	19	25	18	19	17	
Quartz	15	25	27	25	21	26	25	25	20	30	27	22	25	26	31	20	27	
Biotite	5	8	9	8	7	4	7	11	9	9	5	6	5	6	8	4	7	
Chlorite	2	1	2	2	2	4	1	2	2	Tr.	2	1	1	1	Tr.	1	2	
Hornblende	Tr.	Tr.	Tr.	Tr.	--	Tr.	Tr.	Tr.	Tr.	1	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	
Allanite	Tr.	--	Tr.	Tr.	--	Tr.	--	--	--	Tr.	--	--	--	Tr.	--	--	Tr.	
Pyrite	--	Tr.	Tr.	Tr.	Tr.	Tr.	--	--	Tr.	--	--	--	--	--	--	Tr.	--	
Hydrous iron oxide	--	Tr.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Sphene, Apatite, Zircon, Magnetite, Nyrmekite, Sericite, Calcite, Clinozoisite, Epidote, Clay (unidentified)	Each constituent occurs in trace amounts (< 1%) in all thin sections.																	
Rock type	QM*	G**	G	G	G	G	QM	QM	G	G	QM	G	G	QM	G	G	G	

* Quartz monzonite
** Granodiorite
1/ Determined by flat-stage extinction angles

Powder-density measurements were made on 26 samples from the U-15A borehole and five outcrop samples from the Climax stock. The method used by the writer to determine powder density is similar to that suggested by Krumbein and Pettijohn (1938, p. 501). Pycnometer bottles with side arm and thermometer attachments were filled with deaerated distilled water and weighed on an analytical balance to 0.1 milligram accuracy. The temperature of the water was recorded and the weight recorded as M_1. The bottle was partly emptied and weighed. About three grams of powdered rock were added to the bottle; the bottle, powder, and water were again weighed and the difference between the weighings gave the weight of rock powder (M_2). The pycnometer bottle was placed in a desiccator, and a vacuum was pumped to free trapped air around the powder. The pycnometer bottle was filled with water and the weight was recorded as M_3. The powder density was computed as follows:

$$\text{Density} = \frac{\text{Mass of powder}}{\text{Volume of powder}} = \frac{M_2}{(M_1 + M_2 - M_3)}$$

The average density by the powder method is about 2.69 g per cc and the range is from 2.66 g per cc to 2.71 g per cc. Comparison of the average density values (table 2) for the pycnometer and water-saturation methods shows that the methods give similar results with about the same accuracy. Because the water-saturation method is faster, any future density measurements of granite should be made by this method.

PERMEABILITY

Permeability measurements were made on one fresh borehole sample (G-700) and one outcrop sample (FP-63) of the Climax granite using distilled water. The measurements were made with a permeameter similar to an instrument described by Ohle (1951, p. 687). The permeability of the outcrop samples (10^{-4} millidarcies) was found to be considerably higher than the permeability of the borehole sample (10^{-13} millidarcies). The outcrop sample chosen was relatively unweathered and unfractured, but the permeability is apparently increased several times by only slight weathering.

MAGNETIC SUSCEPTIBILITY

Magnetic susceptibility measurements were made by W. Huff of the U. S. Geological Survey on twenty-seven 1-inch x 1 inch cylindrical core samples taken from various depths of the U-15A granite exploration borehole. Several outcrop samples were also measured in order to compare the magnetic properties of borehole and weathered outcrop samples. The results are shown in table 5. The locations of the outcrop samples are shown in fig. 1. The measurements were made at a field strength of one gauss.

Table 5.--Magnetic susceptibility and magnetite content of samples from the U-15A granite borehole

ample number and depth	Magnetic susceptibility (K_s 10^{-3} cgs units)	Pct. Magnetite by weight	Pct. Magnetite by volume	Pct. Magnetite by modal analysi
G-63	1.65	1.3	0.7	0.3
G-160	1.16	1.2	0.6	0.6
G-160A	0.36	0.3	0.2	-
G-165	0.46	0.4	0.2	-
G-236	0.43	0.3	0.2	0.2
G-277	1.45	0.7	0.4	0.1
G-321	1.68	1.0	0.5	0.8
G-374	1.38	0.8	0.4	0.3
G-414	2.96	1.5	0.8	0.5
G-488	3.47	1.5	0.8	0.8
G-555	2.01	1.2	0.6	0.6
G-555A	2.14	1.1	0.6	-
G-600	3.13	1.4	0.7	0.6
G-600A	2.58	1.4	0.7	-
G-693	3.25	1.6	0.8	0.9
G-700	3.07	1.3	0.7	-
G-739	3.07	1.3	0.7	0.4
G-739A	2.90	1.4	0.7	-
G-800	3.26	1.6	0.8	0.7
G-800A	2.66	1.1	0.6	-
G-812	2.07	1.4	0.7	0.6
G-833	3.25	1.6	0.8	0.3
G-854	3.43	1.5	0.8	0.5
G-900	3.48	1.8	0.9	0.4
G-900A	3.27	1.4	0.7	-
G-1000	2.93	1.3	0.7	0.5
G-1000A	2.89	0.9	0.5	-
	Av. 2.38	Av. 1.2	Av. 0.6	Av. 0.5

The core samples on which magnetic susceptibility measurements were made consist of light- to medium-gray, medium-grained and equigranular quartz monzonite and granodiorite. The composition of the samples was determined by petrographic modal analysis, and the estimated mineralogic composition of the samples is shown in table 4. Most of the samples from the borehole show slight alteration of biotite and hornblende to chlorite. The more calcic cores of the zoned plagioclase feldspars are in places altered to sericite, calcite, and clay. A few core samples (G-165 and G-236) show more intense alteration of biotite and hornblende to chlorite, and most of the rock shows intense alteration of the plagioclase feldspars. The potassium feldspar is only slightly altered.

Magnetite occurs in small amounts in all samples of the Climax granite (table 4). Because the magnetic susceptibility of magnetite is several thousand times larger than the magnetic susceptibility of the other minerals in the granite, the bulk magnetic susceptibility of the samples is primarily determined by the magnetite content of the rock. The magnetite content of the granite was estimated by two methods in order to formulate an expression which would approximately relate magnetic susceptibility and magnetite content. The two methods are: (1) mechanical separation, and (2) modal analysis.

The first method used to determine the magnetite content consisted of crushing and grinding the samples to about 150 mesh. A grinder with ceramic plates was used in order to minimize contamination of the sample with iron. The powdered samples were washed in an ultrasonic vibrator, dried in an oven, and weighed on an analytical balance. The magnetic fraction was separated from the powder with a magnetic separator and a hand magnet. The magnetic fraction was weighed and the percent magnetic material calculated. No significant amounts of magnetic grains were found upon regrinding the samples to 200 mesh; therefore, it is assumed that nearly all of the magnetic grains were liberated by grinding the samples to 150 mesh.

The magnetic fractions separated from the powdered samples were analyzed by several techniques in order to determine the purity and oxidation state of the magnetic material. X-ray diffratograms confirmed that the magnetic fraction was mostly magnetite, and semiquantitative spectrographic analyses (table 6) showed that relatively small amounts of titanium, magnesium, manganese, and chromium, which commonly occur in magnetite, are present.

Table 6.--Semiquantitative spectrographic analyses of four magnetite samples from the U-15A exploration borehole, Nevada Test Site, Nye County, Nevada

Field No.	G-63	G-700	G-1000	G-1100		G-63	G-700	G-1000	G-1100
Si	0.3	0.3	1.5	0.7	La	0	0	0	0
Al	.7	.3	.7	.3	Li	0	0	0	0
FeM		M	M	M	Lu	0	0	0	0
Mg	.015	.007	.15	.03	Mo	0	0	0	0
Ca	.07	.07	.15	.07	Nb				
Na	.07	.07	.15	.07	Nd	0	0	0	0
K	.7	.7	.7	.7	Ni	.003	.0015	.0015	.0015
Ti	.07	.07	.07	.07	Os	0	0	0	0
P	0	0	0	0	Pb	0	0	0	0
Mn	.07	.07	.07	.07	Pd	0	0	0	0
Ag	0	0	0	0	Pr	0	0	0	0
As	0	0	0	0	Pt	0	0	0	0
Au	0	0	0	0	Rb	-	-	-	-
B	0	0	0	0	Re	0	0	0	0
Ba	.0015	.0007	.007	.0015	Rh	0	0	0	0
Be	0	0	0	0	Ru	0	0	0	0
Bi	0	0	0	0	Sb	0	0	0	0
Cd	0	0	0	0	Sc	0	0	0	0
Ce	0	0	0	0	Sn	0	0	0	0
Co	.0015	.0015	.0015	.0015	Sr	0	0	.003	.001
Cr	.015	.015	.015	.007	Sm	0	0	0	0
Cs	-	-	-	-	Ta	0	0	0	0
Cu	.007	.003	.003	.003	Tb	0	0	0	0
Dy	0	0	0	0	Te	0	0	0	0

Table 6.--Semiquantitative spectrographic analyses of four magnetite samples from the U-15A exploration borehole, Nevada Test Site, Nye County, Nevada - cont'd

Field No.	G-63	G-700	G-1000	G-1100		G-63	G-700	G-1000	G-1100
Er	0	0	0	0	Th	0	0	0	0
Eu	0	0	0	0	Ti	0	0	0	0
F	-	-	-	-	Tm	0	0	0	0
Ga	0.01	0.01	0.01	0.01	U	0	0	0	0
Gd	0	0	0	0	V	.07	.07	.07	.07
Ge	0	0	0	0	W	0	0	0	0
Hf	0	0	0	0	Y	.0015	.0015	.0015	.0015
Hg	0	0	0	0	Yb	-	-	-	-
Ho	0	0	0	0	Zn	0	0	0	0
In	.005	.005	.005	.005	Zr	.015	.015	.015	.015
Ir	0	0	0	0					

Figures are reported to the nearest number in the series 7, 3, 1.5, 0.7, 0.3, 0.15, etc., in percent. These numbers represent midpoints of group data on a geometric scale.

Comparisons of this type of semiquantitative results with data obtained by quantitative methods, either chemical or spectrographic, show that the assigned group includes the quantitative value about 60% of the time.

Symbols used are:

- = not looked for.

0 = looked for but not found.

M = major constituent - greater than 10%.

With number = below number shown: here standard detectabilities do not apply.

Chemical analyses for total and ferrous iron by the volumetric method were made on four magnetite samples by D. L. Skinner of the U. S. Geological Survey. Recalculation of the data to show FeO, Fe_2O_3 in magnetite, and excess Fe_2O_3 shows that the magnetite samples do not contain large volumes of excess Fe_2O_3 (table 7). The excess Fe_2O_3 is probably in the form of hematite or maghemite rather than allied with magnesium, manganese, or zinc in the form of magnetite series minerals. These elements occur in small amounts in the magnetite (see table 6) and would use only a small fraction of the excess Fe_2O_3. Column 5 of table 7 shows that the samples are relatively pure magnetite and that the amount of impurity correlates well with the greatest amount of silicon and aluminum (table 6). The silicon and aluminum probably occur in quartz or feldspars, which slightly contaminate the magnetite samples.

Table 7.--Chemical analyses of four magnetite samples (percent by weight) for FeO and Fe_2O_3 from samples of the U-15A borehole, Nevada Test Site, Nye County, Nevada

Sample No. and Depth	FeO	Fe_2O_3 (as magnetite)	Fe_2O_3 (excess)	Remainder
G-63	26.9	59.9	7.0	6.2
G-700	23.6	52.4	19.0	5.0
G-1000	24.4	54.4	10.8	10.4
G-1100	28.8	64.2	1.5	5.5

Analyst D. L. Skinner, U. S. Geological Survey

The second method used to determine magnetite content consisted of cutting a thin rock slice from the cylindrical cores. A rock thin section was prepared from the rock slice and the volume of magnetite in the thin section was estimated by point counting with a petrographic microscope. This method is known as modal analysis, which in most cases provides a reliable method of estimating volume percent of minerals in thin section (Chayes, 1956). The accuracy of this method depends on the relative amount of the minerals in the thin section and the grain size of the rock relative to the area of the thin section under consideration.

Table 5 gives the percent magnetite by modal analysis for several samples of the granite. A total of 1800 points were counted for each thin section. Comparison between percent magnetite by modal analysis and by mechanical separation with a hand magnet indicates that the results by modal analysis are more variable. Comparison of the means of several values indicates that no significant differences occur at the level of 3 standard errors for a count traverse of 1800 points on a constituent averaging about 0.6 percent. A minimum of 4000 points would be necessary to increase the accuracy in order to plot magnetic susceptibility vs. magnetite content.

The average value for magnetic susceptibility (table 5) is about 2.4×10^{-3} cgs units, and the average value for magnetite by volume is about 0.6 percent. A few samples such as G-160A, G-165, G-236, and G-930, have values of magnetic susceptibility and magnetite content that are much lower than the average of all samples. These samples were from zones in which the magnetite was probably altered to hematite or maghemite. Magnetic susceptibility values appear to be separated into 2 groups; the average magnetic susceptibility value above 374 feet is somewhat lower than the average value below 414 feet. This partition of the data suggests that either the magnetite has been altered in the upper zone or that the lower zone is a different compositional phase of the Climax stock that contains more magnetite.

Table 8 shows the magnetic susceptibility and magnetite data for a few outcrop samples of the Climax granite. It appears that the weathered outcrop samples have slightly lower values of magnetic susceptibility than the fresh rock from the borehole.

Table 8.--Magnetic susceptibility and magnetite content of outcrop samples of the Climax granite

Sample number	Magnetic susceptibility ($K_s \times 10^{-3}$ cgs units)	Pct. Magnetite by volume	Pct. Magnetite by weight
FP-63	2.25	0.7	1.3
HG-8	1.17	0.8	1.5
HG-7	2.38	1.0	2.0
HG-19	.012	.005	.01

Previous investigators, for example, Mooney and Bleifuss (1953) report that magnetic susceptibility and percent magnetite by volume are approximately related by the following empirical expression:

$$K_s = AV^B$$

where K_s = Magnetic susceptibility

A = Constant of proportionality

V = Percent magnetite by volume

B = Exponent

Mooney and Bleifuss (1953, p. 386) report that the relationship for some granitic rocks of low magnetite content (less than 2 percent) from Minnesota is as follows:

$$K_s = 1.94\ V^{.47}$$

A logarithmic plot of the magnetic susceptibility and volume percent magnetite data obtained by the mechanical separation method for the Climax granite was made and the best straight line by least squares was fitted to the plot (fig. 2).

A moderately good correlation between magnetic susceptibility and percent magnetite exists for the Climax granite, and the following expression approximately relates the two parameters:

$$K_s = 4.3V^{1.38}$$

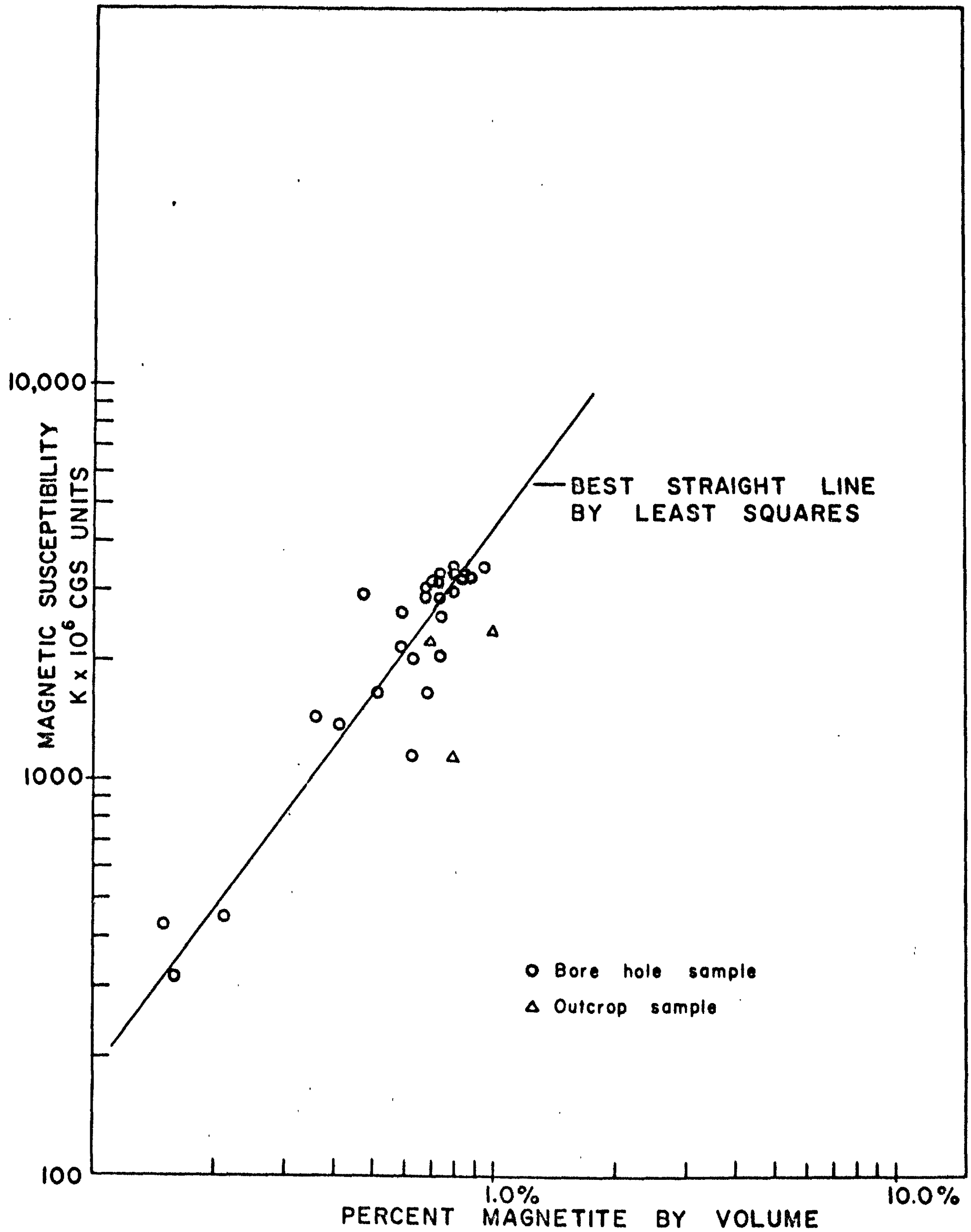


FIGURE 2. MAGNETIC SUSCEPTIBILITY VS MAGNETITE CONTENT FOR CLIMAX GRANITE

The constant of proportionality and the exponent are larger for the Climax granite than values for some Minnesota granitic rocks, (Mooney and Bleifuss, 1953) but agree well with the values reported by Balsley and Buddington (1958, p. 789). Variation among expressions relating magnetic susceptibility and magnetite content for various rock types is usually explained in terms of the demagnetization factor or the differences in field strengths at which the samples are measured.

THERMAL CONDUCTIVITY

Thermal conductivity measurements were made with a divided bar-type apparatus on 14 granite samples split from samples used for porosity, density, permeability, and magnetic-susceptibility measurements. The preparation of samples and method used is similar to that reported by Keller (1958, p. 6-1).

Granite core samples 1-1/2 inch in diameter were cut to about 1/4 inch thickness, and the flat faces of the discs were polished. A granite disc was placed in a stack among discs of copper and a standard (isolantite) (fig. 3). In order to make good thermal contact, the surfaces were coated with silicone grease and the entire stack was put under 250 pounds/sq. inch pressure. A heat source was placed at the top of the stack to provide heat flux through the discs; the base of the stack was water cooled. The top of the stack was about 32°C, and the base of the stack was about 14°C. Thermocouples were used to measure temperature differences between standards and the granite discs.

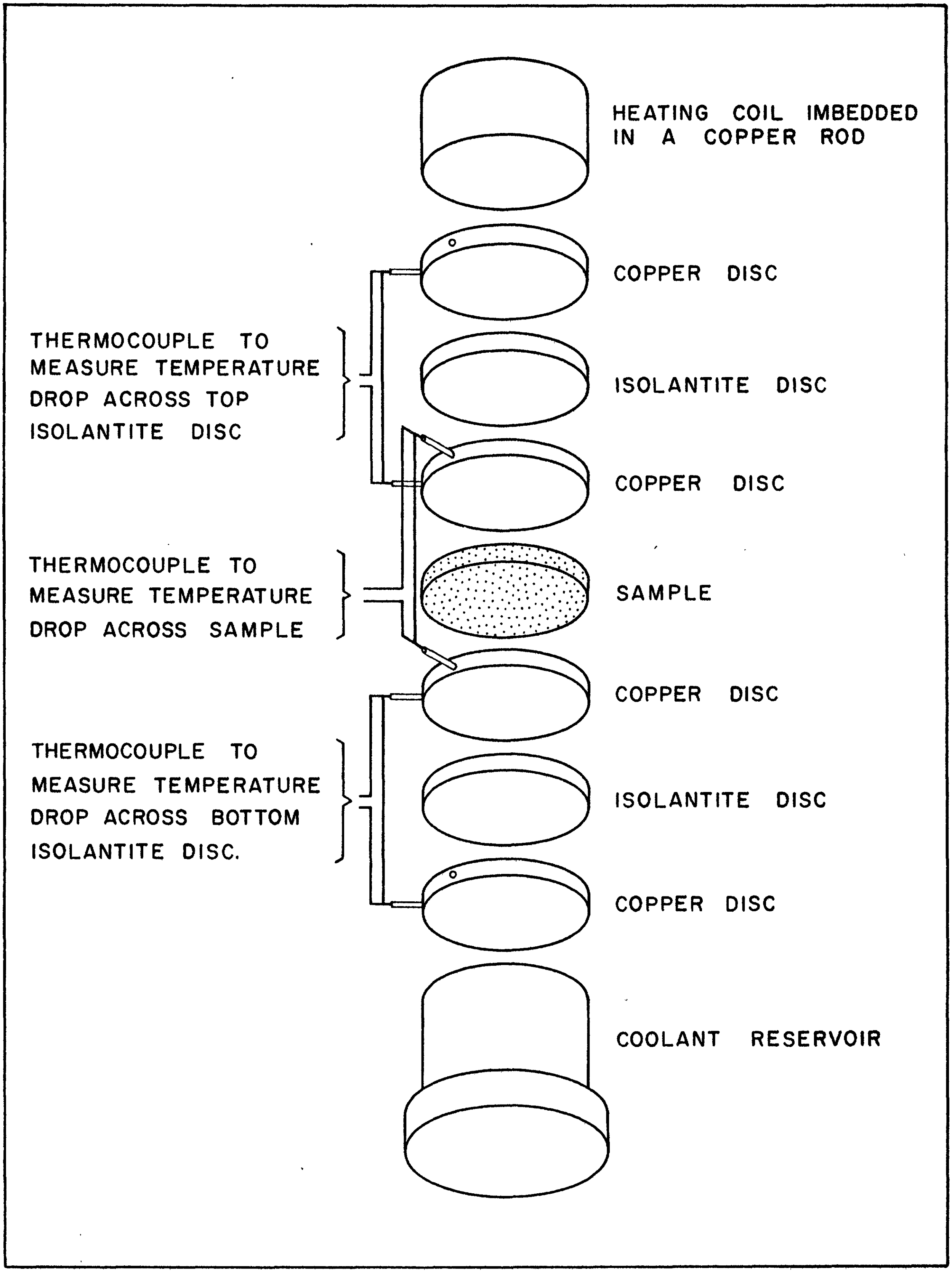


Figure 3. Diagram of apparatus used in measuring the thermal conductivity of rock samples. After G.V. Keller (1958)

Table 9 lists the results of the thermal-conductivity measurements and theoretical thermal conductivities calculated from the modal composition of the samples as suggested by Birch and Clark (1940, p. 625-626).

The modal composition of some of the samples was estimated from two rock thin sections made from each granite disc used for thermal-conductivity measurements. The estimated volumetric percentage of the major mineral constituents were averaged for the two thin sections, and this average value (table 10) was used in the calculation of thermal conductivity. Comparison of the values obtained from two thin sections from the same granite disc indicates that two standard errors of the mean value for major minerals is about 3.0 percent.

Table 9.--Measured and calculated thermal conductivities of granite samples from the U-15A borehole, Nevada Test Site, Nye County, Nevada

Sample No. and depth	Thermal conductivity cgs units	Calculated Thermal conductivity by cgs units
G-63	6.0×10^{-3}	7.9×10^{-3}
G-144	5.7×10^{-3}	8.5×10^{-3}
G-236	5.8×10^{-3}	8.1×10^{-3}
G-277	5.7×10^{-3}	8.0×10^{-3}
G-400	8.1×10^{-3}	
G-500	6.6×10^{-3}	8.5×10^{-3}
G-600	7.2×10^{-3}	
G-700	5.6×10^{-3}	
G-800	6.3×10^{-3}	
G-854	5.8×10^{-3}	7.9×10^{-3}
G-900	6.3×10^{-3}	
G-1000	7.1×10^{-3}	
G-1100	5.7×10^{-3}	7.4×10^{-3}
G-1200	5.7×10^{-3}	7.7×10^{-3}

Table 10.--Modal analyses of eight samples from the U-15A Climax granite exploration borehole used for calculation of thermal conductivity, Nevada Test Site, Nye County, Nevada

Mineral (volume percent)	G-63	G-144	G-236	G-277	G-500	G-854	G-1100	G-1200
								Sample number and depth
Quartz	26.0	31.0	28.6	28.5	31.4	27.3	24.9	24.5
Potassium feldspar	17.7	25.8	15.8	17.4	26.3	20.5	20.2	20.5
Plagioclase feldspar An 35	47.0	35.0	47.4	47.0	34.0	44.1	48.8	44.3
Biotite	7.0	4.5	5.5	4.6	5.7	5.5	2.3	7.0
Chlorite	1.6	3.1	1.6	1.3	1.9	1.4	1.9	1.8
Allanite Apatite Calcite Clay (unidentified) Clinozoisite Epidote Magnetite Myrmekyte Sercite Sphene Zircon	Each constituent occurs in trace amounts (< 1%) in each sample							

Thermal conductivity values for individual minerals of the Climax granite which were used in the calculations of theoretical thermal conductivities were taken from Birch and Clark (1940, p. 630) and Carte (1955, p. 482). The calculations were made assuming that the mineral constituents are in parallel arrangement. Because reliable thermal conductivity values for some minor constituents of the granite are not available, the samples were assumed to consist of quartz, potassium feldspar, plagioclase feldspar, biotite, and chlorite. These minerals form at least 95 percent by volume of the samples.

The measured thermal conductivities are consistently lower than the calculated thermal conductivities (table 9). The reasons that calculated and measured thermal conductivity values differ are: (1) contact resistance between sample and copper discs in the divided bar-type apparatus will give a lower value than the true value, (2) calaculated values will be larger than the correct value because contact resistance between grains is neglected in the calculation of thermal conductivity, (3) experimental error associated with the measuring process, and (4) reliable thermal-conductivity values for all minerals in the samples are not available.

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