KEILHAUITE, A GUIDE MINERAL TO THE STERLING GRANITE GNEISS OF RHODE ISLAND

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Introduction

During the study of the heavy accessory minerals of a suite of specimens of the Sterling granite gneiss from Exeter, Rhode Island, sphene with abnormally low indices of refraction was found. Upon further examination, this mineral proved to be the variety keilhauite. Samples of the granite were examined from widely separated outcrops, and whereever sphene was found, it proved to be this variety. Crystals of normal sphene were not found in the Sterling granite gneiss. Several specimens of the Milford granite to the north were examined, but no keilhauite was found. The two specimens of Milford granite examined contained a mineral so badly altered to leucoxene that its optics could not be determined. The keilhauite from the Sterling granite gneiss from Exeter was unaltered.

The writer is greatly indebted to Dr. Alonzo Quinn of Brown University for his aid in obtaining the specimens for this work, and to Dr. Esper S. Larsen, Jr., and Dr. Harry Berman for their many helpful suggestions during the course of this study. The writer also desires to thank Mr. W. E. Richmond for the *x*-ray photographs of keilhauite and sphene which he kindly made.

Location

The specimens studied were all fresh, unweathered samples and were obtained from recent road cuts. A traverse was made along the Ten Rod Road from the village of Exeter in Exeter township, west to the Nooseneck Hill Road, thence south-south-west about a mile to the new Beach Pond Road, and then due west along the Beach Pond Road to the Connecticut boundary (Fig. 1). Six specimens from outcrops spaced at least a mile apart and one specimen from a road cut near the Kent Dam of the Scituate Reservoir, twelve miles north of the eastern part of the traverse, were studied. Samples of the Milford granite and of keilhauite and sphene from the Harvard University collections were examined for comparison. The sphene from Manton, Rhode Island, was furnished by Dr. Alonzo Quinn of Brown University.

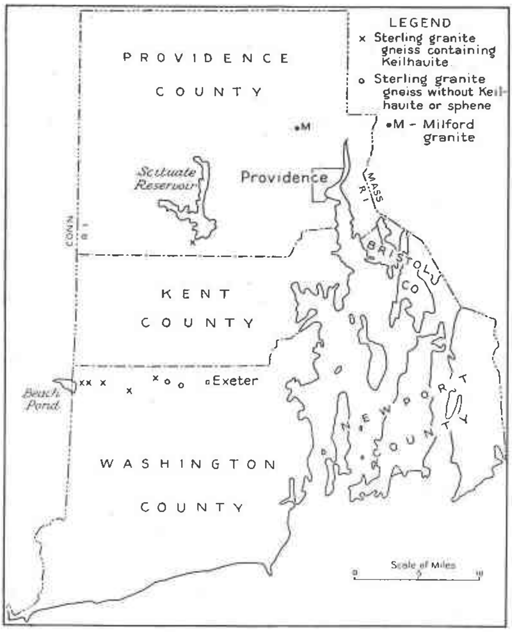

FIG. 1. Index map of Rhode Island, showing location of specimens studied.

METHODS USED

About seventy-five grams of each specimen were crushed to pass an eighty-mesh screen, washed free of dust, and passed through bromoform. The heavy fraction was subdivided with an electromagnet and the keilhauite concentrated in the weakly magnetic fraction.

The optical properties of the keilhauite were determined by immersing the grains in solutions of yellow phosphorus and sulphur in methylene iodide as described by West.[1]

CHARACTERISTICS OF KEILHAUITE

Keilhauite was distinguished from normal sphene on the basis of its somewhat larger optic angle and its appreciably lower indices of refraction. The refractive indices vary somewhat, but are generally lower than those of most sphenes. Below is a comparison of the indices of refraction of keilhauite from Rhode Island, Norway, and South Africa with sphene from Rhode Island.

[1] West, C. D., Immersion liquids of high refractive index: *Am. Mineral.*, vol. **21**, pp. 245–249, 1936.

	α	β	γ	2V	Sp. Gr.	
Y708	1.855	1.874	1.972		3.50	keilhauite, Exeter, R.I.
Y710	1.870	1.890	1.990			keilhauite, Exeter, R.I.
Y721	1.843	1.870	1.943	35–40°	3.557	keilhauite, Exeter, R.I. (analyzed)
87737	1.889	1.910	2.032			keilhauite, Arendal, Norway
89494	1.882	1.900	2.000	30°		keilhauite, Kahn Mine, S.W. Africa
Manton	1.900	1.918	>2.060	10–15°	3.52	sphene, Manton, R.I.

It should be noted that the indices of refraction for keilhauite as given by Larsen and Berman[2] and Winchell[3] are high, and probably inaccurate, as suggested to the writer by Dr. Larsen. In all cases the dispersion was strong, $r>v$, and the optical character positive.

Several kilograms of the rock containing the keilhauite of lowest refractive indices, Y721, were crushed and about one gram of keilhauite was carefully separated. This keilhauite was analyzed by F. A. Gonyer with the following result:—

	Percentages	mol. ratios
SiO_2	29.85	.497
TiO_2	30.65	.384
Al_2O_3	7.32	.072
Fe_2O_3	6.17	.039
FeO	none	
MnO	none	
MgO	none	
CaO	22.37	.399
H_2O	0.32	
Y_2O_3 } Ce_2O_3 }	3.58	.013
	100.26	

A comparison of the analysis of keilhauite with analyses of sphene was attempted, but was difficult because of the lack of good sphene analyses. Most of the analyses are over fifty years old and were made before the introduction of more refined methods of chemical analysis, and in many of these but three constituents were determined, SiO_2, TiO_2 and CaO. The writer wishes to point out the need for more accurate chemical analyses of sphene with careful determinations especially for titania, alumina, and ferric iron.

The amount of silica in five keilhauite analyses[4] examined seems to be about the same as in the Rhode Island keilhauite, while in twelve

[2] Larsen, Esper S., and Berman, Harry, The Microscopic Determination of the Nonopaque Minerals, *U. S. Geol. Survey*, Bull. **848,** p. 143, 1934.

[3] Winchell, N. H., and Winchell, A. N., Elements of Optical Mineralogy, Part II, Descriptions of minerals, 3rd ed., John Wiley & Sons, Inc., New York, p. 205, **1933.**

[4] Doelter, C., Handbuch der Mineralchemie, **III,** 1, pp. 59–66, 1918.

sphenes, including the variety grothite, it ranges from 28.26% to 36.79%. Titania varies from 26.67% to 29.01% in the keilhauites, slightly lower than that of Rhode Island, and varies from 30.40% to 41.41% in the sphenes. Alumina, ferric iron, and rare earths—R_2O_3—range from 1.68% to 11.65% in the sphenes, and from 12.81% to 24.22% in the keilhauites. Lime is generally lower in keilhauite than in sphene, 17.15% to 22.37% in keilhauite and 20.51% to 31.41% in sphene.

X-ray powder patterns for the Rhode Island keilhauite and for sphene from Renfrew, Canada, show identical spacing and intensity. It would appear therefore that keilhauite and sphene have the same fundamental structure. Zachariasen[5] studied the structure of sphene. In keilhauite and some sphenes R_2O_3 apparently replaces both lime and titania. The following formulas express the compositions closely:

$Ca\ Ti\ SiO_5$	sphene
$(Ca_4,R''')\ (Ti_4,R''')\ (SiO_5)_5$	keilhauite
$R'''=Al''',Fe''',Y''',Ce'''$.	

Conclusions

This study indicates that keilhauite might be used as a guide mineral to distinguish the Sterling granite gneiss from other nearby granite gneisses of similar appearance. Further work may, however, show that the keilhauite is confined to but a portion of the Sterling. For rapid work, but a small quantity of the rock would need to be crushed and the α index alone determined. A great many such immersions could be made in a few hours. Further work might show similar variations in the optical properties of zircon which would make this mineral of value for correlation in some cases.

The writer also wants to emphasize the fact that there appears to be a gradation in chemical composition and optical properties from keilhauite to sphene. A series of chemical analyses of keilhauite and sphene would probably show a fairly simple relation between the index of refraction and the R_2O_3 and TiO_2 content of the mineral.

[5] Zachariasen, W. H., The crystal structure of titanite: *Zeits. Krist.*, vol. **73**, pp. 7–16, 1930.