

MINERALOGY AND GEOCHEMISTRY OF THE READ
MAGNETITE DEPOSIT, SOUTHWESTERN
STEVENS COUNTY, WASHINGTON

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LUDWIGITE FROM THE READ MAGNETITE DEPOSIT
STEVENS COUNTY, WASHINGTON

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ABSTRACT

The Read magnetite deposit of contact metasomatic origin has been formed along the contact of probable Cambrian limestone with granite of Mesozoic age. Notable among the various minerals formed is ludwigite, which appears to occupy a hanging wall position, or is generally farther from the granite than other minerals in the zone, and which appears to be a selective replacement of forsterite. Other nonmetallic contact metasomatic minerals include abundant diopside; lesser amounts of almandite, andradite, and hedenbergite; and minor amounts of spinel, epidote, tremolite, quartz, sanidine, labradorite, orthoclase, apatite, humite group minerals, serpentine, calcite, and dolomite. Metallic minerals include abundant magnetite; lesser amounts of pyrite, chalcopyrite, and pyrrhotite; and very minor amounts of scheelite and sphalerite. Accessory metallic elements include tin, titanium, manganese, and probably molybdenum. The minerals are believed to have formed mainly in response to a decline in temperature inward from the contact. Magnetite, sphalerite, and possibly other metallic minerals appear to have formed in the pneumatolytic phase. Greatest loss of material was in carbon dioxide and lime; greatest gain was in silica, iron oxides, magnesia, boron, and alumina. Ultimate sources of boron probably were in Cambrian and Precambrian metamorphic rocks that were intruded and assimilated by the granite.

INTRODUCTION

THE Read magnetite deposit was discovered by J. C. Read in 1901. Most of the development appears to have been done during the following 20 years and consisted of 5 shallow shafts, two short adits, and several open cuts (19). The most satisfactory places to study the mineralization are at Shafts 1 and 5 and an open cut just northeast of Shaft 3 (Fig. 1). There has been no production, although a few tons are reported to have been smelted in the adjacent community of Fruitland. Broughton (5) has described the geology in detail, mentioned the presence of 10 minerals, including ludwigite for the first time, and has outlined the areas of maximum magnetic intensity as indicated by a dip needle. A specimen of ludwigite given to Bennett by Gordon Glasgow of Hunters, not known at first to be from the Read deposit, was identified at Pullman in 1941 by Sheldon L. Glover, W. C. Warren, and W. A. G. Bennett. Other specimens in the Division collection were collected by A. K. Guard and by John P. Thomson. In 1944 Frederick K. Vreeland of Rogue River,

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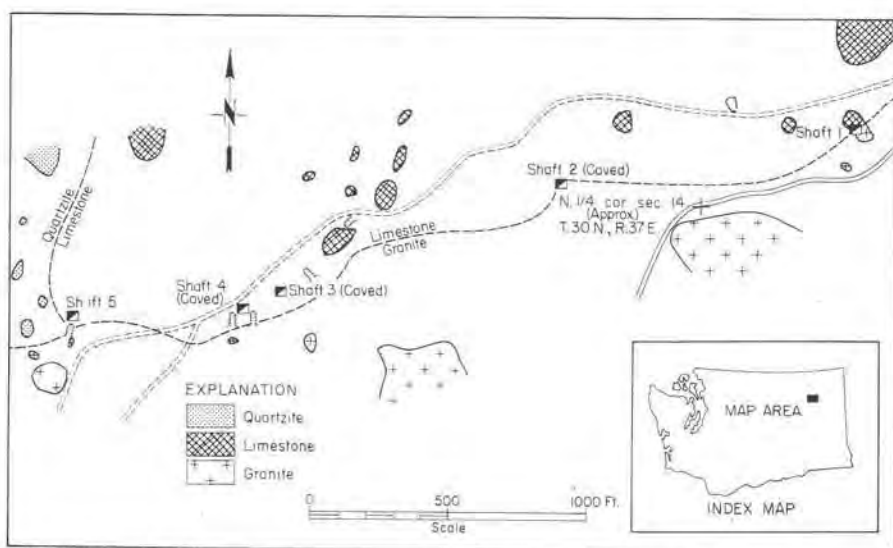
Oregon estimated 0.5 percent tin in a spectrographic analysis of Glasgow's specimen.

Twenty additional minerals and four metals are here reported for the first time.

This paper is the result of a request by W. T. Schaller of the U. S. Geological Survey for samples of the ludwigite and his suggestion that the Division of Mines and Geology report further on the mineralogy and geochemistry of the deposit and especially with reference to the occurrence of the ludwigite.

A separate paper by W. T. Schaller and Angelina C. Vlisidis, "Ludwigite from the Read Magnetite deposit, southwestern Stevens County, Washington," will be published in this journal.

In the preparation of this paper the writer is indebted to Dr. Schaller and others of the U. S. Geological Survey and especially to Mr. Marshall T.



Geology by W. A. Broughton, 1945

FIG. 1. GEOLOGIC MAP OF THE READ IRON DEPOSIT, STEVENS COUNTY, WASHINGTON

Hunting, Supervisor, Washington Division of Mines and Geology; also to Mr. Gerald W. Thorsen of the Division staff for his recognition of an obscure grain of sphalerite enclosed in the ludwigite.

The Read magnetite deposit as shown on the Hunters quadrangle of the U. S. Geological Survey is mostly in the north half of sec. 14, T 30 N, R 37 E, about 4 miles east of Hunters, in the Cedar Canyon mining district of Stevens County and about 45 miles northwest of Spokane. The sparsely wooded area is at an altitude of about 2,800 feet and is near the head of the northeast fork of Alder Creek, which drains the south slope of a westward-projecting spur from the Huckleberry Mountains.

The deposit has been formed along the intrusive contact of limestone of

probable Cambrian age with granite of Mesozoic age. According to Broughton the limestone strikes generally N 50° E and dips northwestward at angles between 80° and 90°. The contact zone trends roughly N 85° E and dips 75° to NW.

MINERALOGY OF DEPOSIT

Shedd, Jenkins, and Cooper (19) reported magnetite, chalcopyrite, wolastonite, tremolite, and a little fluorite at the Read deposit. Broughton (5) mentions minute crystals of scheelite, a small amount of garnet, and considerable ludwigite in the contact zone, which, according to him, in Shaft 1 is 2 feet wide, hydrothermally bleached, and mineralized with small pods and grains of magnetite. Further study of specimens that represent a continuous 5-foot section across the contact zone about 20 feet east of Shaft 1 shows, next to the granite, mainly iron-free diopside (beta index of refraction, about 1.671), epidote (beta index, 1.75), veinlets of quartz and orthoclase, and 1-inch bands of almandite (index of refraction, between 1.82 and 1.83), also a little actinolite and chlorite. At about 8 inches from the contact a little sanidine is present with quartz and epidote that shows an aluminum to iron ratio of 5:2 (12), considerable almandite, and diopside with about 25 percent of hedenbergite (beta index, about 1.687). Rock specimens that represent the next 1-foot width show diopside with less iron (beta index, 1.684), a minor amount of labradorite (An 65), and almandite (index of refraction, about 1.84), with numerous inclusions and alternating isotropic and birefringent bands. Spinel, containing many minute birefringent inclusions, occurs in diopside at about 1½ feet from the granite, as dark-green crystals several millimeters across, as disseminated fine grains, and as aggregates. Spectrographic analysis of a conspicuous spinel fragment indicated 2 percent zinc, or 6 percent $ZnAl_2O_4$. Using Winchell's (21, p. 83) diagram and a determined refractive index of 1.745, the fragment would appear to contain 16 percent hercynite, 78 percent spinel proper, and 6 percent gahnite. Similar minerals represent the next 1½ feet, but the ferroan diopside appears to grade into an iron-free diopside (beta index, 1.671; gamma index, 1.695) that lies adjacent to partly serpentinized forsterite, which is bordered by 1½ to 2 feet of ludwigite. Adjacent to the ludwigite on the hanging wall is coarse-grained calcitic limestone.

Ludwigite seen in an edgewise view of a block, 13 by 9 by 7 inches taken from the dump of Shaft 1 shows numerous white, irregular or ragged appearing inclusions of forsterite, and apatite is present as creamy-white patches an inch or more across. The apatite appears to contain, on the basis of optical data (21, p. 199) about 65 percent of fluor-apatite and 35 percent of chlor-apatite molecules, respectively. A quarter-inch grain of brown sphalerite was found enclosed by the ludwigite, which ranges from fine to coarse fibrous, many shiny prism faces being as much as 4 by 20 mm and tending to be elongated to the plane of the zone on the steeply dipping hanging wall.

The opencut 100 feet northeast of Shaft 3 (Fig. 1) is about 100 feet (surface dimension) from the contact of the granite. It shows, across a 15-foot face, starting from the south, the following: forsterite that encloses magnetite and reddish-brown radiating prisms of ludwigite and a little calcite, apatite

as colorless 0.5 to 2 mm prisms, and chondrodite (beta index, about 1.632) that is optically positive with a $2V$ of about 70° , with multiple twinning and birefringence resembling that of forsterite or diopside. The central two-thirds of the opencut consists mostly of limestone crossed by veins, or vein-like zones, between 6 inches and a foot in width and narrowing upward. These veins contain for the most part ludwigite that encloses as well as borders massive creamy-white mixtures of apatite, probably clinohumite, and a little calcite. The presence of two humite group minerals is suggested by the relative dif-

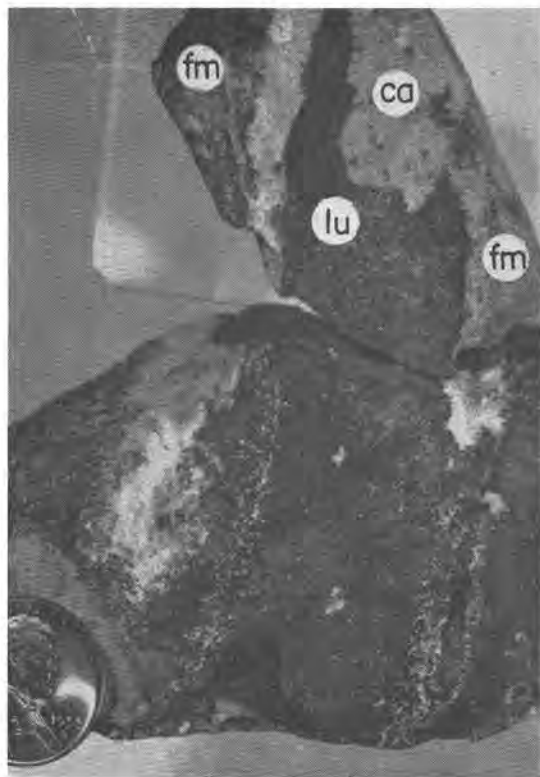


FIG. 2. Forsterite and magnetite (fm), chondrodite and apatite (ca), and ludwigite (lu).

ference of extinction angles measured on multiple twinning, ranging from 4° to 23° on fragments that show an optic axis at the edge of the field. Fragments perpendicular to Z presumably would show higher values for extinction angles (21, p. 514; 7, p. 630-631), but none showing twinning was observed. The north side of the opencut shows forsterite, and diopside with 30 percent of hedenbergite.

Figure 2 shows a mixture of forsterite and magnetite in about equal amounts apparently being replaced by chondrodite with some apatite (N_0 about

1.654), and this last assemblage surrounds on all but one side magnesian ludwigite that is reddish brown, fine grained, highly magnetic, and extensively altered. The ludwigite shows brown to blue-green pleochroism. The white material gives chemical tests for calcium and phosphorus, and spectrographic analysis of the residue from an acid leach shows much magnesium, boron, and silicon, somewhat lesser amounts of manganese, and minor amounts of iron and calcium.

At the west end of the Read magnetite deposit, ferroan diopside (beta index, 1.684) and magnetite, a little forsterite, a veinlet of grayish-white asbestiform tremolite, and a little calcite compose the contact rock in the face of a 3-foot opencut that lies 15 feet northwest of the nearest outcrop of granite. This association is followed on the northwest for a few feet by forsterite, magnetite, and ludwigite as sporadic but relatively large, finely fibrous rosettes; by iron-free diopside (beta index, 1.671), slightly altered to serpentine; and finally by a second zone of forsterite, magnetite, and ludwigite as sporadic rosettes. Minerals found along the south edge of Shaft 5, starting at the southwest corner and 43 feet northwest of the granite, include forsterite that encloses magnetite and ludwigite that has prism faces 1 to 4 mm long, some of it showing minor alteration along hair-like veinlets. The foregoing association is succeeded by forsterite that predominates over magnetite and chlorite (index of refraction, 1.562); by ludwigite with a $\frac{1}{8}$ -inch veinlet of forsterite; by magnetite, pyrite, chalcopyrite, and apparently pyrrhotite; by white sugary forsterite, magnetite, and ludwigite in rosettes with prisms 12 mm long; finally by diopside, pure andradite (index of refraction, 1.895), hedenbergite (beta index, about 1.74), and some magnetite. The west edge of the shaft, from the south and although not sampled in detail, again shows forsterite and magnetite with sporadic rosettes of ludwigite. Still farther along the edge the ludwigite appears in masses that grade into an altered zone of magnetite, chlorite, serpentine, serpentinized forsterite, amphibole, and probably a member of the humite group, followed by an association of diopside and magnetite, in a 50-50 ratio, and a little penninite. Finally, masses of ludwigite again appear with small inclusions of forsterite (beta index, 1.651). A veinlet 1 mm wide in the ludwigite appears to contain serpentine, chlorite, a fibrous mineral resembling anthophyllite, and another with absorption suggesting tourmaline.

Further observations on ludwigite from the west side of the shaft are as follows: A prism 12 mm long shows transverse parting or cleavage (?); crushed fragments of a segment of it show a high order of light transmission for ludwigite, with many that give an acute bisectrix that shows X = dark green to black and Y = light green; $2 E, 62^\circ$; a calculated $2 V$ or 32° ; and beta index, 1.85. A rhomb, 0.48 mm by 0.42 mm viewed in the direction of the c axis, gave internal angle values of $113^\circ 21'$ and $66^\circ 39'$, the average of two readings for each. Forsterite and diopside along the north side of the shaft show much alteration to serpentine and other minerals, and along the east wall from the south these contact zone silicates are associates with asbestiform tremolite, considerable magnetite, a minor amount of chalcopyrite, and chlorite, followed by diopside and magnetite in equal amounts near the northeast corner.

Serpentinous hydrothermal alteration of limestone, well exposed in a circular area near the center of a small knoll just northwest of the shaft, apparently was not accompanied by deposition of uranium minerals that were the objective of the prospecting. About 200 feet farther northwest up a ravine, a small outcrop of contact rock shows diopside and almandite (index of refraction, 1.77).

GEOCHEMICAL ASPECTS

The foregoing account of the deposit, based on the examination of 75 specimens, shows that many of the common contact metamorphic minerals are present, such as those mentioned by Barth (1, p. 279) for the Olso region, by Knopf's (11) summary of many deposits, and by Steidtmann and Cathcart (20) for the York tin region, Alaska. Iron, zinc, copper, manganese, titanium, aluminum, calcium, magnesium, tungsten, and tin are present among the metals, probably also molybdenum, together with silicon, chlorine, fluorine, sulfur, boron, and phosphorus, all of which have entered into an assemblage of minerals represented by magnetite, pyrite, chalcopyrite, sphalerite, scheelite, powellite (?), almandite, andradite, diopside, hedenbergite, spinel, forsterite, epidote, wollastonite, tremolite, quartz, sanidine, labradorite, orthoclase, apatite, chondrodite, clinohumite (?), ludwigite, tourmaline (?), serpentine, calcite, and dolomite. Some additional hydrothermal minerals remain to be identified, and a more thorough search probably would reveal other contact metasomatic minerals.

At Shaft 1, the most abundant minerals, diopside, forsterite, and ludwigite occur in that order inward from the contact of the granite. This order suggests a temperature gradient in a dolomitic limestone country rock (1, p. 286-290; 14). According to Barth the temperatures of most contact deposits do not exceed that at which diopside forms. However, the presence of sanidine, and the reported occurrence of wollastonite by Shedd, Jenkins, Cooper, indicate a range in temperature from a probable maximum of 650° at the contact down to 250° in the forsterite zone. Assuming that the temperature at the contact might have reached 650°, there is the possibility that brucite, periclase, monticellite, akermanite, and spurrite exist here.

Although some of the iron in the contact zone undoubtedly represents an original amount in the dolomitic limestone, a very considerable amount has been added from the granite. This added iron is in the magnetite and ludwigite, and there is some reason to believe that a part of it entered other minerals such as diopside and garnet. At Shaft 1 there is less iron in the diopside and garnet and less magnetite present, whereas at Shaft 5 there is generally more iron in diopside and in garnet and more magnetite is present. The metasomatic zone at Shaft 1 is narrow and its dip is steep, whereas the much larger area of metasomatism at Shaft 5 probably indicates a flatter dip of the granite underground (20, p. 88), and probably accounts for the obviously more complex relationships of the minerals. It appears that, in contrast to diopside in parts of the contact zone, the forsterite here is apparently free of iron. This iron-free metasomatic forsterite also contrasts with peridotite (igneous) forsterite, which commonly contains varying amounts of iron. This

tendency of the forsterite to be free of iron is perhaps explicable by Ramberg's (16, p. 287) equation: $2\text{MgFe}_2\text{O}_4 + \text{Fe}_2\text{SiO}_4 = \text{Mg}_2\text{SiO}_4 + 2\text{FeFe}_2\text{O}_4$. He explains further, "The distribution of divalent iron and magnesium in minerals is informative. Iron is a little bigger than magnesium, but yet it has a larger polarizing power, because of its nonnoble-gas structure. For that reason magnesium tends to go to the silicates, divalent iron to the complex oxides." Whether or not Ramberg views the above reaction as taking place without the agency of a fluid medium, both magnesioferrite and magnetite have been observed in deposits around fumaroles (Zies, in 17; 15). Leith and Harder (13; in 18) suggest ferrous chloride reacting with water to form magnetite, hydrochloric acid, and hydrogen, and Geijer (8) suggests iron fluoride and silicon fluoride reacting with calcium carbonate to form andradite and fluorite with liberation of carbon dioxide. It seems likely that iron was transported for the most part under pneumatolytic conditions. That fluorine, rather than chlorine, probably was the medium by which the iron was introduced is suggested by the presence of fluorite, apatite, and humite group minerals which formed somewhat later and at a lower temperature. Harker (10) on the other hand favors introduction of iron in liquid solutions following the pneumatolytic stage.

Besides the presence of iron in diopside, magnetite, sulfides, and other minerals, much of it entered into ludwigite, which is the most unusual, if not unique feature, of the mineralogy at the Read deposit. If its extent be along the entire length of the zone between Shafts 1 and 5, in depth for the same distance, and average 2 feet in width, there would be about 55,000 tons of boron present in the deposit. It is believed that the forsterite formed first, and was later replaced by ludwigite, that is, in those places where the latter occurs in masses with ragged, corroded, or resorbed inclusions of various sizes of forsterite. It has been stated in preceding paragraphs that the ludwigite is sporadic and occurs as rosettes, especially where there is an intimate intermixture of forsterite and magnetite. This may indicate a temperature too high for abundant deposition or replacement, higher diffusion rate of the boron relative to iron, difference in size of ions and probably other factors. Whatever the specific reason, the ludwigite selectively replaced the forsterite in those places where it occurs in masses and probably crystallized simultaneously in those places where it occurs as rosettes in an intimate association with the magnetite and forsterite. It thus appears that boron together with iron, by sheer preponderance (law of mass action), was able to displace the strong bond between silicon and oxygen, pick up much of the magnesium, and form ludwigite. The temperature of formation of the replacement must have been just above the hydrothermal for the most part, but in places just below, to permit of minor hydrothermal effects in the ludwigite and adjacent parts of the contact zone. Finally, the deposition of the ludwigite appears to have depended on mutual abundance of boron and iron and a magnesium silicate host, whose materials were also in part transported a little earlier in the metasomatic process. The transference of magnesium, silicon, and fluorine has recently been discussed by Geijer (8, p. 212).

The Read deposit shows the characteristic gains and losses of materials

during metasomatism. The wall rock, if a dolomite, contained approximately 47 percent carbon dioxide, 30 percent lime, and 21 percent magnesium. These amounts would be reduced somewhat by silica, iron, and alumina originally present. The predominant minerals in the contact zone at Shaft 1, expressed in terms of their oxides and these averaged in accordance with the widths occupied by the several minerals, give an overall composition approximately as follows: 31.2 percent MgO, 28.8 percent SiO₂, 7.4 percent FeO, 15.3 percent Fe₂O₃, 4.5 percent Al₂O₃, 6.1 percent CaO, and 6.7 percent B₂O₃. Thus, the greatest loss was in carbon dioxide, followed by lime; the greatest gain was in silica, followed in order by iron oxides, magnesium, boron, and alumina. Gilluly (9) in the Fairfield and Stockton quadrangles in Utah, found lime to be the major item removed, followed closely by carbon dioxide, and much less magnesia; and found silica to be the major item introduced followed closely by sulfides, alumina, and potash in that order, and by other items in much smaller amounts.

As to the ultimate source of the unusually large amount of boron contributed by the granite to the contact metasomatic zone, it could have been in the paligenetic assimilation and concentration from formations that contained detrital boron-bearing minerals, the concentration being aided by the high mobility of boron (Goldschmidt and Peters in 17, p. 493; 16, p. 267-268). If it is generally true that schists and quartzites are higher in boron content than carbonate rocks, a likely source would be the Cambrian Addy Quartzite, and Precambrian greenstone, conglomerate, and argillaceous rocks that lie immediately to the east of the Read deposit and under it at depth. But there is the further question of why boron metasomatism is apparently lacking along the contact of the granite with the same Cambrian limestone to the south, all the way to the Spokane River (3, 4, 6) as well as at other granite-carbonate contacts in northeastern Washington. It is obvious that special conditions prevailed. Bateman (2) has mentioned that to form contact metasomatic mineral deposits 1) "certain types of magma are necessary; 2) the magma must contain the ingredients of mineral deposits; 3) it must be intruded at depths not too shallow; and 4) it must contact reactive rocks." It is believed that these qualifications are met in the local situation, but in addition the following are considered to be worth mentioning: 1) the Huckleberry Greenstone could have supplied additional iron and magnesium (this formation does not extend much beyond the Read deposit on the south); 2) the batholith forms a north-eastward projecting salient along the sides of which at depth there could have been a funneling of fluids or solutions upward along the contact; and 3) the dolomitic limestone along the contact is closely folded into a syncline, thereby closing up joints, bedding surfaces, and other openings (in the same way that a synclinal axis is often resistant to agencies of erosion) to any stoping effect the granite may have had, and allowing more time for soaking up or diffusion of metasomatic materials.

To give some idea of the amount of material involved in this process, as stated above, there might be on the order of 55,000 tons of boron in the contact zone. Taking a minimum amount of 10 grams per ton of boron in such rocks as quartzites and schists, assuming that those east of the Read deposit compare

in content of boron with those in southern Lapland (17, p. 491) there would need to be assimilated some 0.6 cubic mile of boron-bearing rock.

WASHINGTON DIVISION OF MINES AND GEOLOGY,
OLYMPIA, WASH.,
April 4, 1962

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LUDWIGITE FROM THE READ MAGNETITE DEPOSIT STEVENS COUNTY, WASHINGTON¹

WALDEMAR T. SCHALLER AND ANGELINA C. VLISIDIS

ABSTRACT

Analysis of a purified sample of the ludwigite yielded: B₂O₃ 16.84, MgO 35.77, FeO 8.16, MnO 0.16, Fe₂O₃ 36.77, Al₂O₃ 2.00, TiO₂ 0.10, SnO₂ 0.20, CaO 0.14, H₂O⁻ 0.02, H₂O⁺ 0.00, Insol. 0.10, Sum 100.26. Calculated ratios: B₂O₃ 0.97, (Mg, Fe²⁺, Mn) 4.02, (Fe³⁺, Al, Ti, Sn) 1.01. Sp. Gr. 3.860. Rare single crystals with only prism {130} and with lower (4.76%) FeO content are at least 5 to 6 cm long and from half to a centimeter thick.

INTRODUCTION

THE first sample of ludwigite from Stevens County, Washington, was received by the U. S. Geological Survey in Washington, D. C., in 1941. It accompanied a sample of black scaly material from the Consumes Copper mine in El Dorado County, Calif., which had been called ludwigite by Austin F. Rogers (4) of Stanford University. This scaly mineral was forwarded on March 11, 1941, by Prof. Rogers at the request of W. T. Schaller, U. S. Geological Survey, to whom it seemed that Rogers' description indicated that his black scaly material might be related to the lustrous coal-black, foliated paigeite from Alaska, described a few years before by Knopf and Schaller (3). However, this supposed black scaly ludwigite or paigeite, from California, was found, on further examination, to be a dark-colored mica-like mineral, probably an altered biotite, and not a borate.²

The accompanying small sample of ludwigite was from a then unknown locality near Chewelah, Stevens County, and indicated that this occurrence must have been known prior to March 1941 though no published mention of its occurrence in the State of Washington, antedating Broughton's (1) published statement could be found. His report gives the locality as being the Read magnetite deposit mostly located in the north half of Section 14, Township 30 North Range 37 East, in the Cedar Canyon mining district of southwestern Stevens County, about four miles east of Hunters (5, 1). This would be about 45 miles northwest of Spokane.

In the summer of 1955, a letter was received from W. A. G. Bennett, Geologist, Washington Division of Mines and Geology, Olympia, Washington, stating that he was forwarding some specimens of this ludwigite. A com-

¹ Publication authorized by the Director, U. S. Geological Survey.

² Tests made by W. T. Schaller did not yield a boron flame and the particular sample on which Rogers obtained a green flame boron test may have contained admixed axinite, as this mineral from this same mine had been identified and analyzed by Schaller (Axinite from California, U. S. Geol. Survey Bull. 490, p. 42-46, 1911).

posite sample of these specimens furnished the material for the complete analysis shown in Table 1. In addition partial analyses were also made on the sample received from Rogers and also on a sample of the largest crystals described below.

Rogers described (letter of March 11, 1941) his sample as being "fine fibrous with a silky luster." Bennett's samples are somewhat coarser and in general this ludwigite resembles that from several other localities, forming black prism or radiating fibrous and spherulitic aggregates. In average size the individual prisms are about five to ten millimeters long and only a few are as much as a millimeter thick. On one specimen though several single crystals embedded in the more normal fine-grained aggregate are so large relative to ludwigite in general that they were at first considered to be some other mineral. The largest of these crystals, broken at both ends and hence originally much larger, is 5 to 6 cm long and in cross section $6\frac{1}{2}$ mm (short diagonal) and $12\frac{1}{2}$ mm (long diagonal) thick. It is a simple crystal, the only observed form being {130} in the orientation (a axis = 0.7558) chosen by Eakle (2) in his description of the analogous magnesian vonsenite from North Hill, Riverside, California.

In the much finer-grained matrix of these larger crystals, where individual prisms can be distinguished from the more fibrous aggregates, they too seemed to show only the simple prism {130}. These ludwigite crystals from Washington thus seem to differ from the well-defined single crystals from the Cottonwood area in Utah and from Crestmore, California, which have numerous well-formed faces in the prism zone. In size, these larger crystals from the Read deposit compare with the columnar aggregates of ludwigite from the Gorman tin district in southern Kern County, California, which extend over four inches in length on the available specimen. This Kern County occurrence of ludwigite was mentioned briefly by Wiese and Page (6), the identity of the black prisms with ludwigite having been established by Miss J. J. Glass (6, p. 50-51).

X-ray powder diffraction patterns of the ludwigite from Washington received from Rogers (X-ray film 3111), of the specimen analyzed (film 8545), and of the large single crystals (film 8544), are identical and typical of all patterns of the various members of the ludwigite-vonsenite series.

CHEMICAL COMPOSITION OF LUDWIGITE

Three analyses (only one complete) were made on the ludwigite from the Read magnetite deposit. A complete analysis of a composite average sample is shown in Table 1. The sample was prepared for analysis by combining small fragments from the several specimens furnished by Bennett which were then crushed to 100 mesh, the resultant dust, magnetite, and gangue removed and the ludwigite then washed with dilute nitric acid to remove any calcite present. For the second sample a few grams of the specimen furnished by Rogers were similarly purified and partial analysis thereof made (first column of Table 2). The iron percentages are close to those shown in Table 1). For the third sample, small fragments were broken off from several of the

TABLE 1

ANALYSIS AND MOLECULAR RATIOS OF A COMPOSITE SAMPLE OF LUDWIGITE FROM THE READ MAGNETITE DEPOSIT, STEVENS COUNTY, WASHINGTON. ANALYST: ANGELINA C. VLISIDIS

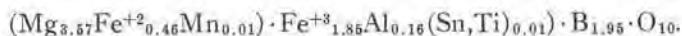
	Percent	Molecular ratio	Sum of ratios	Integral
B ₂ O ₃	16.84 ^a	0.2418	.2418	0.97
MgO	35.77	.8872	1.0031	4.02
FeO	8.16	.1136		
MnO	.16	.0023		
Fe ₂ O ₃	36.77	.2302		
Al ₂ O ₃	2.00	.0196	.2524	1.01
TiO ₂	.10	.0013		
SnO ₂	.20	.0013		
CaO	.14			
H ₂ O ⁻	.02			
H ₂ O ⁺	.00			
Insol.	.10			
	100.26			

^a Average of 16.80, 16.81, 16.90.
Sp. gr. 3.860.

large embedded crystals, crushed and purified as stated above. The results are shown in the second column of Table 2.

As anticipated, with only half as much FeO present as in the sample completely analyzed (Table 1), this latter material transmits much more light in crushed fragments and the usual pleochroism is shown by many pieces.

The ratios calculated from the complete analysis (Table 1) agree closely with the established formula for ludwigite, 4(Mg,Fe)O·Fe₂O₃·B₂O₃. The atomic ratios calculated by equivalent weights, based on 10 oxygens are:



Noteworthy are the purity of the sample the absence of H₂O⁺ with very low hygroscopic water, (H₂O⁻), and the relative small amounts of the minor elements Mn, Al, Ti, and Sn. The specific gravity (pycnometer) is 3.860, average of 3.862 and 3.857. The crushed and purified 100-mesh sample is not magnetic. The grains of ludwigite do not jump to a 2-inch alnico magnet. The finely crushed mineral, observed in an immersion oil of $n = 1.73$, is practically opaque—only on the thinnest edges or in the fine dust-like particles is light transmitted.

TABLE 2

PARTIAL ANALYSES OF ADDITIONAL SAMPLES OF LUDWIGITE FROM THE READ MAGNETITE DEPOSIT, SOUTHWESTERN STEVENS COUNTY, WASHINGTON

	Roger's specimen, percent	Large crystals, percent
FeO	8.67	4.76
Fe ₂ O ₃	35.39	37.57
Insol.	.86	0.20
Sp. gr.	—	3.831

The main mass of ludwigite from the Read iron prospect in Washington is close in composition to that from Philipsburg, Montana; Cottonwood area in Utah; and Korea. The single large crystals have a low FeO content, similar to that of some of the ludwigite from the Cottonwood area in Utah; from Colorado Gulch, Montana; Idaho; Peru; and Japan.

The two analyses (Tables 1 and 2) of ludwigite of similar fiber size agree closely and probably are representative of the composition of the bulk of the mineral at the Read deposit. The much larger crystals embedded in the finer grained ludwigites have only about half as much FeO and consequently must be correspondingly richer in magnesia.

WASHINGTON DIVISION OF MINES AND GEOLOGY,
OLYMPIA, WASH.,
April 4, 1962

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