LARGE MAGNESIA-RICH TRIPHYLITE CRYSTALS IN PEGMATITE

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ABSTRACT

Crystals of triphylite, up to several inches across, occur in a quartz-albite pegmatite at Newport, New Hampshire. The forms $c\{001\}$, $b\{010\}$, and $m\{110\}$ are present on all crystals. The form $l\{120\}$ is usually present but $\epsilon\{021\}$ and $n\{031\}$ are less commonly observed. A new form, probably $\{121\}$, was observed on one crystal. A chemical analysis shows a high FeO:MnO ratio and reveals the presence of 7.38 per cent MgO. This abnormally high content of MgO is believed to account for the relatively low indices of refraction, and probably also for the low specific gravity of the material. Curves showing the variation in composition and optical properties of the lithiophyllite-triphylite series (modified after Winchell) are given and discussed.

INTRODUCTION

Large crystals of triphylite in a pegmatite occur near the town of Newport, New Hampshire, at an abandoned feldspar working which is known locally as the "Smith Mine." The location (72° 15′ 00″ West Longitude and 43° 21′ 27″ North Latitude), at the boundary of the Claremont and Sunapee, New Hampshire quadrangles, is about $4\frac{1}{2}$ miles west of Newport village. The "mine" is easily reached by the dirt road on the south side of Sugar River, between Claremont and Newport.

COUNTRY ROCK

The country rock into which the pegmatite is intruded is composed of metamorphosed sediments of the Littleton formation (Lower Devonian). The rock immediately surrounding the pegmatite is a medium-grained to coarse-grained schist composed essentially of quartz, muscovite, and biotite. Minor constituents are sillimanite, staurolite, garnet, oligoclase, apatite, chlorite, magnetite, and zircon. Locally, however, sillimanite or staurolite constitute a large proportion of the schist. This mineral assemblage places the rock in the transitional zone between middle and high grade metamorphism.

Schistosity and bedding are parallel and both structures strike roughly north-northeast and dip 20 to 35 degrees to the east.

The schist has been replaced by black tourmaline, muscovite, and albite in a zone extending a few inches from the contact with the pegmatite. The planar distribution of tourmaline, which was determined by the schistosity, gives the rock a distinct banded appearance and a gneissic structure. Megascopic study indicates that tourmaline was the only mineral introduced in any quantity, but microscopic examination (1, p. 378)

shows albite and muscovite to have replaced the rock also in considerable amounts.

Pegmatite

The pegmatite intrudes the mica schist as an easterly dipping, tabular body with contacts essentially concordant with the bedding and schistosity of the country rock. Locally tongues or apophyses from the main pegmatite cut across the schistosity or displace it considerably. The maximum thickness of the pegmatite exposed is 20 feet; and the outcrop of the body, though somewhat irregular because of the low dip, extends at least 300 feet parallel to the strike.

Xenoliths of schist are common and range from a few inches to a few feet across. These, in many cases, show the effects of replacement like the schist wall-rock. The boundaries are generally indistinct and the inclusion may grade imperceptibly into the pegmatite.

No exhaustive study of the mineralogy and paragenesis of the pegmatite was made. Albite (some cleavelandite) and quartz constitute most of the mass; potash feldspar is notably absent. Muscovite and black tourmaline are present in smaller quantities, whereas triphylite and its alteration products, garnet, and biotite occur only locally. According to Landes' classification (2, p. 96) the pegmatite is of the complex, quartz diorite type with lithium and phosphate phases.

The pegmatitic material is believed to have come originally from the extensive body of Bethlehem gneiss (late Devonian) which lies immediately to the east. This large body of gneiss, known as the Mt. Clough pluton, was the source of hundreds of similar pegmatites many of which have long been famous for mineral collecting and as sources of feldspar and mica. The large and numerous pegmatites of Orange, Grafton, and Acworth may be included here.

Triphylite

Crystal Habit. Triphylite occurs most characteristically in euhedral crystals up to four inches long. The most perfect crystals, however, average about an inch in length. Though many specimens show well-formed crystals, in most cases curved and twisted faces are present. This deformation is much more common and pronounced on faces in the vertical zone [001]. Such irregularities may be due in part to uneven growth, but it seems apparent that they are more properly the result of slight shearing in the pegmatite itself. In several crystals the external aspect of orthorhombic symmetry has been destroyed and the deformed crystals appear monoclinic. As a result of this deformation the basal pinacoid in several crystals was found to be shoved as much as 15 or 20 degrees from its original position.

It was found impossible to isolate complete crystals from the quartz-feldspar matrix as the mineral was so easily shattered. It was possible, however, to isolate crystals sufficiently complete to measure their interfacial angles. The simple Penfield contact goniometer was used because none of the material was suitable for reflection work. This instrument proved quite satisfactory in the attempt to determine the crystal faces present.

The forms universally present and usually equally developed are $c\{001\}$, $m\{110\}$, and $b\{010\}$. A great number of crystals also show poorly developed $l\{120\}$ faces, but on many this form is as perfect as any other.
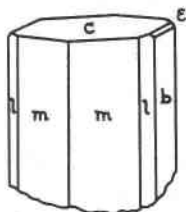

FIG. 1. Typical crystal of triphylite from Newport, New Hampshire, showing the forms $c\{001\}$, $b\{010\}$, $m\{110\}$, $l\{120\}$, and $\epsilon\{021\}$. (Dana orientation).
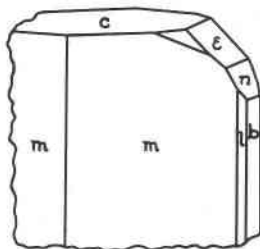

FIG. 2. Triphylite crystal from Newport, New Hampshire, showing the forms $c\{001\}$, $b\{010\}$, $m\{110\}$, $l\{120\}$, $\epsilon\{021\}$, $n\{031\}$, and a new form, probably $\{121\}$. (Dana orientation).

Faces of the $\epsilon\{021\}$ form were found on several crystals (Fig. 1) but $n\{031\}$ was observed on only one (Fig. 2). Two small pyramid faces, one clearly developed, were discovered on a somewhat deformed crystal, possessing faces of all the above mentioned forms. No letter has been assigned to this form in Fig. 2. The most careful measurements indicate the symbol is probably $\{121\}$. As far as the writer is aware this is the first pyramid form to be reported for triphylite. In no case were faces of the forms $w\{102\}$, $e\{101\}$, or $v\{302\}$ observed. The triphylite, therefore,

shows six of the nine forms heretofore reported for the species, and in addition reveals the presence of a new form, probably {121}.

The relationship between the Dana and Goldschmidt settings for triphylite is shown by the following table:

Dana	Goldschmidt	Occurrence on Newport triphylite
c{001}	P{001}	universally present
b{010}	M{010}	universally present
m{110}	T{210}	universally present
l{120}	l{110}	usually present
ε{021}	o{011}	observed on several crystals
n{031}	n{032}	observed on one crystal
w{102}	w{102}	not observed
e{101}	u{101}	not observed
v{302}	v{302}	not observed
{121}	{111}	probably new form

Physical Properties. A perfect cleavage parallel to {001} is always present on the triphylite, but the less perfect cleavage parallel to {010} is not so easily observed on all specimens. The prismatic cleavage {110} is good in some cases but is recognized only with difficulty on most crystals. By noting the cleavages, large mineral fragments may be readily oriented without the aid of crystal faces. The fracture of the triphylite is uneven to subconchoidal. The hardness of 4 is slightly less than generally reported. The specific gravity of the purest material was determined both by means of a chemical balance and the Berman torsion microbalance. The average value was found to be 3.44. The luster is resinous to vitreous on fresh surfaces but is readily dulled upon exposure to air. Unaltered material is green and nearly transparent when unfractured. The streak is colorless.

Much of the material is unsuitable for optical work due to the numerous fractures and alteration products. The following optical data, however, were obtained from fresh material. The indices of refraction and optic angle were determined for sodium light.

$\alpha = 1.675$	dispersion strong
$\beta = 1.684$	$r < v$
$\gamma = 1.685$	$X = c$
optically negative	$Y = a$
$2V = 25°$	$Z = b$

Microscopic cavities nearly filled with liquid are extremely abundant in some specimens of triphylite. In many cases these are rectangular in cross section, but most commonly they are curved or very irregular.
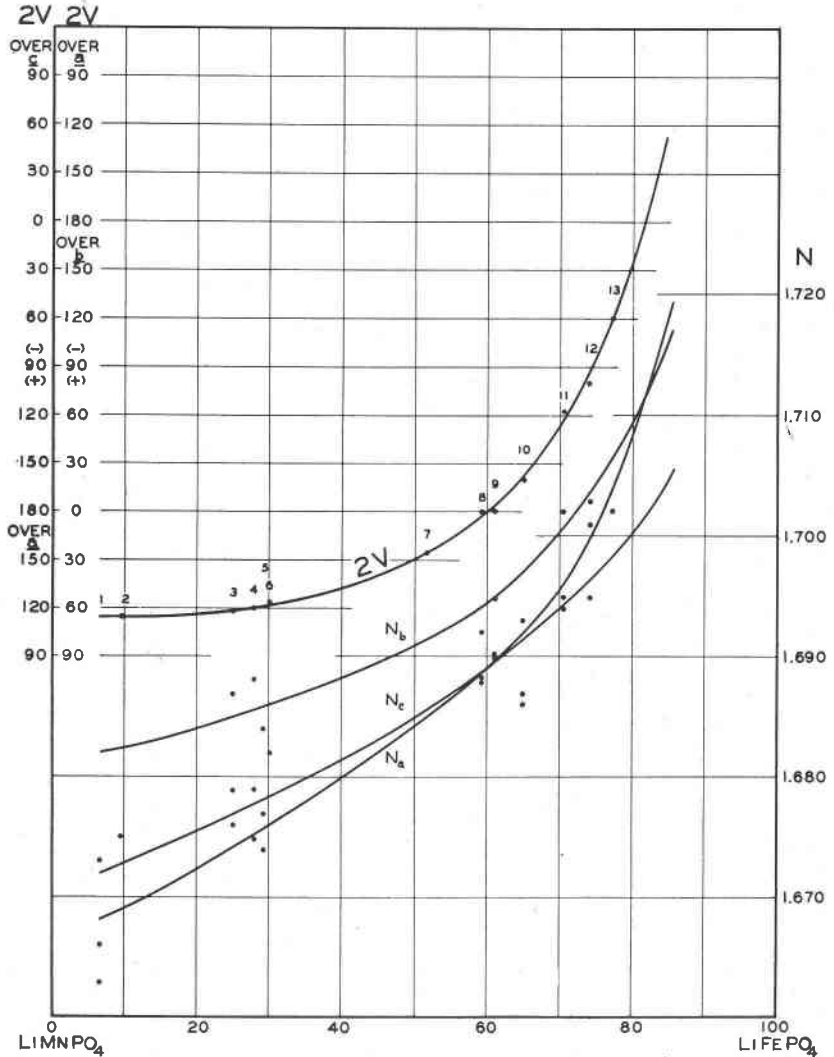
FIG. 3. Variation in composition and optical properties of the lithiophyllite-triphylite series.
1—Landes, *Am. Mineral.*, **10**, 382 (1925).
2 and 3—Penfield and Pratt, *Am. Jour. Sci.*, [3], **50**, 389 (1895).
4—Berman and Gonyer, *Am. Mineral.*, **15**, 377 (1930).
5—Landes, *Am. Mineral.*, **10**, 382 (1925).
6—Penfield and Pratt, *Am. Jour. Sci.*, [3], **50**, 389 (1895).
7—Quensel, *Geol. Fören. Förhandl. Stock.*, **59**, 77 (1937).
8—Penfield and Pratt, *Am. Jour. Sci.*, [3], **50**, 389 (1895).
9—Wherry, *U. S. Nat. Mus., Proc.*, **49**, 466 (1915).
10—Switzer, *Am. Mineral.*, **23**, 811 (1938).
11 and 12—Mäkinen, *Bull. Geol. Com. Fin.*, **35**, 96 (1913).
13—Penfield and Pratt, *Am. Jour. Sci.*, [3], **50**, 389 (1895).

Chemical Composition. The optical properties of the triphylite from Newport did not check well with those of analyzed specimens. According to the curves in Fig. 3, which is a modification after Winchell (3, p. 150), the optical character, 2V, and orientation of the Newport material indicate 80 per cent $LiFePO_4$ (about 36 per cent FeO) but the indices of refraction do not fit the curves well at all. This suggested something peculiar about the chemistry, as did the low specific gravity of the material (Fig. 4). It seemed advisable, therefore, to have a rather complete analysis of the material made. This was done, on carefully selected material, by Mr. Justa M. Lindgren in the Applied Chemistry Testing Laboratory at the University of Illinois. The analysis is as follows:

P_2O_5	46.03
Fe_2O_3	0.00
FeO	32.93
MnO	3.11
MgO	7.38
CaO	0.00
Na_2O	1.05
Li_2O	8.36
K_2O	0.45
SiO_2	0.33
Al_2O_3	3.19
H_2O+	0.57
H_2O-	0.20
	103.60

The analysis indicates the Newport triphylite to be unusual in several respects. As far as the writer is aware, this material is the lowest in MnO of any yet reported. More important and unusual than this, however, is the high content of MgO. Few analyses of specimens of this series show more than 1 per cent MgO and only two were found in the literature with more than 2 per cent MgO. One of these (2.39 per cent MgO) is an old analysis on triphylite from Bodenmais (4, p. 436) but is not accompanied by optical data. The other (2.30 per cent MgO) is on triphylite from near Grafton, New Hampshire (5, p. 466). This analysis is more recent and is accompanied by optical data. Most of the chemical analyses of material studied optically in detail show no determination for MgO. Perhaps only a trace of MgO is present in these specimens; yet we are not certain.

It is believed that the high content of MgO in the Newport material will explain why such an iron-rich triphylite has such low indices of refraction. Similarly it may explain the low specific gravity.

The reason for such a high percentage of alumina in the analysis is not clear at present. It cannot be due to contaminating feldspar because of the low silica content.
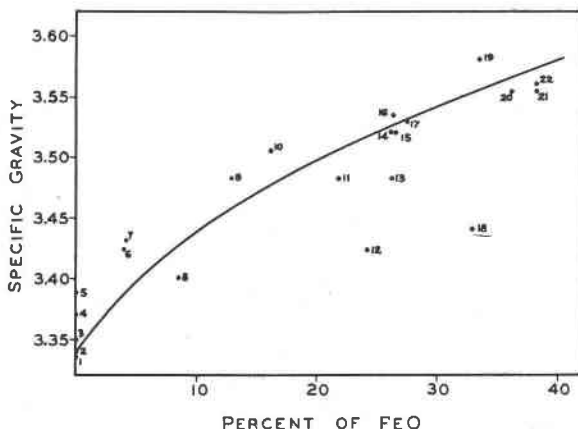
FIG. 4. Variation in composition and specific gravity of the lithiophyllite-triphylite series.
    1–5—Zambonini and Malossi, *Zeits. Krist.*, **80**, 449 (1931).
    6 and 7—Brush and Dana, *Zeits. Krist*, **2**, 546 (1878).
    8—Penfield, *Am. Jour. Sci.*, [3] **26**, 176 (1883).
    9—Penfield, *Am. Jour. Sci.*, [3] **17**, 228 (1879).
    10—Penfield, *Am. Jour. Sci.*, [3] **26**, 176 (1883).
    11—Walker, *Contr. to Canad. Min.*, 10 (**1931**).
    12—Quensel, *Geol. Fören. Förhandl. Stock.*, **59**, 77 (1937).
    13—Penfield, *Am. Jour. Sci.*, [3], **17**, 226 (1879).
    14 and 15—Penfield, *Am. Jour. Sci.*, [3], **13**, 425 (1877).
    16—Penfield, *Am. Jour. Sci.*, [3], **17**, 226 (1879).
    17—Wherry, *U. S. Nat. Mus., Proc.*, **49**, 466 (1916).
    18—Triphylite from Newport, New Hampshire.
    19—Penfield, *Am. Jour. Sci.*, [4], **9**, 20 (1900).
    20—Penfield, *Am. Jour. Sci.*, [3], **17**, 226 (1879).
    21 and 22—Oesten, *Pogg. Ann.*, **107**, 436 (1859).

In Fig. 3 the writer has prepared curves, modified after Winchell (3, p. 150), on the optics of the lithiophyllite-triphylite series, making use of all recent data. The optic angle curve was originally constructed by Penfield and Pratt (6, p. 390) and later modified by Winchell. It is presented again in Fig. 3 with additional data. This curve appears to be more reliable than the index curves for determining relative proportions of the two end members of the series. The index curves of Fig. 3 (slightly modified after Winchell) are constructed making use of more recent data. Though not very accurate, these curves do show what was noted years ago by Penfield and Pratt (6), that with an increase in FeO there is an increase in indices of refraction. An increase in FeO also changes the optic angle and orientation, and the series passes twice through the uniaxial condition.

It has already been mentioned that most of the chemical analyses of

material studied optically in detail show no determination for MgO. This is particularly true of the several analyses by Penfield and Pratt (6) where determinations were made only for FeO and this percentage weight subtracted from 45.3 (the mean percentage weight of bivalent oxides) to obtain the amount of MnO present. It is obvious that such a procedure can no longer be considered as even approximate for determining the ratio of FeO to MnO, because MgO may be present in large amounts. It is necessary to determine at least two of the oxides and desirable to know three because calcium may be present in considerable amounts. In other words a complete analysis is highly desirable.

The relationship between specific gravity and FeO content of the lithiophyllite-triphylite series is shown in Fig. 4. The values shown for pure $LiMnPO_4$ (artificial) were determined by Zambonini and Malossi (7, p. 449) to be 3.334 to 3.34 for the purest crystals. Artificial crystals containing black inclusions gave higher values (3.35–3.39). Other points in the graph represent the various data collected from the literature. The distribution of points in the graph shows a general increase in specific gravity with FeO content. The curve gives the general picture but cannot be considered as very accurate. Several points fall far below the curve. It is not at all clear why the triphylite represented by number 12 in Fig. 4 should have so much FeO and yet so low a density. As already suggested, the low specific gravity of the Newport material (number 18) might be explained by the high MgO content. Perhaps to a lesser degree the numerous liquid inclusions in the Newport triphylite help to explain its low specific gravity.

The chemical analysis of triphylite from Newport shows the unnamed member $LiMgPO_4$ to be present in a relatively large amount. Not enough data are available to construct optical curves for the three component system $LiFePO_4$–$LiMnPO_4$–$LiMgPO_4$. We can conclude, however, that whereas FeO increases the indices and specific gravity, MnO and MgO decrease these values. Furthermore, MgO appears to be more effective in reducing the indices and specific gravity than MnO.

Alteration. Where exposed to surface weathering, triphylite alters readily to a brownish material, probably composed of the oxides of iron and manganese. A much more common and uniformly distributed alteration product of triphylite is vivianite. This occurs in tiny irregular stringers cutting the triphylite, and as film-like layers along the basal cleavage fractures. The vivianite is deep blue and is so intimately distributed that it imparts a distinctive blue color even to very small fragments of the green triphylite. It is also found in streaks and films penetrating and coating quartz, albite, and muscovite.

The optical properties of the vivianite were determined to be as follows:

$\alpha = 1.580$	$r < v$
$\beta = 1.602$	$X =$ deep blue
$\gamma = 1.632$	$Y =$ colorless
optically positive	$Z =$ pale olive green
$2V =$ ca. $80°$	$X \perp$ perfect cleavage $\{010\}$
dispersion moderate	$Z \wedge$ poor cleavage $\{100\} =$ ca. $29°$.

These data compare very closely with those given by Larsen for vivianite from Mullica Hill, New Jersey (8, p. 160).

No chemical analysis of the vivianite was made because of the impurities and lack of sufficient material.

ACKNOWLEDGMENTS

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