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# SATTERLYITE, A NEW HYDROXYL-BEARING FERROUS PHOSPHATE FROM THE BIG FISH RIVER AREA, YUKON TERRITORY

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## ABSTRACT

Satterlyite occurs as yellow to brown grains (up to 1×1×40 mm) in nodules in shales along the Big Fish River in northeastern Yukon Territory. It has a hardness of 4½ to 5, no cleavage, a vitreous lustre and a density of 3.68 g/cm³ (meas.) and 3.60 g/cm³ (calc.). The mineral is uniaxial negative, $n_\omega$ 1.721, $n_\epsilon$ 1.719, dichroic in thick grains with $\omega$ pale yellow, $\epsilon$ brownish yellow, absorption $\epsilon > \omega$. Satterlyite is hexagonal, space group $P\bar{3}1m$, $P31m$ or $P312$; $a$ 11.361, $c$ 5.041Å, $c:a = 0.4437$, $V = 563.5$Å³, $Z = 6$. Strongest lines in the X-ray powder diffraction pattern are: 4.49 (50) (10$\bar{1}$1), 3.520(70) (20$\bar{2}$1), 2.990(40) (21$\bar{3}$1), 2.840(80)(22$\bar{4}$0), 2.473(100) (22$\bar{4}$1), 1.886(40) (22$\bar{4}$2), 1.640(40)(60$\bar{6}$0), and 1.447(60) (51$\bar{6}$2, 22$\bar{4}$3), all in Å, for CuK$\alpha$. The chemical formula of satterlyite is, ideally, $(Fe^{2+}_{1.17}Mg_{0.35}Fe^{3+}_{0.18}H_{0.16}Na_{0.10}Mn_{0.04})_{\Sigma 2.00}PO_4(OH)$. The mineral, a hexagonal polymorph of wolfeite, is named after Dr. Jack Satterly of the Royal Ontario Museum.

## SOMMAIRE

La satterlyite se présente en grains allant du jaune au brun, de dimensions maxima 1×1×40mm, que l'on trouve en nodules dans les shales le long de la rivière Big Fish, dans le Nord-Est du territoire du Yukon. Les cristaux de ce minéral, sans clivage, de dureté 4½ – 5 et à éclat vitreux, possèdent une densité de 3.68 (mes.), 3.60 (calc.). Optiquement uniaxes négatifs, $n_\omega$ 1.721 (jaune pâle), $n_\epsilon$ 1.719 (jaune brunâtre), ils sont dichroïques en lame épaisse avec absorption $\epsilon > \omega$. La satterlyite est hexagonale, de groupe spatial $P\bar{3}1m$, $P31m$ ou $P312$; $a$ 11.361, $c$ 5.041Å, $c/a = 0.4437$, $V = 563.5$Å³, $Z = 6$. Les raies les plus intenses du cliché de poudre (radiation CuK$\alpha$) sont (en Å): 4.49(50)(10$\bar{1}$1), 3.520(70) (20$\bar{2}$1), 2.990(40)(21$\bar{3}$1), 2.840(80)(22$\bar{4}$0), 2.473 (100)(22$\bar{4}$1), 1.886(40)(22$\bar{4}$2), 1.640(40)(60$\bar{6}$0) et 1.447(60)(51$\bar{6}$2, 22$\bar{4}$3). De formule idéalisée $(Fe^{2+}_{1.17}Mg_{0.35}Fe^{3+}_{0.18}H_{0.16}Na_{0.10}Mn_{0.04})_{\Sigma 2.00}PO_4(OH)$, la satterlyite est une forme polymorphique de la wolféite. Elle est dédiée au Dr Jack Satterly, du Royal Ontario Museum.

(Traduit par la Rédaction)

## INTRODUCTION

Satterlyite is a new mineral found in nodules in shales along the Big Fish River in the northeast corner of the Yukon Territory, just west of the Yukon-Northwest Territories boundary (Lat. 68°30′N and Long. 136°30′W). These nodules measure up to 10 cm in diameter. Some are megascopically monomineralic, consisting only of satterlyite; others show satterlyite in direct contact with quartz, pyrite, wolfeite and maricite, a sodium iron phosphate described by Sturman *et al.* (1977).

The mineral and name were approved by the Commission on New Minerals and Mineral Names, I.M.A. Type material (grams) is preserved in the collections of the Royal Ontario Museum as specimen M34649.

We are pleased to name this mineral in honor of Dr. Jack Satterly who for many years was a geologist with the Ontario Department of Mines. Since 1971, Dr. Satterly has been resident in the Royal Ontario Museum as a Research Associate in the Department of Mineralogy and Geology. We are particularly happy to have this paper included in the issue honoring Prof. J. D. H. Donnay.

## APPEARANCE AND PHYSICAL PROPERTIES

Satterlyite is pale yellow to pale brown and has a pale yellow streak. It is transparent, has a vitreous lustre and does not fluoresce under ultraviolet light. The mineral has a hardness of 4½ to 5 and no cleavage. The density measured with the Berman balance is 3.68(5) g/cm³. The density calculated for the empirical formula is 3.60 g/cm³. The mineral occurs as grains up to 1×1×40 mm elongate parallel to [0001] in radiating aggregates.

Pale brown fragments from specimen M34649 gave the following optical data: uniaxial negative, $n_\omega$ 1.721(1), $n_\epsilon$ 1.719(2), $n_\epsilon - n_\omega = -0.002$,

dichroic in thick grains with $\omega$ pale yellow, $\epsilon$ brownish yellow, absorption $\epsilon > \omega$. Yellow grains from another specimen gave slightly lower refractive indices: $n_\omega$ 1.718 to 1.720, $n_\epsilon$ 1.716 to 1.718, $n_\epsilon - n_\omega = -0.0023$ by direct measurement. Some grains show undulatory extinction and are biaxial with $2V_x = 10°$ to 20°.

## Crystallographic and X-Ray Data

No crystal faces were observed. Single-crystal X-ray study shows that satterlyite is hexagonal and belongs to Laue class $\bar{3}m$. The possible space groups are $P\bar{3}1m$, $P31m$ and $P312$. The unit-cell parameters obtained from the precession study are: $a$ 11.36, $c$ 5.033Å, $c:a$ 0.4430; $V$ 562.49Å$^3$. Those refined from the X-ray powder diffraction data given in Table 1 are: $a$ 11.361, $c$ 5.041Å, $c:a$ 0.4437, $V$ 563.48Å$^3$, $Z = 6$. The powder data were obtained from Guinier films; intensities were estimated from films exposed for different lengths of time. The powder patterns of satterlyite from six different specimens are identical.

## Chemical Composition

Analytical data for satterlyite were obtained as follows: $Na_2O$, MgO, MnO, $SiO_2$, $P_2O_5$ and total Fe were determined by electron microprobe analysis; $H_2O$ was determined by the Penfield method; a ferrous to ferric iron ratio of 6.42:1.00 was determined by wet chemical means. The electron microprobe data were obtained using an Applied Research Laboratories AMX electron microprobe equipped with a Tracor–Northern NS–880 energy-dispersive spectrometer. The operating conditions were: accelerating voltage 15kV, sample current *ca.* 1.5 nA, beam diameter *ca.* 2 $\mu$m. Spectral standards: Na, NaCl; Mg, MgO; P, $Ca_2P_2O_7$; Mn, Mn metal; Fe, $Fe_2SiO_4$, and Si, $SiO_2$. Analytical standards: Na, Mn, and Fe, riebeckite; Mg, MgO; P, $Ca_2P_2O_7$; Si, $SiO_2$. Further details are given by Corlett in Sturman *et al.* (1977).

TABLE 1. X-RAY POWDER DIFFRACTION DATA FOR SATTERLYITE

| I | $d_{obs}$ | $d_{calc}$ | $hk\bar{i}l$ | I | $d_{obs}$ | $d_{calc}$ | $hk\bar{i}l$ |
|---|---|---|---|---|---|---|---|
| 5 | 5.68 | 5.681 | $11\bar{2}0$ | 40 | 1.886 | 1.885 | $22\bar{4}2$ |
| 20 | 4.93 | 4.920 | $20\bar{2}0$ | 1 | 1.851 | 1.852 | $31\bar{4}2$ |
| 50 | 4.49 | 4.486 | $10\bar{1}1$ | 20 | 1.773 | 1.773 | $33\bar{6}1$ |
| 10 | 3.77 | 3.770 | $11\bar{2}1$ | 5 | 1.759 | 1.760 | $40\bar{4}2$ |
| 15 | 3.718 | 3.719 | $21\bar{3}0$ | 30 | 1.744 | 1.746 | $42\bar{6}1$ |
| 70 | 3.520 | 3.521 | $20\bar{2}1$ | 5 | 1.682 | 1.682 | $32\bar{5}2$ |
| 5 | 3.278 | 3.280 | $30\bar{3}0$ | | | 1.680 | 0003 |
| 40 | 2.990 | 2.993 | $21\bar{3}1$ | 5 | 1.668 | 1.668 | $51\bar{6}1$ |
| 80 | 2.840 | 2.840 | $22\bar{4}0$ | 40 | 1.640 | 1.640 | $60\bar{6}0$ |
| 30 | 2.520 | 2.521 | 0002 | 5 | 1.618 | 1.618 | $43\bar{7}0$ |
| 100 | 2.473 | 2.475 | $22\bar{4}1$ | 1 | 1.591 | 1.590 | $20\bar{2}3$ |
| 1 | 2.442 | 2.442 | $10\bar{1}2$ | 1 | 1.551 | 1.551 | $50\bar{5}2$ |
| 10 | 2.398 | 2.400 | $31\bar{4}1$ | 1 | 1.541 | 1.540 | $43\bar{7}1$ |
| 5 | 2.304 | 2.304 | $11\bar{2}2$ | 5 | 1.532 | 1.531 | $21\bar{3}3$ |
| 10 | 2.242 | 2.243 | $20\bar{2}2$ | 60 | 1.447 | 1.447 | $51\bar{6}2$ |
| 15 | 2.209 | 2.211 | $40\bar{4}1$ | | | 1.446 | $22\bar{4}3$ |
| 5 | 2.086 | 2.086 | $21\bar{3}2$ | 1 | 1.420 | 1.420 | $44\bar{8}0$ |
| 5 | 2.060 | 2.060 | $32\bar{5}1$ | 1 | 1.405 | 1.405 | $53\bar{8}0$ |
| 1 | 1.998 | 1.999 | $30\bar{3}2$ | 1 | 1.386 | 1.388 | $40\bar{4}3$ |
| 10 | 1.974 | 1.975 | $41\bar{5}1$ | 25 | 1.375 | 1.375 | $60\bar{6}2$ |
| | | | | 15 | 1.367 | 1.367 | $44\bar{8}1$ |

Data obtained on ROM #M34649 with CuKα, Guinier camera

TABLE 2. CHEMICAL ANALYSES OF SATTERLYITE

| | 1 | 2 | 3 | 4 | 5 | Av. |
|---|---|---|---|---|---|---|
| $H_2O$ | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 |
| $Na_2O$ | 1.5 | 1.5 | 1.2 | 1.6 | 1.6 | 1.5 |
| MgO | 7.5 | 7.0 | 7.0 | 7.0 | 7.0 | 7.1 |
| MnO | 1.2 | 1.2 | 1.3 | 1.2 | 1.7 | 1.3 |
| FeO | 43.1 | 43.8 | 42.8 | 43.2 | 42.7 | 43.1 |
| $Fe_2O_3$ | 7.5 | 7.6 | 7.4 | 7.5 | 7.4 | 7.5 |
| $SiO_2$ | 0.2 | 0.0 | 0.2 | 0.2 | 0.2 | 0.2 |
| $P_2O_5$ | 35.1 | 34.6 | 35.3 | 34.1 | 34.8 | 34.8 |
| Total | 101.3 | 100.9 | 100.4 | 100.0 | 100.6 | 100.7 |
| | Number of ions based on 5 oxygen ions | | | | | |
| H | 1.15 | 1.17 | 1.16 | 1.18 | 1.16 | 1.16 |
| Na | 0.10 | 0.10 | 0.08 | 0.11 | 0.10 | 0.10 |
| Mg | 0.37 | 0.35 | 0.35 | 0.35 | 0.35 | 0.36 |
| Mn | 0.03 | 0.03 | 0.04 | 0.03 | 0.05 | 0.04 |
| $Fe^{2+}$ | 1.20 | 1.23 | 1.20 | 1.22 | 1.20 | 1.21 |
| $Fe^{3+}$ | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 |
| Si | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 |
| P | 0.99 | 0.99 | 1.00 | 0.98 | 0.99 | 0.99 |
| Σ | 4.04 | 4.06 | 4.03 | 4.07 | 4.05 | 4.06 |

Constituents present in ROM #M34649 expressed in weight %.

$Na_2O$, MgO, MnO, $SiO_2$, $P_2O_5$ and total iron by electron microprobe (Dr. M.I. Corlett, analyst).

$Fe^{2+}/Fe^{3+}$ by titration and $H_2O$ by Penfield method (Dr. E.J. Brooker, X-ray Assay Laboratories, Ltd., analyst).

The $Fe^{2+}/Fe^{3+}$ ratio and the $H_2O$ content were determined on about 200 mg each of carefully hand-picked grains. The electron microprobe analysis were carried out on five grains. The analytical data for satterlyite are given in Table 2 where it is assumed that the $Fe^{2+}/Fe^{3+}$ ratio and the water content are constant in all five grains. From the average of the five sets of data, and based on a total of five oxygen ions, the chemical formula of satterlyite is $(Fe^{2+}_{1.21}Mg_{0.36}Fe^{3+}_{0.19}H_{0.16}Na_{0.10}Mn_{0.04})_{\Sigma 2.06}P_{0.99}Si_{0.01}O_{4.00}(OH)_{1.00}$ or ideally, $(Fe^{2+}_{1.17}Mg_{0.35}Fe^{3+}_{0.18}H_{0.16}Na_{0.10}Mn_{0.04})_{\Sigma 2.00}PO_4(OH)$ Thus, satterlyite is a hydroxyl-bearing ferrous phosphate. The type material is magnesian satterlyite.

The specific refractive energy of satterlyite using the Gladstone–Dale constants given by Mandarino (1976) is 0.202. A value of 0.196 is

calculated from the refractive indices and measured density; the calculated density gives 0.200.

## Thermal Properties

A 16.8 mg sample of satterlyite was subjected to simultaneous differential thermal and thermogravimetric analyses in a Mettler Thermal-analyzer using an oxygen atmosphere. The DTA showed broad exothermic peaks at 527° and 782°C and an endothermic peak at 957°C. The TGA showed weight loss beginning at about 531°C and continuing to about 603°C, after which a weight gain began and continued to about 943°C.

## Related Species

Satterlyite has the same general chemical composition as wolfeite, but satterlyite is hexagonal whereas wolfeite is monoclinic. DTA curves of the two minerals show no indication of inversion before decomposition begins.

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