Nealite
a new mineral from Laurion, Greece

by **Pete J. Dunn**
Department of Mineral Sciences
Smithsonian Institution
Washington, D.C. 20560

and **Roland C. Rouse**
Department of Geology and Mineralogy
University of Michigan
Ann Arbor, Michigan 48109

ABSTRACT

Nealite, $Pb_4Fe(AsO_4)_2Cl_4$, is a new mineral found in the slags of Laurion, Attike, Greece. It forms prismatic or bladed crystals in radial or parallel growth and is associated with aragonite, annabergite and georgiadesite on the two known specimens. Nealite is triclinic, space group $P1$ or $P\bar{1}$, with a = 6.537(7), b = 10.239(7), c = 5.582(5) Å; α = 96.20(5)°, β = 89.39(10)°, γ = 97.74(7)°, V = 368.1(5) Å³ and Z = 1. The strongest lines in the X-ray powder diffraction pattern are: 3.542 (10) 021, $1\bar{2}1$; 6.480 (8) 100; 4.237 (7) $\bar{1}20$, $\bar{1}01$, 101; 10.09 (6) 010; 3.247 (6) $\bar{1}21$, 200; 2.783 (6) 201, 002. Electron microprobe analysis yielded FeO = 4.8, ZnO = 0.6, PbO = 68.8, Cl = 10.3, As_2O_5 = 17.3, less O = Cl = 2.3, sum = 99.5 percent. Nealite is bright orange with a light orange streak, has adamantine luster, no cleavage and is very brittle. The calculated density is 5.88 g/cm³. Refractive indices all exceed 2.00. The name is in honor of the late Leo Neal Yedlin.

INTRODUCTION

About five years ago, the late Neal Yedlin of New Haven, Connecticut, brought to the attention of the senior author a bright orange mineral from Laurion, Attike, Greece. There was but one crystal, which Mr. Yedlin willingly sacrificed so that he might know what he *had* rather than keep an unknown mineral in his micromount collection. The unknown was found to possess a unique but unidentifiable powder diffraction pattern, but the crystal was inadvertently lost during preparation for other investigative procedures. It was this unfortunate incident which prompted Mr. Yedlin to comment about what he jokingly referred to as a horrible situation, to wit: "To consume your only specimen and *not* know what you *had,*" (Yedlin, 1974). Subsequent to this incident, Mr. Yedlin found one more specimen of the orange unknown and, notwithstanding his prior experience, he brought it to the Smithsonian for further study. Within months, yet another specimen was obtained from Curt Segeler, of New York City, and the present study was initiated.

This unknown orange mineral from Laurion, Greece, is now a valid new mineral species, a triclinic lead iron arsenate chloride. We take great pleasure in naming this new species *nealite* in honor of Leo Neal Yedlin (1908–1977). His contributions to mineralogy were truly broad in scope and impact; he would gladly sacrifice part or all of any specimen which was needed for scientific study. The breadth of Yedlin's contributions and perspectives on his personality have been presented by Bentley *et al.* (1979) and need not be repeated here. We are pleased to name for Neal Yedlin a species he discovered and it is also interesting to note that the other species which bears his name, yedlinite (McLean *et al.,* 1974), was also found by him.

The new species and the name were approved by the I.M.A. Commission on New Minerals and Mineral Names, prior to publication. Type material is preserved in the Smithsonian Institution under catalog #137115. The name is pronounced nēl•īt.

DESCRIPTION

Nealite crystals are prismatic to bladed in habit and occur in clusters, which are either radially divergent or exhibit parallel growth. The crystals are too small for goniometric measurement or precise assignment of Miller indices to all of the forms. On the type specimen, nealite crystals occur in a radial group (Fig. 1) of bladed crystals which are tabular on {010}, and elongated and striated parallel to [001]. On the specimen obtained from Mr. Segeler, nealite occurs as stout to elongated prismatic crystals, both isolated and in parallel growth (Figs. 2 and 3). The associated minerals are aragonite, annabergite, georgiadesite, goethite and some lead oxychlorides of unknown identity.

The extreme paucity of nealite and the very small crystal size precluded the determination of some optical and physical properties. Nealite is bright orange in color with a light orange streak, and an adamantine luster. No cleavage was observed. The hardness could not be measured due to the extremely small crystal size. The mineral is very brittle. The observed density is greater than 4.27 g/cm³; the calculated density is 5.88 g/cm³. Optically, nealite has refractive indices greater than 2.00, is non-pleochroic, and is length-slow parallel to the long dimension of the crystals. The orientation of the indicatrix could not be determined. Nealite does not respond to ultraviolet radiation.

CHEMISTRY

Nealite was chemically analyzed using an ARL-SEMQ electron microprobe, utilizing an operating voltage of 15 kV and a beam current of 0.15 μA. The standards used for analysis were PbO for lead, synthetic ZnO for zinc, synthetic olivenite for arsenic, NaCl for chlorine, and hornblende for iron. The data were corrected using a modified version of the *MAGIC-4* computer program. A wavelength-dispersive microprobe scan indicated the absence of any elements with atomic number greater than nine, except those reported herein. The paucity of material precluded a spectrographic analysis, but no light elements are common in the geochemical environment of nealite.

Our initial attempts at analysis were frustrated by the presence of other, as yet unidentified, lead oxy-chloride compounds in intimate intergrowth with nealite. Hence, to ensure reliability of the data, we analyzed the very crystal used for the single-crystal studies. It was analyzed unpolished, on a flat face, and the resultant analysis is presented as Table 1, together with the theoretical composition.

Figure 1. **Scanning electron micrograph of a sub-parallel group of bladed nealite crystals from the type specimen. Small spherules on the face of the crystals are glue inadvertently spilled on the crystals during mounting. NMNH 137115 (280x).**

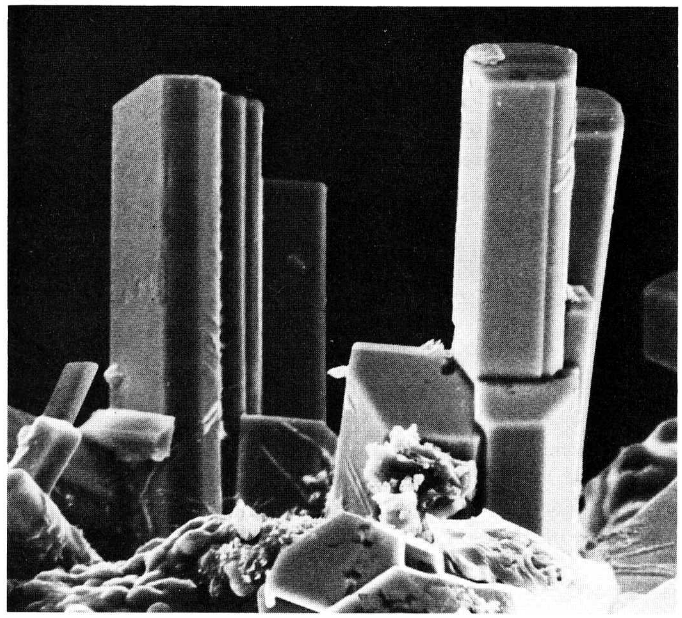

Figure 2. **Scanning electron micrograph of crystals of nealite from the Segeler specimen (1190x).**

Iron was determined as ferrous by microchemical test. Assuming two arsenic atoms per unit cell, the analysis yields the formula $Pb_{4.10}(Fe^{2+}_{0.89}Zn_{0.10})_{\Sigma 0.99}As_2O_{8.16}Cl_{3.86}$, in excellent agreement with the proposed formula, $Pb_4Fe(AsO_4)_2Cl_4$ with Z = 1. Nealite is slowly soluble in cold 1:1 hydrochloric acid.

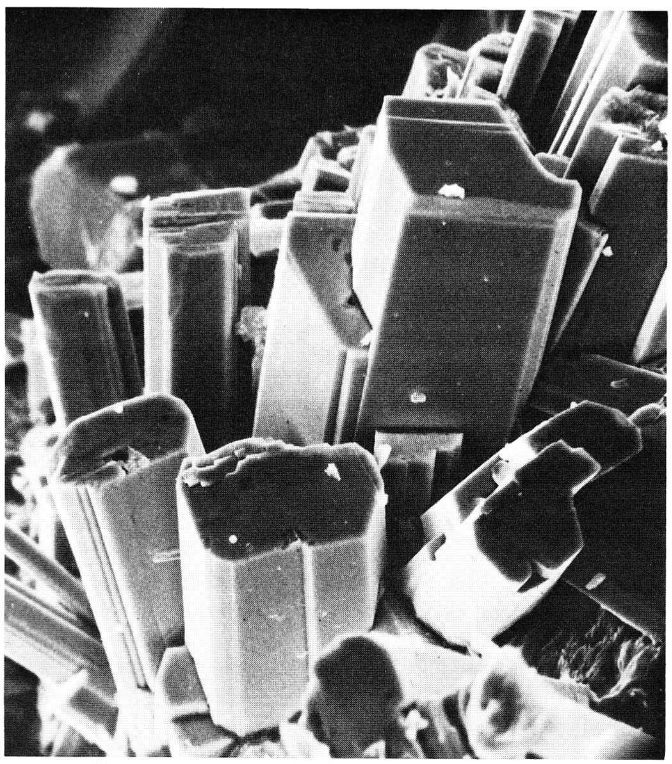

Figure 3. **Divergent spray of nealite crystals similar to those shown in Figure 2. (980x).**

Table 1. **Microprobe analysis of nealite.**

	$FePb_4(AsO_4)_2Cl_4$	NEALITE
FeO*	5.51	4.8
ZnO	----	0.6
PbO	68.45	68.8
Cl	10.87	10.3
As_2O_5	17.62	17.3
Total	102.45	101.8
O = Cl	2.45	2.3
Total	100.00	99.5

Accuracy of data: 4 percent of the amount present.
* Iron determined as total iron and calculated as ferrous on the basis of microchemical test.

CRYSTALLOGRAPHY

Only one crystal of nealite was of sufficient size and quality to be utilized for single-crystal X-ray study. This crystal was examined by the precession, Weissenberg, and rotating crystal methods and found to be triclinic, $P1$ or $P\bar{1}$, with a = 6.537(7), b = 10.239(7), c = 5.582(5) Å, α = 96.20(5)°, β = 89.39(10)°, and γ = 97.74(7)°. The unit cell has a volume of 368.1(5) $Å^3$ and contains one formula weight. The crystal was twinned by two-fold rotation around [001]. Cell parameters were refined by least-squares using thirteen reflections from a Gandolfi photograph. The latter was obtained using a powdered sample, $CuK\alpha$ radiation, and an NBS silicon (a = 5.43008 Å) internal standard. Indexing was accomplished with the aid of single-crystal photographs. Powder diffraction data for nealite are presented in Table 2.

OCCURRENCE

Nealite is found as microscopic crystals lining cavities in slags from Laurion, Attike, Greece. The Laurion mines were worked as early as 600 B.C. by the Athenians and later by a French zinc-mining company. The extraction of lead and silver by the smelting processes of the early Greeks was not efficient and some of these metals remained in the slag, which was dumped into the sea. The sea water reacted with the slags to produce the rare and exotic minerals for which Laurion is now justly famous. Included in this suite of unusual minerals are laurionite, paralaurionite, penfieldite, fiedlerite, diaboleite, boleite, pseudoboleite, cumengeite, georgiadesite and others. For the reader interested in learning more about the Laurion minerals and a discussion of the arguments for these

Table 2. **X-ray powder diffraction data for nealite.**

I_{obs}	d_{obs}	d_{cal}	hkl
6	10.09	10.09	010
8	6.480	6.477	100
1	5.823	5.817	$\bar{1}10$
«1	5.078	5.145	110
«1	4.661	4.655	011
7b	4.237	4.267	$\bar{1}20$
		4.223	$\bar{1}01$
		4.206	101
5b	3.919	3.950	$0\bar{2}1$
		3.887	$\bar{1}\bar{1}1$
2	3.668	3.668	111
10	3.542	3.547	021
		3.537	$1\bar{2}1$
3	3.358	3.362	030
6	3.247	3.247	$\bar{1}21$
		3.239	200
1	3.028	3.023	$0\bar{3}1$
5	2.971	2.970	210
«1	2.908	2.909	$\bar{2}20$
5	2.874	2.873	$1\bar{3}1$
5	2.833	2.833	130
6	2.783	2.792	201
		2.775	002
5b	2.765	2.752	$0\bar{1}2$
		2.744	$\bar{2}11$
5b	2.643	2.658	$\bar{2}\bar{1}1$
		2.638	$\bar{1}31$
		2.623	$\bar{1}\bar{3}1$

I_{obs}	d_{obs}	d_{cal}	hkl
2	2.581	2.581	211
1	2.558	2.554	$\bar{1}02$
		2.547	102
1	2.460	2.465	$\bar{1}40$
		2.449	$\bar{1}12$
1	2.427	2.434	131
		2.426	$1\bar{2}2$
2	2.262	2.263	$0\bar{3}2$
3	2.086	2.090	$\bar{2}\bar{3}1$
		2.089	$\bar{3}20$
		2.081	$\bar{1}\bar{3}2$
2	2.058	2.064	$\bar{2}\bar{1}2$
		2.056	310
		2.053	$2\bar{4}1$
1	2.038	2.036	$3\bar{1}1$
		2.035	032
2	2.006	2.009	301,$\bar{3}11$
		2.004	$\bar{1}50$
1	1.980	1.988	231
		1.982	$3\bar{2}1$
«1	1.951		
«1	1.932		
2	1.890		
3b	1.825		
3	1.711		
1b	1.670		
«1	1.644		
2	1.600		

114.6 mm Gandolfi camera, NBS silicon internal standard, CuKα radiation, visually estimated intensities, b = broad line.

compounds being considered legitimate mineral species, we recommend the recent paper by Kohlberger (1976).

Nealite has been found on only two very small specimens of the Laurion slags. On the type specimen, nealite occurs as a single isolated cluster of crystals («0.1 mm) in a cavity about 4 mm in diameter. The only other mineral in the cavity is a colorless crystals of aragonite. An adjacent cavity on the same specimen is lined with a druze of georgiadésite crystals, thus making the type nealite specimen the second known specimen of georgiadesite.

On the second nealite specimen, provided by Curt Segeler, the bright orange nealite crystals line fractures in the slag, and are more abundant. The specimen is severely oxidized and friable. In addition to abundant cellular goethite, nealite is associated with dull green annabergite.

ACKNOWLEDGEMENTS

The authors are indebted to Mary Jacque Mann of the Smithsonian SEM laboratory for assistance with the photomicrography. Curt Segeler provided additional specimens. Robert Jaxel provided many references to the mineralogy of Laurion, Attike, Greece, for which we are most thankful. Richard Johnson and Frank Walkup painstakingly prepared polished sections of minute nealite crystals, and Charles Obermeyer provided technical assistance with the microprobe. To all of these we express our gratitude.

To a very great degree, we are indebted to the late Neal Yedlin, who initiated not only this study, but many others, and provided the inspiration and impetus for a large number of mineralogical research efforts. His influence will be long remembered.

REFERENCES

BENTLEY, R., PERLOFF, L., KROTKI, C., FRONDEL, C., and MANDARINO, J. A. (1979) Neal Yedlin — a memorial. *Mineralogical Record,* **10**, 231–237.

KOHLBERGER, W. (1976) Minerals of the Laurium mines, Attica, Greece. *Mineralogical Record,* **7**, 114–125.

McLEAN, W. J., BIDEAUX, R. A., and THOMSSEN, R. W. (1974) Yedlinite, a new mineral from the Mammoth mine, Tiger, Airzona. *American Mineralogist,* **59**, 1157–1159.

YEDLIN, N. (1974) Yedlin on micromounting. *Mineralogical Record,* **5**, 238–240.