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ON LEUCOPHOENICITES

I. A NOTE ON FORM DEVELOPMENTS

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INTRODUCTION

Leucophoenicite, $3Mn_2SiO_4 \cdot Mn(OH)_2$, is generally regarded as a member of the manganese humite group. However, unlike the monoclinic members alleghanyite, $2Mn_2SiO_4 \cdot Mn(OH)_2$, and sonolite, $4Mn_2SiO_4 \cdot Mn(OH)_2$, which seem to be normal members of the manganese humite series, being isotypic with chondrodite and clinohumite respectively, leucophoenicite does not appear to have the orthorhombic symmetry expected for the manganese analogue of humite. The detailed studies on leucophoenicite morphology by Palache (1928) led him to conclude that "No interpretation of the highly peculiar assemblage of forms offered the slightest resemblance to the form series of any member of the humite group to which leucophoenicite is related chemically" (p. 316).

Leucophoenicite is one of the more conspicuous and abundant of the accessory minerals from Franklin, New Jersey[1] occurring as raspberry-red to pink masses usually associated with green willemite and coarse granular franklinite. In most specimens it appears as a replacement mineral and Palache considered it a pneumatolytic product, somehow connected with the pegmatite lenses which intruded certain portions of the ore body. Crystals of leucophoenicite, however, appear to be confined to open hydrothermal veins and display a wide variety of developments and a range of colors from pink to red to brown.

No structure-cell studies on leucophoenicite have been done to my knowledge, and this effort was undertaken to elucidate the species as a

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[1] I have discovered that many of the 'hydrotephroites' from Pajsbreg, Sweden are leucophoenicites, which adds interest to the species.

portion of work on manganese olivines and humites in general. This work turned out to be full of surprises! There appear to be no less than four kinds of leucophoenicites, distinguishable by their powder patterns and structure cells and to a lesser extent physical properties and paragenesis. Briefly stated, the various leucophoenicites can be divided crystallographically into two categories which I call *m*-leucophoenicites and *o*-leucophoenicites. The *m*-leucophoenicites have pseudo-orthorhombic cells with monoclinic intensity relationships, the pseudo-orthorhombic cell translations being closely analogous to humite but requiring a doubling of *c*. All single crystals of pink and red leucophoenicites examined so far belong here. The *o*-leucophoenicites are of three types: The orthorhombic isotype of humite; the orthorhombic member closely analogous to humite but with doubled *c* which is represented in the abundant massive raspberry-red material from Franklin and some 'hydrotephroites' from Pajsberg; and orthorhombic members with unusually large identity translations along the *c* axis, normal to the assumed tephroite and pyrochroite layers. Some specimens show manifestations of semi-random structure, with streaks parallel to this translation on Weissenberg photographs. Many of the so-called 'hydrotephroites' and platy brown leucophoenicites belong here.

The paper concerns the *m*-leucophoenicite crystals of Palache and a revision and discussion of their morphology. Regarding the crystal chemistry of the *o*-leucophoenicites, the work is as yet incomplete and shall be reported later. In particular, their chemical variations must be assessed which at present are unknown variables.

CRYSTAL MORPHOLOGY

Palache (1928, p. 315) lists all the forms and their frequencies obtained from the 15 different crystals he examined. Taking the combinations for each crystal alone leads to the obvious monoclinic morphology for the mineral, but if all the forms for all crystals are plotted collectively without regard to weighting on the basis of frequency, the relationship to humite is readily apparent. Figure 1 shows a gnomonic projection of all the forms recorded with *b*(010) polar to fully display the pseudo-orthorhombic character. Palache's reciprocal cell is indicated by the ruled lines running NW-SE. The pseudo-humite cell chosen in this paper is indicated by the ruled lines running NE-SW. In effect, Palache's (100) has been rotated into his $(20\bar{1})$ position, a rotation of $-13°16'$. For the sake of clarity his form letters are retained and for the sake of discussion the poles of the forms are weighted as to frequency by the circular areas. In Table 1, Palache's ϕ_2 values are transformed by the addition of $+13°16'$, thus bringing his *c*(001) position to 90°. My cell was chosen from the

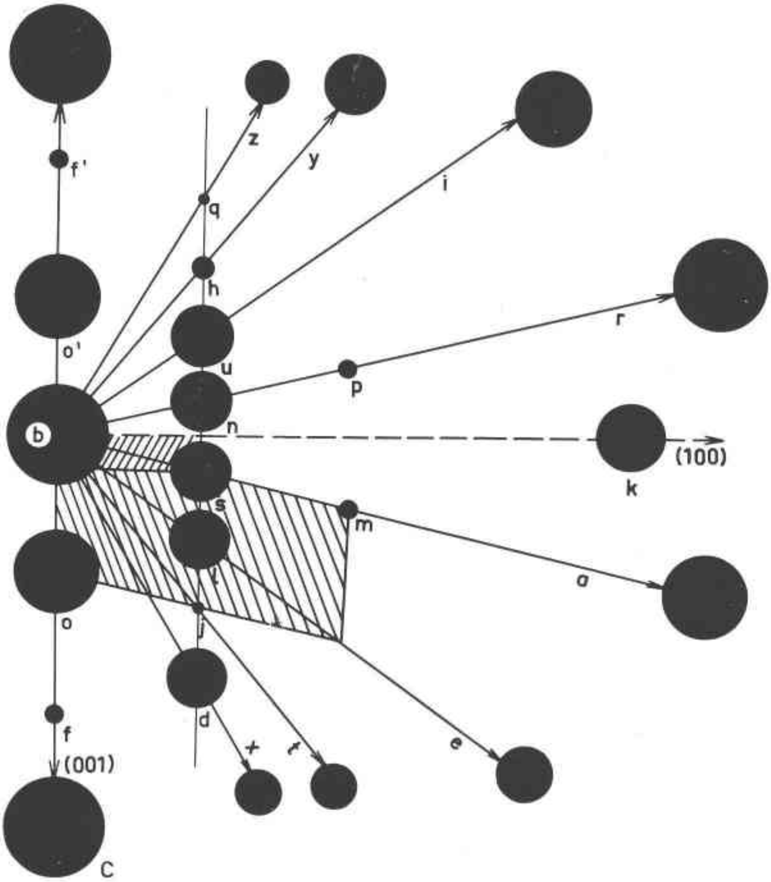

FIG. 1. Gnomonic projection of *m*-leucophoenicite with *b*(010) polar, the forms as cited by Palache (1928). Palache's cell is denoted by hatch marks running NW-SE. The cell in this study has hatch marks running NE-SW. Frequencies of forms are depicted by the circular areas. Palache's form letters are retained in this study.

structure-cell ratios of $a:b:c=2.2250:1:9.3250$, $\beta=90°0'$, obtained from single crystal rotation and Weissenberg data for one crystal and its powder data, yielding $a=10.78\pm.05$ Å, $b=4.845\pm.004$ Å, $c=45.18\pm.10$ Å, space group $B2_1/d$. The structure cell chosen here emphasizes the pseudo-orthorhombic character of *m*-leucophoenicite and is related to humite cell dimensions by a halving of *c*. The non-absent reflections for $h0l$ have $h+l=4n$ with $h, l=2n$ and for hkl, $h+l=2n$. The space group is a reoriented $P2_1/c$. The discovery of the *c*-axis translation twice that of humite prompts further investigation on humite minerals. In Table 1, the ρ_2 and ϕ_2 values computed therefrom are shown to be in fair agreement

TABLE 1. LEUCOPHOENICITE. FORM REVISION

Palache	Moore	$\phi_2(P)^1$	$\rho_2(P)^1$	$\phi_2(P+13°16')$	$\phi_2(\text{calc.})^2$	$\rho_2(\text{calc.})^2$
c 001	001	76°44′	90°00′	90°00′	90°00′	90°00′
b 010	010	—	0 00	—	—	0 00
k $\bar{2}11$	410	−13 48	61 05	−00 32	00 00	60 55
f 012	018	76 44	41 36	90 00	90 00	40 38
o 011	014	76 44	23 55	90 00	90 00	23 47
x 103	107	46 22	90 00	59 38	59 06	90 00
t 102	105	37 18	90 00	50 34	50 02	90 00
e 101	103	22 42	90 00	35 58	35 36	90 00
a 100	101	00 00	90 00	13 16	13 25	90 00
m 110	212	00 00	42 56	13 16	13 25	42 44
d 123	117	46 22	41 50	59 38	59 06	41 11
j 122	115	37 18	35 28	50 34	50 02	34 59
l 121	113	22 42	29 13	35 58	35 36	28 56
s 120	111	00 00	24 56	13 16	13 25	24 48
pseudo-mirror image forms:						
z $10\bar{4}$	$10\bar{7}$	−73 09	90 00	−59 53	−59 06	90 00
y $10\bar{3}$	$10\bar{5}$	−64 15	90 00	−50 59	−50 02	90 00
i $10\bar{2}$	$10\bar{3}$	−49 37	90 00	−36 21	−35 36	90 00
r $10\bar{1}$	$10\bar{1}$	−27 32	90 00	−14 16	−13 25	90 00
p $11\bar{1}$	$21\bar{2}$	−27 32	43 03	−14 16	−13 25	42 44
q $12\bar{4}$	$11\bar{7}$	−73 09	42 04	−59 53	−59 06	41 11
h $12\bar{3}$	$11\bar{5}$	−64 15	35 44	−50 59	−50.02	34 59
u $12\bar{2}$	$11\bar{3}$	−49 56	29 26	−36 40	−35 36	28 56
n $12\bar{1}$	$11\bar{1}$	−27 32	25 02	−14 16	−13 25	24 48

[1] Palache's calculated data.

[2] Based on structure-cell ratios (this study).

with Palache's transformed data. It was found in the course of powder X-ray studies on different leucophoenicite crystals that the ratios may vary slightly and consequently the slight differences between the transformed data of Palache and the computed data using structure-cell ratios for one crystal reflect in part the differences in axial ratios from crystal to crystal.

DISCUSSION ON THE MONOCLINIC CHARACTER OF m-LEUCOPHOENICITE

In Table 2, the frequency of forms are listed both for the new (hkl) and their pseudo-mirror image forms $(hk\bar{l})$. The great differences in form frequencies between *t*(105) and *y*($10\bar{5}$), *l*(113) and *u*($11\bar{3}$), and *s*(111) and *n*($11\bar{1}$) are readily apparent. Furthermore, the forms and their pseudo-mirror images only rarely seem to have similar dimension on the crystals (see Palache, 1935, pp. 104–105). Also, *d* (117) appears to be a common form, whereas *q* ($11\bar{7}$) is rare. This is shown in Figure 1. These facts are

TABLE 2. LEUCOPHOENICITE. FREQUENCY OF FORMS

Leucophoenicite[1]				Humite[2]	
	$a:b:c=2.2250:1:9.3250$			$a:b:c=2.1605:1:4.4013$	
Face (pseudo-mirror image)	Moore symbol	Frequency	Paired[3]	Form	Frequency
c	001	11	—	c (001)	2
b	010	11	—	b (010)	3
k	410	4	—	o_2 (410)	2
f	018	2	—	e_2 (014)	1
o	014	9	—	e_4 (012)	2
$x(z)$	107	5(4)	4		
$t(y)$	105	4(7)	0	i_1 (205)	1
$e(i)$	103	7(10)	7	i_2 (203)	2
$a(r)$	101	8(12)	6	i_3 (201)	3
$m(p)$	212	2(2)	1	n_2 (211)	2
$d(q)$	117	6(2)	1		
$j(h)$	115	1(2)	0		
$l(u)$	113	7(6)	1		
$s(n)$	111	5(6)	2		

[1] Fifteen crystals.

[2] Four crystals. Not appearing on leucophoenicite: a(100)(1), m(210)(1), o_1(430)(1), e_1(015)(2), e_3(013)(2), e_5(011)(4), n_1(213)(2), r_1(4·1·10)(1), r_2(418)(2), r_3(416)(4), r_4(414)(2), r_5(412)(2).

[3] Number of crystals where both a form and its pseudo-mirror image appear.

perhaps the most likely reasons why Palache could not recognize the relationship to humite.

Table 2 also tabulates forms and their frequencies for humite. This tabulation is based on only four crystals, the ones depicted in Dana (1898, pp. 534–536), the cell therein requiring a simple doubling of a to obtain the ratios 2.1605:1:4.4013, consistent with the structure-cell ratios of 2.158:1:4.400 (Taylor and West, 1929). The indices based on these ratios require a doubling of h for the forms listed in Dana and note that when comparing *m*-leucophoenicite with humite in Table 2, a mental doubling of l for humite is required. The similarity between *m*-leucophoenicite and humite is obvious, though the common *m*-leucophoenicite forms (113) and (111) are missing in humite and the common humite forms (011) and (416) are missing in *m*-leucophoenicite.

MORPHOLOGICAL ANALYSIS OF M-LEUCOPHOENICITE

The apparently peculiar form development of *m*-leucophoenicite seems to be remarkably consistent with the Bravais Law and the Donnay-

TABLE 3. MORPHOLOGICAL ANALYSIS OF LEUCOPHOENICITE

Violations	Symbol	Frequency
a	001	
f	002	
a	003	
	004	L(11)
a	100	
c	101	
a	102	
a	005	
c	103	
a	104	
f	006	
c	105	
a	007	
a	106	
g	008	
c	107	
f	200	
a	201	
	202	L(10)
a	203	
a	009	
a	108	
d	204	
b	010	
a	011	
	012	?
a	205	
a	013	
c	109	
f	0, 0, 10	
	014	M(9)
a	110	
	111	M(5)
	206	M(8)
a	112	
a	015	
	113	M(7)
a	207	
a	1, 0, 10	
a	014	
a	0, 0, 11	
	016	?
	115	S(2)
d	208	
a	017	
c	1, 0, 11	
a	116	
g	0, 0, 12	
	018	S(2)
a	209	
	117	M(4)
a	300	
	210	?
c	301	
a	211	
	212	S(2)
a	302	
a	1, 0, 12	
a	213	
c	303	
a	019	
a	0, 0, 13	
a	118	
	2, 0, 10	M(5)

Code:

L	large	M	medium	S	Small
a	$hkl\ h+l\neq 2n$	*b*	$0k0\ k\neq 2n$	*c*	$h0l\ l\neq 2n$
d	$h0l\ l=2n, h\neq 2,6,10\ldots$	*e*	$h0l\ l=4n$, h $\neq 4,8,12\ldots$	*f*	$h00, 00l, h, l\neq 4n$
g	already accounted for	?	forms expected to be present, but not observed.		

Harker Principle. Roughly stated, the forms listed here though seemingly unusual, are a consequence of the unusual cell shape and the space group derived from the orientation chosen in this paper. In Table 3, the interplanar spacings for m-leucophoenicite are tabulated in decreasing values.

Furthermore, the indices in conflict with the glide conditions, the screw axis, and the B-face centering are coded from a to f depending on their extinction violation. Effectively, all coded indices should lose their rank and since the higher orders are also listed, they can be considered eliminated from the table. Of the 63 symbols listed, only 14 should appear as face forms, their relative degree of frequency roughly corresponding to their position in the table. For this argument, it is assumed that all fifteen of Palache's crystals are *m*-leucophoenicite with space group $B2_1/d$. As the cell is orthogonal, the pseudo-mirror image forms need not be considered independently: the frequency of a form and its pseudo-mirror image is taken as the average of the two.

Of the list of spacings arranged as to decreasing reticular density, all but two of the fourteen observed forms—the pseudo-mirror image forms excluded—can be found: *b*(010) and *k*(410) are missing. For the former, the screw axis necessitates a higher order (020) and as for the latter, it may be considered a minor form on the basis of the observed data. Even more noteworthy is that the arrangement of forms and their prominence almost faithfully obey the Bravais Law and the Donnay—Harker Principle. Within this series, only three forms are missing on the observed m-leucophoenicite crystals, which are expected to be present: (012), (016), and (210), but even then, the latter two are fairly well down the list. It appears that the form development for *m*-leucophoenicite is not so peculiar after all!

The really interesting problem which begs explanation is the monoclinic (though markedly pseudo-orthorhombic) symmetry of *m*-leucophoenicite and the existence of leucophoenicite 'polytypes', results which hopefully shall be reported in a future paper. Informative in this respect would be studies on the hypothetical manganese norbergite, $Mn_2SiO_4 \cdot Mn(OH)_2$, but as yet no such compound has been discovered.

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