SYNTHESIS OF THE SODALITE GROUP AND SUBSOLIDUS EQUILIBRIA IN THE SODALITE-NOSELITE SYSTEM

TAKESHI TOMISAKA

*Department of Mineralogical Sciences and Geology, Faculty
of Literature and Science, Yamaguchi University,
Yamaguchi, Japan*

and

HANS P. EÜGSTER

*Department of Geology, The Johns Hopkins University,
Baltimore, Maryland, U. S. A.*

ABSTRACT

The main end members of the sodalite group, that is, chlorine sodalite, bromine sodalite, iodine sodalite, hydroxylsodalite, carbonate noselite, sulfate noselite, chromate noselite, molybdate noselite and tungstate noselite, were synthesized under hydrothermal and dry conditions, and the cell edges a_0 and cell volumes V of these minerals were determined. These minerals can be divided into two subgroups: the sodalite subgroup, which includes chlorine sodalite, bromine sodalite, iodine sodalite and hydroxylsodalite, and the noselite subgroup, which includes carbonate noselite, sulfate noselite, chromate noselite, molybdate noselite and tungstate noselite. The X-ray powder diffraction patterns of the four end members of the sodalite subgroup make their appearance only as $h+k+l=2n$. Those of five other end members which belong to the noselite subgroup appear as $h+k+l=2n$ and $h+k+l=2n+1$.

The dissociation temperatures of chlorine sodalite and sulfate noselite are $1230^\circ \pm 5^\circ\text{C}$ in chlorine sodalite and $1255^\circ \pm 5^\circ\text{C}$ in sulfate noselite, and complete solid solution was found to exist between chlorine sodalite ($\text{Na}_8\text{Al}_6\text{Si}_6\text{O}_{24}\text{Cl}_2$) and sulfate noselite ($\text{Na}_8\text{Al}_6\text{Si}_6\text{O}_{24}\text{SO}_4$) at temperatures above 1050°C . Compositions of the chlorine sodalite-sulfate noselite solid solutions were determined from the cell edges a_0 obtained by measuring the shifts of the 211, 310 and 222 reflections ($\text{CuK}\alpha$). A solvus of the chlorine sodalite-sulfate noselite series was determined at temperatures below 1050°C . Polymorphic relationship was discovered in the sulfate noselite in the noselite subgroup.

Introduction

The term 'sodalite group' applies to a family of minerals of the approximate composition, $(R)_{4-8}(AlSiO_4)_6(Cl_2, SO_4, CO_3, (OH)_2, S)$ where $R=Na, Ca, K$. The general chemical formula of this mineral group is $R_{4-8}(XSiO_4)_6(Y)$. The chemical compositions of natural and artificial minerals are as follows:

$R=Na, Ca, K, Mn^{+2}, Fe^{+2}, Zn, Li, Ag$

$X=Al, Fe^{+3}, Be$

$Y=Cl_2, Br_2, (OH)_2, SO_4, CO_3, WO_4, S$

The molecular ratios of Y ($Cl_2, SO_4, CO_3, (OH)_2, S$) in the chemical compositions of natural sodalite and noselite are shown in Table 1

Table 1. Molecular ratios of Y ($Cl_2, SO_4, CO_3, (OH)_2, S$) in natural sodalites and noselites.

Cl_2	SO_4	CO_3	$(OH)_2$	S	References
0.6837	—	0.0519	0.2644	—	Medved, D. B. (1954). <i>Am. Min.</i> , 39, 623.
0.7362	—	—	0.1543	0.1095	Deer, W. A., Howie, R. A. & Zussman, J. (1963). <i>Rock-Forming Minerals</i> . 4, 292.
0.8815	—	—	—	0.1185	
0.8146	—	0.0239	0.1615	—	
0.6903	—	—	0.3097	—	
0.6452	—	0.0339	0.3209	—	
1.0000	—	—	—	—	
0.6116	—	—	0.1205	0.2679	
0.0661	0.4053	—	0.5286	—	
0.0949	0.7773	—	0.1278	—	
0.0564	0.4709	—	0.4727	—	
0.0242	0.9758	—	—	—	
0.0659	0.7656	0.0527	0.1158	—	
0.0408	0.8080	—	—	0.1512	
0.0476	0.8658	0.0866	—	—	Barth, T. F. W. (1932). <i>Am. Min.</i> , 17, 469.

Fig. 1. Chemical compositions of natural minerals in the sodalite group.

Table 2. Compositions and names of end members of natural sodalite group

Names	Compositions
sodalite	$\text{Na}_8(\text{AlSiO}_4)_6\text{Cl}_2$
noselite	$\text{Na}_8(\text{AlSiO}_4)_6\text{SO}_4$
hydroxylsodalite	$\text{Na}_8(\text{AlSiO}_4)_6(\text{OH})_2$
carbonate sodalite	$\text{Na}_8(\text{AlSiO}_4)_6\text{CO}_3$
sulphur sodalite	$\text{Na}_8(\text{AlSiO}_4)_6\text{S}$

and Fig. 1. In defining possible end members of natural sodalite group, five general types must be considered. The compositions and corresponding names of the five probable end members can be represented as in Table 2. The sodium ion is partly replaced by calcium ion. The chemical formula of haüyne is as follows:

Friedel and Friedel (1890) reported that they had synthesized sodalite by hydrothermal reaction of mixtures of $3\text{Na}_2\text{O}$, $3\text{Al}_2\text{O}_3$, 6SiO_2 and 2NaCl , and by heating at about 500°C of mixtures of muscovite

and NaCl or mixtures of kaolinite and NaCl. Prener and Ward (1950) synthesized sodalite by heating in nitrogen at about 900°C of mixtures of $3\text{Na}_2\text{CO}_3$, $3\text{Al}_2\text{O}_3$, 6SiO_2 and 2NaCl . Barrer and White (1952) synthesized sodalite from sodium aluminosilicate gels and an excess of sodium chloride under hydrothermal condition, and Barrer, Hinds and White (1953) by hydrothermal reaction of analcite with a saturated solution of NaCl. Medved (1954) synthesized sodalite by heating at the temperature of 1060°C, 24~72 hours, of stoichiometric mixtures of Al_2O_3 , SiO_2 , NaOH and NaCl. Sudo and Matsuoka (1958) synthesized sodalite by hydrothermal reaction at 90°C of volcanic glass or ash in solution of NaOH (4~8%) and NaCl (10~40%).

Hydroxylsodalite had been synthesized by Borchert and Keidel (1947) by hydrothermal reaction of kaolinite in a concentrated solution of NaOH. Wyart and Michel-Lévy (1949) synthesized hydroxylsodalite by hydrothermal reaction of mixtures of NaOH, Al_2O_3 and SiO_2 . Barrer and White (1952) synthesized hydroxylsodalite by using sodium aluminosilicate gels, to which was added an excess of NaOH in solution, and Barrer, Hinds and White (1953) by hydrothermal treatment of analcite. Sudo and Matsuoka (1958) synthesized hydroxylsodalite by hydrothermal reaction of volcanic glass or ash in a solution of NaOH (40%).

Barth (1932) synthesized noselite from mixtures of glass of nepheline composition and Na_2SO_4 . Barrer and White (1952) synthesized noselite from sodium aluminosilicate gels and an excess of sodium sulfate. Barrer, Hinds and White (1953) synthesized noselite by hydrothermal reaction of analcite with a saturated solution of Na_2SO_4 .

Other crystalline phases of sodalite structure type have been synthesized by Barrer and Baynham (1956) by heating at 250°C aluminous chabazite with fused AgNO_3 . The formation of tungstate noselite in which the SO_4 -site in noselite structure was replaced by WO_4 molecule has been reported by Saalfeld (1959). Barrer and

Falconer (1956) reported that they had produced "basic sodalite", "lithium basic sodalite", "silver basic sodalite" and "potassium-rich basic sodalite", by ion exchange as a solid state reaction in feldspathoids. The preparation of Br- and Li-bearing sodalite was reported by Weiberg (1905), and the replacement of NaCl by other salts (NaBr, NaNO₃, etc.) was demonstrated by Barrer (1954). The preparation of sulfur-bearing sodalite was reported by many investigators.

In this paper, we are reporting the experimental results and crystallographic data from the synthesis under hydrothermal and dry conditions of the main end members of sodalite group: chlorine sodalite, bromine sodalite, iodine sodalite, hydroxylsodalite, carbonate noselite, sulfate noselite, chromate noselite and tungstate noselite. We have determined the variation of cell sizes with its compositions and the solvus curve of the chlorine sodalite—sulfate noselite series, and the dissociation temperatures of chlorine sodalite and sulfate noselite. Also, we have discovered the existence of polymorphic relationship in sulfate noselite.

Experimental Method

Synthesis of Nepheline:

The starting material for the synthesis of sodium nepheline was sodium bicarbonate (NaHCO₃), γ -alumina and cristobalite which were weighed out in stoichiometric proportion. Then the mixture was ground for three hours in acetone. With this mixture, two experiments were made. In one experiment, the mixture was heated at 700°C in argon for 10 hours to drive off CO₂ and H₂O, and after grinding once again, the mixture was crystallized by heating at 800°C for 24 hours. This grinding and heating was repeated three times. In the other experiment, the mixture was heated in sealed Pt tubes at 700°C with a conferring pressure of 2,000 bars, with no water added to the charge.

Synthesis of Minerals of Sodalite Group:

Experiments were carried out in sealed Pt, Au or Ag capsules, enclosed in a conventional cold pressure vessel (TUTTLE, 1949) or in an autoclave. The charge, *i. e.*, starting materials with water under hydrothermal conditions, and starting materials with no water under dry conditions, was sealed in a thin-walled container, made from Pt, Au or Ag tubing, with both ends welded. For experiments under atmospheric conditions, sealed Pt, Au or Ag tubes or Pt crucibles were used.

The products of the experiments were identified by X-ray diffraction and microscope techniques.

Experimental Results

Sodalites of nine different compositions have been synthesized during the course of this investigation. They are as follows:

chlorine sodalite	$\text{Na}_8(\text{AlSiO}_4)_6\text{Cl}_2$
bromine sodalite	$\text{Na}_8(\text{AlSiO}_4)_6\text{Br}_2$
iodine sodalite	$\text{Na}_8(\text{AlSiO}_4)_6\text{I}_2$
hydroxylsodalite	$\text{Na}_8(\text{AlSiO}_4)_6(\text{OH})_2$
carbonate noselite	$\text{Na}_8(\text{AlSiO}_4)_6\text{CO}_3$
sulfate noselite	$\text{Na}_8(\text{AlSiO}_4)_6\text{SO}_4$
tungstate noselite	$\text{Na}_8(\text{AlSiO}_4)_6\text{WO}_4$
molybdate noselite	$\text{Na}_8(\text{AlSiO}_4)_6\text{MoO}_4$
chromate noselite	$\text{Na}_8(\text{AlSiO}_4)_6\text{CrO}_4$

For dry and hydrothermal runs, a preparation was made by grinding together in acetone a small amount of synthetic nepheline and sodium chloride in chlorine sodalite, synthetic nepheline and sodium bromide in bromine sodalite, synthetic nepheline and sodium iodide in iodine sodalite, synthetic nepheline and sodium hydroxide in hydroxylsodalite, synthetic nepheline and sodium carbonate in carbonate noselite, synthetic nepheline and sodium sulfate in sulfate

noselite, synthetic nepheline and sodium tungstate in tungstate
 noselite, synthetic nepheline and sodium molybdate in molybdate
 noselite, and synthetic nepheline and sodium chromate in chromate
 noselite. In hydrothermal synthesis, these minerals were synthesized

Table 3. Experimental data on syntheses of chlorine sodalite,
 bromine sodalite, iodine sodalite and hydroxylsodalite.

Run #	Starting materials	Temp. (°C)	Pressure (bars)	Time (hours)	Remarks Optics & X-ray
Chlorine sodalite					
HR-Cl-1	Ne ₆₀ NaCl ₄₀	850	2000	130	Sod > NaCl
HR-Cl-2	Ne ₆₀ NaCl ₄₀	750	2000	240	Sod > NaCl + Nep
HR-Cl-3	Ne ₇₅ NaCl ₂₅	800	2000	240	Sod
DR-Cl-1	Ne ₇₅ NaCl ₂₅	800	2000	240	Sod
DR-Cl-2	Ne ₂₅ NaCl ₇₅	750	1	240	Sod + NaCl
DR-Cl-3	Ne ₂₅ NaCl ₇₅	700	1	240	Sod + NaCl > Nep
Bromine sodalite					
DR-Br-1	Ne ₃₀ NaBr ₇₀	720	1	28	Sod + NaBr > Nep
DR-Br-2	Ne ₃₀ NaBr ₇₀	800	1	240	Sod + NaBr
DR-Br-3	Ne ₇₅ NaBr ₂₅	750	1000	240	Sod
Iodine sodalite					
DR-I-1	Ne ₃₀ NaI ₇₀	650	500	160	Sod + NaI > Nep
DR-I-2	Ne ₃₀ NaI ₇₀	710	1000	160	Sod + NaI > Nep
DR-I-3	Ne ₃₀ NaI ₇₀	760	1	90	Sod + NaI
DR-I-4	Ne ₇₅ NaI ₂₅	750	1000	240	Sod
Hydroxylsodalite					
HR-OH-1	Ne ₅₀ NaOH ₅₀	90	1	48	Sod > Zeolite
HR-OH-2	Ne ₅₀ NaOH ₅₀	150	1	50	Sod > Zeolite
HR-OH-3	Ne ₇₅ NaOH ₂₅	800	2000	240	Sod
DR-OH-1	Ne ₄₀ NaOH ₆₀	350	1	120	Sod + ?
DR-OH-2	Ne ₇₅ NaOH ₂₅	800	2000	240	Sod

HR: hydrothermal run, DR: dry run, Sod: sodalite, Ne: nepheline,
 Nep: nepheline

Table 4. Experimental data on syntheses of carbonate noselite, sulfate noselite, chromate noselite, molybdate noselite and tungstate noselite

Run #	Starting materials	Temp. (°C)	Pressure (bars)	Time (hours)	Remarks Optics & X-ray
Carbonate noselite					
HR-CO ₃ -1	Ne ₇₅ (¹ / ₂ Na ₂ CO ₃) ₂₅	800	2000	240	Nos
DR-CO ₃ -1	Ne ₅₀ (¹ / ₂ Na ₂ CO ₃) ₅₀	720	500	240	Nos > Na ₂ CO ₃
DR-CO ₃ -2	Ne ₇₅ (¹ / ₂ Na ₂ CO ₃) ₂₅	800	2000	240	Nos
Sulfate noselite					
HR-SO ₄ -1	Ne ₆₀ (¹ / ₂ Na ₂ SO ₄) ₄₀	850	2000	130	Nos > Na ₂ SO ₄
HR-SO ₄ -2	Ne ₅₀ (¹ / ₂ Na ₂ SO ₄) ₅₀	750	2000	240	Nos > Na ₂ SO ₄ > Nep
HR-SO ₄ -3	Ne ₇₅ (¹ / ₂ Na ₂ SO ₄) ₂₅	800	2000	240	Nos
DR-SO ₄ -1	Ne ₇₅ (¹ / ₂ Na ₂ SO ₄) ₂₅	800	2000	240	Nos
DR-SO ₄ -2	Ne ₈₀ (¹ / ₂ Na ₂ SO ₄) ₇₀	800	1	240	Nos + Na ₂ SO ₄
Chromate noselite					
DR-CrO ₄ -1	Ne ₂₀ (¹ / ₂ Na ₂ CrO ₄) ₈₀	800	1	40	Nos + ?
DR-CrO ₄ -2	Ne ₆₀ (¹ / ₂ Na ₂ CrO ₄) ₄₀	800	2000	240	Nos + ?
DR-CrO ₄ -3	Ne ₇₅ (¹ / ₂ Na ₂ CrO ₄) ₂₅	800	2000	240	Nos
Molybdate noselite					
DR-MoO ₄ -1	Ne ₂₀ (¹ / ₂ Na ₂ MoO ₄) ₈₀	740	1	100	Nos + ?
DR-MoO ₄ -2	Ne ₇₅ (¹ / ₂ Na ₂ MoO ₄) ₂₅	800	2000	240	Nos
Tungstate noselite					
DR-WO ₄ -1	Ne ₂₀ (¹ / ₂ Na ₂ WO ₄) ₈₀	750	600	100	Nos + ?
DR-WO ₄ -2	Ne ₇₅ (¹ / ₂ Na ₂ WO ₄) ₂₅	800	2000	240	Nos
DR-WO ₄ -3	Ne ₈₀ (¹ / ₂ Na ₂ WO ₄) ₇₀	800	1	100	Nos + ?

HR: hydrothermal run, DR: dry run, Ne: nepheline, Nos: noselite.
Nep: nepheline

by putting in platinum tubes the starting material and distilled water in the approximate weight ratio of 3:1.

Experimental data on the synthesis of these minerals are shown in Tables 3 and 4. All samples were run on an X-ray diffractometer, using Ni-filtered $\text{CuK}\alpha$ radiation. Silicon was used as an internal standard for determination of lattice parameter. The X-ray powder patterns of these synthetic and natural minerals are given in Tables 5 and 6. From these results, the sodalite group is divided into the following two subgroups:

<i>Sodalite subgroup</i>	<i>Noselite subgroup</i>
chlorine sodalite	carbonate noselite
bromine sodalite	sulfate noselite
iodine sodalite	tungstate noselite
hydroxylsodalite	molybdate noselite
	chromate noselite

The X-ray powder diffraction patterns in the sodalite subgroup make their appearance only as $h+k+l=2n$. Those of five other end members which belong to the noselite subgroup appear as $h+k+l=2n$ and $h+k+l=2n+1$. The cell dimensions and cell volumes of these minerals are shown in Table 7. These results indicate the variation of cell dimensions with its composition. Tungstate noselite has the largest cell volume, and hydroxylsodalite the smallest cell volume. Also, this variation seems to indicate that the non-silicate portion, that is, anion of the chemical formula, controls the cell size of each of these minerals.

Dissociation Temperatures of Chlorine Sodalite and Sulfate Noselite:

The results from the experiments for determination of the dissociation temperatures of chlorine sodalite and sulfate noselite are given in Table 8. The chlorine sodalite dissociates at temperatures higher than $1230^{\circ} \pm 5^{\circ}\text{C}$, and sulfate noselite at temperatures higher

Table 5. X-ray powder diffraction data of chlorine sodalite, bromine sodalite,

<i>hkl</i>	Chlorine sodalite					
	Natural sodalite from the Princers Mine, Canada		Dry synthesis $P=2000$ bars $T=800^{\circ}\text{C}$		Hydrothermal synthesis $P_{\text{H}_2\text{O}}=2000$ bars $T=800^{\circ}\text{C}$	
	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>
100	—	—	—	—	—	—
110	6.2580	100	6.2598	90	6.2583	77
111	—	—	—	—	—	—
200	4.4306	31	4.4330	25	4.4349	23
210	3.9722	7	—	—	—	—
211	3.6226	130	3.6238	120	3.6236	130
300, 221	—	—	—	—	—	—
310	2.8094	52	2.8089	30	2.8098	30
311	—	—	—	—	—	—
222	2.5643	90	2.5643	67	2.5651	58
320	—	—	—	—	—	—
321	2.3734	100	2.3729	66	2.3748	58
400	2.2219	7	2.2201	7	2.2201	5
410, 322	—	—	—	—	—	—
411, 330	2.0925	120	2.0928	100	2.0951	79
331	—	—	—	—	—	—
420	1.9872	24	—	—	1.9878	12
332	1.8945	15	1.8941	11	1.8947	10
422	1.8135	18	1.8140	11	1.8132	10
510, 431	1.7425	16	1.7437	10	1.7429	9
520, 432	—	—	—	—	—	—
521	1.6222	14	—	—	1.6217	6
440	1.5711	45	1.5713	6	1.5712	26
522, 441	—	—	—	—	—	—
433, 530	1.5239	25	1.5239	25	1.5241	13
600, 442	1.4813	38	1.4815	21	1.4814	19
532, 611	1.4418	37	1.4420	24	1.4421	23

iodine sodalite and hydroxylsodalite. ($\text{CuK}\alpha_1$, $\lambda=1.54050\text{\AA}$, Ni-filtered)

Bromine sodalite		Iodine sodalite		Hydroxylsodalite	
Dry synthesis $P=1\text{ atm.}$ $T=800^\circ\text{C}$		Dry synthesis $P=1\text{ atm.}$ $T=700^\circ\text{C}$		Dry synthesis $P=1\text{ atm.}$ $T=350^\circ\text{C}$	
d	I	d	I	d	I
—	—	—	—	—	—
6.3420	8	6.3781	9	6.1950	86
—	—	—	—	—	—
4.4774	16	4.5105	20	4.3793	13
—	—	—	—	—	—
3.6531	130	3.6873	130	3.5742	130
—	—	—	—	—	—
2.8321	10	2.8550	3	2.7684	26
—	—	—	—	—	—
2.5834	24	2.6037	15	2.5279	39
—	—	—	—	—	—
2.3902	50	2.4096	43	2.3404	31
2.2380	8	2.2537	13	2.2004	5
—	—	—	—	—	—
2.1121	57	2.1258	47	2.0638	26
—	—	—	—	—	—
—	—	2.0150	9	1.9544	5
—	—	—	—	1.8658	8
1.8230	8	1.8393	5	1.7881	8
1.7513	7	1.7666	5	1.7164	13
—	—	—	—	—	—
—	—	1.6457	10	—	—
1.5811	6	1.5934	9	1.5489	13
—	—	—	—	—	—
1.5341	4	—	—	1.5014	16
1.4900	13	1.5028	10	—	—
1.4510	16	1.4624	16	—	—

Table 6. X-ray powder diffraction data of sulfate noselite, carbonate
($\text{CuK}\alpha_1$, $\lambda = 1.54050 \text{ \AA}$,

<i>hkl</i>	Sulfate noselite					
	Natural noselite from Rieden, Eifel, Germany		Dry synthesis $P = 2000$ bars $T = 800^\circ\text{C}$		Hydrothermal synthesis $P_{\text{H}_2\text{O}} = 2000$ bars $T = 800^\circ\text{C}$	
	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>
100	—	—	9.0544	80	9.0541	47
110	6.4384	31	6.4025	120	6.3938	74
111	—	—	5.2307	21	5.2293	12
200	4.5559	9	4.5296	19	4.5314	12
210	—	—	4.0543	10	4.0609	7
211	3.7110	130	3.7040	150	3.7020	130
220	—	—	—	—	—	—
300, 221	—	—	3.0218	25	3.0256	8
310	2.8809	25	2.8689	61	2.8693	30
311	—	—	—	—	—	—
222	2.6279	31	2.6186	120	2.6195	70
320	—	—	2.5172	23	2.5188	11
321	2.4348	9	2.4261	28	2.4261	12
400	2.2761	7	2.2705	36	2.2695	16
410, 322	—	—	2.2038	66	—	—
411, 330	2.1458	18	2.1402	7	2.1402	30
331	—	—	—	—	—	—
420	—	—	—	—	—	—
332	—	—	1.9367	12	1.9362	6
422	—	—	—	—	—	—
510, 431	1.7861	11	1.7804	43	1.7816	16
520, 432	—	—	1.6838	6	—	—
521	—	—	1.6583	15	1.6586	6
440	1.6093	7	1.6055	32	1.6061	12
522, 441	—	—	1.5811	5	—	—
433, 530	1.5612	5	1.5576	14	1.5588	5
600, 442	—	—	1.5136	18	1.5139	6
532, 611	1.4762	5	1.4732	25	1.4739	7

noselite, chromate noselite, molybdate noselite and tungstate noselite.

Ni-filtered)

Carbonate noselite		Chromate noselite		Molybdate noselite		Tungstate noselite	
Dry synthesis $P=2000$ bars $T=800^{\circ}\text{C}$		Dry synthesis $P=1$ atm. $T=850^{\circ}\text{C}$		Dry synthesis $P=1$ atm. $T=720^{\circ}\text{C}$		Dry synthesis $P=1$ atm. $T=720^{\circ}\text{C}$	
d	I	d	I	d	I	d	I
8.9809	10	9.1010	26	9.1415	33	9.1484	33
6.3692	40	6.4440	32	6.4573	24	6.4571	4
—	—	5.2510	8	5.2740	13	5.2795	23
—	—	4.5382	8	4.5637	7	4.5692	10
—	—	—	—	4.0860	8	4.0876	18
3.6834	130	3.7074	130	3.7289	130	3.7290	130
—	—	—	—	3.3296	5	3.2300	8
2.9994	107	—	—	3.0428	11	3.0463	16
2.8478	24	2.8746	13	2.8879	5	—	—
2.7113	7	—	—	2.7518	4	2.7549	9
2.6044	48	2.6221	42	2.6345	31	2.6365	16
2.4942	20	2.5187	10	2.5314	11	2.5340	13
2.3953	20	2.4279	10	2.4391	16	2.4414	23
2.2525	13	2.2725	16	2.2816	20	2.2832	17
2.1865	9	—	—	—	—	2.2164	8
2.1277	22	2.1425	26	2.1510	23	2.1527	26
—	—	—	—	—	—	2.0954	4
—	—	—	—	—	—	2.0332	4B
—	—	1.9379	9	1.9458	11	1.9469	10
1.8375	7	1.8520	3B	1.8635	7	1.8637	7
1.7068	17	1.7822	13	1.7894	7	—	—
—	—	—	—	1.6943	5	1.6967	7
—	—	1.6604	7	1.6656	12	1.6680	13
1.5959	15	1.6074	11	1.6131	12	1.6148	10
—	—	—	—	—	—	1.5897	7
—	—	1.5594	5	—	—	—	—
—	—	1.5156	11	—	—	—	—
1.4650	10	1.4752	12	—	—	—	—

Table 7. The cell dimensions and cell volumes of chlorine sodalite, bromine sodalite, iodine sodalite, hydroxylsodalite, carbonate noselite, sulfate noselite, chromate noselite, molybdate noselite and tungstate noselite.

Mineral name	Condition of synthesis		Cell dimension ($\text{\AA}$)	Cell volume ($\text{\AA}^3$)
	Temp. ($^{\circ}\text{C}$)	Pressure (bars)		
chlorine sodalite	800	2000*	8.881 ± 0.002	700.46
	800	2000	8.880 ± 0.002	700.23
	750	1	8.878 ± 0.002	699.75
	1050	1**	8.881 ± 0.002	700.46
	natural sodalite from the Princers Mine, Canada		8.880 ± 0.002	700.23
bromine sodalite	750	1000	8.932 ± 0.002	712.60
	800	1	8.935 ± 0.002	713.32
iodine sodalite	750	1000	9.014 ± 0.002	732.41
	760	1	9.015 ± 0.002	732.65
hydroxylsodalite	800	2000	8.756 ± 0.002	671.30
	350	1	8.754 ± 0.002	670.84
carbonate noselite	800	2000*	9.004 ± 0.002	729.97
	800	2000	9.005 ± 0.002	730.21
	800	1	9.014 ± 0.002	732.41
sulfate noselite	800	2000*	9.075 ± 0.002	747.38
	800	2000	9.074 ± 0.002	747.13
	800	1	9.090 ± 0.002	751.09
	1050	1**	9.090 ± 0.002	751.09
chromate noselite	800	2000	9.078 ± 0.002	748.12
	800	1	9.089 ± 0.002	750.84
	1000	1**	9.092 ± 0.002	751.58
molybdate noselite	800	2000	9.112 ± 0.002	756.55
	740	1	9.124 ± 0.002	759.55
	1000	1**	9.126 ± 0.002	760.05
tungstate noselite	800	2000	9.128 ± 0.002	760.54
	750	600	9.132 ± 0.002	761.55
	800	1	9.135 ± 0.002	762.30

* Hydrothermal synthesis ** Heat treatment of synthetic sample

Table 8. Experimental data on dissociation temperatures of chlorine sodalite and sulfate noselite.

Run #	Starting materials	Temp. (°C)	Pressure (atm.)	Time (hours)	Remarks Optics & X-ray	Others
Sod-1	natural sodalite*	1000	1	24	Sod+Nep	vessel : open Pt foil
Sod-2	"	950	1	24	Sod>Nep	"
Sod-3	"	1200	1	10	Sodalite	vessel : sealed Pt tube
Sod-4	"	1225	1	5	Sodalite	"
Sod-5	"	1235	1	30	Carn>Sod	"
Sod-6	synthetic sodalite	1225	1	10	Sodalite	"
Sod-7	"	1235	1	10	Carn>Sod	"
Sod-8	"	1250	1	10	Carn>Sod	"
Sod-9	"	1350	1	10	Carn	"
Nos-1	synthetic noselite	1230	1	6	Noselite	"
Nos-2	"	1250	1	6	Noselite	"
Nos-3	"	1260	1	10	Carn>Nos	"
Nos-4	"	1275	1	10	Carn>Nos	"
Nos-5	"	1330	1	10	Carnegieite	"

* Natural sodalite from the Princers Mine, Canada.

Nep: nepheline, Sod: sodalite, Nos: noselite, Carn: carnegieite

than $1255^{\circ} \pm 5^{\circ}\text{C}$, in a sealed Pt tube. But the dissociation reaction in chlorine sodalite occurs even at temperatures below 950°C in an open tube.

The Sodalite—Noselite Series

Change of Cell Sizes with its Composition:

Solid solution members of the chlorine sodalite—sulfate noselite series were synthesized at temperatures from 1050° to 1100°C , in sealed Pt tubes (Table 9). The products were examined by microscope

Table 9. $2\theta_{211}\text{CuK}\alpha$, $2\theta_{310}\text{CuK}\alpha$, $2\theta_{222}\text{CuK}\alpha$, a_0 and V of sodalite-noselite series.

[Starting Materials	Temp. (°C)	Pres. (bars)	Time (hours)	211		310		222		$a_0(\text{\AA})$	$V(\text{\AA}^3)$
				$2\theta_{\text{CuK}\alpha}$	d	$2\theta_{\text{CuK}\alpha}$	d	$2\theta_{\text{CuK}\alpha}$	d		
$\text{Ne}_{75}(\text{NaCl})_{25}$	800	2000	240	24.565	3.6238	31.858	2.8089	34.990	2.5643	8.881	700.46
synthetic sodalite	1050	1	264	24.563	3.6241	31.855	2.8095	34.995	2.5640	8.881	700.46
$\text{Sod}_{60}\text{Nos}_{20}$	1050	1	640	24.442	3.6418	31.711	2.8215	34.825	2.5761	8.922	710.21
$\text{Sod}_{60}\text{Nos}_{40}$	1050	1	640	24.339	3.6570	31.573	2.8336	34.672	2.5871	8.960	719.32
$\text{Sod}_{50}\text{Nos}_{50}$	1100	1	640	24.283	3.6652	31.506	2.8395	34.600	2.5923	8.979	723.91
$\text{Sod}_{40}\text{Nos}_{60}$	1050	1	640	24.232	3.6728	31.440	2.8453	34.533	2.5972	8.997	728.27
$\text{Sod}_{20}\text{Nos}_{80}$	1050	1	640	24.075	3.6964	31.216	2.8652	34.319	2.6157	9.058	743.18
$\text{Ne}_{75}(\frac{1}{2}\text{Na}_2\text{SO}_4)_{25}$	800	2000	240	24.038	3.7020	31.170	2.8693	34.230	2.6195	9.074	747.13
synthetic noselite	1050	1	240	23.990	3.7093	31.110	2.8747	34.160	2.6247	9.090	751.09
synthetic noselite	1050	1	640	23.975	3.7116	31.075	2.8779	34.144	2.6259	9.106	755.06

and by X-ray powder diffraction to ascertain that only one phase was present.

The complete solid solution was found to exist between chlorine

Fig. 2A. X-ray calibration curves for reflections $2\theta_{211}, \text{Cu K}\alpha$ against compositions in the chlorine sodalite-sulfate noselite series. Data from Table 9.

Fig. 2B. X-ray calibration curves for reflections $2\theta_{310}, \text{Cu K}\alpha$ against compositions in the chlorine sodalite-sulfate noselite series. Data from Table 9.

Fig. 2C. X-ray calibration curves for reflections $2\theta_{222}$, Cu K α against compositions in the chlorine sodalite–sulfate noselite series. Data from Table 9.

Fig. 3. Changes of cell edges and cell volumes against compositions in the chlorine sodalite–sulfate noselite series. Data from Table 9.

sodalite and sulfate noselite at the temperature of 1050°C. The cell dimensions were determined by measuring distances between the peaks on an X-ray powder diffractometer pattern, taken at room temperature, from the internal standard silicon 111 peak, $\text{CuK}\alpha$ $2\theta = 28.465^\circ$, to the sodalite peaks 211, 310 and 222. In Table 9 the value of each 2θ angle listed is an average of thrice-repeated measurements. Fig. 2 shows the $2\theta_{211}$, $2\theta_{310}$ and $2\theta_{222}$ curves versus composition, obtained by plotting the data of Table 9. In Table 9 the 2θ values are converted to unit cell dimensions on the basis of the value $\text{Cu K}\alpha$, $\lambda = 1.5418 \text{ \AA}$, and these unit cell dimensions are shown in Fig. 3 along with cell volumes versus composition in mol percentage.

Chlorine Sodalite-Sulfate Noselite Solvus:

The experimental results defining the limits of solid solution in the chlorine sodalite-sulfate noselite join are listed in Table 10 and shown in Fig. 4. The pressure was atmospheric pressure except for three hydrothermal experiments at 2 kbars (HR-1, HR-2 and HR-3, at 600°, 800° and 850°C) in which $\text{Ne}_{75}(\text{NaCl}_{60} \text{ } ^{1/2}\text{Na}_2\text{SO}_4 \text{ }_{60})_{25}$ mixtures were used.

The solvus curve was drawn along the junctions of temperature-composition points from two opposite directions, *i. e.*, exsolution and solid solution. Intermediate chlorine sodalite-sulfate noselite solid solutions, produced at temperatures above the solvus, were used as starting materials for exsolution experiments. Then, they were held at temperatures below the solvus, whereupon two phases exsolved. Solid solution experiments were carried out with equal amounts of the synthetic end-members, chlorine sodalite and sulfate noselite, thoroughly mixing them by grinding, and inducing solid solution by holding them at given temperatures. The reactions took place at 600°C, but at 500°C equilibrium was not reached.

The error in the location of the solvus, estimated from the scattered points in Fig. 4, is ± 3 mol percentage at the sides, and $\pm 10^\circ\text{C}$

Table 10. Experimental data on determination

Run #	Starting Materials	Temp. (°C)	Press. (bars)	Time (hours)	211	
					$2\theta_{\text{CuK}\alpha}$	d
HR-1	$\text{Ne}_{75}(\text{NaCl}_{50} \cdot \frac{1}{2}\text{Na}_2\text{SO}_{4.50})_{25}$	600	2000	240	24.550 24.058	3.6260 3.6990
HR-2	"	800	2000	240	24.542 24.080	3.6271 3.6957
HR-3	"	850	2000	240	24.539 24.110	3.6275 3.6911
DR-M1	$\text{Sod}_{50} + \text{Nos}_{50}$	600	1	720	24.540 24.053	3.6274 3.6998
DR-U1	$(\text{Sod}_{50}\text{Nos}_{50})_{\text{ss}}$	600	1	720	24.521 24.081	3.6302 3.6955
DR-M2	$\text{Sod}_{50} + \text{Nos}_{50}$	700	1	720	24.540 24.061	3.6274 3.6985
DR-U2	$(\text{Sod}_{50}\text{Nos}_{50})_{\text{ss}}$	700	1	720	24.532 24.070	3.6286 3.6972
DR-M3	$\text{Sod}_{50} + \text{Nos}_{50}$	800	1	240	24.545 23.980	3.6267 3.7109
DR-U3	$(\text{Sod}_{50}\text{Nos}_{50})_{\text{ss}}$	800	1	240	24.520 24.102	3.6303 3.6923
DR-M4	$\text{Sod}_{50} + \text{Nos}_{50}$	800	1	408	24.527 24.024	3.6293 3.7042
DR-U4	$(\text{Sod}_{50}\text{Nos}_{50})_{\text{ss}}$	800	1	408	24.521 24.036	3.6302 3.7023
DR-M5	$\text{Sod}_{50} + \text{Nos}_{50}$	900	1	240	24.506 24.053	3.6323 3.6997
DR-U5	$(\text{Sod}_{50}\text{Nos}_{50})_{\text{ss}}$	900	1	240	24.445 24.115	3.6413 3.6904
DR-M6	$\text{Sod}_{50} + \text{Nos}_{50}$	900	1	720	24.469 24.076	3.6378 3.6962
DR-U6	$(\text{Sod}_{50}\text{Nos}_{50})_{\text{ss}}$	900	1	720	24.462 24.082	3.6388 3.6953
DR-M7	$\text{Sod}_{50} + \text{Nos}_{50}$	1000	1	240	24.515 23.995	3.6310 3.7086
DR-U7	$(\text{Sod}_{50}\text{Nos}_{50})_{\text{ss}}$	1000	1	240	24.322 24.290	3.6594 3.6642
DR-M8	$\text{Sod}_{50} + \text{Nos}_{50}$	1000	1	570	24.387 24.192	3.6498 3.6788
DR-U8	$(\text{Sod}_{50}\text{Nos}_{50})_{\text{ss}}$	1000	1	570	24.340 24.224	3.6568 3.6740
DR-M9	$\text{Sod}_{50} + \text{Nos}_{50}$	1050	1	312	24.302	3.6624
DR-U9	$(\text{Sod}_{50}\text{Nos}_{50})_{\text{ss}}$	1050	1	312	24.304	3.6621
DR-M10	$\text{Sod}_{50} + \text{Nos}_{50}$	1050	1	576	24.308	3.6615
DR-U10	$(\text{Sod}_{50}\text{Nos}_{50})_{\text{ss}}$	1050	1	576	24.306	3.6618
DR-M11	$\text{Sod}_{50} + \text{Nos}_{50}$	1025	1	500	24.318 24.285	3.6601 3.6624
DR-U11	$(\text{Sod}_{50}\text{Nos}_{50})_{\text{ss}}$	1025	1	500	24.302	3.6624

of solvus of sodalite-noselite series

310		222		a_0	Compositions
$2\theta_{\text{CuK}\alpha}$	d	$2\theta_{\text{CuK}\alpha}$	d		
31. 837	2. 8108	34. 969	2. 5658	8. 886	Sod ₉₇ Nos ₃
31. 195	2. 8670	34. 255	2. 6176	9. 064	Nos ₉₆ Sod ₄
31. 822	2. 8120	34. 954	2. 5669	8. 889	Sod ₉₆ Nos ₅
31. 225	2. 8644	34. 302	2. 6142	9. 055	Nos ₉₁ Sod ₉
31. 817	2. 8124	34. 948	2. 5673	8. 892	Sod ₉₄ Nos ₆
31. 252	2. 8620	34. 345	2. 6110	9. 049	Nos ₈₆ Sod ₁₄
31. 830	2. 8113	34. 960	2. 5664	8. 888	Sod ₉₆ Nos ₄
31. 201	2. 8665	34. 263	2. 6171	9. 065	Nos ₉₅ Sod ₅
31. 812	2. 8129	34. 932	2. 5684	8. 896	Sod ₉₃ Nos ₇
31. 232	2. 8638	34. 302	2. 6142	9. 054	Nos ₉₀ Sod ₁₀
31. 829	2. 8114	34. 955	2. 5668	8. 888	Sod ₉₆ Nos ₄
31. 211	2. 8656	34. 270	2. 6165	9. 061	Nos ₉₄ Sod ₆
31. 839	2. 8105	34. 947	2. 5674	8. 890	Sod ₉₅ Nos ₅
31. 222	2. 8646	34. 289	2. 6151	9. 057	Nos ₉₂ Sod ₈
31. 832	2. 8111	34. 980	2. 5650	8. 886	Sod ₉₆ Nos ₄
31. 082	2. 8772	34. 150	2. 6254	9. 093	Nos ₉₅ Sod ₅
31. 794	2. 8144	34. 918	2. 5694	8. 897	Sod ₉₁ Nos ₉
31. 250	2. 8621	34. 320	2. 6128	9. 047	Nos ₇₇ Sod ₂₃
31. 816	2. 8125	34. 941	2. 5678	8. 892	Sod ₉₄ Nos ₆
31. 141	2. 8719	34. 231	2. 6194	9. 082	Nos ₉₁ Sod ₉
31. 801	2. 8138	34. 931	2. 5685	8. 894	Sod ₉₃ Nos ₇
31. 157	2. 8705	34. 250	2. 6180	9. 077	Nos ₈₈ Sod ₁₂
31. 789	2. 8148	34. 912	2. 5698	8. 898	Sod ₉₁ Nos ₉
31. 147	2. 8714	34. 271	2. 6164	9. 071	Nos ₈₆ Sod ₁₄
31. 718	2. 8210	34. 828	2. 5759	8. 920	Sod ₈₁ Nos ₁₉
31. 252	2. 8620	34. 362	2. 6097	9. 046	Nos ₇₅ Sod ₂₅
31. 746	2. 8185	34. 862	2. 5734	8. 912	Sod ₈₅ Nos ₁₅
31. 217	2. 8651	34. 318	2. 6130	9. 056	Nos ₈₀ Sod ₂₀
31. 740	2. 8191	34. 852	2. 5742	8. 913	Sod ₈₄ Nos ₁₆
31. 222	2. 8646	34. 323	2. 6126	9. 054	Nos ₇₉ Sod ₂₁
31. 790	2. 8148	34. 925	2. 5689	8. 898	Sod ₈₈ Nos ₁₂
31. 130	2. 8729	34. 188	2. 6229	9. 085	Nos ₉₂ Sod ₈
31. 535	2. 8369	34. 648	2. 5888	8. 967	Sod ₅₇ Nos ₄₃
31. 510	2. 8391	34. 600	2. 5923	8. 977	Nos ₅₁ Sod ₄₉
31. 641	2. 8276	34. 743	2. 5820	8. 940	Sod ₇₀ Nos ₃₀
31. 401	2. 8487	34. 481	2. 6010	9. 007	Nos ₅₅ Sod ₃₅
31. 614	2. 8300	34. 713	2. 5842	8. 947	Sod ₆₆ Nos ₃₄
31. 431	2. 8461	34. 525	2. 5978	8. 997	Nos ₆₀ Sod ₄₀
31. 525	2. 8378	34. 625	2. 5905	8. 973	Sod ₅₄ Nos ₄₆
31. 525	2. 8378	34. 630	2. 5902	8. 972	Sod ₅₄ Nos ₄₆
31. 540	2. 8365	34. 633	2. 5899	8. 969	Sod ₅₅ Nos ₄₅
31. 520	2. 8382	34. 634	2. 5899	8. 970	Sod ₅₄ Nos ₄₆
31. 554	2. 8352	34. 647	2. 5889	8. 966	Sod ₅₇ Nos ₄₃
31. 512	2. 8390	34. 604	2. 5920	8. 976	Nos ₄₉ Sod ₅₁
31. 521	2. 8382	34. 631	2. 5901	8. 973	Sod ₅₃ Nos ₄₇

Fig. 4. The chlorine sodalite—sulfate noselite solvus.

at the top. The composition at the top of the solvus is $\text{Sod}_{54}\text{Nos}_{46}$, and the temperature at the top is $1035^{\circ} \pm 10^{\circ}\text{C}$.

Space Groups of Sodalite and Noselite, and Polymorphism of Noselite:

Pauling (1930) reported that he perceived 432 reflexion in a Laue photograph and 210 reflexion in an oscillation photograph, and he showed that the lattice was a primitive cubic one in close approximation to a body-centered cubic one, and chose the space group $P\bar{4}3n$ for sodalite. Barth (1932), and Deer, Howie and Zussman (1963) chose the space group $P\bar{4}3m$ for sodalite and noselite. Kalaczkowska (1935) chose the space group $I\bar{4}3m$ for sodalite by taking roation photographs. Recently, Ueda and Tatekawa (1964) reported that the space group of sodalite is neither $P\bar{4}3n$ nor $P\bar{4}3m$ but $I\bar{4}3m$ by taking Weissenberg photographs of natural sodalites from four different localities.

We perceived weak 210 reflexion on an X-ray powder diffraction pattern of sodalite from the Princers Mine, Canada, but in the X-ray

Table 11. The changes by heat treatment at temperatures 400°, 600°, 700°, 800° and 1100°C, of X-ray powder diffraction patterns of natural noselite from Rieden, Eifel, Germany.

<i>hkl</i>	Natural noselite from Eifel, Germany		Heat treatment $T=400^{\circ}\text{C}$ $P=1$ atm. Time=120 hours		Heat treatment $T=600^{\circ}\text{C}$ $P=1$ atm. Time=240 hours		Heat treatment $T=700^{\circ}\text{C}$ $P=1$ atm. Time=72 hours		Heat treatment $T=800^{\circ}\text{C}$ $P=1$ atm. Time=240 hours		Heat treatment $T=1100^{\circ}\text{C}$ $P=1$ atm. Time=100 hours	
	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>
100	—	—	9.1317	12	9.1290	11	—	—	—	—	—	—
110	6.4384	31	6.4467	39	6.4467	35	6.4467	40	6.4477	37	6.4384	33
111	—	—	5.2721	6	5.2715	7	—	—	—	—	—	—
200	4.5559	9	4.5474	8	4.5488	7	—	—	4.5455	7	—	—
211	3.7110	130	3.7203	130	3.7192	130	3.7130	130	3.7145	130	3.7124	130
310	2.8809	25	2.8808	29	2.8806	28	2.8732	20	2.8775	23	2.8749	25
222	2.6279	31	2.6288	49	2.6291	46	2.6240	40	2.6285	45	2.6233	47
321	2.4348	9	2.4340	13	2.4340	15	2.4292	11	2.4348	15	2.4307	19
400	2.2761	7	2.2772	15	2.2772	15	2.2736	14	2.2772	15	2.2746	16
a_0	9.104Å		9.109Å		9.107Å		9.088Å		9.105Å		9.091Å	

powder diffraction patterns of synthetic minerals of sodalite subgroup only the reflexions of $h+k+l=2n$ make their appearance (Table 5).

However, in the synthetic minerals which belong to the noselite subgroup the strong reflexions of $h+k+l=2n+1$ appear in the X-ray powder diffraction patterns, and this fact is a definite reason that the lattice of synthetic noselite subgroup is a primitive one (Table 6). But, in noselite from Rieden, Eifel, Germany, the reflexions of $h+k+l=2n+1$ do not appear in the X-ray powder diffraction pattern but appear as weak reflexions in oscillation photographs. The various lattices of the transitional states from a primitive cubic one ($P\bar{4}3m$) to a primitive cubic one in close approximation to body-centered cubic one ($I\bar{4}3m$) seem to be found in noselites. The changes by heat treatment of the X-ray powder diffraction patterns of natural noselite from Rieden, Eifel, are shown in Table 11. This noselite, by annealing at temperatures of $400^{\circ}\sim 600^{\circ}\text{C}$, gives rise to a phase in which appear more distinct reflexions of $h+k+l=2n+1$.

With regard to the structural relationship between sodalite and noselite, Saalfeld confirmed Machatschki's suggestion (1934) that the $(\text{SO}_4)^{-2}$ ions (one per cell) are distributed in disorder among the two sites, (000) and $(\frac{1}{2}\frac{1}{2}\frac{1}{2})$, which are occupied by chlorine in sodalite, and he has shown that the space group of a synthetic tungstate noselite is $P\bar{4}3m$, and is the same as that of sulfate noselite. On the other hand, Barth (1932) showed that the $(\text{SO}_4)^{-2}$ ions occupy only the (000) sites and not the $(\frac{1}{2}\frac{1}{2}\frac{1}{2})$ sites. It is induced that in Barth's orderly model the reflexions of $h+k+l=2n+1$ appear distinctly, and in Saalfeld's disorderly model they do not appear. Recently, Kubo and Yamaguchi (1967) gave an experimental datum which confirmed this hypothesis.

The cell dimensions of the synthetic minerals of the noselite subgroup change according to difference of the conditions of syntheses as shown in Tables 7 and 9; especially in sulfate noselite the change from $9.074\text{\AA}$ to $9.106\text{\AA}$. But, the cell dimensions of the minerals of

the sodalite subgroup are nearly constant. This polymorphic relationship in sulfate noselite seems to be the order-disorder polymorphism, which is related to the order-disorder distribution of $(\text{SO}_4)^{-2}$ ions in the two sites, (000) and $(\frac{1}{2} \frac{1}{2} \frac{1}{2})$. This problem requires further investigation by means of detailed structural analysis.

Summary

The results of our experiment can be summarized as follows:

1. The nine end members of sodalite group, that is, chlorine sodalite, bromine sodalite, iodine sodalite, hydroxylsodalite, carbonate noselite, sulfate noselite, chromate noselite, molybdate noselite and tungstate noselite, are synthesized under hydrothermal and dry conditions.
2. These minerals can be divided into two subgroups on the basis of the characteristics of the X-ray powder diffraction patterns and the chemical formulae. The minerals which belong to the sodalite subgroup are chlorine sodalite, bromine sodalite, iodine sodalite and hydroxylsodalite. Those of the noselite subgroup are carbonate noselite, sulfate noselite, chromate noselite, molybdate noselite and tungstate noselite.
3. The variation of cell dimensions with its composition seems to indicate that the non-silicate portion, that is, anion of the chemical formula, controls the cell size of each of these minerals. Tungstate noselite has the largest cell volume, and hydroxylsodalite the smallest cell volume.
4. The dissociation temperatures of chlorine sodalite and sulfate noselite are $1230^\circ \pm 5^\circ\text{C}$ in chlorine sodalite and $1255^\circ \pm 5^\circ\text{C}$ in sulfate noselite.
5. The chlorine sodalite-sulfate noselite series make complete solid solution at temperatures above 1050°C . The solvus of this series was determined at temperatures below 1050°C under atmospheric pressure.
6. These experiments indicate that there exist high- and low-tem-

perature forms of sulfate noselite. It seems that the polymorphism is related to the order-disorder distributions of $(\text{SO}_4)^{-2}$ ions (one per cell) among the two sites, (000) and $(\frac{1}{2} \frac{1}{2} \frac{1}{2})$, and there are transitional states between the order form and the disorder form. The structural relation of high- and low-temperature forms in the sulfate noselite is expected to exist in the other minerals which belong to the noselite subgroup, but, to prove it, we must conduct further research by means of detailed structural analysis.

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