

THE MINERALOGICAL COMPOSITION OF SOME  
NEPHELINE ALTERATION PRODUCTSA. D. EDGAR, *Department of Geology, University of Western  
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## ABSTRACT

Sixteen samples of variously labelled alteration products of nepheline, principally "hydronephelites" and "ranites," have been examined by  $x$ -ray diffraction methods. The majority of these samples consist mainly of natrolite, a phase resembling the "anhydrous" natrolite of Peng (1955) and a variety of minor minerals. In view of the discrepancies between the data of Peng (1955) and Fang (1963), it is suggested that this "anhydrous" natrolite does not in fact represent a dehydrated form of natrolite. The  $x$ -ray patterns indicate no lines corresponding to the synthetic nepheline hydrates and it is concluded, both from experimental and theoretical considerations, that "hydronephelites" and "ranites" are not the natural analogues of these synthetic products.

## INTRODUCTION

The terms "hydronephelite," "ranite" and "gieseckite" are often applied to low temperature, alteration products of nepheline. It is now generally recognized that "hydronephelite" and "ranite" are not true mineral species but intimate mixtures of some of the following: natrolite, other zeolites, muscovite, various feldspathoids and alumina minerals. No definite distinction, if any exists, has been made between these substances. The name "hydronephelite" was first used by Clarke (1886) for material from Litchfield, Maine, intimately admixed and derived from the alteration of sodalite. Clarke proposed that the formula for this mineral was  $\text{HN}_2\text{Al}_3\text{Si}_3\text{O}_{12} + 3\text{H}_2\text{O}$ . "Ranite," named after the Norse sea-god, Ran was proposed by Paijkull (1874) for material from Låven, Lange-sundsfjord, Norway, of composition  $(\text{Na}_2\text{Ca})\text{Al}_2\text{Si}_2\text{O}_8 + 2\text{H}_2\text{O}$ . Brögger (1890) has suggested that "ranites" are similar to spreustein, one of many names given to natrolites from the augite-syenites of this area. The term "gieseckite," named after its discoverer Ch. Giesecke, who brought samples from Akulliorsuk and Kangerdluarsuk, Greenland, in the early years of the nineteenth century, was originally described by Allan (1813). This material occurs in Greenland in compact feldspar and was reported as a hydrous pseudomorph after nepheline. "Gieseckite" also occurs at Diana, Lewis Co., New York, as a substance with waxy appearance and optical properties suggesting it is colloidal.

It has been suggested that "hydronephelite" may be the natural analogue of the synthetic nepheline hydrate I (Barrer and White, 1952), but no  $x$ -ray data on natural "hydronephelite" have been published to substantiate this suggestion. Numerous writers have reported "hydronephelites" as low temperature alteration products of nephelines but the

physical appearance and chemical composition of this substance appears to be very varied.

Walker and Parsons (1926) describe "hydronephelite" as white-pink procellanous alteration of cancrinite in nepheline syenites from the French River area, Ontario. Chemical analyses and specific gravity determinations of this material showed it to be heterogeneous. Large variations were found in the  $\text{SiO}_2$ ,  $\text{CaO}$  and  $\text{Na}_2\text{O}$  contents of three analysed samples: The  $\text{CaO}$  and  $\text{Al}_2\text{O}_3$  contents being much higher than those of natrolite and the  $\text{Na}_2\text{O}$  content considerably lower. Tilley and Harwood (1931) described a fibrous "hydronephelite" in the titanaugite rocks at Scawt Hill, Co. Antrim and gave refractive indices ( $\omega=1.490$ ,  $\epsilon=1.500$ ) comparable to those for nepheline hydrate I ( $\alpha=1.499$ ,  $\gamma=1.503$ ). Thugutt (1932) suggested that "hydronephelite" was a mixture of natrolite and hydrargillite and that it could be distinguished from natrolite by its lower birefringence. From an analysis of optically homogeneous "hydronephelite" from Hawaii, Dunham (1933) suggested that this material might be a solid solution of natrolite and diaspore as the analysis showed considerably higher  $\text{Al}_2\text{O}_3$  than required by the natrolite formula. Moyd (1949), describing the nepheline-bearing rocks of south-eastern Ontario, has reported individual nepheline crystals showing as many as three zonally arranged alteration products—opaque white cancrinite, fine-grained pink material "(hydronephelite)" and fine grained green material "gieseckite." The "hydronephelite" is believed to be a mixture of muscovite and natrolite and the "gieseckite" a fine grained muscovite. Moyd believes the "hydronephelite" and "gieseckite" are produced by low-temperature hydrothermal activity. Oftedahl (1952) showed that "hydronephelite" consists of mixtures of natrolite and a pseudo-hexagonal mineral which he suggested might be true "hydronephelite."

Experimental evidence indicates that nepheline, of ideal composition  $\text{NaAlSi}_3\text{O}_8$ , is not stable at temperatures below about  $500^\circ\text{C}$ . at moderate water vapour pressures in the presence of excess water (Barrer and White, 1952; Sand *et al.*, 1957; Saha, 1961) but decomposes to produce nepheline hydrate I. Barrer and White (1952) published refractive indices and  $d$  values of this phase and suggested that it probably had orthorhombic symmetry. Edgar (1964a) confirmed this symmetry and published indexed  $d$  values and approximate cell parameters. This author has also shown that nepheline hydrate I can only be preserved at room temperature by rapid cooling.

Saha (1961) has shown that nepheline hydrate I can only be grown from starting compositions of  $\text{NaAlSi}_3\text{O}_8$ , and that the presence of any excess silica completely inhibits its growth, suggesting that nepheline

hydrate I would be an unlikely phase in nepheline-bearing rocks, as natural nephelines invariably contain silica in excess of that of the ideal composition ( $\text{NaAlSiO}_4$ ). Further evidence that nepheline hydrate is unlikely to be found in nature is shown by unsuccessful attempts to synthesize hydrothermally a nepheline hydrate from a composition of  $\text{Na}_3\text{KAl}_4\text{Si}_4\text{O}_{16}$  (more closely approaching the composition of natural nephelines) even at temperatures as low as  $300^\circ\text{C}$ . and at a water vapour pressure of  $1,000\text{ kg/cm}^2$  (Edgar, unpubl. data). Saha (1961) also shows that the hydrothermal treatment of natural nepheline, under conditions similar to those which produce nepheline hydrate I from the synthetic composition, produce analcite. These experimental results strongly indicate that nepheline hydrate I is unlikely to be found in nature, although, as Saha (1961) has pointed out, the possibility that this phase occurs metastably in the hydrothermal experiments should be kept in mind. Certainly it seems improbable that the pseudo-hexagonal mineral coexisting with natrolite in the "hydronephelite" described by Oftedahl (1952) can be the same as nepheline hydrate I as it seems unlikely that natrolite, containing considerably more silica than ideal nepheline ( $\text{NaAlSiO}_4$ ), could coexist with a phase which apparently cannot exist with any silica in excess of that represented by  $\text{NaAlSiO}_4$ .

The present study was undertaken with two objectives in mind; first, to determine by  $x$ -ray powder diffraction methods what minerals were common in "hydronephelites," "ranites" and "gieseckites"; and second to show whether any of these minerals correspond with the synthetic nepheline hydrates. For this purpose, ten samples labelled "hydronephelite," three samples labelled "ranite" and one sample labelled "gieseckite" were  $x$ -rayed. In addition, a sample labelled "spreustein after sodalite" and one labelled "nephelite var. elaeolite" were examined. Ten of these samples were from Ontario localities and the remainder from Langesundsfjord, Norway.

#### DESCRIPTION OF SAMPLES

Of the sixteen samples studied, four were obtained from the Dana mineral collection of the University of Western Ontario, eight were obtained from the Department of Mineralogy, Royal Ontario Museum, Toronto, through the courtesy of Dr. J. A. Mandarino, two were obtained from the Geological Survey of Canada, Ottawa, through the courtesy of Mr. H. R. Steacy, one was obtained from the Ontario Department of Mines, Toronto, through the courtesy of Dr. D. F. Hewitt, and one was obtained from the University of British Columbia, Vancouver, through the courtesy of Dr. R. M. Thompson. Brief descriptions and localities of each sample are listed in Table 1.

TABLE 1. DESCRIPTIONS OF SAMPLES

No.	Donor	Locality	Description
a) <i>Samples Labelled Hydronephelite</i>			
1	G.S.C. <sup>1</sup>	French River, Ontario	Bright pink mineral occurring at the contact between massive yellow cancrinite and a pink syenite. Mr. Steacy (pers. comm.) states that hydronephelite yielded a good x-ray pattern for natrolite with a few extra lines.
2	O.D.M.	Blue Mountain, Methuen Twp., Ontario	Pink hydronephelite in patches and stringers in a drill core of coarse grained nepheline syenite.
3	U.W.O. (5376)	Princess Quarry, lot 25, Concession XIV, Dungannon Twp., Ontario	Massive reddish hydronephelite in nepheline pegmatite.
4	U.W.O. (4497)	Goulding-Keene Quarry, lot 12, Concession XI, Dungannon Twp., Ontario	Massive reddish hydronephelite in nepheline pegmatite. Hydronephelite also occurs along cleavage planes of nepheline crystals.
5	U.W.O. (6128)	York River Quarry, lot 12, Concession XI, Dungannon Twp., Ontario	Similar to sample 4.
6	R.O.M. (M19962)	Port Coldwell, Ontario	Earthy reddish material in coarse grained nepheline syenite.
7 <sup>2</sup>	R.O.M. (E2186)	Läven, Langesundsfjord, Norway	Dull grey material, in patches of very coarse-grained nepheline syenite or nepheline pegmatite.
8	R.O.M. (M15065)	Bigwood Twp., Ontario	Massive pale pink material associated with fine-grained syenite.
9	R.O.M. (E2187)	Läven, Langesundsfjord, Norway	Similar to sample 7.
10	R.O.M. (M19890)	Lot 29, Concession IV, Glamorgan Twp., Ontario	Lilac coloured material in patches and stringers in coarse-grained nepheline syenite.
b) <i>Samples Labelled Ranite</i>			
11	R.O.M. (M6287)	Läven, Langesundsfjord, Norway	Dull grey material in medium-grained nepheline syenite.
12	R.O.M. (M16288)	Port Coldwell, Ontario	Massive reddish material, in coarse-grained pyroxene-rich nepheline syenite.
13	G.S.C.	Barkevik, Langesundsfjord, Norway	Massive pink material in coarse-grained nepheline syenite.
c) <i>Others</i>			
14 <sup>3</sup>	R.O.M. (E2191)	Ytтро Arö, Langesundsfjord, Norway	Pale pink material, in medium-grained biotite-rich nepheline syenite.
15 <sup>4</sup>	U.B.C. (M375E2)	Läven, Langesundsfjord, Norway	Appears to contain two varieties of nepheline, pink massive material and reddish purple crystals in coarsely crystalline biotite rich rock.
16 <sup>5</sup>	U.W.O. (1809)	Craigmont, Raglan Twp., Ontario	Dull green material.

<sup>1</sup> Abbreviations of Donors: G.S.C.—Geological Survey of Canada; O.D.M.—Ontario Department of Mines; R.O.M.—Royal Ontario Museum; U.B.C.—University of British Columbia; U.W.O.—University of Western Ontario. Bracketed numbers after donor indicate their sample numbers.

<sup>2</sup> Also contains thompsonite.

<sup>3</sup> Labelled spreustein after sodalite.

<sup>4</sup> Labelled nephelite var. elaeolite.

<sup>5</sup> Labelled giessckite.

## PREPARATION OF SAMPLES

*Separation.* All specimens were examined with a binocular microscope and the most suitable material selected for further study. Because of the fine grained nature and similarity in specific gravity of most "hydronephelites" and "ranites," no attempt was made to separate the components of these materials by heavy liquid techniques. In the majority of samples, the colour of the alteration product was sufficiently distinctive from the host minerals (mainly nepheline and albite) to permit separation by hand-picking. Accordingly, the "hydronephelites" and other samples were crushed to pass about 100 mesh and approximately one half gram was separated by this method.

*X-ray examination.* Smear mounts of the separated material were prepared and run on a Philips high angle diffractometer using filtered Cu-radiation, and the following settings: scan speed  $\frac{1}{4}^{\circ} 2\theta/\text{min.}$ , chart speed 15 inches/hour, slit widths  $1^{\circ}$ . Periodic checks on the alignment of the goniometer were made by running an external Si standard. The d values quoted are believed accurate to within  $\pm 0.1$  at low angles and  $\pm .01$  at high angles. The  $2\theta$  values for each sample were measured and converted to d spacings. These spacings were then used to identify the minerals present in the "hydronephelites" and other material.

*Optical examination.* The fine grained nature of the majority of samples did not make optical examination feasible. A thin section of sample 2 revealed a mass of fibrous material which could not be positively identified. Refractive index measurements were made on the crushed samples by the oil immersion method. These confirmed in all cases the x-ray identifications of the major mineral components.

*Specific gravity measurements.* As a further confirmation of the x-ray identifications, the specific gravities of a few selected samples of "hydronephelites" and "ranites" were made using a Berman balance. For this purpose small chip samples were examined optically to ensure purity and their specific gravities determined using pure toluene as a liquid media.

## RESULTS

*X-ray analysis.* The d spacings, visually estimated intensities and identification of the sixteen samples studied are listed in Table 2. In some samples, the number of mineral phases and the poorly crystallized sample did not permit positive identification of all minerals present. In other cases, certain peaks could not be identified. These cases are indicated in Table 2.

TABLE 2. RESULTS OF X-RAY ANALYSES

Sample No. 1			Sample No. 2			Sample No. 3		
d(Å)	I (est.)	Mineral	d(Å)	I (est.)	Mineral	d(Å)	I (est.)	Mineral
6.5	50	Na	9.9	80	M	6.5	80	N or Na
6.3	20	Ca	7.1	20	?	5.9	10	Na?
5.8	70	Na	5.6	50	An	5.64	15	Na
4.70	20	Ca	5.2	10	?	4.53	10	N
4.63	50	Na	5.0	60	M	4.41	10	?
4.40	60	Ca?	4.47	40	M	4.15	20	Na
4.13	50	Na	3.75	30	M	4.10	15	N
4.09	50	N	3.65	30	Ab+An	3.47	10	N or Na
3.64	50	Ca	3.42	70	An	3.23	100	Ne?
3.49	10	N or Na	3.33	100	M	3.19	10	N or Na
3.36	10	Ca?	3.23	50	Ne?	3.14	10	Na
3.23	100	Ca	3.19	90	Ab	3.01	50	Ne?
3.20	80	N or Ab	3.08	10	An	2.95	10	Na
3.16	20	N or Na	3.03	5	Ct?	2.93	5	N
3.02	80	Ct?	2.93	10	An or Ne?	2.85	40	Na
2.93	30	Na	2.56	5	M	2.83	50	N
2.84	60	N or Na	2.00	40	M	2.17	7	N
2.73	15	Ca				1.79	5	N
2.56	15	N or Na						
2.40	10	N or Na						
2.15	5	N?						
2.10	5	Ct						

  

Sample No. 4			Sample No. 5			Sample No. 6		
d(Å)	I (est.)	Mineral	d(Å)	I (est.)	Mineral	d(Å)	I (est.)	Mineral
6.6	100	Na	6.5	10	Na	6.5	100	Na
5.9	50	Na	6.4	8	Ab	6.1	30	?
4.67	40	Na	5.6	5	An?	5.9	70	Na
4.55	30	N	4.01	15	Ab	4.63	50	Na
4.37	50	Na	3.85	7	Ct?	4.37	60	Na
4.15	60	Na	3.76	20	Ab	4.12	60	N or Na
4.11	70	N	3.41	20	An?	3.51	10	N or Na
3.28	10	Ne?	3.18	100+	Ab	3.26	5	?
3.20	30	N or Na	3.02	25	Ct	3.19	50	N or Na
3.15	40	Na	2.96	5	Ab	3.16	50	Na
3.04	40	Ne?	2.88	20	Na	3.10	10	Na
2.95	30	Na	2.32	5	Ab	2.94	40	Na
2.86	60	Na	2.12	7	Ab	2.85	100	Na
2.57	10	N or Na	1.98	7	?	2.67	10	N
2.45	10	Na				2.57	20	Na
2.42	7	N				2.51	5	?
2.25	7	N				2.44	20	Na
2.20	5	?				2.41	10	?
2.18	20	Na				2.32	5	N or Na
1.85	5	N?				2.31	5	?
1.83	5	?				1.87	5	N
1.80	5	N or Na				1.73	5	N
1.72	5	N or Na				1.46	5	N or Na
1.70	5	N or Na						
1.63	5	N or Na						

For list of abbreviations, see page 985

TABLE 2--(continued)

Sample No. 7			Sample No. 8			Sample No. 9		
d(Å)	I (est.)	Mineral	d(Å)	I (est.)	Mineral	d(Å)	I (est.)	Mineral
9.8	5	M?	6.6	70	Na	6.4	30	Ab
6.4	40	Ab	5.9	60	Na	3.88	5	Ct
4.21	10	Ne	4.64	70	Na	3.85	10	Ne
4.10	10	?	3.47	70	Na	3.80	70	Ab
4.03	10	Ab	4.13	50	Na	3.72	10	?
3.85	20	Ne	3.50	10	N or Na	3.68	10	Ab
3.76	20	M	3.35	20	M?	3.49	10	?
3.68	20	Ab	3.27	5	Ne	3.39	10	?
3.48	15	M	3.17	30	N or Na	3.25	100+	Ne
3.36	25	M	3.04	90	Ct?+Ne?	3.20	100+	Ab
3.24	100	Ne?	2.94	30	Na	3.04	10	Ct
3.19	100	Ab	2.86	100	Na	2.97	15	Ab+Ne?
2.95	15	Ab	2.68	50	N	2.94	10	?
2.93	15	?	2.57	20	N or Na	2.91	7	Ne
2.90	15	Ne	2.44	10	Na	2.44	5	Ab
2.61	5	Ne	2.42	5	N or Na	2.17	10	Ab?
2.56	5	Ab	2.28	20	Ct	1.87	5	Ct?
2.44	5	Ab	2.19	10	Na	1.82	5	Ab
2.32	5	Ab	2.10	5	Ct	1.72	5	Ab
2.16	25	M?	2.06	5	N or Na	1.58	7	Ab
2.12	15	Ab	1.91	5	Ct	1.46	5	Ab
1.81	15	Ab	1.46	5	N or Na			
1.66	5	Ab?						
1.59	5	Ab						
1.57	5	Ne						
1.47	5	Ab						

  

Sample No. 10			Sample No. 11			Sample No. 12		
d(Å)	I (est.)	Mineral	d(Å)	I (est.)	Mineral	d(Å)	I (est.)	Mineral
10.0	30	M	6.4	25	Ab	6.5	100	Na
5.6	50	An	4.25	7	Ne	5.9	50	Na
5.3	10	?	4.04	20	Ab	4.63	30	Na
5.1	5	?	3.87	20	Ne	4.37	40	Na
4.98	10	M	3.79	30	Ab	4.14	40	Na
4.87	15	An	3.67	20	Ab	3.98	20	?
4.65	15	Ca?	3.49	10	?	3.87	30	?
4.51	20	M?	3.38	15	?	3.18	30	N or Na
4.37	10	?	3.25	50	Ne	3.10	10	Na
4.13	10	M	3.19	100	Ab	2.94	10	Na
3.66	40	An	3.15	30	?	2.86	90	Na
3.44	100	An	3.04	50	Ne	2.18	5	Na
3.34	50	M	2.96	20	Ab	2.03	5	N or Na
3.08	40	?	2.94	20	Ne?	1.63	5	N or Na
3.04	40	Ct?	2.57	7	Ab			
2.93	20	An	2.12	5	Ne			
3.00	30	M	1.89	5	Ab?			
2.67	20	An						
2.56	20	M						
2.35	5	?						
2.09	5	Ct?						
2.00	5	M?						

TABLE 2—(continued)

Sample No. 13			Sample No. 14			Sample No. 15		
d(Å)	I (est.)	Mineral	d(Å)	I (est.)	Mineral	d(Å)	I (est.)	Mineral
6.5	100	Na	6.5	80	Na	6.6	100	Na
5.9	40	Na	6.1	100	Na?	6.1	10	?
4.64	50	Na	5.9	30	Na	5.91	15	Na
4.59	30	N	4.63	30	Na	4.64	80	Na
4.37	50	Na	4.37	20	Na	4.39	30	Na
4.15	60	Na	4.14	40	Na	4.14	70	Na
3.50	25	N or Na	3.60	5	?	3.51	25	N or Na
3.27	10	?	3.50	5	N or Na	3.28	20	?
3.25	30	Ne?	3.26	5	Ne?	3.19	20	Ab?
3.16	30	Na	3.19	30	Na	3.18	25	N or Na
3.10	15	Na	3.17	30	?	3.11	5	Na
2.94	30	Na	3.15	40	Na	3.08	5	Na
2.81	100	N	3.10	10	Na	2.95	20	Na
2.67	20	N	2.94	25	Na	2.92	15	N
2.57	5	N or Na	2.85	50	Na	1.86	60	Na
2.44	5	Na	2.67	5	N	2.68	20	N
2.41	5	N or Na	2.44	5	Na	2.18	40	Na
2.19	10	Ne?	2.20	5	?	2.07	5	N or Na
2.18	20	Na	2.19	5	?	1.81	10	N or Na
1.80	5	N or Na	2.18	10	N or Na	1.72	10	Na
1.58	25	N or Na	1.86	5	N			
1.46	7	N or Na	1.80	5	N or Na			
1.41	5	N or Na	1.70	5	N or Na			
			1.53	5	N or Na			

  

Sample No. 16			
d(Å)	I (est.)	Mineral	<i>Abbreviations</i>
10.72	70	M	Ab = albite (or soda-plagioclase)
7.2	100	Ch	An = analcite
4.77	50	Ch	Ca = cancrinite
4.51	70	Ch or K	Ch = chlorite
3.55	50	Ch	Ct = calcite
3.35	25	Ch	K = kaolinite (or other clay mineral)
3.34	25	M	M = mica (muscovite)
2.74	20	K	N = natrolite
2.59	30	Ch	Na = "anhydrous" natrolite (nomenclature of Peng, 1955)
2.56	40	Ch or M	Ne = nepheline
2.50	30	Ch or K	? = unidentified
2.39	20	Ch or M	
1.99	20	K or M	
1.81	10	Ch	
1.76	10	Ch	



The exact composition of the micas, chlorites, nephelines and cancrinites were not determined, although in the case of mica, the  $x$ -ray data would appear to indicate that the predominant mica is close to muscovite in composition. No evidence was found to suggest the presence of paragonite which Saha (1961) found associated with nepheline hydrate I in his synthetic studies. It is well known that nepheline  $d$  spacings depend on their composition (Smith and Tuttle, 1957) and cancrinites are also known to have variable  $d$  spacings depending on their compositions (Edgar, 1964b). The plagioclase is probably fairly close to albite in composition. In a few samples, the relative peak intensities did not correspond exactly to those given in the A.S.T.M. index and in the literature. No explanation can be offered for this discrepancy. Sample 16 gave a very poor  $x$ -ray pattern which is in accordance with the suggestion by Dana that "gieseckite" is disordered.

In ten of the sixteen samples, natrolite was found as the major mineral. Plagioclase and nepheline were the major minerals in two samples, analcite in one sample, chlorite in one sample, mica in one sample and plagioclase in one sample.

One interesting result was the appearance of  $d$  spacings corresponding to "anhydrous" natrolite (Peng, 1955) in all samples containing natrolite. The cell sizes, and hence  $d$  values, of "anhydrous" natrolite are problematical. The  $d$  values given by Peng (1955) indicate an increased cell size for the "anhydrous" form of natrolite. This, however, does not agree with the cell sizes given by Fang (1963) for "dehydrated" natrolite in which the dehydrated form had smaller cell sizes than those of regular natrolite. Fang (1963) determined the dehydration temperature using a furnace attachment on oscillation and precision cameras and showed that natrolite dehydrated sharply at 300° C. This temperature is in fairly good agreement with that obtained by the DTA method of Peng (1955) with the exception that Peng found that the dehydration process took place in the temperature range 300°–490° C. This is more fully discussed below.

The possibility that some of the secondary minerals in these samples are due to poor separation cannot be overlooked. This is particularly true in sample 1 (French River, Ontario) in which cancrinite is intimately associated with "hydronephelite." In none of the samples studied do the  $d$  spacings correspond to those of nepheline hydrates I or II (Barrer and White, 1952), nor is there any evidence of diaspore or other alumina-bearing minerals.

*Specific gravity determinations.* Results of specific gravity determinations of six of the samples are given in Table 3. These correspond fairly closely

TABLE 3. SPECIFIC GRAVITY DETERMINATIONS

Sample No.	Specific Gravity ( $\pm 0.005$ )	Minerals Present in Order of Estimated Abundance
2	2.556	Muscovite (2.76 <sup>1</sup> )—Albite (2.5)—Analcite (2.22–2.29)
3	2.371	Natrolite (2.25)—Nepheline (2.55–2.65)
4	2.270	Natrolite (2.25)
6	2.328	Natrolite (2.25)
8	2.457	Natrolite (2.25)—Calcite (2.715)
16	2.662	Chlorite (2.6–3.0)—Muscovite (2.76)— Kaolinite (2.61)

<sup>1</sup> Figures in brackets are specific gravities from Winchell and Winchell (1956). *Elements of Optical Mineralogy*, Part II. John Wiley and Sons, Inc., New York.

to results to be expected from consideration of the various proportions of different minerals in each sample.

#### DISCUSSION OF RESULTS

*Comparison with synthetic products.* As mentioned previously, no *d* values corresponding to nepheline hydrates I and II were found in the samples studied. Although the samples were limited both numerically and geographically and, with the exception of ranite, none are from the type locality, they are believed to be typical “hydronephelites” and “ranites.” It seems unlikely therefore that the nepheline hydrates found in synthetic systems will be found in nature as components of “hydronephelites.” The fact that nepheline hydrates cannot be synthesized from starting material other than pure  $\text{NaAlSiO}_4$ , and that they can only be preserved at room temperature by rapid quenching techniques tends to support this conclusion.

*Mineralogical compositions of hydronephelites, etc.* On the basis of the samples studied, it would appear that “hydronephelites” and “ranites” have similar mineralogical compositions, and are similar in physical appearance. One or both of these terms should possibly be discarded.

The mineral phases found in these samples are typical of the alteration products of nepheline bearing rocks to be expected in a low temperature hydrothermal environment. The presence of analcite as the major mineral in one sample confirms Saha's (1961) experiment in which he produced analcite by the hydrothermal treatment of natural nepheline. Mica, as sericite, is a well known low temperature alteration product of plagio-

clase. The presence of plagioclase (close to albite in composition) and nepheline as major phases in a few samples might suggest that environmental factors, probably principally temperature and/or abundance of water, were different from the conditions under which the samples containing hydrous phases had formed.

One of the most interesting phenomena found in this study is the presence of peaks which correspond closely to those listed by Peng (1955) for a phase which he claimed was "anhydrous" natrolite. As mentioned previously, the data of Peng are not in agreement with that of Fang (1963) who, using different techniques, found that dehydrated natrolite had smaller cell sizes than the "anhydrous" natrolite of Peng. As a decrease in cell size would probably be expected with a water loss, it seems likely that Peng's  $d$  values do not represent those of an anhydrous form of natrolite. Until further data are available, no explanation can be given why similar phases appear both in "hydronephelites" and in the natrolite crystals used in the DTA experiments of Peng. It must, therefore, be concluded that the material found in the present samples is probably not "anhydrous" natrolite although this term is retained in this paper after the usage of Peng. Further support for this conclusion is given from the experiments described in the following paragraph.

Several inconclusive heating experiments were attempted to convert samples entirely to natrolite or "anhydrous" natrolite. Sample 15 was heated at atmospheric pressure in an open container to 550° C. and quenched in an attempt to convert all of the natrolite to "anhydrous" natrolite. This resulted in a product consisting of plagioclase, nepheline and other minor unidentified phases. In a second experiment, sample 14 was heated at 250° C. under 1,000 bars water vapour pressure in a sealed gold capsule with excess water in an attempt to convert all of the "anhydrous" natrolite to natrolite. This resulted in considerably lowered intensity of the characteristic  $d_{3.11}$  "anhydrous" natrolite peak and a slightly lowered intensity of the  $d_{3.08}$  "anhydrous" natrolite peak (Peng, 1955).

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## REFERENCES

- ALLAN, T. (1813) *Ann. Phil.* **2**.
- BARRER, R. M. AND E. A. WHITE (1952) The hydrothermal chemistry of the silicates. Part II, synthetic crystalline aluminosilicates. *Jour. Chem. Soc.* **286**, 1561-1571.
- BRÖGGER, W. C. (1890) *Zeit. Krist.* **16**, 234.
- CLARKE, F. W. (1886) Minerals of Litchfield, Maine. *Am. Jour. Sci.* **31**, 262-272.
- DUNHAM, K. C. (1933) Crystal cavities in lavas from the Hawaiian Islands. *Am. Mineral.* **18**, 369-385.
- EDGAR, A. D. (1964a) A note on the lattice parameters of nepheline hydrate I. *Am. Mineral.* **49**, 1139-1141.
- (1964b) Studies on cancrinites: II—stability fields and cell dimensions of calcium and potassium-rich cancrinites. *Canad. Mineral.* **8**, 53-67.
- FANG, J. H. (1963) Cell dimensions of dehydrated natrolite. *Am. Mineral.* **48**, 414-417.
- MOYD, L. (1949) Petrology of the nepheline and corundum rocks of southeastern Ontario. *Am. Mineral.* **34**, 736-751.
- ØFTEDAHL, C. (1952) On "apoanalcite" and hydronephelite. *Norsk Geol. Tidssk.* **30**, 1-4.
- PAJKULL, S. R. (1874) Inaug. Diss., *Ber. Chem. Ges.* **7**, 1334.
- PENG, C. J. (1955) Thermal analysis study of the natrolite group. *Am. Mineral.* **40**, 834-856.
- SAHA, P. (1961) The system  $\text{NaAlSiO}_4$  (nepheline)— $\text{NaAlSi}_3\text{O}_8$  (albite)— $\text{H}_2\text{O}$ . *Am. Mineral.* **46**, 859-884.
- SAND, L. B., R. ROY, AND E. F. OSBORN (1957) Stability relations of some minerals in the  $\text{Na}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2-\text{H}_2\text{O}$  system. *Econ. Geol.* **52**, 169-179.
- SMITH, J. V. AND O. F. TUTTLE (1957) The system  $\text{KAlSiO}_4-\text{NaAlSiO}_4$  I. The crystalline phases. *Am. Jour. Sci.* **255**, 282-305.
- THUGUTT, ST. J. (1932) Sur l'épinatrolite, mineral composant l'hydronephelinite. *Arch. Mineral. Soc. Sci. Lettres Varsovie*, **7**, 143-144.
- TILLEY, C. E. AND H. F. HARWOOD (1931) The dolerite-chalk contact of Scawt Hill, Co. Antrim. *Mineral. Mag.* **22**, 429-468.
- WALKER, T. L. AND A. L. PARSONS (1926) Minerals from the new nepheline syenite area, French River, Ontario. *Univ. Toronto Studies, Geol. Ser.* **22**, 5-14.

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