

## Synthesis of Scapolite under Magmatic Conditions

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### Abstract

Scapolite was synthesized from a calcite-bearing nepheline syenite in the presence of H<sub>2</sub>O-rich and CO<sub>2</sub>-rich aqueous vapor phases in the melting interval at pressures between 3 and 6 kbar. Electron-microprobe analysis of a scapolite formed at about 6 kbar and 900°C in the presence of a CO<sub>2</sub>-rich aqueous vapor phase gives a structural formula of NaCa<sub>3</sub>Al<sub>5</sub>Si<sub>7</sub>O<sub>24</sub>(CO<sub>3</sub>) (CO<sub>3</sub> assigned arbitrarily). This formula is equivalent to 3 plagioclase (An<sub>67</sub>) + 1 calcite.

A reconnaissance study of phase relations in the melting interval of a calcite-bearing nepheline syenite was carried out in conjunction with a study of melting relations of a simple nepheline syenite with H<sub>2</sub>O and H<sub>2</sub>O + CO<sub>2</sub> vapor phases (Millhollen, 1970, 1971). In the process of this reconnaissance study, scapolite was synthesized at relatively high temperatures and pressures in the melting interval of the calcite-bearing nepheline syenite. Other minerals synthesized in this study include cancrinite, garnet, clinopyroxene, and amphibole.

The chemical composition and norm of the calcite-bearing nepheline syenite is given in Table 1. This rock is from the York River area near Bancroft, Ontario, Canada (Tilley, 1958). The mode contains albite, microcline, nepheline, biotite, minor magnetite, and considerable calcite (15.4 wt percent in the norm).

Experimental runs were made from 0.5 to 6 kbar in cold-seal and internally-heated pressure vessels. Sealed capsules (PdAg or Au) initially contained distilled water or oxalic acid, together with powdered crystalline nepheline syenite. Oxalic acid produces a vapor phase consisting of H<sub>2</sub>O:CO<sub>2</sub> = 50:50 mole ratio under these conditions (Holloway, Burnham, and Millhollen, 1968), but some runs in this study were made with slightly dried oxalic acid that produced a vapor phase of H<sub>2</sub>O:CO<sub>2</sub> = 48:52 mole ratio. During runs above the solidus, some calcite dissociated and some water was dissolved in the melt, so the vapor composition varied from H<sub>2</sub>O-rich in runs with distilled water to relatively CO<sub>2</sub>-rich in runs with oxalic acid. The solubility of CO<sub>2</sub> in nepheline syenite melts under these conditions is believed to be low (Millhollen, 1971).

Figure 1 shows the approximate lower limits of synthesis for scapolite in runs with a H<sub>2</sub>O-rich vapor phase (curve c) and with a relatively CO<sub>2</sub>-rich aqueous vapor phase (curve d). Because of the variable ratio of H<sub>2</sub>O:CO<sub>2</sub> in the vapor for runs above the solidus, these curves in *P-T* projection compare results obtained under variable conditions and are therefore purely descriptive. Scapolite is present at temperatures and pressures above these curves, but the upper synthesis limits were not determined. Curves c and d could not be located exactly because of the difficulty in distinguishing scapolite in small amounts from calcite, which was invariably present. Therefore, scapolite may be present to somewhat lower temperatures than indicated by the dashed curves. No scapolite was identified in runs below 3 kbar.

Also shown in Figure 1 are solidus curves for the Blue Mountain nepheline syenite with nearly pure H<sub>2</sub>O (curve a) and with H<sub>2</sub>O:CO<sub>2</sub> = 50:50 mole ratio (curve b) (Millhollen, 1971). The solidus curves of the calcite-bearing nepheline syenite could not be located readily, but apparently lie very close to the solidus curves shown (Millhollen, 1970). Comparisons of curve a with curve c and of curve b with curve d indicate that in the presence of both H<sub>2</sub>O-rich and CO<sub>2</sub>-rich aqueous vapor phases, respectively, scapolite is stable within the melting interval at relatively high pressures in this system.

An electron-microprobe analysis of scapolite formed at 900° and 6 kbar with a CO<sub>2</sub>-rich vapor phase (from slightly dry oxalic acid) is given in Table 1. In thin section the scapolite in this charge forms large euhedral crystals with moderate birefringence. In addition to about 7 percent scapolite, this charge

contains clinopyroxene, amphibole, calcite, and more than 50 percent glass (melt). Although some chlorine is present in the bulk rock (Table 1), the scapolite was formed in a CO<sub>2</sub>-rich environment, so the deficiency in the scapolite analysis in Table 1 (about 3.7 percent) is probably mostly due to CO<sub>2</sub>. This analysis gives a structural formula of NaCa<sub>3</sub>Al<sub>5</sub>Si<sub>7</sub>O<sub>24</sub>(CO<sub>3</sub>), with CO<sub>3</sub> being assigned arbitrarily. This is consistent with the conclusions of Orville (in preparation) and Evans, Shaw, and Haughton (1969) that at Ca/(Na + Ca) = 0.75 substitution of CO<sub>3</sub> for Cl is complete. This formula is equivalent to 2(CaAl<sub>3</sub>Si<sub>2</sub>O<sub>8</sub>)·(NaAlSi<sub>3</sub>O<sub>8</sub>)·(CaCO<sub>3</sub>) or 3 plagioclase (An<sub>67</sub>) + 1 calcite. Orville (in preparation) indicates that natural scapolites of this composition (also called mizzonites) are very common.

It is difficult to determine the actual reaction by which scapolite is formed here. Since the plagioclase has a relatively low anorthite content (An<sub>13</sub> in the norm), the reaction probably is more complex than simply plagioclase + calcite = scapolite. Also, since the scapolite is formed within the melting interval, the melt phase probably participates in the reaction. Possible reactions are

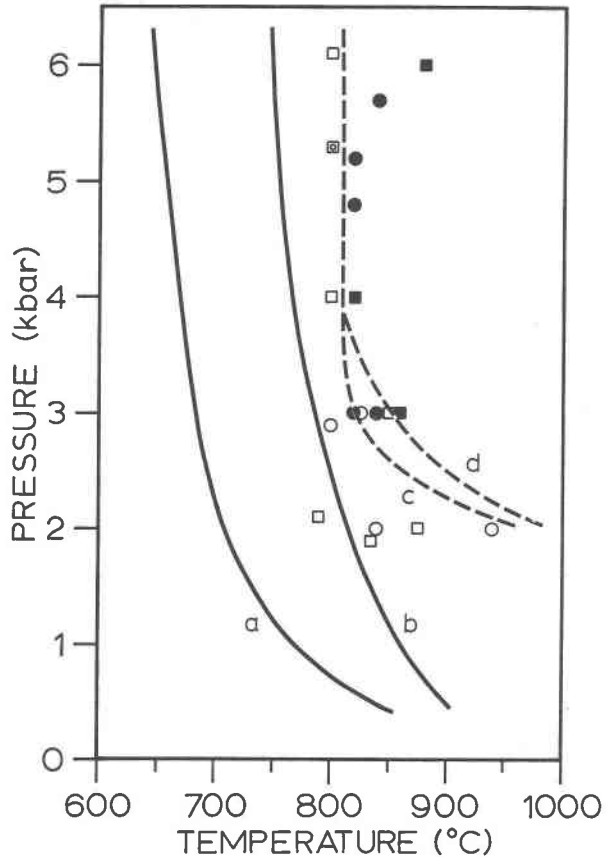


TABLE 1. Compositions of Calcite-Bearing Nepheline Syenite and of Scapolite

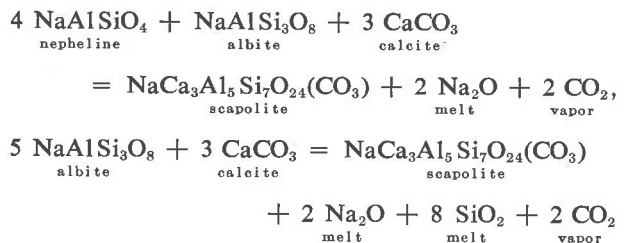
	Chemical Analyses		CIFW Norm*** of	
	Nepheline Syenite*	Scapolite**	Nepheline Syenite	
SiO <sub>2</sub>	45.00	46.7	Or	18.73
Al <sub>2</sub> O <sub>3</sub>	20.58	27.8	Ab	27.62
TiO <sub>2</sub>	0.13	0.03	An	4.09
Fe <sub>2</sub> O <sub>3</sub>	1.02	nd	Ne	26.78
			Ol	2.00
FeO	0.84	0.31	Fo	(1.48)
MnO	0.10	nd	Fa	(0.52)
MgO	0.85	0.13		
CaO	9.45	17.8	Il	0.25
			C	0.67
Na <sub>2</sub> O	9.22	3.43	Mt	1.48
K <sub>2</sub> O	3.17	0.14	Hl	0.21
Cl	0.13	nd	Cc	15.40
CO <sub>2</sub>	6.77	nd	Total	97.23
H <sub>2</sub> O (+)	0.81	nd		
H <sub>2</sub> O (-)	0.03	nd		
Total	98.10	96.34		

\*Analysis by spectrometry and flame photometry, I.A. Kilinc, analyst; except CO<sub>2</sub>, H<sub>2</sub>O<sup>+</sup> and H<sub>2</sub>O<sup>-</sup> determined by J.B. Bodkin. Iron oxides calculated using the Fe<sub>2</sub>O<sub>3</sub>/FeO ratio of Nockolds' (1954) average nepheline syenite.

\*\*Electron microprobe analysis of scapolite from run (D250) at 6.0 - 6.2 kbar and 900°C with a CO<sub>2</sub>-rich aqueous vapor phase (see text). All iron as FeO; nd = not determined.

\*\*\*Weight percent.

FIG. 1. Lower synthesis limit of scapolite. Filled circles indicate scapolite present in runs with H<sub>2</sub>O; filled squares indicate scapolite present in runs with oxalic acid; open circles indicate scapolite absent in runs with H<sub>2</sub>O; open squares indicate scapolite absent in runs with oxalic acid. Curves a and b are solidus curves of Blue Mountain nepheline syenite with H<sub>2</sub>O and with H<sub>2</sub>O + CO<sub>2</sub>, respectively (Millhollen, 1971). Curves c and d are approximate lower synthesis limits of scapolite in calcite-bearing nepheline syenite with relatively H<sub>2</sub>O-rich and CO<sub>2</sub>-rich aqueous vapor phases, respectively.



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