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The occurrence of cebollite in kimberlite and included zeolitized crustal xenoliths

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SUMMARY. Two different parageneses for cebollite, a rare hydrated calcium aluminium silicate, are described, both differing from all previously reported occurrences.

Cebollite forms concomitantly with natrolite from plagioclase in xenoliths of crustal material incorporated in kimberlite. The mineral also occurs as a late stage primary mineral in a phlogopite-rich kimberlite.

Tentative models for the genesis of the mineral in the environments described are proposed. It is suggested that the final stages in the crystallization of diatreme-facies kimberlite are dominated by fluids rich in lime and having a low partial pressure of CO_2.

CEBOLLITE is a very rare hydrous calcium aluminium silicate first described by Larsen and Shaller (1914) from Ceboll Creek near the Iron Hill carbonatite intrusion, Gunnison Co., Colorado. Further work on the formation of cebollite and other minerals due to hydrothermal processes was done by Larsen and Goranson (1932) and Larsen (1941). Tilley and Harwood (1931) identified cebollite from the dolerite-chalk contact of Scawt Hill, Co. Antrim, and Krank (1928) identified the mineral in a melilite-bearing rock associated with carbonatite dykes in Kola. A more recent account by Rodygina (1971) reports the mineral in a skarn in Siberia.

These studies show that cebollite is a low-temperature mineral formed by the deuteric alteration of melilite. In each case cebollite was one of the last minerals to form with the concomitant formation of natrolite. The latter mineral must form at temperatures of less than 250 °C since experimental evidence (Senderov, 1974), shows it to be unstable above this temperature.

Two contrasting paragenesis of cebollite are described in the present investigation. These, however, are linked in common with all other described occurrences in being associated with carbonate-rich assemblages and hydrothermal conditions.

Plagioclase-rich xenoliths of crustal material included in the Letseng-La-Terai kimberlite in Lesotho have been altered to a natrolite + cebollite assemblage, and the kimberlite from the De Beers Mine in Kimberley contains cebollite as a late stage *primary* mineral.

Mineral optics and XRD determination. Optically the mineral is fairly distinctive, although not all the optical properties could be determined due to the fibrous habit, incomplete reaction, and poorly developed crystals in the rocks studied. Debye-Scherrer diffraction photographs provided confirmation.

TABLE I. *Optical and X-ray diffraction data for cebollite*

Cebollite—$Ca_5Al_2(OH)_4Si_3O_{12}$

Habit: fibrous radiating
Relief: medium positive
Colour: colourless to red-brownish
Biref: moderate $\delta = 0.031$
Orient: parallel extinction and length slow
Other: habit is variable and brownish type is felted

Debye-Scherrer camera 5.73 cm

I/I_0	dÅ	I/I_0	dÅ	I/I_0	dÅ
10	3.67	10	2.33	50	1.712
30	3.49	60	2.28	15	1.653
80	3.29	40	2.14	15	1.601
90	3.08	10	2.09	30	1.548
100	2.90	20	1.995	50	1.485
50	2.73	20	1.876	60	1.464
50	2.58	20	1.825		
30	2.47	70	1.753		

Table I summarizes the thin-section optical and

XRD results obtained. These optical and diffraction data match very closely those of Larsen and Goransen (1932) and Neumann and Bergstol (JCPDS card No. 16-695) respectively. There are, however, slight differences, probably due to the use of a smaller camera by the author. The good fit of some seventeen lines with the determinable optical properties confirmed the identification.

Slightly different *d*-spacings obtained may also be due to the material determined here being of slightly different chemical composition as the derivation is from plagioclase and not melilite, which contains magnesium and iron. The cebollite analysed by Shaller (1914) as quoted by Larsen (1941) has considerable amounts of both these elements.

Petrography of cebollite in the xenolithic material. Included within the Letseng-La-Terai kimberlite are abundant crustal xenoliths of Precambrian and Mesozoic age. These consist largely of coarse-grained, plagioclase-bearing Precambrian metamorphites such as gneisses and amphibolites, and Mesozoic Karroo basalt xenoliths. The plagioclase in these rocks has suffered zeolitization to a greater or lesser extent, the zeolite being invariably natrolite. This mineral appears to be a common alteration product of xenoliths within kimberlite as it has been reported from other pipes by Du Toit (1908) and others.

Cebollite occurs closely associated with the natrolite and is developed initially on the original plagioclase grain boundaries. More natrolite forms from the plagioclase until eventually all the plagioclase is converted, and the natrolite is enclosed by fairly large areas of cebollite (figs. 1 and 2).

Larger patches of cebollite are fairly clear with a well-developed fibrous habit and some optical properties are readily determined. This well-developed first-formed material grades outward into a slightly brownish variety with shorter, more randomly aligned fibres giving it a felted appearance. This is in turn intergrown with the edges of the natrolite crystals.

Calcite is commonly, but not invariably, associated with the natrolite + cebollite assemblage and often appears as subhedral grains frequently situated at the original triple boundaries of natrolite or plagioclase grains. Du Toit (1908) reports a natrolite + calcite assemblage but makes no reference to a fibrous mineral that may have been cebollite.

Different xenoliths exhibit different proportions of cebollite and natrolite and this may be due to the more sodic plagioclase forming predominantly natrolite while calcic varieties form cebollite. Du Toit (1908) attributed different proportions of natrolite and calcite to the same variation in the composition of the feldspar although the excess alumina and silica were not accounted for.

Formation of cebollite in the xenolithic material. In the plagioclase-bearing crustal xenoliths of Letsung-La-Terai cebollite appears to form by the following mechanism:

Hydrothermal alteration of the plagioclase to natrolite takes place inwards from the grain boundaries. This reaction releases lime, alumina, and silica, which migrate to the grain boundaries and form cebollite. The following tentative reaction illustrates this process for a specific plagioclase composition.

$$\underset{2\ \mathrm{Ab}}{2(\mathrm{NaAlSi_3O_8})} \underset{+}{+} \underset{\mathrm{An}}{\mathrm{CaAl_2Si_2O_8}} \underset{+\mathrm{water}}{+ 2\mathrm{H_2O}} \rightleftharpoons$$

$$\underset{\text{Natrolite.}}{\mathrm{Na_2Al_2Si_2O_{10}\cdot 2H_2O}} + \mathrm{CaO} + \mathrm{Al_2O_3} + 5\mathrm{SiO_2}. \quad (1)$$

The process appears to need the addition of some lime and removal of some silica for cebollite to form. This is illustrated by the formula for cebollite which is extremely calcic: $\mathrm{Ca_5Al_2(OH)_4Si_3O_{12}}$.

Calcium would invariably have to be introduced to balance the equation although silica would not have to be removed if more calcic plagioclase is altered as plagioclase becomes progressively more alumina-rich and silica-poor towards the anorthite end-member.

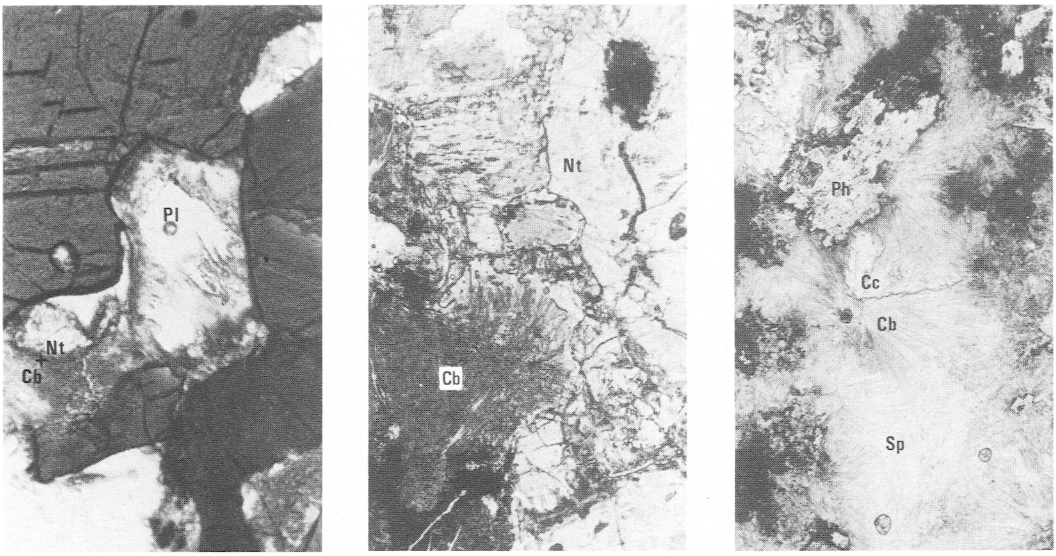
Natrolite appears to be able to form from cold solutions and at temperatures of up to 250 °C (Senderov, 1974). However, the lower-temperature occurrences appear to be restricted to those forming from solution or glasses in volcanic rocks.

Senderov (1974) found that a high pH had the effect of favouring desilication reactions and the formation of natrolite, as opposed to the calcium-rich zeolites, at temperatures of 100 to 200 °C. Under high pH conditions natrolite was obtained from both gels and crystalline starting materials at these temperatures.

In the crustal xenoliths from Letseng-La-Terai the change from plagioclase to natrolite + cebollite involves a desilication reaction and as no calcic zeolite has formed it seems the mineralizing solutions were alkaline.

Sodium hyroxide was used by Senderov (1974) to increase the pH in his experiments. Under natural conditions in kimberlite the pH is probably controlled by a lime-rich solution with a low partial pressure of $\mathrm{CO_2}$, which would have a pH > 9.4 at 25 °C. This solution would also provide a likely source of extra calcium for the formation of cebollite.

From this discussion it can be seen that the formation of natrolite and cebollite was probably controlled by lime-rich hydrothermal solutions of fairly high pH and low $P_{\mathrm{CO_2}}$, at temperatures of



FIGS. 1–3: FIG. 1 (*left*). Plagioclase (Pl) has been altered to a fine felted cebollite (Cb) and natrolite (Nt) assemblage. Plane polarized light. Base of photomicrograph 2 mm. FIG. 2 (*centre*). A much more advanced stage with no more plagioclase remaining. An assemblage of cebollite (Cb) and natrolite (Nt). Ppl. Base 2 mm. FIG. 3 (*right*). Kimberlite with calcite (Cc) and phlogopite (Ph). Fibrous radiating cebollite (Cb) is intergrown with serpentine (Sp) and calcite. Ppl. Base 2 mm.

less than 250 °C in the final stages of kimberlite crystallization.

The paragenesis and formation of cebollite in the De Beers Mine kimberlite. A second, completely different, paragenesis of cebollite occurs in the core kimberlite of De Beers Mine, Kimberley. Cebollite is developed here as a phase within the kimberlite. The mineral occurs as large and small patches of fibrous, sheaf-like aggregates. Calcite and phlogopite are commonly associated and included in the areas of cebollite and in some cases show reaction relationships at the margins of the crystals. In these cases there is no natrolite present, and the cebollite is usually very well developed with only a slight brownish tinge (fig. 3). Here too it is the last mineral to crystallize if it is of a primary nature, which it appears to be.

Development of cebollite in these rocks is probably due to the slight excess of alumina and silica after the formation of phlogopite from the last liquids to crystallize in the kimberlite. Calcium was present in excess as calcite is an abundant coeval phase.

Cebollite is a relatively common minor mineral in this variety of kimberlite, which has calcite and phlogopite as the major groundmass phases and is probably restricted to this variety as the residual liquids in other types are deficient in alumina.

A possible reaction leading to the formation of cebollite in both environments and incorporating the excess CaO, Al_2O_3, and some of the excess SiO_2 from reaction (1):

$$CaO + 4Ca^{++} + Al_2O_3 + 3SiO_2 + 8(OH)^- = \underset{\text{cebollite}}{Ca_5Al_2(OH)_4Si_3O_{12}} + 2H_2O. \quad (2)$$

This reaction would be favoured by a high pH in the last liquids and hydrothermal solutions rich in lime.

Conclusions. Cebollite is probably more widespread in a variety of environments and not necessarily confined to kimberlite or melilite-bearing rocks. Any material containing plagioclase and affected by high-level hydrothermal fluids rich in calcium has the potential to crystallize cebollite provided the pH is high, and the P_{CO_2} is low.

In kimberlites the mineral is probably confined to the diatreme facies type (Dawson, 1971) as outgassing of CO_2 would lower the partial pressure of this component in the final stages of crystallization.

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