

TABLE I. Results of an electron microprobe analysis of triplite from East Kemptville, Nova Scotia

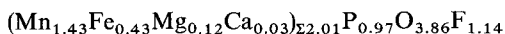
	Wt. %	Mol. ratios	Anion ratios	Cation ratios	Ions
MnO	46.8	0.6597	0.6597	0.6597	Mn 1.43
FeO	14.2	0.1976	0.1976	0.1976	Fe 0.43
MgO	2.2	0.0546	0.0546	0.0546	Mg 0.12
CaO	0.7	0.0125	0.0125	0.0125	Ca 0.03
P <sub>2</sub> O <sub>5</sub>	31.9	0.2247	1.1237	0.4495	P 0.97
F	10.0	0.5263	0.5263	—	F 1.14
Total	105.8		2.5744		O 3.86
Less O ≡ F	4.2		0.2625		
	101.6		2.3119		
			f = 2.1627		
			MW = 219.73		

Notes: Analyst: Pete J. Dunn (see text for operating conditions). Accuracy of data:  $\pm 15\%$  of the amount present for F,  $\pm 3\%$  for all other constituents. Number of ions calculated on the basis of oxygen + fluorine = 5.

regarding the evolved gases because more than one product was evolved at any given time. Between 100° and 675 °C a weight loss consisting of CO<sub>2</sub> and H<sub>2</sub>O amounted to 0.4 wt. %. The run was continued to 1000 °C, but the weight loss was not complete at this temperature. Between 675° and 1000 °C the weight loss was 3.3 wt. % and H<sub>2</sub>O, HF, and PO<sub>2</sub><sup>+</sup> were detected by the mass spectrometer. Additional substances with masses of 28, 47, 76, and 104 were also detected. The presence of fluorine is thought to promote the evolution of unusual products during thermal analysis. The TGA data

suggest that water and carbon dioxide are very minor constituents of the triplite.

Consequently, the empirical formula of the triplite was derived from the analytical data assuming only oxygen and fluorine as anions and is



or, ideally, (Mn,Fe,Mg,Ca)<sub>2</sub>PO<sub>4</sub>F. The density calculated from the unit cell contents and parameters following the procedure outlined by Mandarino (1981) is 3.847 g/cm<sup>3</sup>. The density measured by means of the Berman microbalance is 3.83(1) g/cm<sup>3</sup> at 22 °C.

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## REFERENCES

- Mandarino, J. A. (1981) *Can. Mineral.* **19**, 531-4.  
 — and Sturman, B. D. (1976) *Ibid.* **14**, 127-31.  
 Richardson, J. M., Spooner, E. T. C., and McAuslan, D. A. (1982) *Current Res. Part B, Geol. Surv. Can. Paper* 82-1B, 27-32.

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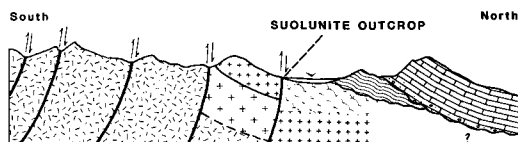
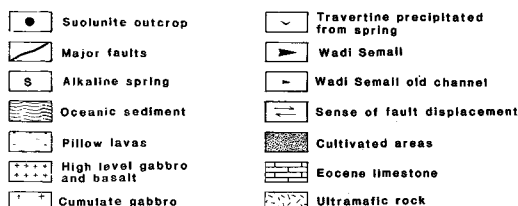
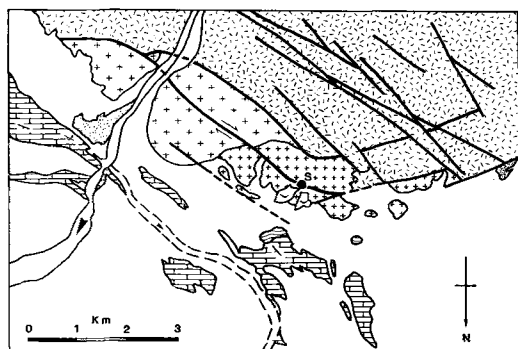
E. T. C. SPOONER

MINERALOGICAL MAGAZINE, MARCH 1984, VOL. 48, PP. 143-6

## A new occurrence of suolunite, from Oman

SUOLUNITE, Ca<sub>2</sub>Si<sub>2</sub>O<sub>5</sub>(OH)<sub>2</sub>H<sub>2</sub>O, is an extremely rare mineral previously reported only from Yugoslavia (Stojanovic *et al.*, 1974) and Mongolia (Huang, 1965; X-ray Laboratory, Hupeh, 1974). Here we report a third well-preserved example

which, in common with the previous occurrences, is associated with faults within arid or semi-arid ultramafic environments. The suolunite is exclusively restricted to a prominent narrow fault zone in basalt and gabbro which overlies ultramafic



SECTION THROUGH SUOLUNITE OUTCROP

FIG. 1. Geological setting of suolunite in Oman.

rock at shallow depth (fig. 1). It occurs as high relief masses, 3 to 4 m proud of the host rock, and takes the form of stellate concretionary aggregates in which successive cycles of precipitation produce alternate fine (0.1 mm) equigranular and coarse (2-3 mm) bladed crystals in concentric layers. Fresh surfaces are translucent cream to opaque with a vitreous lustre and poor cleavage. Exposed surfaces weather to an opaque 1 mm thin, cream-coloured coating of calcite pseudomorphous after suolunite. Suolunite is distinguished from quartz and scapolite by its stellate habit and softness (H 3½), and from carbonate minerals by its dissolution in dilute HCl to yield gelatinous silica.

Its occurrence is essentially monomineralic although 2 or 3% of carbonate inclusions were found in some specimens. The new X-ray diffraction data given in Table I are intermediate between previously quoted spacings (X-ray laboratory, Hueph, 1974, Stojanovic *et al.*, 1974) but display differing peak intensities. The chemical composition given in Table II is by energy dispersive X-ray fluorescence. The field relations clearly show that suolunite is an open-space precipitate coincident

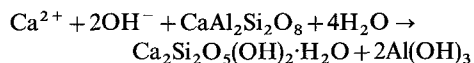
TABLE I. X-ray powder diffraction data for Oman suolunite

<i>I</i>	<i>d</i> Å	<i>T</i>	<i>d</i> Å	<i>T</i>	<i>d</i> Å
18	5.126	25	2.108	2	1.561
9	4.972	15	2.078	6	1.534
100	4.133	24	2.064	3	1.508
4	3.708	22	2.033	10	1.502
81	3.173	47	1.994	4	1.414
2	3.125	37	1.888	17	1.434
62	2.849	38	1.851	9	1.422
3	2.788	9	1.809	4	1.401
85	2.687	9	1.764	7	1.395
51	2.647	68	1.705	4	1.381
37	2.558	15	1.681	10	1.371
23	2.495	4	1.652	20	1.331
20	2.473	6	1.617	11	1.323
25	2.431	32	1.613	11	1.320
26	2.331	18	1.587	4	1.310
25	2.224	13	1.580	11	1.284

Determined by X-ray powder diffraction (Cu-K $\alpha$  radiation), the sample being mounted on a single Si crystal cut to a non-diffracting plane: the sample was lightly ground to give crystal sizes < 2 mm mean spherical diameter thus minimizing particle size effects (Brindley and Brown, 1980) and gently 'dusted' on to the mount to minimize preferred orientation effects.

$a = 11.14$ ,  $b = 19.78$ ,  $c = 6.01$  Å. This compares with  $a = 11.13$ ,  $11.15$ ,  $b = 19.82$ ,  $19.67$ ,  $c = 6.00$ ,  $6.08$  Å for Yugoslavian and Mongolian samples respectively (Stojanovic *et al.*, 1974; Huang, 1965).

with an alkaline spring emergent from a fault zone (fig. 1). The spring is of a highly reactive Ca<sup>2+</sup>/OH<sup>-</sup>-rich (pH 11 to 12) type, derived from low temperature serpentinization of diopside-bearing ultramafic rocks (Barnes *et al.*, 1978). Of the seventy alkaline spring sites investigated, suolunite seems to be restricted to a single occurrence where the spring water emerges from basis rocks overlying ultramafic rocks. Since the ultramafic ground waters are normally low in silica (typically about 1.0 mg l<sup>-1</sup>), an independent silica source is required for suolunite generation. The most likely source is plagioclase:



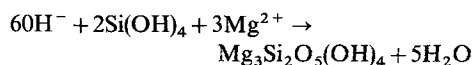
in which suolunite is a precipitate from mobile aqueous phases whilst the Al(OH)<sub>3</sub> component either combines with residual plagioclase to produce various calcium aluminosilicates (or in the case of the Na-albite end-member fraction, analcime) or dissolves in the highly alkaline conditions to give Al(OH)<sub>4</sub><sup>-</sup> ions which are flushed from the system. Evidence in support of the former process is found in the widespread alteration products of plagioclase

TABLE II. X-Ray fluorescence analysis of suolunite

Norm	wt. %	Ideal
		Ca <sub>2</sub> Si <sub>2</sub> O <sub>5</sub> (OH) <sub>2</sub> H <sub>2</sub> O
SiO <sub>2</sub>	41.91	44.78
CaO	44.66	41.79
MgO	0.29	0.0
Al <sub>2</sub> O <sub>3</sub>	0.72	0.0
Na <sub>2</sub> O	0.39	0.0
LOI (H <sub>2</sub> O + CO <sub>2</sub> )	14.14	13.43
Σ	102.11	100.00
Fe <sub>2</sub> O <sub>3</sub> , TiO <sub>2</sub> , and K <sub>2</sub> O all < 0.001 %		
Traces (ppm)		
Rb 1	Pb 6	Nb
Sr 31	Ni 4	Gq 0
Y 0	Cu 5	Th 1
Zr 12	Zn 6	

NB. The low silica, high CaO content is attributable to minor substitution of Al in Si positions and slight weathering to form CaCO<sub>3</sub>. Loss of CO<sub>2</sub> accounts for the high LOI.

found in joints and faults throughout the basic rocks of the area. This 'rodingite' assemblage consists of hydrogrossular Ca<sub>3</sub>Al<sub>2</sub>(OH)<sub>12</sub>, prehnite Ca<sub>2</sub>Al<sub>2</sub>Si<sub>3</sub>O<sub>10</sub>(OH)<sub>2</sub>, and zoisite Ca<sub>2</sub>Al<sub>3</sub>Si<sub>3</sub>O<sub>12</sub>(OH), all of which are relatively basic and retain the immobile Al fraction of the original plagioclase. Field evidence both from Oman and from other rodingite locations (Glennie *et al.*, 1974; Honnorez and Kirst, 1975; Lauder, 1965; Bell *et al.*, 1911; Coleman, 1967) invariably indicates contemporaneous serpentinization of diopside-rich ultramafic rocks (i.e. Ca<sup>2+</sup> and OH<sup>-</sup> generation). Meanwhile under the predominantly alkaline conditions silica, derived from plagioclase dissolution, undergoes significant H<sub>4</sub>SiO<sub>4</sub> dissociation resulting in high silica solubility (Hem, 1970; Siever, 1957) and is therefore available for direct precipitation reactions with Ca<sup>2+</sup> and OH<sup>-</sup>. Alternative aqueous silica sources, dissolved in ephemeral runoff or surface water channelled along the fault, are discounted as such water is invariably characterized by Mg<sup>2+</sup> and HCO<sub>3</sub><sup>-</sup> ions (Table III). Upon mixing with Ca<sup>2+</sup>-OH<sup>-</sup> type water, both these components would undergo alternative reactions to precipitate serpentine and carbonate, thereby precluding suolunite formation:



and



The abundance of either HCO<sub>3</sub><sup>-</sup> or Mg<sup>2+</sup> ions in most natural surface waters, especially in the ultramafic environment (Gibb *et al.*, 1976), therefore accounts for the rarity of suolunite.

TABLE III. Water chemistry from the suolunite area (concentrations in mg l<sup>-1</sup>)

Sample no.	1	2	3
pH	8.2-8.8	8.4	11.4
Ca	14.0-23.0	14.0	66.2
Mg	63-128	41.3	0.002
Na	120-280	20.5	367
K	4.0-8.0	1.6	8.9
SiO <sub>2</sub>	22.0-30.0	21.0	4.6
OH	0	0	34
HCO <sub>3</sub>	107-438	176	0
SO <sub>4</sub>	110-252	55	63
NO <sub>3</sub>	0.5-2.0	5.0	2.4
Cl	180-495	30.0	453
T(°C)	21-36	28	37

1. Perennial surface flow from Wadi Semail, sampled where it crosses the suolunite fault. Figures give the range from biweekly sampling over 15 months.

2. Ephemeral surface flow or shallow (alluvial) ground water from ultramafic areas.

3. Alkaline spring water from close to the suolunite outcrop.

Xonotlite, Ca<sub>6</sub>Si<sub>6</sub>O<sub>17</sub>(OH)<sub>2</sub>, a mineral closely related to suolunite, was not found in Oman but is commonly found in sediments associated with rodingites (O'Brien and Rodgers, 1973). As with suolunite it is an Al-free precipitate from mobile elements and is probably an analogous product generated under higher temperature and differing pH/redox conditions. Indeed xonotlite is produced by the dehydration of suolunite (Huang, 1965).

We conclude that Ca<sup>2+</sup>-OH<sup>-</sup> solutions, generated by serpentinization in the ultramafic environment, react with plagioclase feldspars at low temperatures. The immobile products form the calcium aluminosilicate assemblage commonly referred to as 'rodingite'. The mobile products Ca-Si-OH normally precipitate from alkaline solution as carbonate or serpentine but under exceptional conditions, where Mg and HCO<sub>3</sub> are absent, suolunite or possibly xonotlite may precipitate.

## REFERENCES

- Barnes, I., O'Neil, J. R., and Trescases, J. J. (1978) *Geochim. Cosmochim. Acta*, **42**, 144-5.  
 Bell, M. J., Clarke, E., and Marshall, P. (1911) *N.Z. Geol. Surv. Bull.* 12.

- Brindley, G. W., and Brown, G. (1980) *Crystal Structures of Clay Minerals and their X-ray Identification*. Mineral. Society Monograph 5, 495 pp.
- Coleman, R. G. (1967) *U.S.G.S. Bull.* **1247**, 49.
- Gibb, Sir A. and Partners [in association with the Institute of Hydrology] (1976) *Water Resources Survey of Northern Oman*, 1-6.
- Glennie *et al.* (1974) *Geology of the Oman Mountains*. Verhandelingen van het Koninklijk Nederlands geologisch mijnbouwkundig Genootschap.
- Hem, J. D. (1970) *U.S.G.S. Water Supply Paper*, 1473.
- Honnorez, J., and Kirst, P. (1975) *Contrib. Mineral. Petrol.* **49**, 233-57.
- Huang (1965) *Geological Review (Peking)* **23**, 7.
- Lauder, W. R. (1965) *N. Z. J. Geol. Geophys.* **8**, 475-504.
- O'Brien, A. H., and Rodgers, K. A. (1973) *Mineral Mag.* **39**, 233-40.
- Siever, R. (1957) *Am. Mineral.* **42**, 821-81.
- Stojanovic, D., Dordevic, D., and Derkovic, B. (1974) *Bull Du Mus. D'Hist. Natur. De Belgrade*, ser. A, **29**, 5-15.
- X-ray Laboratory, Hupeh Geol. Coll. (1974) *Scientia Geol. Sinica*, **2**, 117-32.

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## The composition of rhabdophane

RHABDOPHANE is a hydrated phosphate of cerium, yttrium, and other rare earth elements of which Palache *et al.* (1944) say 'the proportions of the elements occurring with cerium have not been fully determined'.

An early analysis of the mineral by Hartley (1882) on a specimen from Cornwall indicated a substantial rare earth content; other analyses have been recorded from Salisbury, Connecticut (Brush and Penfield, 1883), Julianehaab, Greenland (Böggild, 1903), the Kiyu alkali massif (Semenov, 1959), the Lovozero alkali massif (Gerasimovskii, 1937; Vlasov *et al.*, 1959), and Idaho (Adams, 1968). These analyses are semi-quantitative or incomplete and report only total rare earth elements or the ratios of those elements.

This contribution presents a new analysis of rhabdophane from the type locality at Fowey Consols Mine, Cornwall, which indicates quantitatively the distribution of the rare earth elements. Recent XRD studies on this material (Atkin *et al.*, 1983) have shown that it has unit cell dimensions of  $a$   $6.960 \pm 0.003$  and  $c$   $6.372 \pm 0.006$  Å.

*Microprobe analysis.* The analysis for twenty-six elements given in Table I was obtained with a Cambridge Scientific Instruments Microscan 5 electron microprobe using the standards and techniques described by Bowles (1975, 1978)

TABLE I. *Microprobe analyses of rhabdophane from Fowey Consols Mine, Cornwall*

	Wt. %		Molecular proportions calculated to 4 oxygen atoms	
	A	B	A	B
La <sub>2</sub> O <sub>3</sub>	12.19	11.07	0.187	0.171
Ce <sub>2</sub> O <sub>3</sub>	11.85	13.26	0.180	0.204
Pr <sub>2</sub> O <sub>3</sub>	1.02	0.85	0.015	0.013
Nd <sub>2</sub> O <sub>3</sub>	21.18	15.74	0.314	0.236
Sm <sub>2</sub> O <sub>3</sub>	3.49	2.93	0.050	0.042
Eu <sub>2</sub> O <sub>3</sub>	1.78	1.59	0.025	0.023
Gd <sub>2</sub> O <sub>3</sub>	3.24	3.46	0.045	0.048
Tb <sub>2</sub> O <sub>3</sub>	0.34	0.33	0.005	0.005
Dy <sub>2</sub> O <sub>3</sub>	1.69	1.68	0.023	0.023
Ho <sub>2</sub> O <sub>3</sub>	0.40	0.44	0.005	0.006
Er <sub>2</sub> O <sub>3</sub>	1.12	1.13	0.015	0.015
Tm <sub>2</sub> O <sub>3</sub>	0.51	0.42	0.007	0.005
Yb <sub>2</sub> O <sub>3</sub>	0.40	0.76	0.005	0.010
Y <sub>2</sub> O <sub>3</sub>	4.02	8.33	0.089	0.186
CaO	0.26	0.24	0.012	0.011
Fe <sub>2</sub> O <sub>3</sub>	0.38	0.32	0.012	0.010
ThO <sub>2</sub>	—	0.10	—	0.002
U <sub>3</sub> O <sub>8</sub>	0.42	0.18	0.004	0.002
P <sub>2</sub> O <sub>5</sub>	28.59	28.02	1.006-1.01	0.995-1.00
H <sub>2</sub> O	7.12*	9.15*	0.987-0.99	1.280-1.28
	100.00*	100.00*		

\* H<sub>2</sub>O added to give total = 100%, measurement of evolved water of specimen A gave 7.9%. Lu, Hf, Al, Mn not detected (< 0.01%); Ti, Si, Pb detected (0.01-0.03%)