A re-examination of cheralite

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SUMMARY. A new analysis of the type material of cheralite specifies the individual rare earth elements. Unit cell contents are: $(REE_{1.58}Th_{1.15}Ca_{1.03}Pb_{0.05}U_{0.15})_{3.96}$ $(P_{3.67}Si_{0.33})_{4.01}O_{16}$. Refinement of the cell parameters based on new XRD data shows that $a = 6.751_5 \pm 0.0005$ Å, $b = 6.962_5 \pm 0.0005$, $c = 6.468 \pm 0.0005$, $\beta = 103° 53'$, giving a cell volume of 295.2 Å^3. Space group $P2_1/n$.

CONTINUED work by the authors on other rare earth phosphates has led to a re-examination of the type material (MI 28881)* of the mineral cheralite as described by Bowie and Horne (1953) from Kuttakuzhi, Travancore (now in Kerala State), India. Instrumental improvements during the last quarter century permit us to give new and better quality data for cheralite to improve the specification of the type material whilst in no way detracting from the value of the original description.

Cheralite (REE,Th,Ca,U)(P,Si)O_4, is part of an isostructural series of monoclinic minerals of the general form ABO_4 where $A = REE$, Th, U, Ca and $B = $ P, Si, Monazite ($REEPO_4$—Breithaupt, 1829) and huttonite (ThSiO$_4$—Pabst, 1950) are prominent end-members of this series.

Microprobe analysis. The original analysis of cheralite (Bowie and Horne, 1953) and subsequent analyses (Finney and Nagaraja Rao, 1967; Aplonov and Petrova, 1965) have not separated the individual rare earth elements beyond giving results for Ce$_2$O$_3$ and La$_2$O$_3$ or (La,Pr,Nd,Y)$_2$O$_3$. The present analysis using a Cambridge Scientific Instruments Microscan 5 electron microprobe has permitted all the rare earth elements to be identified.

This analysis for 26 elements is given in Table I and has been obtained using the techniques and

standards described by Bowles (1975, 1978) with additional standards from Drake and Weill (1972) and Smellie *et al.* (1978). Full ZAF correction of the results has been obtained using a version of the Mason–Frost–Reed (1969) program expanded to consider a sufficient number of elements.

The analysis of the type material shows that the cell contents are: $(REE_{1.58}Th_{1.15}Ca_{1.03}Pb_{0.05}$ $U_{0.15})_{3.96}(P_{3.67}Si_{0.33})_{4.01}O_{16}$.

The distribution of rare earth elements in cheralite is similar to that shown by monazite, especially monazite from granitic pegmatites (fig. 1). This is not surprising since the cheralite type material is from a granitic pegmatite and there is structural similarity between monazite and cheralite.

X-ray data. The d-spacings (Table II) were determined from diffractometer charts taken with Cu-$K\alpha$ radiation at room temperature (around 22 °C) and a scanning speed of $\frac{1}{8}$° 2θ/min. Quartz ($a = 4.91331$ Å, $c = 5.40488$ Å, at 25 °C) was used as an internal standard. The intensities are relative peak heights. The powder data were provisionally indexed by comparison with published data (Bowie and Horne, 1953) and were refined using the least-squares program (BA 1.0) developed by the late Dr R. J. Davis, Department of Mineralogy, British Museum (Natural History), for the refinement of cell dimensions and enumeration of all possible d-spacings. This refinement gave cell dimensions $a = 6.751_5 \pm 0.0005$ Å, $b = 6.962_5 \pm 0.0005$ Å, $c = 6.468 \pm 0.0005$ Å, $\beta = 103° 53'$, space group $P2_1/n$. Other workers have obtained lower values for the cell parameters of cheralite from the same locality (Table III). The present work confirms the higher values obtained by Bowie and Horne.

The density of cheralite corresponding to the unit-cell contents (Table I) and the above dimensions is 5.39 g cm^{-3}, compared with the measured value of 5.3 g cm^{-3} (Bowie and Horne, 1953).

Infra-red and absorption spectra. The infra-red spectra of cheralite and a monazite from Skardalen

* Numbers preceded by MI refer to specimens in the Mineral Inventory, Institute of Geological Sciences Collection.

TABLE I. *Analyses and unit cell contents of cheralite from Kuttakuzhi, India*

	Wt% I	Wt% 2		Molecular proportions recalculated to 16 oxygen atoms I		Molecular proportions recalculated to 16 oxygen atoms 2	
Ce_2O_3	14.21	12.12	Ce^{3+}	0.836 ⎫		0.710 ⎫	
La_2O_3	⎫	5.19	La^{3+}	⎫		0.306	
Pr_2O_3		1.20	Pr^{3+}			0.070	
Nd_2O_3		5.91	Nd^{3+}			0.338	
Sm_2O_3		1.81	Sm^{3+}			0.100	
Eu_2O_3		0.25	Eu^{3+}	⎬ 0.780	⎫	0.014	⎫
Gd_2O_3		0.45	Gd^{3+}			0.024	
Tb_2O_3	⎬ 13.35	0.05	Tb^{3+}		⎬ 4.03	0.003	⎬ 3.96
Dy_2O_3		0.06	Dy^{3+}			0.003	
Ho_2O_3		0.01	Ho^{3+}			0.001	
Er_2O_3		0.03	Er^{3+}			0.002	
Tm_2O_3		0.12	Tm^{3+}			0.006	
Y_2O_3	⎭	0.08	Y^{3+}	⎭		0.007	
Al_2O_3	tr.	—	Al^{3+}			—	
Fe_2O_3	tr.	—	Fe^{3+}			—	
CaO	6.30	5.99	Ca^{2+}	1.084		1.027	
PbO	0.92	1.15	Pb^{2+}	0.040		0.050	
ThO_2	31.50	31.64	Th^{4+}	1.151		1.153	
U_3O_8	4.05	4.33	$U^{4+,6+}$	0.139 ⎭		0.148 ⎭	
P_2O_5	26.80	27.10	P^{5+}	3.642 ⎱		3.673 ⎱	
SiO_2	2.10	2.08	Si^{4+}	0.337 ⎰ 3.98		0.333 ⎰ 4.01	
H_2O^+	0.06	—					
	99.29	99.57					

Analyses: I—Bowie and Horne (1953); 2—Present work, Yb_2O_3, Lu_2O_3, Hf_2O_3, Al_2O_3, Fe_2O_3, MnO, TiO_2 not detected (< 0.01 %).
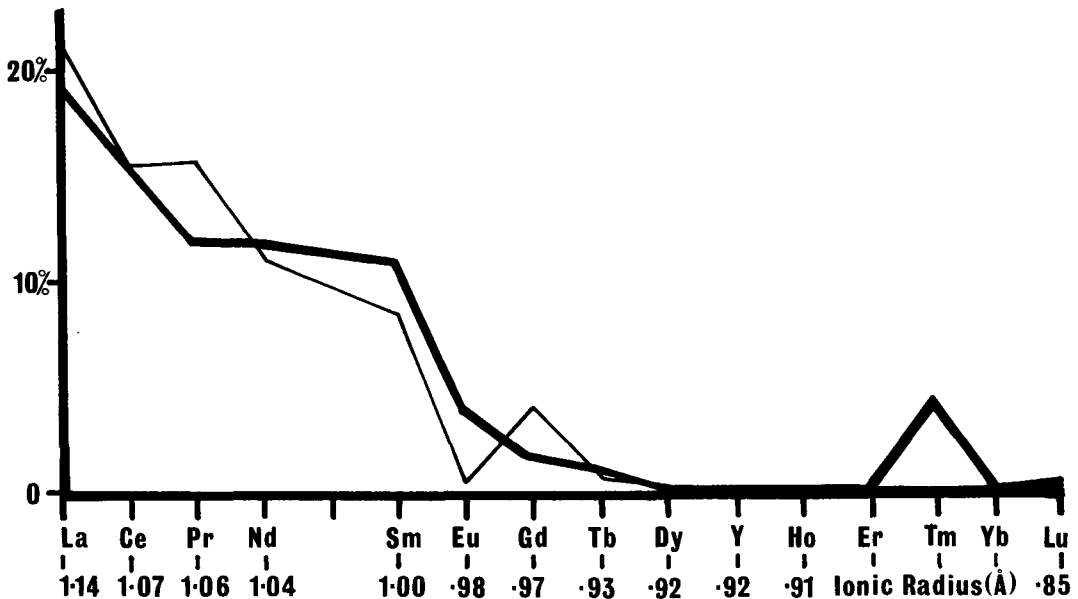

FIG. 1. The rare earth pattern of cheralite (heavy line) compared with the average composition of 104 monazites (thin line) from granitic pegmatites (Fleischer and Altshuler, 1969). The vertical axis shows the rare earth composition expressed as a ratio of the rare earth concentration in average chondritic meteorites and normalized to 100 % Rare Earth + Yttrium.

TABLE II. *X-ray powder data for cheralite from Kuttakuzhi, India*

| I/I_1	d_{obs}	d_{calc}	hkl	I/I_1	d_{obs}	d_{calc}	hkl
10	5.20 Å	5.200 Å	$\bar{1}01$			1.868 Å	103
6	4.77	4.772	110	14	1.867 Å	1.866	$\bar{1}32$
20	4.664	4.663	011			1.866	032
25	4.167	4.166	$\bar{1}11$	6	1.851	1.851	320
12	4.073	4.072	101	4	1.794	1.794	023
10	3.515	3.515	111	5	1.757	1.758	222
30	3.481	3.481	020	18	1.731	1.731	132
58	3.277	3.277	200			1.730	$\bar{2}23$
3	3.139	3.139	002	10	1.6820	1.682	140
100	3.074	3.074	120			1.682	$\bar{3}13$
12	2.965	2.965	210	2	1.638	1.639	400
65	2.862$_5$	2.862	$\bar{1}12$	2	1.621	1.621	$\bar{4}02$
		2.862	012	4b	1.594	1.595	410
8	2.600	2.600	$\bar{2}02$			1.591	330
12	2.435$_5$	2.436	$\bar{2}12$	3	1.575	1.575	$\bar{1}14$
		2.435	112	5b	1.533	1.534	$\bar{2}41$
4	2.386	2.386	220			1.532	$\bar{2}14$
2	2.331$_5$	2.332	$\bar{1}22$	2	1.467	1.467	$\bar{1}24$
		2.331	022			1.466	411
1	2.237	2.237	$\bar{3}01$	2	1.455		
22	2.177	2.177	031	2	1.374$_5$		
12	2.149	2.149	103	2	1.362		
14	2.130	2.130	$\bar{3}11$	3	1.339		
14	2.111	2.111	221	5	1.327		
1	2.016	2.016	131	2	1.301		
16	1.954	1.954	212	4	1.273		
2	1.925	1.925	301	4	1.228		
8	1.887	1.887	$\bar{2}31$				

b = broad.
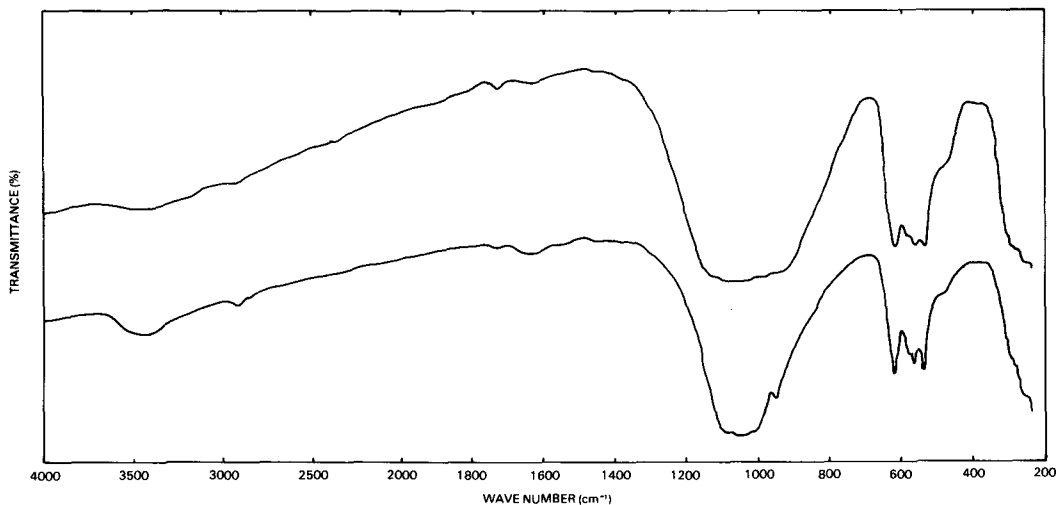
FIG. 2. Infra-red spectra of cheralite (*above*) from Kuttakuzhi, southern India, compared with monazite, Skardalen, Evje, Norway.
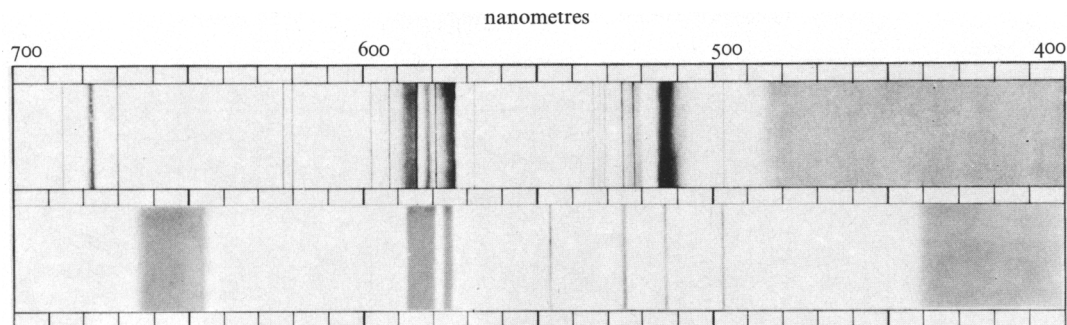
nanometres

FIG. 3. Absorption spectra of cheralite (*below*) from Kuttakuzhi, southern India, and of red gem monazite from Sri Lanka.

TABLE III. *Unit cell parameters of cheralite*

	1	2	3	4
a (Å)	6.70	6.717 ± 0.005	6.74	6.751₅ ± 0.0005
b (Å)	6.87	6.920 ± 0.005	7.00	6.962₅ ± 0.0005
c (Å)	6.39	6.434 ± 0.005	6.43	6.468 ± 0.0005
β	103° 24′	103° 50′ ± 5′	104° 36′	103° 53′
V (Å³)	286	290.4	294	295.2

1—Khubchandani (1956), 2—Nagaraja Rao and Finney (1965), 3—Bowie and Horne (1953), 4—Present work.

Quarry, Evje, Norway (MI 31156) for comparison, were run on a Perkin Elmer 457 spectrophotometer using the KBr disc technique. The traces (fig. 2) are very similar, but the band in the 950 cm^{-1} region was not observed in the cheralite.

The absorption spectrum of the cheralite as seen through a Beck wavelength prism spectroscope is compared in fig. 3 with that of a red gem monazite from Sri Lanka described by Jobbins *et al.* (1977). The bands in the 570-80 nm and 525 nm regions are similar and have been ascribed to rare earths, notably neodymium. A broad band in the cheralite in the 640-60 nm region is not present in the monazite. It may be due to the significant presence of uranium (4.33% U_3O_8) in the cheralite as opposed to 0.4% U_3O_8 in the monazite; the thulium present (and ? holmium) may contribute to this broad band.

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