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DAVIDITE: A REVIEW OF CANADIAN OCCURRENCES, AND REPORT ON A RECENT FIND AT KOMMES LAKE, SASKATCHEWAN

DAVID J. MOSSMAN
Department of Geology, Mount Allison University, Sackville, New Brunswick E0A 3C0

ABSTRACT

A new occurrence of davidite at Kommes Lake, Saskatchewan is reported. Of the six other previously reported Canadian occurrences, the presence of davidite is verified by XRD and electron-microprobe analysis for only two occurrences: the Faraday mine, Ontario, and Kotelmach Lake, Saskatchewan. Davidite from the Faraday mine is characterized by large homogeneous grains. In the Saskatchewan davidite, zoning is prominent. At Kommes Lake, it is expressed by mineral inclusions and in-host element (Fe, Y, Si, U) distribution. Inclusions are not conspicuous at Kotelmach Lake. Metatype material from Radium Hill (Australia) exhibits a maze-like pattern of irregular intergrowths of various opaque phases and is far more complex paragenetically. Chemically, the three Canadian examples are distinct from each other and from the Radium Hill material, most particularly in their Ti, Fe and *REE* contents. All these samples are light-rare-earth-enriched; *REE* contents range from 2.0 to 6.1 weight %.

Keywords: davidite, Canadian occurrences, Foster Lakes area, Faraday mine, chemistry.

SOMMAIRE

On décrit un nouvel exemple de davidite au Canada, au lac Kommes (Saskatchewan). Des six exemples connus antérieurement, on a pu confirmer la présence de davidite par diffraction X et par analyse à la microsonde électronique dans seulement deux cas, à la mine Faraday (Ontario) et au lac Kotelmach (Saskatchewan). La davidite de la mine Faraday se présente en cristaux larges et homogènes. Les cristaux de la Saskatchewan sont fortement zonés; dans ceux du lac Kommes, cette zonation se voit par des inclusions minérales et par la distribution des éléments Fe, Y, Si et U. Les inclusions ne sont pas si frappantes dans les échantillons du lac Kotelmach. Le matériau métatype de Radium Hill (Australie) montre un enchevêtrement de phases opaques en intercroissance, et donc une paragenèse beaucoup plus complexe. Les trois exemples canadiens sont chimiquement distincts l'un de l'autre, et se distinguent aussi du matériau de Radium Hill, surtout par leur teneur en Ti, Fe et terres rares. Tous ces échantillons sont enrichis en terres rares légères; la concentration totale des terres rares va de 2.0 à 6.1% en poids.

(Traduit par la Rédaction)

Mots-clés: davidite, exemples canadiens, région des lacs Foster (Saskatchewan), mine Faraday (Ontario), composition chimique.

INTRODUCTION

Among the uranium-bearing titanates, davidite $(La,Ce)(Y,U,Fe^{2+})(Ti,Fe^{3+})_{20}(O,OH)_{38}$, brannerite $(U,Ca,Ce,Y)(TiFe)_2O_6$, euxenite $(Y,Ca,Ce,U,Th)(Nb,Ta,Ti)_2O_6$ and thorutite $(Th,U,Ca)Ti_2(O,OH)_6$, are possibly the most familiar minerals, although numerous others exist (Fleischer 1983). Recent work has shown that at least six minerals are isotypic with davidite (Gatehouse *et al.* 1978, Haggerty *et al.* 1983). These minerals are: crichtonite $(Sr,La,Ce,Y)(Ti,Fe^{3+},Mn)_{21}O_{38}$, after which the group is named, senaite $Pb(Ti,Fe,Mn)_{21}O_{38}$, landauite $NaMnZn_2(Ti,Fe^{3+})_6Ti_{12}O_{38}$, loveringite $(Ca,Ce)(Ti,Fe^{3+},Cr,Mg)_{21}O_{38}$, lindsleyite $(Ba,Sr)(Ti,Cr,Fe,Mg,Zr)_{21}O_{38}$, and mathiasite $(K,Ca,Sr)(Ti,Cr,Fe,Mg)_{21}O_{38}$. All are of the type $AM_{21}O_{38}$ and are of similar compositions (Segalstad 1984).

A proposed nomenclature of crichtonite-group minerals (Gatehouse *et al.* 1978) classifies them according to the dominant large *A*-site cation. In the case of davidite, with which this report is concerned, the dominant cations are the Ce-group rare-earth elements (*REE*) and uranium. The purpose here is to document the known occurrences of davidite in Canada, and to report on the chemistry of the mineral. For comparative purposes, results are included of a new analysis of davidite from Radium Hill, Australia, where it occurs as the main ore-mineral of uranium. For information on the crystallography, constitution and genesis of davidite, the reader is referred to works by Hayton (1960), Pabst (1961), van Wambeke (1968), Gatehouse *et al.* (1979), Haggerty (1983), Segalstad (1984) and Foord *et al.* (1984). The subject of the genesis of ore-forming uranium–*REE* titanates, likewise beyond the scope of this paper, has been examined by Ferris & Rudd (1971) and Miguta (1976).

MATERIAL

A study of the literature and the catalogued collections of the Geological Survey of Canada reveals a total of six occurrences of davidite in Canada. To this may be added a new discovery made by the late David Harrigan at Kommes Lake, Saskatchewan. Thus, of the seven occurrences, four are from

TABLE 1. LISTING OF KNOWN OCCURRENCES OF DAVIDITE IN CANADA

Number	Area	Location	Remarks, Nature of host rock
16197[1]	Faraday Mine, Bancroft, Ontario	613 crosscut 900 level	Pegmatitic pyroxene granite; previous work by Dr. H. R. Steacy indicates presence of synchysite and davidite
Baska 1-63	Foster Lakes area, Saskatchewan, Kotelmach Lake	Lat: 56°39'35" Long: 105°28'35"	Pegmatitic (green) amphibole-bearing rock (Lang et al. 1962)
Univ. Sask.[2] 4072	Foster Lakes area, Saskatchewan, Kommes Lake	S.E. shore, 30 m NE of Wollaston Post. Lat: 58°26" Long: 102°32'	In fine-grained granite (anatectic meta-arkose?); late-stage deuteric alteration product accompanied by deposition of smoky quartz and bleaching of host rock
K-5	Foster Lakes area, Saskatchewan, Kulyk Lake	550 m NE of Eldorado showing Lat: 56°37'30" Long: 105°28'25"	aplitic, graphic, pegmatitic granite containing allanite and thorianite (D. H. Watkinson, pers. comm. 1979) (see also Watkinson and Mainwaring 1976)
19833[1]	Foster Lakes area, Saskatchewan	Unknown	Identified as 'davidite' in Geol. Surv. Can. catalogue; brannerite partly altered to anatase, set in matrix of quartz and goethite
538[1]	145 km north of Sioux Lookout, Ontario	Bamaji Lake	Reportedly from a pegmatitic host (Lang et al. 1962, p. 248). Material no longer available
McLean Point	Northeastern Nova Scotia	On coast near Tatamagouche	Davidite reportedly part of a complex detrital suite of primary and secondary uranium minerals (Chatterjee 1976) hosted by Carboniferous sandstone
Univ. Sask.[2] 10579	Radium Hill, Australia	Mine dump	Reference sample, metatype davidite from high-temperature pegmatite vein (Whittle 1955, 1959)

[1]Specimen housed in Geological Survey of Canada, Ottawa
[2]Univ. Sask. numbers refer to specimens housed at the University of Saskatchewan.
Source of samples in which davidite has been verified (this study) is: 16197 Geological Survey of Canada, H. R. Steacy; Baska 1-63, provided by D. D. Hogarth; Univ. Sask. 4072, provided by the late David Harrigan of the Saskatchewan Mining Development Corporation (Note: Saskatchewan Research Council analysis of typical host-rock of this sample indicates 2.2% U, 3.5% Fe, 0.86% Ti). Source of samples in which davidite was sought, but not found during this study is: K-5, provided by D. H. Watkinson; 19833, Geological Survey of Canada, donor J. B. Mawdsley; 538, Geological Survey of Canada, McLean Point, provided by H. E. Dunsmore.

Saskatchewan and one from each of the following: Faraday mine, Bancroft, Ontario; McLean Point, Nova Scotia; Bamaji Lake, north of Sioux Lookout, Ontario. General information on all Canadian occurrences as well as on the metatype specimen from Radium Hill is given in Table 1. It has been possible to obtain positive identification of davidite from only three of these occurrences, namely the Faraday mine, Ontario and two occurrences, Kotelmach Lake and Kommes Lake, in the Foster Lakes area of Saskatchewan.

Analytical Procedure

Autoradiographs were first produced of polished thin sections of the various samples in order to identify areas deserving detailed study. Subsequently microscope examination was carried out on the samples prior to electron-microprobe analysis of certain opaque phases. In each instance, a photographic record was made of the areas selected for analysis.

All specimens examined, including the Radium Hill sample, are metamict, yielding diagnostic X-ray patterns only after heating. Heating was carried out in air at about 1050°C for 1.5 hours. X-ray work was carried out using a Debye-Scherrer powder camera, film size 57.3 mm, Cu$K\alpha$ radiation, Ni filter and an exposure time of 1.5 hours. Cell-parameter calculations were not made.

The analyses were performed by Gordon J. Pringle on a MAC electron microprobe equipped with an energy-dispersion spectrometer (EDS). The instrument was operated at 20 kV and a specimen current of approximately 0.01 microamperes. Standards included well-characterized minerals, synthetic phases, synthetic glasses and some pure metals. The beam size varied from 5 to 60 μm depending on the available grain-size and whether the analysis was intended to represent limits of zoning or a general average of a larger area. Peak-overlap corrections were applied using a stripping technique in use at the Geological Survey of Canada based on measured correction-factors. The factors were determined on peaks for pure elements and express the degree of overlap of

TABLE 2. CHEMICAL COMPOSITION (ELECTRON-MICROPROBE DATA) OF DAVIDITE FROM CANADIAN OCCURRENCES

	#16197 Faraday Mine			#4072 Kommes Lake			#1-63 Baska Kotelmach Lake			Radium Hill		
	Weight %		No. of Cations	Weight %		No. of Cations	Weight %		No. of Cations	Weight %		No. of Cations
Al_2O_3	0.2	Al	0.08	0.9	Al	0.36	0.0	Al	0.08	0.6	Al	0.23
SiO_2	0.4	Si	0.14	1.5	Si	0.51	2.6	Si	0.78	1.9	Si	0.63
CaO	0.4	Ca	0.15	0.7	Ca	0.25	0.6	Ca	0.19	0.7	Ca	0.25
TiO_2	49.9	Ti	13.18	49.2	Ti	12.56	66.4	Ti	15.05	53.5	Ti	13.98
ScO	0.0	Sc	0.00	0.0	Sc	0.00	0.0	Sc	0.00	0.3	Sc	0.10
V_2O_3	0.0	V	0.00	0.3	V	0.08	0.0	V	0.00	3.3	V	0.90
Cr_2O_3	0.1	Cr	0.03	0.1	Cr	0.03	3.4	Cr	0.81	1.5	Cr	0.40
MnO	0.9	Mn	0.26	0.4	Mn	0.12	0.7	Mn	0.18	0.3	Mn	0.08
FeO[1]	25.0	Fe	7.35	26.1	Fe	7.41	14.0	Fe	3.53	13.3	Fe	3.73
ZnO	0.6	Zn	0.16	0.2	Zn	0.53	0.0	Zn	0.00	0.4	Zn	0.95
SrO	0.4	Sr	0.08	0.0	Sr	0.00	0.1	Sr	0.02	0.9	Sr	0.18
Y_2O_3	0.6	Y	0.12	2.8	Y	0.51	0.3	Y	0.05	1.9	Y	0.34
ZrO_2	0.1	Zr	0.02	0.3	Zr	0.05	0.8	Zr	0.12	0.8	Zr	0.13
Nb_2O_5	0.7	Nb	0.12	0.0	Nb	0.16	0.3	Nb	0.04	0.0	Nb	0.00
La_2O_3	1.4	La	0.18	2.6	La	0.33	0.2	La	0.02	1.9	La	0.23
Ce_2O_3	2.1	Ce	0.28	3.4	Ce	0.42	1.1	Ce	0.12	1.8	Ce	0.22
Pr_2O_3	0.7	Pr	0.08	0.1	Pr	0.01	0.7	Pr	0.07	0.5	Pr	0.06
PbO	4.6	Pb	0.43	1.4	Pb	0.13	0.8	Pb	0.06	1.5	Pb	0.14
UO_2[2]	9.3	U	0.73	5.2	U	0.39	2.9	U	0.19	9.0	U	0.68
Total	97.41		23.39	96.24		23.77	94.90		21.23	94.16		21.73
Formula	$A_{1.05}M_{22.34}O_{38}$			$A_{0.89}M_{22.88}O_{38}$			$A_{0.29}M_{20.94}O_{38}$			$A_{0.83}M_{20.90}O_{38}$		

Analyst G. J. Pringle. #16197, Faraday Mine, Ontario, average of four analyses in weight % of the oxides; #4072 Kommes Lake, Saskatchewan; #1-63 Baska, Kotelmach Lake, Saskatchewan (average of 2 determinations); Radium Hill, Australia (average of 4 determinations). Structural formulae calculated on the basis of 38 atoms of oxygen.
[1]All Fe expressed as FeO.
[2]All U expressed as UO_2.

that peak on other positions examined. The correction is applied by iteration of these factors in a matrix of simultaneous equations. The correction for matrix effects was made by a full ZAF calculation using the program ERPMAG developed at CANMET, Ottawa.

The electron-microprobe analyses were carried out on portions of specimens that had not been subjected to heat treatment. Eleven analyses were performed (Table 2) and are recast to fit a formula of the type $AM_{21}O_{38}$.

RESULTS

Faraday mine, specimen #16197

The host rock to the ore is a weakly foliated granodioritic pegmatite, substantially modified as a result of propylitic alteration and veining by chlorite and calcite. The main minerals are quartz and weakly zoned and strongly twinned plagioclase. Calcite is abundant, as are discrete grains of apatite and epidote. Irregularly shaped patches of titanite and garnet are widespread. Davidite and rutile are the principal opaque minerals. Davidite is present as large (up to 1 mm in diameter) homogeneous grains (Fig. 1). Minerals most intimately associated with the davidite include: niobian rutile (which occupies a position peripheral to many grains of davidite), titanite, uranothorite, synchysite, calcite, chlorite, zircon, pyrite and chalcopyrite.

Reconnaissance EDS work on the davidite indicates the presence of major Fe and Ti, with minor amounts of U, Pb, Ca and La. The structural formula, $(La_{0.18}Ce_{0.28}Pr_{0.08}Pb_{0.43}Sr_{0.08})_{\Sigma 1.05}$ $(Y_{0.12}U_{0.73}Zr_{0.02}Nb_{0.12}Zn_{0.16}Fe_{7.35}Mn_{0.26}Cr_{0.03}Ti_{13.18}$ $Ca_{0.15}Si_{0.14}Al_{0.08})_{\Sigma 22.39}O_{38}$, is that of a plumbian davidite. Detailed microprobe data on this and several other samples are given in Table 2. The presence of more than 22 cations in the *M* site of specimens 16197 and 4072 may be due to an error in assignment of site occupancy; some U may be present in the *A* site (*cf.* Gatehouse *et al.* 1979).

Within associated chloritic vein material (not shown in Fig. 1) are minute traces of a complex *REE*–Y–Ca silicate (kainosite? caysichite? iimoriite?). Qualitative EDS work indicates that the mineral contains minor U and Th. The total *REE* content is variable, reflecting a probable zonation in the mineral, but consists mainly of the light rare-earth elements Ce and Nd; Nd is evidently lacking in the matrix-associated davidite. In the vein, Ce and Nd attain maximum concentrations in the darkest portions, and at the expense of Si and Y. Calcium content seems to be constant in this silicate.

Kommes Lake, Saskatchewan, specimen #4072

The host rock here is an alaskitic metagranite. Like the specimen from the Faraday mine, the Kommes Lake material contains discrete (0.25 mm in diameter) grains of davidite. The structural formula is $(La_{0.33}Ce_{0.42}Pr_{0.01}Pb_{0.13})_{\Sigma 0.89}(Y_{0.51}U_{0.39}Zr_{0.05}$ $Nb_{0.16}Zn_{0.53}Fe_{7.41}Mn_{0.12}Cr_{0.03}Ti_{12.56}Ca_{0.25}$ $Si_{0.51}Al_{0.26})_{\Sigma 22.88}O_{38}$.

The Kommes Lake davidite is zoned, as shown by a line of inclusions found near the rim of one grain, and a darker central region in the same grain (Fig.

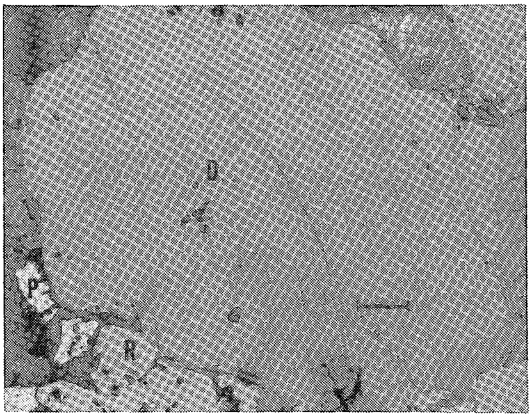

FIG. 1. Photomicrograph of polished thin section of davidite-bearing specimen (16197) from the Faraday mine, Ontario. Davidite (D) forms homogeneous subhedral grains in a predominantly calcite (C) matrix. Grains of rutile (R) are common (bottom of photograph); pyrite (P) appears intergrown among rutile grains. Reflected plane-polarized light, scale bar 0.1 mm.

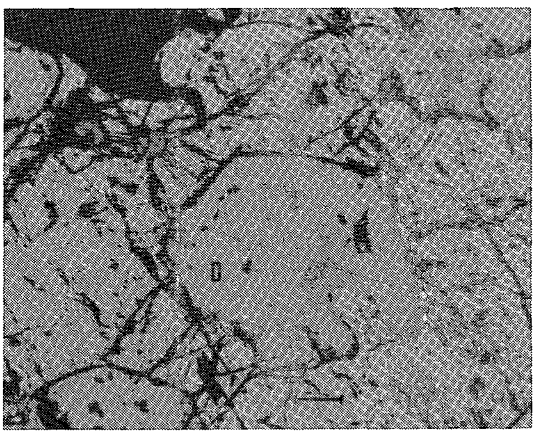

FIG. 2. Photomicrograph of Kommes Lake metagranite (Univ. Sask. 4072) reveals euhedral grain of davidite (D) hosted by lamellar intergrowths of ilmenite–hematite grains. A second davidite grain appears at lower left. The central grain shows a line of inclusions near the rim. The darker central portion of the grain is a characteristic feature of this sample. Unidentified radioactive phase at top left, adjacent to large davidite grain, has developed radial stress-fractures in the surrounding material. Reflected plane-polarized light, scale bar 0.1 mm.

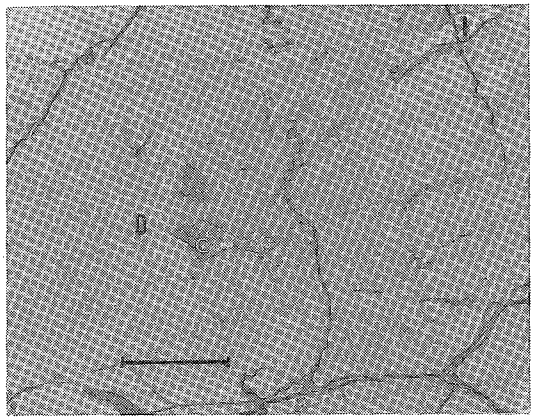

FIG. 3. Photomicrograph of Baska 1–63 (Kotelmach Lake, Saskatchewan) shows part of a dark anhedral grain exhibiting a shattered fabric surrounded by a narrow rim of ilmenite (I) just out of view, top right. Two pools of chlorite and calcite occur at centre of the grain. The stellate-shaped central portion of the grain is davidite, here a slightly transparent red-brown material. Dark lines are cracks. Reflected plane-polarized light, scale bar 0.1 mm.

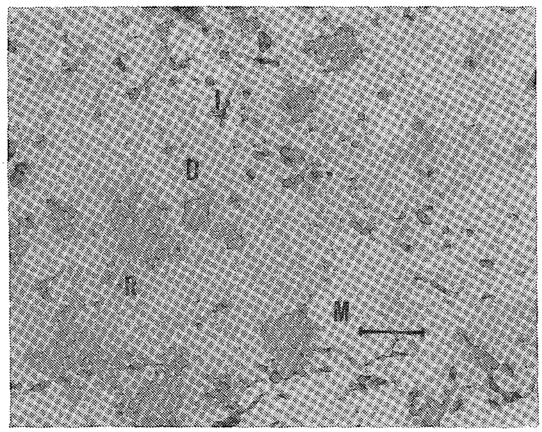

FIG. 4. Photomicrograph of davidite (Univ. Sask. 10579) from Radium Hill, Australia reveals a complex maze-like intergrowth of Ti–Fe–U oxides among which are davidite (D), rutile (R), magnetite (M) and ilmenite (I). Black parts are holes and cracks in the polished section. Reflected plane-polarized light, scale bar 0.01 mm.

2). The results of reconnaissance EDS work show that this zoning, at least in part, reflects the uneven distribution of the elements Fe, Y, Si and U. Uranium, Si, Ca, Ti and Pb tend to be relatively concentrated toward the central (more altered?) portion of grains at the expense of Fe. Darker areas thus have maximum U and minimum Fe contents. Dark areas in the two grains (particularly the smaller one) appear to coincide with a set of faint oblique fractures. The host to the davidite is magnetite containing exsolution lamellae of ilmenite as well as scattered discrete crystals of rutile (Fig. 2).

Baska (Mines), Kotelmach Lake, Saskatchewan, specimen 1-63

According to Mawdsley (1957, p. 39), this deposit is situated about 275 m east of the centre of the east shore of Kotelmach Lake, in a 18-m-wide pegmatite dyke. The rock is a diorite. Relict phenocrysts of clinopyroxene, substantially replaced by tremolite, accompany relict phenocrysts of calcic plagioclase in a mylonitized matrix. The plagioclase is severely saussuritized and chloritized. Patches of prehnite are widespread.

A polished section made from a very small amount of this material reveals the presence of a few anhedral opaque grains in whose cores occur dark, slightly transparent (red-brown) material corresponding to davidite, as identified by electron-microprobe analysis. The structural formula is $(La_{0.02}Ce_{0.12}Pr_{0.07}Pb_{0.06}Sr_{0.02})_{\Sigma 0.29}(Y_{0.05}U_{0.19}Zr_{0.12}Nb_{0.04}Fe_{3.53}Mn_{0.18}Cr_{0.81}Ti_{15.05}Ca_{0.19}Si_{0.78})_{\Sigma 20.94}O_{38}$. As the outer rim is approached in a typical grain, the reflectance decreases slightly, and the Ti and Si contents increase at the expense of both Fe and U. Chromium content remains the same throughout the dark grain. A rim of ilmenite surrounds each grain. Overall the davidite grains display a shattered fabric (Fig. 3), a feature not evident in the other samples of davidite examined in this study. Associated opaque minerals include ilmenite and minor magnetite.

Radium Hill, Australia, #10579

During the mid-1950s, davidite was the major source of uranium from South Australia. Whittle (1955) described the bewildering number of inclusions and the complexities of the intergrowths between davidite and associated opaque minerals. Most of the Radium Hill davidite evidently is massive, as is the material reported on in the present study, although it is interesting to note that a few crystals of davidite regarded as "pseudomorphic" (Whittle 1955, p.32) turned up at Radium Hill.

The sample reported on here is a massive black metallic hand-specimen retrieved from the mine dump. Polished specimens reveal a complex, maze-like pattern of an irregular intergrowth of opaque phases of low reflectance and variable polishing qualities (Fig. 4). Qualitative EDS results show that this material consists of intergrowths of Ti–Fe–U oxides. Rutile is abundant as large discrete grains and also occurs as tiny exsolved blebs in ilmenite. Other opaque phases include magnetite, brannerite and davidite, the latter within rutile and containing major Ti and Fe, minor U, Ca, V, Pb, Si and Al. The structural formula is $(La_{0.23}Ce_{0.22}Pr_{0.06}Pb_{0.14}Sr_{0.18})_{\Sigma 0.83}(Y_{0.34}U_{0.68}Zr_{0.13}Zn_{0.95}Fe_{3.73}Mn_{0.08}Cr_{0.40}Ti_{13.48}Ca_{0.25}Si_{0.63}Al_{0.23})_{\Sigma 20.90}O_{38}$. Biotite and Fe-chlorite are two of the more conspicuous nonopaque phases. Discontinuous veinlets comprised of rutile and phyllosilicates occupy somewhat less than about 5% of the rock.

CONCLUSIONS

Like other examples of davidite in the literature, the four specimens reported on here show a dominance of (La + Ce) group of *REE*. Overall, the *REE* content ranges from 2.0% in the Kotelmach Lake sample to 6.1% in the Kommes Lake sample. These quantities of *REE* will be a minimum for any given modal count for these specimens and for the Faraday mine sample. This is so because the results of qualitative EDS work show that the highest content of *REE* is located in low-reflectance material adjacent to davidite grains and intimately intergrown with them. Some of this low-reflectance material is possibly a stable high-temperature variety of brannerite, which Miguta (1976) reported as commonly enriched in *REE* (and thorium). In light of results obtained by Taylor & Fryer (1983) on trace-element geochemistry of granitoid mineral deposits, the *REE* signature in all of the davidite samples seems compatible with their derivation from magmatic-hydrothermal fluids.

In summary, all of the davidite samples examined crystallized in a granitic to dioritic and pegmatitic geological environment. Chemical differences among even this small a group of specimens are appreciable. However, this is not unexpected in light of the extensive isotypism possible among the uranium titanates and the probable anatectic environment of origin for the western Canadian occurrences.

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