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MINERALOGY AND PARAGENESIS OF THE McALLISTER Sn–Ta-BEARING PEGMATITE, COOSA COUNTY, ALABAMA

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ABSTRACT

The McAllister Sn–Ta deposit (Alabama) is localized in a complex pegmatite that contains large zones of mineralized late-stage replacement-type saccharoidal albite and nearly monomineralic muscovite 'greisen-like' pipes. The dyke is at least 450 m long and averages approximately 9 m in thickness. At least two 'greisen-like' pipes, as much as 7.6 m by 4.5 m in cross-section and extending at least 76 m down a steep easterly pitch, occur near the center of the dyke. The dyke is hosted by an approximately 300-Ma-old pluton of a group referred to as the Rockford Granite, a mesozonal to epizonal two-mica, peraluminous tin-bearing granite. The pluton is genetically affiliated with a well-defined sequence of simple to complex pegmatite dykes and quartz–cassiterite veins that occur near its margin and within the immediately adjacent metasedimentary rocks of the Wedowee Group. An apparent tin-depleted (<6 ppm Sn) halo exists around the McAllister dyke from about 1 m to more than 4 m. The 'greisen' pipes, which hold disordered wodginite, some containing more than 72 wt.% $\mathrm{Ta_2O_5}$, represent the latest mineralizing event in an $\mathrm{H_2O}$-rich and F-poor environment related to crystallization from rare-alkali- and rare-metal-rich fluids derived from the granite–pegmatite system. Minerals identified within the primary pegmatite and its albitized portions are: quartz, albite, K-feldspar, spodumene, muscovite, beryl, apatite, zircon, cassiterite, columbite–tantalite, tapiolite, lithiophorite, topaz, pyrite, and vivianite. Late-stage 'greisen-like' pipes contain muscovite, quartz, disordered wodginite, uranmicrolite, and zircon. Extremely late kaolinite also occurs, largely a result of surficial weathering. Wodginite crystals are generally subhedral to euhedral, and have simple morphology, showing forms {100}, {101}, {111} and {010}. The disordered wodginite locally contains 1.5 to 2.0 wt.% $\mathrm{ZrO_2}$ and 0.8 wt.% $\mathrm{UO_2}$. Refinement of X-ray powder data yielded: *a* 9.497(4), *b* 11.456(4), *c* 5.140(3) Å, *β* 90°33(2)′, *V* 559.19(32) Å^3, $Z = 1$, 60(1)% ordered. Based on an ordered structure, with $A_4C_4B_8\mathrm{O}_{32}$, structural formulas range from $(\mathrm{Mn}_{2.86}\mathrm{Fe}^{2+}_{1.07}\square_{0.07})_{\Sigma 4.00}(\mathrm{Ta}_{1.99}\mathrm{Sn}_{1.23}\mathrm{Fe}^{3+}_{0.22}\mathrm{Ti}_{0.19}\mathrm{U}_{0.02}\square_{0.35})_{\Sigma 4.00}(\mathrm{Ta}_{6.41}\mathrm{Nb}_{1.59})_{\Sigma 8}\mathrm{O}_{32}$ to $(\mathrm{Mn}_{2.08}\mathrm{Fe}^{2+}_{1.75}\square_{0.17})_{\Sigma 4.00}(\mathrm{Sn}_{2.01}\mathrm{Ti}_{0.75}\mathrm{Ta}_{0.71}\mathrm{Zr}_{0.37}\mathrm{Fe}^{3+}_{0.16})_{\Sigma 4.00}(\mathrm{Ta}_{6.68}\mathrm{Nb}_{1.32})_{\Sigma 8}\mathrm{O}_{32}$. Mössbauer data for wodginite indicate that 17% of the total iron is ferric and 7% of the total tin is Sn^{2+}. Cassiterite contains 1.4 to 2.7 wt.% $\mathrm{Ta_2O_5}$, 0.5 to 1.1 wt.% $\mathrm{Nb_2O_5}$, and 0.5 to 1.1 wt.% FeO.

Keywords: McAllister Sn–Ta deposit, disordered wodginite, muscovite, Piedmont, Alabama.

SOMMAIRE

Le gisement d'étain et de tantale de McAllister (Alabama), situé dans une pegmatite complexe, contient des volumes importants d'albite saccaroïde tardive, formés par remplacement et minéralisés, et des conduits de type greisen, presque entièrement constitués de muscovite. Le filon s'étend sur au moins 450 m et a une épaisseur d'environ 9 m. Près du centre du filon, se trouvent au moins deux de ces conduits "greisenisés" à pendage sub-vertical vers l'Est; leurs dimensions atteignent 7.6 × 4.5 × 76 m. La pegmatite recoupe un pluton qui fait partie de la suite de Rockford (300 Ma), composée de granites à deux micas, mésozonaux à épizonaux, hyperalumineux et stannifères. Le pluton est génétiquement lié à une séquence de filons pegmatitiques, à zonation de simple à complexe, ainsi qu'à des veinules à quartz + cassitérite près de sa bordure et dans l'encaissant, constitué de roches métasédimentaires du groupe de Wedowee. Une zone appauvrie en étain (<6 ppm Sn) s'étend de 1 à 4 m du contact avec le filon McAllister. Les conduits "greisenisés", qui contiennent une wodginite désordonnée zonée titrant localement à plus de 72% de $\mathrm{Ta_2O_5}$ par poids, seraient une manifestation du dernier événement de minéralisation, dans un milieu riche en eau et pauvre en fluor. Celui-ci résulterait d'une cristallisation à partir de fluides enrichis en alcalins et métaux rares et dérivés du système granite–pegmatite. Les minéraux suivants ont été trouvés dans la pegmatite saine ou alibitisée: quartz, albite, feldspath potassique, spodumène, muscovite, béryl, apatite, zircon, cassitérite, columbite-tantalite, tapiolite, lithiophorite, topaz, pyrite et vivianite. Les conduits greisenisés contiennent muscovite, quartz, wodginite désordonnée, uranmicrolite et zircon. La kaolinite, très tardive, résulte surtout d'un lessivage de surface. Les cristaux de wodginite sont généralement sub-idiomorphes à idiomorphes, et possèdent une morphologie simple, résultant des formes {100}, {101}, {111} et {010}. Cette espèce peut contenir de 1.5 à 2.0% de $\mathrm{ZrO_2}$ et environ 0.8% de $\mathrm{UO_2}$ (en poids). Un affinement des données obtenues par diffraction X (méthode des poudres) donne: *a* 9.497(4), *b* 11.456(4), *c* 5.140(3) Å, *β* 90°33(2)′, *V* 559.19(32) Å^3, $Z = 1$, degré d'ordre 60(1)%. En utilisant comme modèle la structure ordonnée, avec $A_4C_4B_8\mathrm{O}_{32}$, la formule structurale varie de $(\mathrm{Mn}_{2.86}\mathrm{Fe}^{2+}_{1.07}\square_{0.07})_{\Sigma 4.00}(\mathrm{Ta}_{1.99}\mathrm{Sn}_{1.23}\mathrm{Fe}^{3+}_{0.22}\mathrm{Ti}_{0.19}\mathrm{U}_{0.02}\square_{0.35})_{\Sigma 4.00}(\mathrm{Ta}_{6.41}\mathrm{Nb}_{1.59})_{\Sigma 8}\mathrm{O}_{32}$ à $(\mathrm{Mn}_{2.08}\mathrm{Fe}^{2+}_{1.75}\square_{0.17})_{\Sigma 4.00}(\mathrm{Sn}_{2.01}\mathrm{Ti}_{0.75}\mathrm{Ta}_{0.71}\mathrm{Zr}_{0.37}\mathrm{Fe}^{3+}_{0.16})_{\Sigma 4.00}(\mathrm{Ta}_{6.68}\mathrm{Nb}_{1.32})_{\Sigma 8}\mathrm{O}_{32}$. Des spectres Mössbauer montrent que 17% du fer total dans la wodginite est ferrique, et que 7% de l'étain est sous la forme Sn^{2+}. La cassitérite contient entre 1.4 et 2.7% de Ta_2O_5, et entre 0.5 et 1.1% de Nb_2O_5 et de FeO (en poids).

(Traduit par la Rédaction)

Mots-clés: gisement de Sn–Ta de McAllister, wodginite désordonnée, muscovite, Piedmont, Alabama.

INTRODUCTION

The McAllister tin–tantalum pegmatite deposit is located in Sections 14 and 23, T22N R18E, approximately 3 km west of Rockford, Coosa County, Alabama. The deposit, discovered in 1982 by the Callahan Mining Corporation following reconnaissance stream-sediment and subsequent soil geochemical surveys of the Rockford District, is the first significant tin–tantalum deposit found in the southeastern United States. In addition, it is the first example of the spodumene subtype of the complex type (Černý 1986) of highly fractionated rare-element pegmatite found in Alabama. The nearest similar deposit is at Kings Mountain, North Carolina. Combined reserves of all classes for the deposit are approximately 90,000 kg of Ta_2O_5 and 91,000 kg of SnO_2.

The deeply weathered dyke strikes approximately N60°W for at least 450 m, dips 45°NE, and averages 9 m in thickness. It is thickest at the northwest end, and near its center contains abundant late saccharoidal albite of replacement origin and several high-grade (greater than 1% Ta_2O_5 and 0.1% SnO_2) 'greisen-like' pipes, which also may be of replacement origin. A more detailed report on the economic geology and geochemistry of the deposit is in preparation. The objectives of this paper are to report on the mineralogy and paragenesis of the McAllister Sn–Ta-bearing pegmatite.

ANALYTICAL METHODS

All mineral analyses were carried out with an ARL EMX–SEMQ electron microprobe using both natural and synthetic standards: natural manganotantalite (Mn, Ta) Fe_2O_3 (Fe), synthetic $SrBaNb_4O_{10}$ (Nb), synthetic SnO_2 (Sn), synthetic TiO_2 (Ti), Sc metal (Sc), synthetic $CaWO_4$ (W), natural zircon (Zr), and U metal (U). Operating voltage was 15 or 20 kV, sample current was 10 nA measured on brass, and beam diameter, 1 μm. Data reduction was done using a modified version of MAGIC IV. Emission spec-

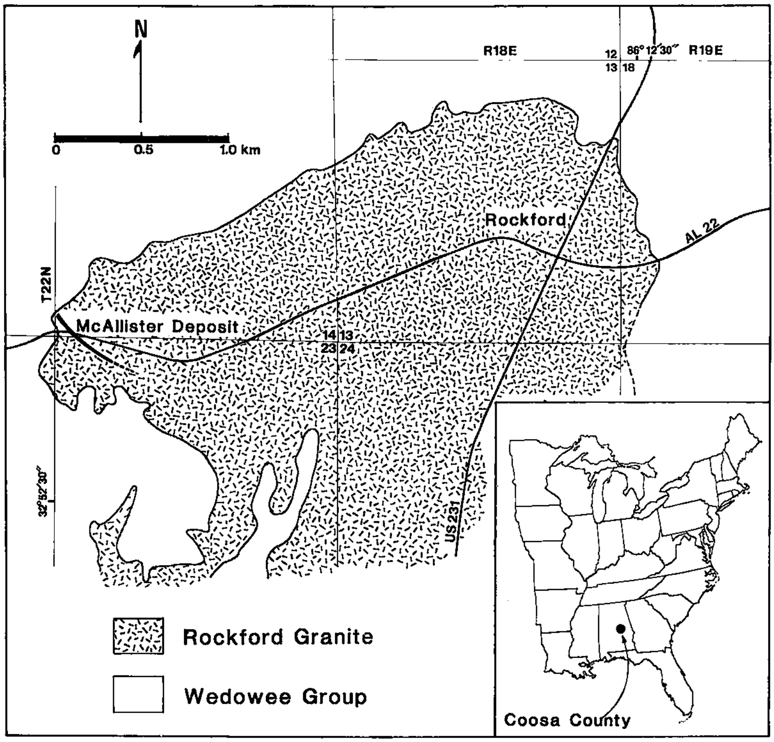

FIG. 1. Location and generalized geological setting of the McAllister Sn–Ta deposit, Coosa County, Alabama.

trographic analyses were done using a direct-reading DC-arc Jarrell-Ash 3.2 m spectrograph. EDS analyses were done using a KEVEX 7000 system utilizing Am and Cd radioisotope sources. Wavelength-dispersion X-ray-fluorescence analyses were done on an automated Philips PW1600 instrument, and samples were prepared according to the method of Taggart & Wahlberg (1980). Sample weights of 0.8 g each were used for the rock analyses; 0.33 to 0.8 g were used for muscovite. Water content was determined by microcoulometric moisture analysis using a Mitsubishi Karl Fisher coulometric titrator model CA-02 with a high-temperature furnace, model VA-21; F was determined by specific-ion electrode, and FeO was determined by colorimetric titration. Mössbauer spectra of wodginite were run using a 302-mg sample mixed with sugar and pressed into a pellet 2.54 cm in diameter. Spectra were determined at room temperature. The analysis of a reference sample (ALCO-805) of the host Rockford Granite (informal name: Deininger *et al.* 1973) for minor and trace elements was done commercially by X-ray Assay Labs, Don Mills, Ontario, using standard neutron-activation procedures. Partial analyses for four muscovite concentrates and one of beryl were performed by atomic absorption spectrophotometry (AAS) at École Polytechnique, Montréal, Québec.

GEOLOGY

Regional setting

The location and general geology of the Rockford District are shown in Figure 1. The district is significant in that it is the most southerly tin district in the southeastern United States and the only one located in the Northern Piedmont of Alabama, a major area of crystalline rocks north of the regionally important Brevard Zone of cataclasis.

The McAllister deposit lies along the northwestern margin of, and is hosted entirely by, a two-mica, peraluminous, ilmenite-series (Ishihara 1981) tin-bearing pluton of the composite Rockford Granite pluton. The pluton is a postmetamorphic or late synmetamorphic intrusive body (Cook & Payne 1975, Hicks 1981, Frinak 1984, Drummond 1987) bounded by metasedimentary rocks of the Wedowee Group (Neathery & Reynolds 1973) of probable Early Paleozoic age. This pluton is considered to be one of a group that is 300 ±20 Ma old (Russell 1978), although some age data for the pluton contradict this. All of the plutons are older than 300 to 320 Ma, based on mineral cooling ages (Russell *et al.* 1987). Preliminary $^{40}Ar/^{39}Ar$ ages of about 320 Ma were obtained by L. W. Snee and J.T. Chesley (U.S.G.S.) for muscovite from two of four 'greisen-like' pipes in the McAllister pegmatite dyke.

Petrology and composition of the Rockford Granite

The Rockford Granite is relatively leucocratic, medium grained, unfoliated, and potassic in its exposed central portion. Near its margin, the pluton is enriched in biotite, is locally coarse grained and sodic, and is more resistant to weathering. Whole-rock compositions of five drill-core samples of the granite from both above (163 and 179) and below (197, 206 and 210.5) the mineralized McAllister pegmatite dyke and of a sample of type K-rich Rockford Granite (AlCO-805) are given in Table 1. In the vicinity of the McAllister deposit, the Rockford Granite is composed of approximately 28% quartz, 40% albite-oligoclase, 16% microcline, 5% biotite, and 10% muscovite, with locally important accessory chlorite, apatite, elbaite, schorl, topaz, zircon, garnet, clinozoisite, and opaque phases, includ-

TABLE 1. CHEMICAL COMPOSITION OF THE ROCKFORD GRANITE

Weight %	163	179	197	206	210.5	ALCO-805
SiO_2	71.1	70.7	69.8	70.5	70.6	69.9
Al_2O_3	14.9	15.4	15.7	15.0	15.3	14.9
Fe_2O_3	0.57	0.80	0.81	0.83	0.76	---
FeO	1.73	1.49	1.81	1.83	1.62	2.28*
MnO	0.04	0.04	0.05	0.05	0.05	0.07
MgO	0.81	0.80	0.92	0.93	0.84	0.67
CaO	2.04	2.06	2.28	2.07	2.01	1.47
Na_2O	3.32	3.30	3.75	3.77	3.39	3.56
K_2O	3.43	3.09	3.01	2.95	3.54	3.43
TiO_2	0.31	0.30	0.35	0.35	0.31	0.12
P_2O_5	0.14	0.15	0.16	0.16	0.17	0.31
LOI (920°C)	1.06	1.61	1.38	1.42	1.33	1.16
H_2O^+	0.83	1.01	0.80	0.88	0.84	---
H_2O^-	0.07	0.12	0.15	0.14	0.11	ND
F	0.06	0.09	0.07	0.09	0.06	0.06
Total (using LOI)	99.45	99.74	100.02	99.86	99.92	99.70
O for F	0.03	0.04	0.03	0.04	0.03	0.03
Total (incl. waters and F)	99.32	99.31	99.63	99.51	99.57	ND

* Total Fe as FeO. ND not determined. Samples 163, 179, 197, 206 and 210.5 are 30 cm lengths of NQ drill core from the immediate proximity of the McAllister dyke. AlCO-805 is reference Rockford Granite from near its type location at the town of Rockford, Alabama. LOI values and totals using the LOI values are included for comparison with the specific values determined for waters and F.

TABLE 2. CIPW NORMS FOR ANALYZED SAMPLES OF ROCKFORD GRANITE

Sample no.	163	179	197	206	210.5	ALCO-805
Q	32.98	34.39	30.09	31.41	31.83	31.97
C	2.39	3.30	2.55	2.26	2.68	3.52
Or	20.60	18.61	18.03	17.71	21.22	20.96
Ab	28.55	28.45	32.17	32.40	29.09	31.15
An	9.36	9.42	10.41	9.37	8.99	5.45
Hy	4.36	3.72	4.52	4.58	4.08	5.98
Mt	0.84	1.18	1.19	1.22	1.12	0.00
Il	0.60	0.58	0.67	0.68	0.60	0.24
Ap	0.34	0.36	0.38	0.38	0.41	0.76
Total	100.02	100.01	100.01	100.01	100.02	100.03
Fe^{++}/total Fe	0.771	0.674	0.713	0.710	0.703	----
Mg-value*	0.539	0.613	0.581	0.582	0.588	0.347
Peralum. Index**	1.157	1.230	1.157	1.140	1.172	1.217
Diff. Index	82.13	81.45	80.29	81.52	82.14	84.08

* Mg/(Mg+total Fe as Fe^{2+}+Mn)
**A/(CNK)

TABLE 3. CONCENTRATIONS OF SELECTED ELEMENTS* IN DRILL-CORE SAMPLES FROM HOLE DT-21 ROCKFORD GRANITE, MCALLISTER DEPOSIT

Element or oxide	FeO%	Ba	La	Ce	Nd	Zn	Ga	Rb	Sr	Y	Zr	Th	Nb	U	Pb
163-164	2.57	979	31	70	34	71	21	118	311	16	125	12	10	27	24
179-180	2.49	861	28	52	30	70	<12	211	305	12	126	20	9	23	23
197-198	2.67	667	32	75	30	49	16	141	304	21	135	20	9	<16	27
206-207.5	2.80	717	34	79	42	58	17	334	301	20	140	<12	10	21	25
210.5-211.5	2.54	779	37	72	31	63	<12	138	279	17	128	13	13	20	21
Mean	2.61	801	32	70	33	62	15	188	300	17	131	14	10	21	24
Std. Dev.	0.12	123	4	10	5	9	4	89	12	3	6	6	2	5	3

* Results of analyses by energy-dispersion. Bi N2, Sn N6, Sb N6 for all samples. All values are ppm except where otherwise indicated.
N Not detected at value shown.

ing magnetite and rare cassiterite. The rock is hypidiomorphic and holocrystalline; the grain size of essential minerals ranges from 0.5 to 20 mm. Oligoclase is typically replaced by untwinned albite, such that albite locally constitutes as much as 26% of selected samples. Details of the mineral chemistry and conditions of crystallization of granites in the Alabama tin belt are given by Green & Usdansky (1984). CIPW norms and additional data for the analyzed samples are given in Table 2.

Ten fresh rock samples collected from bouldery outcrops generally near the margin of the pluton contain 3.4 ppm W, 19.6 ppm Sn, 0.041% F,and 65.5 ppm Li. Additional trace-element data for the Rockford Granite and other spatially related felsic igneous rocks are given in Hicks (1981). Nine granite samples collected from within 0.7 m of the footwall or hanging wall of the dyke, or from horses within the dyke, contain an average of 170 ppm Sn and 12 ppm Ta (ranges: 35–340 ppm Sn, 1–30 ppm Ta). Results of energy-dispersion analyses (EDA) for selected elements in the first 5 samples listed in Table 1 are listed in Table 3. These 5 samples are from less than 1 m to more than 4 m from the dyke.

Additional trace-element data for Sn and Ta (Cook & Foord, in prep.) for 39 samples show Sn ranging from 3 to 13 ppm in the interval 0.8–7 m from the dyke, with 10 samples containing less than 4 ppm Sn. Ta values are below the limit of detection (5 ppm) for all but 4 samples, and all 39 samples are within 6 m of the dyke.

Agreement between the XRF determinations for total iron as Fe_2O_3 and colorimetric titration for FeO, and the EDA determinations for total iron as FeO, is good. The ratio Rb:Sr (average) for the host Rockford Granite is 0.67, which is significantly less than that characteristic of highly evolved tin-rich granites, characterized by a value of 3:1 or more (*e.g.*, Haapala 1985, du Bray 1986). This is in agreement with the differentiation index of the granite (about 82) compared to that of evolved tin-bearing granites, which have a D.I. of 95 or more.

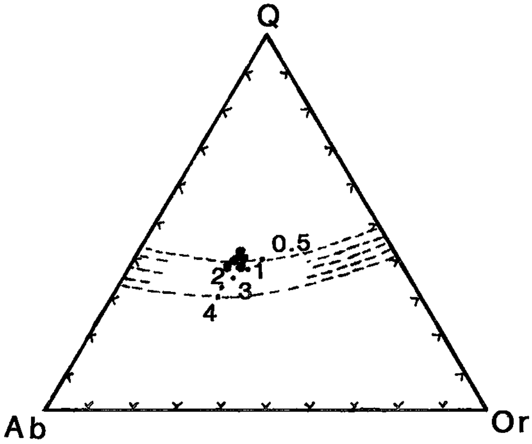

FIG. 2. Triangular Q–Ab–Or diagram showing the compositions of the analyzed samples of Rockford Granite. Isobaric minima (water-saturated conditions) indicated for 0.5, 1.0, 2, 3, and 4 kbar pressure (after Tuttle & Bowen 1958).

Q–Ab–Or values, calculated for CIPW norms, cluster along the 0.5 kbar isobaric minimum and lie to the Ab-rich side of the thermal minimum (Fig. 2), suggesting a depth of crystallization of about 2 km, assuming $P_{total} = P(H_2O)$. The placement of the Q–Ab–Or values may not be accurate because of the Ca and muscovite content of the rocks. Geological evidence, in the form of metamorphic mineral assemblages within the Wedowee Group and geobarometric estimates by Drummond & Allison (1987), indicates a deeper level (15–17 km) of emplacement than that indicated by the calculated Q–Ab–Or values. The presence of unaltered spodumene within the pegmatite and below the zone of weathering, and the absence of other Li-aluminosilicates, also favor pressures of greater than 3 kbars (London 1986, London & Burt 1982a,b). Pressures of greater than 6 kbars were suggested by Green & Usdansky (1984). However, uplift may have occurred during the 300 Ma or more after deposition of the Wedowee Group and regional metamorphism prior to emplacement of the Rockford Granite and genetically related pegmatites, resulting in a higher level of emplacement. Sparse open miarolitic cavities filled with smoky quartz and feldspar are present within the Rockford Granite and may also suggest somewhat lower pressures.

Geology of the dyke and 'greisen' pipes

The mineralogy and composition of the McAllister dyke are both laterally and vertically zoned (Fig. 3). The central part of the dyke contains a small quartz core, the margin of which locally contains laths of opaque green spodumene as much as 0.6 m long and 0.1 m thick. Significant amounts of colorless to pale pink beryl (goshenite–morganite varieties) occur both within the quartz core and as small euhedral grains within adjacent graphic pegmatite. The core is bordered on all sides by a thin-to-thick zone of locally graphic smoky quartz – alkali feldspar pegmatite. This pegmatite phase becomes increasingly dominant to the northwest, where it forms most of the dyke in the northwesternmost trench exposures. The central and eastern portions of the dyke are extensively replaced by saccharoidal albite, particularly beneath the core-pegmatite zone. The dyke thins and splits into several parallel segments with depth. Each segment exhibits pervasive replacement by saccharoidal albite to the greatest depths tested by drilling. Figure 3 shows a characteristic, though atypical, off-center displacement of the quartz core.

Tin and tantalum occur throughout the dyke, averaging 0.07% Ta_2O_5 and 0.08% SnO_2 within the area of proven reserves. Disseminated tantalum minerals are relatively abundant (approximately ten times that in other portions of the dyke) in the central part of the dyke, in areas of muscovite 'greisen-like' bodies and albite replacement. Cassiterite is more abundant toward the eastern end of the dyke and at depth northwest of the core. No cassiterite has been found within the 'greisen-like' pipes.

Two high-grade 'greisen-like' pipes have been delineated in the central part of the dyke, immediately east of the small quartz core. Several other pipes are indicated by trenching and drilling immediately west of the core, but have not been thoroughly defined. The 'greisen-like' pipes are lens-like in section, averaging about 7.6 m in strike length and as

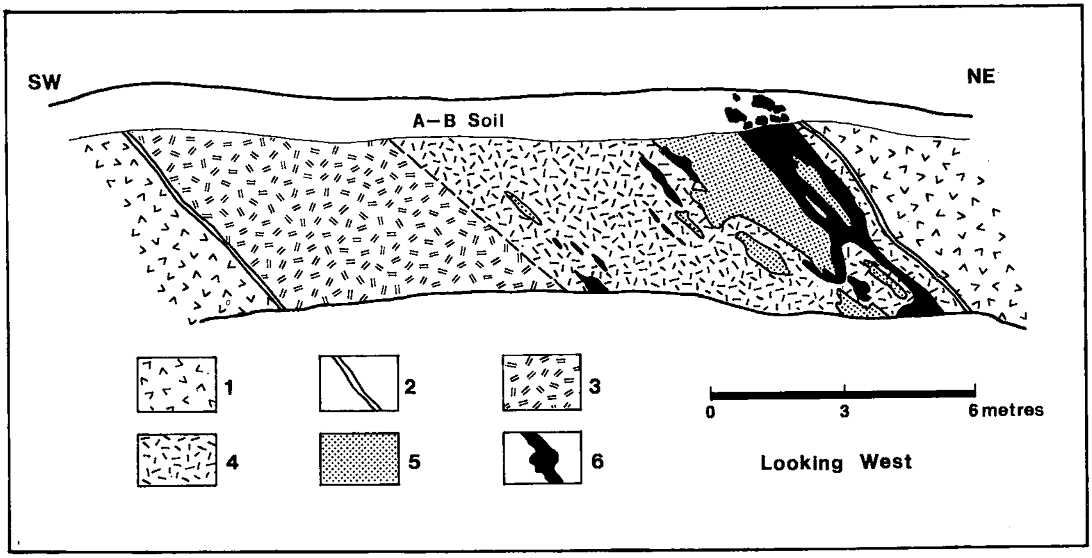

FIG. 3. Geological section through the McAllister dyke along the west face of exploration trench T–2. (1) Rockford Granite saprolite; (2) foliated medium-grained quartz–muscovite selvage; (3) kaolinized equigranular pegmatite and saccharoidal albite, with the latter becoming dominant toward 3–4 contact; (4) kaolinized saccharoidal albite with local masses of yellow muscovite-dominant 'greisen' and lenticular, rubbly smoky quartz; (5) yellow muscovite-quartz 'greisen' with medium-grained tantalian wodginite – wodginite and uranmicrolite; (6) massive rubbly smoky quartz with local spodumene and cesium-bearing beryl.

much as 4.5 m in true thickness. The pipes pitch steeply to the east in the plane of the dyke and extend at least 76 m down pitch. The grade of these pipes is about 1% Ta_2O_5 and 0.1% SnO_2. The 'greisen-like' bodies are mineralogically simple, containing only major muscovite and minor quartz, with local accessory Ta–Nb–Sn oxide minerals and feldspar, and very sparse local fine-grained topaz.

Texturally, these pike-like bodies resemble greisen, but their geological setting, chemistry and mineralogy do not. True greisens are formed by the alteration and reconstitution of granite or chemically similar rock (Bates & Jackson 1980). Introduction of F, and usually B, Be, Sn, W, and Mo as well, occurs in true greisens. Their mineralogy is characterized by the presence of F-bearing mica (muscovite, or one of the Li-bearing micas), topaz and fluorite, and they may contain minerals such as tourmaline, euclase and beryl.

DESCRIPTIVE MINERALOGY AND ANALYTICAL RESULTS

Feldspars

Albite is the dominant feldspar in the central part of the dyke beneath the zone of weathering. Here, albite occurs in thick intervals as generally euhedral, fine- to medium-grained, chaotically aggregated laths that constitute nearly monomineralic saccharoidal albite. Textures observed in deep trenches and drill core suggest a front-like replacement phenomenon wherein highly reactive sodium-bearing fluids replaced large volumes of the original dyke. Zones of partial replacement at saccharoidal albite – graphic pegmatite boundaries show replacement of all minerals, including quartz, by albite.

TABLE 4. EMISSION SPECTROGRAPHIC ANALYSES OF FIVE SAMPLES OF MUSCOVITE AND ONE BULK SAMPLE FROM 'GREISEN' PIPES IN THE MCALLISTER DEPOSIT

Element	BC-5	A T-13 barren pipe	B T-23 pipe	C T-2 high-grade pipe	D T-2 high-grade pipe	T-2* 6 m deep
Fe(%)	0.7	0.5	0.7	0.2	0.3	1.0
Mg(%)	0.07	0.03	0.15	0.02	0.05	0.05
Ca(%)	0.002	<0.002	<0.002	<0.002	<0.002	<0.05
Ti(%)	0.03	0.03	0.05	0.002	0.03	0.02
Si(%)	major	major	major	major	major	major
Al(%)	major	major	major	major	major	major
Na(%)	0.3	0.7	0.7	0.7	0.7	0.3
K(%)	7.0	major	major	major	major	7.0
Mn(ppm)	300	150	150	70	200	700
B	150	150	100	150	100	200
Ba	30	15	70	<2	7	<10
Be	200	15	20	15	150	500
Cr	15	none	none	none	none	20
Cu	3	1.5	none	1	none	5
Nb	100	30	30	15	30	500
Ni	3	none	none	none	none	<20
Pb	20	10	30	15	10	70
Sn	700	500	700	500	300	1000
Sr	20	7	30	none	30	---
V	10	15	15	none	7	<100
Zr	none	150	none	none	none	<50
Ga	150	150	150	150	150	---
Tl	300	200	300	300	300	---
Li	300	200	300	200	200	---
Rb	7000	10,000	>10,000	7000	7000	---
Cs	2000	3000	3000	2000	2000	--- plus 150 ppm As

Note: * One kilogram bulk sample. All other elements not detected at respective limits of detection. Rare alkalis determined by special infrared region emission spectrography. All values ppm except as indicated.

Coarsely crystalline subhedral white oligoclase, locally in giant crystals exceeding 0.3 m across, occurs in the thicker pegmatitic zones in the western part of the dyke, west of the zones of widespread saccharoidal albite. Partly to completely albitized remnants of similar, though smaller, oligoclase crystals are locally conspicuous in quartz-rich pegmatite proximal to the core.

K-feldspar is very rare in the McAllister dyke. In the deepest parts of the dyke, thin zones of partly albitized microcline-rich pegmatite were encountered by drilling. Pink microcline grains several cm across are locally embayed by albite aggregates and occur with white quartz and muscovite.

TABLE 5. CHEMICAL COMPOSITION OF MUSCOVITE FROM FOUR 'GREISEN' SAMPLES FROM THE MCALLISTER DEPOSIT

Oxide	A	B	C	D
SiO_2	45.0	45.2	44.7	44.9
Al_2O_3	35.4	35.8	36.4	37.4
Fe_2O_3	0.80	1.06	0.51	0.54
MgO	0.15	0.20	0.07	0.10
CaO	0.01	0.01	0.01	0.01
Na_2O	0.58	0.63	0.52	0.67
K_2O	9.33	8.72	7.82	9.34
TiO_2	0.11	0.08	<0.02	0.03
P_2O_5	<0.05	<0.05	<0.05	<0.05
MnO	0.03	0.04	0.03	0.03
H_2O^+	5.56	5.16	6.60	4.80
H_2O^-	0.31	0.39	0.34	0.22
F	0.15	0.12	0.11	0.12
SnO_2	0.08	0.10	0.08	0.05
Li_2O	0.13	0.11	0.13	0.11
Rb_2O	1.39	1.48	1.35	1.22
Cs_2O	0.35	0.35	0.40	0.30
Tl_2O	0.03	0.04	0.04	0.04
LOI(920°C)	5.96	5.55	6.75*	5.00*
Total (using waters and F)	99.41	99.49	99.11	99.88
O = F	0.06	0.05	0.05	0.05
Total	99.35	99.44	99.06	99.83

Note: values for Fe_2O_3, MgO, CaO, Na_2O, K_2O, MnO, Li_2O, and Cs_2O are averages of determinations by XRF, emission spectrographic analysis, and AAS methods. Values for Rb_2O are from AAS methods. LOI values are given for comparison with H_2O^+ and H_2O^- values.

*TGA scans at a heating rate of 10°C/min. and over an interval of 25° to 1000°C yielded weight losses of 6.75 and 5.40 percent for samples C and D respectively.

Structural formulas for the four muscovites were calculated according to the method of Foster (1960) and are given below:

A- $(K_{1.62}Na_{0.15}Rb_{0.12}Cs_{0.02})^{+1.92}_{1.91}[(Al_{3.84}Fe_{0.08}Li_{0.07}Mg_{0.03}Ti_{0.01})^{-0.06}_{4.03}(Si_{6.14}Al_{1.86})^{-1.86}_{8.00}O_{20}(OH_{3.78},F_{0.06})_4]^{-1.92}$

B- $(K_{1.51}Na_{0.16}Rb_{0.13}Cs_{0.02})^{+1.82}_{1.82}[(Al_{3.84}Fe_{0.11}Li_{0.06}Mg_{0.04}Sn_{0.02}Ti_{0.01})^{+0.05}_{4.08}(Si_{6.13}Al_{1.87})^{-1.87}_{8.00}O_{20}(OH_{3.59},F_{0.05})_4]^{-1.82}$

C- $(K_{1.36}Na_{0.14}Rb_{0.12}Cs_{0.02})^{+1.65}_{1.64}[(Al_{3.98}Li_{0.07}Fe_{0.05}Sn_{0.02}Mg_{0.01})^{+0.23}_{4.13}(Si_{6.11}Al_{1.88})^{-1.88}_{8.00}O_{20}(OH_{3.26},F_{0.04})_4]^{-1.65}$

D-$(K_{1.60}Na_{0.17}Rb_{0.11}Cs_{0.02})^{+1.90}_{1.90}[(Al_{3.93}Fe_{0.06}Li_{0.06}Mg_{0.02})^{+0.08}_{4.07}(Si_{6.02}Al_{1.98})^{-1.98}_{8.00}O_{20}(OH_{3.75},F_{0.05})_4]^{-1.90}$

Muscovite

Muscovite is the dominant mica-group mineral in the dyke. Muscovite in fine-grained flakes and small aggregates occurs disseminated in the saccharoidal albite and occurs as coarser, nearly colorless grains that are a locally important constituent of the graphic pegmatite.

Large amounts of compact and intergrown flakes of a distinctly yellow muscovite constitute the bulk of the 'greisen-like' pipes. Grain size of the muscovite ranges from <0.5 mm across to 3 mm or more. All of this muscovite is of the $2M_1$ polytype, based on four determinations by X-ray powder-diffraction methods. Results of emission spectrographic analyses for 5 samples of the muscovite from the pipes and one bulk sample of muscovite-dominant 'greisen' are given in Table 4. The spectrographic and X-ray-fluorescence analytical results for the 5 purified muscovite samples are similar. Interesting features are: consistent significant amount of contained tin (300 to 700 ppm) and elevated content of rare alkalis (200 to 300 ppm Li, 0.7 to >1% Rb, and 0.2 to 0.3% Cs) relative to muscovite in a typical granite. The chemical compositions of 4 of the muscovite samples are given in Table 5.

All 4 muscovite samples show variable but low interlayer-cation occupancy (1.65 to 1.92 out of 2.00), and a similar excess of water. The variable but low potassium content is the primary cause for the low occupancy in the interlayer site. Mica sample D is the most normal of the four samples (Table 5). The lower K contents in the other samples are attributed to near-surface weathering and leaching. Perhaps owing to the large ionic radii of Rb and Cs, relative to K, these two elements have not been leached to any appreciable extent. TGA scans for samples C, D, and a reference muscovite (Wards) all show a discrete weight-loss event at about 890°C. All three samples show a steady and continuous weight-loss from 25°C to about 890°C. An additional loss of about 2 wt.% at 550°C in sample C may reflect loss of H_3O^+, but this is not certain. All four (A through D) muscovite samples contain more than 4.00 atoms of (OH,F) if calculated on the basis of 22 oxygen atoms. Illite, characterized by a lower content of tetrahedral aluminum, does not appear to have formed in these samples on the basis of optical, XRD, and chemical data. Based on 12 total anions, ^{IV}Al is very nearly 1.00 for samples A, B, and D, and is slightly greater than 1 for sample C, not lower as would be expected if illite were present.

In terms of atomic percentages of Ti, Mg and Na (Miller *et al.* 1981), the compositions of the 4 muscovite samples from the 'greisen-like' pipes (Fig. 4) are similar to those of muscovite from other granitic pegmatites (Foster 1964, Černý & Burt 1984). However, they are distinctly different from compositions of muscovite from tin-bearing granites and true greisens (*e.g.*, Foster 1964, Neiva 1982, Kwak & Askins 1981). There is a nearly complete range between Mg- and Na-rich (Fig. 4) muscovite from granites, aplites, pegmatites, greisens, and veins (Neiva 1987, Lee *et al.* 1987). Both Mg and Ti are very low or absent, whereas Na is usually present in variable amounts in muscovite from highly evolved and fractionated granitic pegmatites (*e.g.*, Rinaldi *et al.* 1972). The muscovite from the McAllister pegmatite is of the latter type.

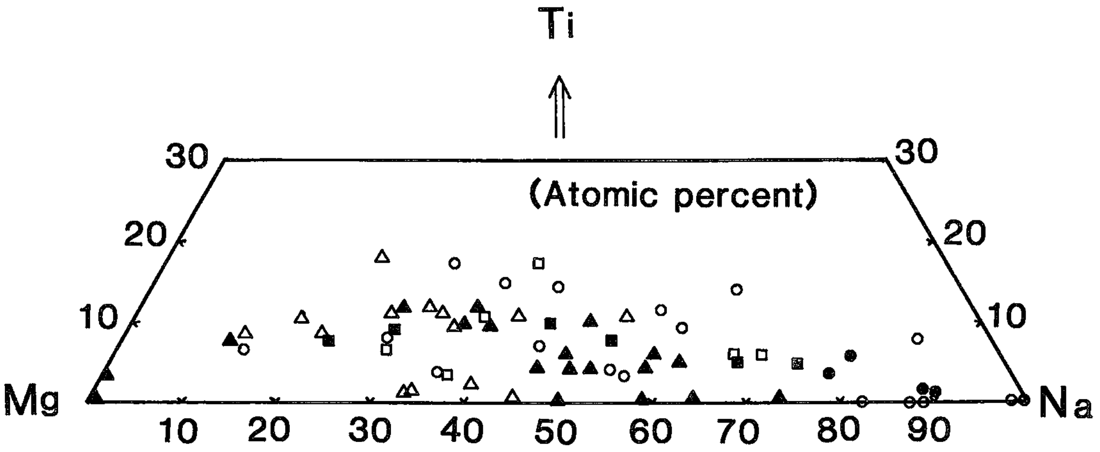

FIG. 4. Triangular Ti–Mg–Na diagram (atomic proportions) showing compositions of muscovite from selected granites, pegmatites, aplites, greisens, and veins. Solid circle: McAllister muscovite, open circle: Foster (1964), open square: Kwak & Askins (1981), solid square: Lee *et al.* (1987), open triangle: Neiva (1982), solid triangle: Neiva (1987).

Nb–Ta oxides

Disordered wodginite. The principal tantalum-bearing mineral in the McAllister pegmatite dyke is wodginite. Depending on the tin and tantalum content, some of the wodginite approaches "mineral T", based on the classification of the wodginite group using the criteria of Ercit (1986, Ercit *et al.*, in prep.) "Mineral T" will be fully described by Ercit *et al.* in a forthcoming issue of this journal.

This is the first reported occurrence of wodginite-series minerals in Alabama, and the fourth occurrence in the United States (Černý *et al.* 1985a). The wodginite occurs in masses of friable light yellow muscovite 'greisen'. No other tantalum oxide except uranmicrolite has been found within the muscovite aggregates. However, columbite–tantalite and tapiolite have been found as resistate minerals on the surface, generally over areas characterized by graphic pegmatite rather than greisen or saccharoidal albite.

Wodginite from the McAllister deposit is unusual in four main characteristics: (1) the crystals are commonly euhedral; (2) the crystals are highly disordered (60% ordered) (Ercit 1986); (3) many of the crystals contain significant amounts of Zr (1.5-1.87% ZrO_2), and (4) the crystals show a mosaic structure, portions being partly metamict, as indicated by a glassy appearance, conchoidal fracture, and X-ray-diffraction data.

Black, euhedral crystals of disordered wodginite grading to nearly "mineral T" show development of forms {100}, {101}, {111}, and {010}. Crystals are flattened along *a* and elongate along *b*. Individual crystals attain 4 mm in length, and aggregates or clusters of crystals, 6 mm across.

Crystallographic data for the wodginite are given in Table 6; X-ray powder data for wodginite, both unheated and heated (in air), are given in Table 7. The refined cell dimensions of the disordered wodginite agree very closely with those obtained by T.S. Ercit (pers. comm. 1984) on a different crystal from the same bulk sample used for the powder refinement (Table 6). Heating the disordered wodginite produced the expected small but distinct decrease in cell parameters, an increase in β, and a decrease of 1.5% in the cell volume. The intensity of reflections in the heated material generally increased slightly compared to those in the unheated material, and several additional minor reflections were resolved (Table 7). Some sharpening of the peaks was also observed in the heated wodginite.

TABLE 6. CRYSTALLOGRAPHIC DATA FOR WODGINITE, AND HEATED WODGINITE FROM THE MCALLISTER DEPOSIT

	Wodginite (This study)$^+$	Wodginite (Ercit, pers. comm. 1984)*	Wodginite (heated at 1000°C, 3 hours) (this study)$^{++}$
a	9.497(4) Å	9.500(5) Å	9.460(4) Å
b	11.456(4) Å	11.465(6) Å	11.422(5) Å
c	5.140(3) Å	5.133(3) Å	5.097(2) Å
β	90°33(2)'	90°31(2)'	90°44(2)'
V	559.19(32) Å^3	559.05(51) Å^3	550.70(29) Å^3

For all samples, Z = 1. * Refinement of the structure indicates 60(1)% order of cations; R = 6.0%, R_w = 5.7% (Ercit 1986).
$^+$ Refinement based on 28 indexed peaks obtained using the computer program of Appleman & Evans (1973). $^{++}$ Refinement based on 36 indexed peaks using the computer program of Appleman & Evans (1973).

TABLE 7. X-RAY POWDER DATA FOR UNHEATED AND HEATED WODGINITE FROM MUSCOVITE 'GREISEN' IN THE MCALLISTER DEPOSIT

	Unheated material			Heated material (in air, 3 hrs)		
hkl	d_{calc}	d_{obs}	I/I_o	d_{calc}	d_{obs}	I/I_o
110	------	------	-	7.286	7.375	4
020	5.728	5.712	1	5.711	5.708	2
200	4.748	4.735	6	4.730	4.710	10
$\bar{1}11$	------	------	-	4.196	4.191	3
111	------	------	-	4.157	4.161	5
021	3.829	3.815	6	3.803	3.793	12
220	3.655	3.652	57	3.643	3.641	76
$\bar{1}21$	------	------	-	3.540	3.539	6
$\bar{2}21$	2.989	2.984	100	2.978	2.974	100
221	2.968	2.973	95	2.950	2.945	85
040	2.864	2.863	15	2.856	2.851	19
002	2.570	2.573	23	2.548	2.547	25
041	2.502	2.501	33	2.491	2.491	40
240	------	------	-	2.444	2.439	3
400	2.374	2.375	18	2.365	2.368	15
$\bar{2}02$	2.269	2.268	4	2.256	2.257	6
241	2.209	2.207	7	2.199	2.199	12
$\bar{2}22$	2.110	2.108	10	2.098	2.099	10
222	2.095	2.095	7	2.078	2.076	10
$\bar{4}21$	------	------	-	2.017	2.014	5
421	2.010	2.009	6	2.000	2.003	4
042	1.913	1.910	10	1.901	1.903	11
440	1.828	1.828	15	1.822	1.823	12
260	1.771	1.771	31	1.766	1.766	34
$\bar{4}02$	1.752	1.752	23	1.745	1.746	18
402	------	------	—	1.722	1.722	32
$\bar{4}41$	1.726	1.727	31	1.721	1.721	25
441	1.718	1.716	25	1.710	1.710	20
$\bar{4}22$	------	------	—	1.669	1.669	3
361	------	------	—	1.549	1.549	10
$\bar{2}23$	1.556	1.557	9	1.546	1.545	10
223	1.547	1.547	7	1.534	1.535	11
620	1.525	1.525	4	------	------	-
$\bar{6}21$	1.466	1.466	28	1.461	1.461	25
621	1.458	1.459	26	1.451	1.452	23
080	1.432	1.433	4	1.428	1.429	4
081	1.379	1.380	8	1.375	1.378	9

+ additional lines

Refinements done using graphite-monochromatized $CuK\alpha_1$ radiation. CaF_2 used as an internal standard. Scan speed 1/2°/min., chart speed 1/2"/min., 40 kV, 20 mA.

TABLE 8. CHEMICAL COMPOSITION* OF WODGINITE FROM THE MCALLISTER DEPOSIT

Oxide	non-glassy, disordered wodginite (av. of 6)	non-glassy, disordered wodginite (one anal.)	glassy, disordered wodginite (av. of 4)	glassy, disordered wodginite (av. of 2)
Ta_2O_5 wt. %	71.5	65.3	69.4	72.2
Nb_2O_5	6.2	7.0	8.0	7.9
MnO	7.1	5.9	8.7	8.2
SnO_2	8.1	12.1	7.7	7.2
FeO	3.6	5.5	3.4	3.6
TiO_2	0.4	2.4	0.9	0.6
ZrO_2	1.8	1.8	1.8	0.0
UO_2	0.8	0.0	0.4	0.2
Total	99.5	100.0	100.3	99.9

Sc and W sought but not found. *Determined by electron microprobe analysis.

Average chemical compositions for several types of wodginite are given in Table 8. The composition of a piece of the crystal adjacent to that used in Ercit's (1986) structure refinement is: MnO 7.7, FeO 4.7, ZrO_2 1.5, SnO_2 11.0, Nb_2O_5 7.5, Ta_2O_5 69.1, total 101.5 wt.% (T.S. Ercit, pers. comm. 1984). This composition agrees well with those given in Table 8. The wodginite commonly contains appreciable Zr. There is no obvious correlation between the uranium content and degree of glassy appearance (metamictization). All of the wodginite is partly disordered.

Structural formulas, calculated on the basis of 32 oxygen atoms, and adjusted to the general formula $A_4B_4C_8O_{32}$ according to the structural constraints determined by Ercit (1986), are given in Table 9. Mössbauer spectra for a 302-mg sample of "mineral T" for ^{57}Fe and ^{119}Sn indicate that 17 ±5% of the total iron present is Fe^{3+}, and 7 ±3% of the total tin is Sn^{2+}.

Uranmicrolite. Very small quantities of bright yellow or yellow-orange anhedral to euhedral grains of metamict uranmicrolite were found to coexist with the wodginite. The mineral usually coats wodginite. Individual grains attain 0.5 mm in maximum dimension. Identification was made on the basis of X-ray powder diffraction, electron-microprobe analysis, and SEM examination. A partial electron-microprobe analysis (average of 5 points) is given in Table 10.

Tapiolite. Several dark brown to black crystals of tin-bearing tapiolite several cm in maximum dimension were recovered from soil overlying the deposit. X-ray-diffraction analysis confirmed the identification of the mineral. A structural formula for the mineral, calculated from results of two microprobe analyses (Table 10), is: $(Fe_{0.85}Mn_{0.03}Ti_{0.03}Sn_{0.06}Ta_{1.72}Nb_{0.26})_{\Sigma 2.95}O_6$.

Columbite-tantalite. Members of the columbite-tantalite group are present in small amounts primarily associated with graphic pegmatite in the western part of the dyke. The mineral typically occurs in lustrous, tabular euhedral crystals up to 4 cm in maximum dimension. Calculated structural formulas based on microprobe data (Table 10) for two crystals (2 analyses each) are: $(Fe_{0.53}Mn_{0.38}Ti_{0.02}Sn_{0.02})_{\Sigma 0.95}(Nb_{1.27}Ta_{0.70}Ti_{0.03}Sn_{0.02})_{\Sigma 2.02}O_6$ and $(Fe_{0.52}Mn_{0.38}Ti_{0.01}Sn_{0.01})_{\Sigma 0.92}(Nb_{1.44}Ta_{0.55}Ti_{0.02}Sn_{0.02})_{\Sigma 2.03}O_6$.

Cassiterite

Cassiterite, an irregularly distributed accessory mineral throughout the dyke, is present typically as individual black to very dark brown subhedral crystals averaging 2 mm across. The crystals are complex, with dominant pyramidal faces. Results of emission spectrographic analyses of two crystals are given in Table 11. Electron microprobe analyses for

TABLE 9. STRUCTURAL FORMULAS FOR WODGINITE FROM THE MCALLISTER DEPOSIT

Disordered wodginite (non-glassy)*

$(Mn_{2.61}Fe^{2+}_{1.09}\square_{0.30})_{\Sigma 4.00}(Ta_{1.63}Sn_{1.40}Zr_{0.38}Fe^{3+}_{0.22}$
$Ti_{0.14}U_{0.08}\square_{0.15})_{\Sigma 4.00}(Ta_{6.79}Nb_{1.21})_{\Sigma 8}O_{32}$

Disordered wodginite (glassy)*

$(Mn_{2.76}Fe^{2+}_{1.00}\square_{0.24})_{\Sigma 4.00}(Ta_{1.66}Sn_{1.35}Zr_{0.37}Fe^{3+}_{0.21}$
$Ti_{0.13}U_{0.08}\square_{0.20})_{\Sigma 4.00}(Ta_{6.33}Nb_{1.67})_{\Sigma 8}O_{32}$

Disordered non-Zr bearing wodginite (glassy)*

$(Mn_{2.86}Fe^{2+}_{1.07}\square_{0.07})_{\Sigma 4.00}(Ta_{1.99}Sn_{1.23}Fe^{3+}_{0.22}Ti_{0.19}$
$U_{0.02}\square_{0.35})_{\Sigma 4.00}(Ta_{6.41}Nb_{1.59})_{\Sigma 8.00}O_{32}$

Disordered wodginite (non-glassy)**

$(Mn_{2.08}Fe^{2+}_{1.75}\square_{0.17})_{\Sigma 4.00}(Sn_{2.01}Ti_{0.75}Ta_{0.71}Zr_{0.37}Fe^{3+}_{0.16})_{\Sigma 4.00}$
$(Ta_{6.68}Nb_{1.32})_{\Sigma 8}O_{32}$

* - assuming that 17% of the total iron is ferric.
**- 8.4% ferric iron of the total iron is needed to fill the C site. An emission spectrographic analysis of wodginite is given in Table 10.

TABLE 10. CHEMICAL COMPOSITION+ OF COLUMBITE-TANTALITE, TAPIOLITE AND URANMICROLITE FROM THE MCALLISTER DEPOSIT

Oxide	columbite-tantalite 1	columbite-tantalite 2	tapiolite	uranmicrolite
Ta_2O_5 wt. %	38.05	31.6	77.7	65.8
Nb_2O_5	41.75	49.3	7.1	2.8
FeO	9.45	9.65	12.55	0.06
MnO	6.65	6.90	0.4	0.1
CaO	0.00	0.00	0.00	1.6
Na_2O	0.00	0.00	0.00	0.0
TiO_2	1.05	0.65	0.5	0.7
SnO_2	1.35	1.05	1.75	0.6
UO_2	0.25	0.06	0.00	23.5++
F	0.0	0.0	0.0	0.0
H_2O*	--	--	--	4.84
Totals	98.55	99.21	100.0	95.16**

*determined by difference, **less H_2O; other elements looked for but not detected: Cl, Al, Si, K, Mg, Ba and Zn. +obtained by electron-microprobe analysis. ++24.9 wt. % UO_3.

TABLE 11. EMISSION SPECTROGRAPHIC DATA FOR SELECTED MINERALS FROM THE MCALLISTER PEGMATITE AND 'GREISEN' DYKE SYSTEM

Element	Cassiterite BC-1	Cassiterite BC-2	Wodginite BC-3	Beryl T-15
Fe%	0.7	1.0	3.0	0.15
Mg%	0.002	0.003	0.01	0.015
Ca%	0.015	0.03	0.03	0.002
Ti%	0.015	0.1	0.15	N
Si%	1.5	1.5	1.5	Major
Al%	0.15	0.2	0.3	0.5
Mn (ppm)	150	1000	30,000	30
Ag	N	1.5	N	N
Ba	50	20	70	50
Be	N	N	7	Major
Cr	7	20	L10	None
Cu	L20	150	L50	None
Nb	7000	7000	50,000	None
Ni	None	20	None	None
Pb	30	100	700	None
Sc	None	None	15	None
Sn	Major	Major	>2%	70
Sr	None	None	50	None
U	None	None	Interference	None
W	None	None	<500	None
Zn	None	None	Interference	200
Zr	700	1000	15,000	None
Ta	2%	>2%	Major	None
Li	n.d.	n.d.	n.d.	3000
Rb	n.d.	n.d.	n.d.	200
Cs	n.d.	n.d.	n.d.	>1%

n.d. - not determined, L - less than value shown, N - not detected. Rare alkalis determined by infrared region emission spectrography. All other elements not detected at respective limits of detection.

the same two crystals of cassiterite indicate the following ranges of constituent elements, expressed as oxides (in wt.%): SnO_2 94.8 to 97.0, Ta_2O_5 1.4 to 2.7, Nb_2O_5 0.5 to 1.1, FeO 0.5 to 1.1, MnO 0.05 to 0.10, TiO_2 0.05 to 0.1. The following elements were sought but not detected: Si, Ca, W, Zn, Sc, P, In, Sb, Mg, As, and Al. Calculated structural formulas range from $(Sn_{0.97}Ta_{0.01}Nb_{0.01}Fe_{0.01})_{\Sigma 1.00}O_2$ to $(Sn_{0.95}Ta_{0.02}Fe_{0.01})_{\Sigma 0.98}O_2$. Microprobe analyses of additional crystals of cassiterite from various locations (*e.g.*, TB–5) along the strike length of the deposit gave similar results. These compositions are typical of cassiterite from rare-metal and rare-alkali pegmatites (*e.g.*, Foord 1982, Maksimyuk & Lebedeva 1968).

Spodumene

Spodumene occurs as opaque, light to medium green euhedral crystals in graphic smoky quartz pegmatite near and at the core boundary. Crystals are largest, up to 0.6 m in length, near the west end of the dyke, where they occur as kaolinized laths in rubbly medium grey quartz with white beryl. Fresh spodumene was encountered only in drill core below the zone of weathering. Analyses of spodumene-rich 1.5 m drill-core intervals indicate maximum alkali metal contents as follows: >1% Li, 2100 ppm Rb, and 1465 ppm Cs. Maximum Sn, Ta, and Be contents of these spodumene-rich intervals are 1160, 4100 and 140 ppm, respectively.

Beryl

Beryl, a locally important and significant mineral, is present as the varieties goshenite and morganite. Crystals are typically stubby prismatic to squat tabular in habit and attain 0.2 m in diameter. Beryl is most easily identified where coarsest grained, near and at the core margin; however, subhedral equigranular beryl locally constitutes approximately 0.08% of the graphic pegmatite portion of the dyke. Results of an emission spectrographic analysis of one sample of morganite are given in Table 11. A partial analysis by V. Kubat (École Polytechnique, Montréal) gave, in wt.%: Fe_2O_3 0.14, MnO 0.008, CaO 0.02, Na_2O 1.69, K_2O 0.13, Li 0.45, Rb 0.29, and Cs 0.965. The elevated rare-alkali contents and low iron are particularly characteristic of morganite, and again are indicative of the environment of deposition (fractionated rare-metal- and rare-alkali-bearing granitic pegmatite).

Lithiophorite

Compact, somewhat sooty lithiophorite occurs as a probable secondary mineral in fracture zones above the water table. These fracture zones are randomly oriented and attain 2 cm in width. An emission spectrographic analysis of the lithiophorite gave (in wt.%): Fe 0.5, Mg 0.01, Ca <0.002, Mn Major, Ba 0.3, Be 0.0007, Co 0.7, Cu 0.03, Mo 0.03, Nb 0.002, Ni 0.03, Pb 0.03, Sc 0.002, V 0.015, Zn 0.15, Zr <0.002, Si 1, Al 5.0, Ce 0.2, Ga <0.005, Li 0.3, Tl 0.02, all other elements not detected.

Other minerals

Sparse accessory minerals identified in unweathered dyke material (sampled in drill core) and in heavy-mineral concentrates from weathered trench-samples include vivianite, autunite, apatite, zircon, pyrite, and topaz. Conspicuously absent are primary lithium phosphates, iron–manganese phosphates of the triplite family, and garnet, all of which are locally common in nearby tin-bearing pegmatites hosted by Wedowee Group metasedimentary rocks (Cook 1974).

Fine-grained blue aggregates of vivianite and albite occur in thin drill-core intervals proximal to the 'greisen-like' pipes. Small autunite plates were noted on a few fracture surfaces in drill core from immediately beneath the zone of weathering. Tan to purplish tan grains of euhedral zircon up to 1–2 mm across locally are intergrown with wodginite and occur in areas where uranmicrolite is conspicuous in panned heavy-mineral concentrates. The zircon is partly metamict, as indicated by diffuse X-ray-diffraction data and lowered indices of refraction. Colorless anhedral topaz occurs very sparingly as minute grains in heavy-mineral concentrates from the eastern end of the dyke. Small, equidimensional, anhedral grains of blue apatite occur locally near the margins of, but within, saccharoidal albite. The mineral fluoresces orange under shortwave ultraviolet light. Water (H_2O^+ and H_2O^-) and F determinations on one sample of purified apatite gave: 0.45% H_2O^+, 0.03% H_2O^-, and 2.98% F.

DISCUSSION: PARAGENESIS OF THE DYKE AND GREISEN PIPES

The McAllister dyke is interpreted to be comagmatic with the Rockford Granite because of district-wide geological relationships, the presence of disordered wodginite-bearing dyke and 'greisen-like' pipes, and other generally similar pegmatites in the area. Geochemical data for the host Rockford Granite indicate a Sn- and probably a Ta-depletion halo adjacent to the McAllister dyke. The Rockford Granite is not a typical tin-bearing granite, as indicated by the Rb:Sr ratio, the differentiation index, and other parameters. The wodginite-bearing 'greisen' pipes are interpreted to represent the latest mineralizing event related to the crystallization of volatile and fugitive constituents in a pegmatitic fluid, as evidenced by the textural relationships and chemical changes observed in the minerals. The concentration of the rare alkalis (Li, Rb, Cs), Be and rare metals (Nb, Ta, Zr, Sn) is strongly enhanced in the dyke. Progressive enrichment of residual liquid, first in Ta relative to Nb and then in Mn relative to Fe, is evident from the chemical zoning and mineral paragenesis of the Nb–Ta oxides. Fe- and Nb-rich columbite crystallized with tapiolite and cassiterite within the early units. Tantalian and niobian cassiterite is present both in the pegmatite and saccharoidal albite portions of the dyke, but not in the 'greisen' pipes. The youngest event, formation of the 'greisen-like' pipes, is characterized by the presence of Mn-, Sn- and U-dominant tantalates exemplified by wodginite and uranmicrolite. The trends of increasing Mn relative to Fe, and of Ta relative to Nb, with continued crystallization of Nb–Ta oxides are well established (*e.g.*, Černý 1982, Černy & Ercit 1985, Černý *et al.* 1985a,b). The elevated tin content (av. 540 ppm) of the muscovite in the greisen bodies, along with the elevated content of rare alkalis, are indicative of the geochemistry of the host rock: a complex rare-element granitic pegmatite. This average tin content is similar to the average (500 ppm) found in biotite from mineralized granites of the Afu Complex, Nigeria (Imeokparia 1982).

Most greisens associated with highly evolved granites are F-rich and commonly contain variable amounts of topaz, fluorite, and Li(Fe) micas. Very few compositions of low-F muscovite, or even muscovite in general, from greisens associated with granitic plutons or from greisenized granite, have been reported in the literature (*e.g.*, Kwak & Askins 1981, Neiva 1982, 1987). The compositions of muscovite (Tables 4, 5) from 'greisen' pipes within the McAllister dyke are very poor in Li, but contain substantial amounts of Rb and Cs. Li/Rb values are about 0.02, which is extremely low compared, for example, to the muscovite of Sn–W deposits in Portugal (Neiva 1982, 1987), in which Li/Rb is about 0.3. Other values, such as Li/Mg, Ba/Rb, and Sn/F, in the muscovite also differ substantially from those of the Portuguese deposits. The four muscovite compositions from the 'greisen' bodies contain an average of 0.13% F and 5.5% H_2O^+. This F content is lower by about an order of magnitude or more compared to that in muscovite in other greisens (Neiva 1982, 1987, Kwak & Askins 1981). Thus, the muscovite is not of greisen-type origin, but is of pegmatitic origin. The mica is extremely similar to the late yellowish green muscovite from the central intermediate zone of the Tanco pegmatite, which is associated with wodginite, microlite, and other accessory minerals (Rinaldi *et al.* 1972).

Values of 2.98% F and 0.45% H_2O^+ for clots of blue apatite in replacement saccharoidal albite are characteristic of fluorapatite; except for the very sparse amounts of topaz, apatite is the only mineral in the dyke system to contain appreciable amounts of F. Uranmicrolite, where present in complex pegmatites, usually contains fluorine, but none was detected in late-crystallized material associated with "mineral T", wodginite and zircon.

These observations, along with the extreme rarity of topaz and apparent absence of fluorite, are indicative of an OH-rich and F-poor system. The light and heavy rare-earth elements (*REE*) are apparently depleted in the dyke, as is indicated by the apparent lack of *REE*-dominant minerals.

CONCLUSIONS

The McAllister pegmatite dyke and contained 'greisen-like' pipes represent a significant discovery for the southeastern United States Piedmont. Large, complex rare-metal, rare-alkali pegmatites were not previously known south of the productive Kings Mountain spodumene district 550 km to the northeast, or in the northern part of the Piedmont Province in general. Even more unusual is the presence of highly disordered wodginite as the principal tantalum ore mineral in association with tantalian cassiterite. Geological evidence indicates that the high-grade 'greisen' pipes represent the final stages of crystallization of a water–Ta–Sn–Nb–Ti–U–Zr-enriched pegmatite-related fluid. Small but potentially high grade Sn–Ta deposits of this sort may represent an attractive target for exploration in this region of the southeastern Piedmont Province.

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