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ALLANITE IN GRANITIC ROCKS OF THE KENORA-VERMILION BAY AREA, NORTHWESTERN ONTARIO

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Abstract

Allanite is a characteristic accessory mineral of the granitic and gneissic rocks in the Kenora-Vermilion Bay area, northwestern Ontario. An important feature of the allanite is its heterogeneous composition which is due to combinations of the following: (1) zonal growth; (2) metamictization; (3) leaching. It is proposed that aqueous fluids at the late stages of magmatic crystallization scavenge rare-earth elements, uranium, and thorium from allanite in granitic rocks and redeposit these elements in much greater concentrations in genetically related pegmatites. This proposed relationship allows one to predict whether a granitic terrain will have radioactive pegmatites: granites with leached allanite are much more likely to have associated radioactive pegmatites.

Sommaire

L'allanite est un minéral accessoire qui caractérise les roches granitiques et gneissiques de la région de Kenora-Vermillion Bay an nord-ouest de l'Ontario. Une importante caractéristique de cette allanite est sa composition hétérogène, attribuable aux effets combinés des facteurs suivants: (1) croissance zonaire; (2) métamictisation; (3)lixiviation. On suppose que des liquides aqueux, pendant les dernières étapes de la cristallisation magmatique, ont récupéré des éléments de terres rares, de l'uranium et du thorium de l'allanite présente dans les roches granitiques, pour les redéposer, en plus grandes concentrations, dans des pegmatites génétiquement associées. Cette hypothèse permet de prévoir si des terrains granitiques peuvent contenir des pegmatites radioactives: les granites, dont l'allanite a été modifiée par lixiviation, sont plus enclins à posséder des associations de pegmatites radioactives.

(Traduit par la Rédaction)

Introduction

Allanite, a member of the epidote family, is an important accessory mineral in granitic rocks and is a carrier of rare-earth elements, minor thorium, and uranium. In addition, this study indicates that the presence of leached allanite in granitic rocks may be indicative of co-genetic uraniferous pegmatites.

Allanite has been noted in granitic rocks throughout the Canadian Shield, notably in the English River subprovince of northwestern Ontario (Černý & Černa 1972); in quartz diorite of the Elbow Lake stock, southeastern Manitoba (A. C. Turnock, pers. comm.); in quartz monzonite of the Lac du Bonnet pluton, southeastern Manitoba (McRitchie 1971); in gneisses and associated granitic rocks of the Hopedale Complex, Makkovik, Labrador (Sutton 1974); in pegmatite and Tazin gneiss in northern Saskatchewan and the Northwest Territories (Mawdsley 1958); and in pegmatite of the Bancroft area, Ontario (Satterly & Hewitt 1955). In addition, numerous other occurrences are listed in Traill (1970).

In the course of studying the petrography of some granitic rocks from west of Vermilion Bay in northwestern Ontario, it was demonstrated that allanite is their characteristic accessory mineral. Its composition is markedly heterogeneous within individual grains, which suggests that the mineral may have undergone a leaching event that removed certain elements. The purpose of the present study is to demonstrate the inhomogeneity of accessory allanite in granitoids and to interpret its possible implications on the metallogenetic characteristics of allanite-bearing plutonic bodies.

Regional Geology

The study area extends from Kenora to Vermilion Bay, a distance of 80 km. The area is made up of the southern part of the English River subprovince and the northern part of the Wabigoon subprovince of the Superior Province in northwestern Ontario (Fig. 1). The English River subprovince here consists of recrystallized orthogneiss and associated migmatite that have been intruded by foliated granodioritic phacoliths (not recrystallized). The Wabigoon subprovince consists of metavolcanic-metasedimen-

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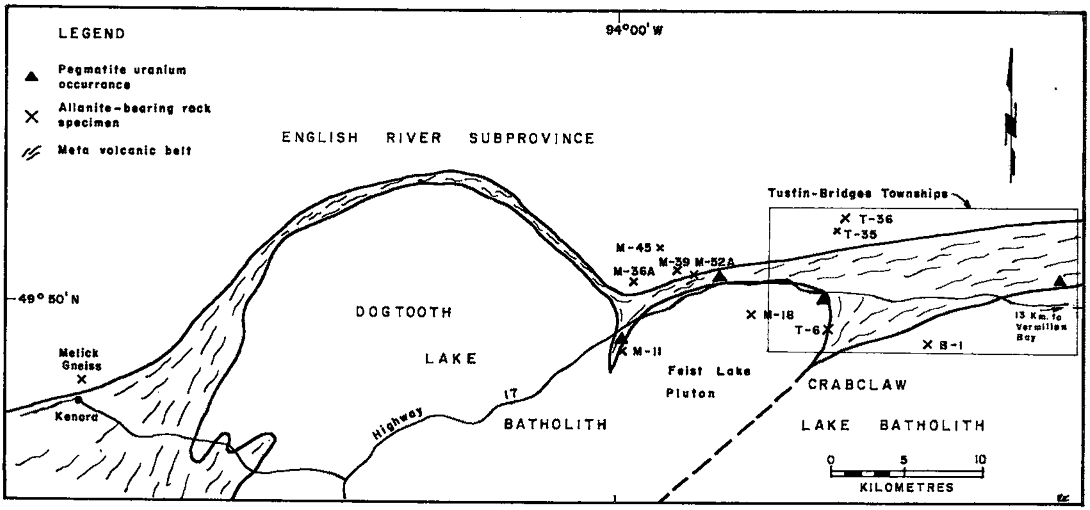


FIG. 1. Map of Kenora–Vermilion Bay area showing sample location sites and general geology of the study area.

tary belts that have been intruded by oval-shaped, diapiric, granitic plutons.

Two metavolcanic belts occur in the study area: the Lake of the Woods metavolcanic belt and the Tustin-Bridges metavolcanic belt (Fig. 1). The Lake of the Woods belt is in intrusive contact with orthogneiss of the English River subprovince to the north, and has been intruded by the Dogtooth Lake batholith to the east. The Tustin-Bridges belt has been intruded (from oldest to youngest) by gneiss of the English River subprovince, granodioritic phacoliths of the English River subprovince, the granodioritic Feist Lake pluton of the Dogtooth Lake batholith, and by the Crabclaw Lake batholith of the Dryberry Dome.

Allanite is relatively abundant in all of the granitic rock units, with the exception of the Crabclaw Lake batholith, where it occurs only in peripheral pegmatite. In addition, allanite has been found in psammitic metasedimentary rocks in the southern part of the Tustin-Bridges metavolcanic belt.

FORM AND HABIT OF ALLANITE

Allanite occurs as black, vitreous, prismatic grains up to 1 cm in length in the Melick gneiss of the English River subprovince, north of Kenora. Both fresh and altered allanite are present. In thin section, the allanite is pale greenish brown, isotropic, and is altered to yellowish orange to reddish brown at its edges (Fig. 2a). In all other granitic and gneissic rocks studied, allanite occurs as oval, orange to yellowish brown metamict grains in amounts ranging from trace to 1%. Apparently, these are allanite grains which have been altered completely. They are generally characterized by three modes or associations: (1) fine-grained (0.2 to 1 mm) metamict grains in the Feist Lake pluton, syenite, and gneiss of the English River subprovince. These grains are commonly rimmed by a shell of epidote (Fig. 3), and are typically associated with biotite, hornblende, sphene, and magnetite. (2) Fine-grained (0.2 to 1 mm) metamict grains in granodioritic phacoliths and biotite gneiss of the English River subprovince. These grains have no rim of epidote and are typically associated with biotite. Some grains are zoned (Fig. 4a). (3) Fine-grained (0.2 to 2 mm), oval, subhedral metamict grains in granite pegmatite of the Crabclaw Lake batholith. These grains are commonly coarser in grain size, have no associated epidote, and some are zoned. They occur generally as discrete grains with no obvious association to other minerals.

ANALYTICAL CONDITIONS

Composition of the allanite was investigated by means of a silicon energy-dispersive spectrometer attached to a Cameca MS 64 electron probe microanalyzer. Analytical conditions consisted of 15 kV operating voltage, 6.0 nanoamperes beam current, 5 micron beam diameter, and an analyzing time of 40 seconds. In addition, several zoning profiles were determined with the use of crystal spectrometers and a moving sample stage. Elements were determined with the following crystals: Fe$K\alpha$ and Ca$K\alpha$ – PET; Ce$L\alpha$ and La$L\alpha$ – quartz 1120 and Al$K\alpha$ – KAP. Standards employed were hastingsite for Fe, adularia for Al, and synthetic anorthite glass for Ca. Element concentrations of Fe, Ca and Al were determined empirically by calibration with the standards. However, no standards were available for Ce and La and only their relative concentrations were determined.

Composition

Composition of the allanite was found to vary considerably from specimen to specimen, and even within the same grains. Three processes can account for this variation: (1) zonal growth in an environment of changing fluid composition; (2) alteration due to metamictization; (3) alteration due to leaching.

Zoning

Compositional zoning was noted in an orange to reddish brown allanite grain (0.3 by 1.0 mm) in pink medium-grained granodiorite from the English River subprovince (M-36A) [for sample numbers, see Fig. 1]. The zoning is symmetrical and resembles plagioclase normal zoning in which a core is surrounded by several concentric euhedral shells (Fig. 4a). The zoning consists of a general compositional variation from rim to rim across the grain, with a pronounced variation in the middle part. Figure 4b shows the elemental variation along several cross-sections of the grains. In general, high con-

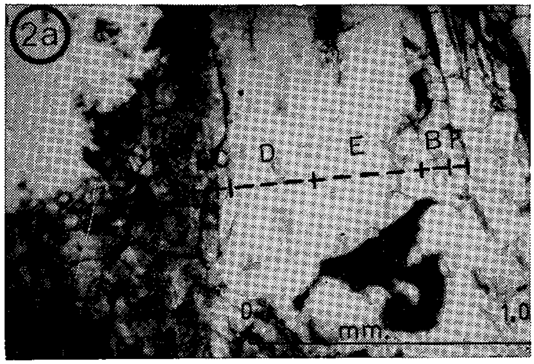
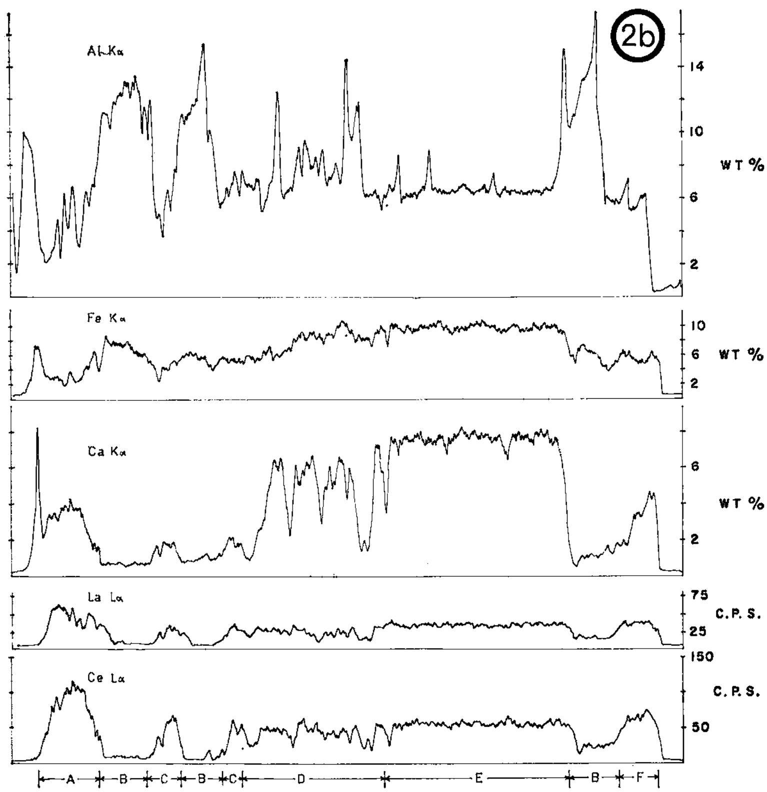


FIG. 2. (a) Photomicrograph of allanite from Melick gneiss. Lighter-colored part is greenish brown whereas darker part is orange-brown. Section across grain is path of microprobe beam, with results shown in 2b.



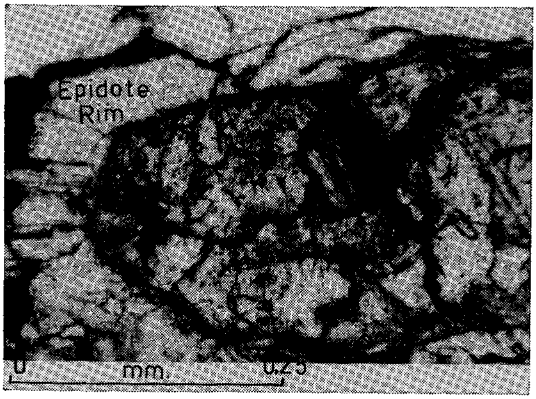


FIG. 3. Shell or rim of epidote surrounding metamict allanite.

centrations of Ca, Ce, and La are maintained in the core, but are depleted toward the rim. In contrast, Al and Fe are low in the core but high in the rim. Ce and La are fairly constant throughout the core. However, one cross-section reveals oscillatory zoning with sympathetic substitution of Ca, Ce, and La by Al and Fe (Fig. 4c). The data seem to be inconsistent with the two main variations in the allanite series as reported by Deer *et al.* (1964), i.e. Ca ⇄ rare earths and Al ⇄ Fe^{2+}. These substitutions are sympathetic, and thus an increase in Ce^{3+} and La^{3+} to replace Ca^{2+} would require a decrease in Al^{3+} and an

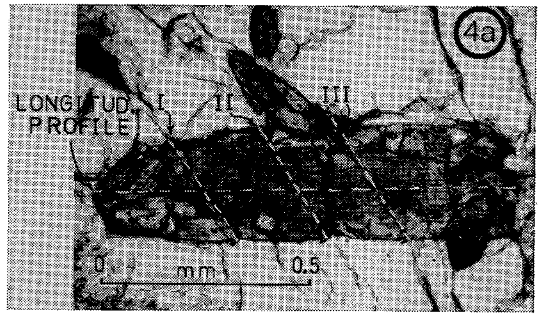
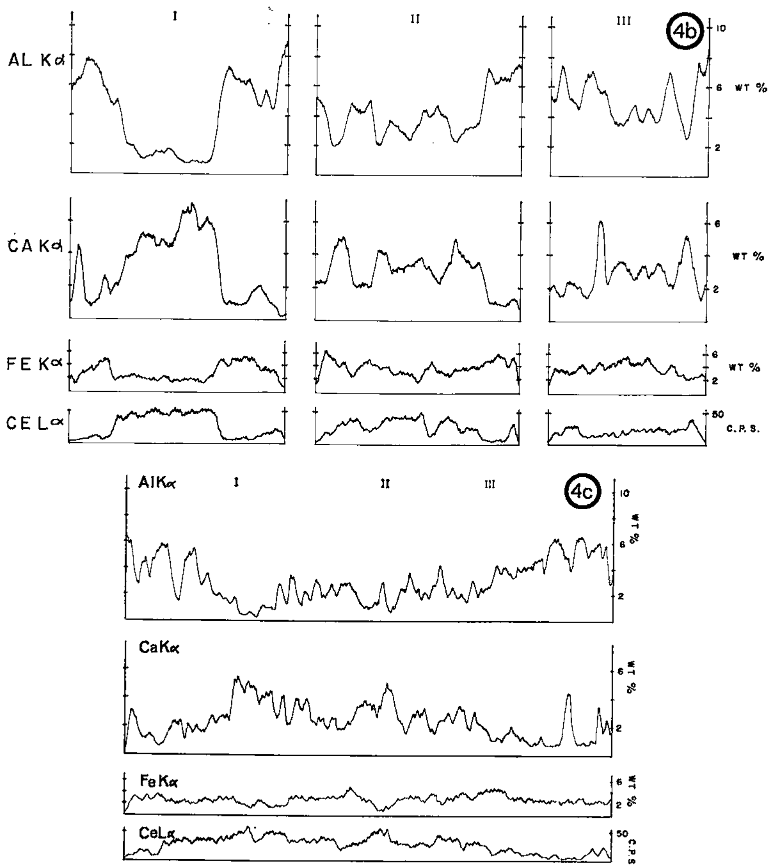


FIG. 4. (a) Zoned allanite M-36A from granodiorite phacolith in English River subprovince. Electron microprobe beam paths are shown, and results are given in 4b and 4c.



increase in Fe^{2+} to maintain charge balance. However, the present study indicates the following substitutions to be more probable in the zoned allanite:

$$(La^{3+}, Ce^{3+}) + Ca^{2+} \rightleftarrows Al^{3+} + (Fe^{3+}, Fe^{2+})$$

Primary zonal growth of the allanite was presumably in response to changing compositional environments of crystallization. Thus, the composition of the magmatic fluid is indicated as becoming richer in aluminum and iron and poorer in cerium, calcium, and lanthanum.

Metamictization

The process of metamictization has affected all of the allanite grains studied. It consists of the destruction of the crystal structure by bombardment with alpha particles which result from the disintegration of the radioactive elements and decay products present in the mineral (Pabst 1952). Isotropic to weakly anisotropic optical effects result, and the grains show nil to weak birefringence under cross-polarized light. Metamictization also lowers the stability of allanite and makes it more susceptible to alteration.

Leaching

Progressive leaching noted in the specimens studied appears to increase in intensity from the greenish brown allanite of the Melick gneiss to the orange-brown allanite in the other rocks. The distribution of elements within the altered, orange-brown metamict grains is heterogeneous and reflects the leaching and remobilization of certain elements; some elements are completely removed from the grains, whereas others are locally enriched.

Allanite of the Melick gneiss demonstrates the complete range of compositional variation possible due to leaching (Fig. 2a, b). In this allanite, a greenish brown isotropic homogeneous core (E in Fig. 2a, b) is surrounded by an altered orange-brown rim of widely variable composition. The outer edges of the rim are relatively enriched in Ce and La, and depleted in Fe, Al, Si (A, F in Fig. 2a, b). Immediately adjacent to the greenish brown core is an area of incipiently altered orange-brown allanite that is less homogeneous in composition and less stable under the microprobe beam (D in Fig. 2a, b). In addition, two other compositional variations are present in the orange-brown rim. One area next to the outer edge is characterized by Fe, Al, and Si only, a composition which agrees with observations made by Hata (1939), who determined that upon weathering, allanite alters to a reddish brown earthy crust consisting mainly of $Fe(OH)_3$, Al_2O_3, SiO_2 and CO_2 (B in Fig. 2a, b). The other variation consists of relatively normal Ce, La contents with depleted Al, Fe and Ca (C in Fig. 2a, b).

The orange-brown allanite from the other rocks in the study area has compositions similar to those within the orange-brown rim of allanite from the Melick gneiss. The typical spectra show a relatively high Ce, La content as in the A and F parts of the Melick gneiss allanite (Fig. 2a, b). However, local compositional variations are also present, as in the following (Fig. 5).

Granodiorite of the Feist Lake pluton. Severe leaching of Th, Ce, La with only minor Ca, Fe remaining, eg. M-18; M-11; severe leaching of all elements except Ce and La which are relatively enriched, eg. T-6.

Gneiss of the English River subprovince. Severe leaching of all elements except for Al and Si in the interior of the grain and local enrichment in Ce, La, Th at some of the edges, eg. T-35.

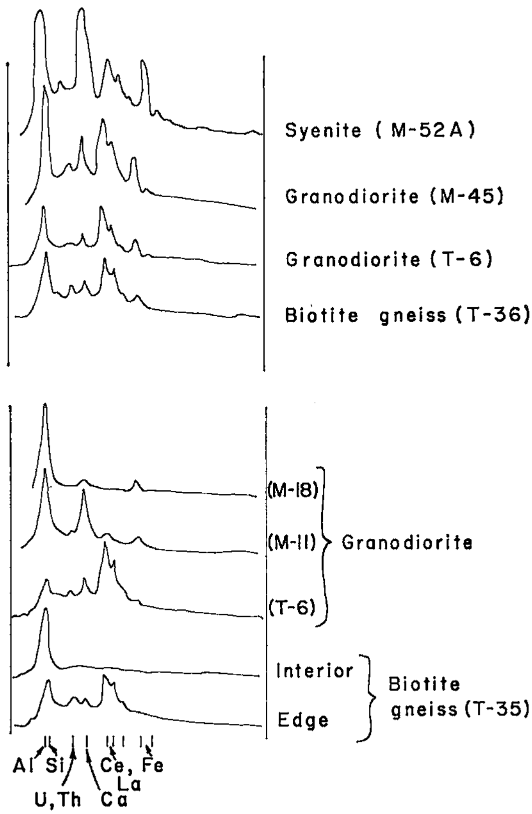


FIG. 5. Spectral analyses of various allanite grains from granitic rocks of the Kenora-Vermilion Bay area: M-45, T-36, T-35 — English River subprovince; T-6, M-18, M-11 — Feist Lake pluton. The upper four spectra are of unaltered allanite and the bottom four are of altered allanite.

Conclusions

The granitic rocks of the area are characterized by the relatively widespread occurrence of allanite with compositions indicative of a distinct enrichment of rare-earth elements in these rocks. Allanite is also the main receptacle for uranium and thorium; thus, its abundance in the southern part of the English River subprovince assists in defining a distinct metallogenetic province.

The English River subprovince is enriched in Li, Rb, Cs, Be, Ce, La, Th, U, Ta, and Nb (Riley *et al.* 1971). These elements mainly occur in isolated deposits within pegmatites. Some of the rare elements in the pegmatites may have remained within magmatic fluids in the form of complexes throughout most of the crystallization interval of the associated granitic rocks. However, aqueous fluids responsible for the formation of the pegmatites were probably also active in leaching the rare elements from carrier minerals in the associated granitic rocks. The presence of leached carrier minerals indicates that their original rare elements may have been deposited in associated pegmatites.

The present study interprets the wide variation in composition of accessory allanite in granitic rocks to be a consequence of leaching. The relative timing of the leaching event is important. As indicated by zoned allanite, the late-crystallizing magmatic fluids were relatively depleted in rare-earth elements compared with the early fluids. However, assuming that pegmatites associated with the granitoid rocks are cogenetic, then the last fluids were enriched in rare-earth elements that must have been derived, not through the process of progressive magmatic differentiation, but through a process of intense leaching or scavenging of earlier-formed allanite in the granitoid rocks.

Acknowledgments

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