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# Beryllium in Granulite-Facies Pegmatites in Archean Napier Complex, Antarctica

Edward S. Grew

*Principal Investigator; University of Maine, Orono, [esgrew@maine.edu](mailto:esgrew@maine.edu)*

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**Final Report for Period:** 06/1998 - 11/2000**Submitted on:** 12/23/2000**Principal Investigator:** Grew, Edward S.**Award ID:** 9813569**Organization:** University of Maine

Beryllium in Granulite-Facies Pegmatites in Archean Napier Complex, Antarctica

### Project Participants

#### Senior Personnel

**Name:** Grew, Edward**Worked for more than 160 Hours:** Yes**Contribution to Project:**

#### Post-doc

#### Graduate Student

#### Undergraduate Student

### Organizational Partners

### Other Collaborators or Contacts

Th. Armbruster (University of Bern, Switzerland), M. Asami (Okayama University, Japan), S. Baba (National Institute of Polar Research, Tokyo, Japan), J. Barbier (McMaster University, Canada), C. Carson (Yale), Andrew Christy (Australian National University), D. Dunkley (Sydney, Australia), M.D. Dyar (Mount Holyoke), A. Ertl (Vienna, Austria), C.A. Francis (Harvard), C.V. Guidotti (University of Maine), E. Halenius (SGAB Analytica, Sweden), U. Halenius (Swedish Museum of Natural History), Y. Hiroi (Chiba University, Japan), Angelika Hoelscher (formerly, Ruhr-University, Bochum, Germany), J.M. Hughes (Miami), A.S. Janardhan (Mysore University, India), M. Kritikos (Stockholm University, Sweden), James J. McGee (formerly, University of South Carolina), T. Miyamoto (Kyushu University, Japan), Paulus B. Moore (Warwick, NY), Y. Motoyoshi (National Institute of Polar Research, Tokyo, Japan), Donald R. Peacor (University of Michigan), K.K.V.S. Raju (Andhra University, Vishakhapatnam, India), A.T. Rao (Andhra U., Vishakhapatnam, India), R.C. Rouse (University of Michigan), W. Schreyer (Ruhr-University, Bochum, Germany), Charles K. Shearer (University of New Mexico), John W. Sheraton (formerly, Australian National University), K. Shiraishi (National Institute of Polar Research, Tokyo, Japan), Shu-Chun Su (Hercules Corp.), K. Suzuki (Nagoya University, Japan), Y. Tabira (Australian National University), M. Yates (University of Maine), K. Yokoyama (National Science Museum, Tokyo, Japan), Y. Yoshimura (Kochi University, Japan).

### Activities and Findings

#### **Project Activities and Findings:**

I originally proposed to study the unique beryllium pegmatites in the Archean ultrahigh-temperature (to 1000-1100 oC) granulite-facies Napier Complex in eastern Casey Bay (67° 22'S, 49° 05'E), Enderby Land, East Antarctica. The primary objective was to test a scenario whereby the beryllium originated in the metasediments hosting the pegmatites rather than being magmatic. Field work was to be carried out as a guest scientist during the 1998/99 austral field season in Enderby Land on the Japanese Antarctic Research Expedition's Project 'Structure and Evolution of East Antarctic Lithosphere'. I had hoped to spend at least a week each at the two localities for distinctive high-temperature assemblages of beryllium minerals in pegmatites that I discovered in 1979, namely 'Christmas Point' and 'Zircon Point'. Upon return from the field, I intended to analyze host rocks for major and trace elements and minerals by the electron microprobe for major constituents and by the ion microprobe for lithium, beryllium and boron. I intended to use mineral compositions and assemblages to determine the evolution and conditions of crystallization of the pegmatites and their host rocks. I anticipated that the results would provide some important insights on the geochemical behavior of beryllium under the high temperatures and low water activities characteristic of the granulite facies.

Due to a severe blizzard that damaged one of JARE-40's helicopters, opportunity to restudy the beryllium pegmatites was limited to one afternoon at 'Christmas Point'.

My activities are summarized as follows:

Fieldwork with the 40th Japanese Antarctic Research Expedition (JARE-40) in Amundsen and Casey Bays, Enderby Land (December 22, 1998 - January 23, 1999) and in Luetzow-Holm Bay (January 31, 1998 - February 17, 1999) in collaboration with Y. Motoyoshi (National Institute of Polar Research), T. Miyamoto (Kyushu), Y. Yoshimura (Kochi), D. Dunkley (Sydney University), C. Carson (Yale University), and other participants of JARE-40

Collections of rock samples in coastal bedrock exposures of Luetzow-Holm Bay. I collected samples of granulite-facies metamorphic rocks, including metapelites, marbles and calc-silicate rocks, and of tourmaline, allanite, zircon and monazite in pegmatites intruding these metamorphic rocks.

Collections of rock samples in coastal bedrock exposures of Casey and Amundsen Bays. I collected samples of the ultrahigh-temperature Napier Complex of Archean age, including sapphirine-bearing metapelites, quartzofeldspathic gneisses and ultramafic rocks. In addition, I collected samples of intrusive rocks, including lamproite, late Archean pegmatites containing orthopyroxene, sillimanite, wagnerite,  $(\text{Mg,Fe})_2\text{PO}_4(\text{F,OH})$ , and a distinctive suite of beryllium minerals, and of Early Paleozoic pegmatites containing beryl, tourmaline, dumortierite, kyanite and muscovite.

Whole-rock geochemistry of quartz-rich granulites and lamproites from Enderby Land in collaboration with J.W. Sheraton (retired from the Australian National University)

Electron microprobe analyses of minerals in quartz-rich granulites, beryllium pegmatites and lamproites from Enderby Land and of minerals related to sapphirine with Martin G. Yates at the University of Maine

Secondary ion mass spectroscopy (ion microprobe) of minerals in quartz-rich granulites and beryllium pegmatites from Enderby Land and of minerals related to sapphirine with Charles K. Shearer at the University of New Mexico

Mineralogical and crystallographical studies of Be and B minerals with Jacques Barbier (McMaster University), U. Halenius (Swedish Mus. Nat. Hist.), A. Christy (ANU) and John Hughes (Miami University).

Petrologic studies on a surinamite-bearing granulite with Sotaro Baba (National Institute of Polar Research), on lamproite with Tomoharu Miyamoto (Kyushu University), and on the quartz-rich granulites and beryllium pegmatites from the Napier Complex.

Age determination of Napier Complex metamorphics and pegmatites using the chemical Th-U-total Pb isochron method (CHIME) in collaboration with M. Asami (Okayama) and K. Suzuki (Nagoya)

Oral presentations reporting research supported by this grant at four national and international meetings, plus a fifth presentation at an international meeting scheduled for January, 2001

Six abstracts published and one abstract in press, all reporting research supported by this grant; five papers published and four papers in review that acknowledge support from this grant

Contribution to Sotaro Baba's education in that I helped him identify and characterize surinamite and understand its paragenesis while he was completing his Ph.D. thesis at Osaka City University.

### **Project Training and Development:**

LAMPROITE (Miyamoto et al., 2000, Polar Geoscience. See publication list)

While on JARE-40, I discovered dikes of lamproite, an ultrapotassic intrusive rock of deepseated origin, on Tonagh Island in Amundsen Bay, the third reported locality for lamproite in Enderby Land. The dikes are NS-trending, subvertical sheets found over a 2 km distance. The bulk composition of the lamproite is noteworthy for its high content of  $\text{K}_2\text{O}$  (9.33-11.66 wt%) and  $\text{P}_2\text{O}_5$  (2.66-4.21 wt%), and relatively low contents of  $\text{Al}_2\text{O}_3$  (7.66-10.15 wt%) and  $\text{Na}_2\text{O}$  (1.03-1.95 wt%). Certain trace elements are also very high, e.g., Be (7-19 ppm), F (0.77-1.44 wt%), Rb (253-479 ppm), Sr (2331-3306 ppm), Zr (1310-2400 ppm), Nb (89-209 ppm), Ba (931-12992 ppm), light REE, Th (13-145 ppm) and U (8-16 ppm). T. Miyamoto obtained Rb-Sr internal isochron ages of  $466 \pm 4$  and  $476 \pm 6$  Ma for the lamproite. Overall, lamproites have intruded the Napier Complex where it was reactivated 500 Ma ago by pegmatite activity and by superimposed amphibolite-facies metamorphism and deformation. The temporal and spatial relationships between the lamproite intrusion and zones of Pan-African reactivation of the Napier Complex is similar the corresponding relationships between the ultrapotassic igneous activity and Pan African deformation and

metamorphism in eastern Queen Maud Land. This suggests that the effect of the amalgamation of east and west Gondwana extended eastward in Antarctica from Queen Maud Land to Enderby Land.

**BERYLLIUM PEGMATITES** (Grew et al., 2000, Polar Geoscience. See publication list)

I discovered two new beryllium pegmatites on JARE-40, adding to the two pegmatites that I discovered in 1979 while on the Australian expedition and first reported on in 1981. In addition, one of the newly discovered pegmatite pods contains sapphirine and khmaralite inferred to be of magmatic origin, a discovery critical to understanding the origin of the beryllium pegmatites.

The results of the field and petrologic studies show that the beryllium pegmatites evolved in three major stages. During the first stage, melt from anatexis of sapphirine-bearing metapelites crystallized as pegmatites in inter-boudin spaces soon after temperatures peaked during an ultrahigh-temperature event at 1000-1100 °C and 7-11 kbar and during the waning stages of associated deformation. The primary carrier of beryllium in the pegmatites at the time of their intrusion was a sapphirine-group mineral that after subsequent annealing recrystallized either to khmaralite (when Be > 0.5 atoms per 20 O) or to beryllian sapphirine. The second stage was a discrete event at ~800-900 °C, ~8-9 kbar, which resulted in reaction of sapphirine with quartz to form corona assemblages of sillimanite + orthopyroxene (or garnet) in the host rocks and sillimanite + garnet + surinamite in the beryllium pegmatites. Other investigators have attributed this second stage to isobaric cooling following ultrahigh-temperature metamorphism, but complete breakdown of pegmatitic sapphirine, together with strain that deformed sillimanite-garnet-surinamite aggregates formed from sapphirine breakdown, requires more than simple cooling in a static environment. The third stage includes two amphibolite-facies metamorphic events at temperatures not exceeding ~700 °C. During this stage, surinamite broke down to beryllian cordierite +/- Al-poor orthopyroxene. The presence of late-formed andalusite as well as kyanite in the pegmatites indicates that pressures decreased to less than 3 kbar.

Geochemical data show no evidence for loss of Be during granulite-facies metamorphism, e.g., Be contents of the quartz-rich granulites hosting the beryllium pegmatites range from 0.8 to 7.1 ppm and average 3.7 +/- 2.1 ppm, comparable to unmetamorphosed and low-grade pelites. The primary host of beryllium in the granulites is sapphirine, the Be content of which is 60 to 600 times the whole-rock Be content. In addition, geochemical data suggest that the pegmatites originated from the host rocks, rather than some distant source. In summary, melting of sapphirine-bearing pelitic rocks under ultrahigh-temperature conditions can extract sufficient beryllium for its concentration in the resulting anatectic melt. S-type granites derived from melting in the lower crust could thus still have Be contents comparable to granites derived from cordierite- or mica-bearing rocks melted at higher levels in the crust.

#### GEOCHRONOLOGICAL DATA ON THE NAPIER COMPLEX

K. Suzuki (Nagoya University, Japan) carried out chemical Th-U-total Pb isochron method (CHIME) of dating on monazite, xenotime, zircon, and polycrase in six samples of ultrahigh-temperature granulites and one of pegmatite from five localities in the Napier Complex (Asami, Suzuki, and Grew, manuscript in review with Precambrian Research). Despite the chronological heterogeneity in many grains, the CHIME ages overall show strong evidence for a major event near 2420 Ma, which is interpreted to date the ultrahigh-temperature metamorphism and intrusion of the beryllium pegmatites, an interpretation consistent with preponderance of ages obtained by other methods on the Napier Complex metamorphics and pegmatites. Ca. 2500 Ma ages have been reported from granulite-facies rocks in the Madras and Nilgiri blocks in South India; these blocks and the Napier Complex could have constituted a single structural unit by late Archean time. The much younger CHIME age of 1094 +/- 67 Ma on monazite in a pegmatite from 'Zircon Point', Casey Bay, confirms 1000-1100 Ma lead loss ages reported for this region. The nature of the 1000-1100 Ma event remains problematic; it could be a granulite-facies metamorphism that affected the beryllium pegmatites in Casey and southern Amundsen Bays, but this interpretation is inconsistent with the presence of pre-1100 Ma unmetamorphosed mafic dykes.

Since completion of the paper submitted to Precambrian Research, K. Suzuki has analyzed xenotime, monazite and zircon in four samples I collected on JARE-40 from the pegmatites at 'Christmas Point'. Preliminary processing of the new CHIME data gives a more complicated picture because the minerals are chronologically more heterogeneous. For example, the core of a large xenotime grain and two zircon grains gave CHIME ages near 2200 Ma, whereas cores and margins of other xenotime grains gave CHIME ages ranging from ca. 750 Ma to ca. 1750 Ma. This heterogeneity could result from the post-intrusion metamorphic events being more intense at 'Christmas Point' than in the areas sampled for the study reported in the paper submitted to Precambrian Research.

#### CRYSTAL CHEMISTRY OF BERYLLIUM MINERALS RELATED TO SAPPHIRINE

Any understanding of Be geochemistry requires a better understanding of how Be is incorporated in minerals, i.e., its crystal chemistry. In collaboration with crystallographers I have obtained new data on beryllium minerals related to sapphirine, i.e., khmaralite, surinamite, 'makarochkinite', hogtuvaite, and welshite. The 'beryllian sapphirine' I first reported from 'Zircon Point' in Enderby Land in 1981 has now been shown to be a new mineral, khmaralite, which contains over 0.7 Be/20 O or 2.5 wt% BeO (Barbier et al., 1999, American Mineralogist. See publication list). Jacques Barbier's crystallographic studies showed that it differs from sapphirine in having doubled a axis due to ordered Be-Al-Si distribution. Barbier's cell parameters and electron diffraction patterns of samples I collected at 'Christmas Point' on JARE-40 show that

superstructure reflections indicative of the doubled a axis first appear when Be content reaches about 0.5 atoms per 20 O or about 1.8 wt% BeO (Grew et al., 2000, see Publication list). Electron and ion microprobe analyses of beryllian sapphirine and khmaralite from Enderby Land and Central Australia (Musgrave Ranges) confirm my 1981 suggestion that Be is incorporated in sapphirine (and khmaralite) by the coupled substitution  $\text{Be} + \text{Si}$  for  $\text{Al} + \text{Al}$  on tetrahedral sites.

W. Schreyer's Ph.D. student A. Hoelscher had synthesized beryllian sapphirine with as much as 1 Be per formula unit of 20 oxygens, more than in khmaralite (Christy, Tabira, Hoelscher, Grew and Schreyer, manuscript submitted to American Mineralogist). Crystallographic studies by A. Christy and Y. Tabira found none of the superstructure reflections corresponding to the doubled tetrahedral chain repeat of khmaralite, which indicates a less ordered tetrahedral arrangement in synthetic beryllian sapphirine. Molar volumes of synthetic sapphirine and natural sapphirine-khmaralite decrease linearly with Be content by the same amount: 2.7% per 1 Be/20 oxygens. Nonetheless, calculations of possible sapphirine breakdown reactions show that it is unlikely that beryllian sapphirine and khmaralite are high-pressure phases. Sapphirine could not be synthesized with more than 1Be/20 O, a limit attributed to avoidance of Be-O-Be bridges (cf. welshite, below).

Jacques Barbier has also newly refined the crystal structures of surinamite in a specimen I collected from 'Christmas Point' and 'makarochkinitite' in a specimen I obtained from the type locality (Urals), but to date he has had no success with hogtuvaite because of this mineral's very fine polysynthetic twinning (Barbier, Grew, Yates and Shearer, in an abstract submitted for presentation at the 2001 annual meeting of the Mineral. Assoc. Canada). Electron microprobe analyses (B from ion microprobe) were used as input for the refinements, whereas Be (+B) contents were determined from the refinements of tetrahedral site occupancies. The structure of surinamite,  $[\text{Mg}_{2.262} \text{Fe}_{2+0.738} \text{Fe}_{3+0.390} \text{Al}_{2.610}] [\text{AlBeSi}_3\text{O}_{15}]\text{O}$  (simplified composition), is highly ordered, for example, there is complete  $\text{Fe}_{2+}/\text{Fe}_{3+}$  ordering along with Mg/Al ordering on the 7 octahedral sites as well as near-perfect ordering on the 5 tetrahedral sites. In contrast, the structure of 'makarochkinitite',  $[\text{Ca}_{1.77} \text{Na}_{0.195} \text{Mn}_{0.03} \text{Y}_{0.005}] [\text{Fe}_{5.105} \text{Mg}_{0.265} \text{Ti}_{0.56} \text{Nb}_{0.07}] [\text{Si}_{4.45} \text{Be}_{1.00} \text{Al}_{0.495} \text{Fe}_{3+0.055} \text{O}_{18}]\text{O}_2$  (simplified composition), is only partially ordered: Be and Si are evenly mixed on the two equivalent tetrahedral sites and the average bond distances do not indicate a strong  $\text{Fe}_{2+}/\text{Fe}_{3+}$  ordering on 6 of the 7 octahedral sites. Comparison of the surinamite, khmaralite and 'makarochkinitite' structures shows a progression from a completely ordered to an essentially disordered cation distribution on both the tetrahedral and octahedral sub-lattices. The absence of tetrahedral Be ordering in 'makarochkinitite', which lacks the superstructure found in khmaralite in spite of its higher Be content, is probably associated with the large octahedral Fe content and the lack of  $\text{Fe}_{2+}/\text{Fe}_{3+}$  octahedral ordering.

I am collaborating with U. Halenius in reporting new data on welshite, a beryllium mineral of the aenigmatite group from the Langban Fe-Mn deposit, Sweden (Grew, Halenius, Kritikos and Shearer, manuscript submitted to Mineral. Mag.). The original description of this mineral left many questions unanswered, and a re-investigation was warranted. New electron and ion microprobe data on two samples of welshite gave analytical totals of 99.36-99.49 wt% and BeO contents of 4.82-5.11 wt%, whereas Moessbauer spectra on one sample indicated that 91% of the iron was tetrahedral ferric and 9% was octahedral ferrous. The resulting formula for this sample is  $\text{Ca}_2 \text{Mg}_{3.8} \text{Mn}_{2+0.6} \text{Fe}_{2+0.1} \text{Sb}_{5+1.5} \text{O}_2 [\text{Si}_{2.8} \text{Be}_{1.7} \text{Fe}_{3+0.65} \text{Al}_{0.7} \text{As}_{0.15} \text{O}_{18}]$ . Welshite could be unique among Be minerals in the presence of Be-O-Be bridges not involving a third tetrahedral cation or a proton, possibly as a result of the presence of the highly charged As and Sb ions in sites near the bridging oxygen.

Elke Halenius and Ulf Halenius have obtained polarized optical absorption spectra on surinamite from 'Christmas Point'. They succeeded in more precisely defining the optical orientation of surinamite by discovering that optical Z makes a small angle to crystallographic a. The recorded absorption spectra show a very strong anisotropy. Four prominent features are recorded in the low energy range (below 18,000  $\text{cm}^{-1}$ ) of the spectra. The band widths, energies, intensities as well as anisotropic behaviour indicate strongly that the bands at 17,500 and 13,500  $\text{cm}^{-1}$  are caused by intervalence charge transfers, which, given the sample chemistry, are ferrous-ferric iron charge transfers. The two less polarised absorption bands recorded at 8,200 and 10,300  $\text{cm}^{-1}$  are characterized by energies, band widths as well as intensities common to spin-allowed electronic d-d transitions in octahedrally coordinated ferrous iron in a large number of silicate minerals.

## PETROGENESIS OF THE BERYLLIUM MINERAL SURINAMITE

Since its discovery in 1976 and prior to 1995, the berylliosilicate surinamite had been reported from only five localities worldwide, including beryllium pegmatites at 'Zircon Point' and 'Christmas Point', Enderby Land. Several new localities were reported from the Eastern Ghats belt, India, in 1995, but from study of other samples from this area that I obtained from A. T. Rao and K.K.V.S. Raju, it is very likely that hypersthene had been misidentified as surinamite.

Sotaro Baba, when he was a Ph.D. student at Osaka City University, found a few grains of a sapphirine-like mineral in a metapelitic gneiss from South Harris, Scotland. I recognized this mineral as surinamite. Baba invited me to join him in a study of this rock, so together we developed a scenario for surinamite paragenesis that would be applicable to surinamite parageneses in general (Baba et al., 2000, Am. Mineral. See publication list). The appearance of a Be-bearing phase, albeit sparsely, in Be-poor granulite-facies rocks (9 ppm Be in the S. Harris gneiss) could be due to the absence of other potential carriers of Be, namely muscovite and primary cordierite, at high temperatures and low water activities. At the 7 presently confirmed surinamite localities, including the one I discovered in a pegmatites at Mt. Pardoe on JARE-40, high-temperature rocks were subjected to a later metamorphic stage when pressure remained the same or increased and temperature remained the same or decreased. Thus surinamite could be an indicator of a distinctive metamorphic history.

## BORON MINERALS

I have continued my research on boron minerals, including collaboration with J. Hughes on demonstrating the presence of extra boron in a tourmaline-group mineral, olenite, where the extra boron substitutes for silicon on a tetrahedral site (Hughes et al., 2000, *Canad. Mineral.*, see publication list). This is the first structural study to unequivocally show boron to occur in amounts significantly greater than three atoms per formula unit in a tourmaline. The studied olenite is from a pegmatite that had been metamorphosed at 2 GPa pressure after intrusion, which suggests that a high-pressure environment may be necessary for incorporation of significant tetrahedral boron in tourmaline. A collaborative study with Y. Hiroi and others has led to the discovery of the iron analogue of grandierite, the new mineral ominelite,  $\text{FeAl}_3\text{BSiO}_9$ , which has been approved by the International Mineralogical Association Commission on New Minerals and Mineral Names (IMA CNMMN #99-025, Hiroi et al., manuscript in preparation). D.R. Peacor and R.C. Rouse have refined the crystal structure.

I discovered prismatine in one of the samples obtained from A. T. Rao and K.K.V.S. Raju; this represents a new locality for a kornerupine-group mineral in India. This prismatine, together with another specimen from India collected by A.S. Janardhan, have been analyzed by both the electron and ion microprobes.

## OTHER MINERALS

Th. Armbruster and his student Clivia Hejny at the University of Bern, Switzerland, are carrying out a systematic crystallo-chemical study of the Fe-Al-Ti oxide hoegbomite, which includes one sample from India that I obtained from A.T. Rao and K.K.V.S. Raju and a second from a beryllium pegmatite at 'Christmas Point'. Hoegbomite in both samples is predominantly the 8H polysome.

### Research Training:

### Outreach Activities:

### Journal Publications

Baba, S., Grew, E.S., Shearer, C.K., Sheraton, J.W., "Surinamite: A high-temperature metamorphic beryllosilicate from Lewisian sapphirine-bearing kyanite-orthopyroxene-quartz-potassium feldspar gneiss at South Harris, N.W. Scotland.", *American Mineralogist*, p. 1474, vol. 85, (2000). ) Published

Barbier, J., Grew, E.S., Moore, P.B. and Su, S.-C., "Khmaralite, a new beryllium-bearing mineral related to sapphirine: A superstructure resulting from partial ordering of Be, Al and Si on tetrahedral sites.", *American Mineralogist*, p. 1650, vol. 84, (1999). ) Published

Grew, E.S., Yates, M.G., Barbier, J., Shearer, C.K., Sheraton, J.W., Shiraishi, K., and Motoyoshi, Y., "Granulite-facies beryllium pegmatites in the Napier Complex in Khmara and Amundsen Bays, western Enderby Land, East Antarctica.", *Polar Geoscience*, p. 1, vol. 13, (2000). ) Published

Hughes, J.M., Ertl, A., Dyar, M.D., Grew, E.S., Shearer, C.K., Yates, M.G., and Guidotti, C.V., "Tetrahedrally coordinated boron in a tourmaline: Boron-rich olenite from Stoffhuetten, Koralpe, Austria.", *Canadian Mineralogist*, p. 861, vol. 38, (2000). ) Published

Miyamoto, T., Grew, E.S., Sheraton, J.W., Yates, M.G., Dunkley, D.J., Carson, C., Yoshimura, Y., and Motoyoshi, Y., "Lamproite dykes in the Napier Complex at Tonagh Island, Enderby Land, East Antarctica.", *Polar Geoscience*, p. 41, vol. 13, (2000). ) Published

### Books or Other One-time Publications

### Web/Internet Sites

URL(s):

Description:

### Other Specific Products

### Contributions

#### Contributions within Discipline:

The findings from this project are contributing to a better understanding of beryllium in geologic systems. This understanding begins with knowledge at the atomic level, namely the incorporation of beryllium in the crystal structures of minerals. Few minerals readily incorporate

beryllium at more than trace levels (few parts per 100,000), and the research I have been involved in has investigated why. One mineral that does incorporate significant beryllium is sapphirine. Crystallographic studies of sapphirine, the new mineral khmaralite closely related to it, and of other minerals more distantly related to it have revealed several mechanisms that favor incorporation of beryllium in sapphirine. The next level is comparison of the beryllium contents of associated minerals. This study has focussed on mineral assemblages from depths of nearly 30 km in the Earth's lower crust. Here sapphirine can concentrate beryllium to a remarkable degree due the crystallographic mechanisms favoring incorporation. Despite the high temperatures at these depths, beryllium is retained in the rocks, for example, sedimentary rocks buried to the depths of the lower crust have beryllium contents close to those of the unburied sediments, i.e., the average is near 4 ppm Be. The presence of sapphirine could be critical in this retention. Results of my research suggest that when metamorphosed sedimentary rocks are melted at depth, beryllium can be incorporated in the melt. This is potentially a source for beryllium enrichments associated with granitic magmas rising from lower to higher levels in the Earth's crust.

I am also writing a chapter entitled 'Beryllium in metamorphic environments (with an emphasis on aluminous compositions)' for the Reviews in Mineralogy volume #43, 'Beryllium: Mineralogy, Petrology and Geochemistry' to be published by the Mineralogical Society of America. My chapter reviews the literature on topics closely related to my research on beryllium pegmatites from the Napier Complex, for example, beryllium contents of minerals and rocks, occurrences of beryllium minerals, and the effect of metamorphism on beryllium contents. I am editing this Reviews in Mineralogy volume, in which other investigators are contributing chapters on a wide variety of topics related to beryllium in general, for example, geochemistry of beryllium and its cosmogenic isotopes, extraterrestrial beryllium, beryllium in the environment, beryllium crystal chemistry and pegmatitic beryllium. When published, the volume is expected to have a wide readership among geoscientists.

**Contributions to Other Disciplines:**

**Contributions to Human Resource Development:**

**Contributions to Science and Technology Infrastructure:**

**Beyond Science and Engineering:**

**Categories for which nothing is reported:**

Organizational Partners

Activities and Findings: Any Research Training

Activities and Findings: Any Outreach Activities

Any Book

Any Product

Contributions: To Any Other Disciplines

Contributions: To Any Contributions to Human Resource Development

Contributions: To Any Science or Technology Infrastructure

Contributions: Beyond Science or Engineering