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Application of Boron Isotopes to Constrain the Depositional Environment of the Precursors to Proterozoic Granulite-Facies Borosilicate Paragneisses, Larsemann Hills, Antarctica

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[Cover](#) |
[Accomplishments](#) |
[Products](#) |
[Participants/Organizations](#) |
[Impacts](#) |
[Changes/Problems](#)

Cover

Federal Agency and Organization Element to Which Report is Submitted:	4900
Federal Grant or Other Identifying Number Assigned by Agency:	0837980
Project Title:	Application of Boron Isotopes to Constrain the Depositional Environment of the Precursors to Proterozoic Granulite-Facies Borosilicate Paragneisses, Larsemann Hills, Antarctica
PD/PI Name:	Edward S Grew, Principal Investigator
Recipient Organization:	University of Maine
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Submitting Official (if other than PD\PI):	Edward S Grew Principal Investigator
Submission Date:	03/22/2013
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	Edward S Grew

Accomplishments

* What are the major goals of the project?

The major goal of the project is to test a hypothesis for explaining premetamorphic boron enrichment of granulite-facies paragneisses in the Larsemann Hills, Antarctica. Was boron originally deposited as borate in non-marine

evaporites and subsequently mobilized by submarine hydrothermal fluids that reacted with clastic sediments and volcaniclastic rocks to form rocks containing 20% or more tourmaline? The main method for achieving this goal is in situ analyses of tourmaline and other borosilicate minerals in boron-rich rocks obtained in the Larsemann Hills for boron isotopes using secondary ion mass spectroscopy. Boron isotopes provide valuable information both on the source of boron and on the processes that redistribute boron during metamorphism.

*** What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?**

Major Activities: 1. Completion of a Master's thesis on boron isotope compositions of borosilicate minerals from the Larsemann Hills, Antarctica, and writing up the results for publication in a peer-reviewed journal.

Specific Objectives: 2. Geochemical characterization of boron-rich rocks and associated paragneisses from the Larsemann Hills

3. Dating of deposition of precursors to the Brattstrand Paragneiss, the basement on which it was deposited and metamorphism.

Significant Results: 1. Weringite from a pegmatite on Almgjothei, Norway had been reported as the 'Fe-dominant analogue' because of its high total Fe (to 8.00 wt% as FeO) and atomic Fe/(Mg + Fe) ratio (to 0.75). A crystal structure refinement ($R_1 = 0.057$) gave 1.21 Fe occupying the one tetrahedral and two 5-coordinated sites present in type werdingite plus a new, largely vacant tetrahedral site. Fe is not dominant at any site, and we cannot show that this werdingite is a Fe-dominant analogue of type werdingite. The results have been published in the *European Journal of Mineralogy* (2011).

2. The Progress granite in the Larsemann Hills contains hoegbomite, secondary fluorite and secondary fluorine-bearing titanite, the latter two plus chlorite resulting from the breakdown of biotite, itself containing relatively high amounts of fluorine and chlorine. Biotite composition and the magnetite-hematite assemblage suggest relatively high activities of halogens and oxygen for crystallization of the granite. The three samples are also unusually enriched in rare-earth elements and thorium. Roland Maas analyzed three Progress granite samples for hafnium, lead, and neodymium isotopes, and the results have been written up in the following abstract on these and related granites that will be published in *Geological Society of America Abstracts with Programs*. Vol. 45, No. 3, p.16 (2013):

Title: CAMBRIAN GRANITES OF PRYDZ BAY, EAST ANTARCTICA: EVIDENCE FOR MELTING OF A TWO-COMPONENT GRANULITE-FACIES CRUST?

Authors: GREW, Edward S.¹, MAAS, Roland², CHRISTY, Andrew G.³, CARSON, Christopher J.⁴, and YATES, Martin¹, (1) School of Earth and Climate Sciences, Univ of Maine, 5790 Bryand Center, Orono, ME 04469, esgrew@maine.edu, (2) School of Earth Sciences, University of Melbourne, Parkville, 3010, Australia, (3) Centre for Advanced Microscopy, Australian National University, RN Roberston Building (#46), Sullivans Creek Road, Canberra, 0200, Australia, (4) Geoscience Australia, PO Box 378, Canberra, 2601, Australia

Abstract: Neoproterozoic granulitic gneisses along the Prydz Bay coast are intruded by Cambrian granites (500-520 Ma). Occurring over ~130 km, the granites are structurally, texturally and mineralogically diverse, ranging from veins (<1 m) of fine-grained, foliated biotite granite to bodies > 1 km across of unfoliated, K-feldspar phyric biotite-hornblende granite. Whole rock compositions are

characterized by high total alkalis, high K/Na, low Mg, Cr, Ni, high Zr (up to 1625 ppm), LREE (up to 2101 ppm Ce) and Th (up to 878 ppm Th; Th/U = 28-142), as well as elevated Ga ($[Ga/Al]*10^4 = 2.9-11.0$) and halogens (726-3953 ppm F, 27-1195 ppm Cl), all characteristics of A-type granites. REE patterns are characterized by variable HREE fractionation and Eu depletion; La/Yb ratios show regional differences, being highest in 3 of the 4 eastern intrusions (LaN/YbN = 217-454) and lowest in the western intrusions (LaN/YbN = 36-67). Sr-Nd-Hf isotope ratios ($^{87}Sr/^{86}Sr$ 0.708- 0.720, ϵNd -8 to -14, ϵHf ~-9) are consistent with magma sources in equivalents of the exposed para- and orthogneisses. A metasedimentary source component could explain the mildly peraluminous (ASI up to 1.13) nature of some of the granites. Initial Pb isotope compositions, measured on feldspars, are characterized by high $^{207}Pb/^{204}Pb$ (15.71-15.77) and low $^{206}Pb/^{204}Pb$ (17.7-18.16) compared to global Pb isotope growth curves. This “high-207/low-206” signature requires Pb isotope evolution in a high-U/Pb reservoir since about 2.5 Ga, followed by a low-U/Pb ($\mu \ll 10$) stage for several 100 Ma prior to granite formation. In the present case, lowering of U/Pb may be related to U removal from older (up to 2.5 Ga) crustal protoliths during the ca. 1 Ga granulite facies event recorded in Prydz Bay gneisses. Co-variation of REE-Y and Sr-Nd isotopes in the granites suggests the presence of two crustal components in the granite source. Component 1 (ϵNd below -14, $^{87}Sr/^{86}Sr > 0.72$) produced melts with strong HREE fractionation and Y depletion (major residual garnet), represented by 3 of the 4 eastern intrusions. Component 2 (ϵNd higher than -7, $^{87}Sr/^{86}Sr < 0.708$) produced melts with lower GdN/YbN (less residual garnet), represented by the western intrusions. Both components contain the high-207/low-206 isotope signature inferred to be linked to the regional granulite gneisses.

3. Roland Maas analyzed K-feldspar in six pegmatites from the Larsemann Hills for lead and neodymium isotopes, and these results have been written up in an abstract accepted for oral presentation at the Winnipeg 2013 GAC-MAC annual meeting on May 22-24, 2013:

Title: Three generations of pegmatites with boron and beryllium minerals in the Larsemann Hills, Prydz Bay, Antarctica: A Pb isotope study

Authors: [GREW, Edward S.](#), Earth Sciences, Univ of Maine, 5790 Bryand Center, Orono, ME 04469, esgrew@maine.edu, MAAS, Roland, School of Earth Sciences, University of Melbourne, Parkville, 3010, Australia, and CARSON, Christopher J., Geoscience Australia, PO Box 378, Canberra, 2601, Australia

Abstract: Three generations of pegmatites cut the Brattstrand Paragneiss, which comprises several B rich units, was metamorphosed in the granulite-facies at ca. 900 Ma. Pegmatites of the earliest generation, D(2-3), form irregular pods and veins up to a meter thick, which are either roughly concordant or crosscut S2 and S3 fabrics and are locally folded, whereas pegmatites of the second generation, D(4), form planar, discordant veins up to 20-30 cm thick. Pegmatites of the youngest generation, D(6), form discordant veins and pods. Tourmaline + quartz intergrowths and boralsilite ($Al_{16}B_6Si_2O_{37}$) are characteristic of D(2-3) and D(4) pegmatites, whereas beryl and primary muscovite distinguish D(6) pegmatites. The spatial distribution of B-bearing pegmatites relative to B-rich units in the Brattstrand Paragneiss, suggest that a local source contributed most to D(2-3) pegmatites and least to D(6) pegmatites. Pb isotope and trace elements were analyzed on acid-leached K-feldspar separated from 3 samples each of the 3 generations. The trace element data confirm that the analyzed Pb largely resides in the K-feldspar. The

207Pb/204Pb ratios for all 9 samples (15.67-15.91) are higher than all common Pb growth curves; this indicates that the pegmatite Pb was derived from an ancient (Archean?) source with a high-U/Pb signature, whereas the wide range in 206Pb/204Pb ratio (17.71-19.97) reflects decrease in U/Pb over a long time period. The 208Pb/204Pb ratios (38.63-42.84) tend to exceed 208Pb/204Pb in growth curves, and 208Pb/204Pb ratios >40 require a source with high Th/Pb and Th/U ratio. There is a systematic shift from radiogenic Pb in D(2-3) pegmatites to unradiogenic Pb in D(6) pegmatites, whereas D(4) are intermediate, overlapping with the two others. The range in uranogenic Pb could reflect mixing of 2 components, one with a very radiogenic Pb (old, high U-Pb upper crust, most pronounced in D(2-3) pegmatites), the other with a multi-stage history involving dramatic lowering of U/Pb, for example upper crust which lost U during a granulite-facies overprint. The second component is most pronounced in the youngest pegmatites. Zircon Hf and whole-rock Sm-Nd data suggest an older crustal source for a part of the detritus in Bratstrand Paragneiss; this source could also be contributing Pb to the pegmatites. Pb data for the D(6) pegmatites plot with data for Cambrian granites intrusive into the Brattstrand Paragneiss suggesting either they share the same or similar source, or that the D(6) pegmatites are differentiates of the Cambrian granites.

Key outcomes or
Other achievements:

1. Under my direction as advisor, JohnRyan MacGregor successfully defended his Master's thesis. His thesis research includes petrographic studies of microstructures in borosilicate-rich rocks from the Larsemann Hills, electron microprobe analyses of borosilicate minerals and associated biotite, cordierite, garnet, orthopyroxene and feldspar using the electron microprobe at the University of Maine, and ion microprobe analyses of boron isotopes in borosilicate minerals. In collaboration with Simon Harley, Cees-Jan de Hoog and Richard Hinton, JohnRyan completed analyses of boron isotope compositions in the borosilicates tourmaline, prismatic and grandidierite in 24 samples of boron-rich rocks from the Larsemann Hills using the ion microprobe at the University of Edinburgh, UK. Attached is a summary of JohnRyan's results from a manuscript in review ("Summary of JohnRyan MacGregor thesis"), which represents progress towards achieving the first major objective of the project.
2. Twenty one whole-rock samples of plutonic and metamorphic rocks (Brattstrand Paragneiss) from the Larsemann Hills, including several containing abundant borosilicates, have been analyzed for major and trace elements by Andrew Christy at the Australian National University, and studied with the petrographic microscope. Boron and lithium were determined commercially. Fourteen of these analyses and 51 analyses done earlier constitute the database for a paper on the geochemistry of the boron-rich rocks and associated paragneisses (Brattstrand Paragneiss), thereby providing the context needed for interpreting the boron isotope data. Attached are the abstract, a table of compositions and selected figures from the paper in press on the geochemistry of these rocks ("Geochemistry Paper"), which represents achievement of the second major objective of the project.
3. Together with Chris Carson, Roland Maas and others, I published a paper in *Precambrian Research* in 2012 reporting the ages of deposition of precursors to the Brattstrand Paragneiss, the basement on which the Brattstrand was deposited and their metamorphism, succeeding thereby in achieving the third major objective of the project.

4. Adam Pieczka, James Evans, Lee Groat, Chi Ma and George Rossman and I have developed a new classification of the dumortierite supergroup and discovered three new minerals in this supergroup: nioboholtite, titanoholtite and szklaryite. The new classification and minerals were approved by the International Mineralogical Association Commission on New Minerals, Nomenclature and Classification (IMA CNMNC).

5. In collaboration with Andrew Locock, Stuart Mills, Irina Galuskina, Evgeny Galuskin and Ulf Hålenius developed a new classification of the garnet supergroup. The new classification was approved by the IMA CNMNC.

6. Research on the evolution of B and Be minerals in collaboration Robert Hazen, who is credited with introducing the concept to the U.S. – I developed a diagram illustrating the increase in mineral species diversity with time, and how it can be related to geologic events, and a plot illustrating the period over which minerals have been found. The attached pdf summarizes the concept of mineral evolution and examples of my plots (“B and Be mineral evolution”).

7. In a paper published with Robert Hazen and Jeffrey Bada in *Origins of Life and Evolution of Biospheres* in 2011 I reviewed the possible role of borate in the RNA World, which is generally thought to have been an important link between purely prebiotic (>3.7 Ga) chemistry and modern DNA/protein biochemistry. This question was revisited in an invited presentation at the 2012 Fall Meeting of the American Geophysical Union:

Title: Could borate have played a role in the RNA World?

AUTHORS: Edward S Grew¹, Jeffrey L Bada², Robert M. Hazen³

INSTITUTIONS (ALL): 1. Dept Earth Sciences, Univ Maine, Orono, ME, United States.

2. Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA, United States.

3. Geophysical Laboratory, Carnegie Institution of Washington, Washington, DC, United States.

ABSTRACT BODY: Two scenarios have been proposed for boron to play a critical role in the stabilization of ribose and other sugars in the ribonucleic acid (RNA) World, >3.8 Ga ago. One scenario envisages oligomeric RNA being synthesized in subaerial intermountane desert valleys in which groundwater was enriched in borate from breakdown of tourmaline (Benner et al. 2012 doi: [10.1021/ar200332w](https://doi.org/10.1021/ar200332w)). In the alternative scenario, borates are enriched in hydrothermal environments (<150°C) in oceanic crust where ferromagnesian minerals are altered to brucite, serpentine and other minerals that can extract borate from the circulating seawater (Holm et al. 2006 doi: [10.1186/1467-4866-7-7](https://doi.org/10.1186/1467-4866-7-7)). Both scenarios presume that (1) B concentrations in non-marine water or sea water were about the same at >3.8 Ma as they are today and (2) plate tectonics was the prevailing regime. The postulated non-marine borate deposits would have been associated with continental collision and subduction with volcanism releasing B, whereas in the second scenario, ocean floor caught up in an early phase of subduction is considered a favorable site for borate formation. Because borate deposits are typically ephemeral and poorly preserved, the lack of evidence in the geologic record for these scenarios does not

invalidate them. For example, the oldest reported non-marine borate deposits analogous to the type postulated in first scenario are only 20 Ma, but metamorphosed borates of Precambrian age have been interpreted to have non-marine evaporite precursors, the oldest being 2.4-2.1 Ga in the Liaoning-Jilin area, China. The first B minerals so far reported in the geologic record are metamorphic dravite-schorl tourmalines in the 3.7-3.8 Ga Isua supracrustal belt (southern West Greenland), where there is good evidence for seafloor spreading and subduction. The precursors to the Isua tourmalines are reported to include B-bearing marine clay minerals and detrital tourmaline. The relatively high Li contents in zircon from Jack Hills, Australia, have been cited as evidence for the presence of granitic (s. l.) "protocontinental" crust by 4.3 Ga (Ushikuba et al. 2008 doi:[10.1016/j.epsl.2008.05.032](https://doi.org/10.1016/j.epsl.2008.05.032); Valley et al. 2010 *Rec Geol Surv W Aust*, 5-7), but the existence of conventional plate tectonics prior to 3.8 Ga remains controversial. Chaussidon & Appel (1997 *Chem Geol* 136, 171-180) concluded that boron isotope compositions ($\delta^{11}\text{B}$) of tourmaline from Isua volcanoclastic rocks provide no evidence for changes of $\delta^{11}\text{B}$ in the mantle or continental crust between now and 3.8 Ga, whereas the very light B ($\delta^{11}\text{B} = -20\text{‰}$) in tourmaline from Isua metachert could indicate that seawater $\delta^{11}\text{B}$ was at least 10‰ less at 3.8 Ga than now and that there was proportionally less B in sediments at 3.8 Ga, i.e., fractionation of B between depleted mantle, oceans, continental crust and oceanic crust was still in progress (Chaussidon & Albarède 1992, *EPSL* 108, 229-241). If fractionation and outgassing of boron had not proceeded very far during the RNA World, neither of the proposed scenarios of borate enrichment is plausible, particularly in the absence of a conventional plate tectonics regime.

* What opportunities for training and professional development has the project provided?

Master's student JohnRyan MacGregor learned how to give talks to students, faculty and other scientists; he became sufficiently proficient to give a 15 minute talk at the Annual Meeting of the Northeast Section of the Geological Society of America in March, 2012.

As a teaching assistant for one year, JohnRyan MacGregor learned the fundamentals of teaching.

JohnRyan MacGregor wrote a Master's thesis and has contributed to writing up his results in a scientific paper, now in review.

Under my direction, Eva Wadoski completed on August 14, 2009, her Master's thesis on pegmatitic borosilicate minerals from the Larsemann Hills, a study closely related to the current project, Eva contributed to writing up the results in her Master's thesis in a scientific paper, now published in the *Canadian Mineralogist*.

I collaborated with former U Maine Ph.D. student Jeffrey Marsh (now graduated) on menzerite-(Y), a new species of garnet he discovered. Menzerite-(Y) was officially approved by the International Mineralogical Association Commission on New Minerals, Nomenclature and Classification. Together with Martin Yates and others Jeff and I have published two papers on menzerite-(Y) in the *Canadian Mineralogist*. Jeff and I have also collaborated in the preparation of three talks and one poster, the last of which he presented at the Fall Meeting of the American Geophysical Union in 2009.

U Maine undergraduate student Jacob Holmes had begun work under my direction on a study of Cambrian granites in Prydz Bay, Antarctica. He received training in the use of rock saws and polishing equipment for the preparation of petrologic thin sections. However, he was unable to complete his training; indeed circumstances forced him to discontinue his studies at U Maine.

* How have the results been disseminated to communities of interest?

Publication in international, peer-reviewed scientific journals

Oral and poster presentations at regional, national and international scientific meetings

Oral presentations at seminars in the School of Earth and Climate Sciences, University of Maine.

Supporting Files

Filename	Description	Uploaded By	Uploaded On
Summary of JohnRyan MacGregor thesis.pdf	pdf	Edward Grew	03/22/2013
Geochemistry paper.pdf	pdf	Edward Grew	03/22/2013
B and Be mineral evolution.pdf	pdf	Edward Grew	03/22/2013

Products

Books

Book Chapters

Grew, E. S., Carson, C. J. Christy, A.G. and Boger, S. D. (2013). Boron- and phosphate-rich rocks in the Larsemann Hills, Prydz Bay, East Antarctica: Tectonic Implications. *Antarctic Thematic Set 2012, Volume I. Antarctica and Supercontinent Evolution* Geological Society of London, Special Publications. NA. Status = ACCEPTED; Acknowledgement of Federal Support = Yes ; Peer Reviewed = Yes

Conference Papers and Presentations

Inventions

Nothing to report.

Journals

Grew, E. S., Carson, C. J. Christy, A.G. Maas, R., Yaxley, G., Boger, S. D. and Fanning, C. M. (2012). New constraints from U-Pb, Lu-Hf and Sm-Nd isotopic data on the timing of sedimentation and felsic magmatism in the Larsemann Hills, Prydz Bay, East Antarctica.. *Precambrian Research*. 206-207 87-108. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: [10.1016/j.precamres.2012.02.016](https://doi.org/10.1016/j.precamres.2012.02.016)

Grew, E. S., Marsh, J.H., Yates, M.G., Lazic, B., Armbruster, T., Locock, A., Bell, S.W., Dyar, M.D., Bernhardt, H.-J. and Medenbach, O. (2010). Menzerite-(Y), a new garnet species, $\{(Y, REE)(Ca, Fe^{2+})_2\}[(Mg, Fe^{2+})(Fe^{3+}, Al)](Si_3)O_{12}$, from a felsic granulite, Parry Sound, Ontario, and a new garnet end member, $\{Y_2Ca\}[Mg_2](Si_3)O_{12}$.. *Canadian Mineralogist*. 48 1171-1193. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Grew, E.S., Armbruster, T., Lazic, B., Yates, M.G., Medenbach, O and Huijsmans, J.P.P. (2011). Werdingite from a pegmatite at Almgjotheii, Rogaland, Norway: the role of iron in a borosilicate with a mullite-type structure.. *European Journal of Mineralogy*. 23 577-589. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: [10.1127/0935-1221/2011/0023-2121](https://doi.org/10.1127/0935-1221/2011/0023-2121)

Grew, E.S., Bada, J.L., and Hazen, R.M. (2011). Borate minerals and origin of the RNA world. *Origins of Life and Evolution of Biospheres*. 41 307-316. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: [10.1007/s11084-101-9233-y](https://doi.org/10.1007/s11084-101-9233-y)

Grew, E.S., Locock, A.J., Mills, S.J, Galuskina, I.O., Galuskin, E.V. and Hålenius, U. (2013). Nomenclature of the garnet supergroup. *American Mineralogist*. 98 NA. Status = ACCEPTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Hazen, R.M., Downs, R.T., Golden, J., Hysten, G., Grew, E.S., Azzolini, D. and Sverjensky, D.A. (2012). Mercury (Hg) mineral evolution: A mineralogical record of supercontinent assembly, changing ocean geochemistry, and the emerging terrestrial biosphere.. *American Mineralogist*. 97 1013-1042. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: [org/10.2138/am.2012.3922](https://doi.org/10.2138/am.2012.3922)

MacGregor, J., Grew, E.S., De Hoog, C.J., Harley, S.L., Yates, M.G. and Carson, C.J. (2013). Boron isotopic composition of tourmaline, prismatic, and grandidierite from granulite facies paragneisses in the Larsemann Hills, Prydz Bay, East Antarctica: Evidence for a non-marine evaporite source.. *Geochimica et Cosmochimica Acta*. NA NA. Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Pieczka, A., Evans, R.J., Grew, E. S., Groat, L.A., Ma, C and Rossman, G.R. (2013). The dumortierite supergroup. I. A new nomenclature for the dumortierite and holtite group. *Mineralogical Magazine*. NA NA. Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Pieczka, A., Evans, R.J., Grew, E. S., Groat, L.A., Ma, C and Rossman, G.R. (2013). The dumortierite supergroup. II. Three new minerals from the Szklary pegmatite, SW Poland: Nioboholtite, (Nb_{0.6}vac_{0.4})Al₆BSi₃O₁₈, titanoholtite, (Ti_{0.75}vac_{0.25})Al₆BSi₃O₁₈, and szklaryite, vacAl₆BA₃+3O₁₅.. *Mineralogical Magazine*. NA NA. Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Wadoski, E.R., Grew, E.S. and Yates, M.G. (2011). Compositional evolution of tourmaline-supergroup minerals from granitic pegmatites in the Larsemann Hills, East Antarctica.. *Canadian Mineralogist*. 49 381-405. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Licenses

Nothing to report.

Other Products

Nothing to report.

Other Publications

Patents

Nothing to report.

Technologies or Techniques

Nothing to report.

Thesis/Dissertations

MacGregor, J.. *Boron isotopic study of the borosilicates tourmaline, prismatic, and grandidierite in granulite facies paragneisses from the Larsemann Hills, Prydz Bay, East Antarctica*.. (2012). University of Maine. Acknowledgement of Federal Support = Yes

Websites

Nothing to report.

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Grew, Edward	PD/PI	12
Yates, Martin	Other Professional	1
MacGregor, JohnRvan	Graduate Student (research assistant)	6

Full details of individuals who have worked on the project:

Edward S Grew**Email:** esgrew@maine.edu**Most Senior Project Role:** PD/PI**Nearest Person Month Worked:** 12**Contribution to the Project:** Overall supervision, writing and processing manuscripts**Funding Support:** None**International Collaboration:** No**International Travel:** Yes, United Kingdom - 0 years, 0 months, 25 days

Martin G. Yates**Email:** yates@maine.edu**Most Senior Project Role:** Other Professional**Nearest Person Month Worked:** 1**Contribution to the Project:** Carrying out or supervising electron microprobe analyses and imaging using the scanning electron microscope and electron microprobe**Funding Support:** none**International Collaboration:** No**International Travel:** No

JohnRyan MacGregor**Email:** johnryan.macgregor@maine.edu**Most Senior Project Role:** Graduate Student (research assistant)**Nearest Person Month Worked:** 6**Contribution to the Project:** Petrography, electron microprobe and ion microprobe analyses and writing of Master's thesis**Funding Support:** 2012 University of Maine Graduate School Government Travel Grant (\$658) 2011 University of Maine Graduate School Government Club Grant (\$600) 2011 University of Maine Graduate School Government Travel Grant (\$425)**International Collaboration:** No**International Travel:** Yes, United Kingdom - 0 years, 0 months, 22 days

What other organizations have been involved as partners?

Nothing to report.

What other collaborators or contacts have been involved?

YES

Impacts

What is the impact on the development of the principal discipline(s) of the project?

MINERAL NOMENCLATURE

Because of my work with Jeffrey Marsh on the new garnet menzerite-(Y), I was invited to join the subcommittee of the International Mineralogical Association Commission on New Minerals, Nomenclature and Classification (IMA CNMNC) on garnet-group nomenclature, and later was selected to chair this subcommittee. The subcommittee completed its recommendations for a classification of garnets, which was approved by the Commission. The classification was written up as a manuscript, which will be published in the April, 2013 issue of American Mineralogist.

Because of my work on borosilicate minerals, I was invited to collaborate with Adam Pieczka, Lee Groat, Jim Evans and others, to develop a classification for minerals related to dumortierite, a borosilicate found in pegmatites in the Larsemann Hills. The recommended classification was approved by the IMA CNMNC, and the manuscript reporting the new classification is presently under review with Mineralogical Magazine.

MINERAL EVOLUTION

As a result of my work on beryllium and boron minerals, e.g., borosilicates from the Larsemann Hills, Robert Hazen invited me to collaborate with him on the evolution of minerals containing these two elements as part of his program on mineral evolution. Boron minerals are of particular interest to Hazen because some investigators have suggested that borate present in the primitive oceans acted as a complexing agent that stabilized ribose, a critical compound in the prebiotic ribonucleic acid world. The results of this aspect of boron mineral evolution were published in 2011 in *Origins of Life and Evolution of Biospheres* and in an abstract for a talk presented at 2012 AGU Fall Meeting. In addition, Hazen has invited me to collaborate on the evolution of the minerals of other elements, for example, mercury minerals in a paper published in *American Mineralogist* in 2012.

What is the impact on other disciplines?

Nothing to report.

What is the impact on the development of human resources?

Instances where as PI, I provided exposure to science and technology for practitioners, teachers, young people, or other members of the public:

1. Sunday with a Scientist, December 18, 2011

I joined other volunteers in presenting 'Sunday with a Scientist: Rocks and Minerals' at the University of Nebraska State Museum in Lincoln. The Museum's monthly 'Sunday with a Scientist' outreach programs are designed to appeal to family audiences. Volunteers from the University and local groups present topics related to science and natural history in a fun and informal way through demonstrations, activities, or by conducting their science on site. Attending were 164 visitors including 70 children. I showed examples from my mineral collection to illustrate the great variety of color and crystal forms in minerals. In addition, visitors could handle 'touchable' minerals showing special properties, such as clear cleavage rhombs of Iceland spar displaying double refraction and ulexite, the so-called 'TV stone.' Children could also color pages printed with outline pictures of minerals, and they could take home sheets with special patterns to cut and fold into paper crystal models. Each visitor could also choose a rock or mineral trading card as a souvenir of the event.

2. Interviews with newspapers, radio and television

—I helped arrange for the article titled “UMaine grad credited with discovering new mineral” on the discovery of menzerite-(Y), which was published in the Bangor Daily News on January 24, 2011

—My interview for the Bangor Daily News concerning two minerals named for me, edgrewite and hydroxyledegrewite, resulted in an article and video titled “University of Maine research professor honored to have 2 minerals named after him” published on December 26, 2012.

—My interview for Maine Public Radio, also concerning two minerals named for me, edgrewite and hydroxyledegrewite, was aired December 27, 2012 with the title “UMaine Mineralogist Wins 'Rock Star' Honors”

—My interview with Fox22 ABC TV news in Bangor, Maine, also concerning two minerals named for me, edgrewite and hydroxyledegrewite was aired January 7, 2013 with the title “UMaine Professor has Two Minerals Named for him”

3. From time to time, I respond to inquiries from the public to identify rocks, minerals or features in samples people have collected.

What is the impact on physical resources that form infrastructure?

Nothing to report.

What is the impact on institutional resources that form infrastructure?

Nothing to report.

What is the impact on information resources that form infrastructure?

Nothing to report.

What is the impact on technology transfer?

Nothing to report.

What is the impact on society beyond science and technology?

Conservation of Localities for Rare Minerals in Antarctica

1. I was invited by the Australian Antarctic Division and Chris Carson of Geosciences Australia to give a talk 'Rare minerals in the Australian Antarctic Territory' at the Antarctic Science Planning Workshop in Hobart, Australia on September 21, 2010. The workshop was one of several organized by the Division to design implementation plans for the newly developed Australian Science Strategic Plan 2011/12-2020/12. The workshop held September 21 concerned 'Vulnerability and spatial protection,' under the theme 'Terrestrial and near-shore ecosystems: environmental change and conservation.' I was invited to report on their relevance to science, their vulnerability to damage by human activity, the need for conservation of bedrock exposures containing rare minerals within the Australian Antarctic Territory, which comprises two pie-shaped slices between 45o E and 160o E. I cited two coastal exposures as prime examples needing protection: Christmas and Zircon Points in Casey Bay in western Enderby Land (49o E), where beryllium minerals occur in anatectic pegmatites, and the Larsemann Hills, Prydz Bay (76o E), where borosilicates and phosphates are extensively developed in granulite-facies metamorphic rocks and anatectic pegmatites. The exposures in Casey Bay and Prydz Bay are type localities for five minerals, three of which are found only in these outcrops. The new minerals, such as the boron-rich phase boralsilite, plus associated rarities such as sillimanite and prismatic crystals several centimeters long and the beryllosilicate surinamite with its pleochroism in blue-green and purple colors, are not only of great scientific interest but also form beautiful mineral specimens that would be of particular appeal to collectors, which adds further urgency to the need for planning to preserve the localities in the field.

2. International discussions are now underway which might offer further protection to the Stomes Peninsula within the Larsemann Hills: the Peninsula has been proposed as an Antarctic Specially Protected Area. There is interest both in Australia and in other nations actively involved in Antarctica in conserving localities for rare minerals. As a result of the workshop in Hobart, Tasmania in September, 2010, staff scientists from Geoscience Australia and I hope that conservation efforts in Antarctica in the future will include not only biological systems, but also the remarkable and

beautiful rare minerals found on the continent. In collaboration with Chris Carson of Geoscience Australia, I wrote up the section 'Description of Values to be Protected' for the Management Plan for Antarctic Specially Protected Area on Stomes Peninsula, now in the final stages of drafting at the Australian Antarctic Division.

Changes/Problems

Changes in approach and reason for change

Nothing to report.

Actual or Anticipated problems or delays and actions or plans to resolve them

Nothing to report.

Changes that have a significant impact on expenditures

Nothing to report.

Significant changes in use or care of human subjects

Nothing to report.

Significant changes in use or care of vertebrate animals

Nothing to report.

Significant changes in use or care of biohazards

Nothing to report.