

KECK GEOLOGY CONSORTIUM

**PROCEEDINGS OF THE TWENTY-SECOND
ANNUAL KECK RESEARCH SYMPOSIUM
IN GEOLOGY**

April 2009
Franklin & Marshall College, Lancaster PA.

Dr. Andrew P. de Wet, Editor
Keck Geology Consortium Director
Franklin & Marshall College

Dr. Stan Mertzman
Symposium Convenor
Franklin & Marshall College

Kelly Erb
Keck Consortium Administrative Assistant

Diane Kadyk
Academic Department Coordinator
Department of Earth & Environment
Franklin & Marshall College

*Keck Geology Consortium
Franklin & Marshall College
PO Box 3003, Lancaster PA 17604-3003
717 291-4132 keckgeology.org*

ISSN # 1528-7491

The Consortium Colleges

National Science Foundation

**KECK GEOLOGY CONSORTIUM
PROCEEDINGS OF THE TWENTY-SECOND
ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY
ISSN# 1528-7491**

April 2009

Andrew P. de Wet
Editor & Keck Director
Franklin & Marshall College

Keck Geology Consortium
Franklin & Marshall College
PO Box 3003, Lanc. Pa, 17604

Stan Mertzman
Symposium Convenor
Franklin & Marshall C.

Keck Geology Consortium Member Institutions:

Amherst College, Beloit College, Carleton College, Colgate University, The College of Wooster, The Colorado College
Franklin & Marshall College, Macalester College, Mt Holyoke College, Oberlin College, Pomona College, Smith College, Trinity University
Union College, Washington & Lee University, Wesleyan University, Whitman College, Williams College

2008-2009 PROJECTS

**THE BLACK LAKE SHEAR ZONE: A POSSIBLE TERRANE BOUNDARY IN THE ADIRONDACK LOWLANDS
(GRENVILLE PROVINCE, NEW YORK)**

Faculty: *WILLIAM H. PECK*, *BRUCE W. SELLECK* and *MARTIN S. WONG*: Colgate University

Students: *JOE CATALANO*: Union College; *ISIS FUKAI*: Oberlin College; *STEVEN HOCHMAN*: Pomona College; *JOSHUA T. MAURER*: Mt Union College; *ROBERT NOWAK*: The College of Wooster; *SEAN REGAN*: St. Lawrence University; *ASHLEY RUSSELL*: University of North Dakota; *ANDREW G. STOCKER*: Claremont McKenna College; *CELINA N. WILL*: Mount Holyoke College

PALEOECOLOGY & PALEOENVIRONMENT OF EARLY TERTIARY ALASKAN FORESTS, MATANUSKA VALLEY, AL.

Faculty: *DAVID SUNDERLIN*: Lafayette College, *CHRISTOPHER J. WILLIAMS*: Franklin & Marshall College

Students: *GARRISON LOOPE*: Oberlin College; *DOUGLAS MERKERT*: Union College; *JOHN LINDEN NEFF*: Amherst College; *NANCY PARKER*: Lafayette College; *KYLE TROSTLE*: Franklin & Marshall College; *BEVERLY WALKER*: Colgate University

**SEAFLOOR VOLCANIC AND HYDROTHERMAL PROCESSES PRESERVED IN THE ABITIBI GREENSTONE BELT OF
ONTARIO AND QUEBEC, CANADA**

Faculty: *LISA A. GILBERT*, Williams College and Williams-Mystic and *NEIL R. BANERJEE*, U. of Western Ontario

Students: *LAUREN D. ANDERSON*: Lehigh University; *STEFANIE GUGOLZ*: Beloit College; *HENRY E. KERNAN*: Williams College; *ADRIENNE LOVE*: Trinity University; *KAREN TEKVERK*: Haverford College

INTERDISCIPLINARY STUDIES IN THE CRITICAL ZONE, BOULDER CREEK CATCHMENT, FRONT RANGE, CO

Faculty: *DAVID P. DETHIER*: Williams College and *MATTHIAS LEOPOLD*: Technical University of Munich

Students: *EVEY GANNAWAY*: The U. of the South; *KENNETH NELSON*: Macalester College; *MIGUEL RODRIGUEZ*: Colgate University

GEOARCHAEOLOGY OF THE PODERE FUNGHI, MUGELLO VALLEY ARCHAEOLOGICAL PROJECT, ITALY

Faculty: *ROB STERNBERG*: Franklin & Marshall College and *SARA BON-HARPER*: Monticello Department of Archaeology

Students: *EVERY R. COTA*: Minnesota State University Moorhead; *JANE DIDALEUSKY*: Smith College; *ROWAN HILL*: Colorado College; *ANNA PENDLEY*: Washington and Lee University; *MAIJA SIPOLA*: Carleton College; *STACEY SOSENKO*: Franklin and Marshall College

GEOLOGY OF THE HÖH SERH RANGE, MONGOLIAN ALTAI

Faculty: *NICHOLAS E. BADER* and *ROBERT J. CARSON*: Whitman College; *A. BAYASGALAN*: Mongolian University of Science and Technology; *KURT L. FRANKEL*: Georgia Institute of Technology; *KARL W. WEGMANN*: North Carolina State University

Students: *ELIZABETH BROWN*: Occidental College; *GIA MATZINGER*, *ANDREA SEYMOUR*, *RYAN J. LEARY*, *KELLY DUNDON* and *CHELSEA C. DURFEY*: Whitman College; *BRITTANY GAUDETTE*: Mount Holyoke College; *KATHRYN LADIG*: Gustavus Adolphus College; *GREG MORTKA*: Lehigh U.; *JODI SPRAJCAR*: The College of Wooster; *KRISTIN E. SWEENEY*: Carleton College.

**BLOCK ISLAND, RI: A MICROCOSM FOR THE STUDY OF ANTHROPOGENIC & NATURAL ENVIRONMENTAL
CHANGE**

Faculty: *JOHAN C. VAREKAMP*: Wesleyan University and *ELLEN THOMAS*: Yale University & Wesleyan University

Students: *ALANA BARTOLAI*: Macalester College; *EMMA KRAVET* and *CONOR VEENEMAN*: Wesleyan University; *RACHEL NEURATH*: Smith College; *JESSICA SCHEICK*: Bryn Mawr College; *DAVID JAKIM*: SUNY.

Funding Provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)

Keck Geology Consortium: Projects 2008-2009

Short Contributions – Adirondacks

THE BLACK LAKE SHEAR ZONE: A POSSIBLE TERRANE BOUNDARY IN THE ADIRONDACK LOWLANDS (GRENVILLE PROVINCE, NEW YORK)

Project Faculty: *WILLIAM H. PECK*; *BRUCE W. SELLECK*; *MARTIN S. WONG* - Colgate University

ANISOTROPY OF MAGNETIC SUSCEPTIBILITY AND TRACE ELEMENT GEOCHEMISTRY OF THE ROCKPORT GRANITE AND HYDE SCHOOL GNEISS

JOE CATALANO: Union College
Research Advisor: Kurt Hollocher

GARNET-FREE AMPHIBOLITES AS GEOTHERMOMETERS: TESTING HORNBLAND GEOTHERMOMETRY IN THE ADIRONDACK LOWLANDS, NEW YORK

ISIS FUKAI: Oberlin College
Research Advisor: F. Zeb Page

ASSESSMENT OF THE BLACK LAKE SHEAR ZONE AS A SITE OF ELZEVRIRIAN SUTURE, ADIRONDACK MOUNTAINS, NEW YORK

STEVEN HOCHMAN: Pomona College
Research Advisor: Harold Magistrale

A CALC-SILICATE UNIT OF THE ADIRONDACK LOWLANDS: ALEXANDRIA BAY, NEW YORK

JOSHUA T. MAURER: Mount Union College
Research Advisor: Mark McNaught

PROTOLITH DETERMINATION OF THE HYDE SCHOOL MARGINAL GNEISSES, ADIRONDACK LOWLANDS, NY

ROBERT NOWAK: The College of Wooster
Research Advisor: Meagen Pollock

Sm-Nd CONSTRAINTS ON THE ANTWERP-ROSSIE GRANITOIDS AND RELATED IMPLICATIONS, ADIRONDACK LOWLANDS, NORTHERN NEW YORK

SEAN REGAN: St. Lawrence University
Research Advisor: Jeffrey R. Chiarenzelli

METAMORPHISM IN THE FRONTENAC TERRANE AND ADIRONDACK LOWLANDS, GRENVILLE PROVINCE, CANADA AND THE UNITED STATES

ASHLEY RUSSELL: University of North Dakota
Research Advisor: Dexter Perkins

GEOCHEMISTRY OF THE EDWARDSVILLE SYENITE IN THE ADIRONDACK LOWLANDS, NEW YORK: IMPLICATIONS FOR TECTONOMAGMATIC PROCESSES IN THE SOUTHERN GRENVILLE PROVINCE

ANDREW G. STOCKER: Claremont McKenna College
Research Advisor: Jade Star Lackey, Pomona College

CALCITE-GRAPHITE ISOTOPE THERMOMETRY NEAR THE BLACK LAKE SHEAR ZONE, ADIRONDACK LOWLANDS, NY

CELINA N. WILL: Mount Holyoke College
Research Advisor: Steven R. Dunn

Funding provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)

Keck Geology Consortium
Franklin & Marshall College
PO Box 3003, Lancaster Pa, 17603
Keckgeology.org

PROTOLITH DETERMINATION OF THE HYDE SCHOOL MARGINAL GNEISSES, ADIRONDACK LOWLANDS, NY

ROBERT NOWAK: The College of Wooster

Research Advisor: Meagan Pollock

INTRODUCTION

Elemental and carbon isotope analysis was performed on the distinctive marginal garnet sillimanite gneisses (MGSG), which envelope the Hyde School Gneiss (HSG), located in the NW Adirondack Lowlands. The findings bolster the intrusive model for this Mesoproterozoic suite, opposed to a metavolcanic origin. The trends observed from major element variation diagrams coupled with rare earth element (REE) plots suggest the MGSG is genetically linked to the alkali-granitic lithology of the HSG through magmatic differentiation. The garnetiferous margins are LREE-enriched and some have negative europium anomalies. The MGSG do not show the HREE-enrichment, which is expected if there had been voluminous melt extraction from these garnet-rich rocks. Also, significant variability and low values of carbon isotope ratios obtained from the graphitic MGSG challenges the importance of marble assimilation during the formation of the margins. The enrichment of Fe and Al within the MGSG is most likely due to hydrothermal alteration. Determining the protolith of the Hyde School Marginal Gneisses aids in the reconstruction of the crustal conditions along the Black Lake Shear Zone (BLSZ), which is theorized to have played an important role in the assembly of the southwestern Grenville Province.

REGIONAL SETTING

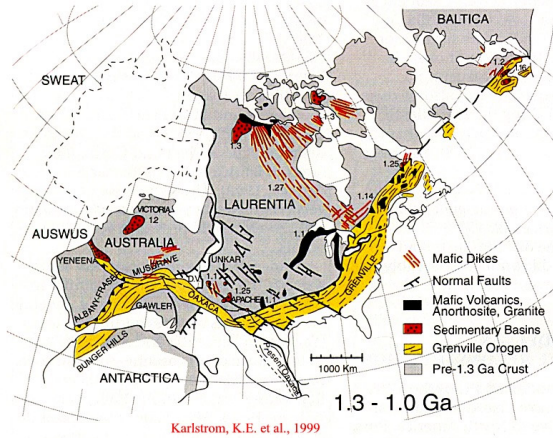
Recent advances in U-Pb absolute dating techniques of zircon has revealed the Hyde School Gneiss (HSG) and the Rockport Granite belong to the same 1172 Ma suite (Wasteneys et al., 1999). The HSG and Rockport Granite intruded during the Elzevirian Orogeny (ca 1300-1160 Ma) of the Grenville

Orogenic Cycle (Wasteneys et al., 1999; Figure 1A). The Elzevirian Orogeny is punctuated by calc-alkaline arc magmatism, the formation of an accretional terrane, and subsequent contact and regional metamorphic episodes (amphibolite facies) within the Central Metasedimentary Belt (Wasteneys et al., 1999). During the Elzevirian Orogeny, the Highland-Green Mt. block was accreted off the shore of the eastern margin of Laurentia around 1220 Ma (Wasteneys et al., 1999; Figure A). The Hyde School-Rockport granitic suites, which are located on either side of the Black Lake Shear Zone (BLSZ), was generated from the collision of the Adirondack Highland-Green Mt. Block with Laurentia (ca. 1172 Ma) (Figure 1A,B,C).

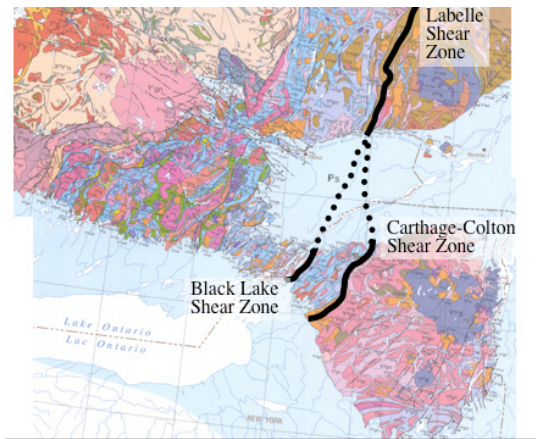
The second stage in the Grenville Orogenic Cycle is the Ottawan Orogeny, ca 1090-1035 Ma (McLelland et al., 2001). The Ottawan Orogeny was marked by a Himalayan-style collision between the eastern margin of Laurentia and the Amazonian Shield. The compression of the crust resulted in granulite facies regional metamorphism within the Adirondack Highlands (McLelland et al., 1996, 2001). However, the granulite facies metamorphic episode is not observed in the Adirondack Lowlands (McLelland et al., 1996). The juxtaposition of the amphibolite facies Lowlands and granulite facies Highlands along the Carthage Colton Mylonite Zone (CCMZ) led many workers to emphasize the role of this fault zone during the tectonic assembly of the Grenville Province (McLelland et al., 1996; Figure 1B).

Recently, the role of the CCMZ during the assembly of the Adirondacks has undergone a reevaluation. Some speculate the BLSZ is the critical shear zone in tectonic assembly and correlates with the Labelle Shear Zone in Quebec, opposed to the CCMZ (Fig

[A]



[B]



[C]

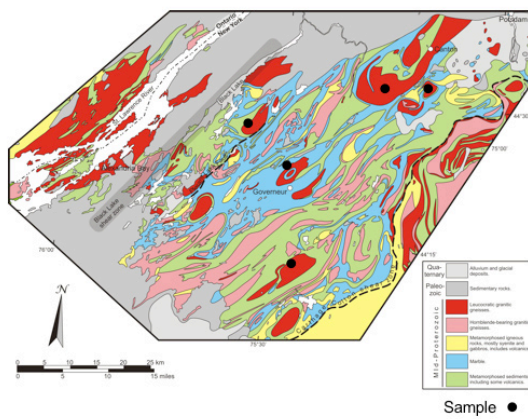


Figure 1A: Cartoon depicting the position of the Laurentia, Australia, Baltica, and Antarctica during the Grenville Orogeny ca. 1.3-1.0 Ga. The collisional belt generated during the Elzevirian and Ottawan Orogenies is shown in yellow (Karlstrom, et al., 1999, fig. 1). Figure 1B: Geological map depicting the Adirondacks, New York and the eastern region of Ontario, Canada. Past workers in the region have linked the Carthage-Colton Shear Zone to the Labelle Shear Zone. However, the Black Lake Shear Zone maybe the critical zone of shearing and connect to the Labelle Shear Zone. The Black Lake Shear zone may also represent the Elzevirian suture zone (Davidson, 1998). Figure 1C: Geological map of the Adirondack Lowlands displaying the MGSG sample sites, map compiled by Joe Catalano and Kurt Hollocher (2009).

ure 1B). Another hypothesis states that the BLSZ may be the suture zone between the Highland-Green Mt. block and the eastern margin of Laurentia, which is suggested by the presence of calc-alkaline tonalitic and granitic suites, one of which is the HSG (McLelland et al., 1996).

The position of the Rockport Granite on the northwest side of the BLSZ and the HSG to the southeast creates an excellent case study for gaining a greater understanding of the crustal conditions along the BLSZ. Examining the origins of the marginal garnet-sillimanite gneisses (MGSG) gives this study a new perspective on the magmatic and metamorphic history of the HSG suite and the surrounding Adirondack Lowlands. The nature of the MGSG is almost a century old debate (Buddington, 1939) that deserves to be reexamined through the lens of new tectonic models and geochemical analyses.

HSG & MGSG formation models

Four main theories have been proposed to explain the origins of the HSG and MGSG. Buddington (1939) was the first to propose a model for the formation of the HSG domes and enveloping garnetiferous units. During his mapping of the northern and northwest Adirondacks, Buddington examined and categorized the fourteen domical bodies of the HSG as belonging to one distinct suite. He theorized that the HSG domes were the product of magma upwelling into the crests of evolving anticlinal folds, a feature termed “phacoliths” by Harker (1909).

Buddington (1939, 1963) postulates the MGSG formed during the late stages of HSG magmatism (Buddington, 1939). He theorizes the MGSG is the product of hydrothermal alteration and replacement of overlying pelitic aluminous country rock. The original protolith of the amphibolite and subsequent MGSG was theorized to be limestone (Buddington, 1939). Buddington (1939) interprets the presence of amphibolite layers included within the HSG as evidence of country rock contamination during emplacement.

McLelland et al. (1992) supports Buddington's (1939) intrusive HSG model. McLelland et al. (1992) cites field relations, mineral assemblages, and high paleotemperatures that exceed the regional temperatures as evidence for an intrusive origin of the HSG. However McLelland et al. (1992) diverges from Buddington's (1939) model by stating that the MGSG is the restite left after the anatexis of pelitic country rock.

Carl and Van Diver (1975) theorize the HSG represents a horizon of preserved metavolcanic sediments. The authors adhere to the assumption that a Grenville stratigraphic sequence remains preserved in the Adirondack Lowlands and elsewhere in the Grenville Province (Carl and Van Diver, 1975). The alkali feldspar lithology seen in the Hyde School and Reservoir bodies formed from the recrystallization of rhyolitic ash or lava flows (Carl and Van Diver, 1975). Then, magmatic differentiation following the volcanic activity resulted in the eruption of the MGSG from the same magmatic source.

According to Carl and Van Diver (1975) the plagioclase rich MGSG rocks are the result of contamination of the alkaskite magma with the surrounding marble or amphibolite country rocks. The thin continuous "beds" of amphibolite are also observed within the MGSG, again suggesting the preservation of a stratigraphic sequence.

Hudson et al. (1998) has undertaken the most recent research regarding the HSG and MGSG. Hudson (1994) and Hudson et al. (1998) concurs with Bud-

dington's (1939) original hypothesis, but diverges from his classification of the MGSG as a paragneiss originating from pelitic sediments. Hudson et al. (1998) proposes the trends observed in variation diagrams are suggestive of magmatic differentiation between the two bodies. The presence of an abundant accessory phase of graphite is explained as the result of assimilation of the MGSG with the adjacent carbonate country rock (Hudson, 1994; Hudson et al., 1998).

METHODS

The fourteen domical bodies that comprise the HSG are well exposed and documented throughout the region (Figure 1C). However, the MGSG outcrops sporadically throughout the Lowlands. We examined where previous workers, such as Hudson (1994), recorded MGSG outcrops to find samples for comparative analysis and aid in the discovery of undocumented marginal bodies. Once an outcrop that fit the mineralogy of the MGSG was discovered a record of the mineral assemblage, GPS or UTM coordinates, and the trend /plunge of the foliation (if it was well defined and the sample was in situ) would be taken.

Three to four hand sample sized specimens were collected from each outcrop. The samples were processed in the Colgate University sample preparatory laboratory. Using an anvil and rock hammer, each sample was broken into two aliquots. One aliquot would be used for a representative hand sample and thin-section billet. The other aliquot was pulverized for geochemical analysis.

Selected samples were pulverized in order to perform loss on ignition (LOI), X-ray Fluorescence Spectroscopy (XRF), and Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Pressed powder disks were analyzed using a Philips PW2404 X-ray fluorescence spectrometer at Colgate University. Samples with trace elemental concentrations of particular interest were prepared and sent to ACME labs for 4-acid Ultraclean ICP-MS. The carbon isotopic analysis of the graphite separates were analyzed using a Costech ECS 4010 elemental analyzer (EA)

online with the Delta Plus Advantage mass spectrometer at Colgate University in the continuous flow mode.

RESULTS & DISCUSSION

Petrography

The almadine - grossular garnets range from 1-35 mm in cross sectional length and 1- 30mm in cross-sectional width. Most of the garnet porphyroblasts are euhedral, however xenoblastic crystals were observed in highly deformed samples. The garnet poikiloblasts display plagioclase, clinopyroxene, orthopyroxene, biotite, quartz, and graphite inclusions (Figure 2A and B). The inclusions are either represented throughout the garnet porphyroblast, or isolated within the core of the crystal (Figure 2A). Examining the inclusion trails within the garnet porphyroblasts reveals pre and synkinematic growth of garnet, relative to the formation of gneissosity (Figure 2B).

Sillimanite appears in two distinct forms: bladed (Figure 2C) and fibrolitic. The bladed forms range between .5 - 5 mm in length (Figure 2C) and occur around the garnet porphyroblasts. Fibrolite constitutes the majority of the matrix (less than 1 mm in length) within the MGSG.

Quartz is prevalent in both the MGSG and MGCG lithologies. Inclusions of quartz within the garnet porphyroblasts are rounded and usually less than 1mm. Highly deformed samples display ribbon quartz, which are between 1 and 3 mm in length. The majority of quartz is classified as granoblastic, and is porphyroblastic with respect to the matrix. Biotite is porphyroblastic, ranging from 3 to 30 mm in length. The pleochroism can vary from dark green to dark reddish brown. The dark reddish brown interference colors are suggestive of Fe and Ti enrichment (Figure 2D).

The presence of granophyric texture suggests the replacement of potassium feldspar to quartz and sodic plagioclase intergrowths, known as myrmekite (Figure 2E). The majority of porphyroblastic plagioclase

feldspar within the MGSG and surrounding feldspar rich country rocks is classified as oligoclase (An_{16-30}) (Figure 2F). Orthoclase is also observed in the MGSG samples (Figure 2F).

Orthopyroxene constitutes the most prevalent pyroxene in the MGSG. The orthopyroxene usually appears xenomorphic and ranges from 1- 25mm in length and 1 to 5 mm in cross sectional width. Clinopyroxene is present within the MGSG as rounded inclusions with the garnet porphyroblasts. Clinopyroxene is also observed within a marble samples collected adjacent to the MGSG.

A small percentage of porphyroblastic microcline

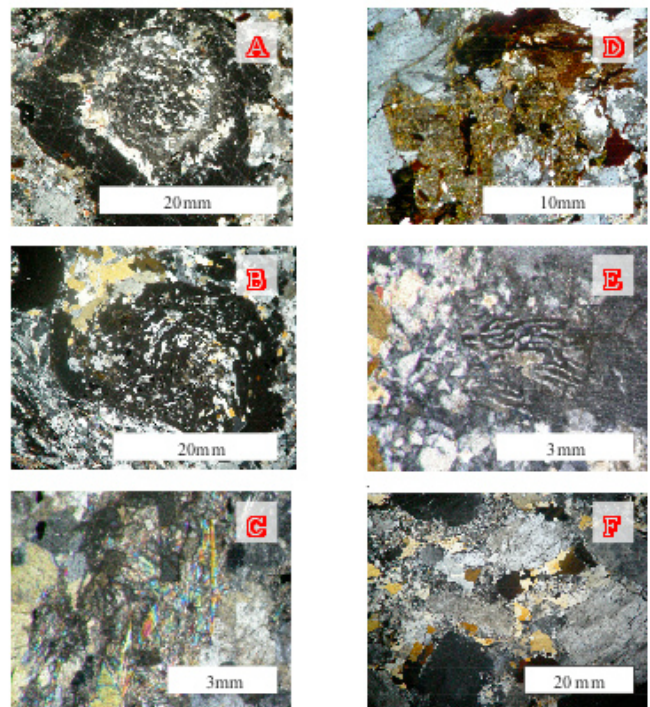


Figure 2A: Photomicrograph of a garnet porphyroblast from the MGSG. The core of the crystal is marked by the presence of inclusions, while the outer zone is devoid of inclusions. Figure 2B: Garnet porphyroblast containing inclusion trails which indicate synkinematic formation of the crystal. Figure 2C: Photomicrograph displaying the less common bladed form of sillimanite. Figure 2D: Collection of biotite grains with a distinctive dark reddish brown pleochroism. Figure 2E: Photomicrograph of myrmekite, which is found along the boundaries of some quartz and plagioclase grains. Figure 2F: Photomicrograph of oligoclase, which comprises the most common feldspar within the sample population. All images are seen under crossed polarized light and given a scale bar in millimeters.

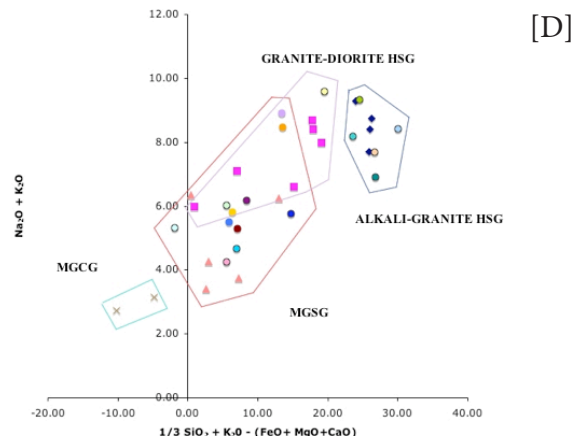
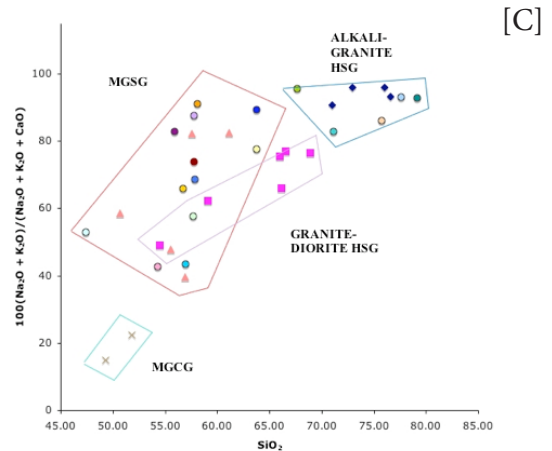
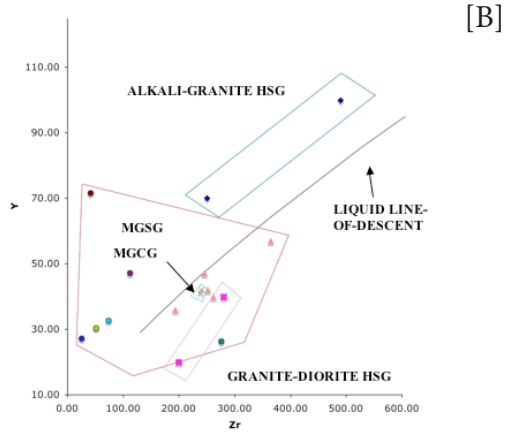
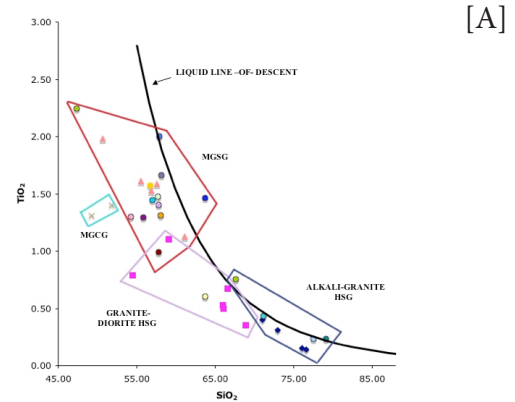
was observed within the MGSG samples. The porphyroblastic microcline is xenomorphic and ranges between 1-5mm in length. The majority of potassium feldspar occurs within the matrix and is less than 1mm in length. The distinctive tartan twinning is not observable in the potassium feldspar crystals that comprise the matrix.

Graphite inclusions were observed within the porphyroblastic garnet. The concentric zoning of the graphite inclusions within the interior of the garnet crystals was not observed but has been previously documented by Hudson (1994).

Geochemistry

The MGSG and marginal garnet-calcsilicate gneisses (MGCG) have low SiO_2 contents compared to other phases of the HSG. However, the MGSG is highly enriched in TiO_2 , Al_2O_3 , FeO , MgO , MnO , and P_2O_5 (Figure 3A). Therefore, a combination of low

Figure 3A: Harker diagram of TiO_2 vs. SiO_2 . The dark blue diamond along with the green, pale blue, light blue, and dark blue green circles = alkali-granite HSG from McLelland et al. (1992), bright pink squares and yellow circle = the granite-diorite HSG from McLelland et al. (1992), orange triangles = MGSG from Hudson (1994), light blue x's = MGCG (marginal garnet calcsilicate gneisses) from Hudson (1994), and the other multicolored circles represent the MGSG samples collected in this study. Each lithological field is labeled along with the liquid line-of-descent. Figure 3B: Conserved trace elemental concentrations of Y and Zr plotted against each other reveals a roughly linear correlation between lithological groups along with the close agreement with the modeled pathway of the liquid line-of-descent. These relationships suggest a genetic link exists between the granitic HSG and marginal units and supports the crystal fractionation differentiation hypothesis. Figure 3C: Applying the felsic differentiation index, $100(\text{Na}_2\text{O} + \text{K}_2\text{O}) / (\text{Na}_2\text{O} + \text{K}_2\text{O} + \text{CaO})$ vs. SiO_2 , demonstrates the granitic and marginal lithologies of the HSG suite fall along the same evolutionary pathway. Figure 3D: The Larsen Index ($= 1/3 \text{SiO}_2 + \text{K}_2\text{O} - (\text{FeO} + \text{MgO} + \text{CaO})$) plotted against the alkalis is a means to determine the alkali content within each suite during the comparable stages of evolution. The Larsen Index demonstrates that the alkali-granite HSG samples are the most enriched in alkali content, followed by the granite-diorite HSG and MGSG samples. The MGCG samples are relatively depleted in terms of alkali concentrations.



silica content and high major oxides places the MGSG at the mafic end of the negative sloping curved trend appears to unite all of the HSG lithological groups together. At the felsic end of the trend is the alkali-granite HSG field. The alkali-granite HSG poses the highest SiO₂ content, and are greatly depleted in major elements, with the exception of K₂O and Na₂O. However, some samples of the MGSG and granite-diorite HSG display K₂O concentrations greater than the alkali-granite HSG sample population. Overall, the HSG granite-diorite samples consistently plot between the MGSG and the alkali-granite fields. However, the granite-diorite HSG bodies display anomalously high concentrations of Na₂O.

The curved trends observed in the Harker (Figure 3A), conserved trace elements (Figure 3B), felsic (Figure 3C), and Larson (Figure 3D) diagrams demonstrate a genetic link between the alkali-granite and granite-diorite lithologies of the HSG and the MGSG and MGCG. Variation diagrams displaying the liquid line- of-descent reveal that the HSG and the MGSG data populations roughly fall along the modeled pathway for Rayleigh crystal fractionation.

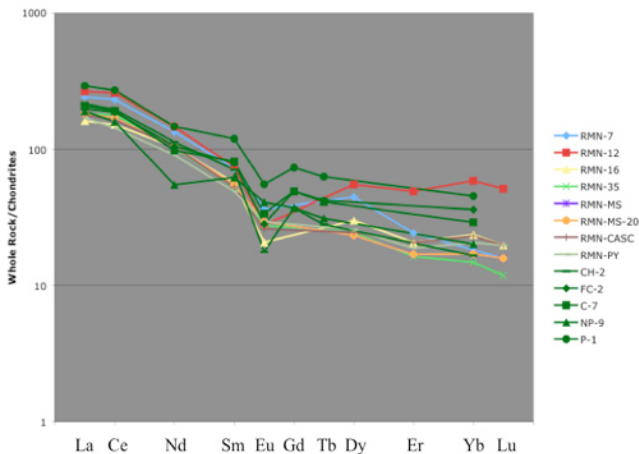


Figure 4: Rare earth element diagrams displaying the LREE enrichment and HREE depletion of the alkali-granite HSG (in green) from Lepak (1983) and yellow (this study) and MGSG (multicolored). The Eu anomaly indicates magmatic origins for both bodies. The close agreement between plots is indicative of a genetic linkage.

Crystal fractionation of the dacitic parental magma resulted in the formation of the marginal units, followed by the petrogenesis of the more evolved granitic lithologies of the HSG.

The strong correlation between the REE concentrations of the MGSG units and the alkali-granite bodies of the HSG bolsters the genetic linkage hypothesis (Figure 4). Both lithologies display enrichment in LREE (Light Rare Earth Element) and HREE (Heavy Rare Earth Element) depletion. The depleted HREE concentrations within the MGSG indicate magmatic garnet was not part of the fractionating assemblage. Therefore, the garnet within the MGSG is metamorphic in origin.

Overall, the carbon isotopic signatures obtained from graphite separates of the marginal bodies reveals lower values when compared with the signatures obtained from adjacent marble packages and the average value for a widespread collection of Lowland marbles (Kitchen and Valley, 1995; Table 1). A t-test confirms the differences between the marble and MGSG data sets. However, considerable variability exists within the sample set reflecting a degree of interaction with the surrounding country

Sample	Average d13C (PDB)	±1 sd	n
Standard			
USGS24	-16.0	0.2	3
Marbles			
RMN-18	1.1	0.0	2
RMN-17	-3.3	0.2	3
MGSG bodies			
RMN-7	-10.6	0.1	2
RMN-ms.csx.casc	-7.4	0.2	3
RMN-casc.rt812	-7.6	0.7	2
RMN-py	-17.4	0.2	1
RMN-12	-3.9	0.2	1
RMN-8	-4.7	0.2	1

Table 1: Average carbon isotopic ($\delta^{13}C$) values of graphite separates obtained from the MGSG units and adjacent marble packages. Each value is calibrated against PDB (Pee Dee Belenmite) and reported as parts per mil ($\delta^{13}C$). One standard deviation is also given from the accepted value (USGS24).

rock. For example, the MGSG enveloping the Gouverneur body possess carbon isotopic signatures that are similar to the values obtained from the adjacent marble graphite whereas the other samples are close to pelite values (Weis et al., 1981). However, the widespread role of carbonate country rock assimilation (Hudson, 1994, and Hudson et al., 1998) during the formation of the MGSG is called into question. Instead, the average MGSG values appear to be consistent with the average $\delta^{13}\text{C}$ obtained from continental lithosphere ($-6 \delta^{13}\text{C}$) or the mantle ($-5 \delta^{13}\text{C}$) (Sharp, 2007). Therefore, the carbon isotopic signatures provide supporting evidence for the magmatic petrogenesis of the MGSG and subsequent HSG from a mantle derived melt.

Many lines of evidence have been employed to demonstrate that the MGSG and HSG are related magmatic bodies. The presence of intrusion breccias and the incorporation of massive amphibolite lens within the HSG foliation (McLelland et al., 1992) bolsters the intrusive origins. Also a lack of textural evidence for the preservation and recrystallization of aphanitic crystals hinders the metavolcanic model. For example, Carl and Van Diver's (1975) assertion that unzoned plagioclase crystals provides evidence for the recrystallization of ash flow tuff can be explained through the processes of high-grade metamorphism. Mineral assemblages formed during peak metamorphic conditions are often unzoned and found in association with reaction rims and granoblastic polygonal shaped grains, which is observed in the HSG suite thin-sections (Figure 2).

Lastly, the anomalously high concentrations of Al and Fe within the MGSG relative to the alkali-granite and granite-diorite may be linked to hydrothermal alteration. Attrition of the major soluble elements within the MGSG with respect to the average alkali-granite HSG composition is observed ($\sim 20\%$ less SiO_2 , $\sim 40\%$ less Na_2O , and $\sim 20\%$ less K_2O). Therefore, it appears K and Na was leached from the MGSG during hydrothermal alteration, raising Fe and Al percent abundances within the margins.

CONCLUSIONS

The goal of this study was to determine the protolith of the distinctive garnet rich rocks that envelope the HSG located in the Adirondack Lowlands, New York. Elemental and carbon isotopic analysis coupled with a petrographic examination of the MGSG and HSG was performed in order to answer this question. This study provides compelling geochemical and petrographic evidence for the intrusive igneous origins of the HSG and MGSG. The REE diagrams confirm the magmatic origins of the HSG and MGSG. A genetic linkage between the MGSG and the granitic lithologies of the HSG was also observed on Harker, differentiation indices, and REE diagrams. Rayleigh modeling suggests crystal fractionation appears to be the primary mode of magmatic differentiation. Carbon isotopic signatures obtained from the graphitic MGSG show considerable variability but ultimately provide supporting evidence for the magmatic petrogenesis of the margins. Lastly, the intrusive igneous origins of the MGSG and HSG demonstrate extensive magmatism occurred along the BLSZ ca. 1172 Ma, which provides supporting evidence for the importance of this shear zone in the assembly of the Southwestern Grenville Province.

REFERENCES

- Buddington, A. F., 1939, Adirondack igneous rocks and their metamorphism: Washington, D.C., Judd & Detweiler, Inc.
- , 1963, Metasomatic origin of large parts of the Adirondack phacoliths: A discussion: Geological Society of America Bulletin, v. 74, p. 353-354.
- Carl, J. D., and Van Diver, B. B., 1975, Precambrian Grenville alaskite bodies as ash-flow tuffs, northwest Adirondacks, New York: Geological Society of America Bulletin, v. 86, p. 1691-1707.
- Davidson, A., 1998, Geological map of the Grenville Province, Canada and adjacent parts of the

- United States of America Geological Survey of Canada, "A" Series Map no. 1947A, 2 sheets.
- Harker, A., 1909, *The natural history of igneous rocks*: New York: Macmillan, 384 p.
- Hudson, R.M., 1994, *P-T-X-t constraints on ductile deformation zones within the Adirondack Lowlands*: Oxford, Ohio, Miami University.
- Hudson, R.M., and Dahl, P. S., 1998, *The origin of garnetiferous mylonitic gneisses in chill margins of the Hyde School Gneiss, NW Adirondacks, NY*, Geological Society of America: Boulder, CO.
- Karlstrom, K. E., Harlan, S. S., Williams, M. L., McLelland, J., Geissman, J. W., and Ahall, K. I., 1999, *Refining Rodinia: geologic evidence for the Australia-western U.S. connection in the Proterozoic*: Geological Society of America Today, v. 9, p. 1-7.
- Kitchen, N. E., Valley, J. W., 1995, *Carbon isotope thermometry in marbles of the Adirondack Mountains, New York*: Metamorphic Geology, v. 13, p. 577-594.
- Lepak, R. J., 1983, *Rb-Sr geochronology and rare-earth element geochemistry of Proterozoic leucogneisses from the Northwest Adirondacks*: Oxford, Ohio, Miami University.
- McLelland, J., Chiarenzelli, J., and Perham, A., 1992, *Age, field, and petrological relationships of the Hyde School Gneiss, Adirondack Lowlands, New York: Criteria for an intrusive igneous origin*: Journal of Geology, v. 100, p. 69-90.
- McLelland, J., Daly, J. S., and McLelland, J. M., 1996, *The Grenville Orogenic Cycle (ca. 1350-1000Ma): an Adirondack perspective*: Tectonophysics, v. 265, p. 1-28.
- McLelland, J., Hamilton, M., Selleck, B., McLelland, J., Walker, D., Orrell, S., 2001, *Zircon U-Pb geochronology of the Ottawa Orogeny, Adirondack Highlands, New York: regional and tectonic implications*: Precambrian Research, v. 109, p. 39-72.
- Sharp, Z., 2007, *Principles of stable isotope geochemistry*: Upper Saddle River, New Jersey, Prentice Hall, 344 p.
- Wasteneys, H., Lumbers, S., McLelland, J., 1999, *Precise zircon geochronology in the Adirondack Lowlands and implications for revising plate-tectonic models of the Central Metasedimentary Belt and Adirondack Mountains, Grenville Province, Ontario and New York*: Canadian Journal of Earth Sciences, v. 36, p. 967-984.
- Weis, P. L., Friedman, I., and Gleason, J. P., 1981, *The origin of epigenetic graphite: evidence from isotopes*: Geochimica et Cosmochimica Acta, v. 45, p. 2325- 2332.