KECK GEOLOGY CONSORTIUM

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

April 2009
Franklin & Marshall College, Lancaster PA.

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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

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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; *LISA SMITH:* Amherst College; *KAREN TEKVERK*: Haverford College

INTERDISCIPLINARY STUDIES IN THE CRITICAL ZONE, BOULDER CREEK CATCHMENT, FRONT RANGE, CO
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Students: *AVERY 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

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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
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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
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Keck Geology Consortium: Projects 2008-2009
Short Contributions – Adirondacks

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

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Research Advisor: Jeffrey R. Chiarenzelli

INTRODUCTION

Understanding the tectonic history of the Grenville Orogenic Cycle, including the Elzeverian, Shawinigan, and Ottawan Orogenies, is an important step in understanding the assembly of North American Craton and the supercontinent Rodinia. In addition, it provides a rare glimpse into the deep crustal architecture of a billion year old mountain belt and an opportunity to explore possible temporal differences of both younger and older orogenic belts. However, because of the strong deformation, high-grade of metamorphism, and complex sequence of events associated with the Grenville Orogen, many important questions remain even after years of field and laboratory work.

The Adirondack Lowlands are an ideal place to study the Grenville Orogen. The Lowlands are part of the Central Metasedimentary Belt and are underlain by a widely recognized supracrustal sequence that includes the Lower Marble, Popple Hill Gneiss, and the Upper Marble (Carl et al., 1990). Analysis of drill core related to zinc exploration in Balmat, New York has, at least locally, allowed the recognition of sixteen different lithologic units in the Upper Marble, including substantial thicknesses of shallow water carbonates and evaporites. In contrast, the nearby Adirondack Highlands consist mostly of granulite facies orthogneisses and highly dismembered and intruded supracrustal belts (Mclelland et al., 1996). The supracrustal sequence in the Lowlands is intruded by a variety of metamorphosed igneous rocks whose age, composition, and origin provide important constrains on the assembly of Adirondack segment of the Grenville Orogeny before, during, and after the Shawinigan Orogen (1.16-1.21 Ma; Carl and deLorraine, 1997; Wasteneys et al., 1999).

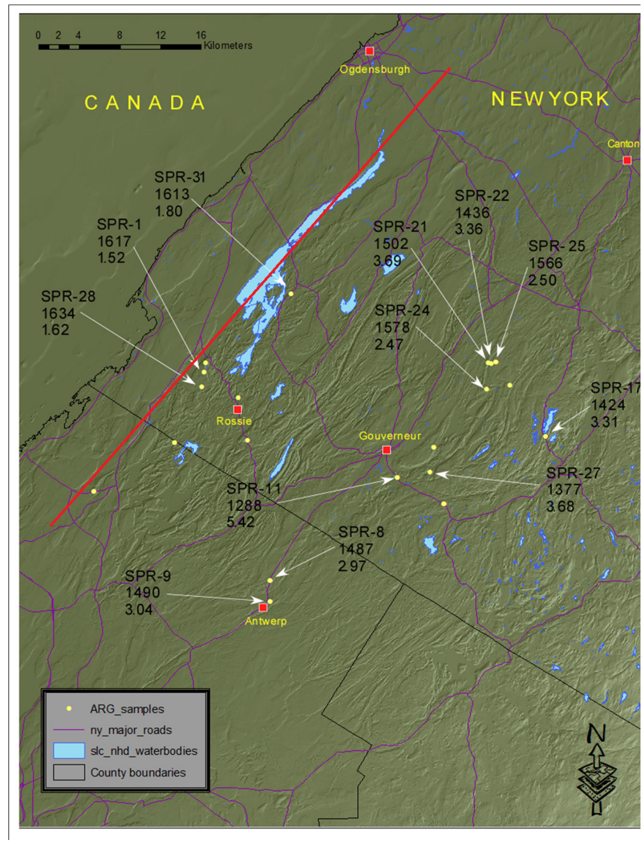

Figure 1: Map of the sample area. Dots are sample locations. Chosen samples for Nd are labeled on the map with corresponding ENd(1200) and TDM. Notice how the ARG abruptly ends at the BLSZ (red line).

The Antwerp-Rossie Granitoids (ARG) make up a meta-igneous suite which occurs between the Carthage-Colton Mylonite Zone (CCMZ) and Black Lake Shear Zone (BLSZ) within the Adirondack Lowlands (Fig. 1) insert figure 1. Plutons of the ARG suite extensively intrude the metamorphosed basal supracrustal rocks, mainly the Lower Marble and pelitic rocks of the Popple Hill Gneiss. The CCMZ has been interpreted as a normal fault formed during the collapse of the orogen (ca. 1050

Ma; Selleck et al., 2005), which juxtaposed the lesser metamorphosed Adirondack Lowlands (mid-upper amphibolite facies) against the granulite facies terrain of the Adirondack Highlands. The BLSZ runs NE –SW just south of the St. Lawrence River. A zircon age of 1207 (+26/-17) Ma indicates that the ARG is the oldest metaigneous rock in the Lowlands (Wasteneys et al.,1999). Other metaigneous units such as the Rockport granite and Hyde School gneiss (HSG) yield U-Pb zircon ages of ca. 1172 (+/-5) Ma (Wasteneys et al., 1999), and occur on either side of the BLSZ. Based on these data the area had to be one contiguous unit by that time, but not necessarily at 1208 Ma.

Carl and deLorraine (1997) made a systematic study of meta-igneous bodies in the Adirondack Lowlands. This involved a large database of geochemical data, both major and several trace elements, and petrographic and field observations. These data provided the basis for grouping suites of rocks while outlining their main differences. They identified the ARG as "massive, homogenous, greenish to gray, medium grained, equigranular, plagioclase- and biotite-rich granites of relatively small size (Carl and deLorraine, 1997)." The Antwerp, Rossie, and Fowler granites all intrude the Lower Marble, other highly deformed marbles of unknown stratigraphic position, and the Popple Hill gneiss, a paragneiss which sits between the lower and upper marbles (Carl and deLorraine, 1997). Drill cores completed by the Zinc Corporation of America (now St. Lawrence Zinc) intersect the Fowler granite (a member of the ARG) and suggest that the Hermon granite and ARG share a similar affinity and may be different textural variants of the same suite (Carl and deLorraine, 1997).

In conjunction with field studies, petrographic, geochemical, and Neodymium (Nd) isotopic data were collected to further constraint the origin of the ARG. The Adirondack segment of the Grenville Orogeny was constructed from ca. 1300 Ma to 1050 Ma during three orogenic events which ended at 1050 with the construction of Rodinia when Amazonia collided with the ancestral North American craton Laurentia (McLelland et al., 1996). The construction of the continental margin occurred during the previous two orogens: the Elzeverian (~1250 Ma) and Shawinigan (1150 Ma; Heumann et al., 2006). The effects of the terminal Ottawan Orogen are not widely recognized in the Lowlands so that the events of the Shawinigan Orogen are not overprinted, as they are in the Highlands. Unraveling the early history of these rocks is very complicated and is a daunting task, but identifying individual magmatic events is an excellent approach to further constrain the tectonic history of the area.

METHODS

Samples were collected along the ARG's exposure during two weeks of field investigation during August of 2008. During the following two weeks, samples were prepared in the Department of Geology at Colgate University. A subset of the rock collected during field activities were selected for preparation of fifteen petrographic thin sections and powders for major and trace element chemistry. Major element chemistry was measured at Colgate University on glass discs using a Philips PW2404 X-RAY Fluorescence Spectrometer by Rebecca Tortorello, assisted by Diane Keller and William Peck. Trace elements were done at ACME Analytical Laboratories in Vancouver using ICP-MS.

At Carleton University in Ottawa, under the guidance of Dr. Brian Cousens, twelve samples were dissolved and Sm and Nd were separated by ion chromatography. Solutions were subsequently dried and loaded on a rhenium filament. Samarium and Neodymium isotopes were measured by TIMS (thermal ionization mass spectrometery). Whole rock powders were spiked with a ^{148}Nd-^{149}Sm mixture preceding dissolution. Eighty-three analyses of the La Jolla standard averaged ^{143}Nd/^{144}Nd ratio's at .511876 +/- 18. ENd values were calculated relative to a modern Chondrite Uniform Resevoir (CHUR) value of .513151 and ^{147}Sm/^{144}Nd = .19767. +/- 0.8 epsilon units of precision based on multiple runs of a geochemical standard and other rock samples (Cousens et al., 2004).

FIELD OBSERVATIONS

The ARG intrudes the basal metasedimentary unit (Lower Marble) in the Lowlands but only occurs to the SE of the BLSZ. In general, members of the ARG are medium-grained, variably deformed, equigranular rocks. Grain sizes range from 0.125 – 2 mm. The ARG discordantly intrudes the suprascrustal sequence, independent of foliation planes. One outcrop in particular, "steer's head" (SPR-11), appears to impart an interesting fabric on the marble it intrudes; the marble seems to have been syn-kinematically deformed during intrusion of the ARG. Deformation of the ARG suite is not strong even after amphibolite facies metamorphism (Mclelland et al., 1996), probably due to the surrounding rheologically weak marble taking up most of the strain.

Figure 2: Photograph of the ARG intruding marble just outside of Antwerp on Rt. 11. Notice the large foliated quartzite xenoliths, showing that deformation of metasediments occurred prior to intrusion.

There is some weak foliation which can be readily identified in thin section, but is difficult to identify in the field. Xenoliths of marble and quartzite can be seen in multiple locations (Fig 2). The ARG can be seen in the field intruding the lower marble, pelitic gneisses, and amphibolites in numerous locations throughout its exposure. No folding can be seen, at least not on outcrop scale.

PETROGRAPHIC AND GEOCHEMICAL OBSERVATIONS

Petrographic analysis was done at St. Lawrence University. The ARG show many textures and mineral compositions indicative of metamorphosed igneous rocks such as equigranular grain distribution and zoned plagioclase. Other features include: relict pyroxenes in a few of the samples, perthite, myrmekite, and quartz with undulatory extinction. Relict pyroxenes are largely replaced by secondary minerals. Trace minerals are consistent throughout the suite and include zircon (some with pronounced zoning), apatite, and monazite. Foliation can be identified in some samples. Recrystallization can be seen at grain boundaries and there is secondary alteration by epidote and amphibole. Alteration can be seen well in pyroxenes which began to react during upper amphibolite metamorphism.

The ARG are peraluminous to metaluminous and show strong linear trends on Harker diagrams, especially when supplemented using the data of Carl and deLorraine (1997). They range from 51.70 to 78.84% SiO_2. AFM diagrams plot alkalis, Fe, and Mg on a ternary plot and can distinctly show whether olivine or clinopyroxene is controlling crystallization. Clinopyroxene crystallization is very pronounced in arc related magmas. On AFM diagrams the ARG show a very pronounced calc alkaline trend (Fig. 3).

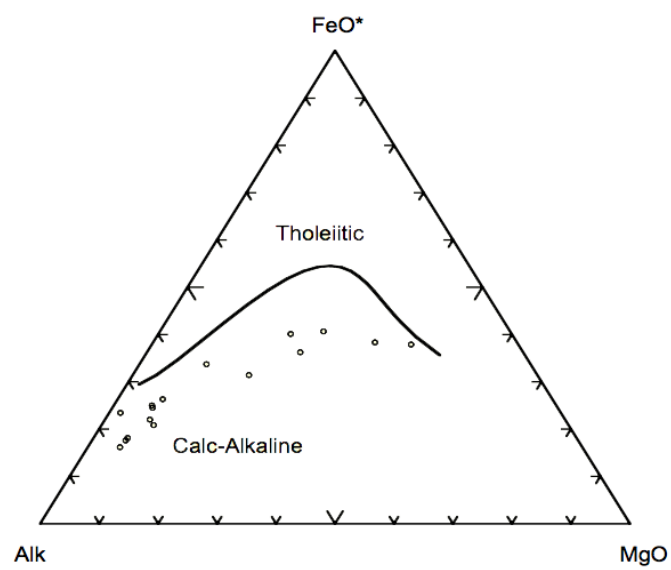

Figure 3: AFM diagram of the 15 samples analyzed. Notice the very pronounced calc alkaline trend.

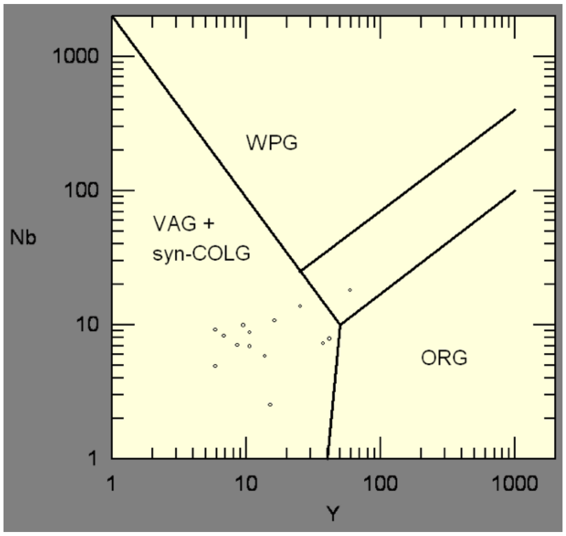

Figure 4: Tectonic discrimination diagram showing Y vs Nb (Pearce et al., 1984). ARG samples plot in the Volcanic Arc Granite (VAG) field.

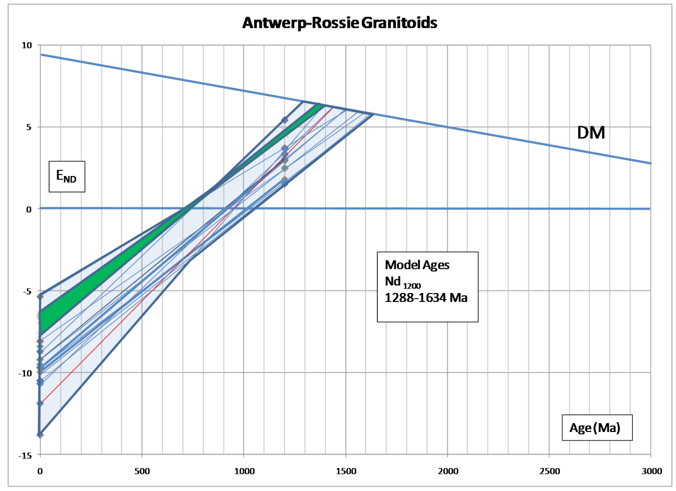

Figure 5: ENd versus age, showing ENd(0) projected to the depleted mantle where it passes through ENd(1200Ma) The dark green field shows gabbros analyzed by Cofflin (2008) which may be mafic equivalents to the ARG. The red line is a sample of the Hermon gneiss. The 300 my between separation and crystallization ages suggests that the ARG is derived from a non-juvenile source, or melted from an enriched source.

On tectonic discrimination diagrams the ARG suite plots within the volcanic arc granite field (VAG; fig. 4) and forms a distinct cluster in comparison with other meta-igneous bodies of the lowlands (Carl and deLorraine, 1997; Pearce et al., 1984) insert figure 4. High field strength elements (HFSE) show negative anomalies in Nb, Ta, Pb, P, and Zr and positive anomalies with Cs, Pb, La, and Nd when plotted relative to primitive mantle.

SM-ND ISOTOPIC ANALYSIS

Neodymium systematics provide a vast amount of information on the source of rocks and can tell a great deal about the tectonic environment of emplacement. Model ages, or mantle separation ages (TDM), are used to determine when a rock was separated from a mantle reservoir. Depleted mantle model ages are typically used, however other reservoirs can also used when depleted mantle is not a realistic assumption. The difference between the mantle separation age and the crystallization age provides a determination of whether a rock is a direct melt of the mantle (juvenile) or had an extended crustal history. Epsilon Nd (ENd(t) where t = Mybp) values provide an estimate of the Sm/Nd ratio of the source of the igneous rock. These are usually calculated against CHUR at the time of crystallization (Dickin, 2005).

The time of separation from a hypothetical depleted mantle source (TDM) from the ARG suite, and one Hermon Gniess sample (1182 Ma; Heumann et al., 2006), range from 1288 to 1634 Ma (average 1504 Ma). In Figure 5, the blue shaded area is the ARG samples insert figure 5. The red line is a sample of the Hermon gneiss, and in the green shaded area are metagabbros that intrude the Upper Marble sequence at Balmat studied by Coffin (2008). These amphibolitic to metagabbroic rocks may be mafic equivalents of the Antwerp-Rossie suite. Epsilon Neodymium (ENd(1200)) plotted against SiO2 concentrations show no apparent trend and thus the isotope systematics are unlikely to be strongly controlled by crustal contamination. Since the ARG show no sign of continental contamination, but have ENd(1200) which plot below the depleted mantle curve show that the suite was likely derived from an enriched mantle source, like those found above active subduction zones.

IMPLICATIONS

Field relationships show that the ARG is a plutonic rock intruding the Lowlands metasedimentary sequence. The suite is observed to have intruded the Lower Marble unit, pelitic gneisses, amphibolites, and has quartzite xenoliths. Carl and deLorraine (1997) suggest that the ARG is seen intruding a highly deformed marble unit at Balmat. The metasedimentary rocks were likely already metamorphosed prior to intrusion because xenoliths are foliated. The ARG is of limited geographic extent; it is not seen in the highlands or north of the BLSZ. The petrology of the samples shows typical igneous mineralogy and textures slightly modified by deformation. The more mafic members have primary pyroxene. Perthite, myrmekite, zoned plagioclase, and zoned zircons occur and show metamorphic modification. Although the ARG range in SiO_2 content (51.7-78.84%), most the samples are felsic or mafic, with a few examples of intermediate composition. Major elements show that they are a coherent suite due to their correlation on Harker diagrams. Also, AFM diagrams suggest that the ARG's are of calc- alkaline affinity. On tectonic discrimination diagrams the samples plot in the volcanic arc granite field (Pearce et al., 1984). Incompatible element plots normalized to primitive mantle display negative Nb and Ta anomalies, generally indicative of subduction-related melting (Aspler et al., 2002). The suite has a TDM average age approximately 300 ma older than crystallization suggesting either a non-juvenile source or that the melt was not derived from a depleted mantle. There is no correlation between ENd(1200) and SiO_2 content which provides further evidence that continental contamination was lacking if not completely absent. Epsilon Neodymium values (ENd(1200)) are all positive and fall between TDM and CHUR (chondritic uniform reservoir) and imply minimal crustal influence.

CONCLUSIONS

The ARG is a suite of plutonic rocks with arc chemistry, and preservation of some igneous textures. The limited geographic occurrence is likely due to intrusion during Shawinigan deformation. Several lines of evidence suggest that the melt was derived from an enriched source likely related to subduction. ENd(1200) shows no relationship with SiO_2, and TDM are ~300 Ma older than the crystallization age. This evidence strongly suggests that continental crust did not play a large role in chemistry before or during melt creation and emplacement. The lithospheric mantle directly above the subducting slab may have been enriched, therefore imparting an enriched signature to the Nd isotope signature. These results are consistent with the BLSZ representing a tectonic boundary, but more work needs to be done.

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