PRECAMBRIAN GEOLOGY OF THE EAGLE LAKE QUADRANGLE, ESSEX COUNTY, NEW YORK

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INTRODUCTION AND REGIONAL BACKGROUND

The Grenville Province of eastern North America has long been interpreted as the roots of an ancient orogenic system that formed approximately 1.0 billion years ago (Hoffman, 1988; McLelland et al., 2010). The entire region formed and evolved during punctuated phases of crustal growth during the Mesoproterozoic involving a variety of tectonic processes including accretion, arc magmatism, back-arc development and collapse, and unique to the Grenville, anorthosite-mangerite-charnockite-granite (AMCG) plutonism. These processes occurred over > 300 my and are collectively referred to as the Grenville Orogenic cycle (Fig. 1; McLelland et al., 1996; Rivers, 2008). The northeast Grenville Province has been shown to have a long history, extending back to ca. 1.35 Ga (McLelland et al., 1993), and contains evidence of long-lived active margin processes (Dickin and McNutt, 2007; Chiarenzelli et al., 2010a). However, the most extensive regional deformation has been interpreted as having formed during a culminating collision at ca. 1.07 Ga (Ottawan orogeny), which resulted in the final assembly of the supercontinent Rodinia (McLelland et al., 1992; 1996; 2001a; 2010; 2011; Rivers et al., 2008). The Grenville Province offers an excellent opportunity to study the growth and modification of mid to lower continental crust during these tectonic processes within the context of a long-lived active margin (Mezger, 1992).

The Adirondack Mountains of northern New York are a large domical uplift and are subdivided into the northwest Adirondack Lowlands and southeast Adirondack highlands separated by the Carthage- Colten shear zone (Streepey et al., 2001; Selleck et al., 2005). The Adirondack Highlands are dominated by granulite facies (meta)igneous rocks in contrast to the Lowlands, which are dominated by supracrustal rocks metamorphosed to amphibolite facies. Another important difference is the timing of deformation in each region. In the Lowlands the majority of deformation was the result of Shawinigan orogenesis (ca.1.17 Ga; Fig. 1b; Wasteneys et al., 1999; Heumann et al.,2006; Chiarenzelli et al., 2010b; Wong et al., 2011a), and evidence for Ottawan deformation (ca. 1.07 Ga; McLelland et al., 2001a) is lacking (Baird and Shrady, 2011). In contrast, the Adirondack Highlands are known to have experienced both Shawinigan and Ottawan phases of the Grenville Cycle. Here, differentiating the effects of these two phases remains a major challenge that is critical for understanding the role and importance of the Ottawan orogeny in the Grenville Province as a whole (Rivers, 2011).

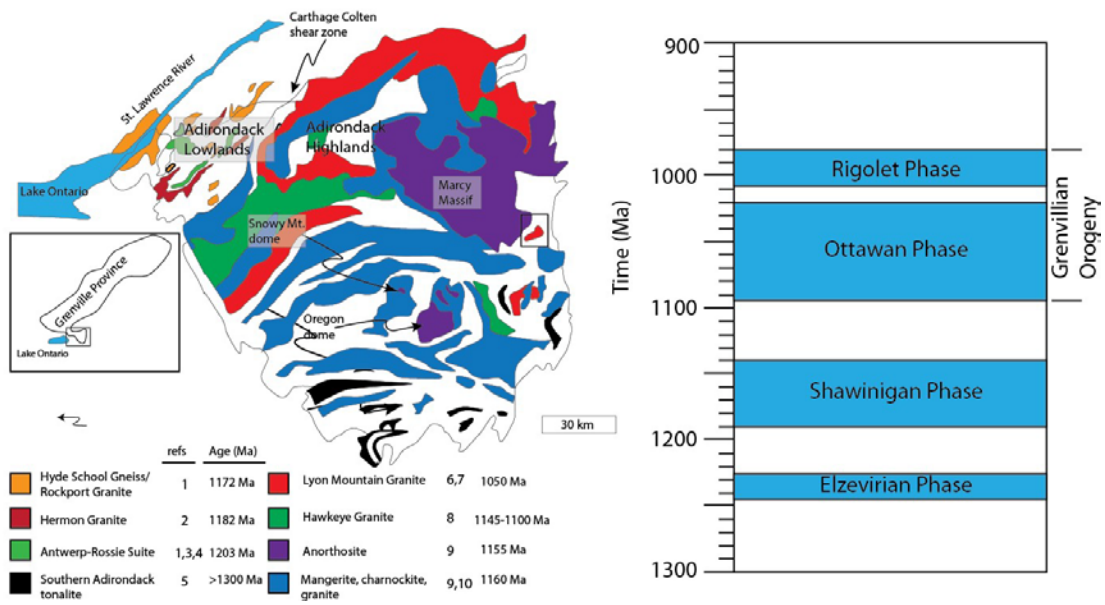

Figure 1: A) A simplified map of the Adirondacks divided into the northwestern lowlands and southeastern highlands. The map displays the distribution of (meta)igneous lithologies (modified from McLelland et al., 2004). Note the Eagle Lake quadrangle is outlined as a black rectangle along the southeastern margin of the Marcy Massif. U-Pb ages listed map below with references: 1. Wasteneys et al., (19999), 2. Heumann et al. (2006), 3. McLelland et al. (1992), 4. Chiarenzelli et al. (2011a), 5. Daly and McLelland (1991), 6. McLelland et al. (2001), 7. Valley et al. (2009), 8. Personal communication (Peter Valley, John Aleinikoff), 9. McLelland et al. (2004), Hamilton et al. (2004). B) A schematic displaying the traditional orogenic phases of the Grenville Province (after Rivers, 2008).

This field trip focuses on the general Precambrian geology of the Eagle Lake quadrangle (ELq) in the eastern Adirondack Highlands. We will discuss recent 1:24,000 scale mapping of the ELq and the historical mining area Hammondville (Geer et al., 2015). The new mapping represents work by Regan, Geer, and Walsh. Provisional mapping by Walton (1960) has proven quite helpful, and provided a foundation for the new work. We will present a new structural nomenclature established during mapping that is regionally transformative and will hopefully be a useful guide for future analytical work. New forward petrologic modeling of the metamorphic assemblages that define a major structural fabric, geochronologic data that constrain the timing of both granite petrogenisis and anatexis of metasedimentary lithologies, and geochemical data from the historical mining district of Hammondville.

The Adirondack Highlands are predominately underlain by granulite facies (meta) igneous lithologies (McLelland et al., 1996). The most voluminous plutonic rocks exposed belong to the anorthosite-mangerite-charnockite-granite (AMCG) suite, which underlies approximately 60 % of the Adirondack Highlands (Hamilton et al., 2004). The petrogenisis of AMCG suites has been debated for decades, but detailed U-Pb geochronologic work presented in McLelland et al. (2004) and Hamilton et al. (2004) shows that granitoid lithologies (1158 Ma) are statistically older than anorthositic and other mafic members of the suite (1154 Ma), but overlap in age (Figure 5e). These data were interpreted as showing that AMCG suites are "… coeval, but not necessarily comagmatic" (McLelland et al., 2004). Geochemical and isotopic analysis performed by Regan et al. (2011) showed that coronitic metagabbros of the Adirondack Highlands (McLelland and Chiarenzelli, 1988) are permissible as the parental magma for the anorthosite. Quartz-bearing end-members were interpreted to have been derived from partial melting of lower continental crust where anorthosite formed via fractional crystallization of an asthenospherically derived gabbroic magma (McLelland et al., 2004; Bickford et al., 2008; Regan et al., 2011). The largest body of anorthosite is the Marcy Massif, which underlies the high peaks region of the Adirondack Mountains (Buddington, 1939). This suite of rocks has been interpreted as the result of lithospheric- mantle delamination at the waning phases of Shawinigan orogenesis (McLelland et al., 2004). Therefore, the deformation and metamorphism present throughout AMCG rocks has been interpreted as Ottawan in age.

The Lyon Mountain Granite Gneiss (LMG: nomenclature after Postel, 1952) is the youngest igneous rock exposed within the Adirondack highlands (Buddington, 1939; Postel, 1952; McLelland et al., 2001a,b,c; Selleck et al., 2005; Valley et al., 2009; 2010). It is a leucogranite that rims the Adirondack Highlands and is host to low-Ti magnetite deposits interpreted as forming via kiruna-type Fe – oxide, copper, gold (IOGC) mineralization processes (McLelland et al., 2001b,c; Valley et al., 2009). The LMG contains no consistent shape-preferred orientation (except in the East Adirondack shear zone; see *Grover et al., trip B-2*), and very little evidence of regionally significant subsolidus deformation, although the nature of layering is currently being debated (McLelland et al., 2001a). The LMG has been interpreted as accompanying orogenic collapse at the tail end of Ottawan orogenesis (McLelland et al., 2001a; Selleck et al., 2005).

ROCK TYPES

The ELq contains a wide variety of Precambrian rocks, and contains all of the lithologies exposed within the Adirondack region, with the exceptions of ca. 1.3 Ga tonalite gneisses exposed within the southern Adirondack Mountains (Daly and McLelland, 1993). Major rock units exposed within the ELq are described below, from oldest to youngest, with approximate ages given from the literature. It is important to note that the majority of geochronology cited below was performed on similar rocks from outside of the ELq.

>1203 Ma Grenville Supergroup (after Davidson, 1998)

Four basic units are currently subdivided: 1) Amphibolitic to pyroxenic gneiss: this unit is predominately composed of fine to medium grained amphibolite with cm-scale boudined leucosome, locally contains opx porphyroblasts surrounded by tonalitic leucosomes, and coarse diopsidite; 2) Calc- silicate and marble: this unit is very poorly exposed but commonly contain coarse quartz and diopside crystals, pegmatitic clinopyroxene-bearing leucosomes; 3) Garnetiferous quartzofeldspathic migmatitic gneiss (+/- sillimanite +/- graphite; classically khondolite): this unit is thought to have formed via anatexis of a pelitic to psammitic lithology, and it is commonly associated with very minor quartzite layers and a small amount of amphibolite; 4) biotite gneiss +/- leucosome +/- garnet: this unit is commonly platy and typically is interlayered with meter to sub-meter scaled amphibolite layers. The supracrustal lithologies of

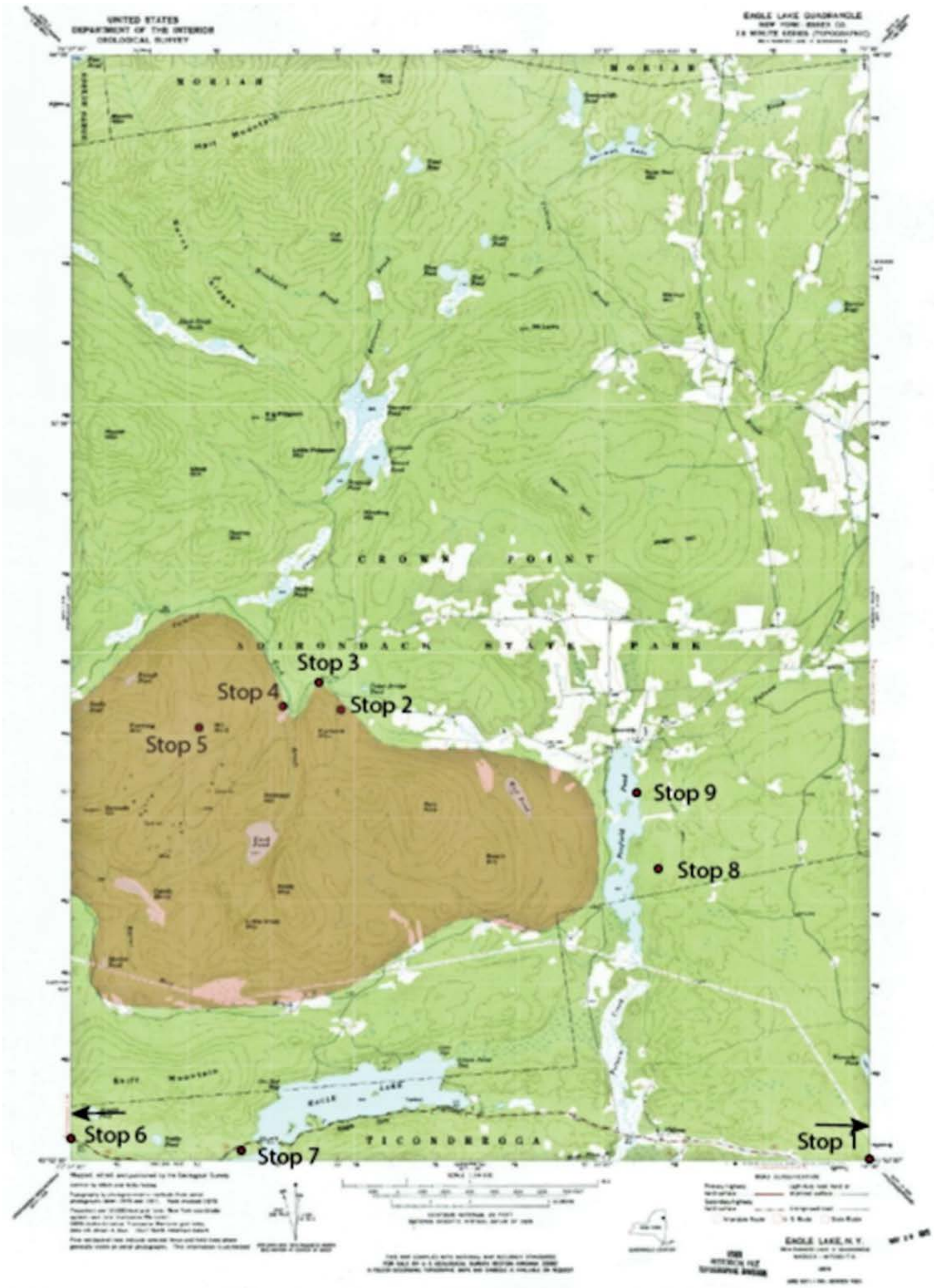

Figure 2: Topographic map of the 7.5 - minute Eagle Lake Quadrangle (ELq) and field trip locations. Shaded region approximates the region mapped at 1:12,000 scale in the area of the historic mining town of Hammondville, NY.

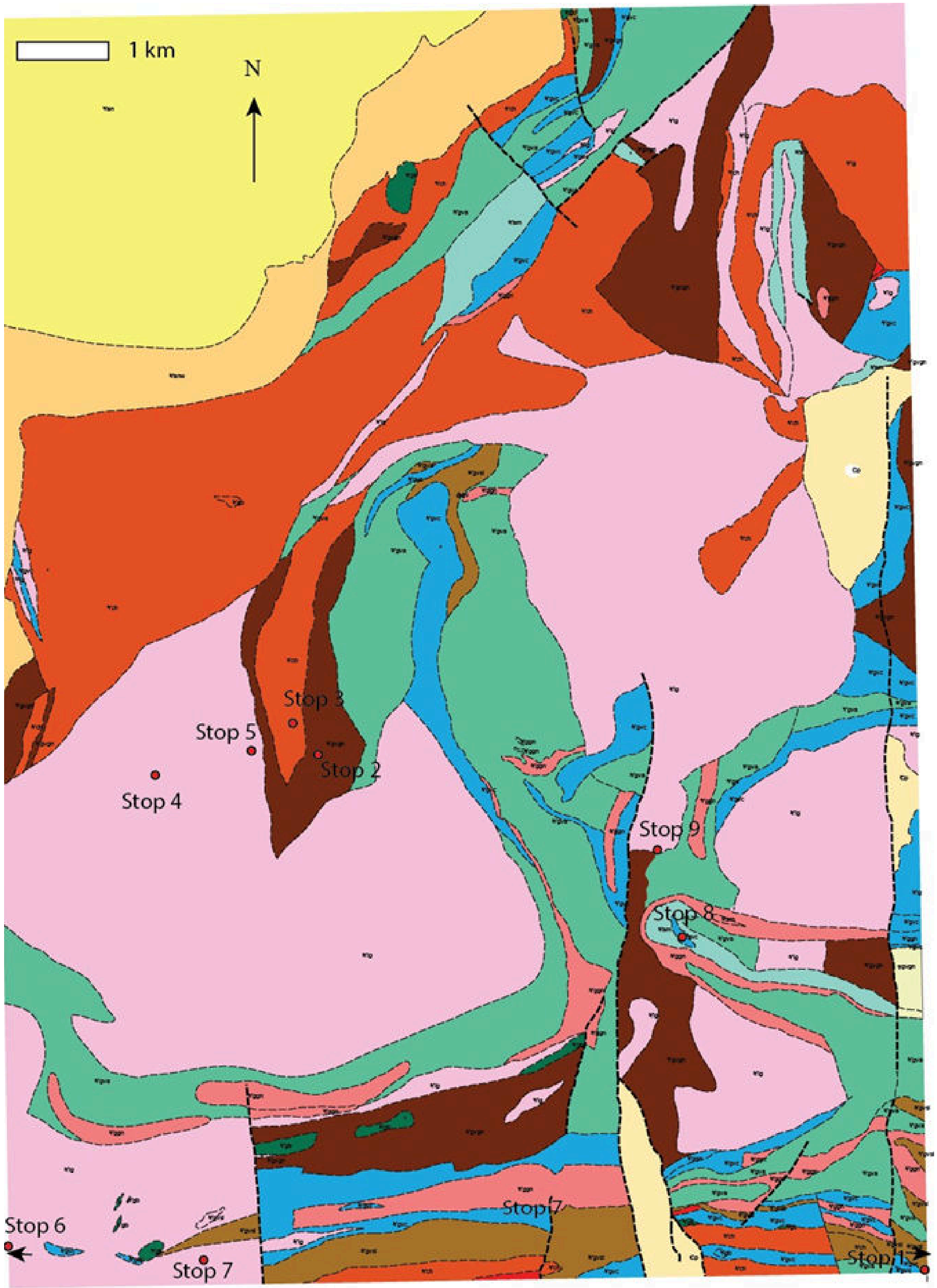

Figure 3a: Preliminary geologic map of the ELq (scaled down from 1:24,000) from March 2015. The map has changed slightly and there will be an updated version on the field trip. See Fig. 3b for the key.

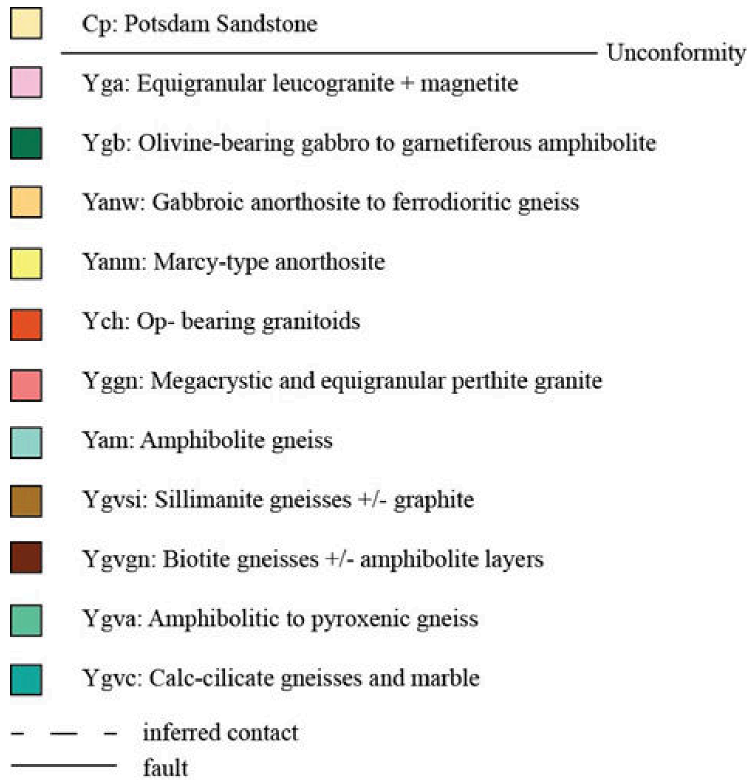

Figure 3b: Description of map units on Fig. 3a.

the ELq are varied and similar to those exposed in the Adirondack Lowlands (Carl et al., 1990; Chiarenzelli al., 2015). These lithologies are interpreted to all have formed during opening and closure of the Trans-Adirondack back arc basin, and based on their potential correlation to the Adirondack Lowlands, and preserved cross-cutting relationships, predate the Antwerp-Rossie suite (ca. 1203 Ma; Chiarenzelli et al., 2012).

Mesoperthite granite gneiss: age unknown

This unit consists of two major components: 1) a biotite –garnet-K-feldspar megacrystic (augen) granitic gneiss and 2) mesoperthite pegmatite. These two components are commonly both present in any one area or exposure of this unit. In places, the transition is exposed where anastomosing strands of variety 1 weave within a larger exposure of variety 2. Effort to obtain a U-Pb crystallization age on this lithology are ongoing. It cross cuts granulite grade fabrics within amphibolite gneisses that are interlayered with calc-silicate gneisses, and are interpreted as members of the Grenville Supergroup. It provides a useful marker layer when tracing out F_2 isoclinal folds (*see below; Figure 7b*). Based on recent mapping it appears to be the same age or older than AMCG lithologies (see below).

Figure 4. Representative field photographs for major units of the Grenville Supergroup. A) Interlayered marble and calc-silicate gneiss exposed along NY 74; B) Quartzofeldspathic gneiss with folded pegmatitic leucosome, suggesting anatexis during D_1; C) Amphibolite migmatite gneiss with an orthopyroxene porphyroblast within quartz-rich leucosome; D) highly migmatized and dismembered amphibolite gneiss with coarse garnet crystals.

Ca. 1158 Ma Mangerite-charnockite-granite

Rocks belonging to this suite have been extensively studied, and have fairly well understood petrologic, geochemical, and isotopic systematics (McLelland et al., 2004; Hamilton et al., 2004; Bickford et al., 2010). We will refer to this group as charnockite after Frost and Frost (2008b). The rocks contain (predominately) primary orthopyroxene, plagioclase, K-feldspar, quartz, and ilmenite, with ubiquitous metamorphic hornblende +/- garnet. This unit is strongly deformed throughout the ELq, it is important to note that as you approach the Marcy anorthosite (*see below*), rocks of this suite contain less quartz, and are predominately monzonitic to ferrodioritic. Porphyroclastic and equigranular varieties occur, but mostexposures contain a well-developed stretching lineation. Hornblende and garnet are typically metamorphic phases associated with granulite facies conditions. Some varieties do not contain opx as a primary mafic phase, and are granites. However, given their structural and petrologic similarity, and geochronologic data confirming an equivalent age (McLelland et al., 2004; Hamilton et al., 2004), these granite gneisses are lumped with other charnockitic lithologies.

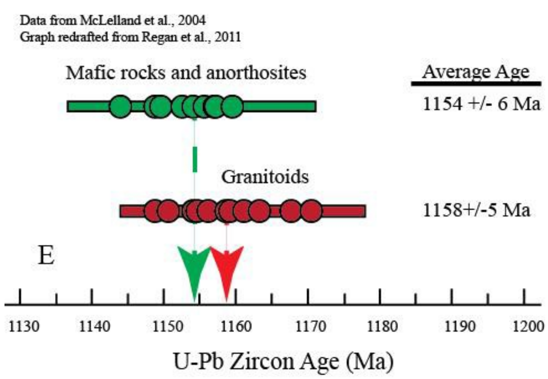

Figure 5: Representative field photographs of some AMCG-related meta-igneous rock types. A) Biotite-garnet-K-feldspar megacrystic granite (augen), B) Coarse garnet porphyroblast within a mangeritic gneiss, notice the inclusion-rich core, C) Interleaved ferrodioritic gneiss and gabbroic anorthosite indicative of the marginal whiteface facies anorthosite, D) Representative field photograph of Marcy-type anorthosite on Hail Mountain. E) SHRIMP U-Pb geochronology of AMCG rocks from the Adirondack Highlands (McLelland et al., 2004).

Ca. 1154 Ma Anorthosite

Anorthosite underlies the majority of the High Peaks region of the Adirondack Highlands, and underlies the northwestern corner of the ELq. The vast majority of anorthosite is undeformed, or weakly deformed with a weak magmatic to tectonic fabric, but contains strong evidence of a high P-T static metamorphic overprint. This anorthosite is dominated by coarse andesine crystals and distinctive labradorite crystals (Marcy-type). Heterogeneously distributed within, and along the margin of the Marcy

– type anorthosite is what has traditionally been referred to as the Whiteface-type (Walton, 1956). It consists of white gabbroic anorthosite that is finer grained, contains andesine xenocrysts, and on average more mafics (orthopyroxene + clinopyroxene + garnet) than the Marcy counterpart. Also, the Whiteface

- type generally contains a heterogeneous mixture of ferrodiorite, that also contains andesine xenocrysts (Figure 5c). In contrast to the Marcy-type anorthosite, which contains little evidence for subsolidus deformation, the Whiteface-type contains a very strong and locally mylonitic fabric. The granulite grade assemblage consisting of cpx + opx +/- grt is associated with this fabric. SHRIMP geochronology of this suite suggests that it is coeval, but statistically younger than quartz bearing members of the AMCG suite (McLelland et al., 2004; Hamilton et al., 2004).

Olivine Metagabbro

This suite of rocks occurs throughout the Adirondack Mountains, most notably as satellite plutons exposed along the margin of the Marcy Massif (Buddington , 1939). Forming km – scale plugs, dikes, and lozenges, these bodies are typically cored by olivine metagabbro with little to no penetrative fabric, preserve ophitic to subophitic textures (Whitney and McLelland, 1983), and contain spinel clouded plagioclase laths. This unit contains ubiquitous evidence for a high grade and static metamorphic overprint similar to the Marcy-type anorthosite. The metamorphic assemblage varies, but consistently contains of early biotite-clinopyroxene-hornblende-garnet coronitic textures around primary olivine, spinel clouded plagioclase, and orthopyroxene (Whitney and McLelland, 1973). It is important to note, that this suite of rocks have been dated to be similar in age to the anorthosite-massif (1146 Ma; McLelland and Chiarenzelli, 1988; McLelland et al., 2004), and has been interpreted to be compositionally admissible as the parent magma for the Marcy massif (Regan et al., 2011).

Commonly exposed along the margins of these bodies are ten to 100 meter-thick enveloping garnetiferous amphibolite that parallels the olivine metagabbro margin. A strong tectonic fabric is accompanied by an increase in modal garnet and hornblende (Lagor et al., 2013), and has been shown to be essentially isochemical with respect to their parental olivine metagabbro protolith. Both major and trace elements show marked consistency, and are even identical to a samples of olivine metagabbro analyzed throughout the Adirondack Highlands (Regan et al., 2011).

Ca. 1070 – 1060 Ma Lyon Mountain Granite (Gneiss)(name from Postel, 1952)

The LMG has been studied extensively, partially due to the fact that it hosts the largest Fe-mines in the Adirondack Mountains. Mined throughout the 1800's, the vast majority of mines closed at the turn of the century, with the last mine closing in the 1970s (McLelland et al., 2001b). The LMG itself is an equigranular microperthite granite with both biotite and magnetite as the primary mafic phases, although occasional hornblende is locally present. Aegerine-Augite is also present outside of the ELq, along with acmitic pyroxenes in some of the ores (Lupulescu et al., trip B1). Adjacent to large Fe- deposits and seams, the perthite has been altered to albite by sodic fluids accompanied the mineralization within the region (Mclelland et al., 2001b,c; Valley et al., 2010; Valley et al., 2011a,b). Elsewhere, a potassic metasomatic event has been recognized by Valley et al. (2011a), which is interpreted to occur between igneous crystallization and sodic alteration, but we have yet identify this as a regionally extensive component within the ELq.

There is little evidence of deformation within the unaltered LMG. It contains no stretching lineation (as of yet), and its layering is not metamorphic or due to deformation at the regional scale (Mclelland et la., 2001a). The LMG crosscuts granulite grade fabrics throughout the ELq, and contains numerous xenoliths of S_2 bearing rock types. Contacts with the LMG are typically parallel to subparallel with granulite-grade fabrics within the country-rock, which it locally crosscuts. Geochemically, the lithology is strongly ferroan, alkali to alkali-calcic (after Frost and Frost, 2008), and has been interpreted as syn-kinematic with collapse, but post-kinematic with respect penetrative Ottawan deformation (McLelland et al., 2001a; Selleck et al., 2005). For more description of large Fe-deposits, see Lupulescu et al., trip B1.

STRUCTURAL DATA AND FIELD RELATIONSHIPS

Structural Data

The Eagle Lake quadrangle contains evidence for at least three phases of folding and two phases of penetrative deformation. The oldest fabric within the ELq (S_1, Table 1) is only preserved within rocks of the Grenville Supergroup. It is commonly defined by migmatitic layering (McLelland and Chiarenzelli, 1988; Heumann et al., 2006) within aluminous paragneisses and amphibolite gneisses. Evidence of S_1 is best preserved within hinge regions of F_2 folds, but is otherwise difficult differentiate, due to a strong S_2 overprint. Older gneissosity and folding are currently not well understood or identified, due to transposition during D_2. S_2 is defined by the axial planes of large isoclinal folds (F_2). The axes of these folds is predominantly moderately plunging to the southeast, but the orientation is currently not well constrained. This phase of deformation effected all lithologies except for the LMG. Therefore D_2 had to occur between AMCG magmatism and emplacement of the LMG. S_1 and S_2 are parallel throughout most of the ELq within the Grenville Supergroup lithologies, and can therefore be thought of as a composite fabric within paragneisses.

Table 1: Proposed structural nomenclature for rocks within the ELq.

Fabric generation	Orientation	P-T conditions	Proposed timing	References
S_1	n/a	Greater than sillimanite	1170 Ma	McLelland and Chiarenzelli, 1988 *New data*
$S_2/F_2/M_2$	Shallowly dipping to east (axial surface); isoclinal folds	From 1.0 GPa and 850°C to 0.6 GPa and 600°C	<1160 Ma and >1070 Ma	*New data;* McLelland et al., 2001, 2004; Valley et al., 2010
F_3	Open upright folds plunging shallowly to the southwest	0.5 GPa and 700°C	1060 Ma; extensional collapse	Mclelland et al., 2001; Selleck et al., 2005; Valley et al., 2011a,b; *new data*
D_4	Boudinage, and pegmatite dikes; trending NE		1050-1000 Ma	Valley et al., 2010, *new data*

Associated with S_2 is a fabric that parallels the margin of the Marcy massif. Although not associated with map-scale F_2 isoclinal folds, the similarity between the pronounced lineation within the marginal fabric and the lineation in the interleaved paragneisses suggests that the fabric surrounding the Marcy massif formed synchronously with F_2. The ca. 1150 Ma anorthosite, underlies a large region in the NW corner of the ELq. The Marcy-type grades from an undeformed core, which preserves igneous textures and transitions outward, into highly deformed tectonites of the Whiteface – type anorthosite and other AMCG lithologies. The fabric has a constant stretching lineation orientation within the ELq and is interpreted as parallel to the axes of F_2 folds.

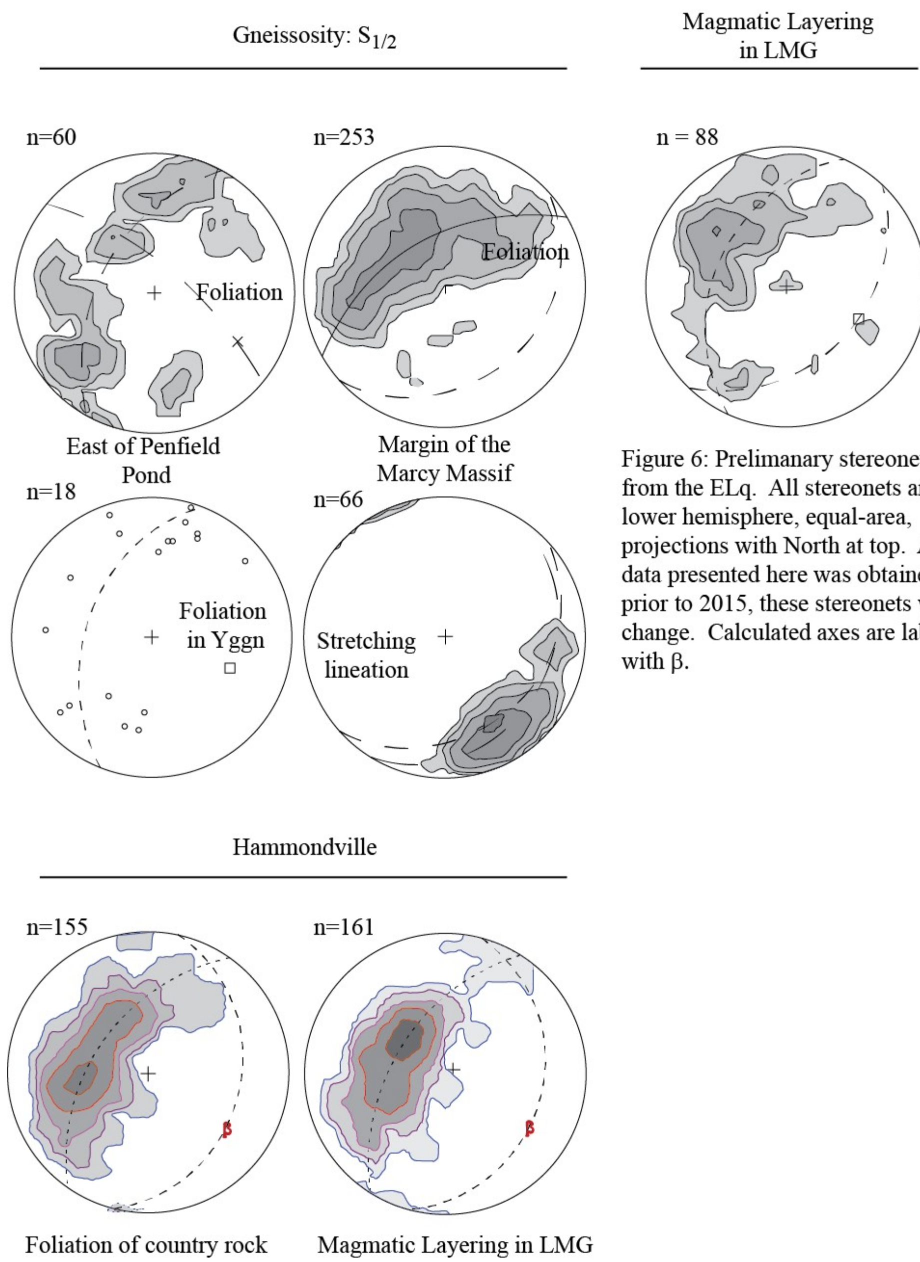

Figure 6: Prelimanary stereonets from the ELq. All stereonets are lower hemisphere, equal-area, projections with North at top. All data presented here was obtained prior to 2015, these stereonets will change. Calculated axes are labeled with β.

The last major phase of deformation, and the major control of the map pattern and stereonet analysis, is large-amplitude, open, upright F_3 folds that plunge 10 – 15° to 110°. These open folds are best developed > 4 km away from the Marcy Massif. All rock types contain evidence of this event, but outcrop-scale D_3 fabrics are not ubiquitous and there remains little evidence for associated widespread D_3 penetrative deformation. A minor phase of D_4 deformation is associated with late, upright, broad amplitude folds and boudinage. Late tabular pegmatite dikes locally follow this fabric and fill boudin necks. Generally, the fabric trends to the NNE, but analysis of this fabric is not yet complete, and may be progressive with respect to D_3.

Field Relationships

There is a large body of work that describes much of the field relationships exposed throughout the Adirondack Mountains (Buddington, 1939; Postel, 1952; *among many others*). More recent descriptions of these relationships are given in several contributions (McLelland and Isachsen, 1986; McLelland et al., 1988a,b).

Table 2: Summary of Grenville-aged rock types and field relationships exposed within the Eagle Lake quadrangle

Rock Type	Relationship	Age	Reference
Lyon Mountain Granite	Cross cuts S_2 and contains xenoliths of rocks with S_2	1070 - 1040 Ma	Buddington, 1939; Postel, 1952; McLelland et al., 2001a,b,c; Valley et al., 2011b
Olivine –bearing metagabbros	Cross cuts S_1; Cross cuts anorthosite; locally contains strong S_2 overprint	1145 Ma	McLelland and Chiarenzelli, 1988; Davidson and Van Breeman, 1988
Anorthosite	Cross cuts and contains xenoliths of Grenville Supergroup	1154 Ma	McLelland et al., 2004
Mangerite, charnockite, granite gneiss	Cross cuts and contains xenoliths of Grenville Supergroup, contains strong S_2 tectonic fabric	1158 Ma	McLelland et al., 2004; Hamilton et al., 2004
Mesoperthite Granite gneiss	Folded by F_2; cross cuts S_1 in Grenville Supergroup	Older than or equal to 1158 Ma	No data
Grenville Supergroup	A minimum of two phases of high grade metamorphism; is cross cut by all igneous rocks; there is currently little to no stratigraphic control in this part of the Adirondack Highlands	Deposition between 1230 and 1203 Ma.	Wasteneys et al., 1998; Chiarenzelli et al., 2010b; 2015

Several field relationships are well demonstrated within the ELq. AMCG lithologies cross cut, contain xenoliths of, and are younger than the Grenville Supergroup. Sillimanite-bearing quartzofeldspathic gneisses are cross cut by gabbroic rocks at Dresdon Station (*see Grover et al., this contribution*), and this is also true for rocks in the ELq. However, there is no question that AMCG rocks contain a granulite facies overprint that is shared with the surrounding supracrustal sequence. Lastly, the LMG cross cuts all lithologies (localities south of Moose Mountain, eastern margin of Skiff Mountain, summit of Skiff Mountain, Mount Lewis, eastern shore of Penfield Pond, Hammondville, others). The LMG contains open, upright, folds that are sub-meter in scale that are parallel to F_3 and pegmatitic segregations within localized boudin necks (alkali granite or pure quartz in composition). Smaller LMG plutons, east of Penfield Pond appear to have been emplaced within the F_3 folds, and are interpreted as syn-kinematic. This is consistent with the interpretation of Mclelland et al. (2001) and Selleck et al. (2005) that interpreted the LMG to be post kinematic with respect to regional granulite grade deformation and metamorphism.

Forward petrologic modelling of D2

Thermobarometric analysis of assemblages that define the S_2 fabric is currently underway in the ELq with the goal of extending existing P-T data from the Adirondack Highlands (Bohlen et al., 1992; McLelland and Whitney, 1980; Spear and Markussen, 1997; Storm and Spear, 2005). Ferrodioritic gneisses within the marginal anorthosite facies consistently yield estimates of 0.9 GPa and 700°C, similar to results presented in Spear and Markussen (1997). However, there has been little to no forward petrologic modeling done throughout the Adirondack Highlands, despite its routine use in many other metamorphic terranes.

There is one large olivine metagabbro exposed along the margin of the Whiteface-type anorthosite east of Cat Mountain. It is cored by coarse-grained olivine-bearing metagabbro engulfed in garnetiferous amphibolite that contains a strong S_2 fabric. The geometry of the coronite and its relationship to the surrounding tectonites mimics that of the Marcy massif, but on a far smaller scale with an undeformed core, surrounded by tectonites of identical composition (Lagor, 2012). Forward modeling using Theriak-Domino (de Capitani and Petrakakis, 2010) and the Holland and Powell database (updated in 2007) was performed on the coronitic metagabbro to understand the P-T evolution during static metamorphism, and the development of the engulfing garnetiferous amphibolite. Due to variations in αH_2O throughout the rocks history, we have calculated a 3-D pseudosection plotting P, T, and αH_2O. Models were run calculating assemblage, modes of garnet, biotite, amphibole, and plagioclase and garnet composition (Figure 8). Together these result show that a single clockwise decompression path beginning above 1.0 GPa can link all existing quantitative thermobarometric points. Thermobarometry and preliminary forward petrologic models were also calculated for a coronitic metagabbro exposed in Newcomb, NY, in central Essex County for comparison, and yield nearly identical results.

There has been a discrepancy regarding the origin of massif type-anorthosite in that petrologically they appear to form near or at the Moho, and appear to be largely derived from asthenospheric mantle (Buddington, 1939; McLelland et al., 1996, 2004; Hamilton et al., 2004; Regan et al., 2011). However, Valley and O'Neil (1982) performed a systematic stable isotopic analysis of minerals from Grenville Supergroup lithologies exposed within the contact aureole of the Marcy Anorthosite.

Minerals formed during contact metamorphism contain depleted O^{18} (relative to SMOW), requiring interaction of an aqueous meteoric component during contact metamorphism, which has to be relatively shallow in the crust. The decompression P-T path described above may reconcile some of the discrepancies between evidence for both deep and shallow petrogenesis of massif-type anorthosite: it is both. In this model, rocks were largely crystallized at depth, but

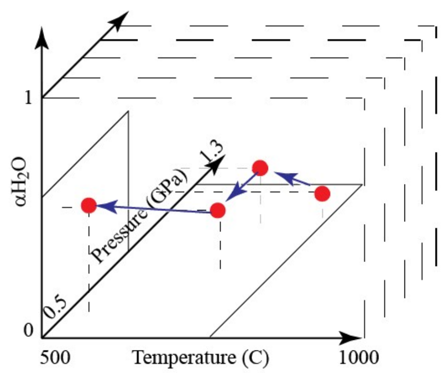

Figure 8: Summary of thermoabarometry and forward modelling

New Quantitative Thermobarometry (both TWQ and Thermocalc)

Rock Type	Location	Assemblage	Pressure	Temperature	Interpretation
Ferrodiorite	Moose Mountain	clinopyroxene + plagioclase + garnet+ quartz	0.9	700	Development of S_2 along margin of Marcy Massif
Coronitic metagabbro	Trout Pond	clinopyroxene + plagioclase + garnet+ quartz	1.2	775	Static metamorphism predating S_2
Coronitic metagabbro	Trout Pond	orthopyroxene + plagioclase + garnet+ quartz	0.6	500	Late requilibration or disequilibrium
Coronitic metagabbro	Newcomb	clinopyroxene + plagioclase + garnet+ quartz	1.2	775	Static metamorphism predating S_2
Coronitic metagabbro	Newcomb	orthopyroxene + plagioclase + garnet+ quartz	0.6	500	Late requilibration or disequilibrium
Garnetiferous amphibolite	Newcomb	orthopyroxene + plagioclase + garnet+ quartz	0.5	525	retrogression during penetrative deformation

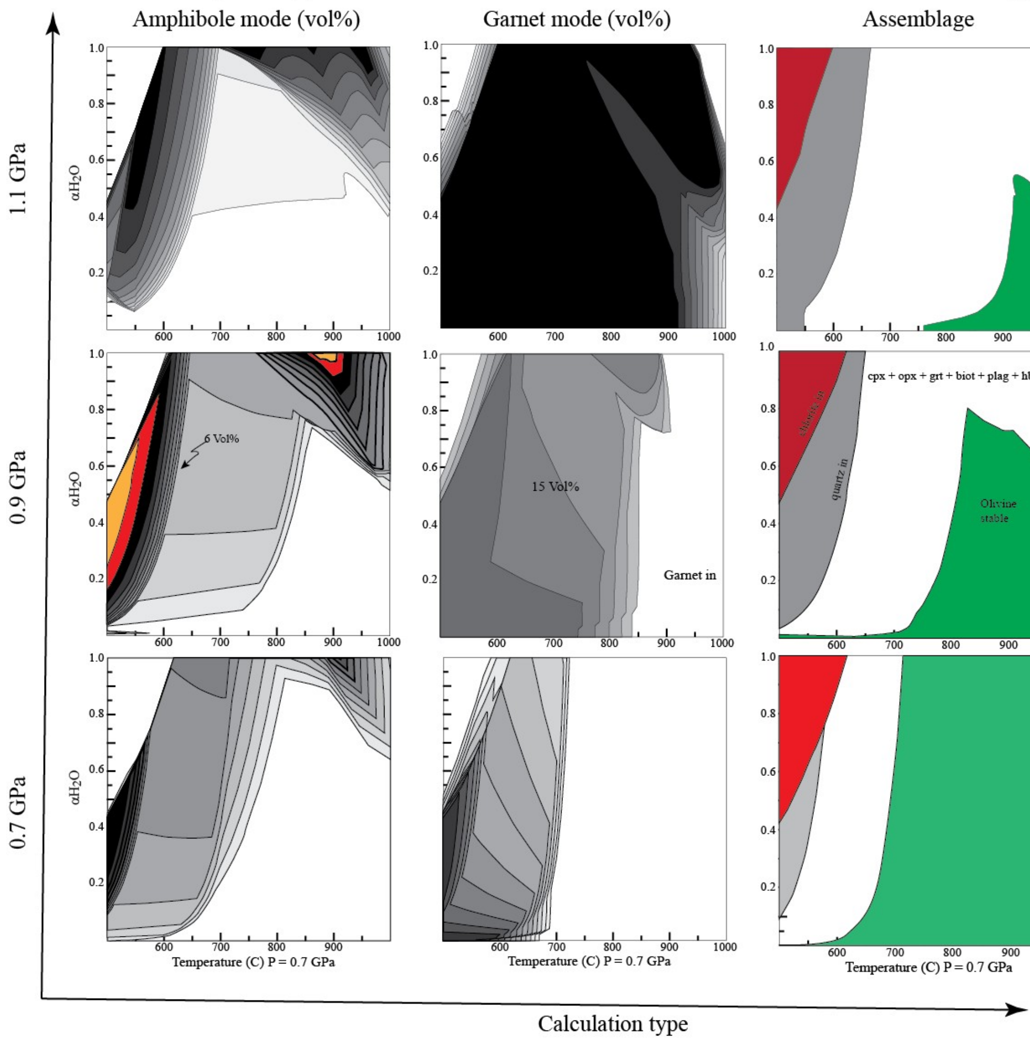

Figure 8. Summary of thermobarometry and forward modelling.

the anorthosite bodies, being positively buoyant, were emplaced at mid to upper crustal levels as a crystal mush. Tectonites exposed along the margin of the massif may have formed during its emplacement. The P-T path described above is derived from rocks with structural fabrics that are prime candidates to have accommodated the emplacement of the Marcy Massif, and shows that such a metamorphic history can be modeled.

Structural evolution

The evolution of the area is summarized schematically in figure 10. The earliest recognized phase of penetrative deformation (D_1) is only exposed within the Grenville Supergroup lithologies within the ELq. It is defined by a high grade metamorphic assemblage, and is associated with migmatization in aluminous paragneisses. Recent geochronology (*stop* 1) from just outside the ELq is consistent with geochronology from the southern Adirondack Highlands (Heumann et al., 2006) that suggests anataxis occurred during the Shawinigan phase of deformation. This is consistent with the field relationships that suggest D_1 predates AMCG plutonism. This fabric may have more than one component, but we are unable to differentiate them now. Subsequent deformation (D_2) involved the isoclinal folding of a preexisting gneissosity in the Grenville Supergroup and the Mesoperthite granite gneiss, and the development of a strong axial planar fabric within AMCG lithologies. This phase of deformation is associated with granulite grade deformation within AMCG and older lithologies, but deformed pre-existing leucosome. This fabric has been interpreted as Ottawan in age (ca. 1080 Ma), but there is no direct link between time and structure necessitating this correlation. The LMG cross cuts and contains xenoliths of rocks that contain an S_2 fabric, suggesting the ca. 1070 Ma LMG post dates D_2.

Future work should focus on deciphering the age and kinematics of the structural fabric. Forward modeling presented above suggests that deformation during D_2 may also be explained by AMCG emplacement at the tail end of Shawinigan orogenesis (Regan et al., 2015). The LMG was effected by late open folding (F_3), and based on the map scale pattern, is preliminarily interpreted as syn-kinematic with respect to F_3 folding.

Geochemistry of the LMG

The LMG has been the focus of a number of analytical studies, including detailed U-Th-Pb zircon geochronology (Mclelland et al., 2011; Selleck et al., 2005; Wong et al., 2011; Valley et al., 2011a,b), paired Hf zircon analysis (Valley et al., 2010), and extensive geochemical analsyes of both major and trace element composition (Whitney and Olmstead, 1988; McLelland et al., 2001a,b,c; Valley et al., 2011a,b; Geer et al., 2015). These analyses have been performed on both ore-hosting and non ore-hosting LMG. Geochemically, the LMG is strongly ferroan (Frost and Frost, 2008) with a limited range of SiO_2 content (predominately > 70 %). On modified alkali lime index vs. SiO_2 diagrams (Frost et al., 2001; modified in Frost and Frost, 2008), they plot as alkali to alkali-calcic, forming a cluster at high MALI (figure 9). Trace elements contain systematic depletions in HFSE and enrichments in LILE, except near magnetite ore seams where host rocks show evidence of sodic alteration (Mclelland et al., 2001c; Valley et al., 2010; 2011a,b; Geer et al., 2015). On tectonic discrimination diagrams after Pearce et al. (1984), the LMG plots from a within plate granite to rift field. All of these data strongly suggest an anhydrous crustal source for the LMG. The incompatible element trend is best explained as an inherited subduction signature from preexisting lithologies in the source region (Valley et al., 2011). Furthermore, the lack of lower SiO_2 variants extensive evidence for a relatively high oxygen fugacity (Wones, 1989; McLelland et al., 2001c), and the strongly ferroan major element composition of the LMG are all consistent with the chemistry of felsic igneous rocks within other extensional settings.

Geochemistry of ore and host rocks within Hammondville and Skiff Mountain

The LMG hosts numerous zones of magnetite mineralization that were mined for iron beginning in the early 19th century. Recently some of these deposits were discovered to contain apatite with elevated levels of REEs (Valley, 2011; Lupelescu, trip B-2). Hammondville was a mining town in the eastern Adirondack Mountains in operation in the 1890s, and was one of the largest producers of iron in the region. Targeted 1:12,000 scale mapping of Hammondville was undertaken to understand the petrogenesis of the LMG and the structural and petrologic relationship of magnetite mineralization and REE distribution. This is part of a larger mapping project in the Eagle Lake quadrangle. Paired ore and host rock samples have been collected for petrologic and geochemical analyses in order to evaluate petrogenetic links between magnetite mineralization and the host granite within the Hammondville region.

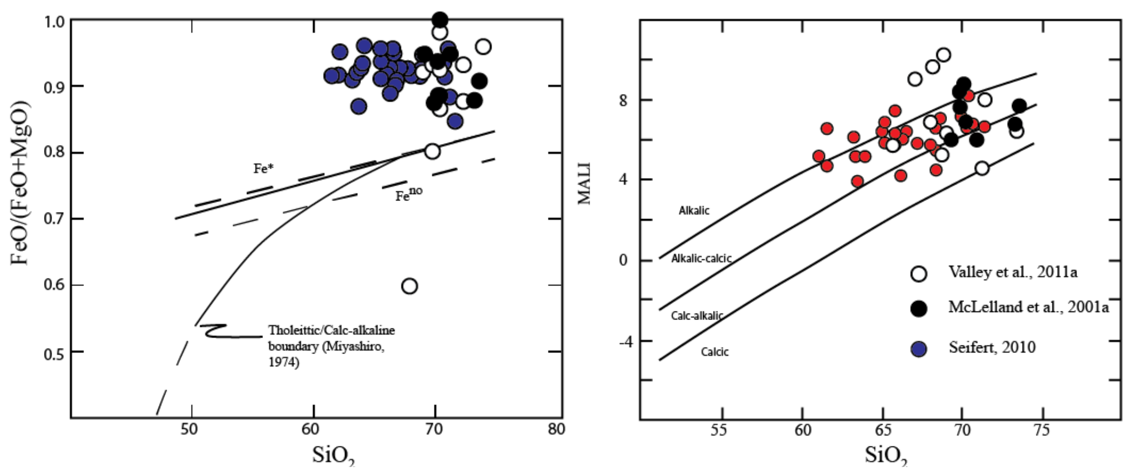

Figure 9. Fe-index and modified alkali-lime index plotted against SiO2 (after Frost et al., 2001; Frost and Frost, 2008; and references therein) for existing geochemistry of the LMG. Also plotted are geochemical data from charnockites sampled throughout the Adirondacks (Seifert, 2010). Please note that the LMG and charnockite gneisses show similar geochemical trends.

The host rock immediately surrounding the magnetite ore in Hammondville is typically a quartz albite rock with amphibole and clinopyroxene. On Harker diagrams there is a clear trend between SiO_2 and Al_2O_3, MgO, $TiO_2Fe_2O_3$ and total alkalis. It is strongly ferroan (Frost and Frost, 2008), similar to past studies (Valley et al., 2011, with a range of SiO_2 from 65% to 75%. They also plot as alkali to alkali-calcic on a modified alkali lime index vs. SiO_2 diagram (Frost et al., 2001; modified in Frost and Frost, 2008). Chondrite normalized REE plots display a slight enrichment in LREE, a pronounced negative Eu anomaly and a depletion in HREE (Sun and McDonough, 1989). The LMG within Hammondville commonly contains a layering interpreted as magmatic in origin because of the lack of strain shown in petrographic thin section, but ongoing discussions surround the role of thermal annealing. Locally, the LMG exhibits strain in areas typically located near major zones of magnetite mineralization.

Ore samples (samples with >34% Fe_2O_3) from Hammondville typically contain magnetite, amphibole, clinopyroxene, quartz and albite. There is a strong Fe_2O_3 trend vs. SiO_2 on a Harker diagram, however other trends in major element composition are lacking. The ore shares similar REE element trends with the hosts including a pronounced negative Eu anomaly and a depletion in HREE on chondrite normalized diagrams (Sun And McDonough, 1989). However, they exhibit a more level LREE tendency and several samples are much more highly enriched than host rock. Anastomosing seams of magnetite range in thickness from < 1cm to roughly 2 m and commonly branch into multiple seams that can have deformed tendrils extending from the main seam. Petrographic analyses show local deformation in some areas of mineralization that can extend into the surrounding host.

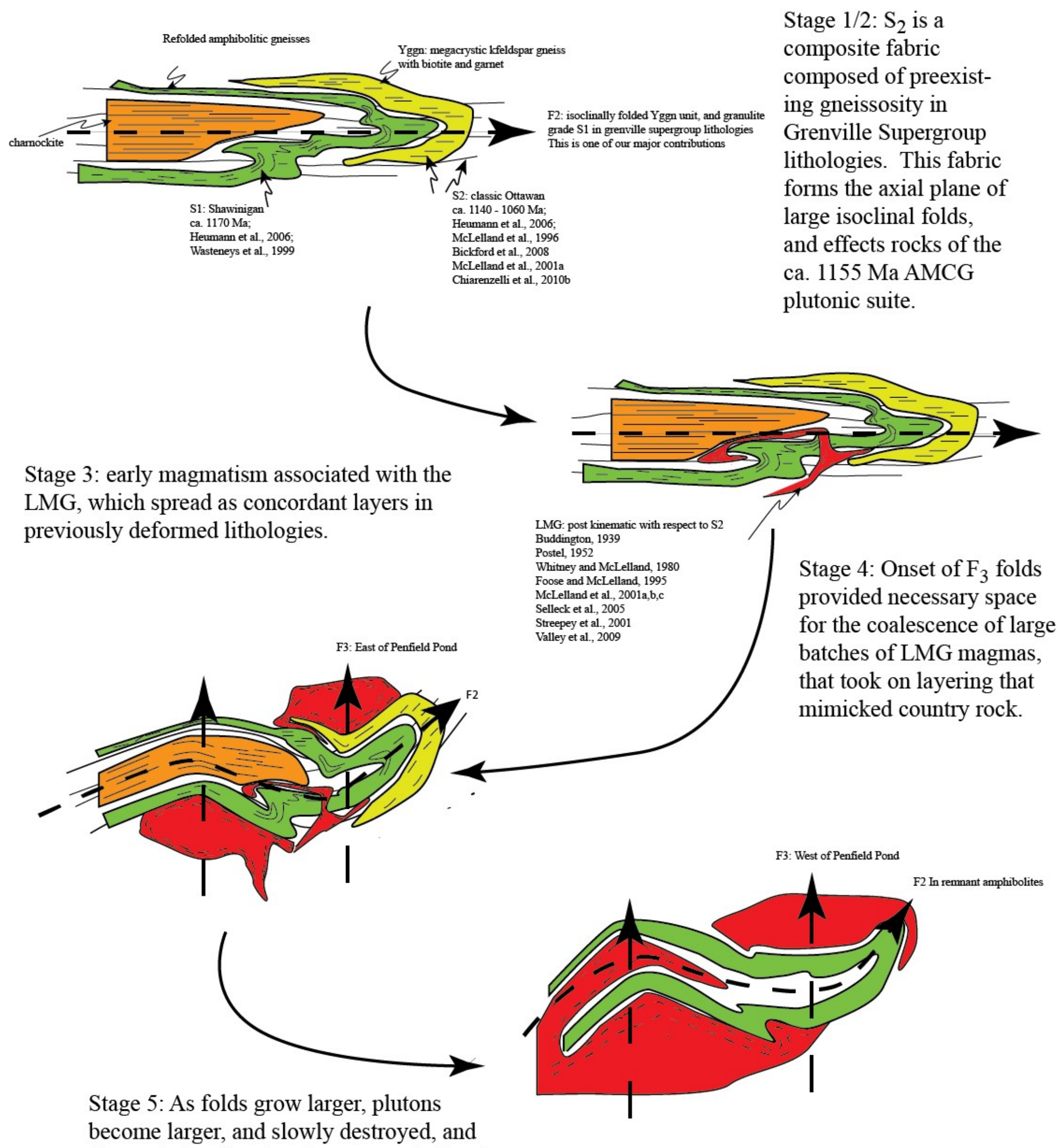

Figure 10: Proposed model describing the structural evolution of the eastern Adirondack Highlands

CONCLUSIONS

The descriptions above provide a basic overview of Grenville Geology of the ELq and beyond. The most important part of this contribution is to put forth a structural nomenclature that is transformative, and represents the major phases of deformation within the ELq and surrounding regions. Good limits exist for the timing of D_1, but little data exists that directly constrains the timing of D_2. Future work should focus on the timing, P-T conditions, and kinematics of this structural fabric.

ACKNOWLEDGEMENTS

First and foremost, we would like to extend a precious thanks to Dr. James McLelland whose rigorous, detailed, and innovative analyses of these rocks has made advances well beyond his predecessors. Secondly, we would like to thank National Cooperative Geological Mapping Fund and the Youth Initiative Fund for providing support to map the Eagle Lake quadrangle. Funding for some of the above geochronology came from a University of Northern Colorado Provost Research and Dissemination grant awarded to Dr. Graham Baird. Paul and Mary-Lloyd Borroughs have been extremely helpful, and beyond nice to the mappers. This project would not be near the place it currently is if it wasn't for their hospitability, friendship, and boathouse. Generous permission from Lyme Adirondack Timberlands (LAT) allowed us to access much of the private land in the quadrangle. Several stops require written permission from LAT to visit these localities; any future visiits must be approved by LAT. The residents of Ticonderoga and Crown Point are acknowledged for their ongoing support. Detailed and thorough reviews were provided by Arthur Merschat and Ryan McAleer, which significantly improved the field trip guide.

ROAD LOG

MEET AT 8:30 AM: Ticonderoga McDonalds Parking Lot (*coordinates in NAD83*)

Location Coordinates: N 43°51.455' W 073°26.258'

0.0 miles: Turn: right out of parking lot and an immediate left onto NY-74

1.0 miles: pull over on right shoulder at long road cut, stop 1.

STOP 1: Roadcut on NY-74, west of Ticonderoga, NY

Location Coordinates: N 43°51.665' W 073°27.495'

The easternmost rock is a poikiloblastic garnet amphibolite that contains garnet-clinopyroxene, plagioclase, and hornblende. Fe-Ti oxides are present as well, though can only be seen in thin section. The garnet crystals can reach upwards of 3 cm in diameter, the best examples are concentrated in the westernmost part of the garnet amphibolite. Schistosity, mostly defined by aligned hornblende and appears to both traverse and wrap around the garnet poikiloblasts, suggesting garnet growth was syn-kinematic.

Further west along the outcrop is a transition zone, marked by a vegetated slope, containing some layers of marble and a rusty weathering paragneiss. West of the transitions zone the vast majority of the outcrop is composed of a garnet-biotite-plagioclase-perthitic microcline-quartz ±

sillimanite migmatitic paragneiss. Leucosome proportion is estimated to be 30-50% and preferentially contains garnet, while biotite is concentrated in the melanosome. Though some texturally late leucosome contains biotite, this can be shown to grade into garnet-bearing leucosome. Both leucosome and melanosome layers are deformed and define a foliation parallel to a schistosity defined by aligned biotite. Quartz and feldspar are granoblastic in both the leucosome and melanosome.

Within the migmatitic paragneiss a number of garnet rich boudins occur, these are possibly deformed and metamorphosed dikes. The boudins indicate stretching in all directions parallel to gneissic layering suggesting a flattening finite strain. Also present within the migmatitic paragneiss are bodies of amphibolite similar to what is present at the east end of the outcrop. Three, 5 to 30 meters wide, unstrained, amoeboid-shaped, pegmatitic granitic plutons also occur in the migmatitic paragneiss.

Mineralogy of the pegmatites includes feldspar, quartz, and biotite. Most feldspar appears to have exsolution lamellae indicating alkali feldspar, but locally plagioclase has been observed. Due to the coarse grain size (upwards of 30 cm for feldspar and quartz and 50 cm. for biotite) the exact lithology has not been constrained, but it is thought to be an alkali-feldspar granite. Locally associated with the pegmatites in the host migmatite are cm. books of graphite.

Fabric orientation is essentially parallel among the garnet amphibolite, the migmatitic paragneiss, and the transitional contact zone between the two. The foliation in the garnet amphibolite and eastern portions of migmatitic paragneiss is approximately 062°, 43° but changes to about 103°, 45° by the westernmost end of the outcrop. Lineation is reasonably parallel to the outcrop face and ranges from a horizontal to 30° plunge, tending 100°. The lineation is defined by aligned hornblende, biotite, or sillimanite, depending on location within the outcrop. Asymmetric tails on garnet poikiloblasts in the garnet amphibolite suggest south side (top) to the west transport.

To constrain timing of geologic events recorded in the outcrop, samples of the migmatitic paragneiss and of pegmatite were processed for U/Pb zircon geochronology. For the paragneiss, given the scale of leucosome and melanosome interlayering, it was not possible to separate the two upon processing, so separated zircon is from both components. Such zircons are euhedral to subhedral, stubby to elongate, yellow to amber to brown in color, and are 100 µm to 500 µm in length.

Cathodoluminescence (CL) of polished grain cross sections show that zircons have a wide variety of internal zoning patterns from oscillatory to irregular zoning (Figure 11 inset). No consistent core-rim zoning pattern (or of any other type) could be generalized for the separated zircon grains. Results of 21 SHRIMP-RG analyses of all types of zircons and all CL zones reveal what it interpreted as a unimodal age distribution. 16 of 21 analyses define a chord with an upper-intercept of 1186 ± 25 Ma, which is interpreted to be the age of migmatization for the paragneiss (Figure 11).

Zircon from one pegmatite body is euhedral to subhedral, equant to stubby, and light pink to purple in color. Zircon size is poorly constrained as most grains are fragments of grains greater than approximately 500 µm. Cathodoluminescence of polished grain cross sections reveal all grains possess oscillatory or sector zoning (Figure 12 inset). No convincing core-rim relationships were found. Fourteen SRHIMP-RG analyses produce what is interpreted as a unimodal distribution of ages. Six if these are nearly concordant and produce a $^{207}Pb/^{206}Pb$ weighted mean age of 1051 ± 25 Ma that is thought to best represent the age of pegmatite formation (Figure 12).

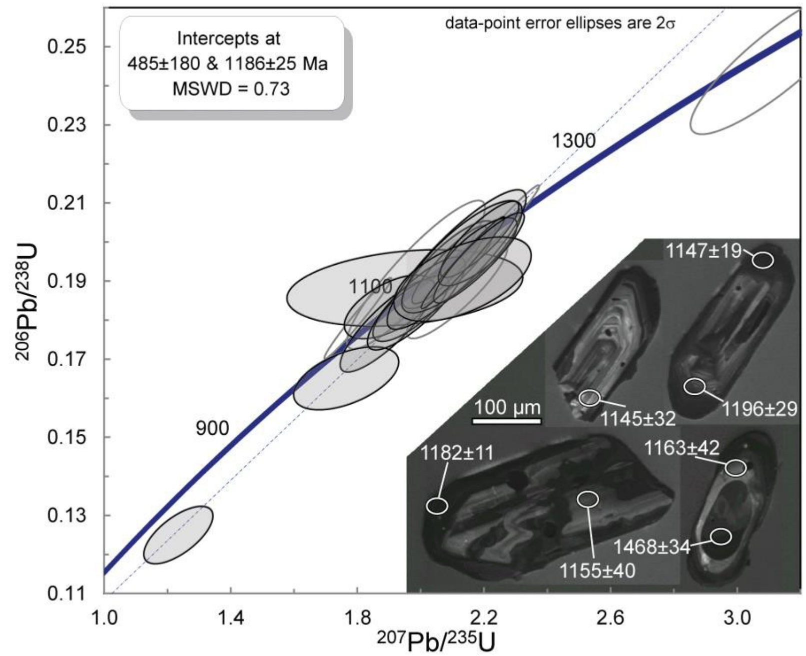

Figure 11. Concordia diagram of U/Pb zircon SHRIMP-RG analysis of the migmatitic paragneiss. Sixteen analyses (shaded) define a chord upper-intercept of 1186 ± 25 Ma (2σ), which is taken as the age of partial melting. One inherited core was analyzed and resulted in a 1468 ± 34 Ma age. Inset shows cathodoluminescence images of representative zircon grains and $^{207}Pb/^{206}Pb$ ages of spot analyses.

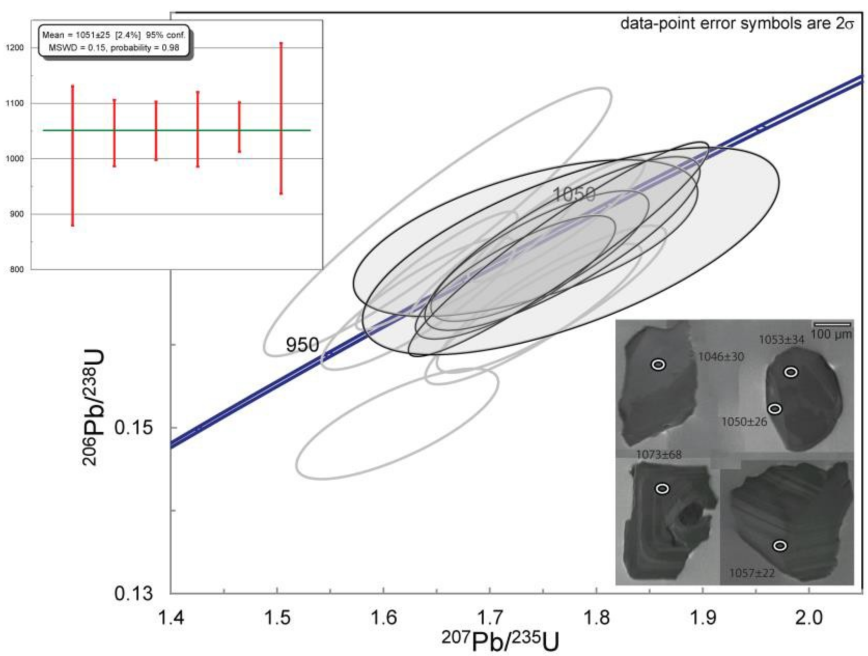

Figure 12. Concordia diagram for 14 U/Pb zircon SHRIMP-RG analyses. Upper-left inset show the $^{206}Pb/^{207}Pb$ weighted mean for the 6 best clustered and concordant analyses (shaded), which produces an age of 1051 ± 25 Ma, thought to be the age of pegmatite. Lower-right inset shows representative grain fragments and spot analyses.

1.0 miles: merge back on NY-74 west (please be careful)

5.4 miles: Turn right onto Corduroy Road (we just drove over a graben, people!)

8.3 miles: Turn left onto Old Furnace Rd

10.9 miles: Pull the car onto the right shoulder (there is really nothing of note here), and walk 235 meters on trail to south, stop 2.

STOP 2: Transposed Grenville Supergroup

Location Coordinates: N 43° 55.548', W 073°34.976'

This is an exposure of metamorphosed and folded meta-siliciclastics of the Grenville Supergroup (Davidson, 1998). Notice the very well layered nature of the rock, the related compositional variability, and the gradational transitions between various layers. Also note several asymmetric folds that are particularly easy to see within leucosome. This suite of rocks saw the following events: 1) deposition, 2) partial melting (M_1), and 3) folding of this migmatitic gneissosity, and the development of axial planar fabric (S_2). These relationships suggest that anatexis and high-grade metamorphism likely accompanied S_1, which is interpreted to be Shawinigan based on the geochronology discussed at stop 1. This suite of rocks is common throughout the ELq, and represents some of the oldest rocks preserved within ELq.

Depart Stop 2, continue on Old Furnace Rd.

11.1 miles: stay left on Old Furnace Rd

11.2 miles: park on right side of road next to mangeritic pavement, stop 3

STOP 3: Contact between mangeritic gneiss and the Grenville Supergroup.

Location Coordinates: N 43°55.753' W 073°35.174'

Several small outcrops are present to the southwest along Old Furnace Road. We will start by the parked cars. In stark contrast to the rocks seen at the previous outcrop, this rock is fairly homogenous. It is a mangeritic gneiss, with hbl +/- grt composing the tails around primary opx (McLelland et al., 1980).

Do you see evidence of more than one phase of deformation within this lithology?

As we move south, we will see a quick transition back into the Grenville Supergroup. This produces an interesting map pattern, a dome structure that is cored by monocyclic mangeritic gneiss, engulfed by meta-siliciclastic rocks of the Grenville Supergroup, with the predominate fabric running parallel to the axial trace of (F2?). However, we know from the previous stop that the predominate fabric we see in the paragneisses is an aggregate of two planar fabrics. The big question is; can we see S1 in the mangeritic gneiss?

Depart Stop 3, continue SW

11.4 miles: turn left onto logging road

12.1 miles: park and walk up old logging road (350 m), stop 4

STOP 4: Hill No. 8

Hill No. 8 is in the northern part of the historic mining town of Hammondville. On the north eastern base is the remains of a great furnace used to melt and separate the ore mined here in the late 19th century (next stop). The remaining slag is the blue stone used on many of the roads in the area that you can see on the drive in and out.

Hill No. 8 was the northern most extent of the mining operations of Hammondville and included two major pits: the Hammond Pit and Number 8 Mine. The number 8 mine is the deepest in Hammondville, reaching depths of up to 1000 ft (Penfield museum, personal correspondence), however the exposure in the Hammond pit is better and more easily accessible.

Magnetite seams in the Hammond pit range from centimeter scale to roughly 2 meters in thickness. The seams display a discrete wavy contact with the host LMG and split into multiple seams in places. They are concordant to the local fabric (038°, 27°) which is much stronger within the vicinity of mineralization. The ore is >70% Fe_2O_3 with slightly elevated REE levels. A thin section of a seam contained beautiful S-C fabrics indicating a reverse sense shear with top to the southeast, Further investigation into the relationship between the timing of deformation and magnetite mineralization is underway. The host LMG immediately surrounding mineralization seems to be very gneissic and contains albite, quartz, amphibole, and pyroxene. It has an Fe_2O_3 content of less than 7%, Na_2O of more that 6.5% and REE levels slightly higher than that of the ore.

A sample of LMG was also collected roughly 100 m from the mine on the western side of Hill # 8 and is elevated in REEs and contains a potassium content an order of magnitude higher than the immediate host. It also records subsolidus deformation, perhaps related to the massive magnetite deposits, however the reverse shear is top to the NW. Again, constraining timing for this is underway.

Turn around and depart Stop 4.

12.9 miles: intersection of logging road with Old Furnace Road, park cars, stop 5

STOP 5: Old Furnace.

Location Coordinates: N 43°55.605' W 073°35.395'

Old Furnace locality. Depart by turning left onto Old Furnace Road.

18.1 miles: turn left onto Paradox Rd

18.7 miles: turn left onto NY-74 (heading east)

19.8 miles: turn right into parking lot with cannonball, park, walk 350 meters west on NY 74, then go north in the woods, stop 6.

STOP 6: Schofield magnetite mine.

Location Coordinates: N 43.888°, W -73.637°.

WARNING: Route 74 is a busy road with lots of heavy truck traffic.
Walk single file and stay well to the side of the road.

Walk west down the road for approximately a quarter mile until you reach a brown and yellow sign marking the boundary of the Adirondack Park. Proceed into the forest for approximately 75 meters to the base of a cliff.

This stop examines the relationship between magnetite ores and the Lyon Mountain granite (LMG) that hosts the ore. Most of the main ore seam has been mined out and is covered by large blocks of mine waste. However there are places where the relationship between the ore and the host granite can be observed. The main ore seam starts here at the base of the cliff and gradually climbs up the hill to the east parallel to the main foliation in the granite. The host rock on either side of the ore seam is albitized granite and is the result of fluid alteration. The amount of albite in the rock gradually diminishes as distance from the mineralized ore zone increases and perthitic feldspar becomes common. The ore is comprised of magnetite and apatite ± quartz. The apatite is generally reddish in outcrop and is extremely enriched in light rare earth elements and high field strength elements (especially Y, Ce and Nd). The mineralogy of the "granite" varies from perthitic feldspar + quartz + magnetite ± clinopyroxene, biotite, and amphibole in the least altered rocks, to quartz + albite + magnetite ± apatite and chlorite in the most altered zones. The contact between the ore and the granite is generally sharp but a large boulder here at the base of the cliff shows numerous mm-thick layers of magnetite. Zircon grains from the ore have been dated at 1000.9 ± 9.2 (2σ) (Valley et al., 2009).

Proceed uphill along the ore seam approximately 75 meters to the east by following an animal trail and scrambling over boulders. Here the ore is perfectly exposed in a large out of place slab and is where the geochronology sample was collected. Even though a reliable age for the host LMG could not be obtained at Skiff Mountain, the age of the zircon in the ore here is at least 34 my younger than that of the granite. This is based on the age of zircon rims in the LMG that was successfully dated near here at Eagle Lake (see EAGLE LAKE STOP; Figure 13).

Continue following the ore seam uphill to the east. Watch for a small outcrop of hematized breccia. The ore seam will disappear under mine waste rock and forest. At this point head directly uphill until reaching a relatively flat area. You will see what appears to be a ditch, sometimes filled with water, backed by a 3-4 m high outcrop. This is the top of the upper ore seam. Follow this relatively flat area to the west. At 43.886056, 73.637028, the top of the upper ore seam is visible. The ore seam is approximately 0.5 m thick with a second 2-3 cm thick vein just above the main ore. The adjacent granite is typically lacking in disseminated magnetite in the vicinity of the veins, but disseminated magnetite reappears where veins are lacking and distal to the ore vein. Near the top of this outcrop small lozenge shaped quartz-feldspar-magnetite pegmatites are present (~20-30 cm long). Follow the upper ore seam west for approximately 60 m. Here 1 m below the ore body, there are two amphibolite layers 10 to 20 cm thick. Recent geologic mapping suggests that these are mafic "screens" that were incorporated in the LMG during intrusion. Zircon grains from one of these layers have been dated at 1046 ± 11 Ma (2σ) (Valley et al., 2011) with rare zircon cores that are ~1150 Ma. These layers and the host LMG have been overprinted by Na fluid alteration providing a maximum age for Na fluid alteration. The increase in albitization around the ore suggests Na metasomatism is coeval with zircon growth and ore mineralization. It is probable that the U/Pb age from zircon in the amphibolite layer is the product of metamorphism or possibly a fluid alteration event that is older than the fluids associated with the growth of zircon in the ore at Skiff Mountain.

Depart by turning right out of parking lot, headed east on NY-74.

21.3 miles: enter small pull off on left, walk 75 meters east on NY-74, stop 7.

STOP 7: The Lyon Mountain Granite Gneiss (after Postel, 1956)

From the cars, walk east about 0.3 miles to an outcrop on the right (south) side of the road. At this locality a granitic pegmatite dike crosscuts the fabric of the LMG. The LMG has been altered by K-rich fluid alteration that has been overprinted by minor Na alteration. The crosscutting dike has also experienced minor Na alteration. Both the dike and the granitic hosts have extreme concentrations of potassium for granitic rocks (~8 wt.% for both rocks). It is not clear if the dike is high in potassium because it intruded an already metasomatized rock and thus was enriched in K_2O by a relatively closed system, or if both the dike and the host were altered by potassium bearing fluids together in an open system. Both the dike and the granite experienced subsequent minor sodic alteration. The dike is comprised of coarse microcline, quartz, and biotite, with minor plagioclase, zircon, apatite, and magnetite ± clinopyroxene and muscovite. Plagioclase is secondary and is present interstitially and in "patch" perthite which crosscuts microcline grains.

A sample from the dike was collected for U/Pb zircon geochronology and was dated by Secondary Ion Mass Spectrometry (SIMS). Zircon crystals from this sample are elongate (300-500 µm long), clear with patchy zonation in BSE images, and typically contain large inherited cores of both AMCG (~1150 Ma) and LMG (~1060 Ma) age. The zircon rims from grains with relict cores and grains without cores have a concordant age of 1030.4 ± 1.8 Ma (2σ) (Valley et al. 2011). The aforementioned field relations imply that Na alteration has to be younger than the U-Pb zircon age of the dike. They also suggest that the forces responsible for fabric development within the LMG must have ended by this time.

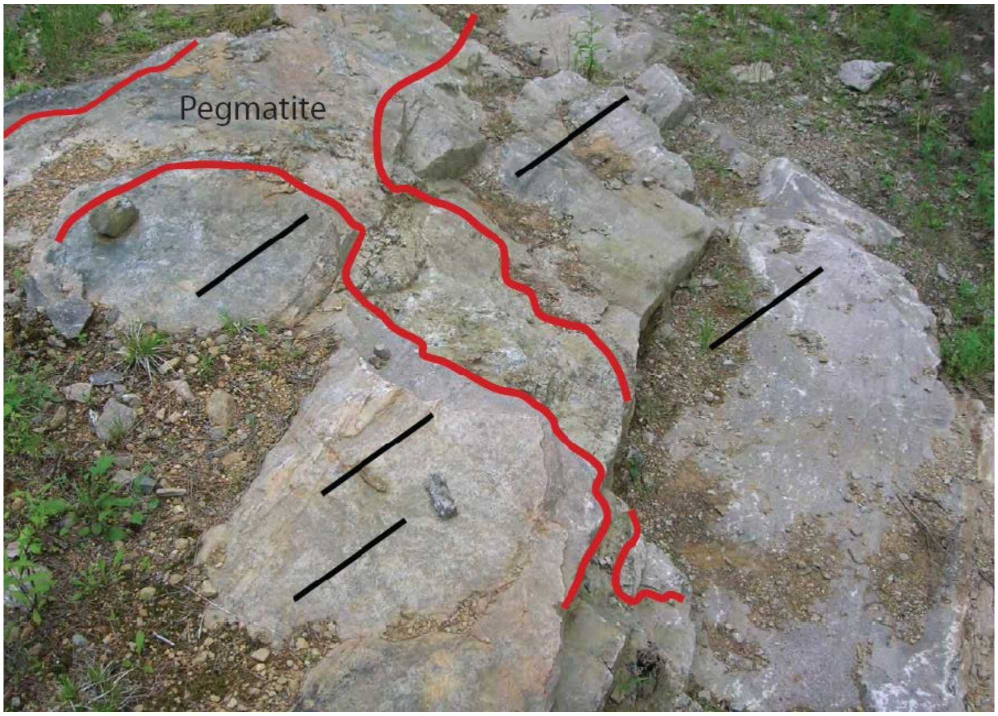

Figure 13: Field photograph showing layering (black lines) in LMG being crosscut by pegmatite dike on 74.

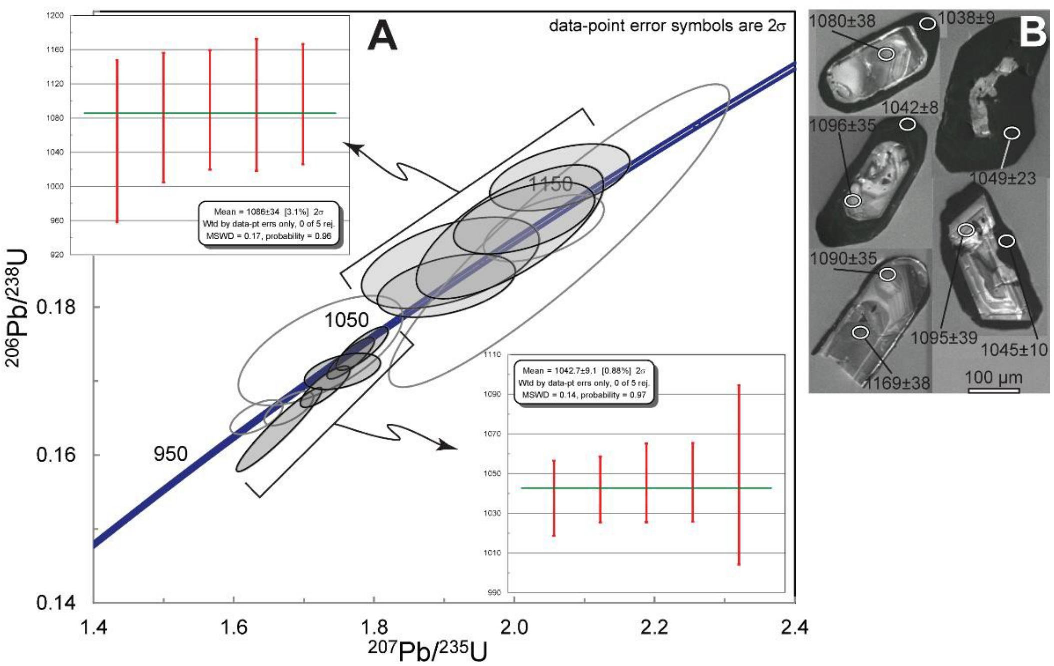

Figure 14: A) Concordia diagram from Skiff Mt. LMG. Shaded ellipses represent analyses used in weighted averages for cores (c. 1086 Ma, upper-left inset) or rims (1043 Ma, lower-right inset). B) Representative zircon cathodoluminescence images and spot analyses. Ages are 2σ $^{207}Pb/^{206}Pb$ ages.

A sample of the host rock was collected within in a few meters of the dike discussed above in order to constrain the timing of Skiff Mt. LMG intrusion. Zircons separated from the sample are euhedral to subhedral, stubby to elongate, typically 200-500 µm long, and are amber to brown in color.

Cathodoluminescence (CL) of polished grain cross sections reveal that most zircons have oscillatory zoned cores and prominent dark rims with subtle and limited oscillatory or patchy zoning (Figure 14). A few grains appear to possess a core, mantle, and rim. In such grains, rim CL is consistent with the rims of other grains, with the mantle and core both having oscillatory zoning. Twenty U/Pb SHRIMP-RG analyses of all zones demonstrate that the cores (or mantle, if three zones are present) are 1086 ± 34 Ma (2σ $^{207}Pb/^{206}Pb$ weighted average, 5 analyses; Figure 14), while rims cluster at 1043 ± 9 Ma (2σ $^{207}Pb/^{206}Pb$ weighted average, 5 analyses, Figure 14). For grains with three zones, only two cores were analyzed and produced 2σ $^{207}Pb/^{206}Pb$ ages of 1169 ± 38 Ma and 1138 ± 28 Ma. These older core ages are interpreted to be inherited, while the c. 1086 Ma age is interpreted to be the magmatic crystallization age of the Skiff Mt. LMG body, with the c. 1043 Ma rim age representing the timing of fluid alteration. Though the timing of fluid alteration age is slightly older than the age of the altered pegmatite dike at the limits of error, we believe that pegmatite dike intrusion and fluid alteration were in close temporal proximity.

Depart and stay east on NY-74

24.7 miles: turn left onto Corduroy Rd

29.5 miles: stay straight

29.7 miles: Turn right onto Towner Hill Road

30.5 miles: stay straight

31.9 miles: Turn right by Gleebus sign

32.9 miles: Take left by amphibolite

33.1 miles: Park at log landing, follow trip leaders into the woods for 30 meters, stop 8.

STOP 8: Highly deformed augen gneiss

Location Coordinates: N 43°54.356’ W 073°31.875’

We are in the eastern portion of the quadrangle, which is dominated by large amplitude, upright folds that contain a calculated β-axis of 10 to 112 (Figure 6). There is no identified axial planar fabric associated with this fold generation (F_3). The rock exposed here is a strongly deformed augen granitic gneiss (Yggn on new 7.5’ quadrangle map). Any one exposure typically contains both pegmatitic (mesoperthitic) varieties that are weakly deformed as well as biotite-megacrystic varieties that are strongly deformed and contain >5% modal garnet (vol%). The latter unit is isoclinally folded (F_2), and contains a very strong S_2 here. Can we see a lineation? Is there evidence of folding at the outcrop scale (F_1)?

This unit is still undated, but is currently thought to be equivalent or older than ca. 1165 Ma.

Depart Stop 8 by turning around.

33.3 miles: Turn right by amphibolite

34.4 miles: Turn left onto Towner Hill Road

36.6 miles: Turn left onto Corduroy Road

36.8 miles: veer onto Corduroy

38.2 miles: take left onto dirt road, park before bridge, hike west (upstream) on dog trail for 2.0 km, stop 9.

STOP 9: Penfield Pond – granite pegmatite cross cutting amphibolitic gneiss

Location Coordinates: N 43°54.992' W 073°32.189'

We are in the hinge of an F_3 fold. We have walked through the LMG the entire way here. This outcrop contains amphibolitic gneiss, which is locally migmatitic, and a concordant lens of mesoperthite granite. The mesoperthite granite is typically associated with the augen gneiss seen at Stop 8, despite the lack of tectonic fabric within the granite. At one location in the outcrop (Fig. 5a,b), the granite cross cuts the amphibolite gneiss at a low angle. This truncation suggests that migmatization predates the mesoperthite granite, and that migmatitic layering is transposed to be nearly parallel to S_2, but may have occurred during S_1.

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