GEOLOGY AND GEOCHRONOLOGY OF THE EASTERN ADIRONDACKS

By

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INTRODUCTION

Geologic background and detail for the Adirondack region is summarized in the introduction section of trip A-1, "Geology and geochronology of the southern Adirondacks" by McLelland, Storm, and Spear. The reader is referred to that section for relevant background information. Here we summarize broad considerations pertaining to the eastern Adirondacks.

The eastern Adirondacks contain a wide variety of rock types, and this trip aims to visit representatives of the major lithologies. Stops include units recently dated by U-Pb geochronology including multi- and single-grain TIMS and SHRIMP II analyses. Results of these investigations are presented in the text of trip A-1, to which the reader is referred. Broadly, the various lithologies fall into the following groups: 1300-1350 Ma tonalites and granodiorites; 1150-1160 Ma anorthosites, mangerites, charnockites, and granites (AMCG suite); 1090-1100 Hawkeye granite; and 1035-1060 Ma Lyon Mt Granite (LMG). The two major orogenic events associated with these are the Elzevirian and Ottawan Orogenies (Moore and Thompson, 1980). The former falls into the interval ca 1350-1170 Ma and involves protracted arc magmatism and accretion capped by a culminating collisional orogeny from ca 1200-1170 Ma (Wasteneys *et al*, 1999). The latter refers to the Himalayan-type collision of Laurentia with Amazonia during the interval ca 1090-1000 Ma. Most of the metamorphic and structural effects present in the Adirondacks are the result of the Ottawan Orogeny, but Elzevirian features can be recognized locally. Both the AMCG suite and the LMG are thought to be late- to post-tectonic manifestations of delamination of overthickened orogens.

Structurally, the eastern Adirondacks are dominated by the same large, recumbent fold-nappe structures (F_2) as found in the southern Adirondacks, and with fold axes oriented dominantly ~E-W parallel to lineation. As in the southern Adirondacks, the fold-nappes are thought to have sheared-out lower limbs, but this has yet to be demonstrated on a map scale. At least two distinguishable upright fold events are superimposed on the nappes: F_3 with shallow plunging ~E-W axes and F_4 with shallow-plunging NNE axes. All of three fold sets affect Hawkeye and older units, and thus must be of Ottawan age. This also the case with the strongly penetrative rock fabric, including strong ribbon lineations, that are present in these rocks and are associated with the large fold-nappes. Intense fabric of this sort is largely absent from the Lyon Mt Granite and this is interpreted to reflect its intrusion in late, post-nappe stages of the Ottawan. In the northern portion of the eastern Adirondacks the NNE, F4, folds become quite tight and have a strong lineation associated with them. This may be the result of rock sequences being squeezed between large, domical prongs of anorthosite. Finally, we note that there exists abundant local evidence of small isoclinal F_1 folds that pre-date F_2. These, and their associated fabrics, are thought to be Elzevirian in origin, and in a few cases this can be shown to be the case.

A dominant feature of the eastern Adirondacks is the great Marcy anorthosite massif that underlies almost all the High Peaks. Over two-dozen zircon age determinations demonstrate that the anorthosite was emplaced at 1150 ± 10 Ma (Table 2, Trip A-1) and that associated granitoids and coronitic metagabbros are coeval with it. These relationships make it clear that thermal energy from the anorthosite had nothing, whatever, to do with the granulite facies that characterize the Adirondack Highlands and post-date the AMCG suite by 60-100 million years. The specifics of Adirondack P,T relationships and uplift history are discussed trip A-1 and its appendix AA-1. It is likely that most of the region experienced peak temperatures on the order of ~800° C and pressures of ~8 Kbar. Based upon extensive isotope work by John Valley and his students, it appears most likely that this metamorphism proceeded under fluid-absent conditions (Valley *et al.*, 1983). Note, however, that this does not exclude the presence of late, post peak, fluids associated with the emplacement of Lyon Mt Granite.

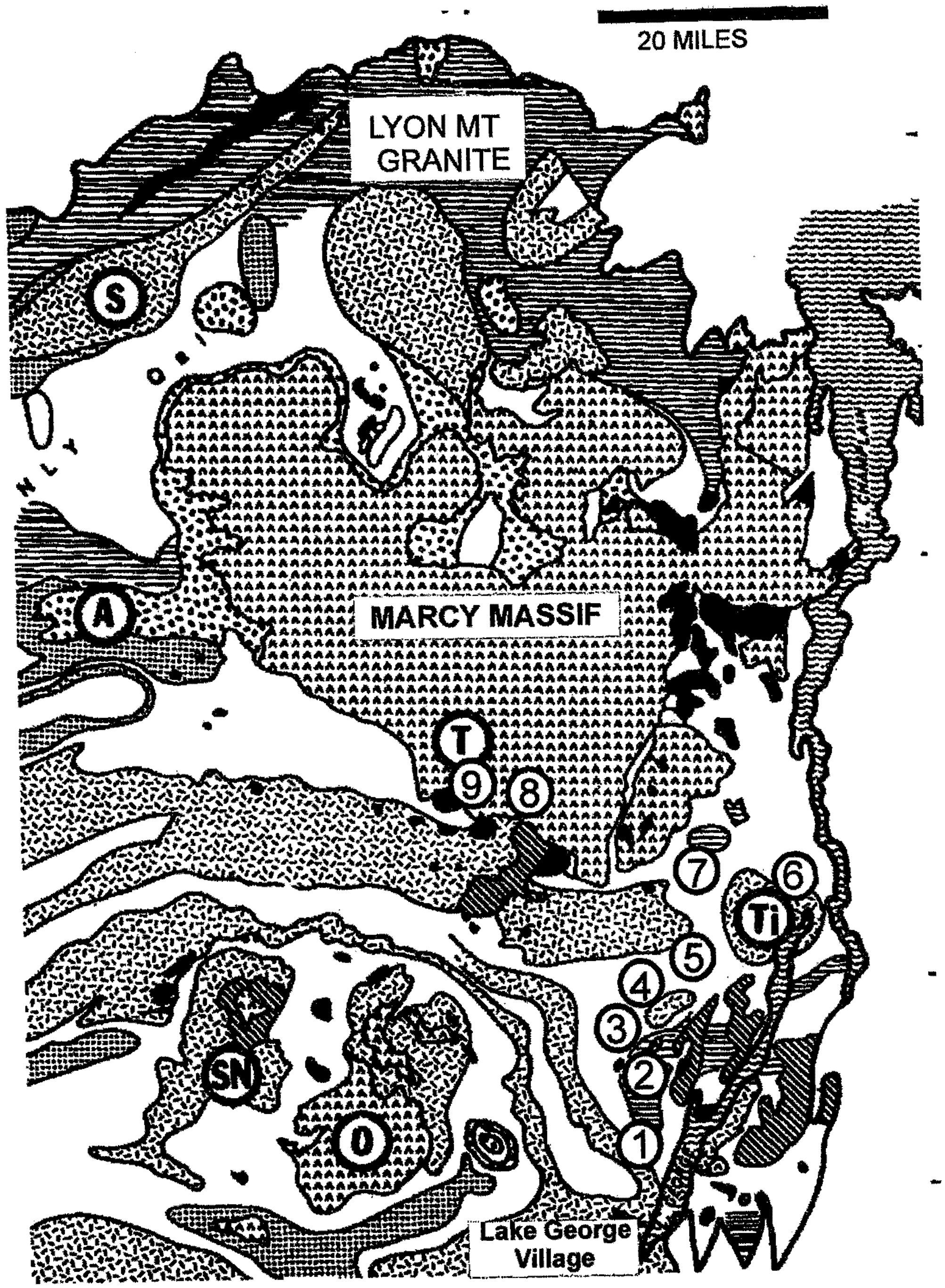

Fig. 1 . Generalized geologic map showing field trip stops. Seetrip A-1 for geologic details. A- Arab Mt anticline, S- Stark anticline, T- Tahawus, Ti- Ticonderoga Dome, O-Oregon Dome, SN- Snowy Mt Dome. See Fig. 3, Trip A-1 for legend .

ROAD LOG

Mileage

0.0 Start in the parking lot of the Fort William Henry Motel and Conference Center, Lake George, NY. T Turn left (south) on Rt. 9.
0.5 Pass Prospect Mt entrance on right.
1.0 Junction with 9N. Turn right at light.
1.2 Turn right (north) on Northway (Rt 87). Note exposures of pink granite along Northway.
4.0 Sulfidic staining on NNE fault in granite.
5.5 Exposure of hornblende granite on left.
5.9 Pegmatite on right.
6.0 Pass metagabbro
6.7 Hornblende granite on both sides.
7.0 Hornblende granite
7.2 Hornblende granite with metagabbro
7.4 Metagabbro, pegmatite, and metasediments on right.
7.5 Take Exit 23 off of Northway
8.0 Turn right at stop sign
8.4 Turn left (north) onto Schroon River Road.
8.8 Junction with Wall St on right. PARK

STOP 1. MEGA-GARNET AMPHIBOLITE. (20 MINUTES). This small roadcut at the intersection of Schroon River Road and Wall Street is an example of what is referred to as a "Poor Man's Gore Mt.". The roadcut contains large (up to 8" across) almandine-rich garnets rimmed by black hornblende and set into an amphibolite matrix that can be shown to have formed from metagabbro. The assemblage is reminiscent of the famous deposits at the Barton Garnet Mine on Gore Mt where garnet growth has been dated at ca 1050 Ma (Mezger *et al*, 1990) using Sm-Nd techniques. The northern contact of the present exposure is characterized by a deformed hornblende-biotite-quartz-oligoclase pegmatite that also crosscuts the interior of the garnetiferous amphibolite. Several other examples of "Poor Man's Gore Mt" occurrences are present in the Adirondacks, and all – including Gore Mt- share in common proximity to high angle faults that host pegmatites, quartz-veins, etc. We propose that the faults served as plumbing systems for hydrous magmas that provided water to the amphibolites at temperatures of ~700°-800° C. This anomalous circumstance resulted in elevated diffusion rates that enhanced garnet growth at a small number of nucleation sites. The hornblende rims represent the excess of hornblende constituents in the area of local garnet growth. Post peak decline in the activity of H_2O, or continued increase of T, caused reactions between garnet and hornblende to produce calcic plagioclase (AN80) and orthopyroxene.

12.6 Bridge across Schroon River
12.7 Stop sign. Turn right (north)
17.7 Park on shoulder of road.

STOP 2. ca 1300 Ma TONALITE. (20 MINUTES). These outcrops consist of tonalitic rocks dated elsewhere as ca 1300-1350 Ma by U/Pb zircon. Their chemistry is calcalkaline, and, together with associated granodiorites, they are interpreted as having formed in one, or more, magmatic arcs during the Elzevirian events of ca 1400-1220 Ma. Locally these units contain xenoliths of, or crosscut, metasedimentary rocks, thus establishing a minimum age for most, if not all, of these units in the Adirondacks. (See Stop 4, Trip A 1-1)

19.7 Junction with Northway (Rt 87). Enter northbound ramp.
31.3 Exit Northway at Pottersville.
31.6 Stop sign. Turn right (north) at junction with Rt 9.
31.7 Continue right on Rt 9.
32.3 Turn right (east) on Glendale Road by Word of Life Bible Camp.

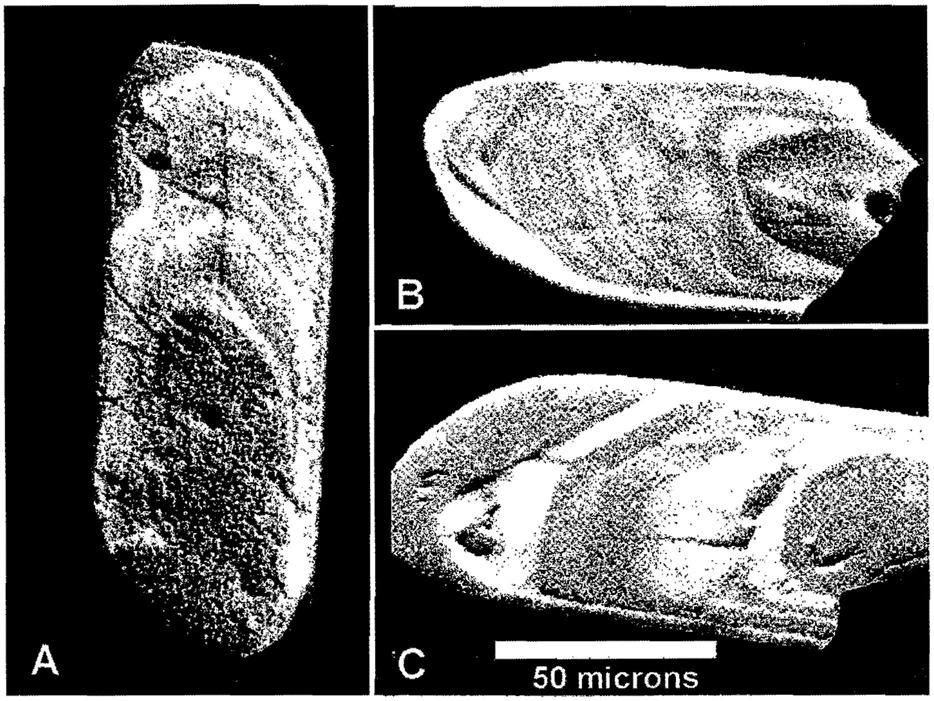

Fig. 2 CL images of zircons from Lyon Mountain Granite at Stop 3. Note the euhedral morphology and sharp terminations as well as the presence of oscillatory zoning in mantling zircon indicative of magmatic growth. Half grains such as B,C yielded 1049 $\pm$ 2 Ma.

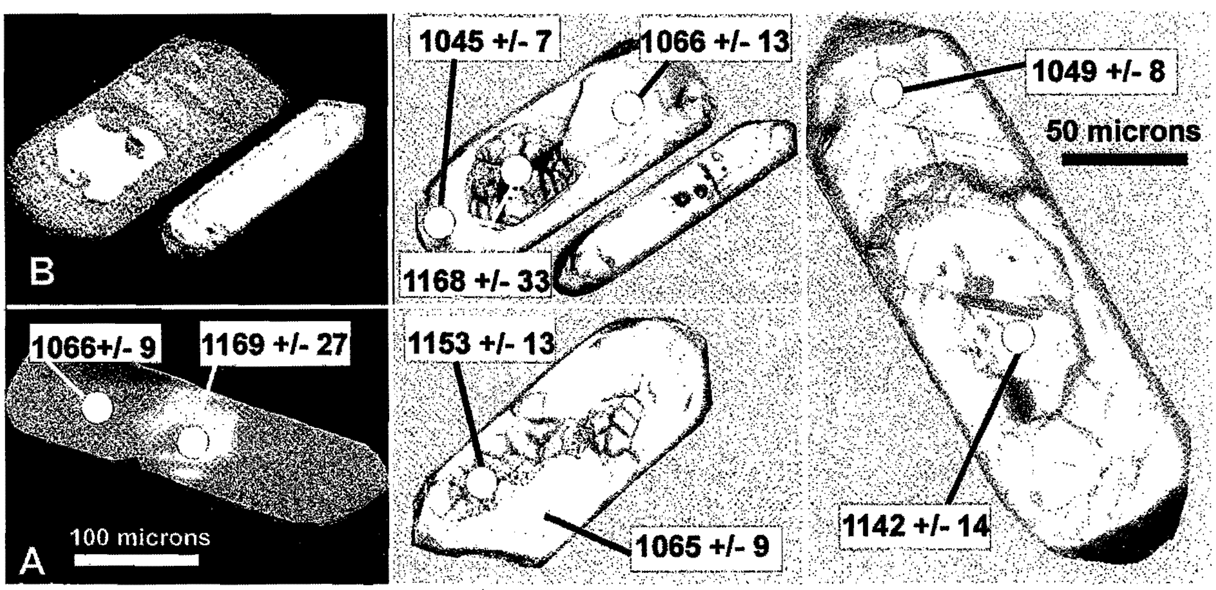

Fig. 3 CL images (A,B) and transmitted light (C,D,E) of typical Lyon Mt Gran2ite. In all cases corroded AMCG cores are surrounded by thick mantles of ~ 1050 Ma zircon that commonly shows excellent oscillatory zoning (E) indicative of magmatic growth.

34.0 Quartz-sillimanite nodules in Lyon Mt Granite.
34.2 Roadcut of Lyon Mt Granite on left (north) side of Road. Park on right next to Smith Pond.

STOP 3. ca 1050 Ma LYON MT LEUCOGRANITE. (30 MINUTES). The medium grained, pink leucogranite is characteristic of the main quartz-microperthite unit of Lyon Mt Granite that occurs in broad tracts across the Adirondack Highlands. The classical low-Ti Kiruna-type magnetite deposits of the Adirondacks are closely associated with the granite, either occurring within it or in rocks (usually metacarbonates) immediately adjacent to it. Magnetite mineralization is commonly accompanied by sodic alteration manifested by checkerboard albite and by quartz-albite (Ab_{98}) replacements of the original quartz-microperthite rocks (McLelland et al., 2002). A total of six occurrences of Lyon Mt Granite from across the Adirondacks have been dated by U/Pb techniques including single and multigrain TIMS and SHRIMP II (Fig. 2). All of these fall into the interval 1050 $\pm$ 10 Ma (McLelland et al., 2001). The present roadcut was dated by single grain TIMS methods and yields an age of 1049 $\pm$ 2 Ma (Fig. 3). Staining of the roadcut reveals that it contains several sheets and layers of quartz-albite one of which is associated with a irregular veinlet of magnetite. Locally, quartz-sillimanite nodules are present in these rocks and are attributed to leaching by high temperature hydrothermal fluids (McLelland et al., 2002). Pegmatites and quartz veins are common.

34.9 Turn left (north) on Short Street
35.4 Turn left (north) on Adirondack Road.
37.3 Turn right (northeast) on Pease Hill Road.
38.2 Stay left at intersection
40.9 Turn left (north) at intersection with Palisades Road.
41.6 Quartz-sillimanite nodules in Lyon Mt Granite included by Walton and deWaard in their "Basement Complex".
43.0 Junction with Rt 8. Turn left (northeast) at stop sign.
43.7 Metapelites assigned by Walton and deWaard to their "Older Paragneiss".
44.3 Marble, calcsilicate of Walton's "Paradox Lake Formation in near continuous outcrop for 2.6 miles.
46.9 Long roadcut of migmatitic metapelite assigned by Walton to the "Treadway Mt Formation". Park.

STOP 4. HIGHLY DEFORMED MIGMATITIC METAPELITES (> 1300 Ma). (30 minutes). The southern and eastern Adirondack Highlands, as well as the Northwest Lowlands, contain a significant thickness of dark garnet-biotite-quartz-oligoclase + sillimanite metapelite accompanied by a garnet-bearing white quartz-feldspar leucosome. McLelland and Husain (1986) interpret the leucosomes as *in situ* anatectic products of the original rock and the dark fraction as restite. Greywacke is a likely precursor. The presence of armored spinel, and rarely corundum, are consistent with this interpretation. In regions of low strain the leucosomes are present as crosscutting, anastamosing, irregular sheets, dikes, and veins of clearly coarse-grained pegmatitic material. As strain increases, the pegmatitic material gets pulled into psuedoconformity, disrupted, and grain size reduced so as to yield porcellaneous layers that are commonly parallel but locally retain their original crosscutting configurations. In short, the apparent layering in these rocks is almost wholly tectonic and has nothing to do with original stratigraphic superposition. They are, in fact, mylonitized migmatites, of the variety referred to as "straight gneiss". As indicated in stop 2, these metapelites are crosscut by the ca 1300 Ma tonalitic suite, and therefore post-date these rocks. Our interpretation is that their current reintegrated compositions are best accounted for by a greywacke-shale precursor, and that these were arc-related, flysch-type sediments approximately coeval with the Elzevirian tonalites. This would also help to explain the relative proximity between these lithologies. The age of anatexis is currently being investigated, but a pilot SHRIMP II study on a leucosome from near Speculator reveals a complicated pattern of zoning and inheritance with cores of age ca 1240 Ma and metamorphic overgrowths of 1010-1040 Ma. Sandwiched between these are mantles with oscillatory zoning and ages of 1170-1180 Ma. We interpret these mantles as zircon grown during anatexis and dating this event as Elzevirian. The absence of further significant anatexis in the granulite facies Ottawan Orogeny (1090-1030 Ma) is thought to be the result of earlier dehydration of the migmatites during the Elzevirian anatexis. Both mafic and granitic sheets can be traced across the roadcut face and reveal the presence of fault offsets. Note that the name "Treadway Mt Formation" assigned to this unit by Walton suggests that it has stratigraphic characteristics and continuity. This assumption is no longer considered to be correct and is, at best, is a lithotectonic assignation.

47.2 Granite and gabbro.

47.9 Large isoclinal fold in quartzites and metapelitic rocks.
48.1 Undeformed gabbro.
48.4 Marble. Park in parking area.

STOP 5. SWEDE MT SEQUENCE. (60 MINUTES INCLUDING LUNCH). The metasediments exposed along the Rt 8 at Swede Mt provide an exceptional opportunity to closely examine both the rocks and structure. At the southwestern end of the sequence (mile 48.9) a well-exposed isoclinal fold can be seen in the large roadcut on the south side of Rt 8. Folded units include marble, quartzite, sillimanite-garnet-quartz-feldspar (khondalite) gneiss, and rusty sulfidic Dixon Schist. The latter is thought to represent a sheared, altered, and graphitic variety of the khondalite. The fold axis trends ~E-W at a low angle of plunge about the horizontal, and its axial plane, which dips from ~50 degrees SW to horizontal, has been folded about upright E-W axial planes. The fold is typical of refolded isoclines in the Adirondacks. Similar rocks at Dresden Station, on the east side of Lake George, are intruded by a metagabbro dated at 1144 $\pm$ 7 Ma. At this locality the metagabbro truncates foliation and even individual garnet grains in the khondalite. These relations indicate that the khondalite was deposited and first metamorphosed in Elzevirian times. Early workers considered the khondalite to be a stratigraphic unit (Hague Gneiss or Spring Hill Pond Formation), but regional mapping suggests that individual units are continuous over distances of miles. Both Dixon schist and the khondalite were mined for flake graphite during the early part of the century. The region around Swede Mt is known as the Dixon National Forest and the former mining hamlet of Graphite is located at mile 49.8.As Rt 8 is followed eastward, an undeformed dolerite dike is encountered. The dike strikes parallel to the highway and has caused brecciation and alteration of the country rock that consists principally of marble at this locality.. At the top of the hill, and across from Swede Pond, a long roadcut exposes typical Adirondack marbles. At the eastern end of these exposures, a thick bed of quartzite is wrapped around the nose of an isoclinal fold. Note the linear features along its axis.
49.7 Elephant rock. Consists of leucocratic sillimanite-garnet-quartz-feldspar gneiss (khondalite).
49.8 Khondalite, Dixon Schist and graphite. Park on right side of road in area leading to old graphite mines.
54.2 Stop sign. Turn left (north) at junction with Rt 9N.
61.2 Charnockite of the Ticonderoga Dome. Park on right side of road.

STOP 6. TYPICAL AMCG CHARNOCKITE OF TICONDEROGA DOME (15 MINUTES). These outcrops were dated at 1113 $\pm$ 10 Ma by Silver (1969) but are certainly ca 1150 Ma member of AMCG suite. Silver's "young" reflects the fact that air abrasion was not yet in use when he did the analyses. Note the strong fabric that is typical of AMCG granitoids.
63.7 Rotary. Bear left (north) on Rt 9N.
64.4 Stop light. Junction with Rt 74. Turn left (west).
65.5 Complex roadcut of marble, calcsilicate, and gabbro.
75.9 Park on right hand (northern) shoulder of Rt 74. DANGEROUS SPOT! USE EXTREME CARE!!

STOP 7. LOW-TI MAGNETITE ORE IN LYON MT GRANITE WITH QUARTZ-ALBITE FACIES. (30 MINUTES). Old magnetite mine workings are located a few hundred feet uphill from the highway and are defined by the excavation of magnetite ore along meter-scale layers dipping ~ 45 degrees north. A meter-thick pillar of magnetite-apatite ore was left in place to support the hanging wall. The area below is strewn with waste rock from the 19th century mining operation. The hanging wall of the mine consists of the quartz-microperthite facies of Lyon Mt Granite (Fig. 2). Thin section study (Fig. 4) reveals that for about 150 ft uphill the perthite is progressively replaced by albite with replacement, and checkerboard albite, increasing in the direction of the mine opening. As the mine opening is approached the amount of K_2O in the rock decreases, and below the mine pillar, the rock consists of quartz-albite rock with magnetite and small quantities of aegerine. McLelland et al (2002) have interpreted both the magnetite and quartz-albite rock to be the result of metasomatic replacement due to the percolation of regional fluids at high temperature. It is thought that the fluids were derived from evolved surface brines rich in Na, Cl, and scavenged iron. Heat from Lyon Mt Granite drove these hydrothermal cells as they penetrated into the outer margins of Lyon Mt Granite plutons shortly after crystallization. This is consistent with oxygen isotope results (McLelland et al, 2002). SHRIMP II geochronology demonstrates that the quartz-albite rock contains cored zircons with mantles showing good oscillatory zoning and ages of ca 1050 Ma. These grains are interpreted as unreplaced zircons remaining from the original quartz-microperthite precursor.

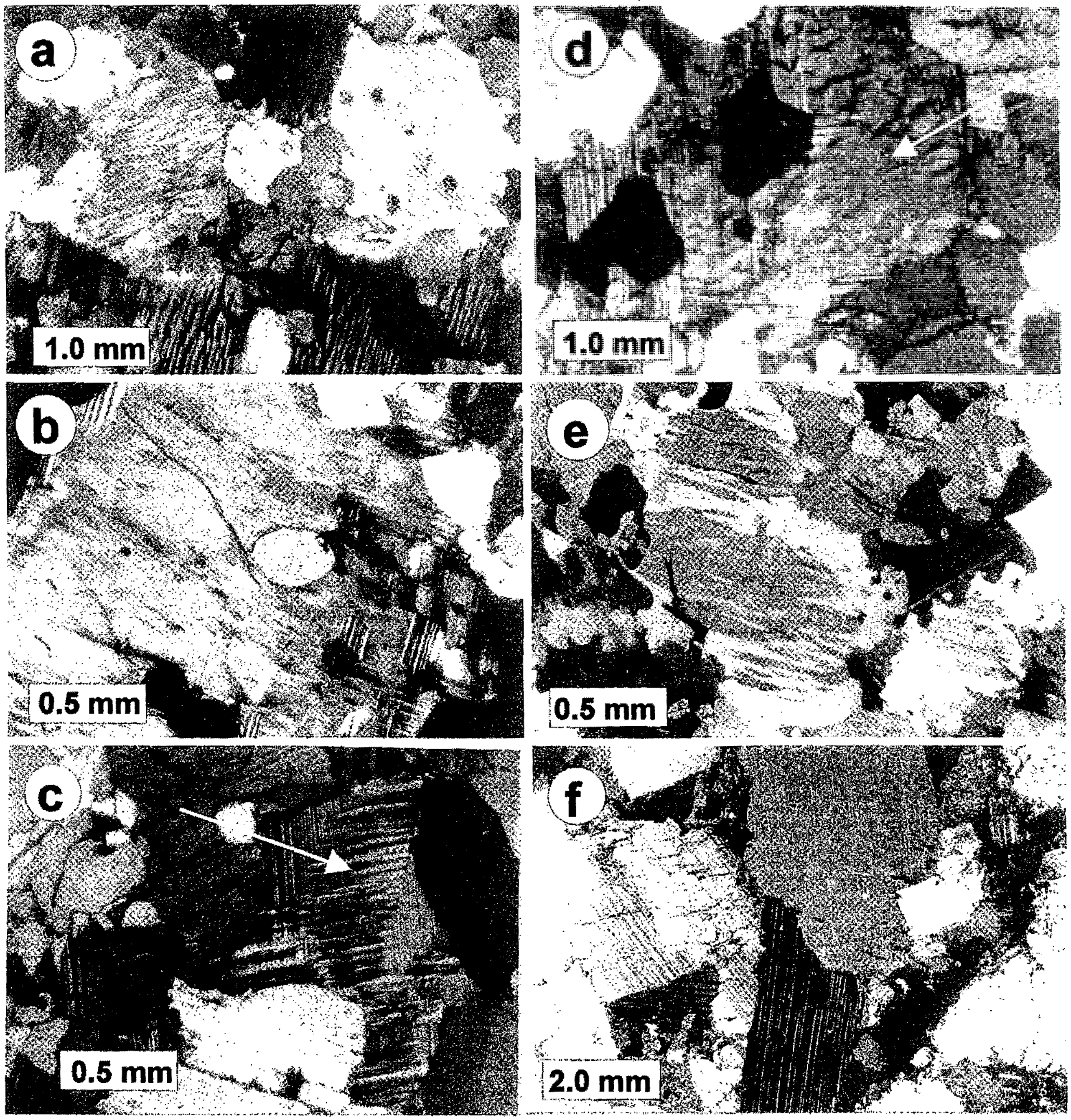

Fig. 4 Photomicrographs (crossed polars) of representative samples of LMG fromSkiff Mt traverse. Photos were chosen to illustrate the progressive replacement of original microperthite (a) by albite leading to checkerboard texture (b). In '(c) most of the dark grain is checkerboard albite and only asmall remnant of microperthite remains (arrow).By (d) only a ghostly remant of microperthite is visible in the checkerboard albite. The grain in (e) thick albite rims have engulfed most of a perthite grain that also shows checkerboard twinning. The end result of this replacemnt is represented by the quartz-albite rock in (f)

76.4 Marble
77.0 Marble then granitic gneiss.
75.5 Marble for next 2.3 miles. Note disrupted amphibolite forming "tectonic fish").
75.6 Junction with Rt 9. Turn right (north) on Rt 9
75.7 Junction with Northway (Rt 87). Turn right on to northbound lane.
83.1 Exit Northway at North Hudson.
83.2 Turn left (west) at stop sign and proceed towards Tahawus and Newcomb on the Blue Ridge Highway.
93.2 Roadcut of anorthosite on right (north) side of highway. Park on shoulder.

STOP 8. MARCY ANORTHOSITE MASSIF DATED AT ca. 1155 Ma. (30 MINUTES). This outcrop has yielded a relatively large volume of remarkably well-formed euhedral zircon grains exhibiting excellent oscillatory zoning. Two of these grains are shown on the guidebook cover. A summary of all Adirondack zircon dating appears in Fig 3 and Table 2 of trip A-1 where it may be seen that that 14 anorthosite suite samples from across the Marcy massif have now been directly dated by SHRIMP II techniques. These cluster tightly about 1155 Ma, which corresponds, almost exactly to the 15 ages for AMCG mangerites and charnockites also shown in Table 2. These results leave little doubt that the Marcy anorthosite and its granitoid envelope were emplaced at ca 1155 Ma. The results also emphasize that the other AMCG complexes in the Adirondacks were emplaced at ca 1155 Ma as well. Attempts to assign a ca 1040 Ma age to the Marcy anorthosite are inconsistent with this geochronology and with field evidence as well. The characteristics of Adirondack massif anorthosite, and a model for its origin and evolution, are presented in Trip A-1 to which the reader is referred for these discussions. The present outcrop is typical of much of the Marcy facies and much of the Marcy massif. Large blue gray andesine grains account for most of the outcrop, but a finer grained matrix is also present. Whether this represents grain size reduction or a distinct magma has not yet been investigated (see Stop 8, Trip A-1). The outcrop contains numerous narrow veinlets of ferrodioritic material that are interpreted as filter-pressed late interstitial magmas from the anorthosite (McLelland *et al*, 1994, see Trip A-1).
96.2 Roadcuts in Whiteface facies of the Marcy massif.
99.2 Large roadcut in coronitic olivine metagabbro. Park on right (north) shoulder.

STOP 9. CORONITIC OLIVINE METAAGABBRO DATED AT 1150 ± 10 Ma. (20 MINUTES). This roadcut is typical of Adirondack coronitic metagabbros that have been described by McLelland and Whitney (1977, see Trip A-1). Under the microscope these rocks display remarkably well-preserved igneous textures most of which are sub-ophitic. Superimposed on these are coronas of garnet and clinopyroxene formed between olivine or pyroxene and plagioclase. During the reaction, the olivine is transformed to orthopyroxene and therefore may be totally exhausted. Excess Fe, Mg, and Na from the reaction site migrates out into surrounding plagioclase to form green hercynitic spinel while, at the same time, Ca displaced from the plagioclase migrates back to the reaction site to form garnet. The effect is to cloud and impart a distinctive pistachio green color to the plagioclase and to reduce its anorthite content. As a consequence, most plagioclase in these rocks has An~32% although normative plagioclase is An~65% (rarely preserved in cores of large grains). The reaction appears to halt at An~28, presumably because plagioclase this sodic no longer participates in the garnet-forming reaction. As of late-August, 2002, this metagabbro had not yet been dated by SHRIMP II. However, an identical metagabbro near the intersection of the Northway and the Blue Ridge Highway yielded abundant zircons many of which were of excellent igneous morphology and showed good zoning. These gave a well-constrained age of 1150 + 14 Ma, and we expect that the same age will be found for the metagabbro at this stop. Coronitic metagabbros of this type occur throughout the Adirondacks but are notably concentrated near the anorthosite massifs. This, coupled with the similarity in age, indicate that these bodies represent batches of the magma that ponded at the core-mantle interface to form plagioclase-rich crystal mushes that ascended to form anorthosite (See trip A-1). The difference is that these gabbroic magmas did not pond but broke through to the upper crust at an early stage. A spectrum of continuous compositions does exist among the metagabbros and suggests that tapping off of these magmas took place at different stages of differentiation.

END OF FIELD TRIP. RETURN TO NORTHWAY AND LAKE GEORGE VILLAGE