THE PISECO LAKE SHEAR ZONE: A SHAWINIGAN CRYPTIC SUTURE IN THE SOUTHERN ADIRONDACK MOUNTAINS, NEW YORK

By

David W. Valentino, Department of Atmospheric and Geological Sciences, SUNY Oswego, Oswego, NY 13126
Jeffrey R. Chiarenzelli, Department of Geology, St. Lawrence University, Canton, NY 13617
Email addresses: david.valentino@oswego.edu, jchiaren@stlawu.edu

ABSTRACT

Highly deformed Piseco granitic gneisses occur in an arching east-west transpressional ductile shear zone (Piseco Lake shear zone) that spans the width of the exposed southern Adirondacks. The highly deformed granitic gneisses have restricted silica content, are metaluminous, alkali-calcic to calc-alkalic, continental arc trace element signatures. These granitic rocks intruded supracrustal gneisses resulting in extensive Shawinigan partial melting. The Piseco Lake shear zone (20-30 km wide) formed in this belt of granitic rocks and correlate with a pronounced arcuate-shaped high magnetic anomaly. The magnetic anomaly extends well beyond the exposed Adirondack basement window.

The shear zone is 20-30 km wide and is believed to be the location of a cryptic suture because it occurs between the Adirondack Highlands (underlain primarily by anorthosite and related granitic rocks, AMCG suite) and the Southern Adirondack Terrane (underlain by calc-alkaline tonalitic arc rocks) (Valentino et al., in press). Within the shear zone, the original megacrystic granite contains lineated quartz and rodded feldspar aggregates up to a meter long in places. Along the axis of the shear zone there are thick (1-2 km), subvertical zones of granitic L-S and L-tectonites. The northern domain of the zone is defined by large foliation domes that are cored by L-tectonite. The southern limbs of the domes steepen toward the south and merge with a wide zone (up to 15 km) of steeply dipping granitic mylonite. Overall, the shear system (domes and steep mylonite zone) forms the core of a region of intense ductile deformation with left-lateral kinematic indicators and subhorizontal E-W ribbon lineations.

The Piseco granitic suite are highly deformed suture-stitching arc plutons that intruded within a sinistral, oblique-convergent, shear system in the deep crust during the Shawinigan orogeny. This is ductile shear zone is the most continuous and largest in the entire Adirondack massif. The shear zone, associated granitic rocks, and the magnetic anomaly abruptly trends toward the south in the eastern Adirondacks. Just beyond this location, the magnetic anomaly appears to be truncated by a branch of the NY-AL magnetic lineament. Following the trace of the magnetic anomaly toward the west, suggests that the shear zone continues for a considerable distance beyond the Adirondack window. It's magnitude, in addition to the magnitude and extend of the associated magnetic anomaly, suggests that the Piseco shear zone penetrates the Moho.

The current field trip is an update on our very long research project, and it's geared toward an undergraduate student audience. All field locations were picked to accommodate large student groups. Sampling is generally prohibited by NYS law in the Adirondack Park, and we encourage future instructors to help preserve the field locations presented herein by showing and discussing, and not removing the spectacular bedrock features. Note that the field guide included here in was pirated and modified from the Friends of the Grenville field conference run by D. Valentino, J. Chairenzelli, D. Piaschyk, L. Williams and R. Peterson in 2008.

INTRODUCTION

The Adirondack Mountains are a relatively recently uplifted (Roden-Tice and Tice, 2005), domal exposure of Mesoproterozoic high-grade gneisses that are part of the contiguous Grenville Province (Figure 1). Sharing many similarities to nearby rocks in Ontario and Quebec, and Grenville basement inliers in the Appalachians (McLelland et al., 2010), the rocks exposed in the Adirondacks record processes in the deep crust related to a series of orogenic events collectively known as the Grenville Orogenic Cycle (McLelland et al., 1988). Undergoing deformation spanning a period of over 250 million years (ca. 1250-1000 Ma), the Grenville Province of Laurentia is a small part of a world-wide system of orogenic belts whose assembly led to the eventual formation of the supercontinent Rodinia.

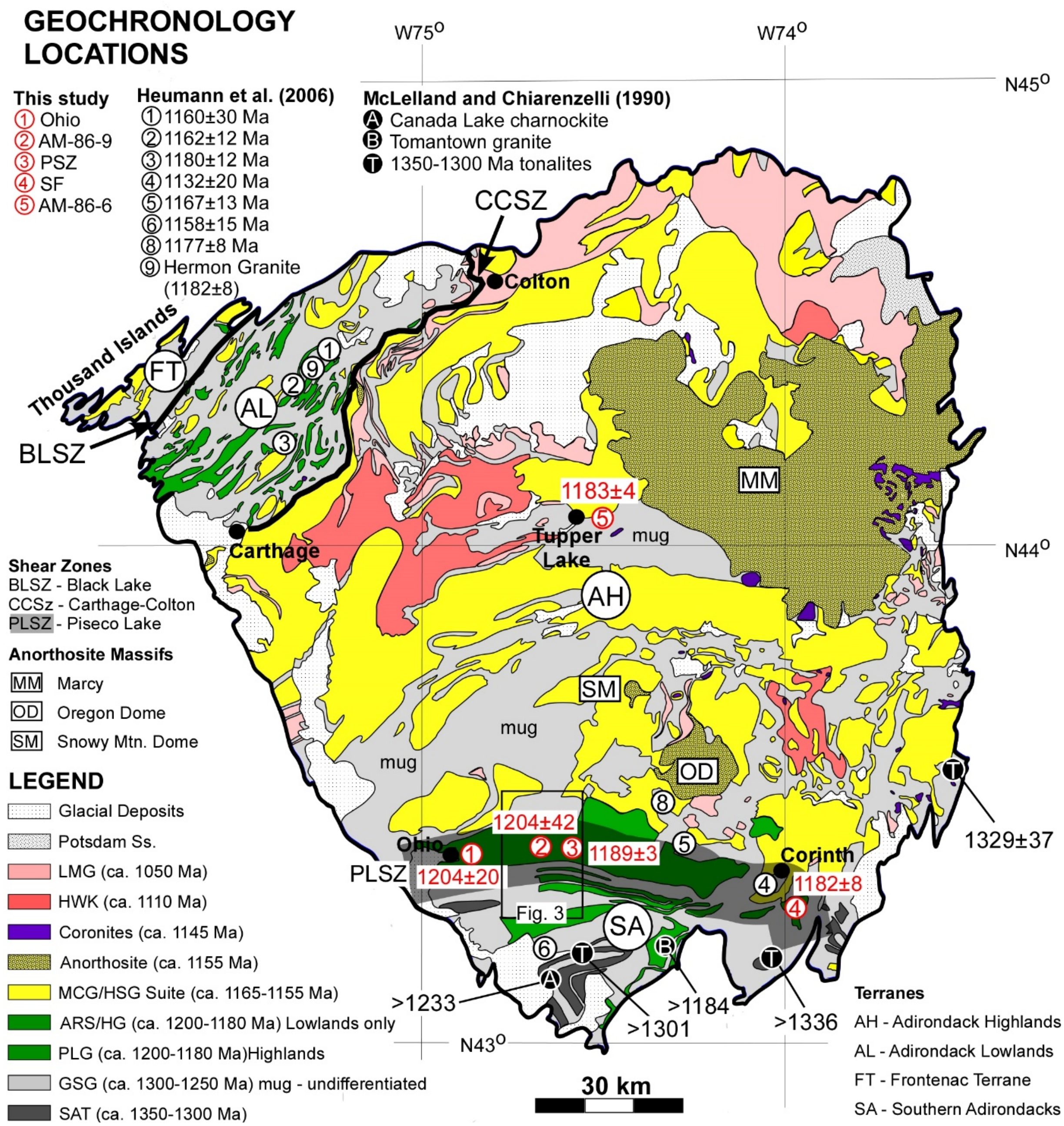


Figure 1. Simplified geological map showing rock suites (from Valentino et al. – in press): ARS – Antwerp-Rossie suite; GSG – metasedimentary rocks of the Grenville Supergroup; HG – Hermon granitic gneiss; HSG – Hyde School gneiss; HWK – Hawkeye granite; LMG – Lyon Mountain granite; MCG – Mangerite-charnockite-granite suite (granitoid part of AMCG suite); mug- mixed metasedimentary and metaigneous rocks that are most likely correlative with GSG; PLG – Piseco Lake gneisses; SAT – Southern Adirondack tonalite suite. U-Pb zircon analysis results (red circles – this study; white circles – Heumann et al., 2006; black circles – McLelland and Chiarenzelli, 1990). Numbered red circles (1-5) are geochronology locations for this study. Location of Figure 3 show as thin black rectangle.

The Adirondacks have been subdivided into the Lowlands and Highlands based on difference in metamorphic grade, predominance of supracustal verses metaigneous rocks, and topography. The Carthage-Colton shear zone in the northwestern Adirondacks (Geraghty et al., 1981; Wiener, 1983), is the boundary between these terranes. The shear zone displays evidence of one or more ductile, high-grade events, as well as, later brittle remobilization and intrusion by leucogranites (Selleck et al., 2005). It has been interpreted as a late, brittle, normal fault accommodating orogenic collapse and, although the earlier ductile history is obscured, thrust and strike-slip kinematics have been noted (Baird and MacDonald, 2004; Wiener, 1983). Traditionally, lithologic similarities with the Central Metasedimentary Belt in Canada has led to inclusion of the Adirondack Lowlands as part of this terrane; whereas, the Adirondack Highlands has been equated to the Central Granulite Terrane of Quebec, again based on lithologic similarities and metamorphic grade. More recently Rivers (2008) has proposed orogen-wide subdivisions based on geochronology, and metamorphic and structural data. He suggested that the Adirondacks were part of a terrane accreted during the Shawinigan Orogeny (ca. 1140-1200 Ma) and subsequently were part of the orogenic lid; part of a medium to low pressure belt of allochthonous rocks that lack the widespread deformation that occurred elsewhere during the Ottawan Orogeny (ca. 1020-1080).

Tectonic models in the South-Central Grenville Province suggest that southeastern margin of Laurentia (present coordinates) has been the site of subduction and accretionary processes for much of the period between 1200-1500 Ma (Carr et al., 2000; Hanmer et al, 2000; Rivers and Corrigan, 2000). Part of this pre-orogenic history includes a period of back-arc, failed rift spreading in the Central Metasedimentary Belt (Dickin and McNutt, 2007) and the opening of a marginal sea within the current location of the Trans-Adirondack Back-arc Basin (Chiarenzelli et al., 2012). This began ca. 1300 Ma and was terminated by the Elzevirian Orogeny at ca. 1240 Ma. The continental arc developed along the leading edge of Laurentia (ca.1300-1350 Ma) was dismembered and dispersed by this subsequent rifting. Fragments of this arc are now found in Ontario, Quebec, the Green Mountains of Vermont, and in the Southern and Eastern Adirondacks, and were accreted to Laurentia during the Shawinigan Orogeny (Figure 1). Collectively these rocks have been called the Dysart-Mt. Holly Complex (Hanmer et al., 2000) after locations in Ontario and Vermont, respectively. The ca. 1300-1350 Ma tonalitic rocks in the Southern Adirondacks (McLelland and Chiarenzelli, 1990) and the Green Mountains of Vermont (Ratcliffe et al., 1991) are considered part of this arc or arcs.

THE PISECO GRANITOID AND SHEAR SYSTEM

The Piseco granitoid suite (Figure 2), located in the southern Adirondacks, was originally thought be part of a basement complex to the Adirondack supracrustal sequence (McLelland and Isachsen, 1986), and were later characterized as granitic members of the AMCG suite (McLelland et al., 1988; 2004; Hamilton et al., 2004). Most recently, evidence supports an independent origin, and slightly older age for these rocks, which are exclusively found within, and along strike, of the highly tectonized Piseco shear zone (Valentino et al., in press). Their ubiquitous high strain prohibits detailed characterization of primary textures at most locations. However, the bulk mineralogy and detailed geochemistry, in addition to very large recrystallized mineral aggregates suggest that these rocks were predominantly igneous, megacrystic, and associated with arc Shawinigan plutononism (Valentino et al., in press).

In contrast to the dominant northeast structural trends throughout most of the Grenville Province, the south-central Adirondack Highlands structural grain is predominantly east-west (Figure 2), including the belt of Piseco granitoids. Across strike, where the overlying Paleozoic cover rocks have been stripped away, this region is greater than ~150 km wide and displays general parallelism of geologic contacts, fold axes, compositional layering, strike of foliation, the trend of mineral elongation lineations and substantial (~5-10 km wide) zones of mylonite. Several large (>20 km across) structural domes, cored by rheologically rigid anorthosite, lie within the zone (Chiarenzelli et al., 2000; Gates et al., 2004; Valentino et al., 2004; Valentino et al., 2008), and kinematic investigations indicate that this zone is dominated by left-lateral transpressive shear (Chiarenzelli et al., 2000; Gates et al., 2004; Valentino et al., 2008). There are a number of large-scale features, such as drag folds and rotated giga-scale clasts (i.e. Snowy Mountain anorthosite body), which are consistent with the abundant meso- and micro-scale kinematic indicators including S-C fabrics, shear bands, and rotated porphyroclasts of various minerals (Gates et al., 2004). Here we designate this east-west striking, broad zone of gneisses as the Central Adirondack Shear System (CASS), and the crust-scale structures of the CASS are interpreted as the consequence of transpressional modification of earlier recumbent folds, analogous to those exposed in the Adirondack Lowlands (Chiarenzelli et al., 2000). The CASS is superimposed on rocks that contain widespread granulite-facies mineral assemblages, deformed migmatitic gneisses, and substantial volumes of supracrustal rocks, all supporting earlier history of compressional tectonism as described above. However, discrete mylonite zones within the CASS were shown to contain retrograde deformation fabrics, with some containing fabric forming greenschist facies minerals, such as biotite, chlorite and muscovite (Price et al., 2003; Valentino et al., 2008). These relationships suggest that structural activity within the CASS outlasted high-grade conditions and continued through denudation, uplift and cooling of the central Adirondacks. It was previously proposed that the locus of deformation within the CCAS, the Piseco Lake shear zone, marks the boundary of oblique-slip convergence between the southeastern margin of Laurentia and the Southern Adirondack arc terrane (Gates et al. 2004; Valentino et al., 2008).

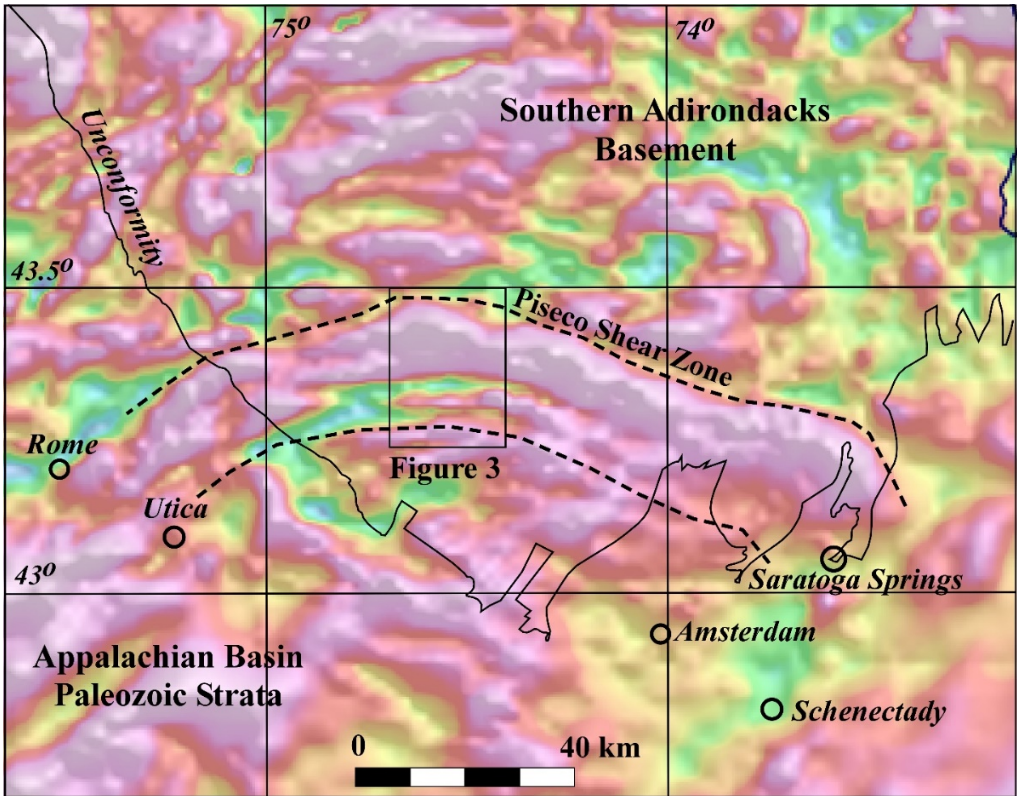


Figure 2. Magnetic anomaly map of the southern Adirondack region. Location is shown on Figure 1.

The Piseco Lake Shear Zone

Several discrete ductile shear zones occur within the CASS (Gates et al., 2004; Valentino et al., 2008; Weimer et al., 2001), with the Piseco shear zone as the most continuous and largest spanning the entire 120 km width of the Adirondack massif and upward of 30 km wide (Figures 2 and 3). A prominent magnetic anomaly correlates with the Piseco Lake shear zone (PLz) and it appears that the zone extends well beyond the exposed limits of the Adirondack massif (Figure 2). Strong deformation in the area surrounding Piseco Lake was first noted by Cannon (1937). Fakundiny (1996) and Fakundiny et al. (1994) proposed a fundamental structural discontinuity in this area based largely on geomorphological criteria and the trace of the Prospect Fault (Valentino et al., 2012). In addition, fundamental lithologic differences have been noted across the boundary as AMCG rocks are rare or absent to the south, whereas tonalitic rocks (ca.1300-1350 Ma) of the Southern Adirondack arc terrane have not been recognized north of it. The PLz is developed in a suite of granitoids (Piseco Lake Granitoids – PLG) that span the width of the Adirondack massif outcrop belt, but more importantly the belt strongly correlates with the pronounced linear magnetic anomaly.

The PLz is defined by spectacular L-S, L>S and L-tectonites developed in the Piseco granitoids, with an east-west arching trend. This trend continues smoothly to the eastern margin of the Adirondack Dome, where before plunging beneath Paleozoic cover rocks to the east at Spier Falls on the Hudson River, where the lineation and foliation gradually transitions to a north-south orientation defining a broad (10's of km) open vertical fold. The PLz comprises parallel structural domains that developed contemporaneously: 1) a broad (10-15 km wide) tabular steeply dipping zone of granitic mylonite (southern domain); 2) a series of flanking upright (5-10 km wide) foliation domes (northern domain) (Cannon, 1937; Glennie, 1973; McLelland, 1984; Wiener et al., 1984). There is no apparent structural discontinuity between the foliation of the southern mylonite zone and the foliation in the dome region. As well, lineations are consistent in orientation and defined by the same minerals within both domains. Collectively, these structural domains make up a zone of ductile deformation that is upward of 30 kilometers wide, crossing the exposed width of the boundary between the Central and Southern Adirondacks.

The Southern Domain – Shear Zone

There is a well-defined textural transition that occurs in variably deformed granitoids in the southern limit of the PLz. From south to north, the granitic rocks exhibit moderately deformed megacrysts of K-feldspar, well developed mylonite with remnant K-feldspar grains (~5-10 mm in diameter) and finally domains of ultramylonite (Valentino et al., 2008). Penetrative foliation is defined by dynamically recrystallized quartz, K-feldspar and plagioclase, and alignment of micas. Rocks within the zone are made of fine-grained aggregates of these minerals in strong alignment. Locally there are 2-6 cm long K-feldspar megacrysts and/or porphyroclasts preserved which are consistent with a plutonic origin. Pegmatitic and aplitic layers provide evidence of strong transposition of primary contacts (Piaschyk et al., 2005; Valentino et al., 2008). Rocks with steeply dipping penetrative mylonitic fabric persist over an across strike distance of more than 10 km, eventually merging with the highly deformed granitoids in the northern domes. Lineations in this zone are subhorizontal and defined by dynamically recrystallized quartz, K-feldspar, plagioclase, and accessory mafic minerals such as hornblende, biotite or chlorite. Shear sense indicators are abundant and occur at the meso- and microscopic scale. K-feldspar megacrysts form Type I S-C fabrics, σ- and δ- porphyroclasts and domino-structures (Figure 4). Where the L-S fabrics are well developed, consistently the shear sense indicators are sinistral across the entire 10 km wide zone of the southern domain.

Northern Domain – Dome

Penetrative foliation and lineations define several upright antiformal domes (Cannon, 1937; Glennie, 1973; Weiner et al., 1984; Valentino et al., 2012) that flank the north side of the steeply dipping mylonite zone (southern domain). These domes have subhorizontal arching axes that trend approximately 110º in the east, 090º in the central region, and 080º in the west. The largest of these domes occurs in the vicinity of Piseco Lake. The foliation on the dome limbs dips moderately with mineral elongation lineations that trend at 110º and plunge about 10º eastward. In the crest of the domes, foliation is not well developed and penetrative lineations are defined by mineral rods, rods of mineral aggregates, and mineral ribbons. Lineations in the domes are intensely developed, and in many places the linear fabric is dominant over the weak foliation (L>>S) with grain aggregate aspect ratios upward of 60:1, in the L-parallel and S-perpendicular plane, as originally noted by McLelland (1984). Some rocks, of considerable thickness ~1-2 km, in the core of the domes lack foliation altogether and are true L-tectonites. Microscopic examination showed that the lineations are defined by dynamically recrystallized ribbons and rods of quartz, K-feldspar, plagioclase, in addition to streaks of magnetite, biotite, chlorite and occasionally muscovite (Valentino et al., 2008).

Like the rocks in the southern domain, shear-sense indicators are abundant in the dome rocks that are not dominated by L-tectonite. They include Type I S-C mylonite, σ - and δ -porphyroclasts of K-feldspar, and asymmetric polymineralic tails around porphyroclasts (Figure 4). These kinematic indicators reveal a consistent sinistral-shear sense on both the north- and south-dipping L-S tectonite domains of the domes.

Magnetic Anomalies

The magnetic anomaly map of North America (U.S.G.S. – Mineral Resources Online Spatial Data) has an interesting distribution of high and low anomalies in the Adirondack region that roughly correlate with major metaigneous and metasedimentary rock bodies (Figure 2). The corresponding magnetic anomaly for the anorthosite bodies is low, while vast regions underlain by charnockitic gneiss express high anomalies. Regions of the Adirondacks with substantially thick sequences of supracrustal rocks generally have low magnetic anomaly signatures, similar to the anorthostie bodies. Magnetic anomaly patterns in the Adirondack lowlands are parallel to the overall northeastern striking geologic structures that control the geographic distribution of various metaigneous and metasedimentary rock bodies. Within the Adirondack Highlands, the northern region can be characterized as having magnetic anomalies with a nebulous, or unorganized, structural pattern, most likely the result of the vast anorthosite bodies that make up the Mount Marcy massif.

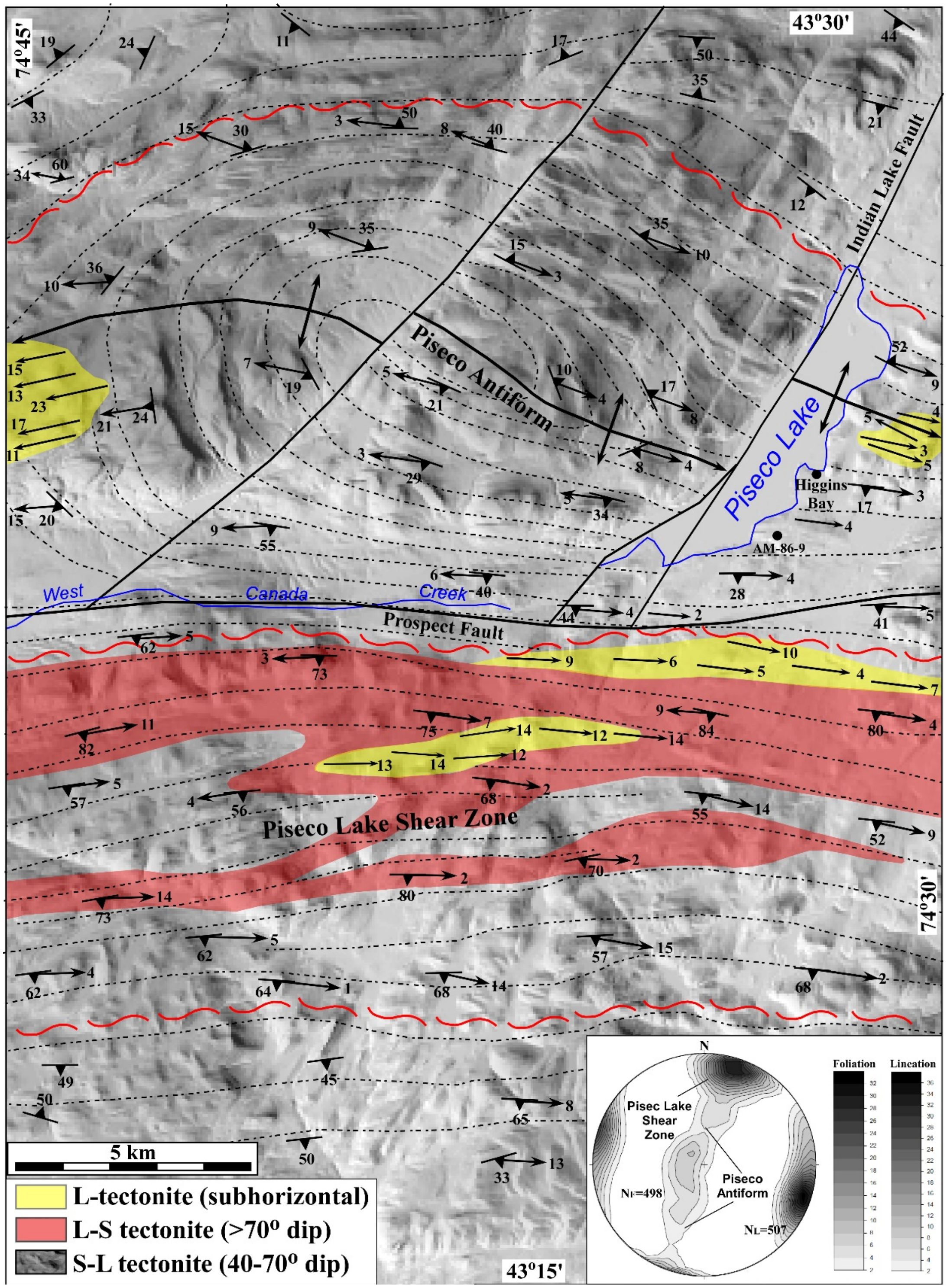


Figure 3. Simplified structural geology map for the Piseco Lake shear zone and dome plotted on a gray-scale digital elevation model. Location is shown on Figure 2. Inset shows lower hemisphere contour stereogram for poles to foliation and lineation data collected in the mapped region. Note that the lineation data is a composite plot for both the antiform and shear zone domains; foliation is designated separately. The sinuous dashes show the approximate boundaries of the Piseco Lake shear zone in this area. The axis of the Piseco antiform is shown in addition to Mesozoic faults (heavy black lines) that offset the antiform axis near Piseco Lake (Valentino et al., 2012).

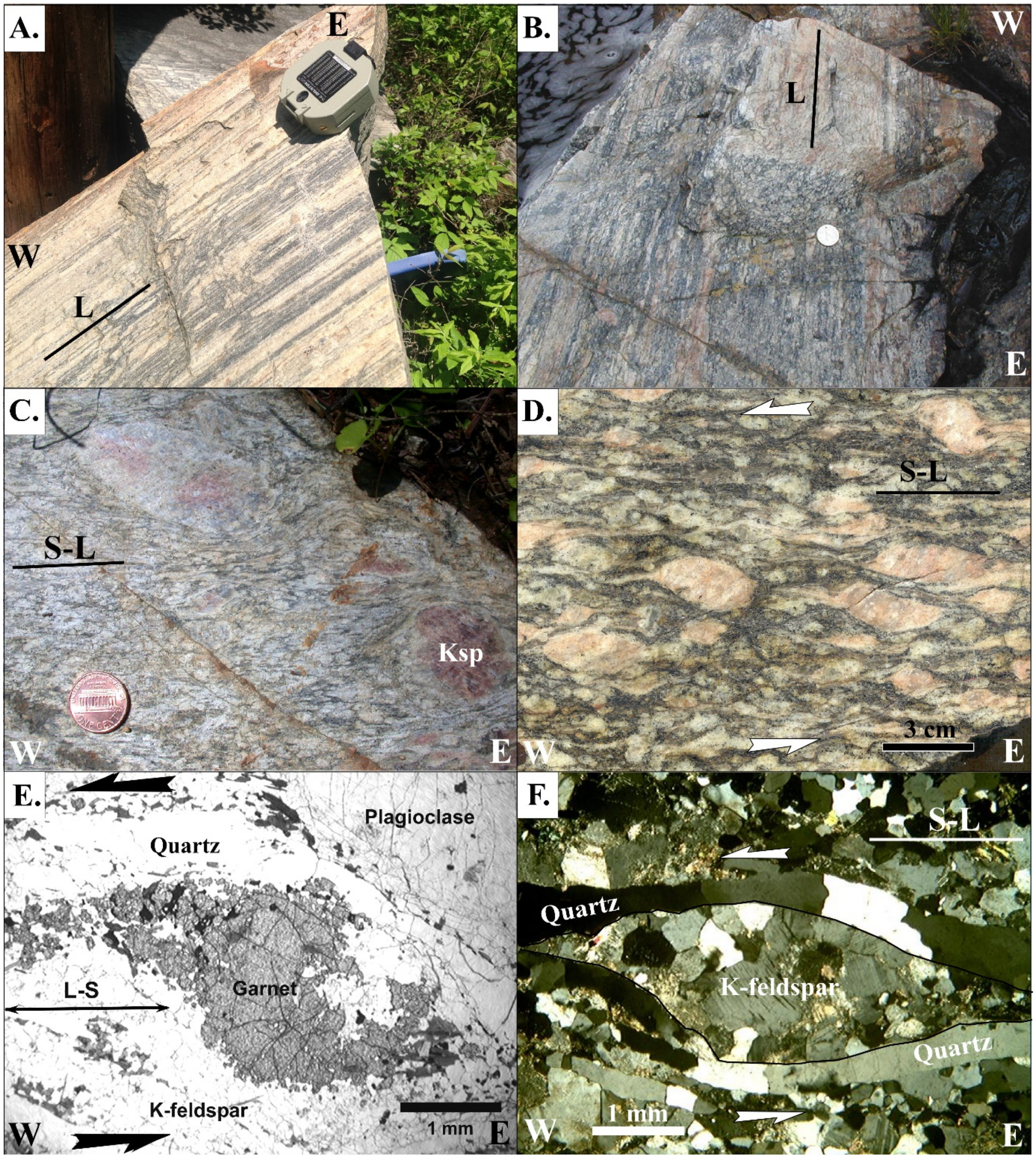


Figure 4. Examples of deformation fabrics in the Piseco shear zone. A. Strongly lineated granitic mylonite from the southern flank of the structural dome near Piseco Lake. B. Tectonite dominated by mineral aggregate elongation lineations from the core of the dome. C. Well developed granitic mylonite from the southern steeply dipping shear zone. D. Augen mylonite with relict K-feldspar megacrysts forming asymmetric σ-porphyroclasts on the northern flank of the dome. E. Photomicrograph of asymmetric garnet enveloped in quartz ribbons, and recrystallized K-feldspar and plagioclase (ppl). F. Photomicrograph of highly deformed granitic gneiss from the Piseco shear zone (xpl) displaying polygonal grains of dynamically recrystallized K-feldspar and quartz ribbons. The aggregate of K-feldspar (center) is surrounded by quartz ribbons and the overall shape forms a recrystallized asymmetric sigma-porphyroclast.

With the exception of small anorthosite bodies with ovoid low magnetic anomalies, the structural pattern of anomalies in the central and southern Adirondacks is strikingly regular and trends roughly east-west parallel to the structures of the Central Adirondack Shear System (Chiarenzelli et al., 2000; Gates et al., 2004; Valentino et al., 2008). One of the most pronounced high magnetic anomalies extends unbroken across the entire exposed width of the southern Adirondacks, forming a broad open arch that curves to a north-south trend in the east and appears to be sharply truncated near Saratoga Spring, NY. This anomaly extends west of the Adirondacks where it bifurcates and continues beneath the Appalachian basin of central NY. This high magnetic anomaly has the most structural continuity for any anomaly associated with the exposed basement geology, and it directly correlates with the highly deformed Piseco granitoid suite and related shear system (McLelland and Isachsen, 1986; McLelland et al., 1988; 2004; Gates et al., 2004; Hamilton et al., 2004; Valentino and Chiarenzelli, 2008).

ORIGIN OF THE PISECO LAKE GRANITOIDS

The limited compositional range, megacrystic texture, coarse grain-size, and large volume of the Piseco Lake granitoids suggest they are an intensely deformed and deep-seated suite of granitic plutons. The occurrence of deformed and transposed cross-cutting aplites and pegmatites is in concert with this interpretation (Piaschyk et al., 2005; Price et al., 2003). Previous U-Pb zircon studies (McLelland et al., 1988; Valentino et al., in press) confirm that the granitic precursors were intruded into the region by at least 1155 Ma and likely earlier (ca. 1200 Ma). The work of Heumann et al. (2006) has suggested that highly deformed paragneisses in contact with the Piseco Lake granitoids underwent anatexis and zircon and monazite growth from 1160-1180 Ma. If the Piseco Lake granitoids provided some, or all, of the heat that facilitated the melting, a significant volume of melt/heat must have been present by 1180 Ma. This is consistent with our preliminary zircon studies previously published (Valentino et al., in press), indicating intrusion prior to AMCG plutonism at ca. 1155-1165 Ma and likely at ca. 1200 Ma.

The fabric in the Piseco Lake granitoids and surrounding mylonitic pssamitic/pelitic gneisses, and hence the gross structure of the shear zone itself, can be tied to zircon and monazite growth during high-grade ductile deformation and melting during the waning phase of the Shawinigan Orogeny (Heumann et al, 2006). This is emphasized by the lack of younger "Ottawan" zircons in many of the paragneiss localities in the northwestern, central, and southern Adirondacks studied by Heumann et al. (2006) and in mylonitic gneiss analyzed for this study. Zircons younger than 1080 Ma are nearly absent, indicating minimal, if any, zircon growth during the Ottawan Orogeny along the Piseco Lake Shear Zone; but volumetrically significant metamorphic zircon growth occurred throughout the Shawinigan Orogeny. This in turn provides further evidence that the gross crustal architecture of the Central and Southern Adirondack Region and Central Adirondack Shear System was developed during the Shawinigan Orogeny. The Piseco Lake granitoids provide direct evidence of the processes at work in the deep crust and likely, upper mantle, just prior to and during, the Shawinigan Orogeny. In essence they, and their intense deformation, set the stage for the voluminous AMCG intrusions that followed (Valentino et al., in press).

The kinematic studies on all scales from microscopic to megascopic (Chiarenzelli et al., 2000; Gates et al. 2004; Valentino et al., 2008) indicate left-lateral motion focused along the shear zone and domes developed in the Piseco Lake granitoids. The focus of this intensive deformation, between two distinct terranes, has led to the conclusion that it demarcates a cryptic suture (Chiarenzelli et al., 2011; 2010a; Valentino et al., in press. Antiformal domes and the counterclockwise rotation of rigid anorthosite bodies (Chiarenzelli et al., 2000; Gates et al., 2004) suggest bulk crustal flow throughout the CASS region, as do vertical zones of L-tectonite and rocks with pronounced linear fabrics. Taken together these observations are consistent with the intrusion of a voluminous suite of suture-stitching plutons of arc affinity within a sinistral, oblique-convergent, ductile shear system during the Shawinigan orogeny.

TECTONIC MODEL

Any tectonic model proposed to explain the origin and deformation of the Piseco Lake granitoids must take into consideration their field relations, age, geochemical and isotopic trends, intense deformation, kinematics, geophysical signature, and the geologic context of the region. Various lines of evidence presented in Valentino et al. (in press) and summarized herein, suggest that the granitoids are the deformed roots of a continental batholith which developed just prior to, and during, the Shawinigan Orogeny and preceded voluminous AMCG plutonism.

Paleogeographically, the plutonic protoliths of the gneisses appear to represent the product of northward subduction of oceanic crust beneath the Southern Adirondack arc, Trans-Adirondack Back-Arc basin, and the southeast edge of Laurentia, believed to be coincident with the Black Lake Shear Zone at this time (Chiarenzelli et al., 2010b; Wong et al., 2012; and Peck et al. 2004; 2013). Telescoping of this basin during closure led to massive shortening and collapse of the basin and attendant SW-directed thrusting and nappe formation. However, the dominant fabric, which overprints early events, was left-lateral plastic deformation related to oblique collision. The imprint of this late Shawinigan event is recorded at all scales from microscopic kinematic features to “mega” porphyroclasts and elongate structural domes (Chiarenzelli et al., 2000; Gates et al., 2004; Valentino et al., 2008) to a regional subhorizontal lineation.

AMCG plutonism began during the waning stages of Shawinigan orogenesis (Valentino et al., in press). This can be seen in the Marcy anorthosite massif where large, relative intact bodies of meta-anorthosite are cut by thin (1-2 cm) garnet-pyroxene shear zones, many with an E-W orientation (Hecklau et al., 2014). Intrusive boundaries, along coarse-gabbroic pegmatites and fine-grained granitic sheets, are often zones of intense strain. This suggests the meta-anorthosite body, although rigid and resistant to ductile deformation in general, underwent ductile deformation along heterogeneities. Coronitic metagabbros, thought to be the parental magmas from which anorthosite was derived via fractional crystallization (Regan et al., 2011), may provide a lower limit on regional ductile deformation associated with the Shawinigan Orogeny. Coronites display a wide range of deformational and metamorphic features ranging from equant bodies with pristine coronitic textures to elongate, curvilinear belts of garnetiferous amphibolite. In many instances garnetiferous amphibolites retain a small core of coronitic metagabbro that survived deformation (Lagor et al., 2013). Dating of one coronitic metagabbro from Dresden Station yielded an age of 1144+/-7 Ma via U-Pb zircon methods (McLelland and Chiarenzelli, 1989) and extends the range of ages generally attributed to the AMCG suite (ca. 1155-1165 Ma) to at least 1144 Ma. This age overlaps the age of 1151+/-9 Ma for monazite growth in the pelitic gneisses intruded by the Dresden coronitic metagabbro (Grover et al., 2013), indicating the growth of high-grade minerals in compositionally appropriate rocks during intrusion of the coronites.

The transition from arc magmatism represented by the Piseco Lake granitoids to intrusion by anorthosite massifs and cogenetic granitic rocks (AMCG suite) occurred within a relative short period of time; at most several tens of millions of years (Figure 5). This spatial and temporal link suggests that intense deformation associated with the Piseco Lake granitoids was the kinematic trigger for AMCG magmatism. Most models for AMCG rocks invoke for slab detachment or delamination, but few details are known. One possible explanation presented by Valentino et al. (in press) and favored here is that highly oblique subduction and orogeny-parallel deformation may have contributed to detachment and delamination. Shear stress may have reactivated old crustal weaknesses (transform-faults) and/or created tears that propagated into the descending slab and lower plate, resulting in splitting and fragmentation of the rigid lithosphere. Catastrophic failure of this type would allow rapid ascent of asthenospheric mantle, decompressional partial melting of the asthenosphere, and subsequent melting of underlying crustal rocks. Given left-lateral kinematics documented, the progressive closure of the ocean basin the foci of asthenospheric rise and production of AMCG magmatic rocks would propagate from west to east.

An analog for this model would incorporate aspects of the Andean margin where subducting slabs of different age and density behave as independent lithospheric “tiles”. These tiles are separated by oceanic fracture zones, subducting at different rates and angles beneath South America, and control the distance between the magmatic arc and trench. In combination with highly oblique convergence, the oceanic fracture zones between these “tiles” would serve as inherent zones of weakness ultimately causing catastrophic tears in the subducting lithospheric plate. A similar scenario involving tearing and propagation of a subducting slab undergoing buckling is currently occurring along the Puerto Rican trench (Meighan and Pulliam, 2013; Meighan et al., 2013).

This tectonic model would not be complete without discussing the proximity of the Piseco shear zone to the New York-Alabama magnetic anomaly lineament (NY-AL), an anomaly that defines a major basement boundary that crosses eastern Laurentia (Steltenpohl et al., 2010). The origin of the anomaly is not definitively known, however, recent researchers have suggested that the linear nature of the anomaly is associated with an intracrustal transcurrent shear system with either dextral or sinistral displacement. Between northwestern Georgia and northeastern Pennsylvania, the NY-AL lineament trends without deviating about 046^{o}, a distance greater than 1000 km (Figure 5). With an easterly change in trend of 15-20^{o}, the lineament is shown to continue northeast and include the Catskill magnetic high extending from northeastern Pennsylvania to the Vermont-Massachusetts border region (Figure 6A). This trend crosses the Scranton gravity high, proposed to be a Neoproterozoic rift basin (Rankin, 1976; Hawman and Phinney, 1992). However, if the 046^{o} trend of the >1000 km long NY-AL lineament is projected into southern New York, it would correspond to the western margin of the Scranton gravity high (Figure 6B), in addition to the apparent truncations of a series of magnetic high anomalies, including the Piseco anomaly, and by association the granitoids and shear zone. Based on the transcurrent deformation associated with the PLz, we propose the zone to be a splay off of the major crustal boundary that is manifest as the NY-AL magnetic lineament (Steltenpohl et al., 2010).

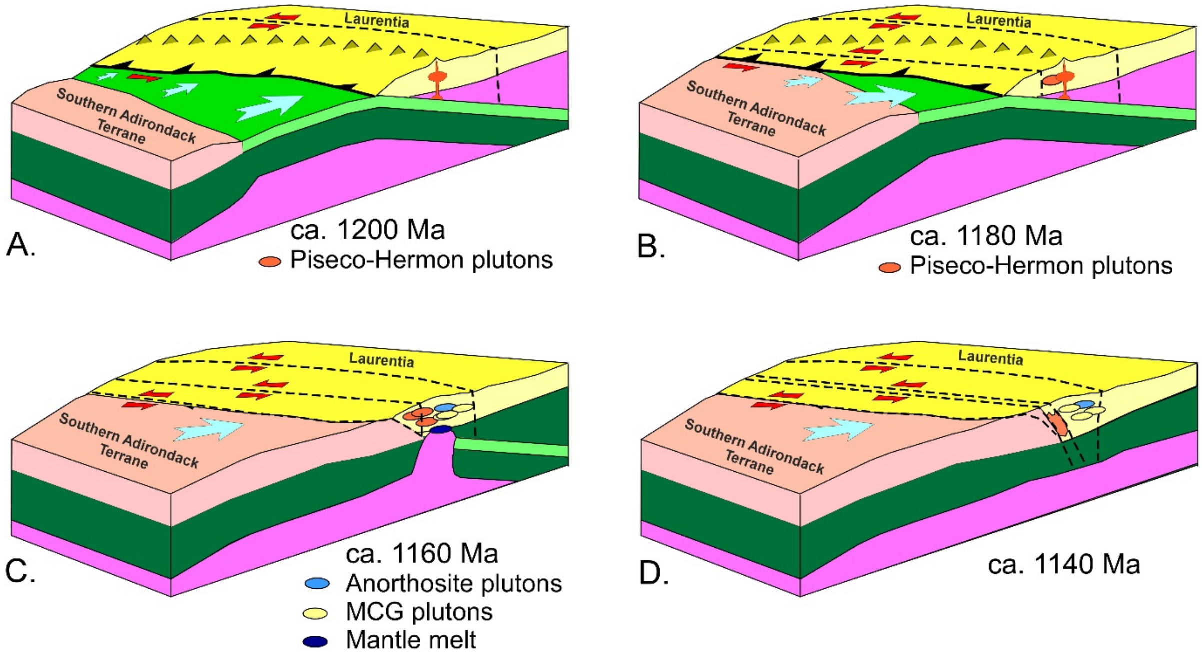
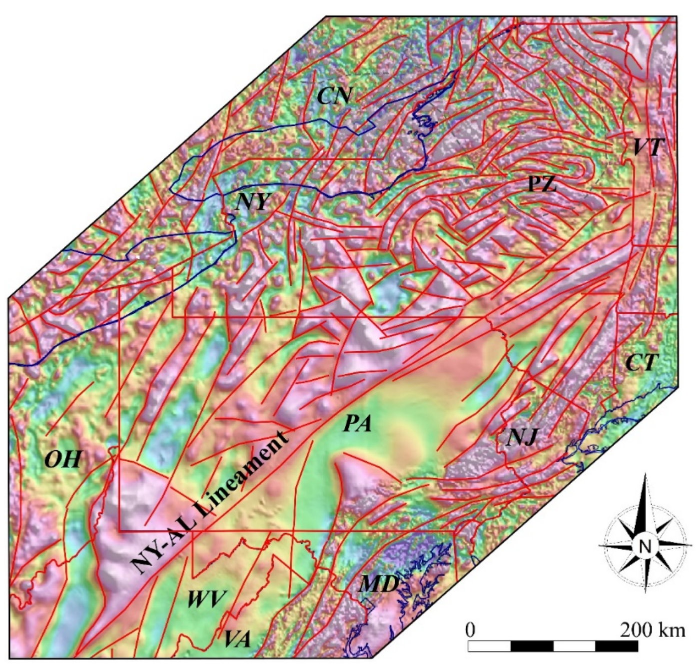
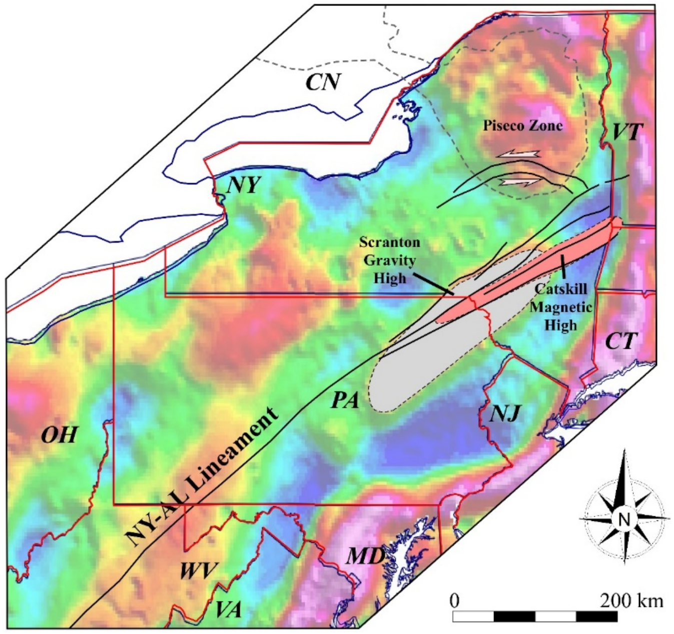


Figure 5. Tectonic model depicting the oblique subduction, subsequent oblique collision and sinistral transform boundary that forms on the granite-stitched suture between the Southern Adirondack Terrane and the Adirondack Highlands (Laurnetia). Refer above for details.



A.



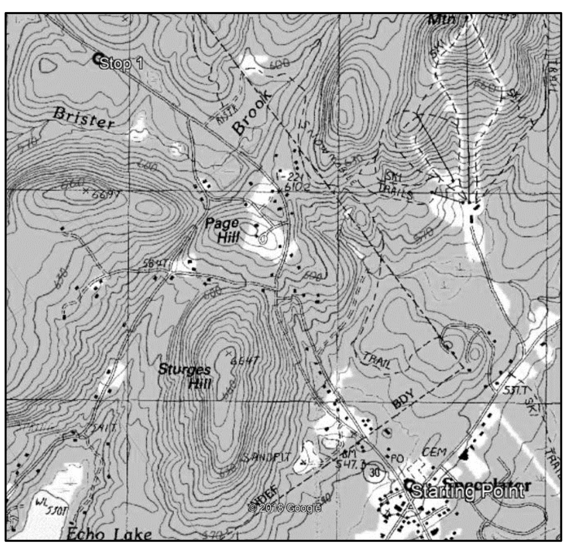
B.

Figure 6. (A) Magnetic and (B) gravity anomaly maps with interpreted lineaments. The New York-Alabama lineament (NY-AL) is labeled along with the Scranton gravity high and the Catskill magnetic high. Outline of the Adirondacks is represented by the dashed line and the Piseco Lake shear zones (PZ) is shown with shear sense arrows (Maps from USGS respository online).

ROAD LOG

Assemble in the parking lot at the Charlie John's market located the intersection of Route 8 and Route 30 in the village of Speculator, New York (Starting Point on map below). From this point the trip heads north on Route 30 to the first stop.

Mileage:
0.0 Assembly point
1.7 Stop 1: Park on the wide shoulder on the east side of Route 30. The outcrop is on the west side of the road, the traffic is light but fast, so be very careful crossing the road.



STOP 1: Supracrustal rocks of the Adirondack Highlands, just north of the Piseco Lake shear zone (18T 549883 m E, 4818851 m N)

There are several rock types that can be observed at this outcrop, along with the contacts and primary compositional layering. The northern ¼ of the outcrop consists of garnet amphibolite, the next ~ ¼ of the outcrop is calc-silicate gneiss and the southern ½ is fine-grained quartzo-feldspathic gneiss locally interlayered with highly folded marble (Figure 7). Complex sheath folds with sub-horizontal tight, isoclinal and sheath folds of foliation and compositional layers dominate the rock, particularly in the gneiss (trend to 110^{o}). Excellent views of the folds are seen on top of the southern part of the outcrop. The contacts between the rock types are also folded in similar fashion. Matrix minerals define lineations that are E-W and subhoriziontal, but are variable in orientation due to folding. Overall, the diverse lithologies and style of deformation are typical for the supracrustal rocks located north of the Piseco Lake grantioids. At this point, note that primary compositional layering is preserved at this outcrop.

Figure 7. Photograph of folded quartzo-feldspathic gneiss and marble (recessed part of outcrop). Note the stalk of grass for scale.

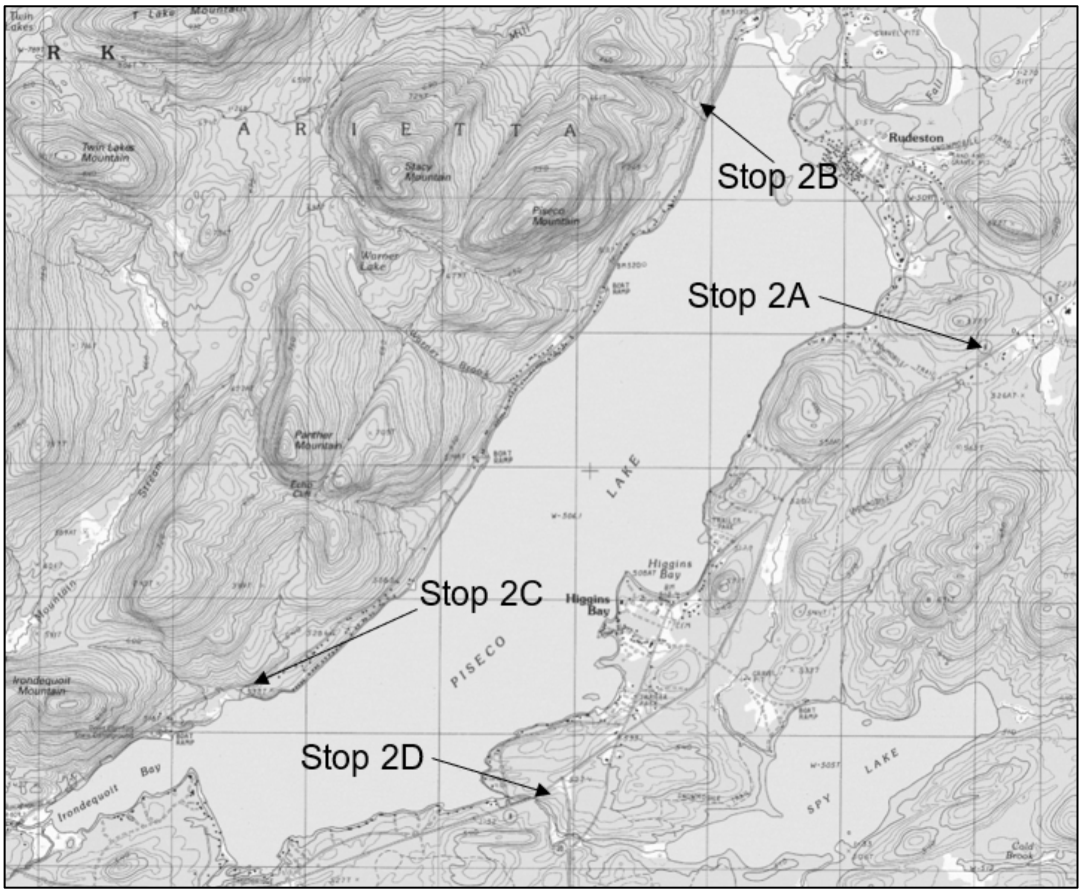
From Stop 1, proceed north to a safe place to turn around, and return to the intersection of Route 30 and Route 8 in the village of Speculator.

Mileage:
3.4 Turn west on Route 8 in the Village of Speculator.
5.4 First roadcut on right is highly lineated granitic gneiss in the margin of the PLsz.
12.2 Intersection with Old Piseco Road in Piseco, NY.
13.3 Park on north side of Route 8 at the low roadcut for Stop 2.

STOP 2A-D: L-S and L>S fabrics in the Piseco dome – driving traverse

Stop 2A: 18T 540256 m E, 4808187 m N
Stop 2B: 18T 537957 m E, 4809931 m N
Stop 2C: 18T 534370 m E, 4805562 m N
Stop 2D: 18T 536919 m E, 4804838 m N

The Piseco Lake shear zone includes the northern foliation domes that merge with the steeply dipping shear zones to the south. This series of field stops shows variations in the attitude and type of fabrics that occur in the core of the dome at Piseco Lake. Stops 2A to 2D are a driving traverse around Piseco Lake, the type location of the Piseco antiform. At all of these localities, dynamically recrystallized feldspars and quartz form spectacular ribbon- and rod-shaped mineral lineations (McLelland, 1984), in addition to accessory biotite and magnetite. In many places, the alignment of ribbons forms the foliation in this outcrop. Individual quartz-ribbons have aspect ratios upward of 60:1. At Stop 2A, the foliation is weakly to moderately developed, and dips shallowly southward at the eastern part of the outcrop, but is steeply dipping at the western end of the outcrop. The transition between these different foliation attitudes is difficult to determine because the intensity of the foliation is variable. Lineations are penetrative on all scales, and consistent in attitude (Trend: 110 º; Plunge: 05 º). Stop 6A occurs on the southern flank of the map-scale dome portion of the Piseco antiform. At the western end of the outcrop there are rods of amphibolite (10-30 cm diameter) within the granitic gneiss.



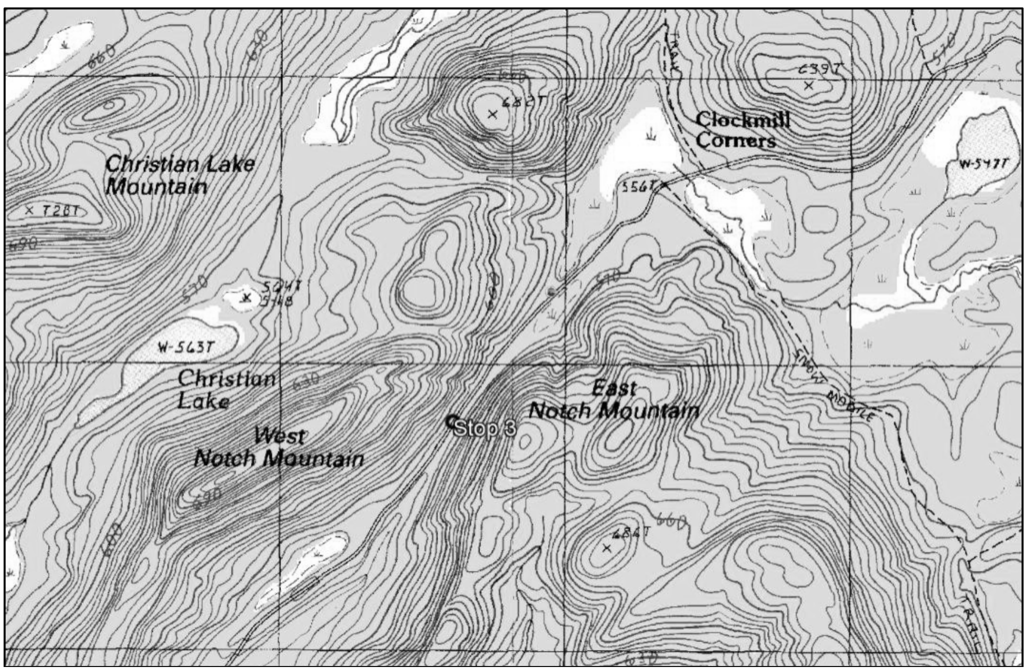
There is an apparent Mesozoic fault that traces down the western side of Piseco Lake and has locally displaced parts of the Piseco dome (Figure 3). At Stop 2B, again the foliation is weakly developed with a penetrative shallowly plunging lineation. However, the foliation, where it can be observed, dips northerly. As you drive southwest along the western side of Piseco Lake, note that the foliation gradually shallows and then dips southerly. There are several outcrops that can be observed where this transition in foliation attitude occurs. The rock fabrics at Stop 2C are similar to those at Stops 2A and 2B, but again the variably developed foliation dips toward the south. Stop 2D is located at the intersection of Rts. 8 and 10, and the folation and lineation is penetrative.

Common to all of these field stops is that biotite and sometimes chlorite blades form microscopic lineations and foliation parallel to the macroscopic structure. Rare grains of hypersthene have been found, but they always have well developed overgrowth textures that include biotite and chlorite. The biotite and chlorite are the most abundant index minerals in the granitic gneiss, and suggest the deformation was last active under low- to moderate- metamorphic conditions, although probably began at much higher conditions to account for the relict grains of hypersthene.

Mileage:
13.3 Turn around and proceed east on Rt. 8 about 0.5 mile. west on Rt. 8.
13.8 Turn north and follow the road around Piseco Lake to Stops 2B and 2C.
22.7 At the intersection with Rt. 8, turn east and proceed about 2.9 miles.
23.6 Turn south onto Rt. 10 and park for Stop 2D. Proceed south on Rt. 10 about 1.2 miles.
24.8 Turn west onto Powley Road (becomes a gravel road) and continue 4.9 miles.
29.7 Park where Powley Road traverses through the Notch.

STOP 3: Steeply dipping mylonite zone of the southern PLsz (18T 530638 m E, 4799018 m N)

Along Powley Road, depending on the time of year and the amount of road maintenance, there are a sub-continuous series of pavement exposures located in the road bed, as well as in the gutter on the east (northeast-bound) side of the road. Due to the nature of this location, the extent of the exposed rock at this stop changes yearly, so some or all of the rock described here may be viewable depending upon the time of the season in which the stop is visited (best later in the summer). The best exposures occur along the road between West and East Notch Mountains.

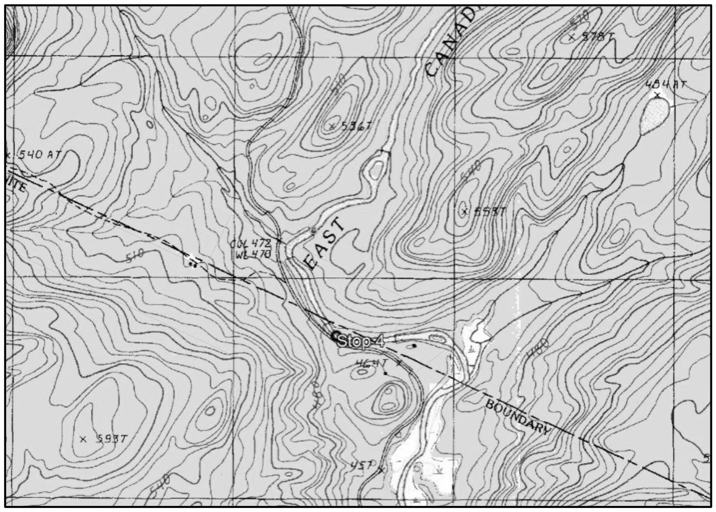


All rocks in this region are very similar in mineral content, and vary only in detail with regard to mineral percentage and fabric type and intensity. The rock is dominantly granitic gneiss with intense subhorizontal to shallowly plunging mineral elongation lineation that trends on average about 095^{o}, with steeply dipping generally east-west striking foliation. Both fabric elements are defined by ribbons of quartz, and ribbons of aggregate feldspar and quartz (generally 1-5 cm long depending upon grain size). Intensity of the fabric varies across strike at the 50 cm scale, with local layers of significantly coarser-grained fabrics (grains up to 1 cm in diameter). There are also places where the foliation intensity varies as seen at the field stops around Piseco Lake. Rare amphibolite bodies that are 10's of cm thick occur within the granitic gneiss. Shear sense indicators are abundant in the granitic rocks and consistently show sinistral shear sense.

Mileage:

35.7 Continue south on Powley Road about 6 miles and park. Outcrops are located along the bank of East Canada Creek.

STOP 4: Southern extent of steeply dipping mylonite (18T 527500 m E, 4790961 m N)

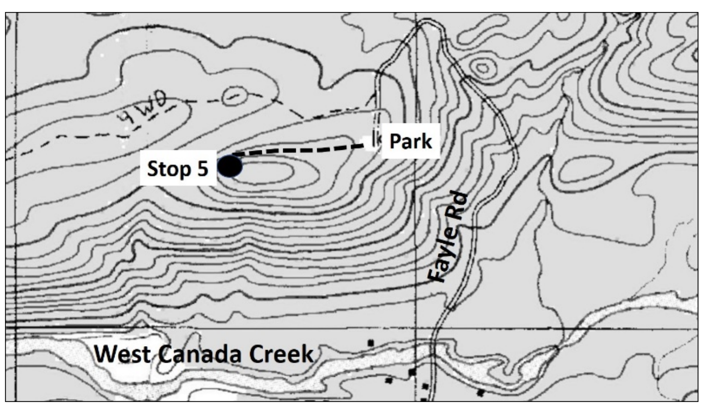


Here the granitic gneiss fabrics contain both a penetrative foliation and lineation. The foliation is steeply dipping and strikes about east-west. Mineral elongation lineation defined by linear aggregates of quartz and feldspar are subhorizontal. The extent of readily available bedrock exposure diminishes south of this location, so this may be the southern-most exposure of the Piseco Lake shear zone. Note that this location is about 21 kilometers across strike from the northern side of the Piseco dome where the pronounced lineation occurs.

Mileage:

46.6 Turn around and proceed back to the intersection of Powley Road and Rt. 10, about 10.9 miles.
47.8 Continue north on Rt. 10 about 1.2 miles to the intersection with Rt. 8.
59.9 Turn west onto Rt. 8 and drive 12.1 miles to Moorehouseville.
61.5 Turn north onto Fayle Road, proceed north. Cross a one lane wood bridge and drive to an opening in the trees at the end of Fayle Road. Park and hike to the west about 350 meters to the west end of the small linear hill.

STOP 5: L>>S and L-tectonite in the core of the Piseco antiform (18T 518563 m E, 4805631 m N)



Excellent outcrops on the northwestern side of a small hill just west of the parking area. Follow the dirt road to a path through the woods, and then head up hill to the south to the outcrops. This outcrop of granitic gneiss contains domains of L>S and L>>S. The L>S domains contain large and numerous σ-type shear sense indicators, some δ-type are present but are much less frequent. The porphyroclasts are large about 1-3 cm and the recrystallized porphyroclastic material is often wrapped with a quartz ribbons. The interpreted shear sense is low-angle and left lateral. The foliation strikes east-west and dips gently to the south. Return to the vehicles by following the path. At this point the trip is over. Retrace your trip to Route 8. If you are headed back to Lake George, then follow Route 8 back to Speculator, NY, then turn south on Route 30.

End of trip.

ACKNOWLEDGMENTS

We would like to thank the many students and staff of the SUNY Oswego Geology Research Field Program whose field work and research efforts helped make this field trip possible. Special thanks to Damian Piaschyk, Lindsay Williams, Rachel Price and Robert Peterson. Chiarenzelli would like to thank the James S. Street Fund at St. Lawrence University for partial support of the analytical work discussed herein.

REFERENCES CITED

Baird, G. B., and MacDonald, W. D., 2004. Deformation of the Diana Syenite and Carthage-Colton Mylonite Zone: implications for timing of the Adirondack Lowlands deformation. in Tollo, R. P., Corriveau, L., McLelland, J., and Bartholomew, M. J., eds., Proterozoic Tectonic Evolution of the Grenville Orogen in North America: Geological Society of America Memoir 197, p. 285-297.

Cannon, R.S., Jr., 1937. Geology of the Piseco Lake Quadrangle. New York State Museum Bulletin, no. 312, 107p.

Carr, S.D., Easton, R.M., Jamieson, R.A., and Culshaw, N.G., 2000, Geologic transect across the Grenville orogen of Ontario and New York: Canadian Journal of Earth Sciences, v. 37, p. 193-216.

Chiarenzelli, J., Hudson, M., Dahl, P., and deLorraine, W. D., 2012. Constraints on deposition in the Trans-Adirondack Basin, Northern New York: Composition and origin of the Popple Hill Gneiss: Precambrian Research, v. 214-215, p. 154-171.

Chiarenzelli, J. R., Valentino, D. W., Thern, E., and Regan. S., 2011, The Piseco Lake Shear Zone: A Shawinigan Suture (abstract): Geological Association of Canada, v. 34, p. 40.

Chiarenzelli J., Regan, S., Peck, W., Selleck, B., Baird, G. and Shrady, C., 2010a. Shawinigan Magmatism in the Adirondack Lowlands as a Consequence of Closure of the Trans-Adirondack Back-Arc Basin: Geosphere, v. 6, p. 900-916.

Chiarenzelli, J., Lupulescu, M., Cousens, B., Thern, E., Coffin, L., and Regan, S., 2010b. Enriched Grenvillian Lithospheric Mantle as a Consequence of Long-Lived Subduction Beneath Laurentia: Geology, v. 38, p. 151-154.

Chiarenzelli, J., Valentino, D., and Gates, A., 2000. Sinistral transpression in the Adirondack Highlands during the Ottawan Orogeny: strike-slip faulting in the deep Grenvillian crust. Abstract presented at the Millenium Geoscience Summit GeoCanada 2000, Calgary, Alberta May 29-June 1st.

Dickin, A.P. and McNutt, R.H., 2007, The Central Metasedimentary Belt (Grenville Province) as a failed back-arc rift zone: Nd isotope evidence: Earth and Planetary Science Letters, v. 259, p. 97-106.

Fakundiny, R. H. 1986. Trans-Adirondack Mountains Structural Discontinuities. In Proceedings of the Sixth International Conference on Basement Tectonics, edited by M. J., Jr. Aldrich, and A. W. Laughlin, pp. 64-75. International Basement Tectonics Association, Salt Lake City, Utah.

Fakundiny, R. H., Yang, J., and Grant, N. K. 1994. Tectonic Subdivisions of the Mid-Proterozoic Adirondack Highlands in Northeastern New York: Northeastern Geology, v. 16, p. 82-93.

Gates, A., Valentino, D., Chiarenzelli, J., Solar, G., and Hamilton, M., 2004. Exhumed Himalayan-type syntaxis in the Grenville Orogen, northeastern Laurentia: Journal of Geodynamics, v. 37, p. 337-359.

Geraghty, E. P., Isachsen, Y. W., and Wright, S. F. 1981. Extent and character of the Carthage-Colton mylonite zone, northwest Adirondacks, New York. U.S. Nuclear Regulatory Commission, NUREG/CR-1865, 83 p.

Glennie, J. S., 1973. Stratigraphy, structure, and petrology of the Piseco Dome area, Piseco Lake 15' quadrangle, southern Adirondack Mountains, New York (Ph.D. thesis). Syracuse, New York, Syracuse University, 45 pp.

Hamilton, M.A., McLelland, J.M., and Selleck, B.W., 2004. SHRIMP U/Pb zircon geochronology of the anorthosite-mangerite-charnockite-granite suite, Adirondack Mountains, NY: Ages of emplacement and metamorphism, *in* Tollo, R.P., Corriveau, L., McLelland, J.M., and Bartholomew, M.J., eds., Proterozoic Tectonic Evolution of the Grenville Orogen in North America: Geological Society of America Memoir 197, p. 337–355.

Hanmer, S., Corrigan, D., Pehrsson, S., and Nadeau, L., 2000. SW Grenville Province, Canada: the case against post-1.4 Ga accretionary tectonics: Tectonophysics, v. 319, p. 33-51.

Hawman, R.B. and Phinney, R.A.,1992. Structure of the crust and upper mantle beneath the great valley Allegheny Plateau of eastern Pennsylvania, 1, Comparison of linear inversion methods for sparse wide-angle reflection data, Journal of Geophysical Research, v. 97, p. 371–391.

Hecklau, S., MacKenzie, K., and Chiarenzelli, J., 2014. Geological investigation of Bennies Brook Landslide, Lower Wolfjaw Mountain, Adirondack High Peaks Region (abstract): NE Geological Society of America Abstracts with Programs, v. 46, p. xx.

Heumann, M.J., Bickford, M.E., Hill, B.M., McLelland, J.M., Selleck, B.W., and Jercinovic, M.J., 2006. Timing of anatexis in metapelites from the Adirondack lowlands and southern highlands: A manifestation of the Shawinigan orogeny and subsequent anorthosite-mangerite-charnockite-granite magmatism: Geological Society of America Bulletin, v. 118, p. 1283-1298.

McLelland, J. M., 1984. Origin of ribbon lineation within the Southern Adirondacks, U.S.A.: Journal of Structural Geology, v. 6, p. 147-157.

McLelland, J. and Chiarenzelli, J., 1989. Age of a xenolith-bearing olivine metagabbro, Eastern Adirondack Mountains, New York. Journal of Geology, v. 97, p. 373-376.

McLelland, J. M. and Chiarenzelli, J. R., 1990. Geochronological studies of the Adirondack Mountains, and the implications of a Middle Proterozoic tonalite suite, *in* Gower, C., Rivers, T., and Ryan, C., eds., Mid-Proterozoic Laurentia-Baltica: Geological Association of Canada Special Paper 38, p. 175-194.

McLelland, J. and Isachsen, Y., 1986, Geologic synthesis of the Adirondack Mountains and their tectonic setting within the Grenville of Canada, *in* Moore, J., Baer, A., and Davidson, A., eds., The Grenville Province: Geological Association of Canada Special Paper 31, p. 75–95.

McLelland, J.M., Selleck, B.W., and Bickford, M.E., 2010. Review of the Proterozoic evolution of the Grenville Province, its Adirondack outlier, and the Mesoproterozoic inliers of the Appalachians, *in* Tollo, R.P., Bartholomew, M.J., Hibbard, J.P., and Karabinos, P.M., eds., From Rodinia to Pangea: The Lithotectonic Record of the Appalachian Region: Geological Society of America Memoir 206, p. 1–29.

McLelland, J., Chiarenzelli, J., Whitney, P., and Isachsen, Y., 1988. U-Pb zircon geochronology of the Adirondack Mountains and implications for their geologic evolution: Geology, v. 16, p. 920-924.

Meighan, H. E., Pulliam, J., Brink, U., Lopez-Venegas, A. M., 2013. Seismic evidence for a slab tear at the Puerto Rico trench, Journal of Geophysical Research: Solid Earth, v. 118, iss. 6, p. 2915-2923.

Meighan, H. E. and Pulliam, J., 2013. Seismic anisotropy beneath the northeastern Caribbean: implications for subducting North American lithosphere, Bulletin de la Societe Geologique de France, v. 184, Iss. 1-2, p. 67-76.

Peck, W., Selleck, B., Wong, M., Chiarenzelli, J., Harpp, K., Hollocher, K., Lackey, J., Catalano, J., Regan, S., and Stocker, A., 2013. Orogenic to post-orogenic (1.20–1.15 Ga) magmatism in the Adirondack Lowlands and Frontenac terrane, southern Grenville Province, USA and Canada: Geosphere, v. 9, p. 1637-1663.

Peck W. H, Valley J. W., Corriveau L., Davidson A., McLelland J., and Farber, D.A ., 2004, Oxygen-isotope constraints on terrane boundaries and origin of 1.18-1.13Ga granitoids in the southern Grenville Province. *in* Proterozoic tectonic evolution of the Grenville orogen in North America, Tollo RP, Corriveau L, McLelland J, and Bartholomew MJ, eds.: Boulder, Colorado, Geological Society of America Memoir 197, p. 163-182.

Piaschyk, D., Valentino, D.W., and Solar, G.S., 2005. Variations in L- and S-tectonite on the northern boundary of the Piseco Lake shear zone, western Adirondack mountains, New York. *in* Valentino, D.W. (ed.), Guidebook for Field Trips for the Annual Meeting of the New York State Geological Association, v. 77**,** Trip B2, 20p.

Price, R., Valentino, D., Solar, G., and Chiarenzelli, J., 2003. Greenschist facies metamorphism associated with the Piseco Lake shear zone, Central Adirondacks, New York (abstract): Northeast Geological Society of America Abstract with Programs, Halifax, Nova Scotia, v. 35, p. 22.

Rankin,D.W.,1976. Appalachian salient and recesses: late Precambrian break-up and the opening of the Iapetus Ocean, Journal of Geophysical Research, v. 81, p. 5605–5619.

Regan, S.P., Chiarenzelli, J.R., McLelland, J.M., and Cousens, B.L., 2011. Evidence for an enriched asthenospheric source for coronitic metagabbros in the Adirondack Highlands: Geosphere, v. 7, no. 3, p. 694-709.

Rivers, T., 2008. Assembly and preservation of lower, mid, and upper orogenic crust in the Grenville Province – Implications for the evolution of large hot long-duration orogens: Precambrian Research, v. 167, p. 237-259.
Rivers, T. and Corrigan, D., 2000, Convergent margin on southeastern Laurentia during the Mesoproterozoic: tectonic implications: Canadian Journal of Earth Sciences, v. 37, p. 359-383.

Roden-Tice, M. K. and Tice, S. J., 2005. Regional-scale mid-Jurassic to Late Cretaceous unroofing from the Adirondack Mountains through central New England based on apatite fission-track and (U-Th)/He thermochronology: Journal of Geology, v. 113, p. 535-552.

Selleck, B.W., McLelland, J.M., and Bickford, M.E., 2005. Granite emplacement during tectonic exhumation: The Adirondack example: Journal of Geology, v. 33, p. 781-784.

Steltenpohl, M. G., Zitez, I., Horton, J. W., Jr., and Daniels, D. L., 2010. New York-Alabama lineament: A buried right-slip fault bordering the Appalachains and mid-continent North America, Geology, v. p. 38, no. 6, p. 571-574.

United State Geological Survey, 2017. Magnetic Anomaly Maps and Data for North America, Mineral Resources Online Spatial Data, https://mrdata.usgs.gov/magnetic/

Valentino, D., Chiarenzelli, J., Hewitt, E., and Valentino, J., 2012. Applications of water-based magnetic gradiometry to assess the geometry and displacement for concealed faults in the southern Adirondacks Mountains, New York, U.S.A.: Journal of Applied Geophysics, v. 76, p. 109-126.

Valentino, D., Chiarenzelli, J., Paaschyk, D., Williams, L., and Peterson, R., 2008. The Southern Adirondack Sinistral Transpressive Shear System: *in* Friends of the Grenville (FOG) Field Trip 2008, D. Valentino and J. Chiarenzelli (eds.), September 28th, Indian Lake, New York, 56p.

Valentino, D. W., Chiarenzelli, J. R. and Regan, S., in press. Spatial and temporal links between Shawinigan accretionary orogenesis and massif anorthosite intrusion, southern Grenville province, New York, U.S.A., Journal of Geodynamics.

Wiener, R.W., 1983. Adirondack Highlands-Northwest Lowlands 'boundary': A multiply folded intrusive contact with associated mylonitization: Geological Society of America Bulletin, v. 94, p. 1081-1108.

Wong, M. S., Peck, W. H., Selleck, B. W., Catalano, J. P., Hochman, S. D., and Maurer, J. T., 2011, The Black Lake shear zone: A boundary between terranes in the Adirondack Lowlands, Grenville Province, Precambrian Research, v. 188, p. 57-72.