KECK GEOLOGY CONSORTIUM

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

April 2009
Franklin & Marshall College, Lancaster PA.

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BLOCK ISLAND, RI: A MICROCOSM FOR THE STUDY OF ANTHROPOGENIC & NATURAL ENVIRONMENTAL CHANGE
Faculty: *JOHAN C. VAREKAMP*: Wesleyan University and *ELLEN THOMAS*: Yale University & Wesleyan University
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Keck Geology Consortium: Projects 2008-2009
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ASSESSMENT OF THE BLACK LAKE SHEAR ZONE AS A SITE OF ELZEVIRIAN SUTURE, ADIRONDACK MOUNTAINS, NEW YORK

STEVEN HOCHMAN: Pomona College
Research Advisor: Harold Magistrale

INTRODUCTION

High grade metamorphic and igneous rocks exposed in the Adirondack region of Upstate New York (Peck et al. Figs. 1 and 2, this volume) record mountain building events on the margin of Laurentia during the Grenville Orogenic Cycle (1.3-1.0 Ga) (McLelland et al., 1996). Of primary concern is the tectonic sequencing of the Grenville Orogenic Cycle, 1350-1000 Ma, which has been divided into the Elzevirian Orogeny (1300-1200 Ma), a period of large scale terrane accretion followed by crustal delamination and magmatism, and the Ottawan Orogeny (1100-1000 Ma), a period of continent-continent collision, perhaps representing the docking of Amazonia with Laurentia (McLelland et al., 1996; Wasteneys et al., 1999). The Elzevirian Orogeny is further divided into three stages, the addition of the Elzevir and Frontenac terranes (1225-1190 Ma), the addition of Adirondack Highlands and Green Mountains terrane (1190-1160 Ma), and delamination and collapse resulting in anorthosite-mangerite-charnockite-granite (AMCG) magmatism (1170-1125 Ma) (McLelland et al., 1996; Wasteneys et al., 1999).

Adirondack rocks exposed today predominantly record the deformation and metamorphism associated with the Grenville Orogenic Cycle and subsequent metamorphic periods, with the strength of more recent metamorphic input overprinting older deformation recorded in these rocks (McLelland et al., 1996). As such, the most dominant structural feature remaining in the region is the juxtaposition of the Adirondack Highlands and Lowlands by the Carthage Colton Shear Zone (CCSZ; Geraghty et al., 1981). The Highlands depict rugged topography and the wide spread occurrence of anorthosite and orthogneiss bodies, whereas the Lowlands are characterized by their flat lying appearance and wide range of metasedimentary (quartzite, marble) and igneous intrusive rocks (McLelland et al., 1996). The existence of the CCSZ as a divider between these distinct regimes has led geologists to name it the location of suture during the second accretionary event of the Elzevirian Orogeny, addition of Adirondack Highlands and Green Mountains of Vermont to the Frontenac Terrane, consisting of the Lowlands and Elzevir Terrane in Canada. The CCSZ is thought to continue north into Canada as the Labelle Shear Zone (LSZ; McLelland et al., 1996).

However, while the CCSZ provides a convenient proposed suture site, evidence to this effect is based solely on the juxtaposition of the Highlands and Lowlands, which recent work suggests is related to late stage extensional feature associated with the collapse of the Ottawan orogen and therefore is unlikely to represent the action of suture. Furthermore, the CCSZ does not lie on strike with the LSZ, making their genetic relation dubious. Geochemical evidence has hinted at a discontinuity existing further to the north crossing the Black Lake Fault (Peck et al., 2004), and this work seeks to characterize the behavior of rocks falling within this region following strike of the Black Lake Fault, which I will tentatively refer to as the Black Lake Shear Zone (BLSZ; Fig. 1).

Conveniently the extent of this proposed shear zone and surrounding region has been intruded by a suite of felsic dikes briefly noted in field maps of the region from the first half of the 20th century (Buddington, 1934; Cushing et al., 1910). The dikes, which intrude a pyroxene rich calc-silicate rock of unknown origin as well as outcrops of quartzite and Rockport Granite, range from undeformed to highly deformed. Examination of the dikes wide range of recorded deformation, geochemistry, and structural characteristics allow us to constrain the magnitude, location, and type of deformation in the proposed BLSZ.

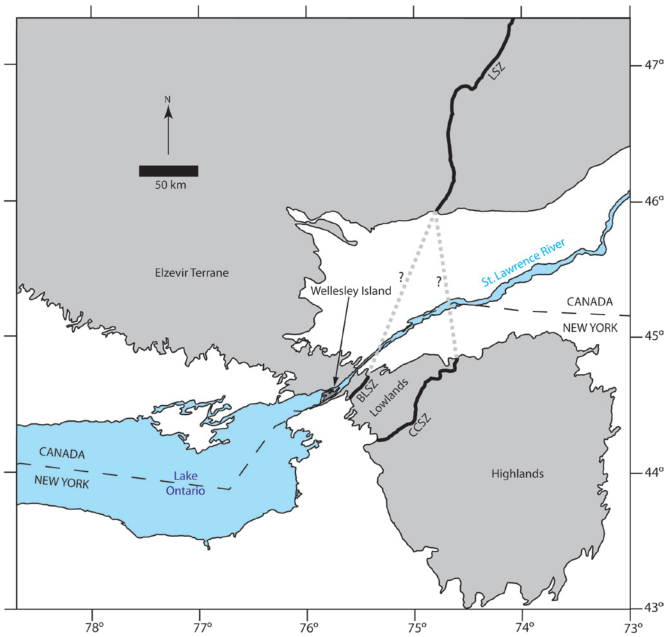


Figure 1: Field area with major terranes and shear zones labeled. Dotted lines represent imaginary connections between shear zones in New York and those extending into Canada; note the better co-linear fit of the BLSZ with the LSZ.

METHODS

Twenty-three felsic dikes from along strike of the BLSZ and off its axis were considered in this study. Strike and dip measurements were taken for each dike and any planar host rock or dike foliation fabrics as well as trend and plunge data for mineral lineations noted within or in close proximity to the dike. Oriented samples of each dike were collected and utilized for oriented thin sections, X-ray fluorescence compositional analysis, and Sensitive High Resolution Ion Microprobe (SHRIMP) age dating.

Hand sample scale observations combined with microstructural evidence from oriented thin sections yields insight into the character of the proposed BLSZ, e.g. shear zone orientation, sense of shear, and components of strike-slip and dip-slip behavior, as well as indications of temperatures of regional metamorphic activity. In combination with analysis of raw structural data, compositional analysis, and absolute age dating it is possible to reconstruct the history of the felsic dikes in this region, and thus understand the nature of the history of the Lowlands region during and following the Grenville Orogenic Cycle.

RESULTS

Field Observations and Microstructural Evidence

The felsic dikes examined fall into three categories based on the strength and variety of strain they record as viewed in hand sample. The highest strained group possessed few if any accessory mafic minerals, and demonstrated dramatic elongation of quartz and some feldspar grains to the extent that it is difficult to pick out individual grains. An intermediate category of strained dikes illustrated foliation fabrics of oblate grains defining planes within 15° of the dikes walls; many of these foliation fabrics were accentuated by the presence of oblate mafic minerals, both pyroxene and hornblende, which made fabric recognition easy. The least strained of the dikes has an essentially strain free appearance with equant equigranular texture; members of this subclass express the widest range in mineralogy, some dikes including mafic minerals, others without. We will refer to these classes as strained grain (Fig. 2a), foliation fabric (Fig. 2b), and unstrained dikes, respectively.

The existence of such drastic variation in metamorphic character throughout a limited variety of rock types suggests a mechanism for differential amounts of deformative action acting upon units in close proximity. Internal to the dikes these differences may be related to structural orientation, specific composition, or age relation, or in the grander scheme of the BLSZ may speak to regions where strain was localized in and around the shear zone. In thin section it is more difficult to distinguish the

a
b


Figure 2: a) Dike of the strained grain category; pencil is 25 cm long. b) Dike of the foliation fabric variety; pencil is 25 cm long.

dikes from one another based on the distinctions observed in hand sample. There is ample microstructural evidence to support the observation of ductile behavior, but dramatic static recrystallization related to high temperatures past the point when deformation ceased has overprinted many classic signs of strain accumulation (Passchier and Trouw, 1998). The ability of metamorphic conditions to deform both quartz and feldspar to ribbons in the strained grain dikes suggests temperatures of deformation well above the brittle-ductile temperature of either mineral, which for quartz begins at 270°C and feldspar at 450°C -500°C (van der Pluijm and Marshak, 2004). However, the formation of quartz ribbons is generally restricted to temperatures of 600°C-700°C (Mainprice et al., 1986), suggesting that members of this subclass, which were found exclusively along strike of the BLSZ, experienced these temperatures. In thin section the ribbons appear statically recrystallized and are discerned by the presence of many quartz and feldspar grains with aspect ratios of 2-4:1 lined up end to end, together outlining the originally strained grain (Fig. 3). Considering thin sections cut perpendicular to the ribbons, oval grains dominate in the absence of elongate structures further illustrating the lineation nature of the original grains (Fig. 3). The ribbons are exclusively orientated northeast-southwest, which suggests their formation through shear in these directions, though sense of shear indicators do not indicate if this strike-slip shear with respect to the BLSZ was right lateral or left lateral.

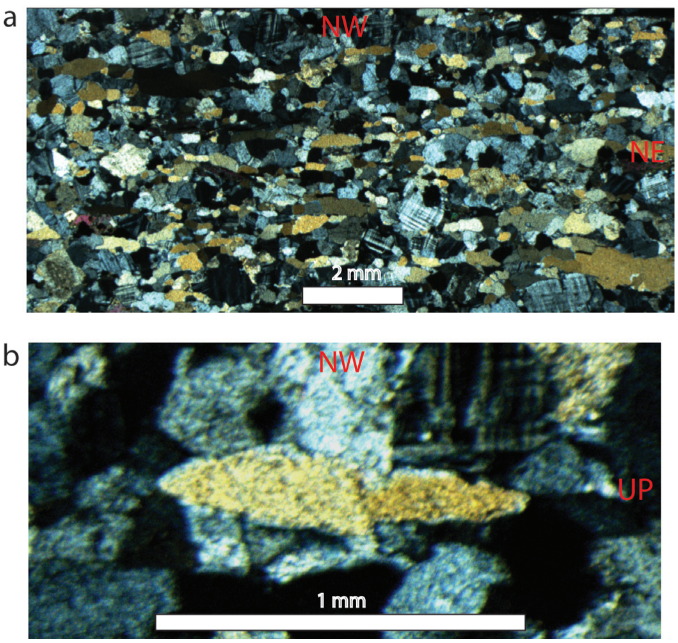
a
b


Figure 3: a) Example of quartz ribbons in a sample. The ribbons have been recrystallized and are now illustrated as several slightly elongate quartz grains lined up end to end. b) The same sample with a perpendicular cut to illustrate that in cross section the ribbons are ovals - thus they are lineations as opposed to oblate grains. Note in both photomicrographs red letters to indicate orientation of the thin section.

In the foliation fabric dikes quartz and feldspar behaves similarly, but often the ribbons are less well formed, which is especially well noted in thin section. In hand sample foliation fabric dikes possess pancake shapes grains of pyroxene and hornblende, indicative of temperatures allowing for ductile behavior in these materials. In general the crystal-plastic transition temperature for pyroxene and hornblende is 700°C (van der Pluijm and Marshak, 2004); however, the juxtaposition in some cases of oblate pyroxene and hornblende with brittle feldspars indicates that they were deformed at 500°C-700°C. In thin section pyroxenes and hornblende look to be right at the brittle-ductile transition, in places fracturing brittley, elsewhere shearing out. Dikes of this variety were noted across the field area, but in general the stronger fabrics were on strike of the BLSZ, suggesting that these dikes indicate that temperatures reached 700°C on-axis, falling to 500°C on Wellesley Island.

The unstrained dikes provide little further assistance in defining a temperature structure as their strain free appearance leaves up in the air the question of whether they were too young and cool to metamorphose, or if they were oriented or geographically located such that they fell out of zones where strain was accumulated.

In addition to insight into thermal structures for the proposed BLSZ, some hand sample scale observations yield information of the kinetics of this system e.g. right/left lateral, reverse/thrust. Hand sample examples of this type were sparse at best in the field region; however, the confluence of drag folds and mineral lineations along one dike at the Interstate-81 outcrop provided some clues. The dike cross cut the host rock foliation and functioned as a mini shear zone producing drag folds indicative of left-lateral behavior (Fig. 4). With only one sample extrapolating these data to represent the entire shear zone is a stretch, but this example provides a rough first order consideration of the greater shear zone's behavior.

A few of the sample thin sections also illustrate sigmoidal grain shapes indicative of shear sense. In all cases grains demonstrate left lateral motion assuming an essentially 90° dipping shear environment (Fig. 4). In other cases sections cut parallel to the shear zone orientation demonstrate sigmoidal grains speaking to the dip-slip component of the system. Grains of this variety demonstrate a thrusting system on a plane dipping steeply to the northwest (Fig. 4).

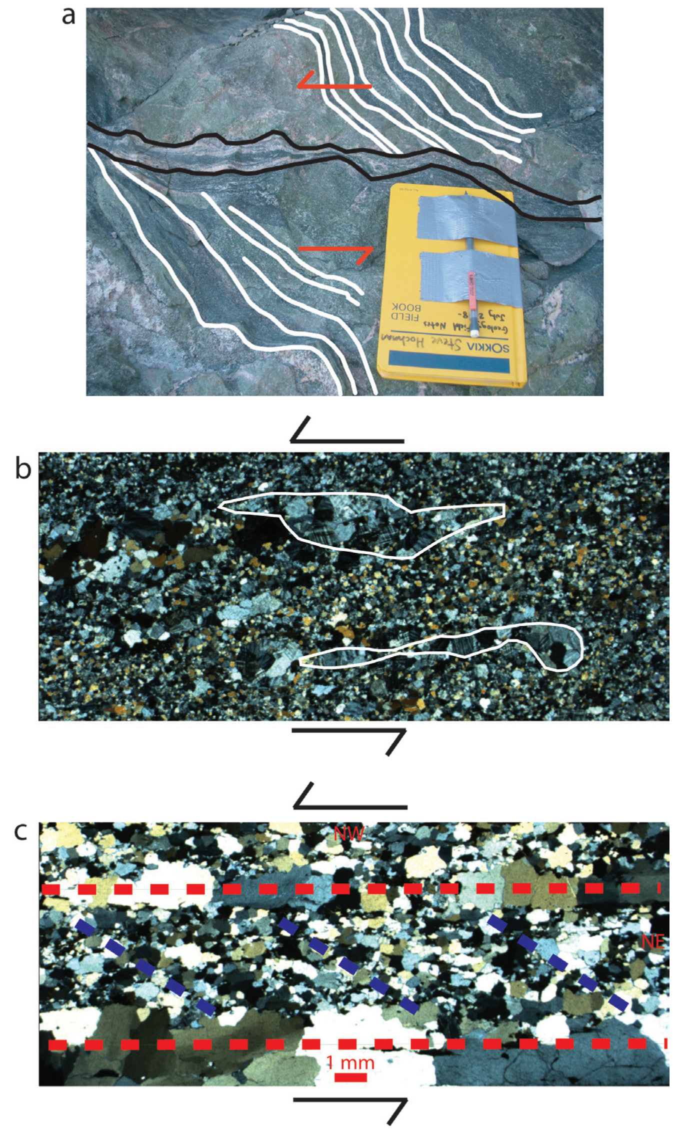


Figure 4: a) Illustration of left-lateral sense of shear based on drag folds on host rock foliation, outlined in white, against felsic dike, outlined in black; folds are generated as the dike maintains its position as the host rock behaves as blocks moving past one another above and below the dike. b) Sigmoidal grains outlined in white illustrate left lateral sense of shear. c) Orientation of red dashed line primary foliation and blue dashed line secondary oblique foliation indicate left lateral sense of shear.

Structural Data

Little geophysical work has defined the northeast-southwest striking Black Lake Fault (Peck et al., 2004) or the associated shear zone at depth. However, proposed suturing action along this boundary led to the development of a strong country rock foliation in the pyroxene rich calc-silicate rock that was subsequently intruded by the suite of granite dikes under consideration; the structural analysis of the orientation of these features may shed light on the types of tectonic motion associated with this boundary throughout the Grenville Orogenic Cycle.

Both progressive simple and pure shear may lead to the development of host rock foliation fabric, each demonstrating characteristic orientation with respect to the shearing direction. Thus it may be inferred that the tectonic setting of the collisional event between the Frontenac and Adirondack Highland terranes during the late Elzevirian would be recorded through the orientation of fabrics developed during this period assuming the BLSZ as the site of suture. More specifically, the orientation of the fabric developed is expected to result from the orientation of the shear zone as it juxtaposed these two continental bodies. Assuming a convergent plate setting, three scenarios for the orientation of suture seem plausible; 1) a northwest dipping thrust system (subduction below the Frontenac Terrane) (Fig. 5a), 2) a southeast dipping thrust system (subduction below the Adirondack Highlands) (Fig. 5b), or 3) a wide and generally vertical suture system (Fig. 5c). The implied resultant country rock foliations for each scenario include, foliations dipping steeply to the northwest, dipping steeply to the southeast, or foliations dipping to the northwest to the northwest of suture, rotating towards a southeasterly dip to the southeast of suture, respectively (Fig. 5d).

Transecting the shear zone, host rock foliations dip to the southeast in regions northwest of the BLSZ center and to the northwest in regions to the southeast (Fig. 5). This collection of dip data fails to match any of the expected scenarios for fabric orientation resulting from suture orientation. Rather, these data present a mirror image of what would be expected from a wide and generally vertical suture system where foliations are expected to dip northwest to the northwest of suture, and southeast to the southeast. These data are interpreted to be the result of dramatic host rock metamorphism postdating

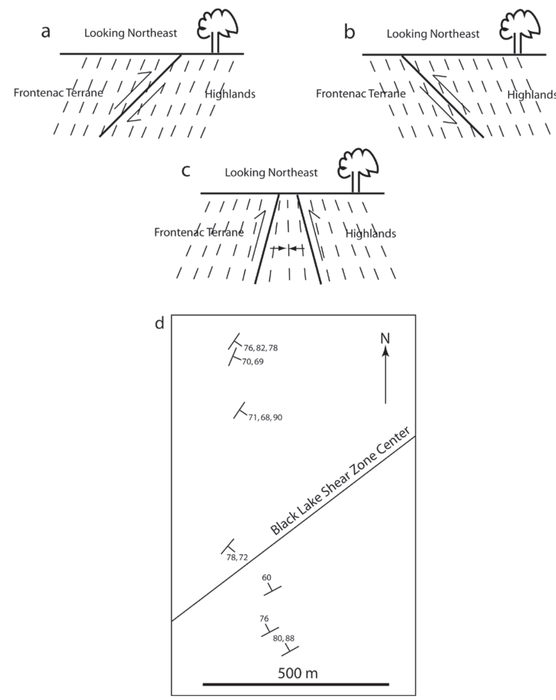


Figure 5: Three shear zone scenarios leading to the formation of country rock fabric. Thick lines represent imagined shear zone boundaries, arrows indicate maximum stress directions, and dashed lines indicate the expected orientation of fabrics originating from shear zone orientations. a) northwest dipping shear zone, b) southeast dipping shear zone, c) broad and generally vertical shear zone. d) Host rock foliation measurements plotted based on their geographical location with respect to the BLSZ.

the accretionary events of the Elzevirian based on the metamorphic structural characteristics noted in the calc-silicate host rock. Such structures include extensive isoclinal folding, boundinage, and pinch and swell structures. However, based on the dramatic change in dip crossing the BLSZ, it is inferred that these data still indicate the influence of potential suture orientation. Whereas either scenario for a dipping suture result in uniform host rock foliation dip across the shear zone, only a generally vertical shear zone would be expected to yield variation in dip as is observed in the plotted data (Fig. 5d). Thus we take this model for suture orientation as a first order approximation of the setting for this accretionary event.

DISCUSSION AND CONCLUSIONS

The zone surrounding the Black Lake Fault illustrates a collection of strained material, potentially representing the location of suture between crustal components adding to Laurentia during the Grenville Orogenic Cycle. While a geochemical story will likely elucidate if the proposed BLSZ represents a discontinuity between terranes or is simply a zone of high strain, felsic dikes from collected throughout the region speak volumes about the dynamics of this system.

The BLSZ represents a generally vertical system, with evidence to suggest a portion of left-lateral strike-slip and thrust dip-slip activity. The behavior of grains on and around the center of the zone point to high metamorphic temperatures, ranging from 500°C off-axis to 700°C on-axis, temperatures which lasted well beyond the major period of deformation and creating the wide extent of static recrystallization recorded in these rocks today.

Further work is currently underway to date these samples, a process that will greatly elucidate the periods through which these processes were active, and to consider their compositional make-up to determine the forces that led to their creation and their geochemical relationship to other rocks in the region.

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