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ORIGINS OF SINUOUS AND BRAIDED CHANNELS ON ASCRAEUS MONS, MARS
Faculty: ANDREW DE WET, Franklin & Marshall College, JAKE BLEACHER, NASA-GSFC, BRENT GARRY, Smithsonian

TROPICAL HOLOCENE CLIMATIC INSIGHTS FROM RECORDS OF VARIABILITY IN ANDEAN PALEOGLACIERS
Faculty: DONALD RODBELL, Union College, NATHAN STANSELL, Byrd Polar Research Center
Students: CHRISTOPHER SEDLAK, Ohio State University, SASHA ROTHENBERG, Union College, EMMA CORONADO, St. Lawrence University, JESSICA TREANTON, Colorado College.

EOCENE TECTONIC EVOLUTION OF THE TETON-ABSAROKA RANGES, WYOMING
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INTERDISCIPLINARY STUDIES IN THE CRITICAL ZONE, BOULDER CREEK CATCHMENT, FRONT RANGE, COLORADO
Faculty: DAVID DETHIER, Williams College
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SEDIMENT DYNAMICS OF THE LOWER CONNECTICUT RIVER
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Students: MICHAEL CUTTLER, Boston College, ELIZABETH GEORGE, Washington & Lee University, JONATHON SCHNEYER, University of Massachusetts-Amherst, TIRZAH ABBOTT, Beloit College, DANIELLE MARTIN, Wesleyan University, HANNAH BLATCHFORD, Beloit College.

ANATOMY OF A MID-CRUSTAL SUTURE: PETROLOGY OF THE CENTRAL METASEDIMENTARY BELT BOUNDARY THRUST ZONE, GRENVILLE PROVINCE, ONTARIO
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Students: KENJO AGUSTSSON, California Polytechnic State University, BO MONTanye, Colgate University, NAOMI BARSHI, Smith College, CALLIE SENDEK, Pomona College, CALVIN MAKO, University of Maine, Orono, ABIGAIL MONREAL, University of Texas-El Paso, EDWARD MARSHALL, Earlham College, NEVA FOWLER-GERACE, Oberlin College, JACQUELYNE NESBIT, Princeton University.

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PETROLOGY AND STRUCTURE OF THE CENTRAL METASEDIMENTARY BELT BOUNDARY THRUST ZONE ITS HANGING WALL, GRENVILLE PROVINCE, ONTARIO
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GEOCHEMISTRY AND GEOCHRONOLOGY OF CENTRAL METASEDIMENTARY BELT BOUNDARY THRUST ZONE THRUST SHEETS IN SOUTHERN ONTARIO, GRENVILLE PROVINCE
KENJO S. AGUSTSSON, California Polytechnic State University, San Luis Obispo
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GARNET-BIOTITE GEOETHERMOBAROMETRY OF THE CENTRAL METASEDIMENTARY BELT BOUNDARY THRUST ZONE OF THE GRENVILLE PROVINCE, ONTARIO, CANADA
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USING STRUCTURAL ANALYSES TO ASSESS POSSIBLE FORMATION MECHANISMS OF THE
CHEDDAR GNEISS DOME
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INTRODUCTION

The southern Grenville Province in Ontario (Fig. 1) exposes metasedimentary, metavolcanic, and meta-plutonic rocks of the 1.3–1.2 Ga Central Metasedimentary Belt (CMB) sitting on top of orthogneiss-dominated 1.7–1.4 Ga rocks of the Central Gneiss Belt (CGB, Easton 1992). The boundary between these tectonic belts is the Central Metasedimentary Belt boundary thrust zone (CMBbtz; Fig. 2 and 3): a region of annealed, heterogeneously deformed mylonitic tectonites and marble mélange tectonites surrounding dismembered metaplutonic thrust sheets (Hanmer, 1988; Hanmer and McEachern, 1992). The provenance of these thrust sheets and dismembered blocks (i.e. if they originate from the CGB, CMB, or elsewhere) is generally unclear.

Structurally above the CMBbtz are the Bancroft Terrane and the Harvey-Cardiff Domain (Fig. 2). The Bancroft Terrane may be a deformed extension of the CMB, which it resembles lithologically, or it may be a supracrustal package deposited on the margin of Laurentia, now the CGB (Carr et al., 2000). The position of the CMB during its formation is unclear. The Harvey Cardiff Domain of the CMB includes a lithologically distinctive suite of four granitic gneiss domes with strongly deformed mantles of amphibolite and marble. The CMBbtz, Bancroft Terrane, and Harvey-Cardiff Domain all share similar structural geometries: east-dipping lithologic boundaries associated with a strong foliation in the same orientation and a sporadic but consistently oriented stretching lineation that is down-dip and associated with a top-to-the-west sense of shear.

This project focuses on quantifying peak pressure and temperature conditions during thrusting of the CMB over the CGB. We also explore possible protoliths for metaplutonic rocks in the CMBbtz thrust sheets. Finally, we report preliminary results from analysis of foliation and kinematic evolution of a gneiss dome from the Harvey-Cardiff Domain and a newly identified shear zone at the boundary of the Bancroft Terrane and the Harvey-Cardiff Domain.

CONTROVERSIAL TECTONICS

Although the term “terrane” pervades the literature on this region, the nature and origin of these distinctive and strongly deformed suites of rock is controversial. The western CMB is dominated by greenschist- and
amphibolite facies metasedimentary and 1.29–1.24 Ga metavolcanic and volcanoclastic rocks that are intruded by suites of gabbroic, tonalitic, and granitic plutons (Easton, 1992). The volcanic rocks have arc geochemical signatures and are dominated by mafic tholeiitic suites, but include intermediate and felsic rocks, some with calc-alkaline signatures. Carr et al. (2000) term this region the Composite Arc Belt, and interpret this package of rocks to be a collage of volcanic arc environments, some of which were formed on oceanic crust away from Laurentia. This tectonic interpretation is controversial, as others have assigned these rocks to rifting and back-arc environments underlain by continental crust and developed on the Laurentian margin (e.g. Hanmer et al., 2000). The youngest cross-cutting plutonic rocks appear to constrain terrane amalgamation of the Composite Arc Belt to 1.24–1.22 Ga (Carr et al., 2000).

The timing of accretion of the Composite Arc Belt to the Central Gneiss Belt is also controversial, as there is evidence for two deformation events in the CMBbtz at ca. 1.19 and 1.08–1.06 Ga (McEachern and van Breemen, 1993). The 1.08–1.06 Ga event is interpreted to date the most pervasive deformation, and CGB rocks structurally below the CMBbtz only record the 1.08 Ga metamorphism, which is interpreted by Timmermann et al. (1997) as representing docking of the Composite Arc Belt. The tectonic significance of the 1.19 Ga event and new 1.12 Ga metamorphic ages (Peck and Kylander-Clark, unpub. data) from the CMBbtz is unknown. The work presented below informs but does not resolve some of these longstanding debates about regional tectonics.

**STRUCTURAL GEOLOGY OF THE HANGING WALL OF THE CMBbtz**

The top of the CMBbtz has historically not been well defined in the field. Carlson et al. (1990) propose that it is an extensional shear zone called the Bancroft shear zone (BSZ). The BSZ is controversial in this context because it clearly records late extension after peak Grenville orogenesis, and it does not offset any metamorphic isograds, implying it does not accommodate regionally significant displacement. More to the point, if the BSZ is the top of the CMBbtz, then the fundamental relationship between the CMBbtz and the adjacent Harvey-Cardiff domain is one of tectonic collapse. This interpretation is starkly at odds with the equally controversial terrane accretion model for the different suites of rock in the CMB. Recently, Easton and Carr (2009) proposed the newly-mapped Salerno Creek deformation zone (SCDZ) as
the boundary between the CMBbtz and the Harvey-Cardiff domain.

Two student projects focus on the structural geology of SCDZ. Naomi Barshi’s work shows that the steep lineation in the SCDZ is associated with both extensional (E side down) and contractional (E side up) sense of shear. Barshi documents both senses of shear using clast tiling and sigma and delta porphyroclasts, mostly in a meta-granite that crops out sporadically along the SCDZ. She suggests that the SCDZ may have accommodated both types of events (early terrane accretion or thrusting in the CMBbtz, followed by later extension associated with tectonic collapse). Barshi’s quest for dateable monazite associated with deformation fabrics in the SCDZ was tragically unsuccessful. Calvin Mako completed a more process-oriented project in the SCDZ. He looked at meter-scale strain localization and fabric development in a gabbro caught up and variably deformed in the SCDZ. His work shows that deformation (and the development of gneissic fabric) involved grain size reduction of both hornblende and plagioclase. Associated with this deformation are changes in amphibole composition and crystallographic preferred orientation, without similar changes in the feldspar.
A common problem with conventional geother-mobarometry is that results using different mineral assemblages or calibrations can be difficult to compare. Two student projects focused on using a carbon isotope thermometer in marbles as a way of assessing metamorphic temperatures in a series of transects across the Elzevir and Bancroft terranes. Jacquelyne Nesbit documented an east to west gradient of increasing metamorphic temperatures from \(\sim 600^\circ C\) south of the Anstruther dome to \(\sim 700^\circ C\) in the western Bancroft terrane, broadly agreeing with but refining published thermometry. Bo Montayne’s northwest/southeast transect from north of the Cheddar Dome to northwest of the Redstone thrust sheet yielded different results: no temperature gradient was detected and temperatures are consistently higher (averaging \(\sim 750^\circ C\)). Higher temperatures in Montayne’s northern transect may have been predicted by extrapolation of thermometry in the Harvey-Cardiff Domain and further east, but the magnitude of the difference between the northern and southern transects is surprising. Because these data were collected in two different laboratories, a direct lab-lab comparison of selected samples will be carried out.

**METAMORPHIC PETROLOGY OF THE CMBBTZ**

A major objective of student projects was to obtain constraints on the conditions of the metamorphism of the CMBBtz. Previous thermobarometry and phase equilibria studies had focused on the CGB footwall and the CMB hanging wall, inexplicably leaving the CMBBtz’s amphibolite-facies metamorphism poorly characterized (see Streepey et al., 1997 and references therein). Four students undertook projects to better understand the metamorphic history of the area. Two of those projects were petrologic studies of a variety of metamorphic rocks in the CMBBtz (+Bancroft) and Elzevir terrane. Neva Fowler-Gerace examined garnet-bearing schists and gneisses, mainly metabasites, from the Elzevir and Bancroft terranes. Garnet-biotite temperatures from these rocks range from between 620 and 780°C and cluster around 650–700°C. Assemblages that constrain pressure are more limited in these rocks, with most giving pressures in the range 6-8 kbar with a few in the 9-10 kbar range. Abigail Monreal focused on pelitic schists and gneisses from around the Dysart and Redstone thrust sheets in the westernmost CMBBtz. The petrology of these units is consistent with \(\sim 650–800^\circ C\) and a range of pressures up to 11 kbar, which will be further constrained using mineral composition data.

Fault-bounded orthogneiss blocks within the CMBbtz range in size from outcrop-sized to 10s of square kilometers and contain a variety of lithologies (Fig. 3; Hanmer, 1988; Hanmer and McEachern, 1992). Hanmer (1988) proposed that the tonalitic Redstone, Dysart, and Glamorgan sheets could have once been a coherent plutonic body that has been dismembered. This question has been debated in the literature, as has the tectonic significance of these rocks. Unpublished geochronology and reconnaissance geochemistry of the Redstone and Dysart thrust sheets (Lumbers et al.,
1990) has linked them to similar rocks in the Adirondacks and Vermont (Fig. 1). Kenjo Agustsson studied the geochemistry and geochronology of the Redstone and Dysart bodies. He found that both bodies have igneous ages of 1.33-1.30 Ga, and contain a similar suite of calc-alkaline tonalites and amphibolites with associated tholeiitic amphibolites having MORB-like rare earth element compositions. Agustsson suggests that these rocks formed in an Andean setting at the Laurentian margin, followed by a backarc rifting episode.

Also present in the suite of meta-igneous thrust sheets are enigmatic blocks made predominately of massif-type anorthosite. These bodies have received little petrologic attention, and have been broadly correlated as belonging to one or another of the larger thrust sheets. The Allsaw anorthosite body was the focus of Edward Marshall’s research. This body has undergone variable deformation and has been partially converted to scapolite, apparently by infiltration of CO₂-rich fluids from the surrounding marble units. Easton (1990) linked the Allsaw anorthosite with the adjacent Glamorgan thrust sheet, but new rare earth element data point to an affinity with other Grenville anorthosites, and not the Glamorgan complex. Marshall documents both channelized and pervasive infiltration of this body, producing scapolite ±zoisite assemblages consistent with metasomatism under upper amphibolite facies conditions.

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