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***The Vermont Geological Society's***
***Spring Meeting***

***April 23, 2011, 8:30 AM***
***Delehanty Hall, Room 219***
***University of Vermont, Burlington, Vermont***

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# ABSTRACTS

BEDROCK GEOLOGY OF THE BLINN HILL PLUTON, EAST-CENTRAL MAINE

Cailey B. Condit, Geology Department, Middlebury College, Middlebury, VT 05753

The Blinn Hill pluton, as previously defined, is an approximately 25 $km^2$ Late Silurian granitoid body within Ordovician metasedimentary rocks of the Cape Elizabeth Formation (Liberty-Orrington belt). Previous maps have shown the pluton to be a single simple intrusive body that is bound to the northwest by a segment of the Norumbega fault system. However, the Blinn Hill pluton and immediately surrounding rocks have never been studied in detail and, given the age of the rocks, a detailed study of this region should provide constraints on the Late Silurian–Devonian Acadian orogeny. The purpose of this work is to study the rocks of the Blinn Hill pluton in detail though a combination of fieldwork, petrography, and whole-rock geochemistry.

Detailed geologic mapping has revealed what was previously shown as a single simple intrusion can be divided into four northeast-trending mappable rock units. From northwest to southeast these include: (1) mylonitic granodiorite, (2) foliated biotite granodiorite, (3) foliated two-mica granite, and (4) muscovite granite and migmatite. The mylonitic granodiorite on the northwest contact of the plutonic complex is associated with the Norumbega fault system. Fabrics within the foliated biotite granodiorite and foliated two-mica granite match fabrics in the surrounding Cape Elizabeth Formation country rocks. Whole-rock geochemistry has been obtained for each of the plutonic rock types and $SiO_2$ content ranges from 66-75 wt. %.

Clearly the Blinn Hill Pluton is not a single homogeneous intrusion; rather it represents several different intrusive rock units of differing compositions and relationships to regional deformation. These rocks may represent a series of different successive intrusions emplaced during the Acadian Orogeny. The foliated varieties reflect deformation by later Acadian tectonic activity. The northwestern margin of the intrusive body has been sheared by the Norumbega fault system.

## A SURVEY OF MICROSTRUCTURES ACROSS A MAJOR LITHOTECTONIC BOUNDARY IN THE TOWN OF CRAFTSBURY, NORTHERN VERMONT II

Maggie McMillan, Geology Department, University of Vermont, Burlington, VT 05405, Jon Kim, Vermont Geological Survey, Waterbury, VT 05671, and Keith Klepeis, Geology Department, University of Vermont, Burlington, VT 05405

The town of Craftsbury straddles a major lithotectonic boundary called the Richardson Memorial Contact (RMC), which divides the western Pre-Silurian (PS) aged metamorphic rocks of the Green Mountain Belt (GMB) from those of the eastern Silurian-Devonian (SD) aged rocks of the Connecticut Valley Belt (CVB). Phyllitic quartzites (Moretown Fm) and black phyllites (Cram Hill Fm) comprise the GMB whereas black phyllites and quartzites (Northfield Fm) and siliceous marbles interlayered with black phyllites (Waits River Fm) comprise the CVB. Although originally defined as a Silurian unconformity, the RMC and its equivalents in Vermont and S. Quebec locally are coincident with a high angle Devonian fault.

The Ordovician Taconian Orogeny only deformed and metamorphosed PS rocks whereas the Devonian Acadian Orogeny affected rocks on both sides of the RMC. Bedrock mapping in Craftsbury defined two dominant foliations for each orogeny (Taconian = S1, S2; Acadian = S3, S4). At the mesoscale, the S1/S2 composite in the Moretown Fm is "pinstriped" with alternating Qtz and Mica domains with intrafolial F2 folds. Flattened quartz grains in S1/S2 display a strong shape-preferred orientation (SPO). In the Cram Hill Fm, quartz and mica pressure shadows surround albite grains parallel to lineation and show a west-side-up sense of shear. The same kinematics was found in Montpelier while opposite kinematics were recorded in S. Quebec and Massachusetts. Analysis of thin sections showed a preserved Taconian composite tectonic fabric that records high strains relative to the Acadian fabrics. Garnets were found on both sides of the RMC in the southern part of town.

In SD rocks, S3 varies from a closely spaced to continuous cleavage that is associated with the overall structure of the CVB. In the marbles, flatted grains of albite and calcite, graphite bands, and alternating Qtz and Mica domains define S3 and record moderate to high strains east of the RMC. The regional folding event (F4) produced a superposed crenulation cleavage (S4) that is related to the D4 Brownington Syncline and deformed the RMC. This fabric has asymmetric conjugate cleavages that record opposite senses of shear. The S4 strongly overprints earlier fabrics expressed in thin section. S4 cleavage planes are spaced, smooth, parallel, discrete, and pressure solution enhanced.

## K-AR DATING OF ILLITE-RICH ROCKS IN THE CHAMPLAIN VALLEY, VERMONT: AN INVESTIGATION OF POST-TACONIAN FAULTING AND FLUID FLOW

Braden Rosenberg, Braden, Geology Department, Middlebury College, Middlebury, VT 05753, Edward Meyer, Earth Sciences, Dartmouth College, Hanover, NH 03755, Peter Ryan, Geology Department, Middlebury College, Middlebury, VT 05753, and D.D. Eberl, U.S. Geological Survey, Boulder, CO 80303

The main tectonic event to affect northwestern Vermont during the Phanerozoic was the Ordovician Taconian orogeny. Subsequent events in the northern Appalachians include the Devonian Acadian Orogeny, the late Carboniferous to Permian Alleghanian Orogeny, and Mesozoic extension. The purpose of this study is to perform K/Ar dating of a series of illite-rich rocks in order to constrain episodes of fluid flow and illite crystallization associated with compressional (and possibly extensional) events. Targets for K/Ar dating include (1) illites in fault clays of the Champlain Thrust, a fault which was first activated during the Taconian Orogeny; (2) illites from a Middle Ordovician K-bentonite bed on the shores of Lake Champlain; (3) illites in fault clays from a high-angle normal fault that juxtaposes Cambrian Winooski Dolostone and Monkton Quartzite; and (4) illite, illite-smectite (I/S) and authigenic K-feldspar in clay fractions from Brandon Lignite, a feature that appears to have formed via hydrothermal alteration of phyllitic layers in the Cambrian Dunham Dolostone. These samples were separated into 2-1, 1–0.5, 0.5–0.2, and <0.2 μm size fractions. Each fraction may represent distinct crystallization periods, as has been shown in previous studies elsewhere. The following represent preliminary K/Ar dates from various size fractions: (1) illites in Champlain Thrust fault clays range from Carboniferous (325 ± 5 Ma; 1–0.5 μm) to Late Jurassic (153 ± 4 Ma; <0.15 μm); (2) illites in the Middle Ordovician K-bentonite range from Devonian (400 ± 5 Ma; 2–1 μm) to Carboniferous (327 ± 4 Ma; <0.15 μm); (3) dates on illites from the high-angle fault are pending; and (4) illites, I/S and Kspar from the Brandon Lignite produce preliminary ages of 316 ± 5 Ma (2–1 μm) and 321 Ma ± 5 Ma (1–0.5 μm). The abundance of Devonian and Carboniferous ages suggests post-Taconian illite growth during episodes of fluid flow associated with the Acadian and Alleghanian orogenies. XRD analysis using the program MudMaster suggests multiple generations of illite growth which may correspond to renewed episodes of fault motion. The Jurassic age of the finest illites in the Champlain Thrust fault clay may relate to Mesozoic unroofing in the Northern Appalachian which has been documented by numerous apatite and zircon fission-track studies.

## A GRAVITY SURVEY ACROSS THE HINESBURG AND CHAMPLAIN THRUSTS IN CHITTENDEN COUNTY, VERMONT

Michael Ingram, Geology Department, University of Vermont, Burlington, VT 05405

This project investigates a -48 mGal Bouguer anomaly in Chittenden County, VT, that is bounded by the Champlain (CT) and Hinesburg (HT) Thrusts. The existing anomaly was modeled by 13 of Bothner's (1993) surveys from a regional gravity survey of Vermont and New Hampshire. I hypothesized that a greater number of gravity surveys in the region of the -48 mGal anomaly would enhance the geometry of the anomaly, and that cross section modeling of the underlying geology could explain the presence of the anomaly.

I collected data with a Worden gravimeter at 70 locations within the area of the -48mGal anomal. This data was then corrected for the effects of instrument drift, Earth tides, elevation, and excess mass from the Earth beneath the survey location. These corrections yielded a simple Bouguer anomaly ranging from -5.7 to -72.3 mGals. This simple Bouguer anomaly was contoured to create a simple Bouguer anomaly map, which shows a contrast to the Bouguer anomaly map produced by Bothner (1993). I found a sharp gradient from high to low values crossing the HT with an E-W trend, and the sharpest gradient from high to low crossing the HT in Williston, with a SW-NE trend. West of the HT the gravity anomaly gradually decreases to its lowest value along the border of Lake Champlain, with the gentlest gradient in the middle of the upper plate of the CT. The E-W gradient of decreasing values is prominent throughout the towns of Hinesburg, Shelburne, and Charlotte, whereas the S-N gradient is prominent in the towns of

Williston, Essex, and Burlington. By contrast, Bothner modeled an enclosed low in the towns of Shelburne, South Burlington, and Williston.

The results from this gravity survey have led to a more detailed Bouguer anomaly map, which will be used to create a profile of the anomaly. This profile will be used to model the density and structural geology of my study area. The VGS has produced a cross-section of the Hinesburg Thrust that will be tested to explain the anomaly in the structural model, and has also proposed a dome-basin fold pattern in this part of the Champlain Valley.

## NATURE AND ORIGIN OF A STEEP METAMORPHIC GRADIENT ALONG THE EDGE OF THE ACADIAN METAMORPHIC HIGH IN SOUTH-CENTRAL MAINE

Kelsey Fredston-Hermann, Geology Department, Middlebury College, Middlebury, VT

The Devonian-aged Acadian metamorphic high in south-central Maine abruptly terminates to the southeast along a very steep transition to lower grade rocks. Here, over the course of about one kilometer, pelitic rocks of the Appleton Ridge Formation abruptly transition from chlorite zone to sillimanite zone. The purpose of this research is to provide a detailed study of this abrupt metamorphic transition in one of the best exposed and least altered portions of the zone.

The study involved a detailed petrographic examination of more than 200 thin sections distributed across an approximately 12 $km^2$ field area centered on the metamorphic transition. Mineral assemblages from each thin section were recorded and used to map four distinct metamorphic zones (chlorite, biotite, staurolite, and sillimanite) separated by three isograds. Andalusite is common in the staurolite and sillimanite zones and indicates the metamorphism involved relatively low pressures. Interestingly, garnet can be found throughout the study area – including in the lower grade chlorite and biotite zone rocks. Mineral chemistry shows that garnets in these lower grade zones are very high in manganese (ave. $X_{Mn}$ = 0.74 for cores in the chlorite zone; ave. $X_{Mn}$ = 0.65 for cores in the biotite zone), but profiles indicate minimal zoning. In contrast, garnets from the staurolite and sillimanite zones are not as manganiferous (ave. $X_{Mn}$ = 0.62 for cores in the staurolite zone; ave. $X_{Mn}$ = 0.47 for cores in the sillimanite zone) but do preserve very distinct chemical zoning profiles with manganese concentrations systematically decreasing from core to rim (with concomitant increases in iron).

The one kilometer transition from chlorite to sillimanite zone rocks along the edge of the Acadian metamorphic high in south-central Maine likely reflects a very high thermal gradient and/or a syn- to post-metamorphic "compression" of previously wider-spaced isograds. Additionally, the presence of garnet in lower-than-normal grade rocks (e.g., within the chlorite and biotite zones) is almost certainly due to the presence of relatively high amounts of manganese in the protoliths which served to stabilize garnet at lower than normal metamorphic conditions.

## GEOCHEMICAL AND SULFUR ISOTOPE ANALYSIS OF TACONIC SLATES: IMPLICATIONS FOR ARSENIC SOURCE AND MOBILITY IN A BEDROCK AQUIFER SYSTEM

Ali Thompson, Geology Department, Middlebury College, Middlebury, VT 05753

In western Vermont, elevated arsenic levels are found in groundwater of the Taconic region, and the source of the arsenic is believed to be Cambro-Ordovician slates of the Taconic Belt. Previous research of bedrock wells in the Taconic Allochthons (St. Catherines, Hatch Hill-West Castleton, Pawlet, and Brezee formations) indicates that 24 % of bedrock water wells contain arsenic concentrations above the EPA MCL of 10 ppb. Within the Taconics, 34 % of wells in the lower-grade Giddings Brook slice contain As $\geq$ 10 ppb, whereas only 5 % of well in the higher-grade Bird Mountain and Dorset Mountain slices contain As $\geq$ 10 ppb. As-bearing pyrite is believed to be the source based on Fe-As and $SO_4$-As correlations in groundwater (Clark et al., 2010) and microscopy-geochemical analysis (Mango, 2009). The objective of this project was to carry out a geochemical study of the rocks of the Taconics to examine the mineralogical sources of arsenic and to examine the effect of low-grade metamorphism on arsenic concentration in meta-sedimentary rock.

Whole rock geochemistry indicates that the lower grade Giddings Brook slice slates contain an average of 98 ppm As ($N$ = 30), while the higher grade Bird Mountain slice contains 2 ppm As ($N$ = 8). Three samples from the thrust zone separating the Giddings Brook and Bird Mountain slices contained an average of 74 ppm As. Within the Giddings Brook slice, lithology appears to be important, with black and grey slates exhibiting an average of 163 ppm ($N$ = 9); green slates contain 16 ppm ($N$ = 15) and purple slates contain only 2 ppm ($N$ = 1). Ordovician black slates are organic-rich and have very high $d^{34}S$ values (40 - 50 ‰), consistent with a highly-anoxic depositional environment that would have facilitated fixation of As into sediments and into pyrite. Sulfur isotope analysis of groundwater samples with elevated As produces $d^{34}S$ values ranging from 18 to 27 ‰; these values fall on a mixing line between bedrock end-members, lending strength to the argument that As is derived from pyrite in the bedrock.

**References**

Clark, A., Smith, T. & Mango, H. (2010). Elevated arsenic in domestic wells from the Taconic allochthons in southern Vermont [abstract]. *Geological Society of America Abstracts with Programs, 42* 185.

Mango, H. (2009). Sources of Arsenic in Drinking Water and Groundwater Flow Pathways in Southern Vermont. *Geological Society of America Abstracts with Programs,* Vol. 41, No. 3, p. 8.

## GROUNDWATER INVESTIGATION IN CRAFTSBURY, VT, USING INTEGRATED GEOPHYSICAL TECHNOLOGIES

Ted Crook, Geology Department, University of Vermont, Burlington, VT 05405

Hydrogeologic investigations commonly employ geophysical technologies to explore subsurface features without need for laborious and costly excavation. In the summer and fall of 2010 I began a project with the objective of employing geophysical technologies to identify groundwater bearing features in Craftsbury, VT. I conducted surveys using two geophysical technologies: Ground penetrating radar (GPR) and an Electromagnetic induction (EMI) profiler. The initial surveys identified a significant anomaly in the electrical properties of the underlying bedrock. EMI data revealed a long, narrow zone of contrasting high and low electrical conductivity, trending north-south along a gently sloping field. High electrical conductivity zones in bedrock can be associated with the presence of groundwater, deposits of metal ore, or some other highly conductive material including graphite. This project integrates geophysical data with observation and analysis of surface geology to determine the nature of the electrical anomaly. Results to date indicate that the responsible feature is most likely a layer of water saturated rock. Bedrock at this location is a formation of sandy, low-grade marble with interbedded phyllite; surface exposures reveal that it is highly porous rock with dissolution along preferential planes. The trend of the electrical anomaly parallels the strike of bedding planes, suggesting that they are related. Water in this soluble material would be expected to have a high concentration of dissolved ions, forming an electrolytic solution of high electrical conductivity. These results demonstrate the potential of EMI as a component of an integrated approach to identifying water-bearing geologic features. EMI equipment is increasingly portable and user friendly, making it as a useful tool for preliminary surveys in groundwater exploration.

## GEOCHEMISTRY AND RADIONUCLIDE POTENTIAL IN A FRACTURED BEDROCK AQUIFER SYSTEM, CRAFTSBURY, VT

Erik Brooks, Geology Department, Middlebury College, Middlebury, VT 05753

The Town of Craftsbury is bisected by the Richardson Memorial Contact (RMC, a Silurian unconformity locally coincident with a Devonian fault), which separates bedrock of the Pre-Silurian (PS) Green Mountain Belt (GMB) from bedrock of the Silurian-Devonian (SD) Connecticut Valley Belt (CVB). The GMB is composed of phyllites and phyllitic quartzites; the CVB consists of siliceous marbles, phyllites and isolated granites. The Ordovician Taconian Orogeny only deformed and metamorphosed PS rocks whereas the Devonian Acadian Orogeny affected rocks on both sides of the RMC.

A recent groundwater study in the Montpelier and Barre West quadrangles (VT) found that some wells completed in SD rocks had elevated Gross Alpha (GA) and radium levels, whereas wells completed in PS rocks west of the RMC did not (Kim et al. 2005). Gamma-ray surveys by Walsh and Satkoski (2005) demonstrated that SD rocks are more radiogenic than PS rocks, and that phyllite beds in the Waits River Fm were elevated in radionuclides relative to quartzite and marble beds.

Geochemical analysis of the major bedrock formations in Craftsbury implicates monazite as a dominant radionuclide host mineral in the CVB, since SD phyllitic rocks contain higher levels of Th, U, and rare earth elements yet less Zr than the PS Moretown Fm. Radionuclide concentrations in the Waits River Fm phyllites are similar to those found by Walsh and Satkoski (2005).

Water analysis revealed that GA in Craftsbury is lower than in Montpelier despite similar rock geochemistry. Furthermore, no strong correlation was found between GA and the formations from which the wells draw, suggesting that the physical hydrogeology of the aquifer exerts significant control over groundwater chemistry. Water drawn from all formations exhibits a Ca-HCO3 signature, and few groundwater constituents can be correlated with any statistical significance, suggesting that water flows between lithologic units and that secondary calcite may occur along fractures in all bedrock units. GA is positively correlated to depth and the lowest yielding well had the highest GA, indicating that residence time is also an important factor. Precipitation may also influence GA variance over time: the lower GA values found in

Craftsbury could be due to greater precipitation (and thus aquifer dilution) in 2008-2010 than in 2003-2005.

**References**

Kim, J., Walsh, G., and King, S., 2005, Lithologic control on naturally occurring radioactivity and ground water chemistry across the Richardson Memorial Contact, central Vermont. *Geological Society of America Abstracts with Programs,* vol. 37 no. 1: p. 78.

Walsh, G., and Satkoski, A. 2005, Surface gamma-ray survey of the Barre West Quadrangle, Washington and Orange Counties, Vermont. Scientific Investigations Report 2005-5276: 19 p., U.S. Geol. Survey.

## INVESTIGATION INTO EFFECT OF CLIMATE VARIABLES ON $\delta^{13}C$ IN TREE CHRONOLOGIES FROM VERMONT

Rachel Gregory, Geology Department, University of Vermont, Burlington, VT 05405, and Cardiff University, United Kingdom

In New England, there is a distinct lack of long-term climate data, with instrumental records only covering the 20$^{th}$ century. The aim of this project is to develop a 60-year stable isotope ratio chronology (1950-2010) from tree rings for a site in the western Green Mountains, Vermont. Currently, there are no stable carbon isotope ratio chronologies developed from tree rings for sites in New England, despite their strength as a proxy record in moist mid-latitudes and their value in determining past climatic conditions. For this study, tree cores of Eastern hemlock (*Tsuga canadensis*) were sampled in the summer of 2010 and processed using standard dendrochronological techniques. Further analysis of the tree cores will include processing of individual tree-ring samples (n=60) to alpha-cellulose and measuring of stable carbon isotopic ratios with a stable isotope ratio mass spectrometer. We will correlate the $\delta^{13}C$ time series with local climate data to determine the climate variables that have the greatest influence over the $\delta^{13}C$ values. In later analysis, this relationship will be used to reconstruct past climate. We hypothesize that the $\delta^{13}C$ time series will be most strongly correlated with maximum temperature during the warm season (June-August) and that the $\delta^{13}C$ ratios will be most strongly influenced by photosynthetic rate. The results of this project will establish the relationship between climate and $\delta^{13}C$ in the recent past, and provide the foundation upon which past climate (prior to the 20$^{th}$ century) will be constructed. The $\delta^{13}C$ time series constitutes the necessary first step in gaining greater insight into past climate in western Vermont.

## A HIGH RESOLUTION CHRONOLOGY FOR HOLOCENE GLACIATION AND MELTING OF SIYEH GLACIER AT CRACKER LAKE, GLACIER NATIONAL PARK, MONTANA

Thomas A. Crocker, Geology Department, Middlebury College, Middlebury VT 05753

The alpine glaciers of Glacier National Park (GNP) have rapidly retreated over the past 150 years from their maximum extents at the end of the Little Ice Age. Some models predict the glaciers will disappear entirely over the next few decades. To better understand the changes that are occurring in GNP now, it is necessary to reconstruct how these glaciers behaved before 1850AD. A 317-cm sediment core was retrieved from Cracker Lake (1801 m), below Siyeh ("Sigh-ee") Glacier, on the eastern side of the Continental Divide in GNP during July 2010. According to USGS visual records, Siyeh Glacier lost ~75% of its area between 1966-2005AD. AMS radiocarbon dating of 5 terrestrial macrofossils reveals that the sediment core spans ~2,200 years with every centimeter representing ~7 years of sedimentation. A multi-proxy laboratory analysis concentrated on sediment indicators of Siyeh Glacier's past extent and activity at the head of Cracker Lake. Peaks in fine silt, L*, LOI1000, and flux carbonate represent periods of Siyeh Glacier melting (~975-1075AD, 1325-1400AD and 1850-present day). Peaks in coarser grain sizes, a*, b*, and magnetic susceptibility represent times of increased erosion in the Cracker Lake watershed not associated with Siyeh Glacier (~200-400AD, 475-675AD, 1375-1500AD). Levels of bedrock-derived carbonate in the core reveal unprecedented retreat rates of Siyeh Glacier in the mid-19$^{th}$ century, synchronous with several other glaciers in GNP at the time. Siyeh Glacier retreated most rapidly from ~1850-1890AD. Beyond this unparalleled period of rapid melt, the most significant period of Siyeh Glacier melting has occurred from ~1960AD through present day. The three largest pulses in carbonate flux at Cracker Lake in the core (representing periods of glacial retreat) are synchronous with the three warmest intervals in the Northern Rocky Mountains according to tree ring records of summer temperatures over the last millennium. Extremely low levels of biogenic silica and high concentrations of silt throughout the core suggest that Siyeh Glacier has been present at Cracker Lake, creating consistently cold and turbid water, for the past 2,200 years. Complete disappearance of Siyeh Glacier would significantly alter the hydrology and ecology of the Cracker Lake watershed.

## HARRISON GLACIER THROUGH THE HOLOCENE: A MULTI-PROXY LAKE SEDIMENT STUDY IN GLACIER NATIONAL PARK

Alena M. Giesche, Geology Department, Middlebury College, Middlebury, VT 05753

Contemporary glacial retreat is strongly linked to anthropogenic climate change, making historical glacial behavior an important area of study. Harrison Glacier is located in Glacier National Park (GNP), Montana, at a mean elevation of 2541 m and an area of 1.4 km$^2$. Because it faces south-southeast, it is theoretically quite susceptible to melting. However, this glacier is the largest remaining and second-slowest retreating glacier in GNP. To better understand the history of the Harrison Glacier before the historical Little Ice Age advance, a 620-cm long sediment core was retrieved from Harrison Lake ~8 km below the glacier in July 2010. A depth-age model based on six AMS radiocarbon dates indicates that the core extends to 4 ka BP, with a resolution of ~6 years/cm. This high-resolution core was analyzed in the lab for multiple proxies including magnetic susceptibility, X-radiography, grain size analysis, bulk density, color spectrophotometry, loss on ignition, biogenic silica content, and carbon-nitrogen ratio. Organic content and biogenic silica content exhibit synchronous centennial-scale oscillations. Mean grain size, organic content, and biogenic silica were notably low during the Little Ice Age (~A.D. 1400-1850) while the abundance of fine silt was high, suggesting downstream effects of rock flour derived from the glacier. Older minima of mean grain size, organic content, and biogenic silica ca. 1500, 2400, and 3200 BP may represent other episodes of glacier expansion. The biogenic silica content of the modern sediment is near the lowest value reached in the record, while organic content is near a record high, suggesting that the current combination of biologic productivity in the watershed and meltwater delivery from the Harrison Glacier is unprecedented in the past 4000-years.

## A MULTI-PROXY INVESTIGATION OF THE MOKOWANIS RIVER HEADWATERS USING A SEDIMENT CORE FROM COSLEY LAKE MONTANA

Lukas Rahlson, Geology Department, Middlebury College, Middlebury, VT 05753

Studies have projected that most glaciers in Glacier National Park will disappear by 2030. In order to better understand the history of glacial fluctuations, a 503-cm long sediment core was retrieved from Cosley Lake about 5.5 km downstream from the Whitecrow Glacier and downstream from the glacierized Mokowanis River Headwaters. A dense diamicton interpreted as till was encountered at the base of the core, indicating that the record extends back to the latest Pleistocene deglaciation. That constraint, combined with 4 AMS radiocarbon analyses and a tephra layer assumed to be from the Mazama eruption, was utilized to develop a depth-age model for the core. Multiple sediment properties were investigated in the laboratory at 1- or 2-cm intervals, corresponding to an average resolution of 30-60 years/sample. Analyses included biogenic silica, organic matter, carbonate content, color spectrophotometry, magnetic susceptibility, bulk density, and grain size distribution. Low levels of biogenic silica indicate that the lake was not productive before about 8600 BP. Sediment near the base of the core has high values of mean grain size, redness (a*), and carbonate content. These values decrease steadily until 8600 BP after which they level out. This major shift at 8600 BP indicates a profound change in the style of sediment being delivered to Cosley Lake at that time, perhaps reflecting final progradation across the valley of the alluvial fan that now separates Cosley from the next lake upstream. In more recent sections of the core, the amount of organic matter and carbonate in the sediment fluctuate at a significant ~80-year period that may be driven by behavior of the surrounding glaciers. Oscillations in the abundance of fine silt also exhibit significant fluctuations of ~130 years. Together, these proxy time-series should support development of an environmental history of the Cosley Lake-surrounding glacier system spanning from the latest Pleistocene to the present.

## ISOSTATIC UPLIFT AND X-RAY ANALYSIS OF WINTER "CLAY" DEPOSITS OF GLACIAL LAKE WINOOSKI, NORTH CENTRAL, VERMONT

Rebecca Derr, Geology Department, University of Vermont, Burlington, VT 05405

Glacial Lake Winooski formed in Vermont ~13,900 to ~13,700 years ago as the retreating Laurentide Ice Sheet blocked the west-flowing drainage of the Winooski and Lamoille rivers. During this time Glacial Lake Winooski covered a large area of northern Vermont in the drainage basins of the Winooski and Lamoille rivers east of the Green Mountains. Here I measure how the northern half of Vermont, specifically the area of Glacial Lake Winooski, has responded isostatically to the ice sheet's retreat. To accomplish this goal I visited 19 different deltas that were deposited in the lake in efforts to constrain the tilt of what was once a level lake surface. I used a GPS meter to carefully mark the exact location of measurement points on the deltas and a high precision altimeter to get elevation readings at those points. I calibrated the altimeter at fixed locations, close to each delta, with known elevation in order to ensure the most accurate measurements possible. After these data had been compiled and corrected for pressure changes during the day of measurement I calculated a regression plane for the data using the program Mathematica. I have concluded that, beginning at the outlet of Glacial Lake Winooski in Williamstown, the slope of the land surface is increasing 1.25 m/km to the NNW (352°). Isostatic uplift since the retreat of the ice sheet has also been measured from Glacial Lake

Hitchcock in the Connecticut River Valley increasing 0.899 m/km to 339° (Koteff and Larson, 1989), Glacial Lake Memphremagog in the Lake Memphremagog drainage basin increasing 1.2 m/km to the northwest (Parent and Occhieti, 1999), and Glacial Lake Vermont in the Champlain Valley (Rayburn, Knuepfer, and Franzi, 2005).

Additionally, samples of winter clay layers deposited by Glacial Lake Winooski were taken from 3 sites around the Waterbury Reservoir. A preliminary analysis using x-ray diffractometry showed compositions of muscovite, chlinochlore and chlorite. Sample 1 had 76.5(16)% muscovite and 23.5(4)% chlinochlore, sample 2 had 74.6(16)% muscovite and 25.4(6)% chlinochlore, and sample 3 had 80.1(19)% and 19.9(6)% of muscovite and chlorite respectively. It was interesting to note that the clay layers did not consist of clay minerals, but rather of finely ground up phyllosilicates from metamorphic rocks.

## REACTIVITY OF STREAM SEDIMENTS CONTAINING NICKEL AND CHROMIUM

Laura Wilson, Geology Department, University of Vermont, Burlington, VT 05405

Elevated levels of nickel and chromium have been found in the stream sediments near the Vermont Asbestos Group (VAG) Mine in Lowell, VT. Heavy metals can cause adverse environmental and human health effects. To determine the extent of the contamination, concentrations of heavy metals were mapped by collecting and analyzing sediments with a handheld X-ray fluorescence spectroscopy (XRF). Lateral transects of stream sediments were collected from Hutchins Brook, downstream of the mine, at five locations. Additional samples were taken in Dark Branch and Gihon River to determine how far sediments from the VAG mine may reach downstream. Samples were sieved to 2mm, crushed to 500µm and then micronized. Handheld XRF was used to determine elemental composition of each processed sample. Five samples were sent to Washington State University to be melted into beads and analyzed by wavelength-dispersive XRF (WDXRF) for calibration of the handheld XRF. Handheld XRF calibration data indicates that readings of micronized and unprocessed samples are higher than bead data and higher than WDXRF values, but can be linearly fit and a correction calibration factor applied to more accurately present field data. ArcGIS was used with GPS and handheld XRF data to map the concentrations of Ni, Cr, and As. Downstream extent and lateral distribution of metals was considered to determine areas of sources and sinks for heavy metals. Results indicate that the downstream extent of contamination from VAG mine sediments is around 1.5 miles upstream of the Hutchins Brook and Dark Branch confluence.

Metal release to stream water or groundwater depends on environmental conditions as well as the metals mineral phase. Mobility of the metals was examined by conducting batch experiments under different conditions. Batch experiments using subsamples of five samples from areas with high Ni and Cr, were conducted at pH 3, 7, and 9.5 under oxic conditions. Samples were also run at pH 7 and 9 under anoxic conditions. Solution samples were taken at 7, 14, and 33 days and analyzed with inductively coupled plasma atomic emission spectroscopy.

A greater concentration of Ni was mobilized at lower pH than at higher pH values. Cr and As release did not change greatly with varying pH. Preliminary data does not indicate a difference between oxic and anoxic metal mobility for Ni, Cr, or As.

## COSMOGENIC $^3$He DATING OF OUTBURST FLOODS ON THE SNAKE RIVER PLAIN, IDAHO

Arthur Clark, Geology Department, Middlebury College, Middlebury, VT 05753

The central Snake River Plain contains a rich array of mega-flood features such as dry cataracts, large boulder lag deposits, and amphitheater-headed canyons. Previous studies on the geomorphology of the Snake River Plain of Idaho have proposed several possible formation mechanisms for the amphitheater-headed canyons including old river systems, spring sapping, and mega-flood events. One traditionally cited hypothesis is that these features were carved by the Bonneville outburst flood About 17.5 ka. However, recent studies using cosmogenic $^3$He dating suggests that earlier mega-floods may have played an important role in carving the canyons. The purpose of this study is to use cosmogenic $^3$He dating of mega-flood deposited boulders to determine the exact timing of past flood events in an effort to better understand the formation of these canyons.

Olivine bearing basalt samples were collected from mega-flood features for cosmogenic $^3$He dating from sites at the Eden pot holes, Box Canyon, Blue Lakes Canyon, Boulder Ridge, and Devils Corral. Cosmogenic exposure ages for $^3$He dates from olivine in the Blue Lakes samples support the hypothesis for mega-floods prior to the Bonneville. Six of the eight samples from that sight have a grand mean exposure age of 20.7 ka ± 1.1 ka. These ages are significantly higher than the mean ages of 17.8 ka ± 1.0 ka for three boulders deposited by the Bonneville flood near Pocatello, Idaho (Cerling and Craig, 1994), but match very well with a mean age of 19.7 ka ± 1.1 ka reported by Cerling et al. (1994) for two flood-deposited boulders in the Big Lost River area. Based on this agreement, we propose that floodwaters from the Big Lost River flood may have joined the Snake River near Twin Falls, contributing to the formation of Blue Lakes Canyon. Our own ages from flood-deposited boulders in the Big Lost River area are scattered, however, three of the eight samples have ages between 24 and 25.4 ka. Because these boulders are sourced from a relatively low cliff wall (~4-6 m), the possibility of inheritance is likely, and may explain the slightly older ages. It is anticipated that there will be a range of dates obtained from the remaining canyons that may also support a complex history of pre-Bonneville flooding.

## PETROGENESIS OF TWO NEW EUCRITES FROM NORTHWEST AFRICA

Cameron Mercer, Geology & Physics Depts, Middlebury College, Middlebury VT 05753

Meteorites provide important insights into the origin and evolution of the Solar System, and many originate from planetary bodies that have not been sampled by human or robotic spacecraft. They are broadly separated into one of three categories: (1) stony meteorites consisting predominantly of silicates; (2) iron meteorites composed almost entirely of metal; and (3) stony-irons, which contain nearly equal proportions of silicates and metal. The howardite, eucrite, and diogenite (HED) group constitutes the largest collection of basaltic stony meteorites known, and are widely considered to be the products of basaltic igneous processes on the dwarf planet 4 Vesta. Thus, HED meteorites in particular provide a window into understanding geologic processes that occur on small, differentiated planetary bodies.

In this study, two eucrites recovered in 2009 from Northwest Africa are characterized by petrography, mineral chemistry, and whole-rock chemistry in order to gain insight into their petrogenesis. The two meteorites are alike; they are unbrecciated basaltic eucrites with mineral assemblages of pyroxene, plagioclase, minor ilmenite, chromite, quartz (tridymite), and troilite, and rare apatite. They have generally subophitic to ophitic textures, though grain sizes may vary drastically, and primary pyroxenes have been recrystallized in areas. Pyroxenes compositions are generally bimodal, with ferroan pigeonite and augite endmembers. Plagioclase is calcic, roughly ranging in composition from $An_{79}$-$An_{95}$. Chromite compositions are unusually titanian for basaltic eucrites, with ~10.4-17.6 wt% $TiO_2$ compared to the usual ~3-6 wt%. Whole-rock compositions indicate that these samples are likely “main-group” eucrites, with Mg# ~38 and with low abundances of minor incompatible elements. As main-group eucrites, they may have formed either from the residual liquids of a cooling, global magma ocean, or as primary partial melts of a parental body with a chondritic composition.

## THE PETROGENESIS OF ALKALIC ROCKS IN THE SPRINGERVILLE VOLCANIC FIELD, EASTERN ARIZONA

Taylor Smith, Geology Department, Middlebury College, Middlebury, VT 05753

The Springerville Volcanic (SVF) field encompasses a 3000 sq km region situated on the southern margin of the Colorado Plateau in northeastern Arizona. The field consists of over 400 cinder cones and their associated, mostly basaltic, flows, ranging from late Pliocene to Pleistocene in age. Forty-five square kilometers of the previously unmapped south-central region of the field were covered during the 2010 field season. Results of this mapping, combined with previous work, suggest that the region contains flows younger than 0.5 Ma, making this region the youngest yet mapped.

The purpose of this work is to use chemical compositions of rock samples to document how the various lava flows are related and to understand how and where the lavas formed. To this end, a suite of 32 samples was collected comprised of each new flow mapped. These flows are generally alkali basalts, with $SiO_2$ values ranging from 46.3 to 52.7, and magnesium numbers ranging from 38.9 to 65.6. Rare earth plots are consistent with a continental basalt classification, and show enrichment in the light rare earth elements (LREEs). These flows are thought to have originated as a partial melt of a garnet peridotite source that then underwent fractional crystallization processes. Olivine and pyroxene compositions, coupled with microscopy, indicate that they were the main fractionating phases, and that plagioclase tended to stay in the melt and crystallize last.

Geochemical data has important implications for the volcanic history of the field. Trace element plots show strong correlations, indicating that volcanism may have originated from a single magma source. This source likely tapped fertile mantle, as the flows are all LREE enriched. The source may have had a relatively deep residence, as plagioclase is not an important fractionating phase. Crustal contamination is not a major factor in the evolution of alkalic rocks in the SVF, and thus fractional crystallization is posited as the main driver of differentiation in the SVF.

## INTEGRATING TITANIQ THERMOBAROMETRY WITH GARNET PORPHYROBLASTS TO DETERMINE *P-T-D* HISTORIES OF QUARTZ RECRYSTALLIZATION

Kyle T. Ashley, and Laura Webb, Geology Department, University of Vermont, Burlington, VT 05405, and Frank Spear and Jay Thomas, Earth & Environmental Sciences Department, Rensellaer Polytechnic Institute, Troy, NY 12180

Applications of the Ti-in-quartz (“TitaniQ”) thermobarometer since its initial development include investigations of igneous rocks, metapelitic samples, mylonites, etc. This study tested the application of the thermobarometer on inclusions in Al-silicate porphyroblasts to refine or determine *P-T-D* paths. Does the quartz in different microstructural contexts record pressures and temperatures at different points along the *P-T-D* path? In garnet porphyroblasts, chemical profiles and *P-T-X-M* diagrams can be integrated to predict *P-T* conditions during growth, and can be compared to that of the quartz inclusions. Cathodoluminescence (CL) imaging at 415 nm (blue) corresponds to [Ti] in quartz, which allows for qualitative analysis of Ti-distribution in a single grain or between neighboring grains.

Samples were collected from the Strafford Dome, Eastern Vermont. Garnet- and staurolite/kyanite-grade rocks were obtained for further analysis. Samples with different porphyroblast inclusion trail microstructures were selected for including inter-, syn- and post-tectonic grains. Quartz grains in all inclusions (and also matrix material) have darker cores that record low (~2.7–3.7 ppm) [Ti]. One porphyroblast that grew syn-tectonically with $D_2$ (TM783) has inclusions that contain similar rim [Ti] throughout the garnet (~5.5 ppm). Matrix grains contain bright rims with [Ti] up to 7.8 ppm. Zoning in the garnet shows a decrease in Mn and an increase in Mg from core to rim, which is attributed to an increase in pressure and a slight decrease in temperature.

Plotting [Ti] isopleths in sample TM783 against the known summary *P-T* history of the Strafford Dome (and compared to *P-T* path of garnet growth for the sample) suggests the 5.5 ppm [Ti] to be associated with the end of $D_1$ and the 7.8 ppm to be associated with the end of $D_2$ (post porphyroblast growth, at peak P). This suggests quartz recrystallization occurred prior to being included, and again after nappe emplacement when garnet growth ceased. The [Ti] isopleths from cores of the quartz grain do not intersect any *P-T* expected for Acadian Orogeny deformation for the dome, and are probably relics of early prograde deformation or protolith conditions.

## PRESIDENT’S LETTER

Most of the fields are bare of snow except for the odd patch in a shady spot. I look up into the woods and patches of bare ground and rock outcrops stand out dark against the snow. The streams are swollen and every hillside seep glistens with flowing water in the sunlight. Yes, it's actually spring--and to a geologist that means it's time for planning the field season.

I gather the aerial photos and field maps so that I can study over them. I get out my leather work boots and look them over. They need a good greasing and new laces, but maybe they'll last the season. I meant to replace the cracked mirror in my Brunton, but didn't get to it; too late now--that will wait till next winter. Rock hammer, check. Shovels, check. Trowel to find and sharpen, check. I unearth the clinometer that I had stashed away, see that the GPS has fresh batteries, and look in vain for the 200 foot tape. Where did that get to? Ah yes, loaned out. Must track that down right away. Soon those white patches in the woods will shrink enough, and then we're off!

In the meantime, please check out the exceptional set of student abstracts in this issue and try to attend our Spring meeting on April 23 at UVM. Also, note that our summer field trip, which is scheduled for July 30, is a joint trip with the New Hampshire Geological Society. Woody Thompson from the Maine Geological Survey will be leading us on an exploration of the surficial geology of the Upper Connecticut River Valley. I've been on many trips with Woody and he is a great trip leader.

Respectfully submitted,
George Springston

## ANNUAL MEETING MINUTES

The Executive Committee met on 28 March and discussed several items. Dave Westerman, Treasurer, updated the Committee on finances and discussion followed that addressed developing a plan to have the finances evolve by predicting annual income, annual expenses, and the level of a prudent reserve, so that we can manage research grants and other expenses as effectively as possible.

Jon Kim, Chair of the Advancement of Science Committee, reported that we are currently offering research grants twice a year, at three per each half year and with a $700 cap per grant. This rate can continue for this year and will be reexamined as we decide on the proper level of budget for this program. General consensus was that the VGS should look to continue funding student research as much as is possible.

An agenda was established for the upcoming Spring Meeting at UVM. In addition to a large number of student presentations, a potluck lunch will take place. The number of student presentations is large, but the Committee saw this as a good problem.

The possibilities were discussed for a summer field trip that is combined with the New Hampshire Geological Society. Possible field trip leaders were discussed, as was the nature of the trip. Various Committee members agreed to continue to work on the details for the trip.

A brief discussion took place on editorial responsibilities for the Green Mountain Geologist. All attendees agreed to work in concert to submit materials for the GMG, and Rick Dunn will compile, edit and publish the document. Most members receive the GMG electronically, greatly reducing our costs, and the cost of mailing some copies continues to be graciously covered by the Geology Department at Middlebury College.

Submitted by D. Westerman and R. Dunn

# TREASURER'S REPORT

The Society continues to be in good financial health, with a current balance of $6,411.84. The income side of our operational expenses includes receipt of $1,385 for 2011 dues along with $1,020 as contribution to the research grant fund. Late dues payments will probably bring the total to about $2,500, a figure comparable to income in recent years. The Society has been offering two cycles of $2,100 for research grants each year for the past few years, but this can't continue without adjustments somewhere; either income will have to rise or total expenses will have to decrease. Discussion of this issue at the recent meeting of the Executive Committee included consideration of generating income by raising the annual dues to $20, making a stronger effort to encourage research fund gifts by members, and exploring the idea of having Vermont consulting firms support the research fund. Consensus of the Committee was to avoid reducing our research grant program if possible.

Being fully aware of the long-term need for balancing our income and expenses, the Executive Committee approved continuation of funding for student research at the current level of $2,100 for the next cycle. This decision was influenced by the fact that our fiscal reserve is larger than what would generally be seen as a prudent reserve, and that the Society can afford to have that reserve decreased as we move toward increasing our income to match our needs.

Contributions to the Research Fund are most gratefully acknowledged, with the following members contributing thus far in 2011: Dennis S. Albaugh, Eric T. Lapp, Alexis P. Nason, David Butterfield, Sharon Strassner, Ronald B. & Anita H. Krauth, Peter J. & Thelma B. Thompson, Timothy W. Grover, Donald H. Hill, David West, George Springston, Roger & Terry Thompson, Alex G. Czuhanich, Jefferson P. Hoffer, Frederick D. Larsen, Barbara L. Hennig, Laurence R. Becker, Arthur W. Gilbert, Jr., Andrew & Laura McIntosh, Art Stukey, Peter Ryan, David S. Westerman, Peter Adams, Jeanne C. Detenbeck, Craig Heindel.

Respectfully submitted,
David S. Westerman, Treasurer

# ADVANCEMENT OF SCIENCE COMMITTEE REPORT

The Advancement of Science Committee received one application for the VGS Research Grant Program by the April 1st deadline. The following grant will be evaluated in the near future:

Ian Honsberger, M.S. Candidate, University of New Hampshire, Title- "Metamorphic History of an Ultramafic-Mafic-Pelitic Rock Package in Stockbridge, Vermont".

The Vermont and New Hampshire geological societies will run a joint field trip on Saturday July 30th, 2011. Woody Thompson of the Maine Geological Survey has graciously volunteered to lead a surficial geology trip on both sides of the upper Connecticut River valley. Barbeque to follow. Meeting place and time will be established in the near future.

Respectfully Submitted,
Jon Kim

## VERMONT STATE GEOLOGIST'S REPORT

**State Geologists Report – Spring 2011**

The Vermont Geological Survey was an active participant at the Geological Society of America- Combined Northeastern/ North-Central Section Meeting from March 20-22 in Pittsburgh, PA. We were involved in presentations on groundwater quality and quantity and structural geology with our academic partners at Norwich University, Middlebury College, and the University of Vermont. The list of presentations with annotation is shown below:

Poster Presentation #1 with Norwich University partner
Kim, J., Springston, G., and Gale, M., 2011, Evaluation of Groundwater Resources in the Town of Craftsbury, Vermont Using Bedrock, Surficial, and Topographic Maps: Geological Society of America, Abstracts with Programs, v. 43, #1, p. 106.

*This poster focused on how bedrock, surfical, and topographic maps are integrated with water well logs to delineate areas of higher and lower well yields. Higher well yields correlated with specific bedrock formations, thicker surficial deposits, and close proximity to streams and lakes.*

Poster Presentation #2 with Middlebury College partners
Brooks, E., Kim, J., and Ryan, P., 2011, Geochemical Analysis of Groundwater Quality in the Fractured Bedrock Aquifer of the Town of Craftsbury, NE Vermont: Geological Society of America, Abstracts with Programs, v. 43, #1, p. 107.

*This poster focused on the quality of groundwater sampled from bedrock wells in Craftsbury. We tested for health-related parameters such as Arsenic, Uranium, Lead, and Gross Alpha (naturally-occurring radioactivity) among numerous other metals and non-metals. We sampled from each of the major bedrock formations in town to check for differences.*

Poster Presentation #3 with Middlebury College partners
Thompson, A., Ryan, P., Hattori, K., and Kim, J., 2011Geochemical and Sulfur Isotope Analysis of Taconic Slates: Implications for Arsenic Source and Mobility in a Bedrock Aquifer System, Geological Society of America, Abstracts with Programs, v. 43, #1, p. 106.

*This poster focused on the elevated Arsenic levels that have been found in groundwater in southwestern Vermont and its relationship to the general bedrock type (slates). This study proposes a correlation between a specific mineral (pyrite) found in the slates and the elevated Arsenic levels in groundwater. It also suggests that the temperature and pressure that the rocks experienced controls the arsenic content.*

Poster Presentation #4- with University of Vermont partners
McMillan, M., Kim, J., and Klepeis, K., 2011, A Survey of Microstructures Across a Major Lithotectonic Boundary in the Town of Craftsbury, Northern Vermont: Geological Society of America, Abstracts with Programs, v. 43, #1, p. 116.

*The Vermont Geological Survey has mentored 9 UVM undergraduates since 2002 on mapping-based projects. This poster focused on the folds and faults found in Craftsbury.*

**Private Well Testing**
Senator Virginia Lyons held a session of the Senate Natural Resources and Energy Committee on Feb 9 to hear about a Middlebury College environmental seminar study of "Arsenic Contamination in Vermont's Private Wells". The Vermont Geological Survey (Jon Kim) cooperated with Middlebury on the geology and spacial data presentation of groundwater quality results. Senator Lyon has since submitted a bill that includes testing of new wells. Arsenic, lead, uranium, gross alpha radiation and coliform bacteria were discussed on Feb 9. The State Toxicologist was in attendance and asked that manganese and fluoride also be considered as additional naturally-occurring contaminants of concern. Helen Mango of Castleton State College also contributed data to the arsenic analysis.

## ANNOUNCEMENTS

### SUMMER FIELD TRIP

The Society will hold its Summer Field Trip on July 30th, in conjunction with the New Hampshire Geological Society. The trip will focus on surficial geology and will be led by Woody Thompson of the Maine Geological Survey. Watch your email and the next edition of this newsletter for more information on the meeting time and place.

If you have an idea for a future trip, please feel free to contact any member of the Executive Committee to promote your idea!

# VERMONT GEOLOGICAL SOCIETY CALENDAR

July 30: Summer Field Trip, upper Connecticut River Valley

October 1: Student Research Grant Program applications due, to Jon Kim. Please see the website for format information

The **Vermont Geological Society** is a non-profit educational corporation.
The **Executive Committee** of the Society is comprised of the Officers, the Board of Directors, and the Chairs of the Permanent Committees.

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**Vermont Geological Society**
**Department of Geology and Environmental Science**
**Norwich University**
**Northfield, VT 05663**

***ADDRESS CHANGE?***
*Please send it to the Treasurer at the above address*

## Vermont Geological Society
## Spring Meeting
## April 23, 2011, 8:30 AM
## Delehanty Hall, Rm 219, Trinity Campus
## University of Vermont, Burlington, Vermont

Directions to Delehanty Hall:

Delehanty Hall is located at 180 Colchester Avenue, in Burlington, Vermont. It can be reached from I-89 by taking Exit 14E and following Route 2 (Williston Road) to the west to the intersection with East Ave. A right on East Ave will take you to Colchester Ave and upon crossing this you will enter a complex of university buildings that includes Delehanty Hall (behind Mann Hall).