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

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EOCENE TECTONIC EVOLUTION OF THE TETONS-ABSAROKA RANGES, WYOMING
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Students: *JESSE GEARY*, Macalester College, *KATHERINE KRAVITZ*, Smith College, *RAY MCGAUGHEY*, Carleton College.

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Keck Geology Consortium: Projects 2010-2011
Short Contributions— Teton Range, Wyoming

EOCENE TECTONIC EVOLUTION OF THE TETON RANGE, WYOMING
JOHN CRADDOCK, Macalester College, DAVE MALONE, Illinois State University

FAULT-GENERATED CARBONATE INTRUSIONS FOUND AT WHITE MOUNTAIN, HEART MOUNTAIN DETACHMENT, WYOMING
JESSE GEARY, Macalester College
Research Advisor: John P. Craddock

INSIGHTS INTO THE ORIGIN OF THE SOUTH FORK DETACHMENT, WYOMING, USING CALCITE STRAIN ANALYSIS
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U-PB DETRITAL ZIRCON PEAK, WYOMING MOUNTAIN
RAY MCGAUGHEY, Carleton College
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FAULT-GENERATED CARBONATE INTRUSIONS FOUND AT WHITE MOUNTAIN, HEART MOUNTAIN DETACHMENT, WYOMING

JESSE GEARY, Macalester College
Research Advisor: John P. Craddock

ABSTRACT

In Wyoming, along the bedding plane portion of the Eocene Heart Mountain detachment, the presence of carbonate ultracataclasite (CUC) has been observed in several locations. At White Mountain the CUC appears not only along the horizontal detachment, but as vertical dikes intruded ~120 m into allochthomous upper plate carbonates. The well- lithified, microbrecciated material injected into the overlying metamorphosed Missippian Madison Group rocks is texturally, petrographically, and geochemically (XRF) identical to the basal CUC material found along the 2° dip slope of the Heart Mountain detachment. Both exhibit lithological characteristics formed under cataclysmic activity containing concentric spherules, armoured lapilli, and country rock fragments embedded in a fine-grained calcite matrix.

INTRODUCTION

The Heart Mountain detachment facilitated southeastward transport of upper plate rocks over 30 mi from the northern Absaroka Mountains, toward the western margin of the Bighorn Basin. Emplacement along the Heart Mountain detachment is broadly contemporaneous with igneous activity in the Absaroka volcanic province (Craddock et al., 2009). Recent studies have greatly narrowed the timeframe for detachment activity between 49.7 and 49.5 Ma (Rhodes et al., 2007; Smith et al., 2003). This narrow time frame supports catastrophic emplacement of upper plate rocks possibly due to volcanic collapse (Malone, 1995), rapid tectonic denudation (Pierce, 1987), or a rapid continuous allochthon without denudation (Beutner and Gerbi, 2005). Not only is the exact rate of emplacement debated, but also the mechanism that facilitated catastrophic motion along the low-angle (2° dip) fault plane, with minimal deformation in the hanging wall or below the detachment. Several mechanisms have been proposed including detachment fluids (Templeton, 1995), contemporaneous dike intrusion (Ahranov and Anders, 2006), and frictional heating between carbonate layers (Craddock et al., 2009).

White Mountain contains the only metamorphosed upper plate blocks, and the thickest (3 m) layer of CUC observed in the massive 3400 km2 emplacement area of Mississippian Madison Limestone liberated along the Heart Mountain detachment (Craddock et al., 2009). Carbonate ultracataclasite exposed along the detachment at White Mountain has been described in detail, but the material injected into the overlying marbles has yet to be analyzed. Through petrographic and geochemical analysis of the CUC injectites we hope to shed light on the dynamics of this complex fault system.

METHODS

The CUC material was analyzed through SEM-EDS, XRF, and petrographic techniques. XRF analyses of the CUC samples were performed at McGill University in Montreal using a Philips PW2440 4kW X-ray fluorescence spectrometer system. Prior to analysis, samples with unaltered faces lacking signs of weathering were cleaned and pulverized in Iron and Tungsten drums to ensure accurate geochemical results.

RESULTS

White Mountain is composed of an allochthonous, upper plate block of metamorphosed Madison Limestone crosscut by sub-vertical andesitic and clastic dikes, intruded by a large stock of Eocene trachyandesite prior to emplacement. All this rests on a veneer of CUC marking the SE-dipping Heart Mountain detachment. The detachment CUC is most easily observed on the southwestern side of White Mountain where it juts forth through the loose marble above, and the Cambrian Snowy Range limestone below. These details are lost on the scale of the published geologic maps (1:62,500; Pierce et al., 1982). The detachment CUC was originally interpreted as "tectonic carpet" produced during tectonic denudation (Pierce 1979), later as a volcanic tuff (Pierce et al., 1991), and a fault microbreccia (Hauge, 1985) and again as a tectonic sediment (Anders et al., 2010). The CUC is composed of a microbrecciated calcite matrix with small proportions of volcanic glass and andesitic fragments, various calcite-quartz "melt" spherules, spheroidal Fe oxide and sulfide fragments and armoured lapilli clasts (Craddock et al., 2009). We have now observed this same CUC material within dikes of various orientations above the detachment in the marbles. CUC injectites are not observed below the detachment, nor does available exposure permit direct observation of the contact of the injected CUC with the sub-horizontal detachment CUC below (Fig. 1).

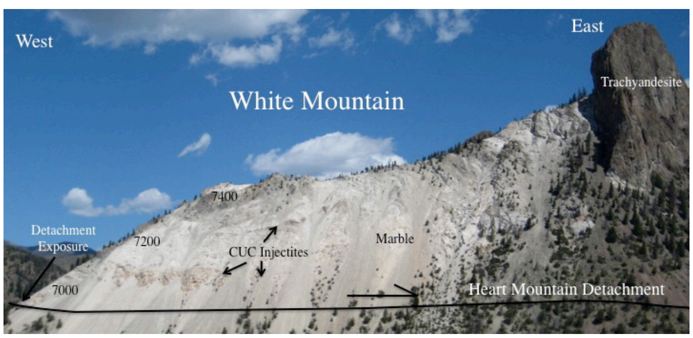

Figure 1. White Mountain is centrally located in the bedding-plane portion of the Eocene Heart Mountain detachment in northwestern Wyoming. Locations of carbonate ultracataclasite (CUC) parallel and normal to the Heart Mountain detachment are shown (elevations in vertical feet).

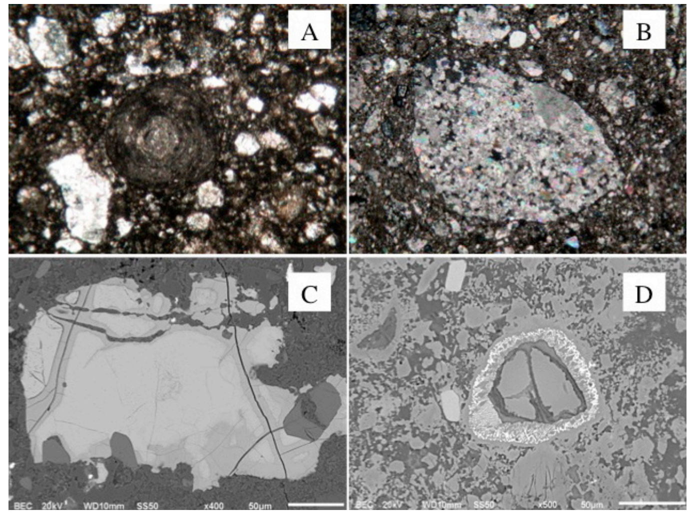

Figure 2. Photomicrographs and SEM images of White Mountain Injectites including armored lapilli and concentric spherules (A), carbonate clast in micro-calcite matrix (B), fractured ilmenite grain (C), and concentric spherule (D) held in calcite microbreccia.

White Mountain X-Ray Flourescence Geochemsitry

	Injectite CUC Sample 1	Injectite CUC Sample 2	Detachment CUC Sample 1	Detachment CUC Sample 2	Marble (Upper plate)	Detection Limits (ppm)
Major elements (wt %)						
SiO2	10.68	10.61	7.62	7.70	1.60	60
TiO2	0.11	0.11	0.10	0.10	0.02	25
Al2O3	2.30	2.61	1.95	2.02	0.32	120
Fe2O3	1.41	1.47	1.12	1.16	0.47	25
MnO	0.03	0.03	0.03	0.02	0.01	25
MgO	9.31	9.52	12.69	12.62	12.41	95
CaO	40.64	39.39	38.13	37.75	42.70	15
Na2O	0.04	0.01	0.09	0.15	0.02	35
K2O	0.51	0.27	0.31	0.43	0.01	25
P2O5	0.06	0.05	0.47	8.09	0.48	35
BaO	75.24	81.60	144.00	144.00	bd	12
Cr2O3	15.20	18.70	33.00	22.00	bd	10
LOI	31.93	32.64	37.86	37.84	42.46	
Total	97.03*	96.73*	99.98	99.89	100.30	
Trace elements (ppm)						
Sc	11.0	11.0	bd	bd	bd	7
V	18.3	18.0	19.0	20.0	bd	7
Co	bd	bd	bd	bd	bd	10
Ni	bd	3.0	11.0	12.0	7.0	3
Cu	36.0	15.0	22.0	18.0	13.0	2
Zn	bd	bd	bd	bd	bd	2
Ga	2.5	3.8	6.0	5.7	4.5	1
Nb	2.9	2.8	7.4	7.4	8.5	0.3
Pb	6.2	7.5	3.7	4.1	1.7	1
Rb	8.8	5.2	13.9	15.2	5.4	1
Sr	152.5	164.3	169.6	183.0	78.3	1
Th	1.9	2.2	1.3	1.3	bd	1
U	1.6	1.7	4.4	4.4	4.6	1
Y	3.7	3.8	10.8	10.8	10.0	1
Zr	20.8	20.8	7.2	7.2	bd	1
Ce	0.0	27.0	22.0	28.0	33.0	15

Note: Loss on ignition(LOI),Cr and Ba reported as ppm
*The low total is the result of incomplete LOI
Abbreviations: bd-below detection;CUC-"carbonate ultracataclasite"

Table 1. Whole-rock geochemistry of carbonate samples from White Mountain including ultracataclasite lying along the detachment and injected into the hanging wall, and upper plate marble.

Petrography

The detachment CUC is comprised of andesitic clasts, limestone fragments, armoured lapilli, and concentric spherules embedded in well-lithified, microbrecciated carbonate matrix (Craddock et al., 2009). These same lithologies are observed in the petrographic analysis of the CUC injectites (Fig. 2).

Geochemistry

Geochemical profiles of the newly discovered CUC in the upper plate are compared with previously studied profiles of CUC along the detachment and upper plate marble (Craddock et al., 2009). Major-element concentrations of the injectite and underlying detachment CUC preserve nearly identical profiles (varying less than ± 4%). Results show high concentrations of CaO

(40.6-37.8%) in all CUC samples that are comparable to 42.7% concentration in upper plate marbles (Table 1).

DISCUSSION

Pseudotachylite is a siliceous (‘fake glass”) melt found in association with impact sites (Dietz, 1964), along the bases of modern landslides (Pollet et al., 2004), along glacially polished pavements (Bestmann et al., 2006), and in fault zones (Cowan, 1999). Frictional melts associated with fault motions are reported in siliceous rocks along all fault offset types in continental crust, but not in oceanic crust. The oldest fault pseudotachylite is of Penokean age (1850 Ma) in reactivated Archean terrane boundaries of Laurentia (Craddock and Magloughlin, 2005). Pseudotachylite is identified as a thin, aphanitic gray-black filling in faulted rocks, often parallel to the local foliation in cataclasites, and with numerous injectite fillings normal to the offset plane. Internally, pseudotachylite often has vesicles, amygdule fillings, compositional layering, rare kinematic (armoured, rolled grains) features, all in a matrix of melted (aphanitic) and microbrecciated protolith. Fault-generated pseudotachylite is usually a few centimeters thick, and the fault-normal pseudotachylite injectites usually have a penetration depth equal to the fault width (Brodsky et al., 2009). Bjornerud (2009) has observed for a low-angle fault system in New Zealand that multiple phases of pseudotachylite were generated under different conditions along the same system, each presumably related to a different fault-seismic event. The thermodynamics of a fault system that generates a siliceous frictional melt require dynamic, episodic fault offset; the presumption is that pseudotachylite is a byproduct of such fault offset and must have been a seismic event (Sibson & Toy, 2006). This cause and effect have not been observed, presumably because the process is operative at depth.

If the HMD is conceived as a typical low-angle normal fault we should observe at White Mtn. (40 km displacement) a gouge zone of 1000 m., at Heart Mtn. (72 km) a gouge zone of 1778 m, and at Squaw Teats (160 km) a gouge zone of 10000 m. We observe 3, 0.1 and 0.1 meters, respectively, of fault gouge. The CUC found along the HMD is just that, a welded, dense (3.0 gm/cc) carbonate that formed from a carbonate-on-carbonate frictional event that lasted a few minutes (Craddock et al., 2009). Calcite has a melting temperature of 1339°C and the CUC was likely 600-800°C when it formed (Craddock et al., 2009); the CUC was not a calcite melt but it appears to have behaved like a pseudotachylite. For siliceous, fault-generated pseudotachylite the fault-normal intrusion of injectites is approximately the same as the width of the pseudotachylite in the fault zone (Rowe et al., 2005), and all sorts of computations are possible without knowing the dimension of the fault offset (DiToro et al., 2005). On Kodiak Island, where subduction-related pseudotachylite is observed and the fault zone and injectite pseudotachylite dimensions are the same, Brodsky et al. (2009) calculate an injectite intrusion rate of 10 cm/sec. For the HMD system, the relationship is reversed: catastrophic hanging wall implacement with enormous run-out generated a thin CUC gouge material with vertical injectite intrusion ~40 times the width of the average detachment CUC. At present, this observation is made only at White Mountain so the regional HMD implications are not known.

CONCLUSIONS

At White Mountain we report the occurrence of a cataclasite material injected vertically into overlying rock. The cataclasite is identical to the sub-horizontal CUC found along the Heart Mountain detachment. While the CUC material is not a siliceous pseudotachylite, it did behave as a fault-generated fluid and was injected ~40 times farther into the hanging wall (e.g., only upward and not into the footwall) than would be predicted. Future petrologic research of CUC injectites at White Mountain, and further investigation for analogous injected cataclasite at other localities is necessary to fully understand the dynamics of the Heart Mountain detachment.

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