GEOLOGIC EXCURSIONS INTO THE ABSAROKA, BEARTOOTH, AND BIGHORN MOUNTAINS, WYOMING AND MONTANA

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Geological excursions into the Absaroka, Beartooth, and Bighorn Mountains, Wyoming and Montana

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INTRODUCTION

During July-August 1997, a Keck Geology Consortium "junior" research project was based at Hunter Peak Ranch in the valley of Clarks Fork of the Yellowstone River, northwestern Wyoming. Our goal was to study certain aspects of the early Paleozoic (Cambrian) and Cenozoic (Eocene, Pleistocene, and Holocene) geologic history of the area. Our research focused on the structural geology, igneous petrology, geomorphology, sedimentology and paleontology of portions of the Absaroka and Beartooth Ranges east of northern Yellowstone National Park. However, several studies included trips to the Bighorn Basin and the Bighorn Mountains to the east.

PROJECT PARTICIPANTS

The faculty were: Bob Carson, Whitman College; Ed Beutner, Franklin and Marshall College; Joe Cepeda, West Texas A & M University; and Paul Myrow, Colorado College. Visiting geologists were: Clint Cowan, Carleton College; Eric Leonard, Colorado College; Carol Mankiewicz, Carl Mendelson, and Dick Stenstrom, Beloit College; Bob Newton, Smith College; and Alex Durst, Montana State University.

The students were: Rachael Howse and Dawn Morgan, Beloit College; Meg Anderson, Joe Colgan, and Kristin Ulstad, Carleton College; Mike Heublein and Marie Knotwell, Colorado College; Steve DiBenedetto, Franklin & Marshall College; Dawn Chapel, Smith College; Beth Bartel, Whitman College; and Meghan McLaughlin and Cam Miller, College of Wooster.

GEOGRAPHY

The Beartooth Range straddles the Wyoming-Montana state line (Figure 1). Clarks Fork of the Yellowstone River originates in the Beartooths just northeast of Yellowstone National Park; Clarks Fork, a wild and scenic river, flows south, and then east through a deep canyon, until it reaches the Bighorn Basin (Figure 2). To the southwest of Clarks Fork lies the Absaroka Range, which includes the eastern border of Yellowstone National Park. The Bighorn Mountains lie in north-central Wyoming and adjacent Montana, and are east of the Bighorn Basin.

Most of the field work was conducted in and near Clarks Fork valley and Sunlight Basin. Sunlight Creek, a major tributary to Clarks Fork, lies southwest of Dead Indian Pass (2460 m). The Chief Joseph Scenic Highway goes from the vicinity of Heart Mountain (in the Bighorn Basin north of Cody, Wyoming) to Clarks Fork valley; Heasler and others (1996) have written a geologic tour along this highway. Clarks Fork valley can also be accessed from Cooke City, Montana, via Colter Pass (2443 m) and from Red Lodge, Montana via Beartooth Pass (3362 m). The Beartooth Highway, which connects Cooke City and Red Lodge, is the subject of a geologic guide by James (1995). Also, Fritz (1985) wrote a roadside guide to the geology of Yellowstone National Park and vicinity.

North of the Beartooth Highway is the Absaroka Beartooth Wilderness in Gallatin and Custer National Forests of southwest Montana and Shoshone National Forest of northwest Wyoming. Between Yellowstone National Park and Clarks Fork valley, and surrounding Sunlight Basin (except to the northeast) is the North Absaroka Wilderness of Shoshone National Forest. Our research included field work in both wilderness areas and along Clarks Fork and

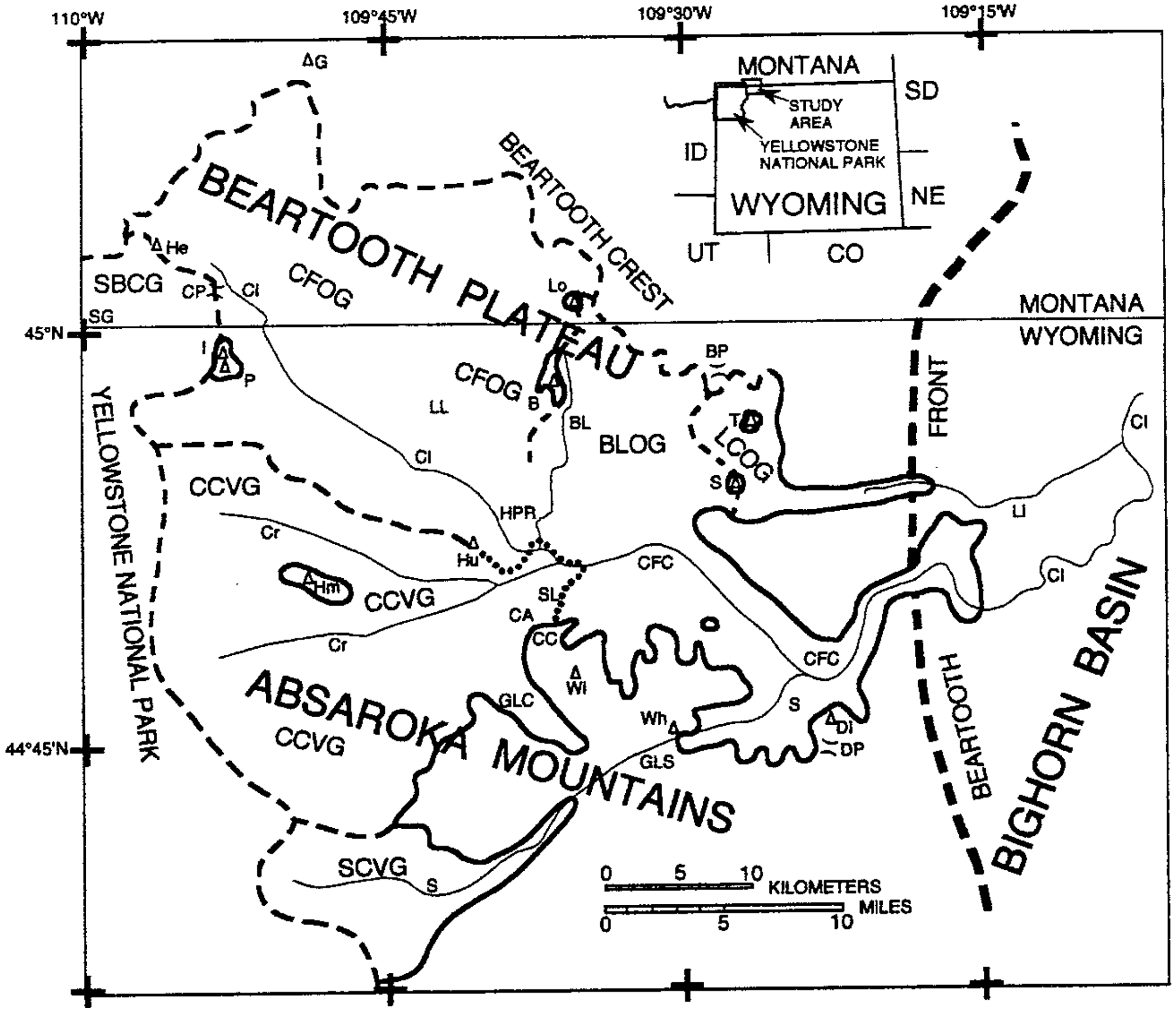

Figure 1. Late Pleistocene glaciers, Clarks Fork region, northwestern Wyoming and adjacent Montana. The approximate extent of ice south of the Beartooth crest and east of Yellowstone National Park is shown. Major glaciers were Beartooth Lake outlet glacier (BLOG), Clarks Fork outlet glacier (CFOG), Crandall Creek valley glacier (CCVG), Littlerock Creek outlet glacier (LCOG), Soda Butte Creek glacier (SBCG), and Sunlight Creek valley glacier (SCVG). Except for streams and the Beartooth Front, solid lines are ice margins at the Pinedale maximum, and dashed lines are ice divides. The dotted line is the eastern extent of the Crandall Creek valley glacier in late Pinedale time. Peaks [triangles] are Beartooth/Clay Buttes (B), Dead Indian Hill (Di), Granite Peak (G), Henderson Mt. (He), Hurricane Mesa (Hm), Hunter Peak (Hu), Mt. Index (I), Lonesome Mt. (Lo), Pilot Peak (P), Sawtooth Mt. (S), Tibbs Butte (T), White Mt. (Wh), and Windy Mt. (Wi). Passes [ )( ] are Beartooth (BP), Colter (CP), and Dead Indian (DP). Streams are Clarks Fork of the Yellowstone River (Cl), North and South Forks of Crandall Creek (Cr), Littlerock Creek (Li), and Sunlight Creek (S). Also shown are Beartooth Lake (BL), Corral Creek alluvial fan (CA), Cathedral Cliffs (CC), Clarks Fork Canyon (CFC), glacial lake Cinderella (GLC), glacial lake Sunlight (GLS), Hunter Peak Ranch (HPR), Lily Lake (LL), Silver Gate (SG), and Swamp Lake (SL).

Figure 2. View southwest from the Bighorn Basin up Clarks Fork Canyon. In the foreground are jökulhlaup-scoured Pinedale terminal moraines. Cuesta-like Bald Peak is capped by east-dipping Mississippian limestone. Beneath the caprock are Cambrian-Devonian carbonates and shales overlying the Precambrian crystalline rocks of the steep-walled glacial trough

its tributaries. In addition, there were geologic excursions to Yellowstone National Park, Grove Creek (south of Red Lodge), Heart Mountain, and the east flank of the Bighorn Mountains west of Sheridan, Wyoming.

The climate of Clarks Fork valley is cool and semi-arid; Holocene soils contain caliche. The surrounding Absaroka and Beartooth Mountains have a colder, wetter climate, with permafrost and patterned ground at Beartooth Pass. See Martner (1986) for data on Wyoming climate. Timberline is at approximately 3000 m. Some forests burned in the area during the Yellowstone fires of 1988 (Figure 3).

GEOLOGY

Previous work. The bedrock geology of Clarks Fork valley and vicinity has been studied for almost a century (e.g., Hague, 1899; Nelson and Prostka, 1980). William Pierce and others mapped the geology of five 15-minute quadrangles in the heart of our research area (Pierce, 1965; Pierce and Nelson, 1968, 1971; Pierce et al., 1973, 1982). The geology in the vicinity of the New World mining district and Cooke City, Montana was mapped by Elliot (1979). William Pierce (e.g., 1973) and many other researchers (e.g., Hauge, 1993) have studied the Heart Mountain detachment.

Until very recently no work has been published on the Quaternary geologic history of Clarks Fork valley. However, Kenneth Pierce (1979) studied the northern Yellowstone mountain ice sheet, Parsons (1939) wrote on the glacial geology of Sunlight Basin and vicinity, and two theses (Ballard, 1976; Hilmoe, 1980) dealt with Quaternary features at the mouth of Clarks Fork Canyon.

Research by the Keck Geology Consortium began here in 1994, with Quaternary geology the focus for the first two summers (Carson et al., 1995, 1996). In 1996 we added research on Cambrian strata and the Heart Mountain detachment (Carson et al., 1997).

Geologic history. The central Beartooth and Bighorn Mountains contain plutonic and metamorphic rocks as old as 3.4 billion years (Mueller et al., 1987). The edges of the Beartooth and Bighorn Ranges, plus the Bighorn Basin between them, have a sedimentary record of all Phanerozoic periods except the Silurian (e.g., Ruppel, 1972)

(Figure 4). The Absaroka Mountains are dominated by Eocene andesitic volcanic and volcaniclastic rocks (e.g., Smedes and Prostka, 1972) (Figure 5).

During the Laramide Orogeny there was uplift of the Beartooth and Bighorn Mountains, with considerable faulting and folding along their edges (Figure 2). During the Eocene, Paleozoic sedimentary rocks and some overlying Eocene volcanics slid many kilometers southeastward along the Heart Mountain detachment (Figures 3, 5, 6). The last few million years have been dominated not only by glaciation but also by repeated and diverse volcanism and deformation associated with the Yellowstone hot spot (e.g., Smith and Christiansen, 1980; Pierce and Morgan, 1992).

The Bighorn Mountains were glaciated during the Pleistocene (Salisbury, 1906a, 1906b). Much of the Yellowstone area was covered by a mountain ice sheet originating as cirque and valley glaciers in adjacent mountains, including the Absaroka and Beartooth Ranges (Figures 5, 7). A large outlet glacier of the Yellowstone ice sheet flowed down the valley of Clarks Fork, terminating on the floor of the Bighorn Basin to the east (Figure 2). Clarks Fork ice was fed largely by cirque glaciers of the southern Beartooth Mountains, but was supplemented by valley glaciers in the Crandall Creek drainage basin, and, to a lesser extent, along Pilot Creek. The Clarks Fork ice moved southward toward Sunlight Basin over two divides, and flowed up tributary valleys, blocking stream drainages and forming lakes such as glacial lakes Sunlight and Dead Indian. During the retreat of the Clarks Fork ice, jökulhlaups (Figure 2) occurred from the release of glacial lakes and perhaps subglacial water (Jaworowski and Carson, 1997).

Upon deglaciation mass wasting occurred from glacially oversteepened slopes, particularly where Cambrian shales crop out (Figure 8). The mass wasting has continued through the Holocene; for example, large earthflows took place beneath Cathedral Cliffs in 1995 (Brunner et al., 1997) and 1996. Streams re-established their drainage systems and locally deposited alluvial fans, created flood plains, and cut gorges in the bedrock.

STUDENT PROJECTS

The 1997 investigations dealt with many aspects of the diverse geology of northwestern Wyoming and adjacent Montana. The student projects can be divided into four partially overlapping groups: Cambrian and Eocene sedimentary rocks, structural geology related to the Heart Mountain detachment, igneous petrology related to the Heart Mountain "hot spot trace," and Quaternary geology.

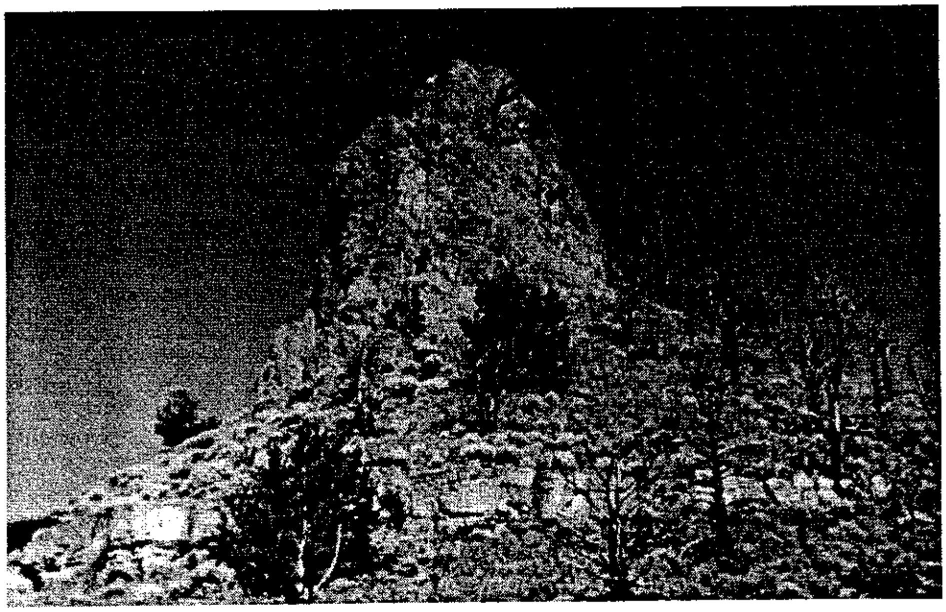

Figure 3. View of the monolith at the southeast end of the ridge between Painter Gulch and Trail Creek. The top of the light-colored cliff of Cambrian-Ordovician carbonates is the Heart Mountain detachment. The monolith, part of a rootless pluton of Eocene shoshonitic porphyry intruded by diorite, was an island ("sea" stack?) in glacial lake Sunlight. The pines (on the right) were killed by the Yellowstone fires of 1988.

AGE		STRATIGRAPHIC UNIT		LITHOLOGY	
Cenozoic	Quaternary			drift, alluvium, colluvium	
	unconformity				
	Tertiary (Eocene)	Absaroka Volcanic Supergroup		tuffs, breccias, and other volcaniclastic rocks; flows, dikes, sills, and stocks; generally andesitic/dioritic	
		Crandall Conglomerate (west)	Willwood Formation (east)	conglomerate with carbonate clasts	clay, sandstone, and shale; thick conglomerate at base
unconformity					
Mesozoic	Cretaceous	seven formations		sandstone, shale	
	Jurassic	three formations		shale, sandstone, limestone, gypsum	
	Triassic	Chugwater Formation		red siltstone, shale, sandstone	
		Dinwoody Formation		siltstone, gypsum, dolomite	
	Permian	Park City Formation		limestone, dolomite, chert, shale	
Paleozoic	Pennsylvanian	Tensleep Sandstone		quartzose sandstone	
	Mississippian	Amsden Formation		shale, siltstone, limestone, dolomite	
		Madison Limestone			
	Devonian	Three Forks Formation		dolomite, shale, limestone	
		Jefferson Dolomite			
		Beartooth Butte Formation		siltstone, limestone	
	unconformity				
	Ordovician	Bighorn Dolomite			
	Heart Mountain detachment horizon (2 m above base of Bighorn Dolomite)				
	Cambrian	Snowy Range Formation	Grove Creek Member	shale, flat-pebble conglomerate	
		Pilgrim Limestone			
		Gros Ventre Group	Park Shale		
			Meagher Limestone		
			Wolsey Shale		
		Flathead Sandstone		quartzose sandstone	
unconformity					
Precambrian	ARCHEAN			granitic rocks, gneiss	

Figure 4. Rock units present in the Clarks Fork area (after Pierce, 1965).

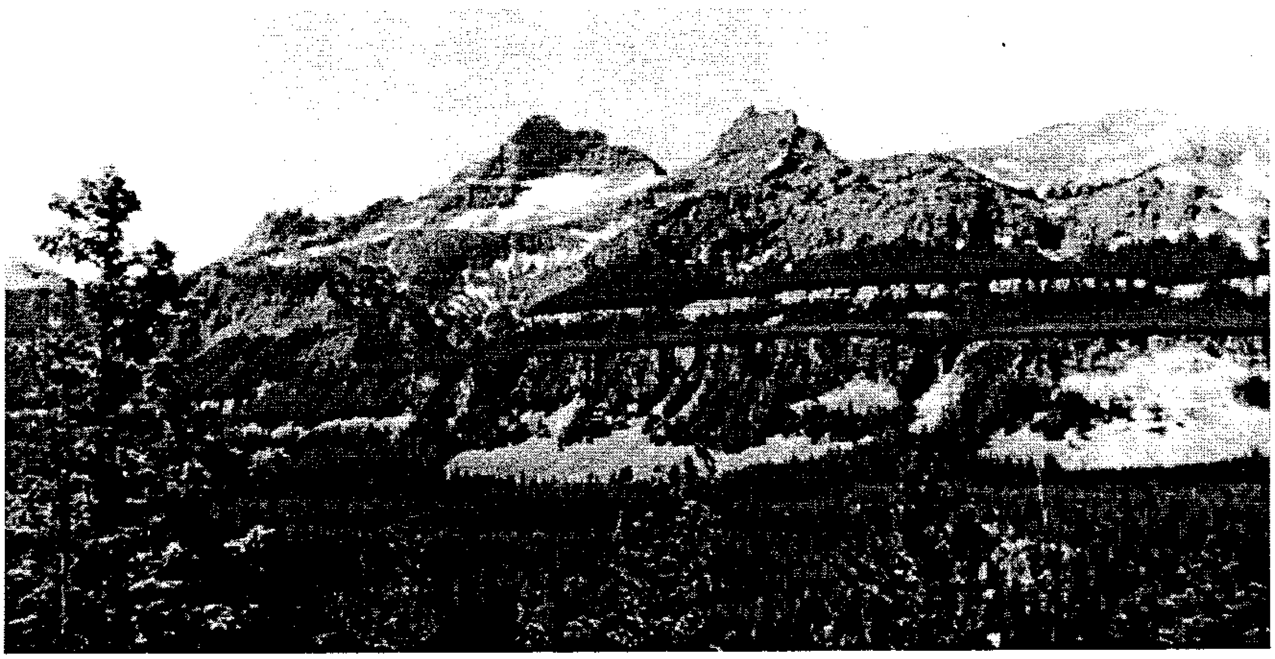

Figure 5. View southwest toward Pilot (left) and Index (right) Peaks, horns which rose above the Yellowstone ice sheet. From the foreground to the peaks are: Precambrian crystalline rocks (mostly forest covered), Cambrian carbonates and shales (intruded by a gray Eocene sill of latite porphyry), the Heart Mountain detachment (at the top of the light-colored cliff), and dark Eocene Absaroka volcanics. The Clarks Fork outlet glacier flowed from northwest (right) to southeast.

Sedimentary rocks. Dawn Morgan worked on the sedimentology, depositional history, and ichnology of lower Paleozoic strata. Precambrian basement rocks in the Clarks Fork River Valley and surrounding area are directly overlain by the Cambrian Flathead and Wolsey formations (Figure 4). An excellent suite of sedimentary and biogenic structures allows for reconstruction of paleoenvironments and depositional history. The coarse sandstone of the Flathead contains large cross-bed sets (>2 m in thickness) produced by tidally-generated subaqueous dunes. Detailed sketches allow for reconstruction of paleotidal conditions and the kinematics of bedform migration. The overlying Wolsey Formation is a shale dominated unit with abundant storm-generated sandstone beds. Subtle fine-scale changes in color, ichnofabric index, and internal sedimentary structures shed light on paleooceanographic conditions, including temporal changes in the degree of oxygen stratification. Substrate and geochemical control on the degree of bioturbation and the nature of trace fossils is elucidated by combining these ichnological observations with stratigraphic and sedimentary data.

Meghan McLaughlin made an integrated stratigraphic study of Upper Cambrian and Lower Ordovician strata of the Grove Creek Member of the Snowy Range Formation(Figure 4). The unit is highly diachronous and variably eroded under the regional unconformity at the base of the Upper Ordovician Bighorn Dolomite. This study provides the first conodont stratigraphy for the type section of the Grove Creek Member, as well as for exposures of the unit in Clarks Fork valley (at Cathedral Cliffs), both of which reach only the uppermost Upper Cambrian below the Bighorn. Conodont biostratigraphy is supplemented by carbon isotope chemostratigraphy for both sections. An additional section on the east flank of the Bighorn Mountains was sampled for both conodonts and carbon isotopes. This exposure has a section of the Grove Creek Member that is believed to span the Cambrian-Ordovician boundary, and will be useful as a comparison with the other two sections. Synchronous changes in the isotopic composition of marine carbonate beds and conodont biozone boundaries have been reported in other sections worldwide and allow for remarkably precise correlation of sections across North America and worldwide. Synchronicity in these stratigraphic perturbations also suggests linkage between marine extinctions and secular changes in the chemistry of ocean water.

Meg Anderson studied the sedimentology of the Crandall Conglomerate (Pierce and Nelson, 1973). The Crandall is a thick conglomeratic valley fill that predates movement along the Heart Mountain fault. Over 35(?) m occur in the lower plate of the fault and close to 200(?) m occur within upper plate exposures. The Crandall valley cut through strata from the Mississippian Madison Limestone to the top of the Cambrian Pilgrim Limestone (Figure 4). The Crandall outcrops appears to follow the axis of a Laramide structure, the Blacktail fold, indicating structural control on the spatial development of the valley. The conglomerate is remarkably devoid of internal organization such as imbrication, grading, and channel deposits. The deposit contains remarkably little clay despite having downcut through nearly 100 m of Cambrian shale. These observations place considerable constraint on the interpretation of depositional mechanisms, climate, and driving mechanisms for downcutting and later filling of the Crandall valley. The age of the Crandall is of considerable importance for resolving conflicting views on the timing and nature of Laramide tectonics and the origin of the Heart Mountain fault.

Structural geology. Three students worked on structural projects related to the Heart Mountain detachment (HMD) fault (Figure 6). Steve DiBenedetto studied the Blacktail anticline. This fold, which trends northwest across the Crandall Creek drainage, was interpreted by Pierce and Nelson (1973) to be a pre-HMD, epidermal pop-up fold developed in response to the incision of the valley in which the Crandall Conglomerate was later deposited. Steve found abundant field evidence for a compressional origin for the fold, and studied the strain in oolitic limestones in the Pilgrim Formation to see if they also record the compressional deformation observed in the fold. He also mapped the Little Bear Creek fault/fold on top of the Beartooths as a possible analog for a lower level of the Blacktail fold.

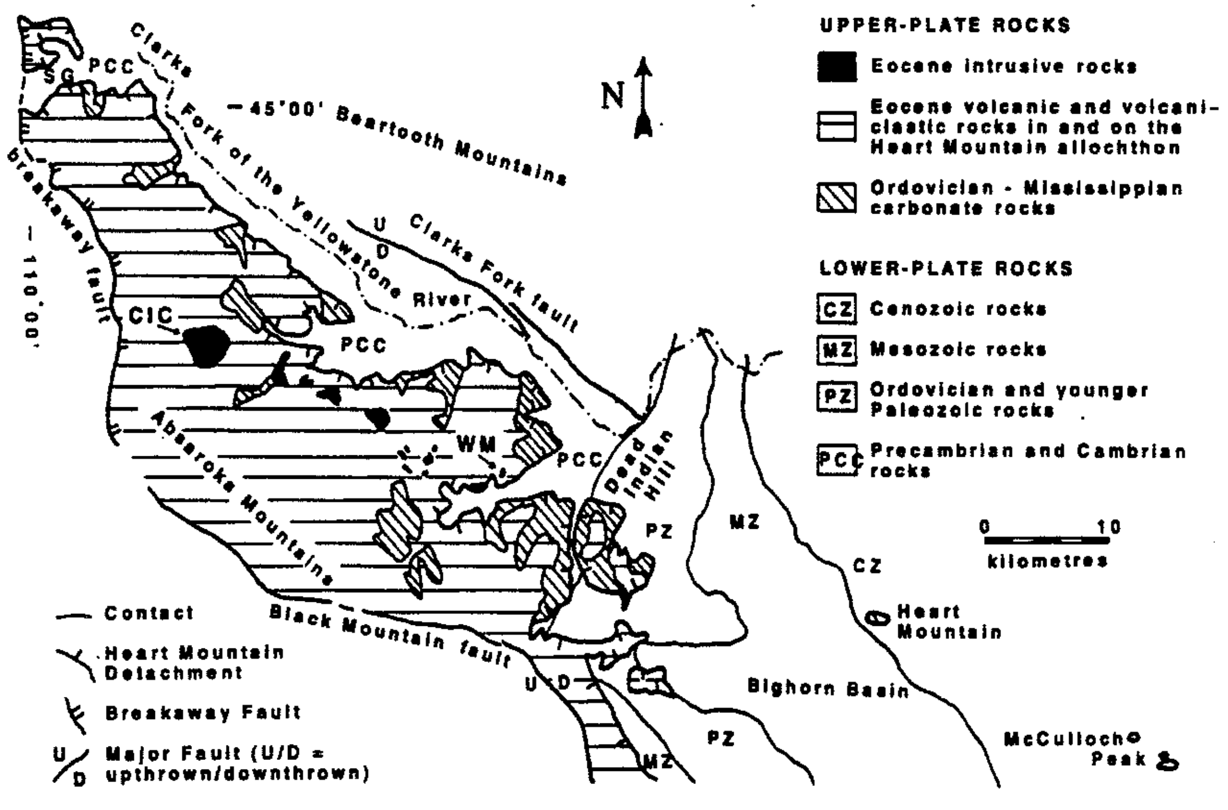

Figure 6. Generalized geologic map of Heart Mountain detachment area (from Beutner and Craven, 1996.) CIC = Crandall intrusive complex; SG = Silver Gate; WM = White Mountain.

Rachael Howse expanded a study of footwall deformation begun last year. Deformation observed ranged from none, seen at a number of localities, to severe deformation (intense brecciation and shearing of shales and thin bedded limestone) observed on a tributary to Squaw Creek. Additionally, a fold in the footwall in the same area, about 10 m below the HMD, appears to represent HMD-related deformation. Rachael undertook microscope studies of the deformed rocks and analyzed the clays in rocks beneath transported plutons to determine whether a thermal signature related to the plutons is present in the footwall.

Kristin Ulstad also expanded a study begun last year, this one on the fault rocks along the HMD. Numerous new localities were sampled and microbreccias were found at most. Kristin's work focused on determining the distribution of glass and volcanic fragments with respect to the potential source of glass, and on the general problem of whether the microbreccias represent a single movement event or multiple events. Additionally, she studied the orientation of microclasts in the thick microbreccia at White Mountain (WM on Figure 6) to determine whether a pattern of preferred orientation is present.

Igneous petrology. The stimulus for the petrologic projects was the scenario proposed by Beutner and Craven (1996) suggesting that volcanic fluids allowed the Heart Mountain upper plate to be emplaced in a single catastrophic event. Three students investigated the petrologic relationships of the igneous rocks associated with the Heart Mountain detachment to determine the character of the igneous activity associated with the volcanic fluidization model. Two plutons that are part of the trend between the Crandall intrusive complex (CIC on Figure 6) and White Mountain were mapped and sampled. In addition, a suite of dikes and related small scale irregular intrusions were mapped and sampled to determine the character of the igneous material that facilitated the motion of the Heart Mountain fault.

Figure 7. View south from one nunatak, Lonesome Mountain, Montana, to another nunatak, Beartooth/Clay Buttes, Wyoming. In the foreground are the Precambrian crystalline rocks of the Beartooth Plateau. Beartooth/Clay Buttes, composed of Cambrian to Devonian carbonates and shales, rose almost 100 m above the ice at the last glacial maximum. The Beartooth Lake outlet glacier flowed south along the east (left) side of Beartooth Butte, whereas the Clarks Fork outlet glacier flowed south along the west (side) of Clay Butte. In the background the Absaroka Range, composed of Eocene volcanics, rises behind Clarks Fork valley.

Joe Colgan mapped the pluton along the ridge east of Painter Gulch on the north side of Sunlight Basin. His goal was to characterize the igneous rocks of this pluton, determine the sequence of intrusion of the various lithologies, and evaluate the possibility of emplacement during the catastrophic event suggested by the Beutner and Craven (1996) model. This intrusion contains a suite of texturally diverse rock types spanning the range from gabbro to diorite.

Marie Knotwell investigated the structure and composition of a rootless pluton on the ridge on the east side of Trail Creek on the north side of Sunlight Basin (Figure 3). The dominant rock type in this pluton is a shoshonitic porphyry that has been intruded by diorite and a variety of finer-grained dikes. Contact relations indicate that the shoshonitic porphyry is the earliest intrusion and was in turn intruded by diorite. Both of these rock types are intruded by late veinlets of diorite.

Cam Miller studied the structure and composition of igneous dikes within the hanging wall of the Heart Mountain detachment and their relationships to faults. The purpose was to test whether dike intrusion and faulting were sequential or contemporaneous. Samples were collected, and structures mapped at three localities. At Painter Gulch, where a listric fault that soles into the Heart Mountain fault has tilted a sequence of Absaroka volcaniclastic rocks, a suite of small dikes intruded along and adjacent to the listric fault was mapped and sampled. At Squaw Creek and at White Mountain, dikes were collected in the hanging wall just above the Heart Mountain fault.

Quaternary geology. Beth Bartel attempted to synthesize and add to the knowledge of the Clarks Fork outlet glacier, and to date its retreat. Specifically, she searched for moraines, striations, and erratics in areas where no data existed, and collected granite samples for cosmogenic dating. The samples are from (1) the Pinedale terminal moraine in the Bighorn Basin (Figure 2), (2) about 2 km in front of the cirque headwalls near Beartooth Pass, and (3) about halfway along the route the ice took from (3) to (1). One area of concentrated field work was near Colter Pass (CP in Figure 1) where it is uncertain whether Yellowstone ice was flowing east toward Clarks Fork, or Beartooth ice was flowing west toward Yellowstone, or both at different times. The other area of concentration was where ice streams west and south of Beartooth/Clay Buttes (B on Figure 1) converged in an uncertain relationship (Figure 7).

Figure 8. View north along the west side of Clay Butte, Wyoming, toward the Precambrian crystalline rocks of Lonesome Mountain, Montana, and the Beartooth Plateau. Clay Butte, composed mostly of Cambrian carbonates and shales dipping gently southwest, is undergoing large-scale mass wasting. Eastward-rotated slump blocks capped by Pilgrim Limestone rise above westward-creeping earthflows.

Mike Heublein worked near where Crandall and Beartooth Creeks join Clarks Fork. McKenna and others (1997) hypothesized (based mostly on striations) that the Crandall Creek valley glacier (CCVG on Figure 1) was the last ice near the river intersection. Mike made dozens of pebble counts, mapped many moraines, and found additional striae to clearly establish the terminus of the late stand of Crandall ice. He also studied meltwater channels near the terminus, and worked on the problem of how far Clarks Fork ice pushed up the Crandall valley. He will supplement one radiocarbon calibrated age of 13,482 BP for deglaciation with cosmogenic dates and possibly another radiocarbon age.

Dawn Chapel studied the spectacular mass-wasting complex on the west slope of Clay Butte (B on Figure 1). She attempted to correlate different styles of mass wasting with different strata above. For example, there are large slump blocks of limestone beneath cliffs of Pilgrim Limestone (Figure 8). Just to the west of this area, a giant earthflow descended all the way to Muddy Creek. Radiocarbon dates from organic matter found along Muddy Creek will help establish the ages of mass-wasting events which dammed the creek. Dawn found a wide variety of types of mass wasting near Clay Butte, including block topples, rock falls, rock slides, and solifluction.

CONCLUSIONS

In the fourth year of Keck projects in northwestern Wyoming, we continued to test new hypotheses and make significant discoveries regarding the geologic history of the area. A few of the highlights of the 1997 research are listed here:

1. The Crandall Conglomerate is an early Eocene fluvial deposit, much of which was deposited by catastrophic flow. Its deposition is not related to Heart Mountain fault movement, but is closely tied with orogenic events that created the Beartooth Mountains.
2. The Blacktail anticline of the footwall of the Heart Mountain detachment is a Laramide contractional fault/fold; weakness along the fold hinge served to localize the channel in which Crandall Conglomerate was deposited prior to movement on the Heart Mountain detachment.
3. The clay minerals in the upper meter of footwall dolomite in the footwall of the Heart Mountain detachment show no signs of a thermal imprint from overlying plutons in the hanging wall, suggesting that the plutons had cooled and that there was limited heat associated with the microbreccia along the fault.
4. Analysis of the microbreccia along the Heart Mountain fault suggests a gas matrix fluidized material which, although it may have been hot, contained relatively little heat. Additionally, the microbreccia at White Mountain (WM on Figure 6) contains a strong compactional fabric.
5. The rootless Painter Gulch pluton is a complex body composed of diorite, shoshonite and andesite, intruded in that order, with each cooled before intrusion of the next; this contradicts the hot-spot model of Beutner and Craven (1996). Pseudotachylyte was found along a number of upper plate faults, which is consonant with catastrophic movement of the Heart Mountain fault.
6. Despite the very low carbon content (0.04%) of glacial lake Cinderella (GLC on Figure 1), we were able to obtain an AMS date of 22630 ± 120 radiocarbon years B.P. These lake beds in Lodgepole valley are overlain by Clarks Fork till and are within a few km of the terminus of this portion of the Yellowstone ice sheet.
7. Coupled with the date of 11,560 ± 180 radiocarbon years from basal peat in the Corral Creek alluvial fan (CA on Figure 1) (Oliver, 1997), the glacial lake Cinderella date of 22,630 radiocarbon years limits the time that ice was present in the central Clarks Fork valley. This portion of the Yellowstone ice sheet reached a maximum just after 22,630 radiocarbon years ago, and retreated upvalley before 11,560 radiocarbon years ago.
8. Using accumulation area ratios of 60-75%, we have determined that the equilibrium line altitude for the Clarks Fork lobe of the Yellowstone ice sheet at the last glacial maximum was 3025 - 2875 m.
9. Striations near Colter Pass (CP on Figure 1) indicate ice flow from the high Beartooths southwesterly down Soda Butte Creek valley (Pierce, 1979). Modeling the Yellowstone ice sheet at its maximum, Locke (1995) hypothesized that ice flowed from northeastern Yellowstone Park easterly into Clarks Fork valley. This hypothesis is supported by indicators from the Crown Butte mining district (He on Figure 1) found to the southeast in the Kersey Lake area.
10. The Clarks Fork outlet glacier and the Crandall Creek valley glacier were phase (McKenna et al., 1997). By studying moraines and erratics, we were able to determine the limit of Crandall ice after Clarks Fork ice ceased to block Crandall valley (figure 1).

11. Mass wasting of the slopes of Beartooth-Clay Buttes (B on Figure 1) likely began upon deglaciation. Radiocarbon dates indicate that giant slumps and earthflows on the west side of Clay Butte were active as recently as a few thousand years ago.

ACKNOWLEDGMENTS

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