Regional Fracture Trends in Clarks Fork Valley, Park County, Wyoming

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INTRODUCTION AND TECTONIC SETTING

Clarks Fork Valley lies along the southern boundary of the Beartooth Range, where the Clarks Fork of the Yellowstone River is entrenched into Precambrian granites and gneiss. The NW-SE trending valley approximately parallels the contact between the Archean basement rock and overlying sedimentary units. North of Clarks Fork Canyon, the eastern front of the Beartooth Uplift is bounded by a series of N-S trending Laramide normal faults and a thrust dipping to the west. Just south of the valley, the Heart Mountain Thrust has displaced most of the Ordovician and younger Paleozoic cover and the Absaroka Volcanics. The rocks underlying the valley are broken into numerous blocks by local steeply dipping Laramide faults and have undergone multiple deformational events. Both the Archean bedrock and overlying sedimentary units are complexly fractured.

Several studies of fracture trends have been conducted in areas surrounding the Clarks Fork Valley, particularly in the Beartooth Range to the north (Spencer, 1959 and Wise, 1964) and the Bighorn Mountains to the east (Hudson, 1969, and Wise, 1964). In addition, Wise (1982) described prominent fracture trends in the Archean basement and overlying Cambrian Flathead sandstone in the Sunlight Creek-Dead Indian Creek region. Together these studies provide a regional pattern of fracture development for the central Rocky Mountains and also suggest a Precambrian control of later Laramide structural features in the area.

The aims of this study are to determine the regional fracture pattern in the Clarks Fork Valley, to compare this pattern to that of the Beartooth Range to the north, to compare the trends in the Archean bedrock with those in overlying Cambrian sedimentary units (Flathead Sandstone, Meagher Limestone, and Pilgrim Limestone), and to relate these observations to the regional tectonic pattern.

DATA COLLECTION

Ground Measurements. Over 4000 field measurements were gathered from 64 stations along the Clarks Fork Valley and southern Beartooth Mountains (Figure 1). Measurement locations were chosen to provide as detailed coverage of the region as time and accessibility allowed. Forty-eight localities of Archean granite and gneiss, 6 localities of Flathead Sandstone, 5 localities of Meagher Limestone, and 5 localities of Pilgrim Limestone were sampled Starting at an arbitrary point on the outcrop, strike and dip measurements were taken of each fracture in the vicinity, excluding those which were exceptionally small and/or irregular. The number of measurements taken at each locality varied, with a greater number being taken at outcrops with systematic and or prominent fracture trends. Nearly all dips measured were vertical or near vertical.. In addition, related structural features, such as dikes, faults, slickensided surfaces, and en echelon shears were noted where observed.

Aerial Photograph Lineaments. One thousand three hundred and fifty-three lineament strike measurements were taken from 1:24 000 aerial photographs of the study area. Lineaments were traced onto transparent acetate. The acetate was then re-aligned to north-south on adjacent photos to minimize distortion on the photo's boundaries.

Structural Features. Major fault strikes were measured from 1:62,500 USGS Deep Lake, Pat O'Hara, and Beartooth Butte, geological maps (Pierce 1965, Pierce and Nelson 1968, Pierce and Nelson 1971).

DATA ANALYSIS

Ground measurements for each individual location were plotted on the lower hemisphere of a 10 cm equal-area Schmidt net using the computer program Stereo for Macintosh. Since all dips measured were near vertical, the fractures appeared only along the perimeter of the Schmidt nets. To make it easier to compare fracture orientations between locations, dip measurements were discarded and strike measurements were replotted as rose diagrams using the computer program Rosy for Macintosh.

The ground measurements for the entire valley were subdivided into 11 geographic / tectonic sections (A-K, Figure 1). The boundaries for each section were chosen to separate areas between major fault zones where possible. The aerial photograph lineaments were divided into the same subdivisions for comparison.

Rose diagrams were plotted for the valley as a whole, subdivisions of the valley. the lineament subdivisions, the major faults in the area, and dike trends. Rose plots were also made separately for each lithology. The rose plots were used to make comparisons between areas, between lithologies, across structural features, and with regional trends in the Beartooth Range and Bighorn Mountains.

Wilson, M.A. and Palmer, T.J., 1992, Hardgrounds and Hardground Faunas: University of Wales, Aberystwyth, Institute of Earth Studies Publications, Number 9, 131 p.

Wilson, M.A., Palmer, T.J., Guensburg, T.E., Finton, C.D., and Kaufman, L.E., 1992, The development of an Early Ordovician hardground community in response to rapid sea-floor calcite precipitation: Lethaia, v. 25, p. 19-34.

Figure 1. Filled and cemented burrows: (a) An organism creates a burrow in the sea floor which is (b) filled in with micritic sediment and preferentially cemented to form (c) a carbonate nodule.

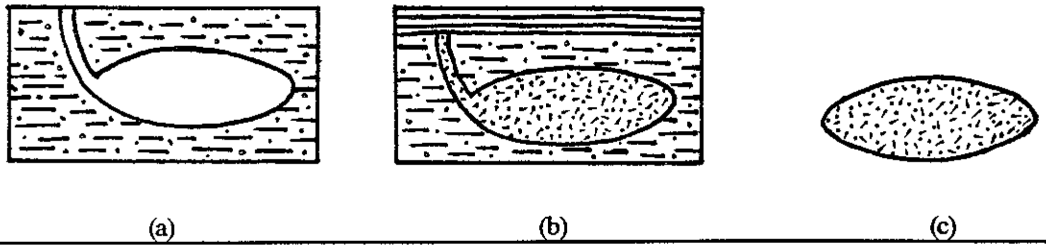


Figure 2. Early diagenetic concretions: (a) A grain or skeletal fragment in the sea floor acts as a nucleus around which (b and c) syntaxial, isopachous, high-Mg cement can precipitate to form (c) a carbonate nodule.

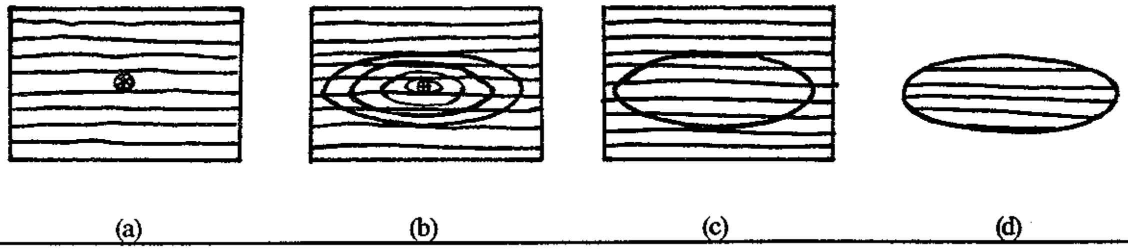


Figure 3. Eroded flat-pebble conglomerate clasts: (a) A flat-pebble conglomerate hardground is (b) eroded into clasts and (c) rounded by wave action. It is likely that non-flat-pebble conglomerate hardgrounds could have been eroded in the same manner.

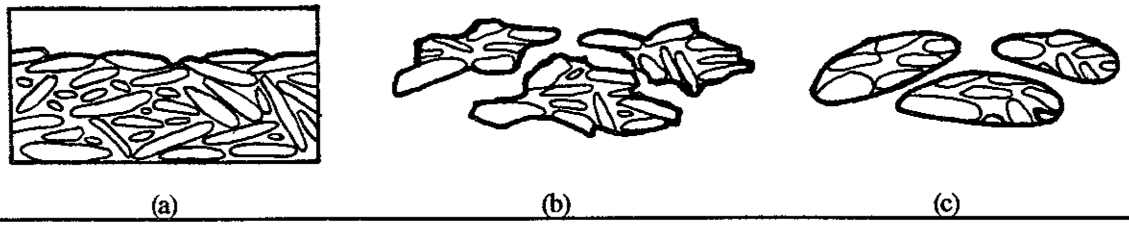
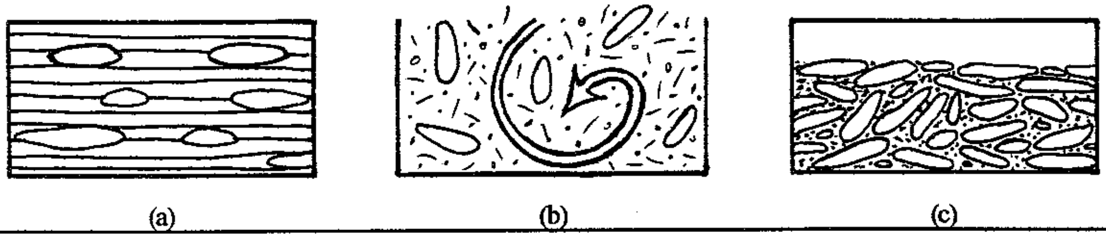


Figure 4. Winnowed cobble lags: (a) Carbonate nodules in the sea floor sediments were (b) exhumed by high energy storm currents which winnowed away the fine-grained sediments resulting in (c) an accumulation of flat pebbles in a cobble lag.



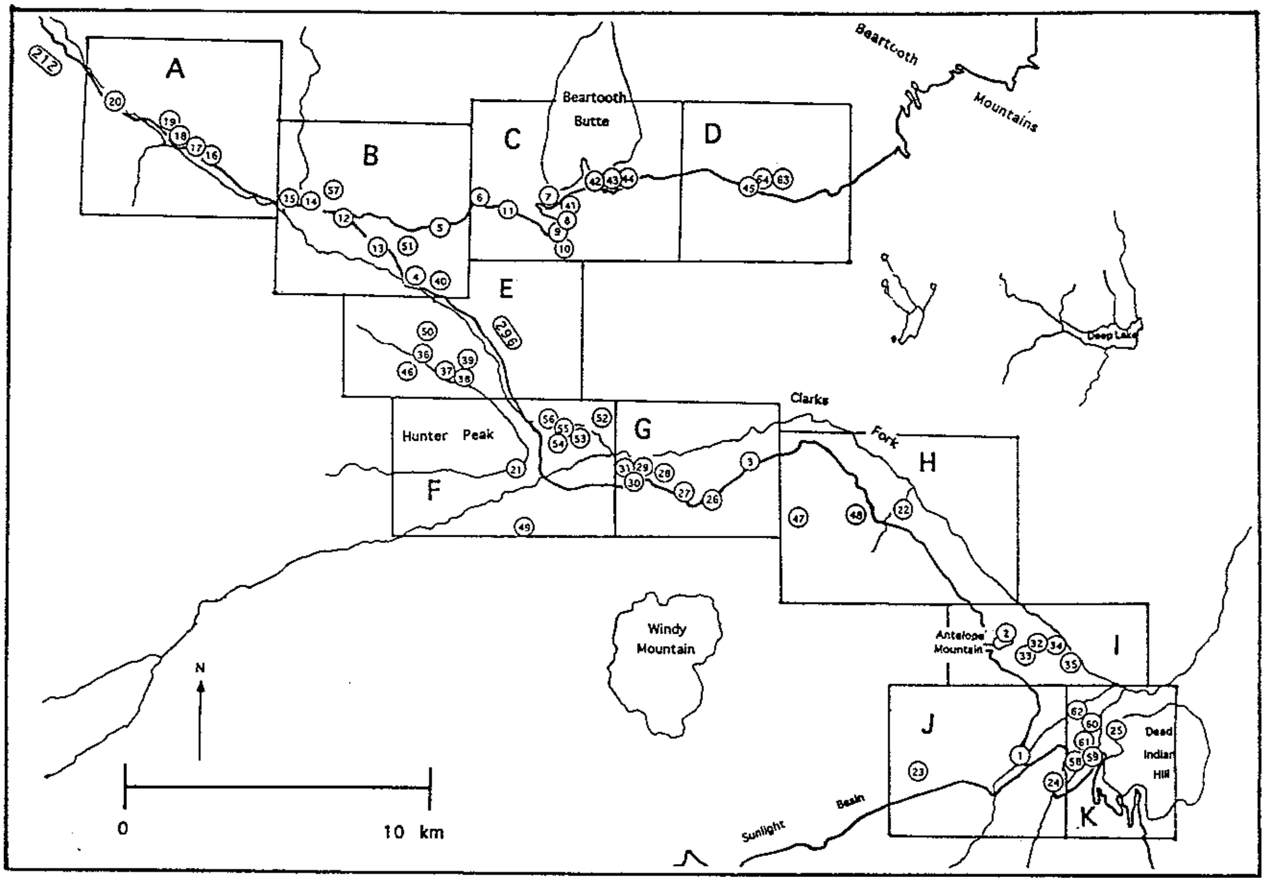


Figure 1. Map of study area showing field measurement localities and subdivisions.

RESULTS AND INTERPRETATION

Fracture Trends - Archean Basement. As expected, fracture patterns in the Precambrian basement rocks are much more complex than in the overlying sedimentary rocks. Regionally. two prominent directions of high-angle fractures occur in the basement rocks: N 15° E and N 25-30° W, with a minor trend of N 85° E. North of the faults along the Clarks Fork valley (sections C & D, Figure 1) the basement rock exhibits two prominent trends: N 10-30° E and N 10-40° W. Some localities show a strong N 60-70° W trend. Lineaments of the same area show principal trends of N 10-30° E and N 60-70° E. South of the fault zone, (sections E-I, Figure 1) the granite exhibits three prominent trends: N 10-30° E, N 20-40° W, and N 80° E - S 80° E, with similar trends appearing in lineaments in the area. At several locations the NE trend is offset by N 80° E striking fractures. Since the N 10-30° E striking fractures are consistent across the fault zone, they appear to postdate the faults. The difference between the N 10° W trend north of the major fault zone and the N 20° W trend south of the zone may be due to reorientation of the principle stress directions within the fault zone during compression. Local faulting south of the fault zone appears responsible for the southern EW trending fractures and their almost complete absence in the northern outcrops.

Fracture Trends - Sedimentary Formations. The principal trends for the Archean basement, Cambrian Flathead Sandstone, Meagher Limestone and Pilgrim Limestone are given in Table I. The N 10-30° E trend exhibits a strong continuity of fractures from the Archean basement rocks up into the overlying sedimentary units. The near EW trend is most prominent in the Meagher and Pilgrim Limestones. The overall principal trends of the basement rocks occur in the overlying Flathead. However when trends are compared between outcrops at the basement-Flathead contact, the patterns do not directly coincide. The closest correlation between the patterns in the granite gneiss and those in the Flathead sandstone occur in the Spring Creek Gorge and Sunlight Basin subsections (sections J & K, Figure 1). The poorest correlation is found at the northern-most contact visited. The strong systematic fractures seen in the Meagher Limestone do not appear in the interbedded Gros Ventre Shale. The incompetent shale beds above and below the Meagher apparently redistributed the applied stresses during deformation and changed the principal fracture trends. Principal fracture trends in the Pilgrim parallel those of the Meagher, Flathead, and Granite.

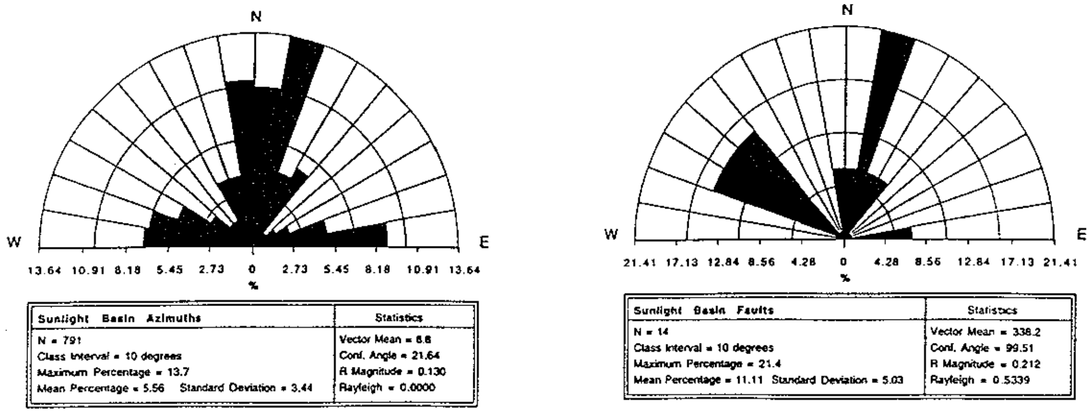
Basement	Flathead SS	Meagher Lm	Pilgrim Lm
N=2780	N=665	N=197	N=586
N 10-30° E	N 10-30° E	N 10-20° E	N 10-30° E
N 80-90° E	N 80° E-S 10° E	-	N 70-90° E
N 30-50° W	N 10-30° W	N 30-50° W	N 10-30° W
-	-	N 60-80° W	N 60-70° W

Table I. Principal Fracture Trends by Lithology; N = the number of azimuth measurements.

Local Faulting. Within the study area, faults exhibit three principal directions, N 10-30° E, N 40-70° W, and N 80° E- S 80° E. Most faults along Clarks Fork Canyon from Hunter Peak southeast to Antelope Mountain trend N 50-70° W. In the Sunlight Creek - Dead Indian Creek region faults principally trend N 10-20° E and N 40-70° W, with a few trending N 80-90 E. Along the eastern front of the Beartooth Range faults trend N 10-30° E. All faults are assumed to be Laramide in Age.

Related Structural Features. Only two basaltic dikes were found in the study area, one trends N 25° E and the other N 55° W. Both were associated with highly faulted, chaotically fractured outcrops. Sets of en echelon shears found south of the valley fault zone trend N 35-36° W and N 55° W, all suggesting right lateral shear.

Sunlight Basin Region. Because of the significant amount of local faulting in Sunlight Creek Basin, (sections J & K, Figure 1), it is useful to examine the fracture trends in this region independently from the rest of the study area. Sunlight Basin exhibits a systematic conjugate joint set of N 10-20° E and N 60-90° W, with minor trends of N 20-30° W and N 30-40° E (Figure 2). Prominent lineaments in the area closely parallel ground measurements and trend N 10-30° E, N 10-30° W, and N 60-80° W. These fracture orientations are consistent throughout the basement rock and overlying sedimentary units. The trends also closely approximate the major fault trends in the area. Wise (1982), interpreted the jointing in this area to be either synchronous with or younger than faulting. The strong consistency of these trends in this area compared to the rest of the valley to the northwest, indicates that local Laramide normal faulting may have locally disrupted and reoriented the stress pattern responsible for the joint formation in the area.



Sunlight Basin Azimuths	Statistics
N = 791 Class Interval = 10 degrees Maximum Percentage = 13.7 Mean Percentage = 5.56 Standard Deviation = 3.44	Vector Mean = 6.8 Conf. Angle = 21.64 R Magnitude = 0.130 Rayleigh = 0.0000

Sunlight Basin Faults	Statistics
N = 14 Class Interval = 10 degrees Maximum Percentage = 21.4 Mean Percentage = 11.11 Standard Deviation = 5.03	Vector Mean = 338.2 Conf. Angle = 99.51 R Magnitude = 0.212 Rayleigh = 0.5339

Figure 2. Azimuths of fractures and major faults in Sunlight Basin (sections J & K, Figure 1).

Comparison to Regional Fracture Pattern. A comparison between principle fracture trends in Clarks Fork Valley to those in the Bighorn Mountains to the east (Hudson, 1969), the Beartooth Mountains to the north (Spencer, 1959), and to microfracture trends in the Middle Rocky Mountains (Wise, 1964), is given in Table II. As indicated, the major fracture patterns seen in Clarks Fork Valley tend to agree with surrounding regional trends. The N 10-15° E trend is prominent throughout the area, in both basement rock and overlying sediments. In the Bighorn Mountains, Hudson found the N 10° E trend to be most prominent lower in the stratigraphic column, becoming weaker to nonexistent in the higher units.

Bighorn Mtn.	**Mid. Rockies;**	**Beartooth Mtn**	**Clarks Fork**
(Hudson, 1969)	[Microjoints]	(Spencer, 1959)	
	(Wise, 1964)		
N 10-17° E	N 10° E	N 0-10° E	N 10° E
N 21-44° E	N 25° E	N 15-25° E	N 15-25° E
-	N 85° E	N 85-90° E	N 80-90° E
N 70-88° W	N 70° W	N 60-70° W	N 60-70° W*
N 37-47° W	N 45° W	N 45° W	N 40-50° W*
-	N 65° E	N 60° E	N 40-60° E *
-	N 10° W	N 15-20° W	N 15-30° W
N 45-58° E	N 45° E	N 45° E	-
* Prominent Trend in Northern Lineaments			

Table II. Prominent fracture and microfracture trends for the Bighorn Mountains, Middle Rocky Mountains, Beartooth Mountains, and Clarks Fork Valley.

SUMMARY AND CONCLUSIONS

It is difficult to discern with certainty the origin and relative ages of the fracture patterns seen in Clarks Fork Valley, due to the high complexity of fracturing, a general absence of datable dikes and mineralization, and a relative absence of stress indicators. However, based on field evidence and comparisons with work done in surrounding areas, some inferences can be made concerning the tectonic history of Clarks Fork Valley. The fracture patterns found in the Clarks Fork Valley suggest at least two major phases of deformation, Precambrian and Laramide. The pronounced development of N 10-30° E trending fractures noted in ground measurements and photo lineaments, coupled with their prevalence in the overlying sedimentary units, and prominence in surrounding Precambrian basement ranges, suggests that these fractures represent a regional Precambrian deformation event. In several locations, this initial trend is offset by prominent EW trending fractures.

Lee and Wise (1983) described two phases of Laramide deformation for the area: a main NE-SW horizontal compression followed by a later phase of WNW-ESE compression. In the Clarks Fork Valley the angle between major faults is consistent with the angle between major fracture sets, suggesting that the faults and fractures were created within the same stress field and the faults possibly formed along the pre-existing fractures. The main phase of Laramide NE compression could account for the prominent NW trending fractures found throughout the valley in both the basement and sedimentary units and seems responsible for the major fault zones, principally along the valley and in the Sunlight Creek Basin. A possible second phase of Laramide deformation involving WNW-ESE compression was partly controlled by the established Precambrian zones of weakness, reactivating many N 10-20° E trending faults and fractures.

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Footwall deformation in the bedding-parallel portion of the Heart Mountain detachment, northwestern Wyoming

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INTRODUCTION

The Heart Mountain detachment is a low angle normal fault that crops out along the southwestern wall of the Clarks Fork Valley and as isolated klippen in the Bighorn Basin of northwestern Wyoming. The fault has been the subject of controversy since its discovery over 100 years ago, and continues to be one of the great puzzles of structural geology. The geometry and mechanism of movement of the Heart Mountain detachment have been extensively debated, but deformation in the footwall of the fault has received little more than brief mention in the literature. The purpose of this study is to characterize footwall deformation in the bedding-parallel portion of the detachment, and to compare footwall deformation to existing models for allochthon movement. A secondary goal of this study is to propose a reason for detachment formation in the Bighorn Dolomite rather than in Cambrian shales only a few meters below.

GEOLOGIC SETTING

The Heart Mountain detachment extends more that 80 km from the break-away fault near the northeast entrance to Yellowstone National Park to Heart Mountain and possibly McCulloch peaks in the Bighorn Basin (see area map, figure 3, Carson et al., this volume). In the Clarks Fork Valley the fault is confined to a bedding horizon in the Ordovician Bighorn Dolomite that slopes only 2° to the southeast. In the area of Dead Indian Hill the fault ramps, cutting up through the stratigraphy and then moving onto the former Eocene land surface in the Bighorn Basin. The allochthon, originally a few kilometers thick and 1300 km^2 in area, thinned during faulting to less than 1 km and spread out to cover an area of more than 3400 km^2. The allochthon moved to the southeast, and its leading edge traveled up to 50 km (Beutner and Craven, 1996). The hanging wall allochthon consists of Paleozoic carbonate rocks and Eocene Absaroka volcanics and is injected with numerous dikes and plutons. Footwall rocks in the bedding-parallel section of the fault are nearly flat lying Paleozoic carbonates and shales, and are relatively undeformed by faulting and are cut by few dikes.

Various models have been proposed for both the overall geometry and mechanism of movement of the Heart Mountain detachment. Reviews of these models are presented in Pierce (1973) and Hauge (1993). A more recent model (Beutner and Craven, 1996) is directly relevant to my research and findings. According to this model, a layer of volcanic gas was injected along a bedding plane in the Bighorn dolomite. This fluidized material was able to buoy the rocks above it, reducing friction to zero across the bedding horizon. Because the hanging wall rocks were on a slight slope, they began to slide by gravity. As the hanging wall moved, it thinned through normal faulting. Eventually gasses along the fault plane escaped through vents or along hanging wall faults, and the allochthon came back into contact with the footwall. Faulting, according to this model, proceeded at catastrophic rates. Evidence for this model includes a string of plutons between White Mountain and Hurricane Mesa that Beutner and Craven (1996) interpreted as analogous to a hot spot trace: as the allochthon moved over a stationary volcanic neck below Hurricane Mesa, magma injected regularly into the hanging wall. Further, Beutner and Craven (1996) reported the presence of accreted grains similar to accretionary lapilli, and delicate, intact shards of volcanic glass in microbreccia along the fault plane. As usual faulting processes would quickly destroy such delicate grains, Beutner and Craven (1996) argued that the most probable source of these intact grains would have been an injection of primary volcanic material and gasses. Models for an injection of gas or steam along the fault plane have earlier been proposed by Voight (1974), Hughes (1970), and Prostka (1978), but the model of Beutner and Craven (1996) is the most comprehensive of these models, and fits best with the characteristics of footwall deformation.

RESULTS

Deformation in the bedding-parallel portion of the Heart Mountain detachment footwall is remarkably limited: the fault crops out along much of 50 km of the Clarks Fork Valley, yet only at three or possibly four locations is deformation extensive. Near vertical fractures are common in the footwall of the detachment, but fracture density is extremely variable. In some places fractures are only 5 cm apart while in others they are spaced up to one meter or more apart. Fractures are consistent in density and orientation at least to the base of the Bighorn Dolomite. To determine whether fractures in the footwall are the result of regional joint set formation or of faulting,