Open-File Report 96-4
Field Trip No. 1

Field Guide for the Detachment Structures of the Eastern Absaroka Range, Wyoming

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Denver, Colorado
1996

FIELD GUIDE FOR THE DETACHMENT STRUCTURES OF THE EASTERN ABSAROKA RANGE, WYOMING

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INTRODUCTION

For more than a century, the Absaroka Range has been an important natural laboratory that has contributed to the education of thousands of students representing most of the colleges and universities of the nation. The purpose of this four-day field trip is to provide a forum in which the various detached extensional structures and large-scale mass movement deposits of the eastern Absaroka Range can be viewed, interpreted, compared, and contrasted. The foremost questions to be addressed will likely include: What factors (e.g., paleotopographic slope; direction and magnitude of bedding dip; seismicity; eruptive processes, presence and pressure of fluids) triggered the formation of these features? What factors facilitated movement across the gently dipping detachment surfaces? Were the detached rocks emplaced gradually or catastrophically? What data can be used to constrain the rates of emplacement? Were rates of emplacement similar throughout the Absaroka Mountains?

This field guide begins with an overview of the regional setting of Absaroka volcanism and associated detached extensional structures. Detailed site descriptions of the various detachments and their associated structures are integrated into the road logs (Figure 1).

Most outcrops that are viewed from a distance on this trip are accessible for detailed examination via hikes of 1 to 2 hours. Time constraints preclude visiting more than a few of these exposures for detailed examination during this field trip, but others meriting such examination are identified for future reference.

The staging area for this trip is the Double Diamond X Guest Ranch in the upper South Fork Shoshone River valley. The ranch is owned by Russ and Patsy Frazier. We warmly thank Russ and Patsy for their friendship and hospitality.

REGIONAL SETTING

The Eocene volcanic succession within the Absaroka Range has been formally named the Absaroka Volcanic Supergroup (AVS) (Smedes and Prostka, 1972). The rocks of the AVS extend over an area of approximately 7000 mi^2 (18,000 km^2) most of which is underlain by a Laramide structural basin (Absaroka Basin); the volcanic rocks overlie rock units which range in age from Archean to Eocene (Figure 2). Deeply-incised valleys provide excellent natural cross sections, and they display a volcanic stratigraphic succession in excess of 6000 ft (1875 m) thick. The rocks of the AVS are unconformably overlain to the west by Quaternary volcanic rocks of the Yellowstone Volcanic Plateau.

The inferred depositional setting of the AVS is a series of high stratovolcanoes with coalescing alluvial aprons (Sundell, 1993), rather like the Cascade Range or Andes Mountains of today. Volcanic centers define two northwest-trending belts, the locations of which are probably controlled by weakness zones within the Precambrian basement (Chadwick, 1970). Volcanism was initiated in southern Montana during late early Eocene time (53 Ma) (Chadwick, 1970), and continued throughout middle Eocene time, with the locus migrating southeastward until culminating in the southeastern Absaroka Range during late Eocene time

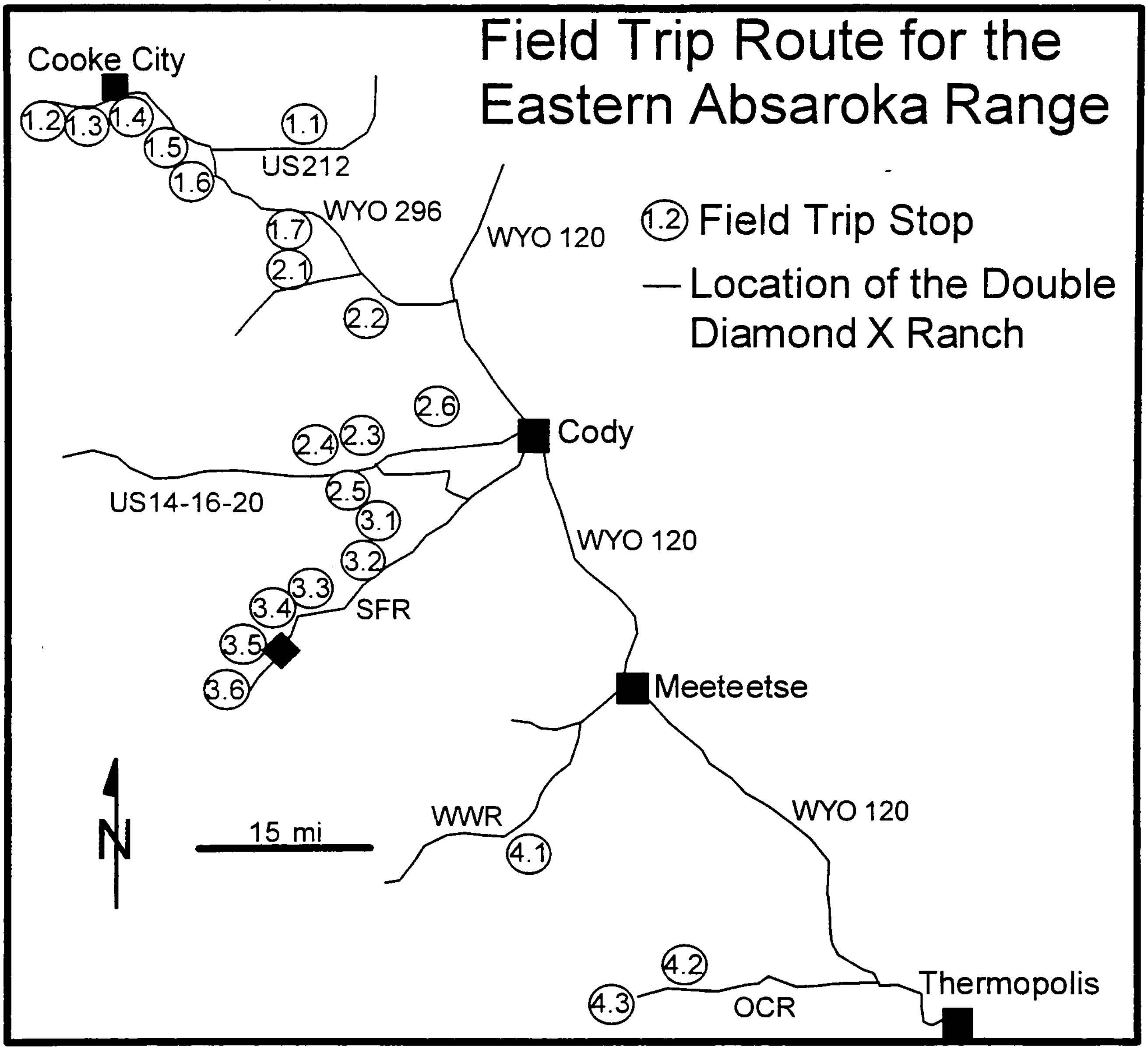

Figure 1. Route map for the 1996 Geological Society of America field trip to the easternAbsaroka Range.

(38 Ma) (Sundell, 1985). Reworked epiclastic volcanic rocks, including volcanic breccias, sandstones, conglomerates, siltstones, and claystones are the predominant rock types. Primary volcanic rocks (lava flows, flow breccias, pyroclastic breccias, and tuffs) increase in abundance near the intrusive centers.

Three groups comprise the AVS: 1) the lower(?) and middle Eocene Washburn Group, 2) the middle Eocene Sunlight Group, 3) and the middle and upper(?) Eocene Thorofare Creek Group (Smedes and Prostka, 1972, Sundell, 1993). Subdivisions of each of these groups will be observed during this trip. The Washburn Group (Wasatchian-Bridgerian in age) includes the Cathedral Cliffs and Lamar River Formations. These units occur primarily in northern part of the Absaroka Range. The Sunlight Group (Bridgerian in age) includes the Wapiti Formation and the Trout Peak Trachyandesite in the north, and the Aycross Formation in the south. The Thorofare Creek Group consists of the Langford, Two Ocean, Wiggins, and Teepee Trail formations. The Langford and Two Ocean formations crop out in the northern Absaroka Range, and the Wiggins and Teepee formations occur through the southerly reaches of the range.

Detached extensional deformation is the dominant structural element of the eastern Absaroka Range. In the northern part of the range, geologic expressions of this deformation - such as the Heart

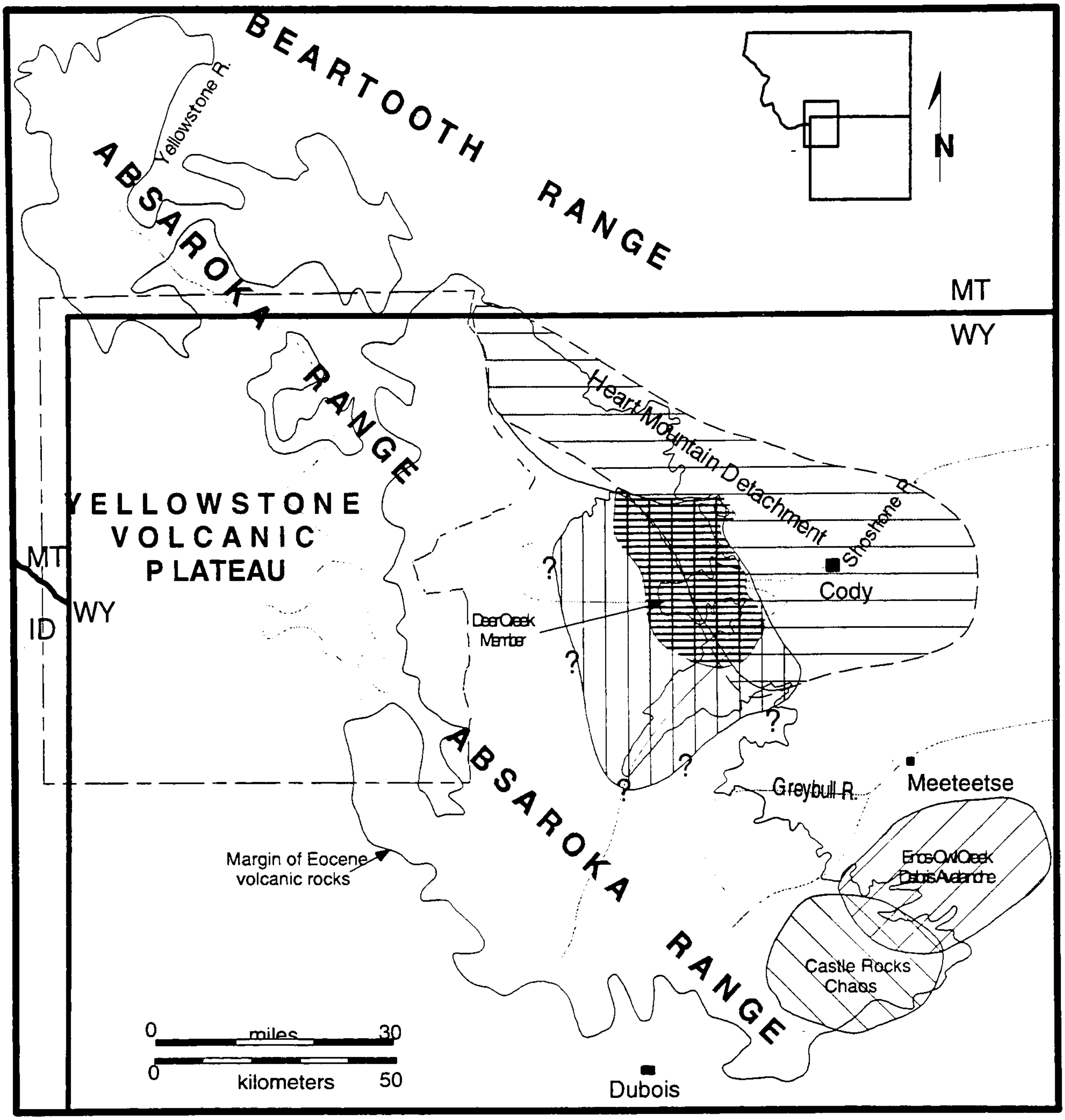

Figure 2. Regional location map showing the distribution of the 1) Heart Mountain Detachment, the Deer Creek Member (both the known - grate pattern and possible extent - vertical), the Castle Rocks Chaos, and the Enos Creek-Owl Creek Debris-avalanche deposit.

Mountain Detachment and associated features - were recognized as structural anomalies in the late 19th century (e. g., Eldridge, 1894), and the ensuing "Heart Mountain problem" has remained unresolved for more than 100 years (e. g., Pierce, 1973; Hauge, 1993; Malone, 1994; Templeton and others, 1995; Beutner and Craven, *In Press*). In the central and southern part of the range, detached extensional deformation was recognized in the middle 20th century (Wilson, 1964, 1975; Rohrer, 1966), but details of its nature and extent were not documented until the late 20th century (e. g., Bown, 1982; Barnes, 1985; Sundell, 1985; Decker, 1990; Malone, 1994, 1995a, 1995b). The dominant lithologies that underwent detached extension in the Absaroka Mountains are volcanic rocks of the AVS (although significant volumes of Paleozoic cratonic sedimentary rocks are involved in Heart Mountain faulting), and an intimate relationship existed between the extrusion/depositon of these volcanic rocks and their detached extensional deformation.

THE HEART MOUNTAIN DETACHMENT

The Heart Mountain detachment is a rootless, low-angle normal fault that accommodated transport of upper-plate rocks for distances of as much as 30 mi (50 km) or more (Figure 3). Transport was largely southeastward, from the northeast flank of the northern Absaroka Mountains, a Laramide volcanic center and basement uplift, toward and into the western margin of the Laramide Bighorn Basin. The detachment is preserved over an area of at least 1300 mi^2 (3400 km^2). It was emplaced in the middle Eocene, during the late stages of the Laramide orogeny. Heart Mountain faulting involved rocks ranging in age from Ordovician to middle Eocene (Figure 4), mostly Paleozoic cratonic strata and andesitic Eocene volcanic rocks. The reader is referred to Pierce (1973) and Hauge (1993) for descriptions of the general features of the Heart Mountain detachment. Other field guides to the area include Tucker (1982) and Hauge (1992).

Based on its relationship to Eocene sedimentary and volcanic rocks, the Heart Mountain allochthon was emplaced during the late stages of the Laramide orogeny. Allochthonous Paleozoic rocks at Heart Mountain and McCulloch Peak overlie nonmarine lower Eocene (Wasatchian) Willwood strata, indicating that emplacement of the allochthon postdated most of the Laramide fill of the Bighorn Basin. Thus, most of the offset across the basement-involved fault zone that defines the boundary between the Bighorn Basin and adjacent uplifts to the west had taken place by the time of Heart Mountain faulting. Wise (1983) has argued that the north-trending portion of this fault zone postdated northwest-trending structures along the Beartooth range front, and he inferred that the northwest-trending boundary between the Absaroka Mountains and the Beartooth Mountains was also probably an earlier Laramide structure. Thus, development of the presently observed basement framework of Laramide structures in the detachment area was essentially complete when Heart Mountain faulting occurred, and little subsequent tectonic deformation has affected the region.

Further constraints on the age of Heart Mountain faulting are provided by relationships west of Buffalo Bill Reservoir, where allochthonous Paleozoic rocks overlie middle Eocene strata (Bridgerian Aycross Formation), indicating emplacement of the allochthonous rocks in this area as middle Eocene or younger (Torres and Gingerich, 1983). A middle Eocene upper age limit for Heart Mountain faulting is also indicated by the Bridgerian age of volcanic rocks overlying the allochthonous Paleozoic rocks at this locality (Torres and Gingerich, 1983). These Bridgerian rocks are assigned to the Wapiti Formation and Trout Peak Trachyandesite (Pierce and Nelson, 1968). The Wapiti Formation and Trout Peak Trachyandesite have been interpreted as postdating Heart Mountain faulting (Pierce, 1987a), which would indicate that faulting was wholly Bridgerian (pre-Wapiti) in age. Alternatively, rocks assigned to the Wapiti Formation have been interpreted as allochthonous (Hauge, 1985), and the Trout Peak Trachyandesite, which locally comprises the hanging wall of the breakaway fault and the Black Mountain fault, has been interpreted as involved in the final phases of Heart Mountain faulting (Hauge, 1990). This alternative interpretation suggests that Heart Mountain faulting was complete slightly later in the Bridgerian (after Trout Peak Trachyandesite time). By either interpretation, Heart Mountain faulting may have been wholly Bridgerian (47.5 to 49.5 Ma; Torres and Gingerich, 1983), though earlier minor movements (Pierce and Nelson, 1973) are not precluded by the data.

Days One and Two (morning) of this field trip provide an introduction to the general features of the Heart Mountain detachment, with emphasis on the relationships between Eocene volcanic rocks and Paleozoic sedimentary rocks above and along the Heart Mountain detachment. The relationship between Eocene volcanic rocks and Heart Mountain faulting is an issue of debate in the current literature (Hauge, 1993; Templeton and others, 1995; Malone, 1995, Beutner and Craven, *In Press*), and very different geologic histories are inferred (Figure 5). The steep-walled glacial valleys of the Clarks Fork of the Yellowstone, its tributaries, and Soda Butte Creek provide excellent roadside views of the detachment and associated features that bear on the debate.

DEER CREEK MEMBER

The Deer Creek Member of the Wapiti Formation consists of blocks (individually as large as several km^2 in area) of vent-medial-facies lava flows, breccias, and sandstones within a thin, heterogeneous matrix of boulder- to sand-sized volcaniclastic material. It is interpreted as the deposit of a large debris avalanche, formed by the collapse of a large stratovolcano within the Absaroka Range during the early middle Eocene. The areal extent and volume of the proximal facies of the Deer Creek Member are ~175 mi^2 (450 km^2) and ~24 mi^3 (100 km^3), respectively. The

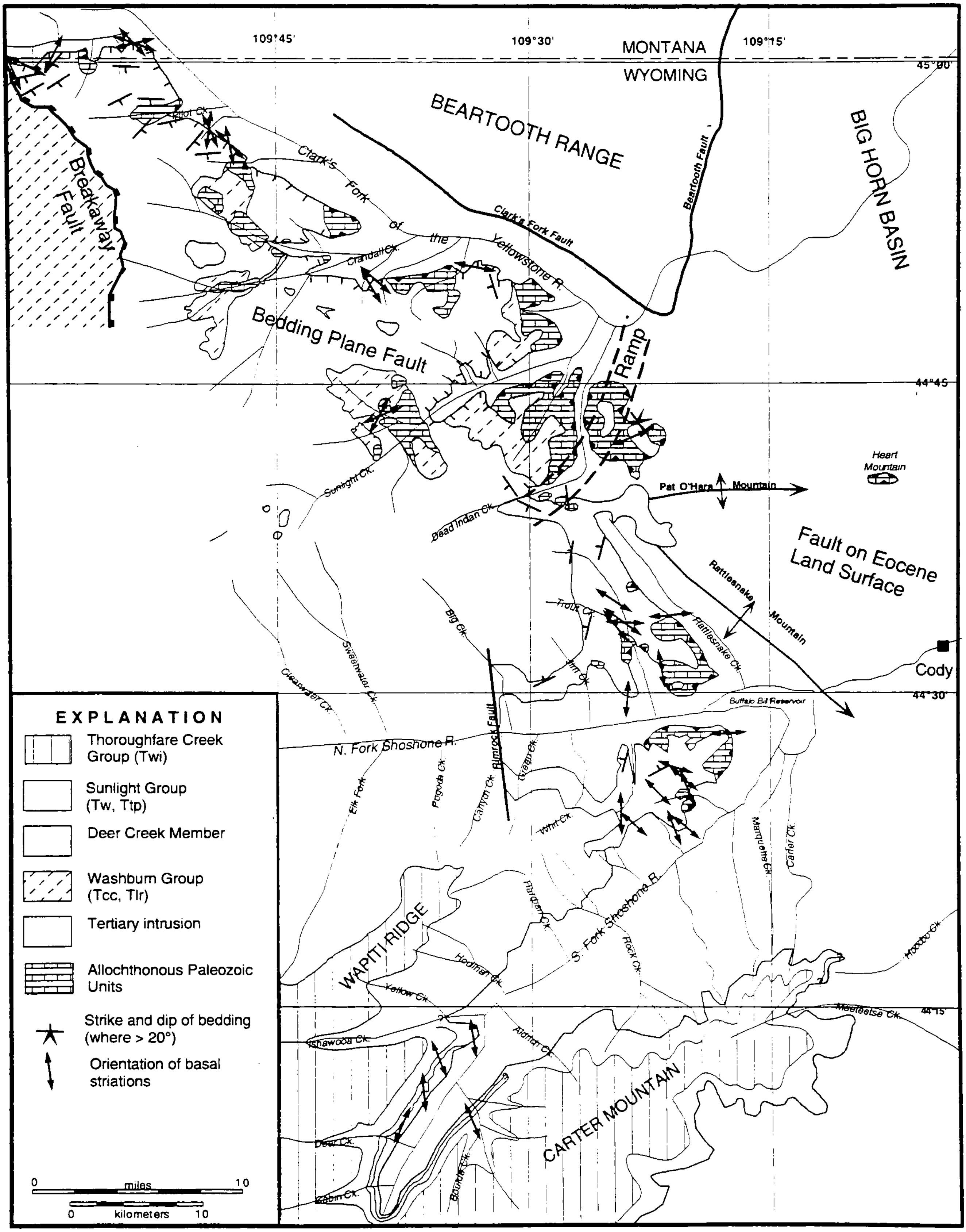

Figure 3. Geologic map of the Heart Mountain Detachment area (Modified from Pierce, 1987a).

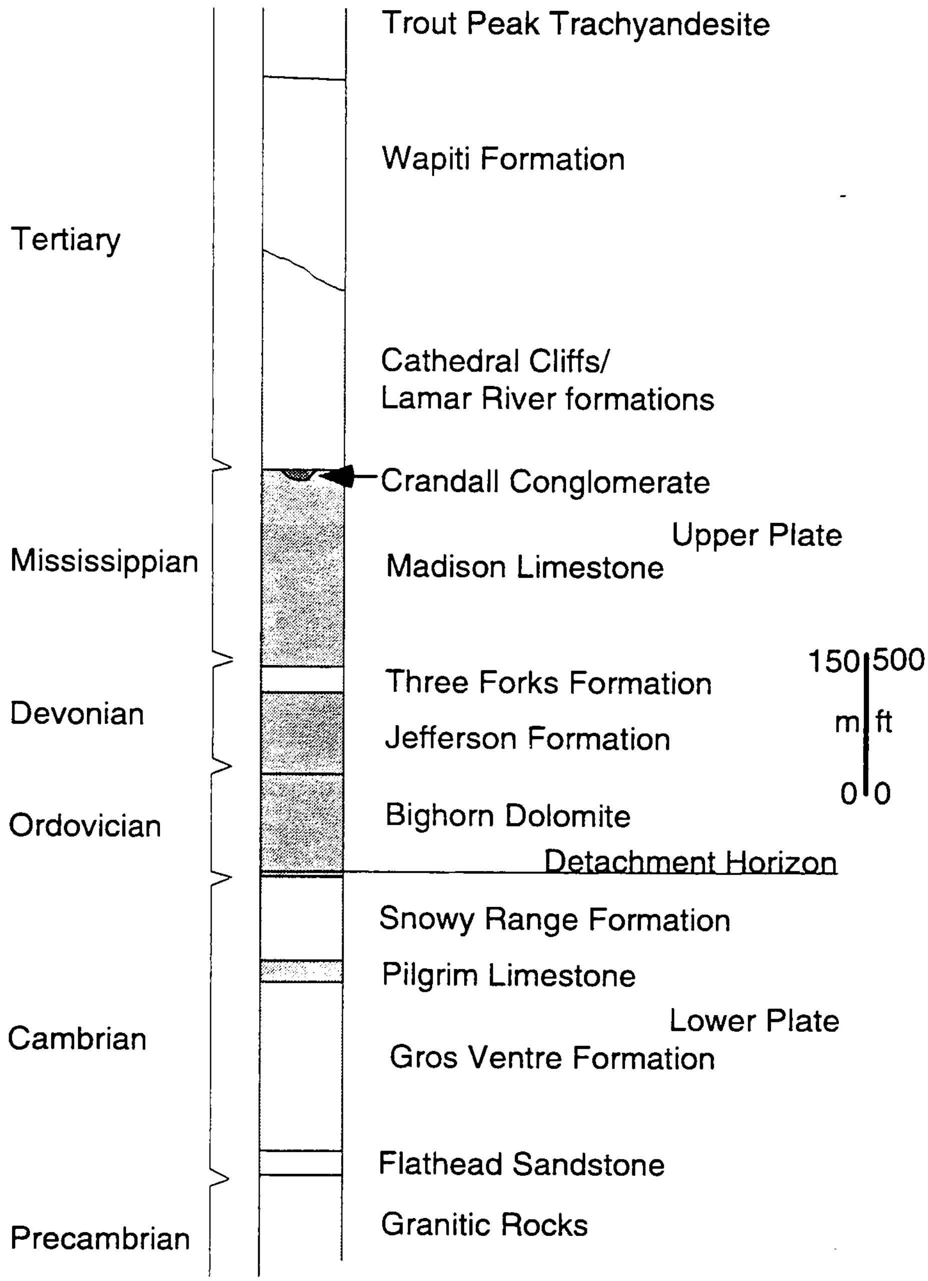

Figure 4. Generalized stratigraphic section showing the formations associated with the Heart Mountain detachment, modified from Pierce (1973). Use of the terms Wapiti Formation, Cathedral Cliffs Formation, and Lamar River Formation in the detachment area has proven problematic (seeHauge, 1985. 1990, 1993). Crandall Conglomerate, of Eocene (?) age (Pierce and Nelson, 1973), overlies units as old as the Snowy Range Formation.

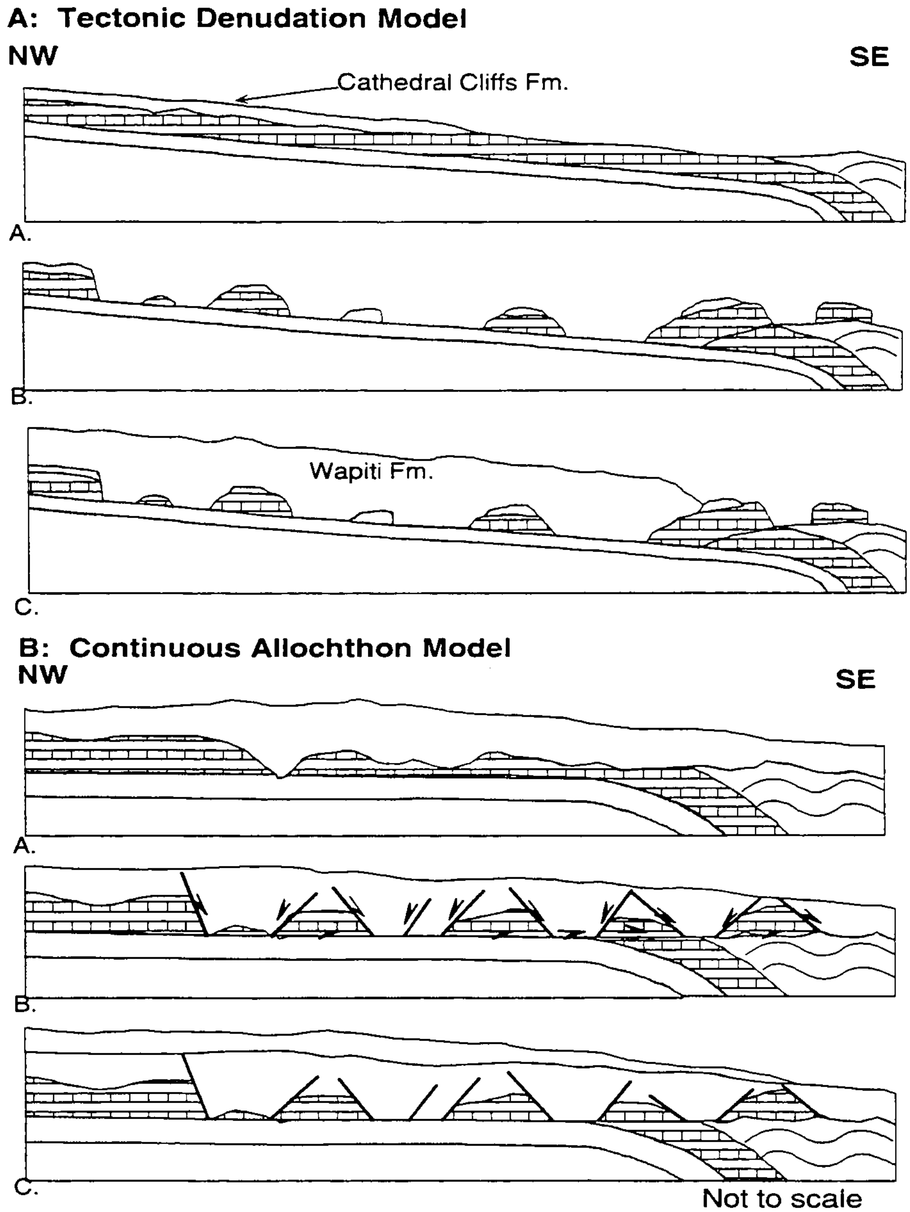

Figure 5. Two models of Heart Mountain faulting.

A: The tectonic denudation model, modified from Pierce (1960). (A) Before faulting occurred, volcanic rocks (Cathedral Cliffs Formation) locally overlay Paleozoic strata. (B) When the detachment formed, Paleozoic strata and overlying volcanic rocks detached along a basal Ordovician bedding plane and wereemplaced at catastrophic rates as numerous detached blocks along the bedding-plane detachment, up atransgressive ramp, and across the Eocene land surface. (C) Immediately after faulting, catastrophic volcanism (Wapiti Formation) blanketed the disrupted terrane.

B: The continuous allochthon model, modified from Hauge (1985). (A) Before faulting occurred, volcanic rocks 0.6 mi (1 km) or more thick overlay deeply eroded Paleozoic strata and younger strata to the southeast. (B) When the detachment formed, Paleozoic strata and volcanic rocks above the detachment underwent lateral translation and extension as a continuous allochthon, and structurally high (largely volcanic) rocks were downfaulted, tilted, and translated. Displacement wasnoncatastrophic [1 cm (0.4 in) per year?] and coeval with volcanism (feeders out of plane of the section). (C) After faulting ceased, volcanism continued.

unit was first described by Malone (1994) and it was later described in detail by Malone (1995a, 1996). The Deer Creek member was assigned to the Wapiti Formation because it is within the type section of that unit as defined by Nelson and Pierce (1968). Further work by Malone (1995b) indicates that a distal facies of the unit also probably occurs throughout the upper South Fork Shoshone River valley (see discussion during Day 3 log).

In its proximal area, the unit extends from the southern end of Sheep Mountain 32 km northward to Dead Indian Creek. The easternmost extent tops Rattlesnake and Pat O'Hara Mountains; to the west, the unit is buried by younger volcanic rocks. A transport distance of 40 km from the center of the inferred source area is indicated. The average thickness of the debris-avalanche deposit is estimated to be ~220 m. Its thickness ranges from zero at its stratigraphic pinch-out to >470 m at the west of Sheep Mountain.

The Deer Creek Member is bounded below by an erosional surface that displays both large- and small-scale paleotopography. Overall, the basal surface slopes an average of 3°-4° to the southeast, with >1000 m of total relief on this surface demonstrated. The top of the unit is an erosional surface as well. Overall, the upper surface is relatively flat and slopes gently 1°-2° to the southeast.

The age of the Deer Creek Member is closely determined. It falls into the same 2 million year window as the emplacement of the Heart Mountain allochthon. Several lines of evidence argue for a rapid, and probably catastrophic emplacement rate:

1) blocks of diverse sizes within a chaotic matrix have been recognized;

2) the presence of clastic dikes within the matrix suggests maintained excess pore-fluid pressures during movement; and

3) the maximum time interval available for the original accumulation of the material involved, avalanche initiation, and avalanche emplacement is about 2 million years. Most of that time was likely used in the accumulation of the material involved, with considerably less time available for initiation and emplacement.

It is likely that the emplacement was dominated by the sliding of large, independent blocks. Friction along the base was at least partially alleviated by high basal pore-fluid pressure within the debris avalanche matrix. These high pore-fluid pressures contributed to the high mobility of the debris avalanche.

Field evidence indicates that the Deer Creek Member was emplaced subsequent to rather than coeval with Heart Mountain faulting. Malone (1994) suggests a modified view of tectonic denudation for the emplacement of the upper plate of the Heart Mountain Detachment. The slide blocks and intervening denuded detachment surface were buried immediately by a very large debris avalanche (Deer Creek Member), rather than by massive outpourings of primary eruptive material. In this view, the lower part of the Wapiti Formation is allochthonous and in depositional contact at the same time, and its interpretation thus depends upon the scale of observation. Future work should address whether or not the Deer Creek Member also occurs in the proximal areas (bedding parallel and break away components) of the Heart Mountain Detachment.

Although an obvious temporal relationship exists for the emplacement of the Deer Creek Member and the Heart Mountain allochthon (both features were emplaced during the same 2 Ma interval during the early middle Eocene), several lines of evidence bear on the question of whether the emplacement of the Deer Creek Member was coincident with or subsequent to the emplacement of the Heart Mountain allochthon. Unfortunately, no direct cross-cutting relationships (straight forward and beyond a reasonable doubt) indicating the relative timing of the emplacement of the two units has been discovered. It is inferred that the emplacement of the Deer Creek Member was subsequent to the emplacement of the Heart Mountain allochthon (Figure 6). The following lines of evidence support this interpretation (Malone, In Preparation for the GSA Bulletin):

1) the Deer Creek Member matrix was nowhere discovered beneath a Paleozoic allochthon;

2) Very little sand- or pebble-sized carbonate rock material was identified within the Deer Creek Member matrix;

3) The trachyandesite dikes that occur within the Deer Creek Member have not been observed to extend into immediately adjacent or subjacent allochthonous upper plate blocks;

4) No normal faults have been observed along the Deer Creek Member-upper plate allochthon contacts; Pierce (1987) describes "burial" relationships of allochthonous Paleozoic rocks by Wapiti Formation rocks throughout the Heart Mountain detachment area; these same "burial" relationships were observed during this investigation but at a larger scale than the descriptions of previous workers; the allochthonous upper plate blocks are buried everywhere by a debris-avalanche deposit rather than by numerous volcanic flows and breccias;

5) Volcanic rocks have never been found south or east of Sheep Mountain or Logan Mountain, indicating that these features served as topographic barriers during emplacement, and transport of the Deer Creek Member was directed west of these topographic barriers;

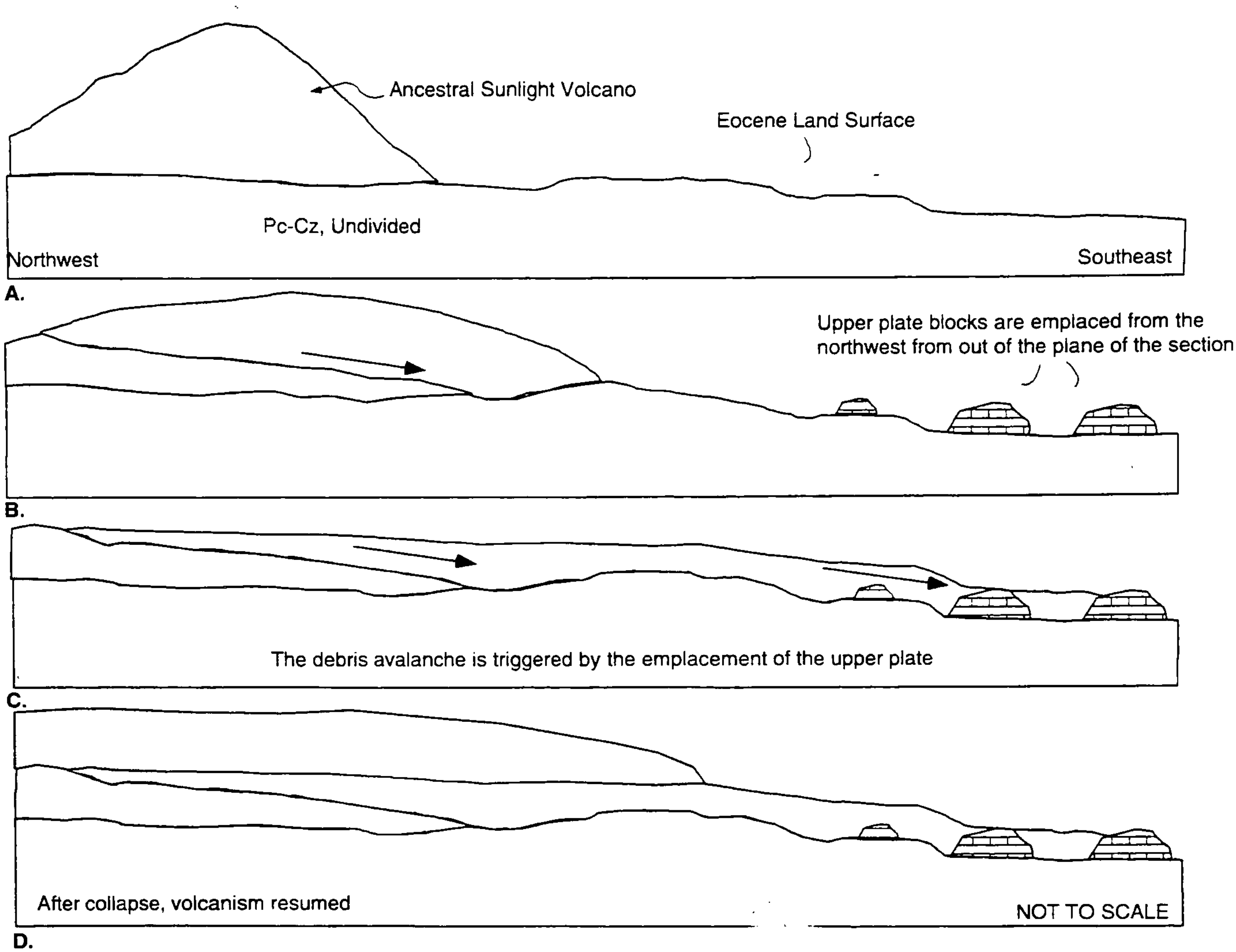

Figure 6. Emplacment model for the Deer Creek Member of the Wapiti Formation (fromMalone, 1994). A: prior to the emplacment of the Deer Creek Member, the Ancestral Sunlight Volcano overlay a deeply eroded terrain on the easter margin of the Absaroka Basin. B: Allochthonous upperplate blocks were emplaced from the northeast on to the Eocene land surface as outlined by Pierce (see Figure 5a). C: immediately following emplacement, the Ancestral Sunlight Volcano collapsed and generated a large debris avalanche (now blocks and matrix of the Deer Creek Member) that buried the Eocene land surface andallochthonous upper plate blocks. D: After collapse, volcanism at the Sunlight Peak vent-complex resumed, resulting in the deposition of the younger Wapiti Formation units.

6) Both the Deer Creek Member and the upper plate allochthons overlie a paleotopographic (erosional) surface with substantial relief;

7) The internal deformation of the Deer Creek Member has a chaotic kinematic pattern and is not consistent with an extensional allochthon;

The interpretation that the Deer Creek Member and the Heart Mountain allochthon were emplaced sequentially does not exclude the possibility that each may have been different stages of collapse of a single large vent-complex. The Heart Mountain allochthon was probably emplaced immediately before the Deer Creek Member, with the intervening time being on the order of minutes or hours. This "immediately following" interpretation satisfies the lack of erosion on the fault plane, a flaw that the previous view of tectonic denudation suffers (Pierce, 1973, 1987). Furthermore, because the emplacement of the Deer Creek Member is inferred to have occurred immediately after emplacement of the Heart Mountain allochthon, the emplacement of the Heart Mountain allochthon may have triggered the stratovolcano collapse that generated the Deer Creek Member. Both features may be part of a retrogressive collapse of the Ancestral Sunlight volcano (Malone, 1994).

CASTLE ROCKS CHAOS

The Castle Rocks Chaos was first recognized by Sundell (1980) and described in detail by Sundell (1985); it was the first gigantic debris-avalanche deposit to be recognized in the pre-Quaternary geologic record. The Castle Rocks Chaos is well exposed in the southeastern Absaroka Range in the valleys of Owl Creek, Cottonwood Creek, and the East Fork of the Wind River. The unit has been mapped throughout a 350 mi^2 (900 km^2) area and involves at least 293 km^3 of rock material. The base of the unit slopes gently to the southeast, and more than 2875 ft (915 m) of total relief on the base is demonstrated. The age of the Castle Rocks Chaos is tightly constrained, and occurs entirely within the Wiggins Formation (Love, 1939), making the unit entirely middle Eocene (Uintan, ~45 Ma) in age. Remnants of the Castle Rocks Chaos occur more than 22 mi (35 km) from the inferred source area.

As with the Deer Creek Member, the source area for the Castle Rocks Chaos is poorly constrained, but is considered to be in the vicinity of the Wood River vent-complex, which was active throughout the deposition of the Wiggins and Teepee Trail formations. The Chaos is thought to have been generated by an edifice collapse of a stratocone in this area, with the resultant mass moving to the south and east along paleodrainages. It is unknown if the emplacement of the Castle Rocks Chaos was accompanied by a volcanic eruption.

Like the Deer Creek Member, the Castle Rocks Chaos is an extremely coarse-grained fragmental deposit comprised of large blocks of volcanic material within a heterogeneous matrix. Blocks are composed dominantly of hornblende andesite porphyry and are as large as 1 km in diameter. In contrast, the blocks of the Deer Creek Member are as large as 12 km across and consist of stratified epiclastic sandstones, breccias, and lesser lava flows. In both units, the block/matrix ratio and overall block size decreases with transport distance.

Sundell (1985) described the emplacement of the Castle Rocks Chaos as a combination landslide-debris flow event. As with the Deer Creek Member, both slide and flow processes were in operation. The dominant emplacement mechanism of the Castle Rocks Chaos is interpreted to have been flow in the distal areas and gravity sliding in its proximal reaches. Flow of the Chaos matrix is inferred to have acted as a fluid medium surrounding the larger blocks, and viscous drag forces exerted by the flowing matrix caused these blocks to be transported.

Although the Castle Rocks Chaos and the Deer Creek Member are as near as 30 mi (48 km) apart and have formed under a similar set of conditions, the two features are clearly distinct in terms of distribution, age, and rock units involved. Sales (1983) postulated that the Castle Rocks Chaos and Heart Mountain detachment (and all intervening rocks as well) were emplaced coevally during the wholesale catastrophic collapse of the entire eastern flank of the Absaroka Volcanic Field during middle Eocene time. Sundell (1985) successfully argued against this interpretation, with stratigraphic refinements - namely the Blue Point Marker.

Sundell (1980) recognized other detached masses in the southern Absaroka Range in the exposure area of the Castle Rocks Chaos and named these masses the allochthonous Wiggins Formation. Where exposed, the allochthonous Wiggins Formation has always been observed beneath the Castle Rocks Chaos. The relationship between the Castle Rocks Chaos and the associated allochthonous Wiggins Formation (the allochthonous Wiggins Formation was renamed detached lower Wiggins in Sundell, 1993) is remarkably similar to the the relationship between the Deer Creek Member and underlying upper plate of the Heart Mountain detachment. The allochthonous Wiggins Formation consists of slightly deformed plates of detached lower Wiggins Formation strata (namely the Sugarloaf tuff beds). Although the allochthonous Wiggins displays little internal deformation, it appears to have been emplaced as numerous independent slide blocks, and is comprised of several different rock units. The emplacement of the allochthonous Wiggins Formation and Castle Rocks Chaos is interpreted to be coeval (Sundell, 1985). This interpretation is based on an identical distribution and kinematic pattern of the two units, i.e., the allochthonous Wiggins Formation has never been recognized without the Castle Rocks Chaos overlying it, and a short span of time separating the two units. It is likely that both the allochthonous Wiggins Formation and Castle Rocks Chaos were emplaced during the same collapse event, with the allochthonous Wiggins Formation, which originally comprised the lower flanks of the edifice, being emplaced first. The emplacement of the allochthonous Wiggins was immediately followed by the emplacement of the Castle Rocks Chaos, which initially comprised the higher areas of the volcanic edifice. This interpretation may be closely analogous to the relationship between the Deer Creek Member and the allochthons of the Heart Mountain Detachment.

ENOS CREEK-OWL CREEK DEBRIS-AVALANCHE DEPOSIT

Allochthons of the Enos Creek-Owl Creek Debris-Avalanche deposit were initially described by Bown (1982a) and were summarized in detail by Bown

(1982b). These rocks were formerly part of the Wood River Detachment Complex (Wilson, 1964; 1975). The unit was originally referred to as the Enos Creek-Owl Creek Detachment (Bown, 1982b), but the name was modified to the Enos Creek-Owl Creek Debris-Avalanche deposit (Bown and Love 1987) based on inferred catastrophic emplacement rates. The unit currently consists of more than 160 remnants (termed klippen by Bown, 1982a) of well-stratified, epiclastic sandstones and breccias of the Teepee Trail Formation (Love, 1939). The remnants occur over an area of 475 mi^2 (1220 km^2)and initially involved a volume of more than 46 mi^3 (187 km^3) of rock material. The east-west width of the remnant field is as much as 25 mi (40 km), and this value is considered the minimum lateral transport distance as the breakaway area has never been recognized.

Individual remnants vary in structural complexity, ranging from undeformed, to intensely folded and faulted, to poorly consolidated masses of disaggregated and brecciated debris. As with the Deer Creek Member, the structural complexity is a function of both the emplacement mechanism and the proximity to source. Block and matrix components, if present, have not yet been defined. The emplacement mechanism has been interpreted as some combination of retrogressive block gliding, gravity sliding, and avalanching, and the unit is considered by Bown and Love (1987) to originally have been a single, intact sheet.

A Quaternary age for the unit has been postulated by Bown (1982b), and the event was possibly triggered by seismic activity associated with the eruption of the 2.0 Ma Huckleberry Ridge Rhyolite at the Yellowstone Caldera. The Quaternary age is tenuous and based primarily on the interpretation that all of the remnants rest upon the same late Tertiary erosional surface.

Sundell (1985) questions the Quaternary age of the Enos Creek-Owl Creek Debris-Avalanche deposit. Most of the large remnants are structurally similar to blocks of the Deer Creek Member deposit and the Castle Rocks Chaos. The principal evidence for a Quaternary age for this unit is the interpretation that the unit everywhere overlies the same high level erosional surface. The erosional surface is in turn interpreted to be Quaternary in age based on the premise that the Big Horn Basin was continuously filled during Eocene to middle Pliocene time. However, this premise has been challenged by the recognition of large paleodrainage systems of late Eocene age that are lower than present drainage systems (Sundell, 1985). It is also possible that the allochthons mapped as part of the Enos Creek-Owl Creek Debris-Avalanche deposit may have been emplaced during three separate events rather than all at once (Sundell, unpublished data). Further work is necessary to resolve these problems.

Remnants of the Enos Creek-Owl Creek Debris-Avalanche deposit occur less than 25 mi (40 km) from the southernmost extent of the Deer Creek Member. Although both units occur at the base of the volcanic succession in their respective areas, it is unlikely that both units were part of the same event.

DAY 1: PROXIMAL AREAS OF THE HEART MOUNTAIN DETACHMENT

INTRODUCTION

Day One begins in Cody, Wyoming. Proceed north from Cody on Highway WYO 120 for 17 miles, then northwest on WYO 296 for 47 miles, then northeast 7 miles on US 212 to the first stop, at the Pilot-Index Overlook on Highway US 212. From there, proceed south and west along Highway US 212 as far west as the Soda Butte Creek picnic area in Yellowstone National Park; then backtrack east along US 212, go southeast along WY 296, and south on WYO 120 to Cody. Ten USGS geological quadrangle maps (see references) cover much of the detachment area and provide a useful reference. Mileages in the road log are approximate. Interval mileage is indented and itallicized

MILEAGE DESCRIPTION

0.0	Cody, Wyoming. Proceed north on WYO 120.
17.0	
17.0	Junction with WYO 296 (Chief Joseph Scenic Highway). Proceed west on WYO 296.
47.0	
64.0	Junction with US 212. Proceed east on US 212.
7.0	
71.0	Turn left into parking lot of Pilot-Index overlook.

STOP 1-1: OVERVIEW OF THE BEDDING PARALLEL (PLANE) COMPONENT OF THE HEART MOUNTAIN DETACHMENT.

This vantage point provides a panoramic view of much of the detachment area. Here we will discuss general features associated with the detachment, which can be summarized as follows (condensed from Hauge, 1993).

The Heart Mountain fault can be subdivided into three components (Figure 3). The first is the breakaway fault, which forms the western boundary of the detachment area and is located near the eastern boundary of Yellowstone National Park. The breakaway fault extends upward from the detachment and ends upward within Eocene volcanic rock, demonstrating that the Heart Mountain detachment is a rootless structure. The breakaway fault is the subject of Stop 1-2 of this field trip, and it is described in detail in the text for that stop.

The second component of the Heart Mountain detachment, which is visible from our present vantage point and is the subject of Stops 1-3 through 1-7 and stop 2-1 of this field trip, is the portion of the basal detachment that parallels bedding in the homoclinal Paleozoic section of the northeastern Absaroka Mountains. The bedding-parallel component of the detachment lies along a footwall bedding plane located about 6 ft (2 m) above the base of the Ordovician section. This stratigraphic position is remarkable from the perspective of rock mechanics, as discussed by Pierce (1973) and Hauge (1993), because the detachment lies along a bedding plane within "strong" dolomite rather than within the thick, "weak" Cambrian shales that underlie it by only a few meters. The detachment does not cut below this stratigraphic horizon (see Hauge, 1983, for minor exceptions to this), and upper-plate units are no older than Ordovician, indicating that the detachment is rootless. The bedding-parallel component of the detachment is bounded to the west by the breakaway, to the northeast by erosion, to the southeast by a footwall ramp, and to the southwest, speculatively, by the Black Mountain fault. The bedding-parallel component of the detachment presently dips an average of 3 to 5° to the south-southwest (Pierce, 1985).

The autochthon in the area of the bedding-parallel component of the detachment exhibits little deformation either related to or subsequent to faulting. In contrast, the allochthon was strongly extended during Heart Mountain faulting. Allochthonous Paleozoic rocks include 1300 ft (400 m) thick untilted sections with little section missing along the detachment; sections tilted up to 30° or more with strata truncating downward at the detachment; and local exposures where Ordovician and Devonian strata are omitted along the detachment, without significant angular discordance between allochthon and autochthon. Volcanic rocks lie between and upon the masses of allochthonous Paleozoic strata, but disagreements exist as to the involvement of these rocks in faulting. Some workers have argued that in most areas the contact between volcanic rocks and the detachment is a "half fault" (Pierce, 1980), the volcanic rocks having been deposited upon the detachment (Pierce, 1987a), or emplaced upon it as a debris-avalanche (Malone, 1994), after it had been tectonically denuded. Others inferred the contact is in many areas (Prostka, 1978) or everywhere tectonic (Hauge, 1982, 1985, 1990; Templeton and others, 1995; Beutner and Craven, *In Press*). This, along with the issue of emplacement rate of of rocks overlying the detachment, is the essence of the current debate about the nature of Heart Mountain faulting.

The third component of the detachment, which is the subject of Day 2, is a footwall ramp that, in general terms, cuts up section to the southeast, from the bedding-parallel component of the detachment near the base of the Ordovician up to the middle Eocene. Whereas the footwall of the bedding-parallel component of the detachment is a structurally simple homocline, the footwall of the detachment ramp is the structurally complex transition from the Absaroka Mountains to the Bighorn Basin, and the configuration of the detachment ramp reflects this footwall structure. Pierce (1957, 1960a, 1985) subdivided the detachment ramp into (1) a "shear thrust" (1957) or "transgressive fault" (1960a), where it climbs abruptly in present-day elevation to the top of Dead Indian Hill, and (2) an "erosion thrust" (1957; after Hewett, 1920) or "fault on former land surface" (1960a) from Dead Indian Hill eastward. The 1-to-3-mi (3-to-5-km) wide "transgressive fault" presently dips about 10° westward; the "fault on former land surface" as much as 30 mi (48 km) wide, presently dips an average of 1 degree (and locally up to 4 degrees) eastward.

Return to vehicles. Turn around, retrace route west along US 212.

7.0

78.0 Junction with WYO 296. Continue west along US 212.

14.2

92.2=0.0 Cooke City, Montana. Continue west along US 212.

3.0

3.0 Silver Gate, Montana.

1.1

4.1 Northeast Entrance to Yellowstone National Park.

1.2

5.3 Turn left into Soda Butte Creek picnic area

0.3

5.6 Park vehicles at last picnic area. Walk 50m up hill to east of easternmost picnic area for a view of the breakaway fault.

STOP 1-2: VIEW OF THE BREAKAWAY FAULT.

From our vantage point the breakaway fault, which forms the western boundary of the detachment area, is exposed across 2100 ft (650 m) of relief (Figure 7). At this locality it dips 70° to the east and cuts steeply down through Eocene volcanic rocks and

Mississippian, Devonian, and Ordovician sedimentary rocks in its footwall, ending near the base of the Ordovician at the detachment. The hanging wall consists of Eocene volcanic rocks. In other areas, due to limited vertical exposure and difficult access, the trace and cross-sectional geometry of the breakaway are less well known. Pierce (1960a, 1980, 1987b) interpreted the breakaway as having been tectonically denuded and interpreted the volcanic rocks overlying it as Wapiti Formation that was deposited on the denuded surface of the breakaway. He described the breakaway fault as a

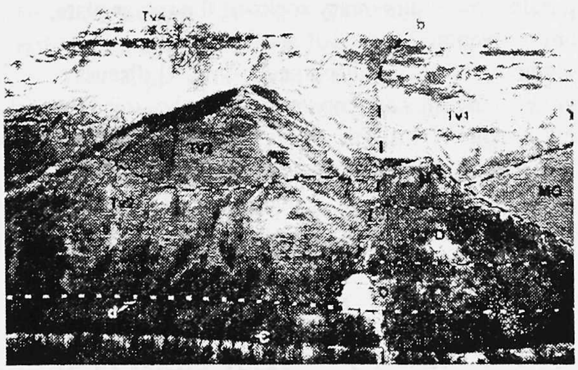

Figure 7. View to south of breakaway of the Heart Mountain detachment. Viewpoint is about 1 mi (1.6 km) north of and 2000 ft (600 m) higher than the northeast entrance to Yellowstone National Park. The breakaway (b) dips steeply (about 70°) eastward and truncates downward at the detachment (d). Rocks visible in the footwall of the detachment are Pilgrim Limestone (cliff near base of photo), about 80 ft (25 m) thick, and overlying shale and limestone of the Snowy Range Formation, about 240 ft (75 m) thick. About 6 ft (2 m) of Ordovician Bighorn Dolomite, not shown, immediately underlies the detachment. The footwall of the breakaway consists of about 300 ft (90 m) of Bighorn Dolomite (O), 300 ft (90 m) of Devonian Three Forks and Jefferson formations (D), 240 ft (75 m) of Mississippian Madison Limestone (M), and about 1300 ft (400 m) of Eocene volcanic rocks, partly snow-covered, of the Lamar River and Cathedral Cliffs formations (Tv1). The hanging wall consists of a basal 600 ft (180 m) of Eocene volcanic rocks (Tv2) variably assigned to the Lamar River Formation (Prostka and others, 1975), Lamar River and Cathedral Cliffs formations (Pierce and others, 1973), and the Wapiti Formation (Pierce, 1980), overlain by about 1500 ft (450 m) of Eocene volcanic rocks (Tv3) assigned to the Wapiti Formation by these workers. The topographically highest volcanic rocks (Tv4), with apparent subhorizontal bedding, are Wapiti Formation and Trout Peak Trachyandesite (Pierce and others, 1973; Prostka and others, 1975); these strata overlap the breakaway out of view to the southeast (Figure 6 of Pierce, 1980) and therefore postdate Heart Mountain faulting. Note apparent southwestward dips of Tv2, evident above Tv2 annotation. Disagreement exists as to whether the upper-plate rocks were tectonically emplaced (Hauge, 1990) or were deposited on the detachment and breakaway (Pierce, 1987a) (see text).

"half-fault," for only one side [the footwall side] is a fault surface; the other side [the hanging-wall side] is a surface of deposition (Pierce, 1980, p. 276). In contrast, the hanging-wall volcanic rocks have been interpreted as in part (Prostka and others, 1975) or wholly (Hauge, 1982, 1985, 1990) allochthonous.

Turn vehicles around and retrace route to Silver Gate.
0.3
5.9 Turn right from picnic area onto US 212.
1.2
7.1 Exit Yellowstone National Park.
1.1
8.2 Pull off road to left (north) near gas station.

STOP 1-3: VIEW OF THE DETACHMENT FROM SILVER GATE, MONTANA (OPTIONAL).

For a distance of 5 km (3 mi) east of the breakaway exposure just described, the detachment is commonly well exposed and is typically overlain by volcanic rocks with a preserved vertical thickness on the order of 500 m. Locally, masses of allochthonous Mississippian and Devonian rocks up to a few tens of meters thick overlie the detachment and underlie the volcanic rocks. The exposure visible from this stop, 2 km east of the breakaway and south of the town of Silver Gate, Montana, was singled out in several publications (Pierce, 1979, 1980, 1987a, 1987b; Pierce and Nelson, 1986) as a showcase example of relationships demonstrating that volcanic rocks lie *in situ* on the detachment (as well as on allochthonous carbonate rocks) and, hence, that tectonic denudation of the detachment is proven. However, according to Hauge (1990), the relationships cited by these authors are also compatible with tectonic emplacement of the volcanic rocks, and other relationships in this area require that at least the basal 200 m of volcanic rocks in this area are allochthonous. The critical features described at this locality are:

1) the contact between the volcanic rocks and the allochthonous Paleozoic rocks, which is interpreted as depositional (Pierce, 1987a) and as a faulted unconformity (Hauge, 1990);

2) faults within the upper-plate Paleozoic rocks, which either do not (Pierce, 1987a, 1987b) or do (Hauge, 1990)

offset the contact between the Paleozoic upper plate and the overlying volcanic rocks;
3) faults within volcanic rocks in the area immediately west-southwest of the exposure of allochthonous Paleozoic rocks, recognized by Hauge (1990); volcanic flow units dipping 30-45° southeast, recognized by Pierce and others (1973) and Hauge (1990);
4) volcanic rocks underlain along the detachment by striated microbreccia a few hundred meters farther west, recognized by Hauge (1985);
5) clastic dikes of fault breccia, interpreted as having been emplaced after Heart Mountain faulting (Pierce, 1987a) or during faulting (Hauge, 1990).

This locality is recommended for detailed examination, with the conflicting interpretations of the relationships in mind. Access, described by Pierce (1987b), is via a climb beginning on the south side of Silver Gate.

Proceed east along US 212.

3.0	
11.2	Cooke City
0.7	
11.9	Park at junction of US 212 and forest service road to Daisy Pass. Walk across US 212 to south side of road.

STOP 1-4: VIEW OF REPUBLIC MOUNTAIN.

This stop affords a view of allochthonous Paleozoic rocks at Republic Mountain and the volcanic rocks that overlie them (Figure 8). The Paleozoic rocks

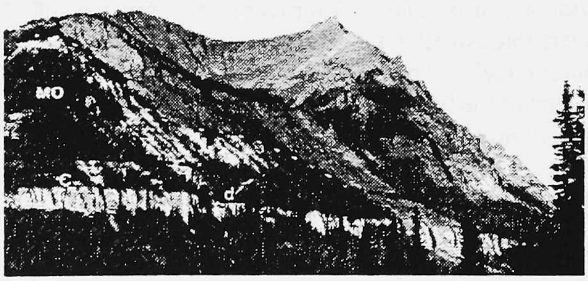

Figure 8. View to west of Republic Mountain, from U. S. Route 212 east of Cooke City, Montana. The allochthon consists of Ordovician, Devonian, and Mississippian sedimentary rocks (MO) overlain by Eocene volcanic rocks (Tv). Note southward dip of volcanic strata, which are Lamar River and Cathedral Cliffs formations of Pierce and others (1973) and Wapiti Formation of Pierce (1978). Detachment (d) parallels footwall strata (C). Prominent cliff in the footwall is Pilgrim Limestone. Total relief shown is about 2500 ft (750 m).

are Ordovician, Devonian, and Mississippian strata that are internally faulted and tilted to small angular discordance with the detachment (Elliott, 1979). These rocks were first recognized as allochthonous by Pierce (1960a). The volcanic rocks are dominantly massive andesitic volcaniclastic rocks, in which primary stratification is difficult to discern. These volcanic rocks have been variably mapped as Wapiti Formation that postdates Heart Mountain faulting (Pierce, 1978) and as Lamar River and Cathedral Cliffs formations (Nelson and others, 1980; Elliott, 1979). Hauge (1983) described a fault contact between the Eocene volcanic and Paleozoic sedimentary rocks of the upper plate. From our vantage point 30° southward dips of the volcanic rocks can be discerned. We will discuss whether these dips are consistent with the volcanic rocks being *in situ* Wapiti Formation (Wapiti vents are south of this area), or are better explained as tectonic dips.

Proceed eastward on US 212.

6.9	
18.8	Park at entrance to Fox Creek campground.

STOP 1-5: VIEW TO WEST OF PILOT PEAK, INDEX PEAK, AND THE UNDERLYING DETACHMENT (OPTIONAL).

This vantage point provides a distant view of a superb exposure of the detachment, Cambrian rocks of its footwall (intruded at this locality by an Eocene latite porphyry sill - Pierce and others, 1973), and volcanic rocks immediately overlying the detachment. The detachment follows a bedding horizon 2 m above the Cambrian-Ordovician contact (Pierce, 1968), and from this view the parallelism of the detachment and footwall strata is evident. The 13-16° southwest dip of the detachment in this area (Pierce and others, 1973) is atypical of most of the bedding-parallel component of the detachment, dips of less than 1°, to the south or southwest, being more typical. The volcanic rocks overlying the exposure of the detachment visible from this stop are interpreted as Wapiti Formation on most published maps (Pierce and others, 1973; Pierce, 1978; Nelson and others, 1980). The Wapiti Formation is defined as postdating Heart Mountain faulting (Nelson and Pierce, 1968). Pierce (1968) interpreted the detachment at this locality as having been tectonically denuded and interpreted the volcanic rocks to be in depositional contact with the detachment. Based on observations of the volcanic rocks along the detachment immediately to the north and south of this exposure (the exposure seen from this stop is too steep to be safely accessible), Hauge (1983, 1985) interpreted these volcanic rocks as allochthonous.

From this perspective the characteristic sharp, planar nature of the detachment is particularly impressive. This and other exposures of the detachment show no direct evidence of subaerial exposure; nowhere is it incised by erosion that postdated faulting but predated the overlying volcanic rocks, and nowhere is it overlain by fluvial deposits. These relationships led Pierce (1957, 1973) to infer that the period of time after tectonic denudation of the detachment and deposition of the Wapiti volcanics was very brief. These relationships were cited by Hauge (1985) as supportive of the argument that tectonic denudation did not occur, and the Heart Mountain upper plate was a continuous allochthon rather than numerous detached blocks.

Upper plate rocks that underlie Pilot Peak include Paleozoic rocks visible in the drainages of Fox and Pilot Creeks, volcanic rocks variably mapped as Wapiti Formation (*in situ*) or Lamar River and Cathedral Cliffs Formations (allochthonous), and Trout Peak Trachyandesite (Pierce and others, 1973). A fault contact between upper-plate Paleozoic and Eocene rocks well exposed in the drainage of Pilot Creek is described in Hauge (1985).

Proceed eastward on US 212.
3.4
22.2 Turn right into Crazy Creek Campground. Park in the loop at the end of the campground road and walk a few meters south.

STOP 1-6: VIEW OF ROCKS OVERLYING THE HEART MOUNTAIN DETACHMENT, FROM PILOT AND INDEX PEAKS TO THE NORTHWEST, TO THE ONEMILE CREEK AREA TO THE SOUTHEAST.

Several features and localities of interest are visible from this vantage point. The first (N60-75W) is many of the features seen at Stop 1-5, seen here in a more distant view. The second is a view up Pilot Creek (N75-80W). On the north side of Pilot Creek, a major unconformity, best viewed in early morning sunlight, is visible (Figure 9). This unconformity separates undeformed, subhorizontal volcanic strata from underlying volcanic rocks that, from this view, show no apparent stratification. The volcanic rocks beneath this unconformity, which are mapped as Lamar River and Cathedral Cliffs Formations by Pierce and others (1973) and as mostly Wapiti Formation by Pierce (1978), are characterized by dips as steep as 36° (Pierce and others, 1973; Hauge, 1983), and are variably interpreted as *in situ* (Pierce and others, 1973: Pierce and Nelson's interpretation) or allochtonous (Pierce and others, 1973; Prostka's interpretation; Hauge, 1983). The volcanic rocks above this unconformity postdate faulting. From the perspective of the continuous allochthon model of Heart Mountain faulting, this view suggests the thickness of the continuous allochthon that was preserved when faulting ceased and the allochthon was overlain by younger volcanic rocks. This preserved thickness, which is less than the thickness of the active allochthon by some unknown amount, is roughly 600 m (2000 ft).

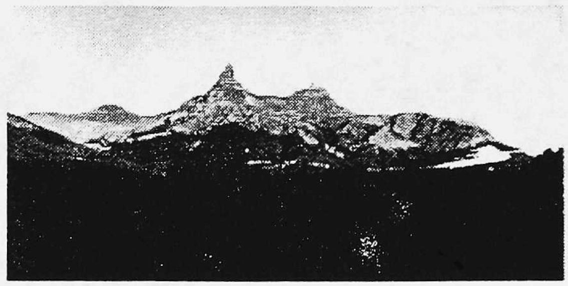

Figure 9. View to west of Pilot Peak, Index Peak, and surrounding area.

Also visible from this stop are Jim Smith Peak (S70W) and the spot where Jim Smith Creek crosses the detachment (S75W). Like the area south of Silver Gate viewed at Stop 1-3, the excellent detachment exposure at Jim Smith Creek has been a focus of disagreement in the literature. Pierce (1966a) and Pierce and others (1991) interpreted the volcanic rocks overlying the detachment on the east wall of Jim Smith Creek as in depositional contact with the detachment, and Pierce and others (1991) interpreted the volcanic rocks on the west wall of the creek as allochthonous (see also Pierce and others, 1973). Hauge (1985) interpreted the volcanic rocks immediately above the detachment on both sides of the creek as allochthonous. Hauge's (1985) interpretation was based on mesoscopic features (Figures 10 and 11) supplemented by thin-section examination. Pierce and others (1991) provide descriptions of thin sections of the detachment horizon that they interpret as incompatible with tectonic emplacement of the volcanic rocks. I (Hauge) view the features described by Pierce and others as compatible with tectonic emplacement of the volcanic rocks. This locality is accessible via a Forest Service road: turn south off of US 212 just west of Crazy Creek, cross the bridge over the Clarks Fork, drive past the B Four Ranch 1.5 mi (this is a Forest Service road; public access is permitted), and hike south about 1 mile. Time and weather permitting, we will visit this locality today.

Throughout the area of exposure of the bedding-plane component of the detachment, numerous normal faults, most probably with small offset, are present in volcanic rocks overlying the detachment. Hauge (1983, 1985) measured the orientations of these faults and their slickenlines, and Buetner and Craven (1996) interpret a vertical contraction axis and a

~horizontal extension axis oriented N59W-S59E. This is compatible with the interpretation that they were emplaced as part of a continuous expanding allochthon (Beutner and Craven, 1996).

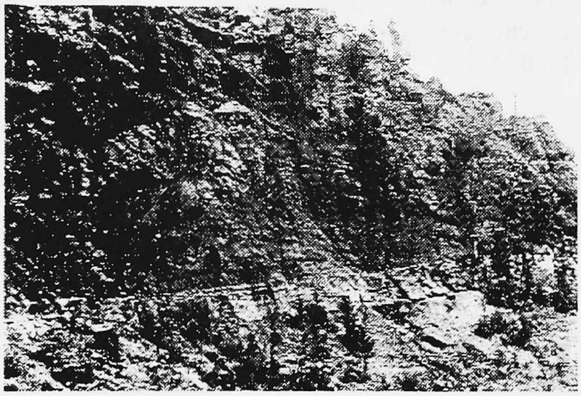

Figure 10. Volcanic rocks along the bedding-plane detachment immediately west of Jim Smith Creek, showing basal shatter zone up to 10 m thick, steeply dipping truncated strata (right of center), and internal faulting of volcanic rocks, The detachment and underlying autochthonous strata are also visible. View is westward. From Hauge, 1985.

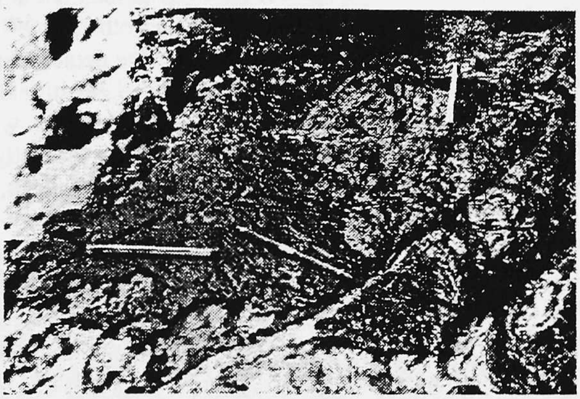

Figure 11. View obliquely downward of detachment at Jim Smith Creek. Pen and pencil in lower half of photo lie parallel to two sets of striae on fault gouge that veneers the autochthon. Pencil at upper right parallels striae on sheared surface ~10 cm above, and subparallel to, the detachment.

	Proceed eastward on US 212.
2.8	
25.0=0.0	Turn right onto WY 296.
7.8	
7.8	Cross Crandall Creek
1.8	
9.6	Pull off highway to the right into Scenic View pull-out.

STOP 1-7: CATHEDRAL CLIFFS AREA.

Several features of interest are visible in this panoramic view. Hunter Peak (elev. 9034 ft), 3 mi (5 km) to the northwest (N60W), is underlain by allochthonous Paleozoic rocks that traveled perhaps 6 to 15 km across the detachment. South of Hunter Peak are the drainage of Crandall Creek (bearing due W to S80W) and the high country of Hurricane Mesa (elev. 11,064 ft) 7 mi (11 km) due west. Windy Mountain (elev. 10,262) is the highest peak visible to the south. Both Hurricane Mesa and Windy Mountain are underlain by Absaroka volcanic and intrusive rocks. The carbonate exposure immediately to the south is Cathedral Cliffs. At this stop we will discuss the relationship between Absaroka volcanic rocks and upper-plate Paleozoic rocks in two areas: at the west end of Cathedral Cliffs (near Corral Creek), and along the length of the face of Cathedral Cliffs.

Corral Creek. The first topic of this stop is the poorly exposed contact between the upper-plate Paleozoic sedimentary rocks and Eocene volcanic rocks that abut them to the west. This area is best viewed from the road that leads to the K-Z Ranch from the west; we will stop at this better vantage point if time permits. The volcanic rocks of this area were mapped as Wapiti Formation, in depositional contact with the detachment and Paleozoic upper plate, by Pierce and Nelson (1971) and Pierce (1978). There has been disagreement in the literature, however, as to whether volcanic rocks in this area were deposited on the detachment and against the allochthonous Paleozoic rocks (Pierce, 1987a) or were tectonically emplaced (Hauge, 1985, 1990) (Figure 12).

Figure 12. Photograph of relationships along the detachment west of Cathedral Cliffs.

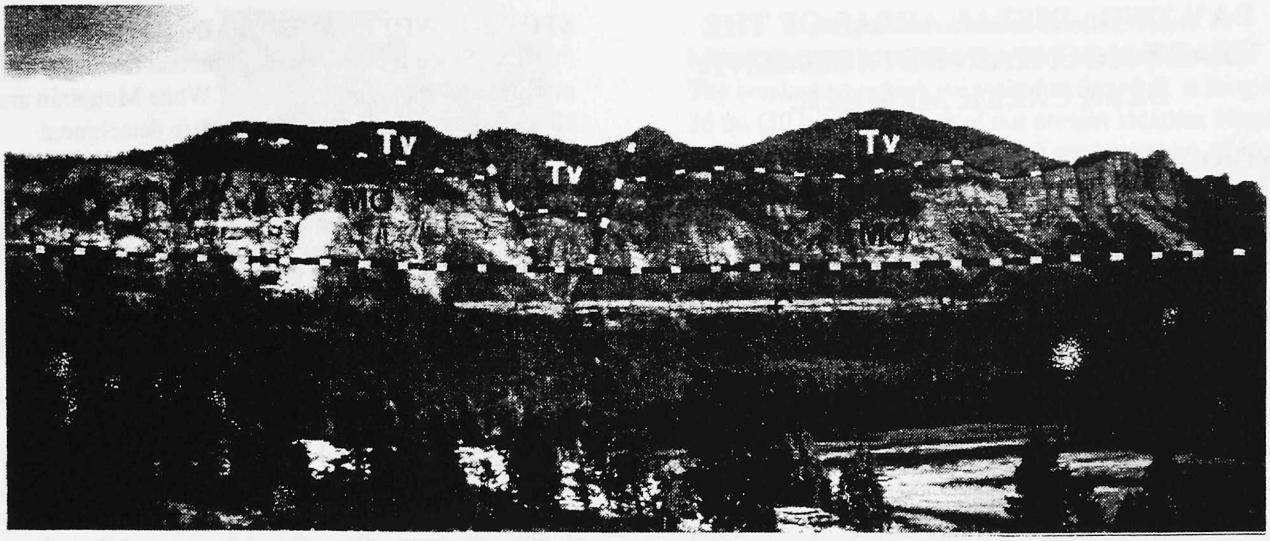

Figure 13. View of Cathedral Cliffs. Dash-C is Heart Mountain footwall rocks, mostly Cambrian; MO is allochthonous Ordovician-Mississippian cratonic strata; Tv is Tertiary volcanic rocks; d is Heart Mountain detachment.

Cathedral Cliffs. Cathedral Cliffs (Figure 13) is a 3 mi (5 km) wide exposure of allochthonous Paleozoic sedimentary rocks, with Eocene volcanic rocks along much of the skyline. The Paleozoic rocks appear remarkably little deformed, despite a probable transport distance of 3 to 9 mi (5 to 15 km). In most of this exposure, the base of the allochthonous Paleozoic rocks consists of shattered Bighorn Dolomite, with little section omitted along the detachment. The allochthonous Paleozoic rocks are bounded to the westby volcanic rocks, as was described immediately above. They are bounded to the east by volcanic rocks that were mapped by Pierce and Nelson (1971) and Pierce (1978) as Wapiti Formation (in depositional contact with the detachment) and were interpreted by Hauge (1983, 1985) as allochthonous.

An asymmetric graben, about 200 m (600 ft) wide at its exposed base, is visible near the center of the exposure of allochthonous Paleozoic rocks (Pierce and Nelson, 1971). Hauge (1990) interpreted this small graben as representative of an early phase of extension of the allochthon. He envisioned downfaulting of Paleozoic and Eocene rocks within grabens such as these, with continued extension leading to the downfaulting of broad expanses of Eocene volcanic rocks to the detachment horizon, such as are seen east and west of Cathedral Cliffs (Hauge, 1990). The involvement of volcanic rocks in the formation of the small graben visible at this stop is indicated by the fault contacts between Eocene and Paleozoic rocks (Pierce and Nelson, 1971; Hauge, 1983) and within volcanic rocks (Hauge, 1983) at this locality.

From this perspective, the volcanic rocks on the skyline seem to overlie the allochthonous Paleozoic rocks. Instead, the volcanic rocks are in fault contact with the Paleozoic rocks across a steeply south-dipping fault. From this vantage, this south-dipping contact can be seen best in the area of the graben and, farther west, where Paleozoic rocks form the highest cliffs.

Numerous Eocene latitic to basaltic dikes intrude the upper plate rocks (both Paleozoic and Eocene) at this and numerous other localities. These dikes, which die out downward at or within a few m of detachment, are restricted to the upper plate. Although many hundreds have been mapped within the allochthon (e. g., Pierce and Nelson, 1971; Nelson and others, 1980), only a few have been identified within the autochthon (Hauge, 1983, 1985). Pierce (1987a) interpreted these dikes as laterally intruded and younger than Heart Mountain faulting. Voight (1974a, b) and Erskine and Kudo (1991) interpreted these dikes as allochthonous, truncated at their bases by Heart Mountain faulting. Hauge (1985, 1990) inferred that they were intruded laterally and are allochthonous, and further he argued that the volume they occupy was created by extension of the allochthon that was accommodated by slip along the detachment. Intrusion of many of these dikes occurred during the final stages of Heart Mountain faulting (Hauge, 1990).

Proceed eastward on WYO 296.

24.2

33.8 Dead Indian Pass.

14.3

48.1 Junction with WYO 120. Turn right (south) toward Cody.

17.0

65.1 Cody, Wyoming. End of Day One.

DAY TWO: DISTAL AREAS OF THE HEART MOUNTAIN DETACHMENT; DEER CREEK MEMBER.

INTRODUCTION

Day Two begins at the Double Diamond X Ranch. Proceed northeast on the South Fork Road to Cody, Wyoming. The caravan will proceed north from Cody on Highway WYO 120 for 17 miles, then northwest on WYO 296 for 24 miles to the Sunlight Basin Road. We will proceed westward into Sunlight Basin to the exposure of the Heart Mountain detachment at the base of White Mountain. We will then retrace our route to Cody, stopping at Dead Indian Pass to view and discuss the footwall-ramp component ("transgressive phase" and "fault-on-former-land-surface phase" of Pierce, 1973) of the Heart Mountain detachment, including Heart Mountain itself. From Cody, we will proceed westward into the Shoshone River drainage, where we will further discuss the "fault on former land surface," emphasizing discussion of the proximal facies of the Deer Creek Member of the Wapiti Formation. Day Two ends at the Double Diamond X ranch for dinner and lodging. USGS geological quadrangle maps (see references) cover much of the area and provide a useful reference. Mileages in the road log are approximate. See the 1990 Wyoming Geological Association Guidebook for a detailed road log.

MILEAGE DESCRIPTION

0.0	Cody, Wyoming. Proceed north on WYO 120.
17.0	
17.0	Junction with WYO 296 (Chief Joseph Scenic Highway). Proceed west on WYO 296.
24.0	
41.0=0.0	Junction with Sunlight Basin Road. Go west on Sunlight Basin Road. Note: mileages within Sunlight Basin are taken from topographic maps and have not been field checked.
5.3	
	Turn right into Wyoming Game and Fish public access fishing area. Proceed ENE approx. 1.4 miles, crossing Sunlight Creek and passing through barbed-wire gates, to the base of White Mountain.
1.4	
6.7	White Mountain

STOP 2-1: WHITE MOUNTAIN

Since the first recognition that the white marbles and monzonitic stock of White Mountain are allochthonous on the Heart Mountain detachment (Nelson, 1969), this excellent exposure of the Heart Mountain detachment has received considerable attention, particularly in light of the possible role of a sill of volcanic gas in triggering and sustaining movement on the detachment (e. g., Hughes 1970a, 1970b, 1970c, 1973; Pierce and Nelson, 1970; Nelson and others, 1972, 1973; Beutner and Craven, 1996).

Beutner and Craven (1996) describe the following mesoscopic features at White Mountain: 1) footwall exposures of several meters of Cambrian Snowy Range Formation, overlain depositionally by 2 meters of Bighorn Dolomite; 2) a sharp planar contact between the footwall and 2 to 3.5 m of well-indurated, massive fault microbreccia; 3) an irregular contact between the microbreccia and the overlying dolomitic marble of the allochthon; 4) an abrupt downward decrease in metamorphism at the base of the allochthon, and a less dramatic decrease at the base of the microbreccia; 5) cataclasite dikes up to 1 m thick within the allochthon. According to Beutner and Craven, thin sections of the detachment microbreccia reveal volcanic glass grains with primary shapes and accreted grains equivalent to accretionary and armored lapilli. They interpret the fault-rock constituents and fabric to imply that injection of volcanic glass along the detachment horizon triggered detachment and catastrophic emplacement of the Heart Mountain allochthon. They also interpret a chain of intrusive plugs that trends NW from White Mountain as a kinematic indicator, akin to a hot-spot trace in the moving allochthon. These observations and inferences, in conjunction with their inferences regarding the kinematics of emplacement of the volcanic rocks associated with Heart Mountain faulting, led them to conclude that Heart Mountain faulting comprised catastrophic emplacement of a continuous allochthon.

An excellent exposure of upper-plate volcanic rocks on the east side of Painter Gulch (Figure 14), 3 mi (5 km) west of White Mountain, is easily accessible via dirt roads shown on 15° topographic quadrangle maps. Pierce (1965b, 1978) and Pierce and Nelson (1971) interpreted these volcanic rocks as younger than Heart Mountain faulting, but Hauge (1983, 1985) and Pierce (1985) interpreted them as allochthonous. Hauge (1985) described a normal fault within the volcanic rocks that is exposed across 200m of topographic relief. This is one of the best accessible exposures of a fault within volcanic rocks in the upper plate.

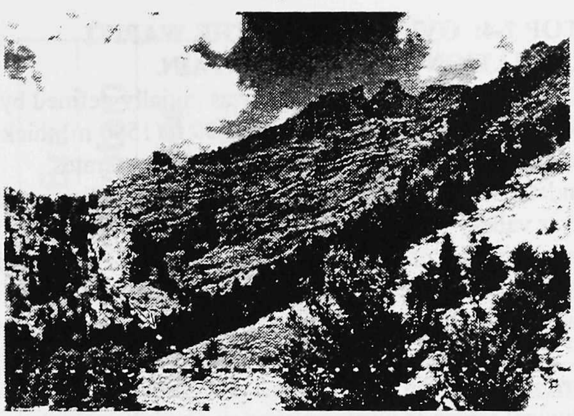

Figure 14. View to northeast of part of the east side of Painter Gulch. Volcanic strata (Tv) are tilted toward the listric fault and downfaulted to the detachment horizon (d), with complete mismatch of preserved section across the fault zone. Volcanic rocks are variably ascribed to the Wapiti Formation (Pierce, 1978), Lamar River Formation (Prostka, 1978), and Cathedral Cliffs Formation (Pierce, 1987a).

Retrace route through Sunlight Basin to WYO 296; turn right onto 296 and proceed eastward up the switchbacks to Dead Indian Pass.

0.0 White Mountain.
6.7
6.7 Junction with WYO 296 (Chief Joseph Scenic Highway).
Proceed east on WYO 296.
10.0
16.7 Pull off Wyoming Highway 296 to right (west) side of highway at the overlook at Dead Indian Pass.

STOP 2-2: VIEW TO WEST FROM DEAD INDIAN PASS; DISCUSSION OF DETACHMENT RAMP.

Dead Indian Pass provides a spectacular view of the Beartooth Plateau to the north, the Clarks Fork fault that bounds its southern flank in this area, and the Absaroka Mountains to the west and southwest. The prominent valley immediately to the west in the Absaroka Mountains is Sunlight Basin, visited at Stop 2-1; the distinctive peak at N80W along the north side of Sunlight Basin is White Mountain. The bedding-parallel component of the Heart Mountain detachment underlies much of the country to the west, where Eocene volcanic rocks overlie Paleozoic strata. Our discussion will focus on the transition from the bedding-parallel component of the Heart Mountain detachment to its transgressive ramp component, which is visible from this vantage point near the foot of Dead Indian Hill. The detachment ramp is described in the text of Stop 1-1.

A perspective on the scale of the Heart Mountain detachment can be appreciated at this stop. The breakaway, which we visited at Stop 1-2, is roughly 30 mi (50 km) northwest of our present location, Heart Mountain is about 15 mi (25 km) east-southeast of our present location, and McCulloch Peak, the most distal klippe of the allochthon, is 30 mi (50 km) to the east-southeast. The Paleozoic strata of Heart Mountain and McCulloch Peak are thought to have originated above the bedding-plane component of the detachment, requiring a minimum displacement of 30 mi (50 km) along the detachment (Pierce, 1957). This displacement magnitude is not representative of the entire allochthon; displacements as small as a few kilometers are suggested for allochthonous Paleozoic rocks near the breakaway. Given the remarkable scale and rootless nature of the Heart Mountain detachment, it remains a most enigmatic feature, despite attention in the literature that spans a century (Hauge, 1993). Whether some form of the tectonic denudation model, the continuous allochthon model, or some as yet unformulated model will best explain Heart Mountain faulting, it is clear at present that the enigma is far from resolved.

Proceed east on WYO 296
14.0
30.7 Junction with WYO 120.
Proceed south on WYO 120.
17.0
47.7=0.0 Junction of WYO 120 with US14-16-20 (Sheridan Rd.) in Cody, Wyoming. Turn right and follow US14-16-20 westward, through the Rattlesnake/Cedar Mountain anticline, past Buffalo Bill Dam, toward Yellowstone National Park.
6.0
6.0 Buffalo Bill Dam.
10.0
16.0 Pull off onto north side of highway for view of the east side of the Trout Creek valley.

STOP 2.3: VIEW OF EAST SIDE OF TROUT CREEK VALLEY

This locality is a spectacular exposure of extensional, domino-style faulting and tilting of Paleozoic strata and overlying subparallel Absaroka volcanic rocks (Figure 15). The volcanic rocks were mapped as Wapiti Formation by Pierce and Nelson (1968, 1969) and as undifferentiated Lamar River and Cathedral Cliffs Formations by Prostka (1978) and Nelson and others (1980) Malone (1994) assigns these rocks to the Deer Creek Member of the Wapiti Formation. Pierce and Nelson (1968) and Hauge (1983, 1990) interpret the Heart Mountain detachment to underlie this exposure at shallow depth. Hauge (1983, 1990) describes normal faults that juxtapose Absaroka volcanic rocks against Paleozoic sedimentary rocks, and presumably sole into the detachment. These relationships support the interpretation that Absaroka volcanic rocks and underlying Paleozoic strata underwent simultaneous extension and translation above the Heart Mountain detachment.

To the north, on the west side of Trout Creek, the Wapiti Formation (Deer Creek Member of Malone, 1996) overlies the Cretaceous Cody Shale. Further to the west, sandstones and variegated shales of the Eocene

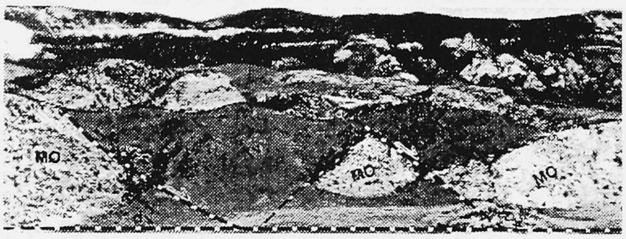

Figure 15. Tilted fault blocks on the east side of Trout Creek, illustrating domino-style extension of the Heart Mountain allochthon.

Willwood Formation, as much as 1000 ft in thickness, unconformably overlie the Cretaceous Strata. Pierce and Nelson (1968) map a normal fault with a throw of about 500 ft along the contact of these units. Malone (1996) maps this contact as a moderately inclined paleotopographic surface at the base of the Deer Creek Member. Several 100 m in diameter blocks of Paleozoic limestone and dolomite, presumably derived from the upper plate allochthons, occur along this contact.

Few large upper plate allochthons of the Heart Mountain Detachment occur west of this paleotopographic barrier. The presence of paleotopographic features such as this support the interpretation that the distal allochthons of the Heart Mountain Detachment overrode a land surface with substantial relief during emplacement.

16.0 Return to vehicles, Continue west on US14-16-20.
1.5
17.5 Turn right (north) on Jim Creek Road. Proceed northward to the driveway of the Four Bear Ranch.
2.019.5 Park at the end of the public road for an overview to the north of the stratigraphy of the Wapiti Formation at Jim Mountain.

STOP 2-4: OVERVIEW OF THE WAPITI FORMATION AT JIM MOUNTAIN.

The Wapiti Formation was initially defined by Pierce and Nelson (1968) as the 5000 ft (1500 m) thick exposures of dark-colored breccias, conglomerates, sandstones, and lava flows-in the North Fork Shoshone River valley. These rocks were previously included in the upper parts of the Early Basic Breccia of Hague and others (1899). The Wapiti Formation is overlain by massive lava flows of the Trout Peak Trachyandesite.

Throughout the deposition of the Wapiti Formation and the Trout Peak Trachyandesite, the principal center of intrusive/extrusive activity was the Sunlight Peak vent-complex (Pierce and Nelson, 1968), as indicated by the distribution of vent-facies rocks and the presence of a spectacular radial dike swarm. No Early Middle Eocene volcanic vents have been described south of the Sunlight Peak area. To the south and east, basin conditions existed then, and a thick sequence of medial-distal-facies volcanic rocks accumulated.

Malone (1996) subdivided the Wapiti Formation into several formal and informal lithostratigraphic units (Figure 16). Several of these units were defined previously and used by earlier workers in laterally adjacent regions. All of these units are time transgressive (with the exception of the Deer Creek Member, which is considered to be isochronous), and recognition is based on rock type, color, and overall texture.

The basal unit of the Wapiti Formation at this locality is the Deer Creek Member. The Deer Creek Member consists here of several blocks (>500 m in diameter) of medial-proximal facies sandstone, breccia, and conglomerate. Strata within these blocks range from steeply inclined to subhorizontal. Several smaller blocks of Madison Limestone occur at various structural positions between the volcanic blocks (Figure 17).

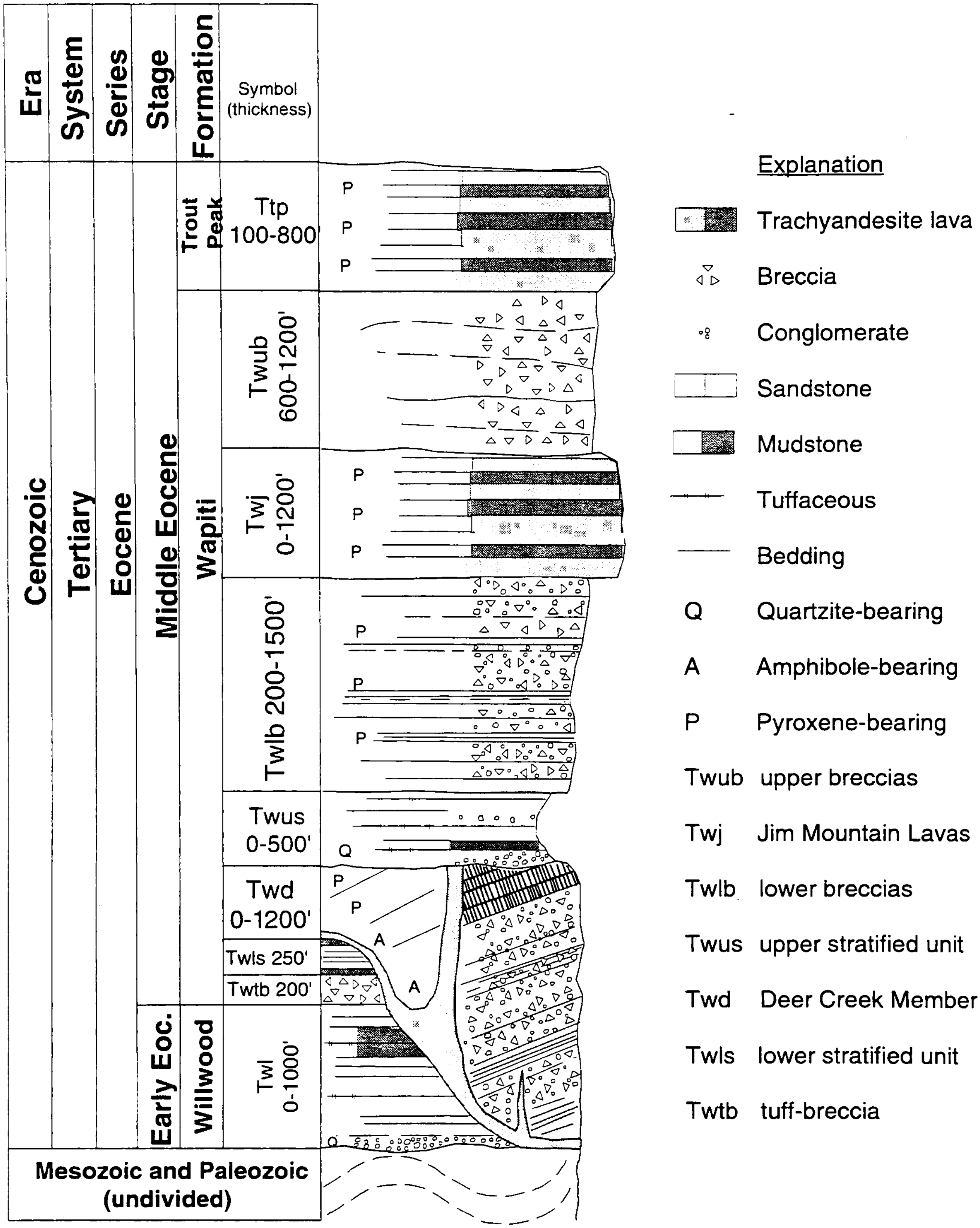

Figure 16. Composite stratigraphic column of Eocene rocks exposed in the lower North Fork Shoshone River Valley (from Malone, 1995).

Figure 17. Chaotic deformation within the Deer Creek Member of the Wapiti Formation. Photograph of the complex internal structure of the Deer Creek Member between Jim and Dunn Creeks. View to the northwest. The debris-avalanche matrix occurs at the base of the unit (Twdm). Several debris-avalanche blocks of different attitudes are separated by dismembered block material (matrix?). Several small (< 50 m in diameter) "floating" blocks of Madison Limestone occur within these zones.

The Deer Creek Member is overlain by a 0-500 ft succession of light-colored, distal-facies, epiclastic rocks (upper stratified member of Malone, 1996) The upper stratified member is very similar to the lower stratified member of the Wapiti Formation that occurs throughout the upper South Fork Shoshone River valley. Many of the conglomerates at the base of the upper stratified member bear quartzite clasts which range from pebble- to cobble-size, and which are typically well-rounded. The provenance of the quartzite clasts is likely the Proterozoic Belt Supergroup strata of the Laramide-age Targhee uplift in Idaho.

The upper stratified member is overlain by a 800+ ft succession of dark-colored, medial-proximal-facies breccias, conglomerates, and sandstones. This succession has been informally named the lower breccias member (Malone, 1996). The lower breccias member is wedge-shaped and thins gradually to the south. Several thin yellow and green tuff beds occur sporadically throughout the unit, recording intermittent explosive eruptions from a distant, and probably northerly source.

Medial-proximal-facies breccias occur throughout the North Fork Shoshone Valley west of the Wapiti area. Further work is necessary to determine the stratigraphic relations between these two areas.

The Jim Mountain Member overlies the lower breccias member and was formally named by Nelson and Pierce (1968) to include the >1000 ft thick succession of trachyandesite lavas within the Wapiti Formation exposed in the steep upper slopes of Jim Mountain. The massive lava flows are in marked contrast with the overlying and underlying breccia units. Individual flows range in thickness from 30-200 ft (10-60 m).

The Jim Mountain Member gradually pinches out to the west in the upper North Fork Shoshone River valley. Where absent, the position occupied by the Jim Mountain Member is marked by an unconformity (Nelson and others, 1980). This unconformity is a relatively persistent marker horizon, and allows recognition of the dominantly proximal-facies upper breccias member above from the medial-facies lower breccias member below.

Malone (1996) defined the upper breccias member of the Wapiti Formation as the dark-colored, massive, vent- and proximal- facies epiclastic and pyroclastic breccias that lie above the Jim Mountain Member and below the Trout Peak Trachyandesite.

Time permitting, we will proceed to the Jim Creek Trail Head and hike to the base of the exposure for a closer inspection of this locality.

Turn caravan around and proceed back down the Jim Creek Road to the junction with US 14-16-20. Numerous outcrops of light gray debris-avalanche matrix occur on either side of the road.

2.0

21.5 Junction with US 14-16-20. Turn right (west). Proceed west to the bridge over the Shoshone River.

0.5

22.0 Turn left (sharp) on to gravel road and proceed east. The grassy foothills to the east are underlain by the Willwood Formation. The bedrock in this area is largely overlain by Quaternary landslide deposits and colluvium.

3.2

25.2 Turn right on the Breteche Creek road. This is a private road. Permission must be secured from Mr. Bo Polk before entering. We will make several short overview stops along this road. Time permitting, we will make a short traverse to the base of a debris avalanche block to observe the contact with the underlying matrix.

3.0

28.2 End of the Breteche Creek Road.

STOP 2-5: BRETECHE CREEK AREA.

In the Breteche Creek area, the Deer Creek Member is poorly exposed and probably consists of a number of smaller blocks whose margins are poorly defined. In many cases, bedding within the blocks is difficult to discern. Smaller blocks, <150 m in diameter, exhibit a wider variety of bedding orientations, a result of the breaking up of larger blocks and greater relative movement between blocks during transport.

A striking feature of the Deer Creek Member of this area is the presence of fragments (as much as 150 m in diameter) of older units suspended at structurally high positions within the unit (Figure 18). Most fragments

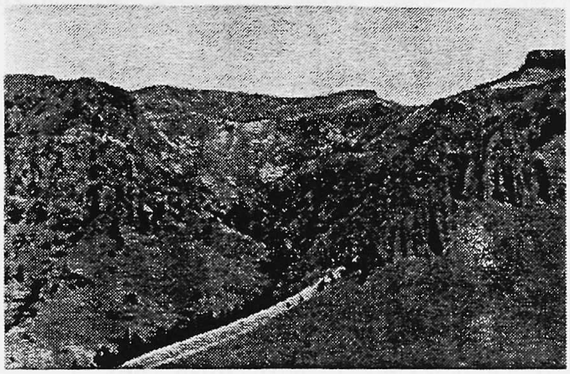

Figure 18. Fragment of Willwood Formation sandstone and mudstone east of Breteche Creek (from Malone, 1996) View to the east. This block is more than 600 ft (190 m) in diameter and occurs about 400 ft (125 m) above the base of the Deer Creek Member. The existence of Willwood Formation blocks within the Deer Creek Member is enigmatic. These blocks were probably entrained from topographic irregularities along the Eocene land surface during emplacement of the Deer Creek Member.

are of the Mississippian Madison Formation, and they were probably derived from the tops and sides of allochthonous upper remnants of the Heart Mountain fault during the emplacement of the debris avalanche. Other fragments are of the lower Eocene Willwood Formation. The origin of the Willwood Formation fragments is less straightforward. Two possibilities exist that could account for these fragments (1) during generation of the debris avalanche, a sector of the volcanic edifice, as well as some of the subvolcanic basement could have been mobilized; and (2) the Willwood Formation fragments could have been entrained from the land surface during emplacement. The former explanation is preferred because it is difficult to visualize the debris avalanche entraining large fragments composed dominantly of incompetent mudstone and having these fragments remain coherent during continued transport.

Turn caravan around and proceed southward to the ranch road entrance.

3.0

31.2 Junction with gravel road. Turn right (east). Proceed east. To the south is the Sheep Mountain allochthon of the Heart Mountain Detachment.

3.4

34.6 Junction with N-S road at west end of Buffalo Bill State Park. Turn right (north).

0.2

34.8 Cross Shoshone River.

0.4

35.2 Junction with US 14-16-20. Turn right (east).

4.2

39.4 Junction of US 14-16-20 with the Mooncrest Ranch road. Turn left (north) on Mooncrest Ranch road. This road runs north for twelve miles along Rattlesnake Creek. This road is a private road. Permission must be granted by Mr. Dick Geving, ranch foreman. Proceed northward. Rattlesnake Mountain is to the east; Logan Mountain is the west.

6.8

46.2 Junction with Logan Mountain Road. Turn left (west). Follow the road to where the gravel ends (approximately 2.5 miles).

STOP 2-6: OVERVIEW OF THE DEER CREEK MEMBER AND HEART MOUNTAIN DETACHMENT FROM THE TOP OF LOGAN MOUNTAIN.

This stop provides an excellent vantage of northernmost (closest to source) mapped extent of the Deer Creek Member. The divide between the Clarks Fork and Shoshone River drainage is the ridge to the north. To the east is the Rattlesnake Mountain anticline. In the lower elevations to the north and west is the Deer Creek Member. The high peaks to the west are Trout and Dead Indian peaks.

Deer Creek Member blocks are commonly elongate or lenticular in shape and they make up about 80-90% of the total volume and area of the Deer Creek Member. The largest block identified thus far is about 7.5 mi (12 km) long and 3 mi (5 km) wide (Figure 19). It occupies most of the area between Rattlesnake and Trout creeks (lower elevations to the west). Blocks decrease in size and increase in number and structural complexity to the southeast. The rock type, facies, and depositional environments of the individual units within blocks are similar to other vent-medial- facies units exposed throughout the northeastern Absaroka Range.

Key marker beds within blocks have not been identified, but a crude coarsening upward stratigraphy has been recognized in some of the larger blocks with vent-facies rocks increasing in abundance toward the tops. The basal parts of blocks are composed primarily of well-stratified, medial-facies epiclastic breccias and sandstones. These units are overlain by massive laharic breccias, flow breccias and trachyandesite lava flows. This coarsening upward relationship is indicative of the pre-collapse stratigraphic configuration of the volcanic edifice, and it reflects a rather mature stage of development. The proportion of vent-facies rocks within blocks is higher in this area and they are the dominant

Figure 19. View to the north of the large backward rotated block along Trout Creek. The stratification within this block dips about 20-30° to the northwest. The thicker layers at the top of the block, where stratification is more apparent, are mostly trachyandesite lava flows. The lower units are mostly breccias and sandstones, and they reflect an internal coarsening upward stratigraphy within individual blocks.

rocks exposed between Robber's Roost and Rattlesnake creeks. This prevalence of vent-facies rocks indicates a proximity to the source area.

Throughout this area, the interior structures of individual blocks are relatively simple with only a slight backward tilt toward the inferred source area. Minor local changes in attitude within the larger blocks are due either to local variations in initial dip or to broad folds and unmappable faults. Bedding within blocks becomes highly deformed toward the base and lateral margins, with folds, faults, and fractures common.

Some of these larger blocks are intruded by swarms of trachyandesite dikes, most of which trend roughly north-south. These dikes are typically perpendicular to bedding. Some dikes are truncated along bedding-parallel shear planes, and all are truncated along block-matrix contacts. This relation indicates that the intrusion of the dike swarm almost surely predates the emplacement of the debris avalanche.

In this area, both the upper plate allochthons and the Deer Creek Member occur within a broad N-S trending paleovalley. At the time of emplacement, Rattlesnake Mountain stood as a prominent topographic barrier to the dispersal of the allochthons. Exposures of the Deer Creek Member do not occur east of this locality.

Time permitting, the contact between the Logan Mountain Block and the Deer Creek Member can be examined in detail. Turn caravan around and proceed back to US 14-16-20. Return to the Double Diamond X Ranch via Cody and the South Fork Road.

DAY 3: DEER CREEK MEMBER OF THE WAPITI FORMATION.

INTRODUCTION

Day 3, like Day 2 begins at the Double Diamond X Ranch. We will spend today observing the volcanic stratigraphy and detached extensional structures in the South Fork Shoshone River valley. The morning stops will include overviews and detailed examinations of the proximal facies of the Deer Creek Member in the Sheep Mountain area. The afternoon stops will focus on the stratigraphy of the upper South Fork Shoshone River valley and the distal facies of the Deer Creek Member. The mileage between stops is approximate.

MILEAGE DESCRIPTION

MILEAGE	DESCRIPTION
0.0	Double Diamond X Ranch on the South Fork Road.
3.5	
3.5	Bridge over the South Fork Shoshone River.
3.3	
6.8	TE Ranch Road
4.4	
11.2	Bridge over Rock Creek
4.7	
15.9	Carter Mountain Road
2.2	
18.1	Park at sign on the north side of the highway that discusses the origin of Castle Rock. This is not the same Castle Rock that we will visit on Day 4 in the North Fork Owl Creek drainage

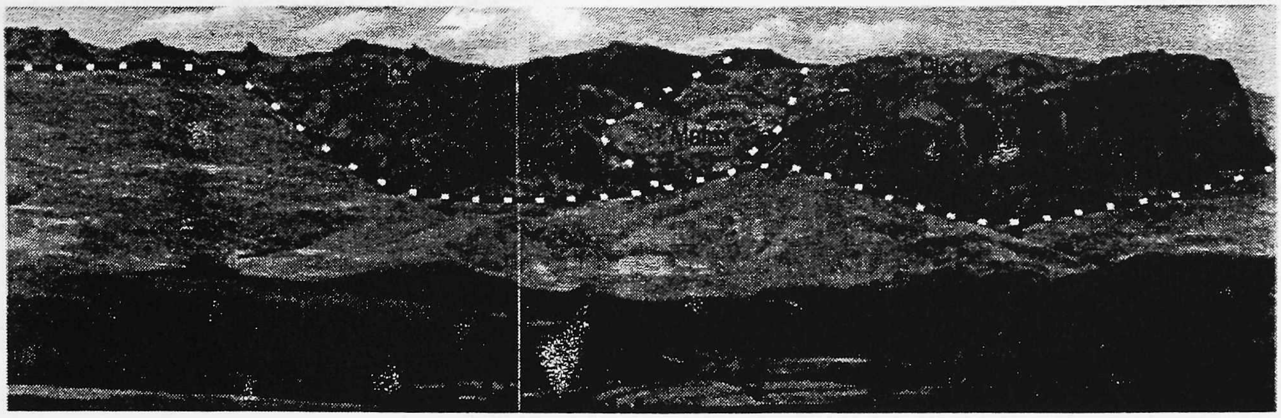

Figure 20. Panaramic view to the north of the type area of the Deer Creek Member of the Wapiti Formation from the South Fork Shoshone River Valley, about 3 km away (from Malone, 1995). The light-colored, grassy foothills are underlain by the Willwood Formation (Twl) and Cody Shale (Kc). The heavy dashed line is the early middle Eocene land surface with more than 1000 ft (321 m) of relief. In this scene, two blocks (>1 km in diameter) are visible (Twdb). The block to the right (east) consists of about 800 ft ofinterbedded breccias, sandstones, and conglomerates, and dips about 25° to the north. The two blocks are bounded by a poorly exposed, lighter-colored interval of matrix. Matrix (Twdm) also occurs beneath each block but is too thin to be resolved from this distance.

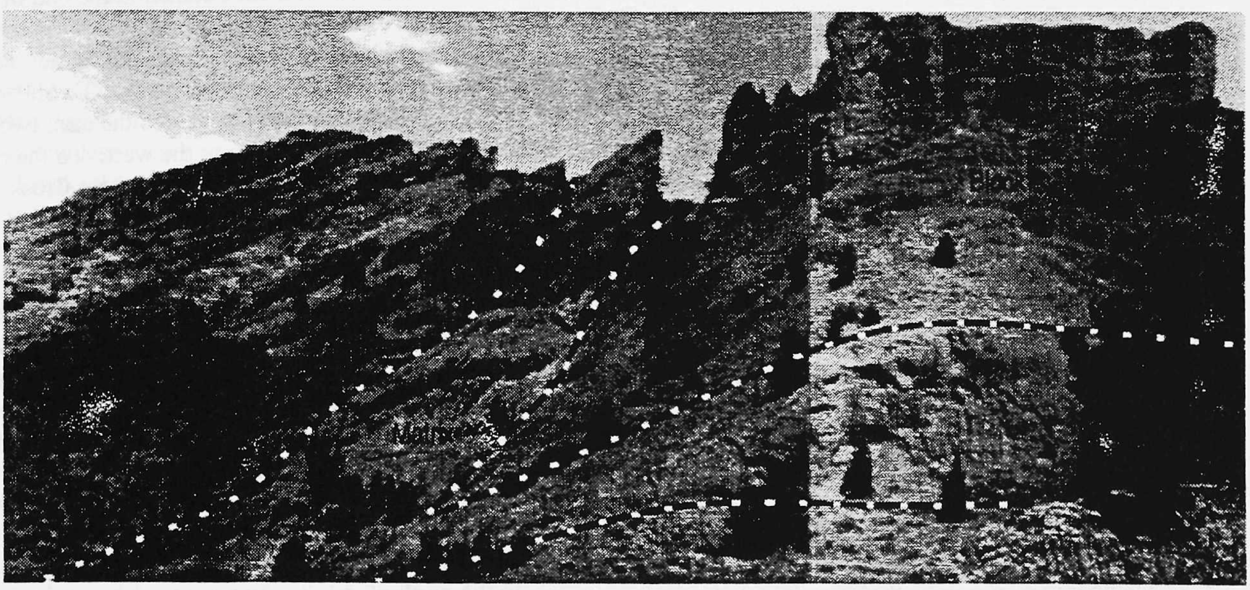

Figure 21. View to the east of the type area of the Deer Creek Member of the Wapiti Formation (From Malone, 1996). Shown here are two blocks separated by a zone of matrix up to 75 ft (23 m) wide. The block to the left (north) dips about 35° to the northwest, and the block to the right (south) dips about 10° to the north. This locality displays an imbricate relationship between Deer Creek Member blocks. The width of photo is about 1000 ft (320 m).

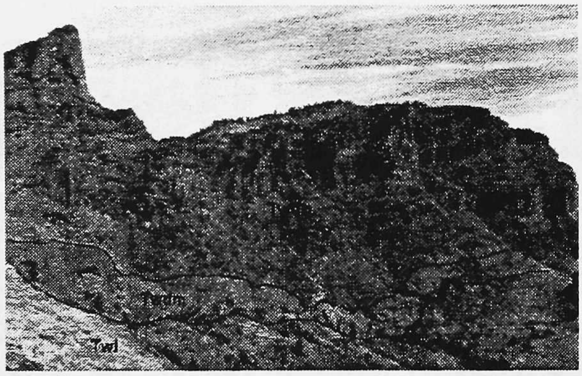

Figure 22. View to the east of the type area of the Deer Creek Member (from Malone, 1996). This locality is the southerly known limit of the unit, and is more than 25 mi (40 km) from the center of the inferred source area near Sunlight Peak. The steep slopes consist of dark brown breccias, sandstones, and conglomerates within the Deer Creek Member block (Twdb). The beds within the block dip about 30° to the northwest. At the base, a 25 ft (8 m) zone of matrix is present (Twdm). The unit here overlies an Eocene paleotopography with as much as 400 ft (125 m) of relief

STOP 3-1: OVERVIEW OF THE TYPE AREA OF THE DEER CREEK MEMBER.

This stop provides an excellent vantage of the type area of the Deer Creek Member (about 2 miles to the north). At this locality the relief on the Eocene land surface, two mountain-size blocks, and the matrix beneath and between these blocks can be observed (Figures 20-22).

The steep dark brown exposures of the eastern block consists of proximal-medial facies breccias, sandstones and conglomerates that dip about 30° to the north. Beneath this block the Deer Creek Member matrix forms a 30 ft (10 m) thick veneer above the Willwood Formation. The matrix at this locality has an imbricate fabric. Petrified wood is locally common between these imbrications and indicate a forest was probably overrun during emplacement. The basal contact of the Deer Creek Member here preserves the early middle Eocene topography.

The grassy covered area between the large blocks consists of a chaotic assortment of matrix, small volcanic blocks, small blocks of the Willwood Formation, and small blocks of Mississippian limestone.

Pierce and Nelson (1969) map a fault contact between the Wapiti Formation and adjacent Willwood Formation along Deer Creek. This interpretation is based on an abrupt change in stratigraphic level of the underlying Willwood Formation west of the inferred fault zone. Malone (1994) interprets the contact to be depositional, and attributes the change in stratigraphic position to the deposition of the younger Deer Creek Member of the Wapiti Formation on the east side of a steep middle Eocene hill that is composed of the Willwood Formation.

A detailed examination of this locality is highly recommended if time permits. The exposure can be reached by several horse trails from the Castle Rock Ranch.

Continue northeast on the South Fork Road.

2.8

20.9 Junction with the lower South Fork road. Turn left (north).

0.2

21.1 Cross the South Fork Shoshone River

1.5

22.6 Junction with Castle Rock Ranch road. Turn left (west). Sheep Mountain allochthon is to the north.

1.4

24.0 Junction with Hidden Valley Ranch road. Turn right (northwest). Proceed northwest to the Hidden Valley Ranch at the end of the lane.

1.1

25.1 Park cars and ask permission for access (Duaine and Sheila Hagen, owners). The Sheep Mountain allochthon is to the east, two smaller allochthons occur to the west. To the north is a large volcanic block of the Deer Creek Member.

STOP 3-2: BEAR CREEK AREA.

This locality provides an excellent opportunity to view the structural relationship between the Deer Creek Member and Heart Mountain Detachment and to observe the small-scale structure of the Deer Creek Member Matrix. Traverse on horse trail along the south side of Bear Creek for about 1.5 miles. The trail slowly climbs up hill away from the creek. Several smaller volcanic and limestone blocks (~10 m in diameter) occur along the trail about 400 ft above the creek. View to the north of the contact between a Deer Creek Member block and an upper plate allochthon of the Heart Mountain detachment (Figure 23). At this locality, the dip of volcanic strata is gently to the northwest. The Paleozoic strata of the upper plate allochthon also dip gently to the northwest. A 10-20 m wide zone of gray matrix occurs between these two blocks. The high-angle truncation of volcanic strata along the contact indicates that these volcanic rocks are allochthonous. Proceed northward down to Bear Creek and up the other side along the contact to view the Deer Creek Member matrix (the climb is about 500 ft).

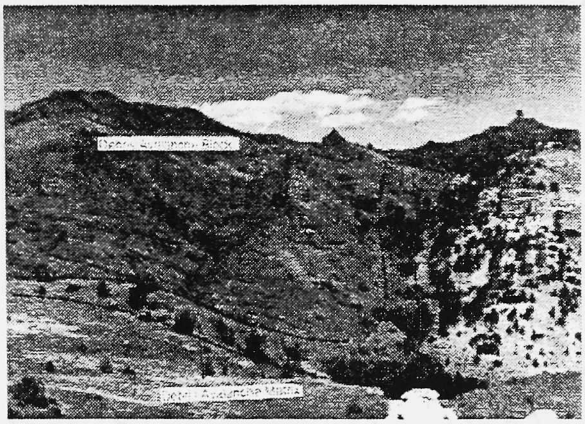

Figure 23. View to the north of the contact between the Deer Creek Member and allochthonous Paleozoic block.

The debris-avalanche matrix is a highly sheared and pervasively brecciated zone that is found beneath and between blocks. The recognition of matrix is the key to mapping the distribution of the unit and to understanding its origin. The matrix is typically light gray and bears a strong resemblance to ready-mix concrete. Most of the matrix consists of sand-sized particles, which consist in decreasing abundance, of lithic fragments, hornblende, pyroxene, glass, feldspar, and quartz. Pebble- to boulder-sized fragments are composed dominantly of light gray and pink hornblende andesite, and lesser dark gray trachyandesite. Matrix usually breaks through, rather than around, enclosed clasts, yielding smooth and rounded outcrops. Matrix was formed by the progressive disaggregation of block material during transport. Thus, matrix is entirely tectonic in origin, and no primary (depositional) layering is present. Matrix as defined here also includes all volcanic fragments <25 m in diameter.

Broken and shattered clasts (ranging from pebble to boulder size) are the most common structural feature within the matrix. Clasts of competent, dark-colored trachyandesite lava display a wide variety of fracture patterns, ranging from well-developed conjugate shear sets to pervasive shattering. Most of the shattering and fracturing of individual clasts does not penetrate the surrounding finer grained material, and the orientations of fractures within adjacent clasts are variable. In some places, minor displacement along the fractures has produced visible offset. In extreme cases, fractures within clasts were intruded by a slurry-like injection of sand-sized material.

Less common, but also significant, are strained clasts. Most strained clasts are composed of incompetent, light-colored, hornblende andesite. As seen in thin section, the boundaries of strained clasts are difficult to discern, and intrusive-appearing contacts between these clasts and the surrounding material are common. The progressive deformation of these incompetent clasts led eventually to their complete destruction and homogenization into the surrounding material.

Planar and curviplanar clastic dikes are found throughout the matrix. Individual dikes range in width from a few centimeters to a meter, and are as much as ten meters in length. Most clastic dikes are light gray and composed dominantly of fine sand- to small-pebble-sized material. At a few localities, multiple episodes of clastic dikes are present and complex cross-cutting relations among dikes are common, indicating that the matrix was dynamic, and that high pore-fluid pressures existed within the matrix throughout the emplacement of the unit. Some of these clastic dikes intrude overlying blocks. These clastic dikes were likely injected late, and they indicate that some blocks were strong enough to support the development of extension fractures during the late stages of emplacement.
Return to vehicles via the horse trail along Bear Creek. Retrace route back along the South Fork Road to the TE Ranch road.

41.4=0.0 Junction of the South Fork Road with the TE Ranch Road.

1.6

1.6 Park at "Entering Shoshone National Forest Sign.

STOP 3-3: OVERVIEW OF THE UPPER SOUTH FORK SHOSHONE RIVER VALLEY.

More than 5000 ft (1550 m) of layered volcanic rocks are exposed in the upper South Fork Shoshone River valley. In this area, rocks from the Wapiti Formation, the Trout Peak Trachyandesite, and the Wiggins Formation have all been identified (Malone, 1995b; Figures 24 and 25). The Willwood Formation is locally exposed at the base of the volcanic succession in the Ishawooa Hills and Slide Mountain areas. The following discussion is modified from Malone 1994 and 1995b. A geologic map and manuscript describing the stratigraphy and structure of this area is in preparation.

The Deer Creek Member in this area is extremely poorly sorted and consists of particles ranging from silt- to boulder-size. No internal stratification within the unit has been recognized, indicating that the entire unit was likely emplaced during a single depositional event. The unit is matrix-supported and resembles a very large laharic breccia. Most clasts consist of well- to sub-rounded, dark gray trachyandesite, red pyroxene andesite porphyry; and light gray hornblende andesite; the dark gray trachyandesite is the most abundant.

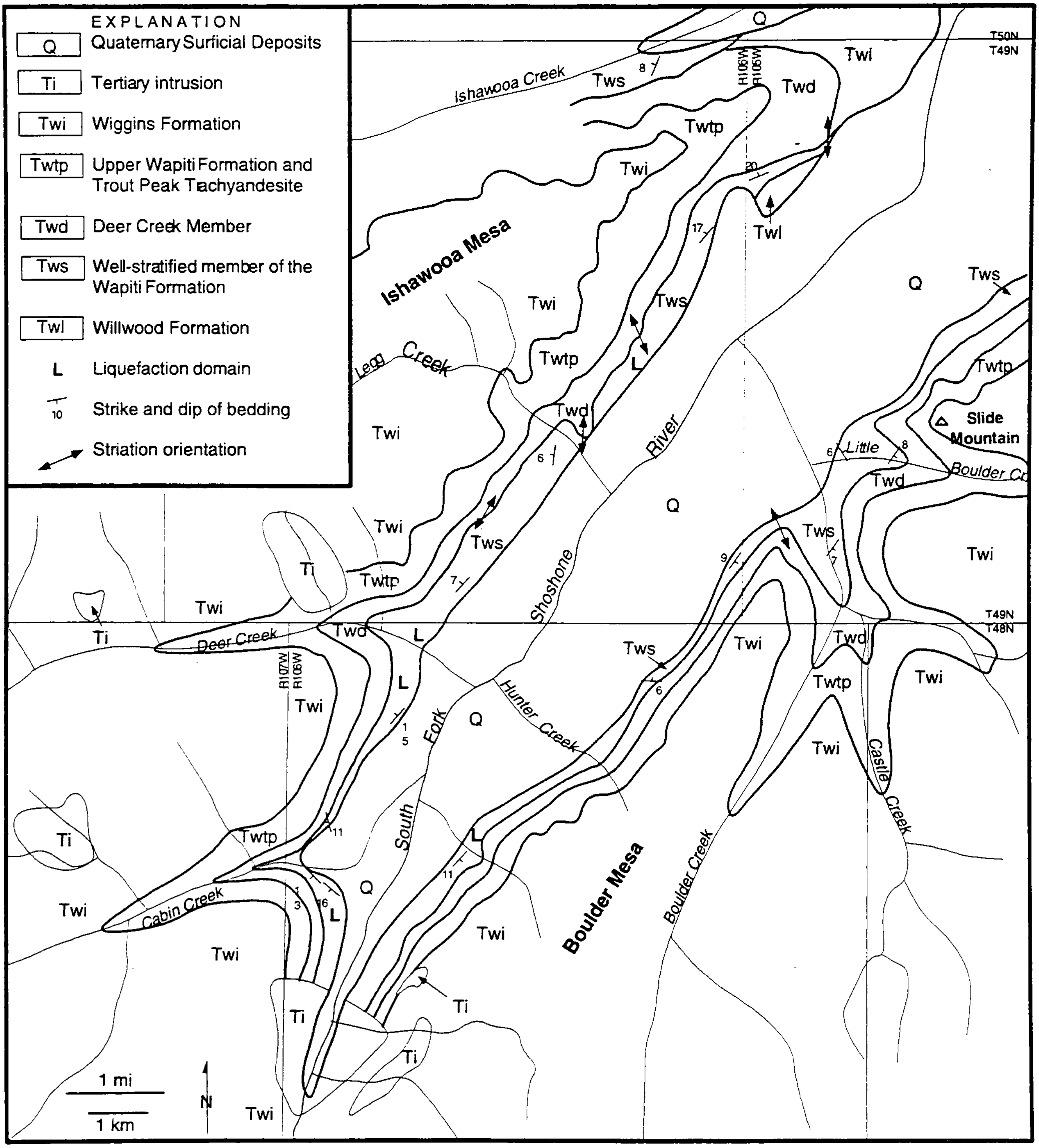

Figure 24. Geologic map of the upper South Fork Shoshone River valley.

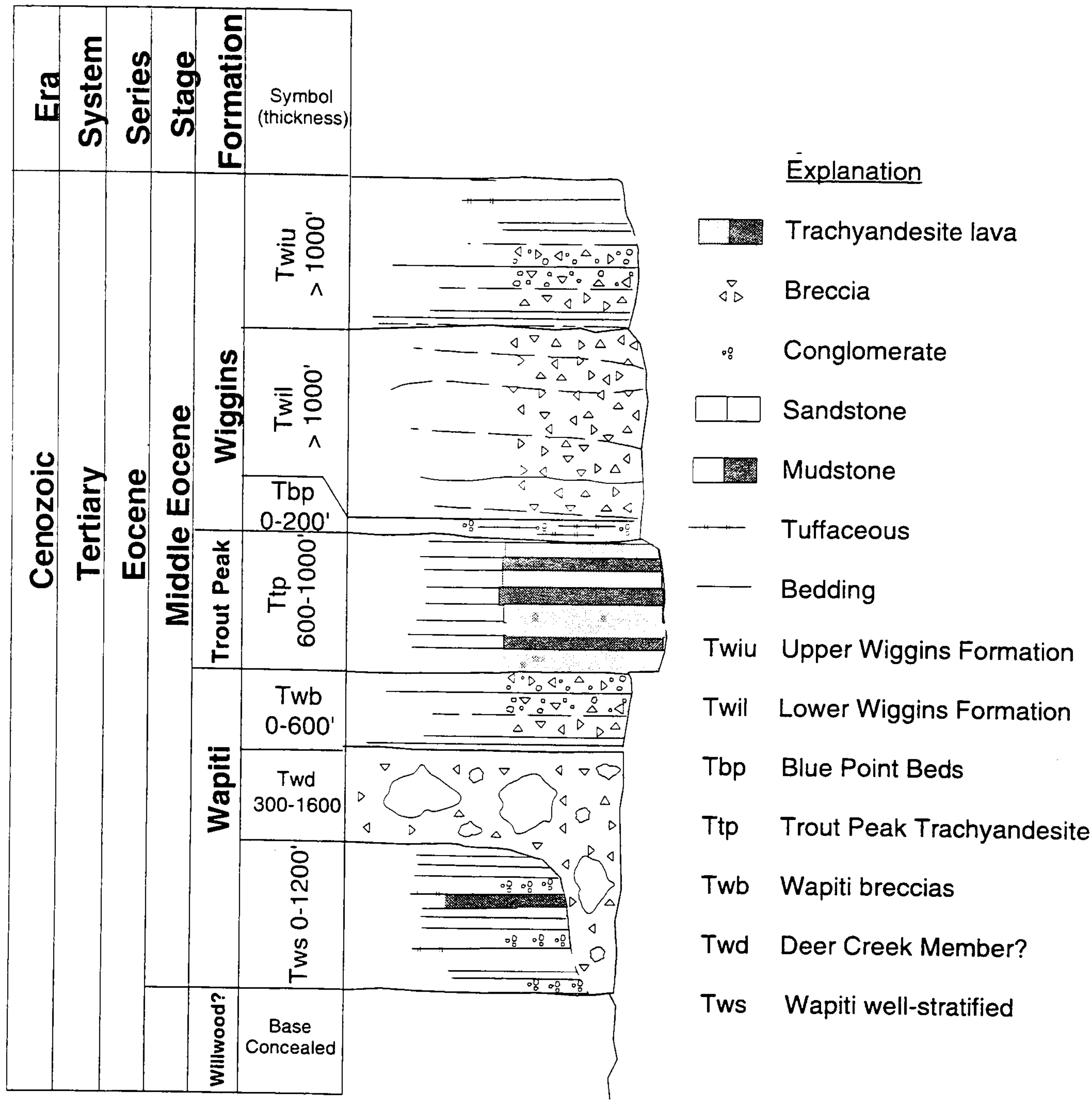

Figure 25. Stratigraphic column of the Eocene volcanic rocks exposed in the upper South ForkShoshone River valley.

Several large, irregular inclusions of trachyandesite lava and epiclastic breccia occur throughout the deposit, but they are concentrated in the middle. Some of these inclusions are comprised of light colored, well-stratified epiclastic sandstones and breccias, but this variety is rare. These inclusions range in size from about 10 ft (3 m) to over 500 ft (155 m) in diameter. Layering within these inclusions is often apparent from a distance, but upon closer inspection it is difficult to discern. Where present, this layering appears to be highly contorted, and it is truncated along the margins of the inclusions.

Contacts of these inclusions range from sharp to gradational. Where contacts are gradational and the volcanic material within and adjacent to the inclusion are texturally similar, the contact is only recognized by a change in color. Where contacts between the inclusions and adjacent material are sharp, the contacts are locally striated - most commonly where the inclusions are comprised of trachyandesite lava. These striations are typically on the inclusion rather than on the surrounding material. In most cases (a total of five striated inclusions were observed), the striations are unidirectional and subhorizontal and indicate laminar rather than turbulent flow.

Decker (1990) interpreted these inclusions as the result of the liquefaction and dismemberment of the overlying lava flows, flow breccias, and epiclastic breccias. In the present study, no disruption of the overlying lava flows was observed, and all liquefaction domains are probably confined to the subjacent well-stratified succession. More likely, most of these inclusions are probably disaggregated debris-avalanche blocks that were suspended and supported buoyantly by the strength of the surrounding matrix material when the predominant transport mechanism evolved from slide to flow. The origin of the lighter colored inclusions is less obvious, as no light-colored strata within Deer Creek Member has been recognized elsewhere. It is possible that these inclusions were incorporated from the subjacent units during emplacement.

The Deer Creek Member here averages about 600 ft (186 m) in thickness, and ranges from a low of 300 ft (93 m) between Sheephead and Hunter creeks to a high of 1600 ft (498 m) between Legg and Schoolhouse creeks. The top of the unit is mostly flat, and the variation in thickness is mainly a function of relief on the lower surface. In general, the unit is sheet-like in geometry, but it thins gradually to the south and west.

In most cases, the relief on the basal surface is less dramatic. Throughout most of the area, the lower contact occurs between 7200 and 7400 ft (2240 m and 2305 m) in elevation. These values are similar to the higher elevations observed along the base of the Deer Creek Member in the lower North and South ForkShoshone River valleys.

It is likely that a distal-facies of the Deer Creek Member occurs throughout the upper South Fork Shoshone River valley. Evidence for this assertion include:

1) the presently known southeastern extent of the Deer Creek Member is only 11 mi (18 km) from the Ishawooa Hills area; the only stratigraphic pinch-out of the proximal facies of the Deer Creek Member occurs near Jordan Creek at an elevation of about 7900 ft (2461 m); this pinch-out is attributed to a paleotopographic high, and the unit could well occur to the southwest of this paleohill at lower elevations;

2) in both areas, the rocks display a similar color, texture, scale, and degree of deformation;

3) in both areas, the units overlie a major early middle Eocene unconformity;

4) sparse kinematic data indicate a southeastward transport direction. This is consistent with a collapse directed outward from the inferred source area.

The structural differences between the two areas can be explained by a difference in the emplacement mechanisms. In the lower North and South Fork Shoshone River valleys, sliding was the dominant emplacement mechanism, and blocks remained relatively intact and undeformed. With further transport, blocks disaggregated, and the dominant emplacement mechanism evolved from slide to flow, with the resultant deposit having characteristics resembling a very large, laharic debris flow deposit.

The total distance from the inferred source area at Sunlight Peak to the extreme southern exposure of the unit in this area is at least 36 mi (58 km). This increases the previously known transport distance by some 18 km. The actual maximum transport distance is probably greater, as the southernmost part is concealed by younger volcanic rocks.

Another implication of the assignment of these rocks to the Deer Creek Member is that a clear distinction can be made between the respective distribution areas of the latter and the upper plate of the Heart Mountain detachment. The closest upper plate remnant is in the Sheep Mountain area which is more than 20 mi (32 km) to the northeast, and no Paleozoic limestone fragments of any size were identified within the Deer Creek Member in this area. This demonstrates that they are areally distinct and is another reason to suggest that the Deer Creek Member and Heart Mountain allochthon were emplaced sequentially rather than coevally.

The emplacement of the Deer Creek Member could have contributed to the liquefaction-related deformation in the underlying well-stratified epiclastic units, and several domains of chaotically dismembered bedding have been identified (Decker, 1990) at Deer Creek Canyon, between Deer and Cabin Creeks, between Sheepeater and Hunter Creeks, and Southwest of Legg Creek. The deformation in these domains has been attributed to *in-situ* liquefaction caused by excess pore fluid pressures resulting from cyclic loading during large earthquakes. It is possible that the liquefaction-related deformation may have been induced by impulsive loading caused by the emplacement of the debris avalanche rather than repetitive loading during earthquakes. Unfortunately, there is no way to evaluate or quantify the relative importance of either stimulus.

Proceed southwest on the South Fork Road

1.9

3.5 Bridge over the South Fork Shoshone River

1.8

5.3 Park at the red U.S. Forest Service gate and proceed north across the sage covered foot hills to the base of the cliff.

STOP 3-4: DISTAL FACIES OF THE DEER CREEK MEMBER IN THE ISHAWOOA HILLS AREA.

This location provides an opportunity to closely observe an outcrop of the distal facies of the Deer Creek Member. Access to the Deer Creek Member is easiest here because the lower contact is a relatively low elevation (paleovalley). The lower 100 feet of the exposure consists of northward-dipping epiclastic sandstone, breccia, and conglomerate. The base of the Deer Creek Member is well-exposed here and changes stratigraphic position rapidly. The underlying well-stratified succession is commonly extensively fractured just beneath the contact. Several large, irregular inclusions of trachyandesite lava can be observed here within the Deer Creek Member. The contacts of these inclusions are striated. These striations are subhorizontal or gently inclined and trend nearly north-south.

Return to the vehicles and proceed south along the South Fork Road.

1.5

6.8 Double Diamond X Ranch on right. Slide Mountain to the east.

0.8

7.6 Ishawooa Mesa Trail Head

1.9

9.5 Bridge over Legg Creek.

STOP 3-5: OVERVIEW OF DRAMATIC PALEOTOPOGRAPHY NORTHEAST OF LEGG CREEK.

Pull vehicles off the road near the bridge over Legg Creek. View to the north of a spectacular paleovalley filled by the Deer Creek Member. During emplacement, the Deer Creek Member filled and topped steep gorges that were carved in the underlying well-stratified succession (Figure 26).

The west contact is nearly vertical for about 1000 ft of paleorelief. The east contact is less steep; the paleoslope on this side of the ancient canyon is about 20°. The origin and preservation of such a feature is enigmatic; it probably would not have been preserved if it had not been immediately and fully buried by the deposition of the Deer Creek Member. This relationship is not recognized on the opposite cliff on the south side of the South Fork valley.

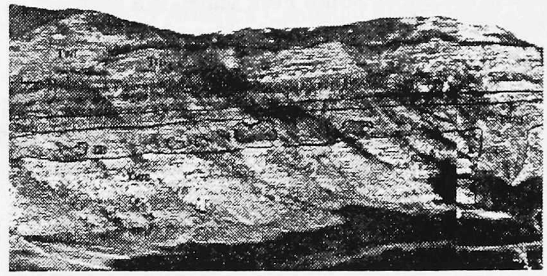

Figure 26. Photograph of Eocene volcanic strata exposed along the northwest side of the Shoshone River canyon between Deer and Legg Creeks. The width of the photograph is about 3 mi (5 km). The volcanic succession is in excess of 4000 ft in thickness. The Deer Creek Member of the Wapiti Formation unconformably overlies a sequence of distal facies breccias, sandstones, and mudstones. Large inclusions of trachyandesite lava within the Deer Creek member are outlined. A spectacular, steep-sided paleovalley that was preserved by the emplacement of the debris avalanche is marked by an X. Tws=Wapiti well-stratified member; Twd= Deer Creek Member of the Wapiti Formation; Twb=Wapiti breccias; Ttp=Trout Peak Trachyandesite; Twi=Wiggins Formation.

Along the west side of this paleovalley, there is evidence of drag of the well-stratified units near the contact. In addition, subhorizontal striations were observed in two places along the contact. Both of these structures indicate that the feature is not merely an unconformity but rather both an unconformity and a fault at the same time.

This relationship is remarkably similar to what is observed along the breakaway of the Heart Mountain detachment, and a brief comparison of the features of each is warranted.

1) Although at its southernmost mapped point, the breakaway is buried by younger Wapiti Formation rocks and is over 30 mi (48 km) away, the Legg Creek locality is along strike with the breakaway fault.

2) Both the breakaway and this structure are half-faults (Pierce, 1979), the lower surface is a fault surface while the upper surface is a site of deposition.

3) Both the breakaway and this structure display a similar relief across a short lateral distance.

4) Massive, dark-colored breccias immediately buried both the breakaway and this feature. It is likely that the Deer Creek Member is present within the hanging wall of both localities.

5) The footwall of each is the western side and consists of light colored, well-stratified medial-distal-facies volcanic rocks.

6) Both structures are similar (probably identical) in age.

Despite these similarities, it is unlikely that this structure in the upper South Fork valley is a southern extension of the breakaway of the Heart Mountain detachment. Other large paleovalleys exist in the Ishawooa Hills area and along Little Boulder Creek. The paleorelief in these areas is less spectacular, but it is still in excess of 800 ft (250 m). Unfortunately, since exposures are limited to the canyon walls, it is impossible to trace these paleovalleys laterally.

Proceed southwest along the South Fork Road.

4.5

14.0 End of the South Fork Road.

STOP 3.6: OVERVIEW OF DISTAL FACIES OF THE DEER CREEK MEMBER AT CABIN CREEK.

The Deer Creek member is beautifully exposed in the steep cliff face just north of and 500 ft above Cabin Creek (Figure 27). At this locality, the unit is approximately 300 ft in thickness. Several large inclusions of bedded distal facies rocks occur near the base of the exposure. Two light-colored dacite dikes intrude the units. The discontinuous geometry of these dikes indicate that the Deer Creek Member was not fully lithified as the dikes intruded. These dikes are related to a series of small plutons in the area that intruded during the deposition of the overlying Wiggins Formation. End of Day 3.

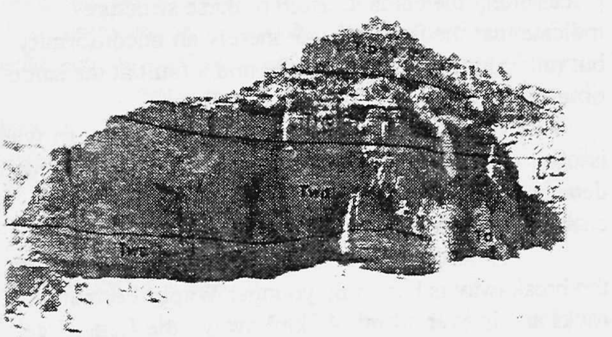

Figure 27. View to the north of the Deer Creek Member northeast of Cabin Creek. The chaotic nature and lack of internal stratification of the deposit is beautifully exposed at this locality. the thickness of the deposit here is about 300 feet. At the east (left) side of the exposure, a light-colored andesitic dike (Td) intrudes the volcanic succession.

DAY 4: DETACHMENT STRUCTURES OF THE SOUTHEASTERN ABSAROKA RANGE.

Day 4 begins again at the Double Diamond X Ranch. We will not return to the Double Diamand X ranch this evening. Today we will travel to the southern Absaroka Range and visit several localities in the Wood River and Owl Creek drainages. Proceed to Cody via the South Fork Road. Turn right on U.S. 16-14-20 and proceed to the intersection with WYO 120. The road log mileage is approximate. Refer to the 1975, 1986, and 1990 Wyoming Geological Association Guidebooks for more detailed road logs and site descriptions.

MILEAGE DESCRIPTION

0.0 Road Junction US 14-20 and WYO 120. Proceed south (right) on WYO 120.

31.3

31.3 Junction with WYO 290; turn southwest (right) toward Pitchfork, Wyoming.

5.5

37.8 Junction WYO 290 with the Wood River Road. Turn south (left) on the Wood River Road towards Kirwin.

7.6

45.4 Renner's Lodge on the west side of the road. Across valley to the east is an allochthon of the Enos-Owl Creek Debris-avalanche deposit that overlies the Willwood Formation.

7.8

53.2 Turn left on the South Fork of the Wood River Road.

STOP 4-1: SOUTH FORK OF THE WOOD RIVER.

Cross the Wood River and proceed one mile along the South Fork of the Wood River to the end of the road. Hike one-half mile up stream to view a paleovalley in the Teepee Trail Formation filled by allochthonous Wiggins Formation.

Retrace route back to Meeteetse.

21.9

75.1=0.0 Junction of WYO 290 with WYO 120. Turn right and proceed south on WYO 120.

31.5

31.5 Intersection of Wyoming 120 with Hamilton Dome Road. Turn west (right) on the Hamilton Dome Road.

5.3
36.8 Intersection of Hamilton Dome Road and Cottonwood Creek Road. Turn right on Cottonwood Creek Road.
11.5
48.3 Overview of the Rhodes allochthon of the Enos-Owl Creek Debris-avalanche deposit.

STOP 4-2: RHODES ALLOCHTHON.

Overview to the north across Cottonwood Creek of the contact between allochthonous Absaroka volcanic rocks of the Aycross Formation and the underlying Willwood Formation. Bown and Love (1987) suggest that this episode of detachment faulting is Quaternary in age. Conversely, Sundell (1985) interprets an Eocene age for the detachment faulting.

Continue to the southwest on Cottonwood Creek Road.
9.0
57.3 Junction of Cottonwood Creek Road and WYO 170 (North Fork of Owl Creek Road). Turn right (west on WYO 170. Proceed for approximately 15 miles up the North Fork of Owl Creek drainage on private ranch roads to the Base of Castle Rocks. We may make a few brief stops to discuss the volcanic stratigraphy and structure in this part of the Absaroka Range.
15
72.3 Park for stop 4-3

STOP 4-3: CASTLE ROCKS AREA.

Castle Rocks is the stratotype of the Castle Rocks Chaos. Hike approximately 1/2 mile up the hill. We will observe the diagnostic features of block and matrix facies of the Chaos and examine the basal contact. Following this stop, the trip disbands. Return to Cody via WYO 170 and WYO 120.

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