The What, How, Why, and When of the Blacktail Fold-Thrust, Clarks Fork River Region Northwest Wyoming: An investigation of the origins of the Blacktail Fold-Thrust and its Relation to Heart Mountain Faulting

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Introduction

The Blacktail fold-thrust is a faulted anticline which folds the Middle Cambrian Snowy Range Formation, Pilgrim Limestone, and underlying shales of the Gros Ventre Formation. The fold-thrust outcrops at three main localities, along the south and north sides of Crandall Creek (SCR, NCR) and along its namesake Blacktail creek (BTC) (Figure 1), southwest of the Clarks Fork valley in NW Wyoming. The purpose of this project was to investigate the origin of the fold-thrust and its timing and relations to the overlying Crandall Conglomerate (see Anderson, this volume) and Heart Mountain Detachment (HMD). The fold-thrust and its relationships to the Crandall Conglomerate and HMD were mapped and examined in the field. Samples from within the fold-thrust and adjacent unfolded areas were collected for strain analysis to be performed on ooids present in the Pilgrim Limestone. *Stereonet* v.4.7 was used to plot strike and dip data and *Fry Analysis* v.5.0 was used to determine the directions and amounts of strain.

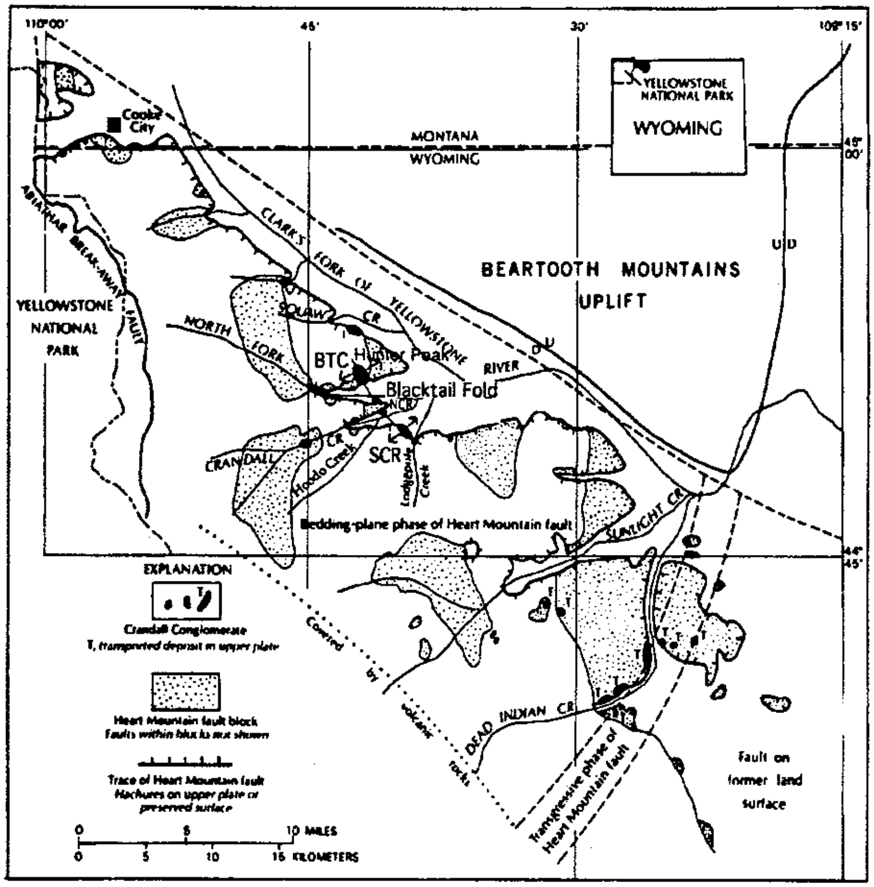

Figure 1. Generalized Geologic Map of the Clarks Fork River region showing location of Blacktail fold-thrust outcrops , position of Crandall Conglomerate outcrops, and extent of Heart Mountain Detachment motions Modified from Pierce and Nelson 1973)

Previous Hypotheses of Fold-Thrust Origin

The fold-thrust's origin has been a subject of debate since 1973 when Pierce and Nelson first hypothesized that the fold "popped-up" into a rift created by an initial small-scale (1-2km) movement along the HMD. According to their models, the weak Snowy Range, the Pilgrim and underlying incompetent shales of the Gros Ventre Formation flowed upward into the rift as a result of the lithostatic unbalance created by the presence of 300m cliffs (Figure 2). They propose that the fault observed at NCR originated as a high angle fault which was rotated to a lower angle as folding developed (Figure 3, Pierce and Nelson, 1973).

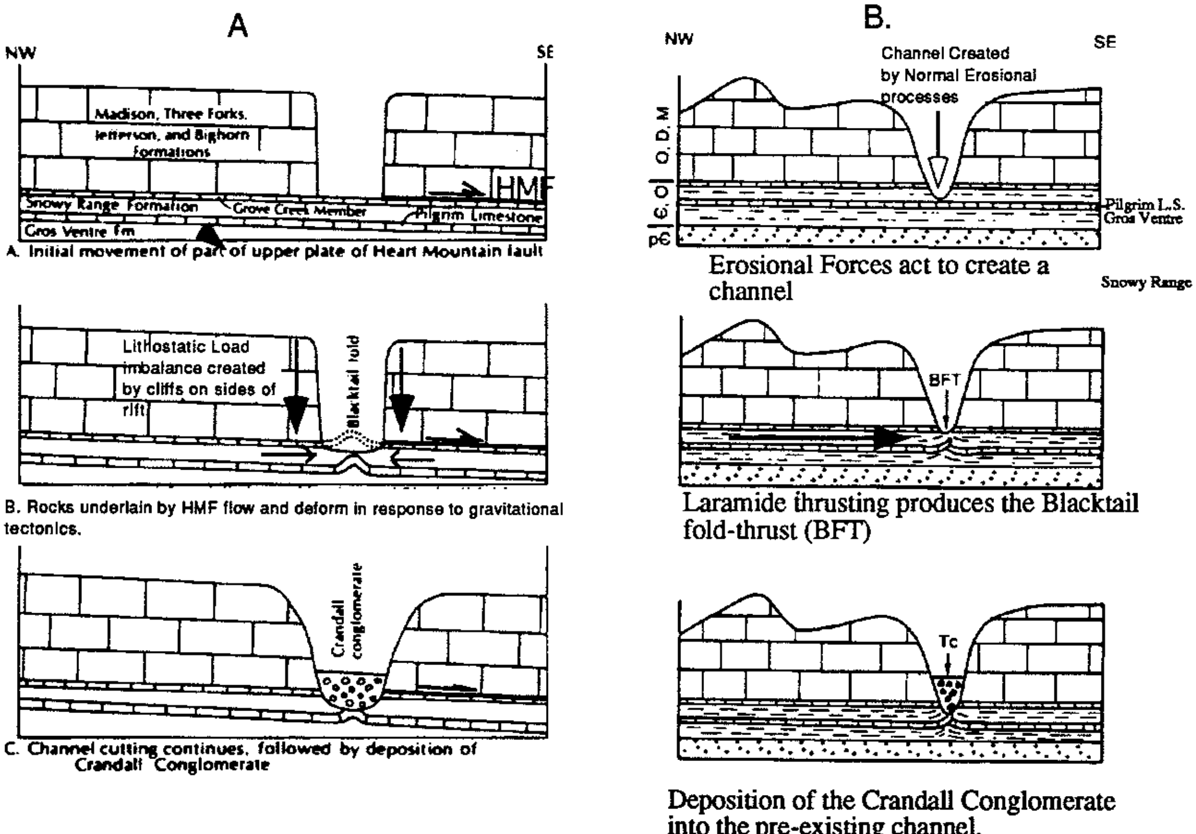

Figure 2. Prior Models of Fold Creation. A. Pierce and Nelson's pop-up model (Modified from Pierce and Nelson 1973). B. Hauge's model of Laramide thrusting into a pre-existing channel (Modified From Hauge 1983).

Hague (1993) proposed that the fold-thrust was created by Laramide thrusting into a stream channel whose location was determined by normal erosional processes (Figure 2). Thus, the fold-thrust was believed to be a contractional structure localized along an erosional feature.

Geometry of the Blacktail Fold-Thrust

The fold-thrust is exposed at the surface for approximately six km, and disappears beneath cover to the NW and SE. Dips of the limbs range from about 20° to 85°, with the steepest limb found on the NE side of the SCR exposure. The hinge changes trend from N50°W in the southeastern portion to N20°W in the northwestern outcrops. The fold-thrust produces approximately 75m of structural relief on the top of the Pilgrim Limestone at the SCR outcrop. In the Gros Ventre Formation just below the Pilgrim in the NCR outcrop, abundant small-scale folding and thrusting is observed. The half-meter scale folds present within this shaley layer tend to verge to the NE on the SW limb and towards the SW on the NE limb. Larger-scale thrusting from the SW is observed in the NE vergence of the SCR exposure and the overriding of the SW limb over the NE limb at the NCR exposure (figue. 3). At the NCR, SCR, and BTC localities the Crandall Conglomerate lies to the NE of the crest of the fold-thrust, and the large Crandall Conglomerate exposure E of Squaw Creek lies to the NE of the projection of the fold-thrust. The HMD overlies the fault and does not cut through the folded rocks of the Pilgrim.

A NW-striking, NE-verging Laramide thrust of a comparable scale to the Blacktail Fold-Thrust juxtaposes Precambrian basement over Cambrian strata along Little Bear Creek in the nearby Beartooth Mountains, approximately 15km to the NE. Within the footwall of this structure is a tight syncline that deforms the Cambrian Meagher limestone. This fold-thrust complex is thought to provide a model for a lower level of the Blacktail fold-thrust.

Strain Analysis

Samples of Pilgrim Limestone containing ooids were collected from within the fold-thrust and from areas outside the region of folded rocks. Oriented thin sections were made in order to undertake strain analysis on the ooids, in an attempt to determine the direction and amount of strain preserved within the folded rocks. The unfolded rocks were examined to test for the regional Laramide deformation present within the area, which is known to have an E-W shortening axis and shortening of 3-7% (Nielsen and others 1996). The orientation of strain axes of the folded rocks were then to be compared to the regional Laramide strain to determine if strains associated with folding and thrusting could be detected.

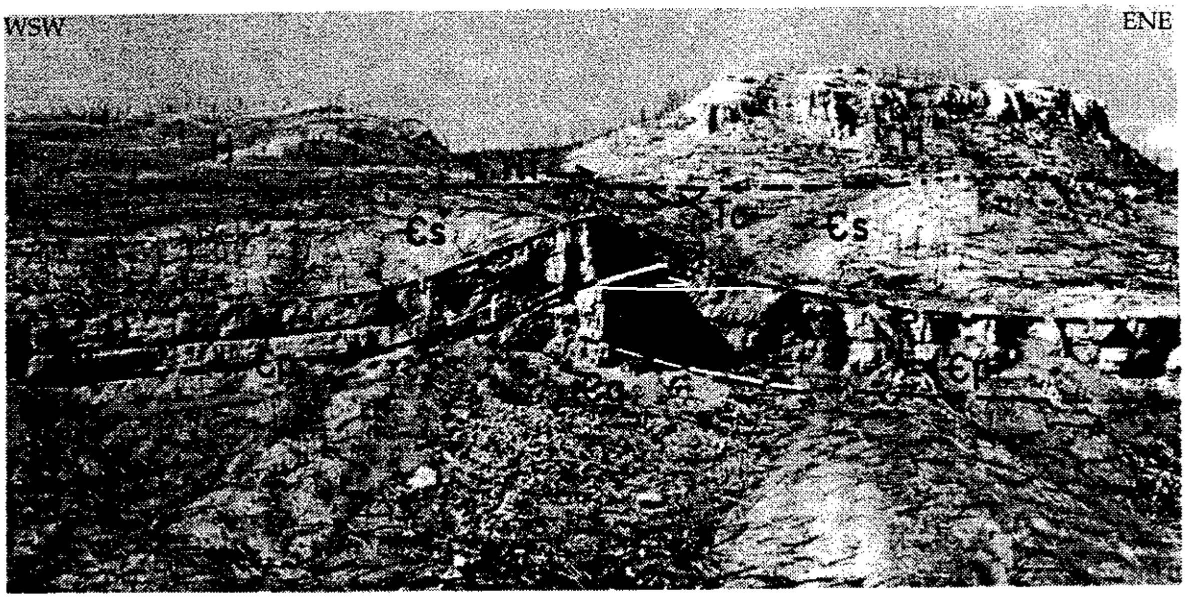

Figure 3. Photograph of the NCR exposure, features include the Gros Ventre Formation (Cg), Pilgrim Formation (Cp) Snowy Range Formation (Cs), Heart Mountain Fault (Hf), Heart Mountain Fault blocks (H), and the Crandall Conglomerate (Tc). Note how fault in the fold-thrust splits, as seen in the thickened Pilgrim of the NE limb. Modified from Pierce and Nelson 1973.

The results of this study were inconclusive. There was no consistent strain direction observed in the ooids of either the folded or unfolded rocks. Axial ratios of the strain ellipses as calculated by Fry-Analysis 5.0 generally yielded axial ratios of less than 1.2:1 and "strain ellipses" of erratic orientations. This relatively small amount of "strain" is not significant and can likely be dismissed as random. These results indicate that the Fry technique is not of sufficient sensitivity to detect the low magnitudes of strain in the ooids of the Pilgrim.

Discussion:

It is proposed that the Blacktail fold-thrust is a fault propagation fold formed during the Laramide Orogeny. This model is favored because it most adequately explains the position of the Crandall Conglomerate off the crest of the fold-thrust, the contractional character of the deformation, and the orientation of the thrust-faults at the NCR and SCR outcrops. Exposures in autochthonous regions and evidence that no Paleozoic rocks stratigraphically higher than the Madison Limestone are found above the HMD support the contention that a late Laramide erosion surface was present at approximately the top of the Madison Limestone. The Blacktail fold-thrust is believed to have extended to this erosion surface, and a zone of weakness would have been present where the axial surface of the fold-thrust intersected the surface. This is believed to have been the controlling factor for the location of the channel in which Crandall Conglomerate was deposited. Once erosion along this weakened zone commenced, continued incision likely would have occurred straight down. Due to the inclination of the axial surface of the fold-thrust, which dips to the SW, as the stream incised straight down the channel would migrate off the crest of the fold-thrust and lie to the SE of the hingeline.

Larger-scale structural evidence points to the conclusion that the fold-thrust was created by Laramide deformation. The fold-thrust trends in a direction that is roughly parallel to Laramide compressional stresses measured in the area. Wise and Obi (1994) determined a stress field with average compression oriented N28°E at the mouth of the Clarks Fork Canyon from fold axes and joint patterns observed there. The average trend of the Blacktail Fold-Thrust (≈N40°W) aligns well with this compression direction.

This model differs from Hague (1993), in that he believes the channel in which the Crandall Conglomerate was deposited predated the thrusting/folding event which created the Blacktail Fold-thrust. Had this been the case, it would have likely resulted in the juxtaposition of the Crandall Conglomerate directly on top of the crest of the fold-thrust. Since the basal Crandall Conglomerate is not folded it is unlikely that deposition and thrusting were occurring simultaneously.

Pierce and Nelson's (1973) "pop-up" model for fold creation does not take into account the field evidence for horizontal shortening or compression observed in the area. The low dip of the fault (30°) and the shortening (>80m) cannot be adequately explained by a pop-up mechanism and vertical movements of the Pilgrim. There was no field evidence for the rotation of the fault at NCR as Pierce and Nelson claimed, as the SW limb of the fold-thrust is continuous and can be traced back to unfolded rocks at the regional dip (Fig. 3).

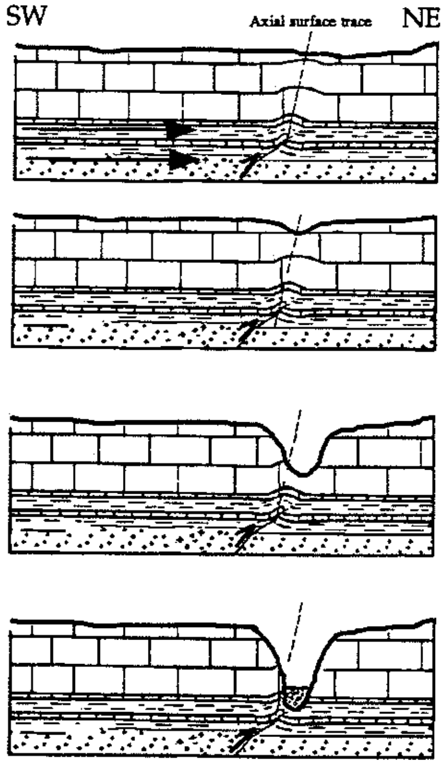

Figure 4. Model for Blacktail Fold-Thrust Formation Presented in this Paper.

Laramide compression produces a basement thrust fault that deforms the Paleozoic rocks. The axial surface of the fold extends to the erosion surface present on the Madison Limestone.

A stream channel begins to form on the exposed fold hinge, a zone of weakness.

The channel incises vertically downward but with depth the fold hinge migrates to the SW along the axial surface.

Channel cutting continues to the top of the Pilgrim Limestone and a change in stream regimen leads to the deposition of the Crandall Conglomerate.

Another problem with the pop-up model lies in the fact that no extension was observed in the Pilgrim Limestone adjacent to the fold-thrust. Flowage of the limestone toward the chasm would have to be accompanied by extension in the limestone adjacent to the fold-thrust. The Meander anticline in the Paradox Basin of New Mexico is an excellent example of a pop-up fold. This unloading structure has adjacent to it the Needles normal fault zone which provides the necessary extension to accommodate the flowage of plastic salts into the core of the anticline (Huntoon, 1983). Flowage along basal salt layers into the Colorado River canyon has produced a symmetric salt anticline with its crest directly under the river channel (Huntoon, 1983). The Blacktail fold-thrust is asymmetrical and the Crandall Conglomerate overlies the steep limb. Thus, neither the geometry of the Blacktail fold-thrust nor its relationships with the Crandall Conglomerate accord with it being a pop-up structure.

Sources Cited

Hague, T.A. 1993, "The Heart Mountain Detachment, northwestern Wyoming: 100 years of controversy." in Snoke, A.W., Steidtman, J.R., and Roberts, S.M., editors, *Geology of Wyoming*. Geological Survey of Wyoming Memoir No. 5, p. 530-571.

Neilson, K.J., and others, 1996, "Calcite Twinning Strains and the Hearth Mountain Detachment: Tracking of Upper-Plate Slide Block Kinematics Motions and an Absence of Detachment-Related Strain Overprints." *Abstracts with Programs* - Geological Society of America, v. 28n. 7, p. 246

Pierce, W.G., and W.H. Nelson, 1973, "Crandall Conglomerate, An Unusual Stream Deposit, and Its Relation to Heart Mountain Faulting." *GSA Bulletin*, v. 84 p. 2631-2944.

Huntoon, P.W. 1982, "The Meander Anticline, Canyonlands, Utah: An unloading structure resulting from horizontal gliding on salt." *GSA Bulletin*, v.93, p. 941-950.

Wise, D.U., and Obi, C.M. 1994, "Laramide Basement Deformation in and Evolving Stress Field, Bighorn Mountain Front, Five Springs Area, Wyoming: Reply." *AAPG Bulletin*, v.78, p.652-655.