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Faculty: *JOHN GARVER*, Union College, *Cameron Davidson*, Carleton College
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Keck Geology Consortium: Projects 2011-2012
Short Contributions— Teton-Absaroka Ranges, Wyoming Project

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STRUCTURAL EVOLUTION OF THE EOCENE SOUTH FORK DETACHMENT, PARK COUNTY, WYOMING

ALISON MACNAMEE, Colgate University
Research Advisor: Martin Wong

INTRODUCTION

The South Fork Detachment (SFD) is named for its exposure along the banks of the South Fork of the Shoshone River in Park County, Wyoming. The fault trace is exposed along strike for at least 35 km in this valley to the southwest of Cody, WY. The full extent of the fault is unknown due to its concealment by younger units. At its southern limit the fault strikes approximately N50°E before disappearing beneath Eocene Absaroka volcanics. The fault has been interpreted to bend at 90° near Buffalo Bill Reservoir and is lost to the northwest under these same volcanics (Beutner and Hauge, 2009).

Historically, the SFD has preoccupied a number of geologists with its complex structures and enigmatic features. However, the region has been thoroughly studied in greater part due to the nearby Heart Mountain detachment. The SFD has been under investigation for nearly a century since its discovery in 1916, during which a number of theories have been proposed as to its origin (Dake, 1918). It has been interpreted to be the front of a massive gravity slide that both predates and is unrelated to the HMD (Blackstone, 1985; Pierce 1957, 1956), the easternmost expression of the Cordilleran overthrust belt (Clarey, 1990), or as the toe of the HMD (Beutner and Hauge, 2009, 2004).

However, the data that informed these interpretations are somewhat poorly constrained. Most of the more recent work (Clarey, 1990; Beutner and Hauge, 2004, 2009) has relied almost exclusively on the mappings of Pierce and collaborators. Much of the observations made in these early maps have since been called into question by other field-based research. Moreover, the oaucity of structural measurements recorded in these maps (in some areas 3-5 per square mile) detracts from the reliability of geometric interpretations. The purpose of this research was to perform a more rigorous investigation of field relationships by mapping critical areas. Structural data were obtained for the creation of new cross-sections. These insights have been complemented by stable isotope analyses in order to better understand the emplacement and deformational history of the SFD.

GEOLOGIC SETTING AND STRATIGRAPHY

The area of the SFD is characterized by a number of geologic features that are crucial to the consideration of the SFD itself. One such feature is the Absaroka Volcanics, a province of thick igneous and volcaniclastic rocks spanning more than 23,000 km2 (Feeley and Cosca, 2003). These plutonic units were erupted from northwest centers from approximately 55 to 45 Ma (Feeley and Cosca, 2003). The Mesozoic units of the upper plate of the SFD are covered, as aforementioned, by the Deer Creek Member. This unit is part of the Wapiti Formation and is evidenced to be a large debris-avalanche deposited by the ancestral Sunlight Volcano with transport to the southeast (Malone, 1995). This unit, dated to be 48.9 Ma, provides a constraint on the age of emplacement of the SFD based on superposition.

Another dominant feature of the region is the Heart Mountain Detachment, the largest known subaerial landslide produced by volcanic collapse (Malone, 1995; Craddock et al., 2009). The detachment spans 3400 km2 and has been transported to the southeast on the order of 30 mi (50 km) (Craddock et al., 2009). The breakaway lies to the northwest in Silvergate, Montana where it has been demonstrated that the HMD is a rootless allochthon (Pierce, 1960). Rocks from the Ordovician through the Eocene are displaced along a very shallowly southeast dipping bedding plane with a detachment in the Bighorn dolomite.

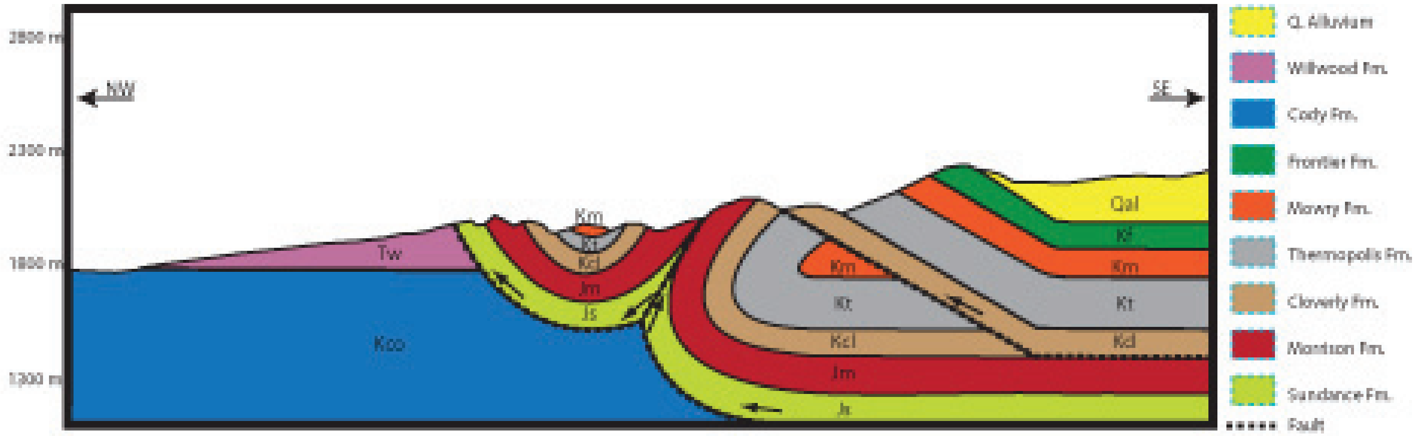

Figure 1. Cross section developed based on new mapping and structural measurements of exposures in the Belknap Creek Quadrangle.

INTERNAL DEFORMATION

The decollement of the SFD is located near the base of the Jurassic Sundance Formation or within the thin and lithologically weak Gypsum Springs Formation just below. From this location it ramps up section to the Cretaceous Cody Shale, ultimately offsetting the upper plate against the Tertiary Willwood Formation. Age constraints on emplacement are the underlying Willwood Formation dated to 50-55 Ma (Torres and Gingerich, 1983) and the overlying Deer Creek Member, approximately 48.9 Ma (Malone, 2005). The area was mapped by Pierce in 1966, but the map offers too few details and constraints for such a structurally complex region. Field mapping was undertaken specifically in the Belknap Creek Quadrangle to gain new insight into the emplacement history of the upper plate. Unfortunately, there is a complete absence of kinematic indicators despite the prevalence of faulting and folding and so the deformational history of the allocthon must be determined by other means.

For this study, structural measurements were taken for the purpose of developing new cross-sections. Faults and fold axes generally trend approximately N50°E with variable levels of exposure along strike. In the northeastern exposure of the upper plate the Sundance is antiformally folded and in fault contact with the Willwood to the northwest. Behind the Sundance the stratigraphy up through the Cretaceous Frontier is homoclinally dipping to the southeast. To the southwest of this sequence is a syncline with the Sundance in fault contact with flat-lying Cody and Willwood (Fig. 1). In the southeast limb of the syncline the Sundance Formation does not reappear and the Morrison limb is faulted against itself. The bedding of the Morrison Formation to the southeast is overturned as demonstrated by ripple marks and the absence of its characteristic basal conglomerate unit. Cloverly bedding is also overturned and in fault contact with its upright self which leads into a homoclinally dipping sequence through the Frontier. Figure 1 reveals some salient points about the behavior of the upper plate. Because the kinematics of the region are not well constrained it is difficult to characterize the sense of motion on faults. It is also unclear whether the fault at the base of the Sundance is the SFD or perhaps a back-thrust. As constructed, Figure 1 mandates that the sequence was emplaced by faulting and tightly folded thereafter. The possibility of a back-thrust and folding of such implies a significant amount of deformation following emplacement in a relatively short period.

Other observations can be said to support multiple stages of deformation. Invoking Pumpelly's Rule, the mesoscopic folding abundant in units such as the Sundance, Morrison, and Frontier could be a paradigm for the larger scale deformation of the upper plate as a whole. The syncline to ancestral anticline sequence in Figure 1 is compatible with observations of the large exposure continued to the southwest. Many cross-sections of this exposure's sequence have been created in an effort to understand the range of magnitude of deformation as well as the behavior of the detachment fault. Viable cross-sections include the detachment dipping to the northwest with transport to

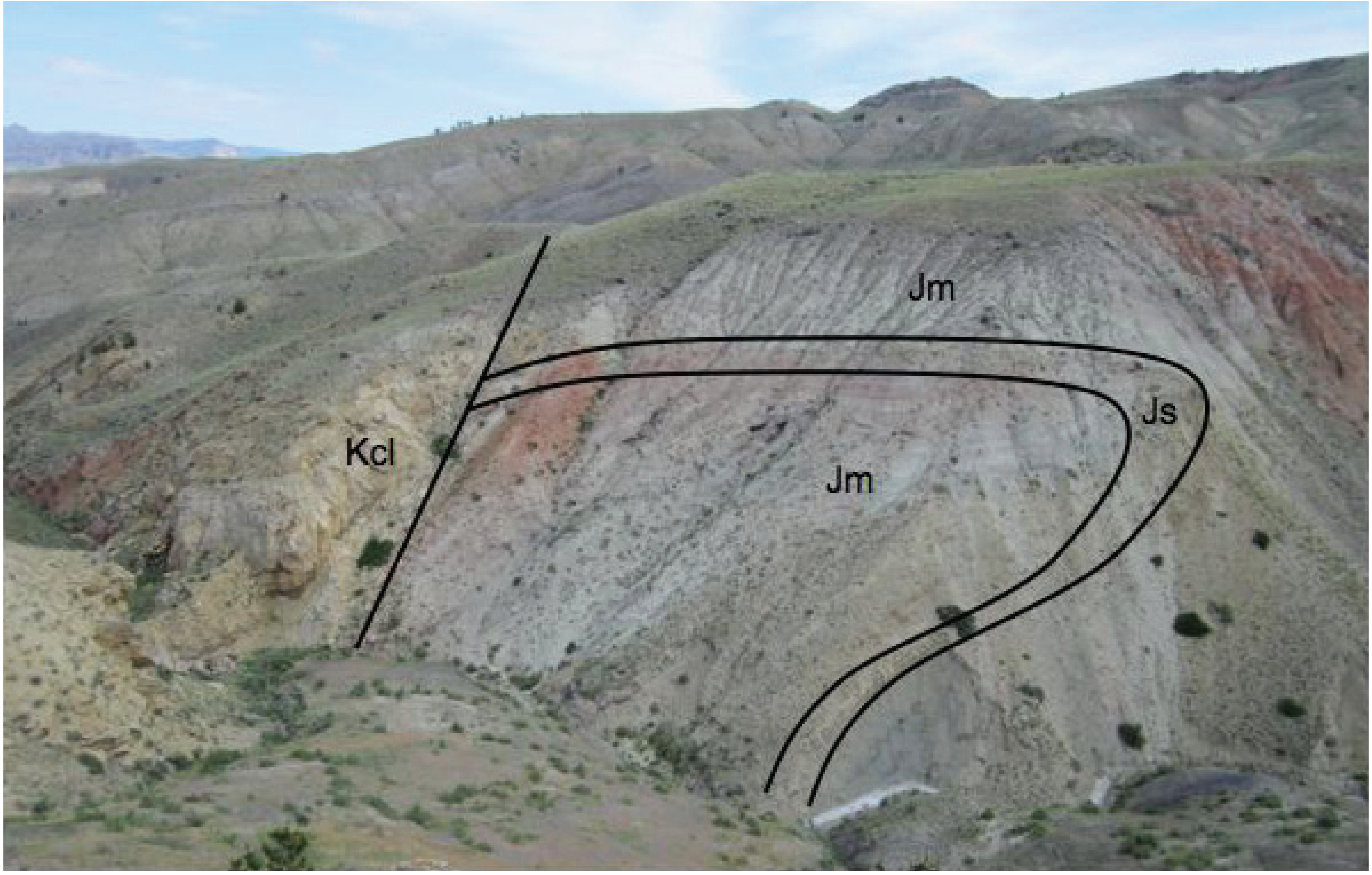

Figure 2. Jurassic Sundance (Js) bedding, less than 1 meter thick, folded and bounded on either side by Jurassic Morrison Formation (Jm) and cut by Cloverly Formation (Kcl).

the southeast, and dipping to the southeast with transport to the northwest. Others drafted show the fault to be folded post-transport which is possible either to the northwest of southeast. (The SFD could also potentially be a rootless detachment based on some models.) From these many permutations of the sequence there may have been as little as a couple of kilometers of shortening, or there may have been significantly more resulting from macroscopic scale folding.

The exposures of the SFD units are beset with numerous complexities, many relating to units out of stratigraphic sequence. One such example is a sequence in the western extent of the mapping area in which Sundance is overlain by Morrison, but the Sundance is then repeated above the Morrison. The relationship between these two units is variable throughout the field area. Another example is a nearby outcrop which shows a thin bed of Sundance folded and bound on either side by Morrison (Fig. 2). This strange sequence is abruptly truncated by a dipping bed of Clovery Formation. These two examples of odd bedding relationships are relatively proximal to one another and so an effort has been made to develop a history that might account for both observations. Figure 3 shows a theoretical sequence of events which begins with a nearly isoclinal anticline, proven possible by cross-sections. In this history the fold hinge is cut by a low-angle fault and transported to the top to the northwest. While in transport, underlying Morrison is thrust up between the limbs of the Sundance, infilling and denuding the Sundance. Finally, the remnant of the fold hinge with a thinned bed of Sundance and in-filled Morrison comes to rest against the Cloverly Formation. This series of events also could have deposited a piece of relatively flat lying Sundance above the Morrison to yield the sequence described.

STABLE ISOTOPE ANALYSIS

Four samples were collected in the field for stable iso-

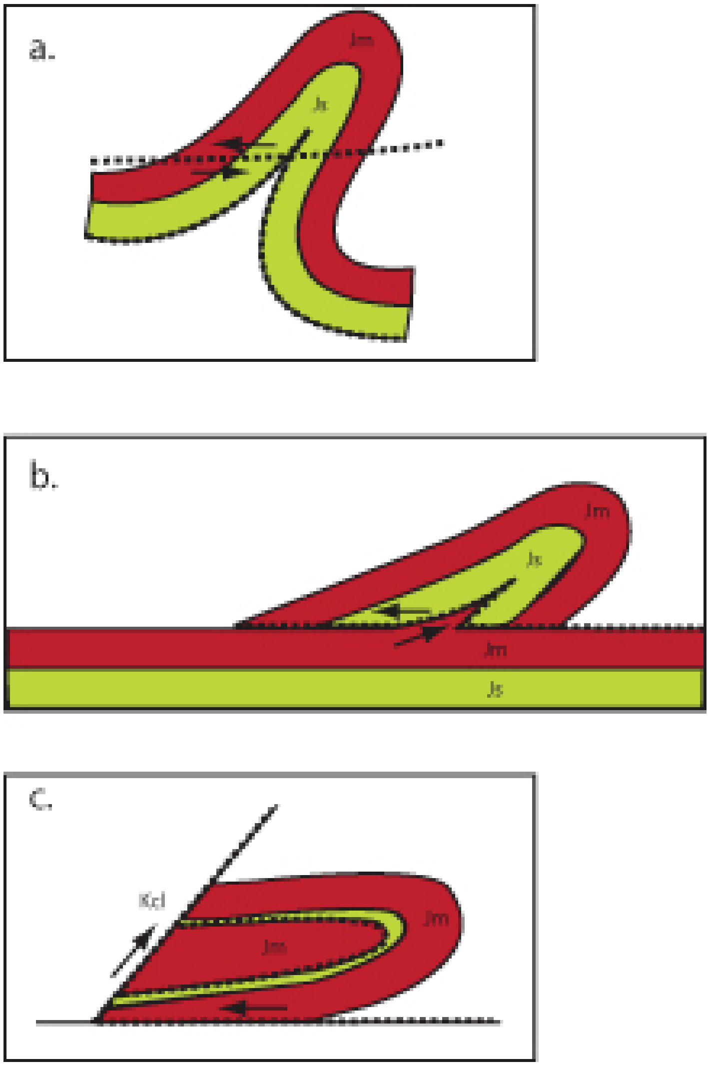

Figure 3. Theoretical development of the sequence pictured in Figure 2.

tope analysis. These included a sample of Sundance host rock and slickenfiber mineral deposits of mainly quartz, calcite, and gypsum found as fault float from one location. An additional sample of Sundance fault float from a second location, and a sample of fault slip from the Morrison were also collected. These samples were prepared according to the methods described by de Groot (2008) and analyzed using a thermal ionization mass spectrometer in Colgate University's Stable Isotope Lab. The results of δ^{18}O were corrected for acid fractionation at 50°C (Swart et al., 1991). The Sundance host carbonate yielded δ^{18}O and δ13C values of 29.84‰ and 2.71‰, respectively, and the fault float (Jurassic Sundance Gouge) showed a δ^{18}O of 16.3‰ and δ^{13}C of 1.15‰ (Fig. 4). Results from the Jurassic Sundance Slip were a δ^{18}O

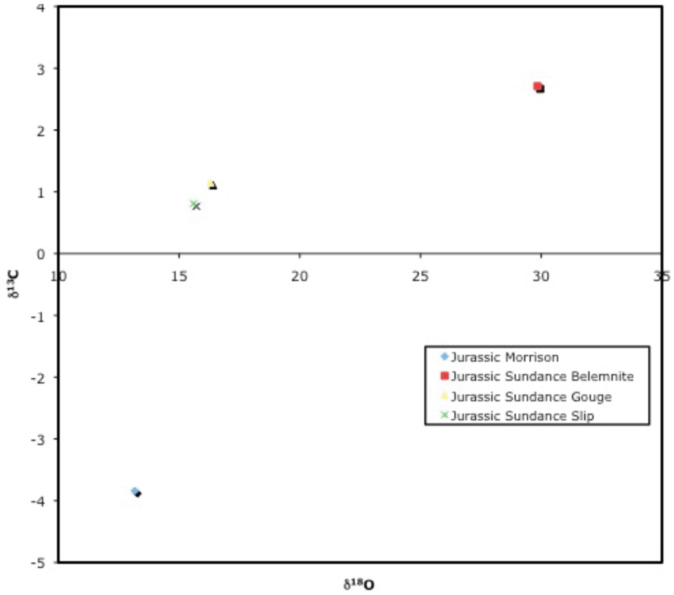

Figure 4. δ^{13}C versus δ^{18}O for host carbonates from the Jurassic Sundance Formation and fault carbonates from the Jurassic Sundance Formation and Jurassic Morrison Formation.

of 15.6‰ and a δ^{13}C value of 0.81‰. The sample of the Jurassic Morrison yielded values of 13.17‰ for δ^{18}O and -3.84‰ for δ^{13}C.

The differences in both δ^{18}O and δ^{13}C values between the Sundance host carbonate and its two fault carbonate samples are indicative of water-rock interaction. The large difference in oxygen isotope values in particular alludes to the presence of meteoric or other types of water during faulting or transport of the SFD. The results of this study can be considered in the context of the work of Doulgas et al. (2003). The focus of Douglas et al.'s research was the role of fluids in the HMD. Douglas et al. (2003) found that Eocene intrusive centers in the New World Mining District generated hydrothermal activity and that this became the source of waters involved with the HMD. The hydrothermal center lies just 5 km from the HMD breakaway and its waters are hypothesized to have been focused along the bedding plane of the HMD and even to have facilitated faulting.

The comparison of this study's results to those of Douglas et al. (2003) as well as Templeton et al. (1995) has bearing on the relationship of the HMD to the SFD which remains in question. Douglas et al. (2003) made the case that the greatest δ^{18}O depletions

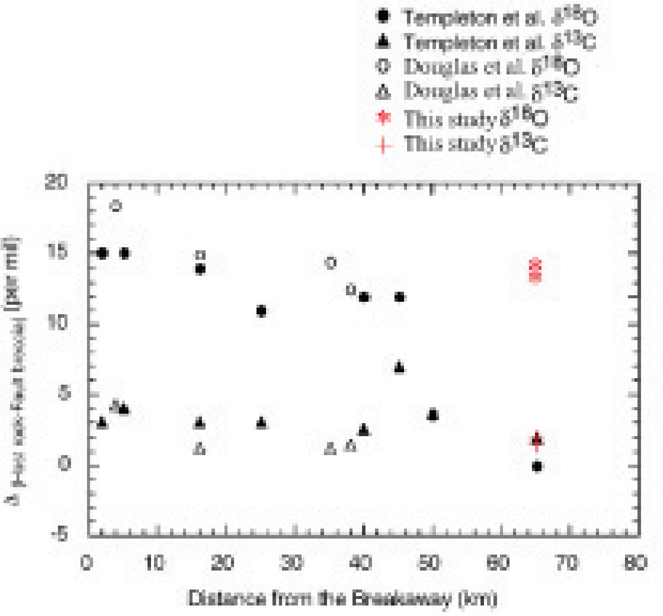

Figure 5. Modified from Douglas et al. (2003). Magnitude of isotopic depletions of fault materials relative to host rocks. Data from Templeton et al. (1995), Douglas et al. (2003), and this study (in red).

of HMD fault materials relative to the host rock was observed nearest to the breakaway and demonstrated that with increased distance to the east along the detachment, depletion decreased. Using the samples of Sundance host and fault material from this study to calculate the respective differences, the data could then be plotted as shown in Figure 5. The difference in oxygen isotopes in the samples of this study is greater than that of samples taken as close as 16 km to the HMD breakaway. This could suggest that the fluid sources for the HMD and SFP near their respecive breakaways are similar or are even the same. If such a relationship is true, it suggests the SFD and HMD may be related. However, the data may be interpreted as showing a lack of relationship between the SFD and HMD. This has implications for the theory of Beutner and Hauge (2009, 2004) that the SFD is the toe of the HMD. Theoretically, if the two were so related, the SFD could be expected to have been displaced in the same way as the HMD. Moreover, the results of Douglas et al. (2003) suggest that fluids should have played a similar role in the South Fork fault system. If the SFD were part of the HMD then the two would have the same fluid source and the same decrease in isotopic depletion with distance from the Silvergate breakaway. Because the samples of this study are 65 km from the HMD breakaway and do not fit this trend, the results suggest that the two are perhaps unrelated or that the SFD has a different fluid source.

CONCLUSIONS

New insights and mapping of the SFD in the critical area of the Belknap Creek Quadrangle provide new constraints on the geometry of the area. More thorough collection of structural data and observations have led to a more complete understanding of the local deformation. Cross-sections reveal synclines and anticlines ranging from tight to isoclinal, some of which are recumbent. These drafts also demonstrate the variability of the of the South Fork fault which can be demonstrated to dip northwest with movement to the southeast or vice versa and still satisfy surface observations. The region is also possibly characterized by a backthrust fault independent of the SFD. Cross sections also support a variety of deformational histories ranging from single to multiple-stage emplacement events and from a couple kilometers of shortening to as much as 10 km. In addition, stable isotope analyses contribute to the understanding of the relationship between the SFD and HMD. Results show that fault rock samples are depleted in oxygen and carbon isotopes relative to host rock samples. This relationship is indicative of water-rock interaction and, therefore, the presence of meteoric fluids on fault surfaces. In the context of the data from Douglas et al. (2003) and Templeton et al. (1995) the data from this study can show depending upon interpretation that the SFD and HMD are either related or unrelated. Few studies of the SFD have been conducted relative to the HMD but the results of this study suggest that further field analysis and isotope analysis will better constrain its emplacement history, especially relative to the HMD.

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