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Left-slip evolution of the North Owl Creek fault system, Wyoming, during Laramide shortening

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ABSTRACT

The kinematics of east-striking faults during the Laramide orogeny in central Wyoming are problematic. These faults are commonly interpreted as thrusts accommodating north-south shortening. In addition, they have been interpreted to postdate northwest-striking faults that accommodate northeast-southwest shortening.

Results of systematic mapping, in conjunction with a detailed kinematic study, in the west Owl Creek Mountains demonstrate that the high-angle, east-striking North Owl Creek fault is dominantly left slip. The fault is linked kinematically with the low-angle Mud Creek thrust in the western Owl Creek Mountains fault system to the east and with the low-angle Black Mountain thrust in the Washakie thrust system 50 km to the west. The role of the fault was to transfer east-northeast–west-southwest shortening between the Washakie thrust system and the west Owl Creek Mountains fault system during Laramide shortening.

A protracted deformation history is required to explain the development of the North Owl Creek fault system. The system is interpreted to have formed by propagation of two lateral ramps: one linking the Mud Creek thrust, the other linking the Black Mountain thrust. Field relations also indicate that initiation of the system was probably not controlled by the orientation of Precambrian shear zones, dikes, or foliations. Instead, they indicate that Precambrian structures and Paleozoic strata have been rotated adjacent to high-angle faults in the North Owl Creek fault system during left-slip motion.

INTRODUCTION

Major faults associated with the Laramide orogeny in central Wyoming (Fig. 1) have two dominant strikes, northwest and essentially east-west (Love and Christiansen, 1985). Knowledge of the geometry and kinematics of the northwest-striking faults has been improved significantly in the last few decades (e.g., Brown, 1988). Such improvements may be attributed to the acquisition and interpretation of seismic data (e.g., Smithson and others, 1978; Skeen and Ray, 1983; Stone, 1985), borehole data (e.g., Gries, 1983a; Blackstone, 1986), new cross-section balancing and modeling techniques for basement-involved structures (e.g., Berg, 1962; Erslev, 1986; Cook, 1988; Spang and Evans, 1988), and in particular, detailed mapping and kinematic analyses of structures (e.g., Winterfeld and Conrad, 1983; Lageson, 1987; Mitra and others, 1988; Steidtmann and Middleton, 1990).

Although limited seismic and borehole data are available (e.g., Gries, 1983b; Ray and Keefer, 1985; Dunleavey and Gilbertson, 1986; Blackstone, 1990), the east-striking faults in central Wyoming are problematic because their geometry, and in particular their kinematics, remain poorly constrained. These faults are often considered anomalous because of the non-

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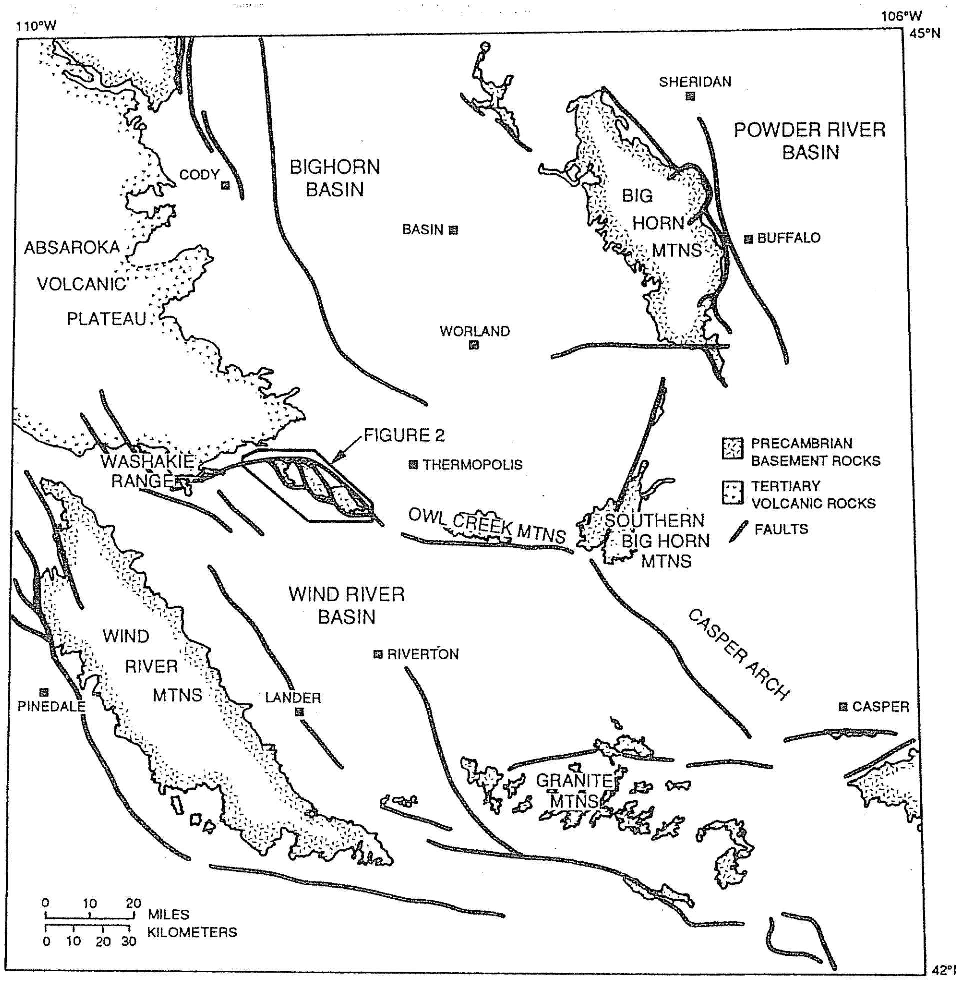


Figure 1. Index map of central Wyoming including approximate location of some of the larger magnitude faults and the location of Figure 2.

orthogonal relation between their trend and the northeast regional compression direction inferred from reconstruction of plate kinematics involving the North American and Pacific plates during the Laramide orogeny (Coney, 1978; Engebretson and others, 1984). Although numerous tectonic models have been proposed to explain the development of these faults, we group them into two possible models based on the implied kinematics: (1) east-striking faults are low-angle thrusts (e.g., Keefer, 1970; Blackstone, 1983, 1990) that postdate northwest-striking thrusts (e.g., Gries, 1983b, 1990); and (2) east-striking faults are high-angle faults that may have significant strike-slip components, and may or may not be coeval with other Laramide structures (cf. Sales, 1968; Stone, 1969; Lowell, 1974; Brown, 1988). In addition, the attitudes of these faults commonly correlate with and are therefore interpreted to be controlled by preexisting zones of weakness in the basement (e.g., Hoppin and others, 1965; Allison, 1983; Brown, 1984, 1988). Despite these speculations on the kinematics of east-striking faults, constraints on their slip direction and magnitude of displacement have never been established.

The present study is part of an ongoing investigation of the kinematics of major faults in the western Owl Creek Mountains, central Wyoming (e.g., Paylor, 1989; Paylor and Lang, 1990). This chapter presents results of one phase of this research, including recent field mapping, aided by interpretation of Landsat Thematic Mapper data and aerial photographs, and structural analysis of the east-striking, Laramide, North Owl Creek fault. The goal of the present study is to determine the direction and magnitude of slip along the North Owl Creek fault in order to constrain the proposed tectonic models. The data reveal that the fault is not dip slip, and that the fault and its associated structures can be explained best as the result of dominantly strike-slip displacement compatible with east-northeast–west-southwest regional contraction. We first describe the geometry and kinematics of the fault and its associated structures, including its relation to structures in the Precambrian basement. We then present a model relating the development of this fault with Laramide faults in the southeastern Washakie Range and discuss the implications of our structural interpretation for regional tectonic development of the area.

GEOLOGIC SETTING

The study area is located in the western Owl Creek Mountains, east of the Washakie Range and southeast of the Absaroka volcanic plateau, central Wyoming (Fig. 1). The North Owl Creek fault lies along the north flank of the western Owl Creek Mountains and separates the Wind River Basin to the south from the Bighorn Basin to the north. As defined originally by Long (1959), the North Owl Creek fault system includes only east-striking faults bounding the north end of Phlox Mountain anticline (Fig. 2). For this chapter, we extend this original definition to include (Fig. 2): (1) the entire North Owl Creek fault; (2) the northern segment of the Mud Creek thrust; and (3) other mesoscopic- and macroscopic-scale faults and folds adjacent to, and related kinematically to, the North Owl Creek fault.

Three en echelon, basement-cored, northwest-trending anticlines compose the east-trending, western Owl Creek Mountains (Fig. 2). With the exception of the southwest-dipping Mud Creek thrust bounding the eastern side of Jenkins Mountain anticline (Blackrock Ridge of Flanagan, 1955), each anticline is bounded on its southwest limb by thrust faults dipping 30° to 60° to the northeast. These thrusts are terminated to the southeast by a suite of east-striking high-angle faults that vary in dip from north to south and bound the southern end of basement exposures in the core of each anticline. To the northwest, these thrusts and anticlines are terminated by the east-striking, high-angle North Owl Creek fault.

The stratigraphic sequence in the sutdy area is well understood (Fig. 3). The oldest rocks include granite, granite gneiss, amphibolite, and mafic dikes of Precambrian age. Cambrian rocks include both competent sandstones in the Flathead Formation, which preserve highly polished slickensided shear surfaces in fault zones, and incompetent shaley units of the Gros Ventre and Gallatin formations, which are typically intensely sheared and attenuated in fault zones. Carbonates in the Ordovician Bighorn Dolomite and the Mississippian Madison Limestone are cliff forming and deformed cataclastically. Sandstones and shales in the Pennsylvanian Amsden Formation are generally missing in fault zones due to attenuation by faulting. Quartzarenites in the Pennsylvanian Tensleep Sandstone are well exposed near faults and preserve numerous slickensided shear surfaces. Limestones in the Permian Phosphoria Formation and sandstones and siltstones in the Triassic Chugwater Formation are typically attenuated and folded adjacent to major faults. Jurassic, Cretaceous, and Tertiary strata are not typically exposed along the North Owl Creek fault in the study area, but are exposed along the margins of the western Owl Creek Mountains.

Contrasting structural interpretations have been proposed recently for the North Owl Creek fault system. Brown (1988) proposed that the east-striking North Owl Creek fault is high angle and left slip, and links kinematically with the southwest-dipping Mud Creek thrust, which is mainly dip slip; together, these faults form the sole thrust upon which the western Owl Creek Mountains were transported to the northeast. In this model, left slip is due to the nonorthogonal relation between the east strike of the North Owl Creek fault and the regional northeast compressional direction. Brown (1988) speculated that the North Owl Creek fault may result from Laramide reactivation of preexisting anisotropies in the basement. Sundell (1990) also interpreted left slip on the North Owl Creek fault and inferred a

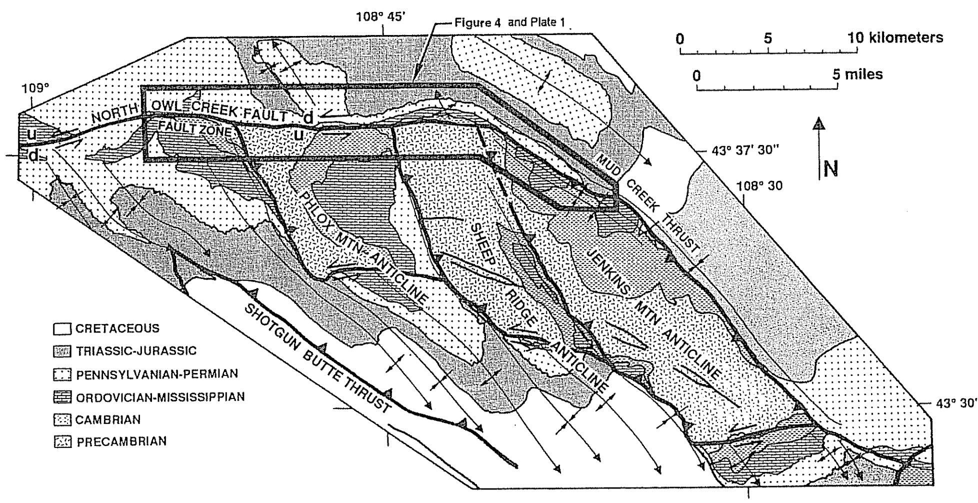
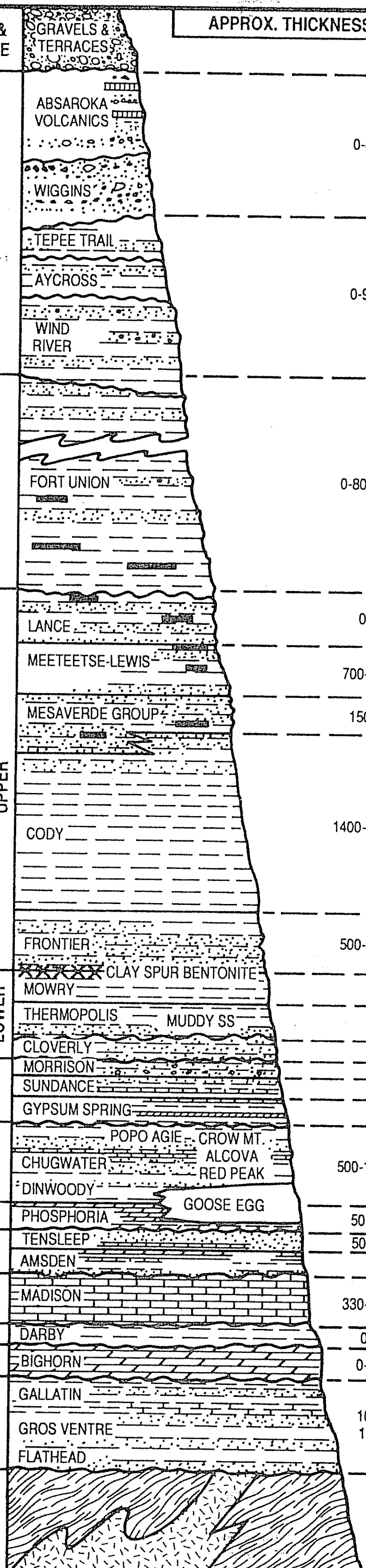


Figure 2. Generalized geologic map of the western Owl Creek Mountains and location of Figure 4. The map is a compilation of our own work and that of Masursky (1952), Flanagan (1955), Powell (1957), Phillips (1958), Long (1959), McGreevy and others (1969), Keefer and Troyer (1964), Keefer (1970), and Blundell (1988).



Era	Period	Epoch	Formation	Approx. thickness	General outcrop description
CENOZOIC	QUAT.	HOLOCENE & PLEISTOCENE	GRAVELS & TERRACES		NUMEROUS TERRACES OR BENCHES NEAR MAJOR DRAINAGES. LOCALLY INCLUDES 600,000 YR OLD LAVA CREEK ASH.
CENOZOIC	TERTIARY	EOCENE	ABSAROKA VOLCANICS	0-4000' +	IGNEOUS FLOW ROCKS, VOLCANIC-DERIVED SEDIMENTS, DIKES, SILLS, PLUGS.
			WIGGINS		GRAY, WHITE, VOLCANIC-DERIVED SHALE, SANDSTONE, CONGLOMERATE, BRECCIA. PLUGS, DIKES, AND SILLS PREVALENT.
			TEPEE TRAIL, AYCROSS	0-9000' +	VARIEGATED VOLCANICLASTICS INCLUDING DRAB SANDSTONE AND SHALE.
			WIND RIVER		BRIGHTLY COLORED (MOSTLY REDS) SHALE, CLAYSTONE, SANDSTONE (CONGLOMERATIC IN PART). RARE FLUVIAL AND LACUSTRINE LIMESTONES. FORMS BAD LANDS.
		PALEOCENE	FORT UNION	0-8000' + -	DRAB SANDSTONE, MUDSTONE, AND COAL BEDS. SOME FOSSIL LEAVES. GENERAL TAN APPEARANCE ON OUTCROP.
MESOZOIC	CRETACEOUS	UPPER	LANCE	0-6000'	SANDSTONE, SHALE, AND FEW COALS. FORMS RESISTANT RIDGES.
			MEETEETSE-LEWIS	700-1500'	MASSIVE WHITE SANDSTONES, AND MANY THIN SHALES AND COALS. GENERALLY LESS RESISTANT THAN FORMATION ABOVE OR BELOW.
			MESAVERDE GROUP	1500' + -	SANDSTONE, SHALE, COAL. FORMS RESISTANT RIDGES.
			CODY	1400-4700'	GRAY, BLACK SHALE, FEW THIN SANDSTONES. MICROFOSSILS AND MEGAFOSSILS ABUNDANT. FORMS VALLEY AND FLAT AREAS.
			FRONTIER	500-1000'	FORMS AN ALTERNATING SERIES OF SANDSTONE RIDGES AND SHALE VALLEYS.
			CLAY SPUR BENTONITE		
		LOWER	MOWRY	370'	FORMS ROUNDED STEEP SLOPES WITH SOME RESISTANT. SILICEOUS BANDS. SILVER-GRAY COLOR ON OUTCROP.
			THERMOPOLIS, MUDDY SS	700'	DARK GRAY TO BLACK SHALE. MUDDY SANDSTONE MEMBER, NEAR CENTER OF SECTION, GENERALLY POORLY RESISTANT.
			CLOVERLY	300'	THIN SANDSTONES AND SHALES, TAN TO BROWN, SIDERITIC. SOME CONGLOMERATE LENSES IN LOWER PART.
	JURASSIC		MORRISON	200'	SHALES, SUBWAXY, AND SOME SANDSTONE AND CONGLOMERATE. WHITE AND LIGHT RED APPEARANCE ON OUTCROP.
			SUNDANCE	200'	GLAUCONITIC SANDSTONE. THIN LIMESTONES AND SHALES. GREENISH COLOR ON OUTCROP.
			GYPSUM SPRING	275'	GYPSUM, SHALE, AND THIN LIMESTONE. LIGHT RED, PINK, AND WHITE ON OUTCROP.
	TRIASSIC		POPO AGIE; CHUGWATER (CROW MT., ALCOVA, RED PEAK)	500-1200'	RED, MAROON SANDSTONE AND SHALE. PALER DINWOODY AT BASE. BEDDED GYPSUM.
			DINWOODY	50'	
PALEOZOIC	PERMIAN		PHOSPHORIA; GOOSE EGG	50-300'	GRAY LIMESTONE. FORMS RESISTANT DIP SLOPES.
	PENNSYLVANIAN		TENSLEEP	50-300'	CLIFF-FORMING, CROSS-BEDDED SAND.
			AMSDEN	300'	DOLOMITE, RED SHALE, SANDSTONE.
	MISSISSIPPIAN		MADISON	330-900'	CLIFF-FORMING. LIGHT GRAY LIMESTONE GROUP.
	DEVONIAN		DARBY	0-250'	SHALE AND DOLOSTONE.
	ORDOVICIAN		BIGHORN	0-500'	MASSIVE, TAN, CLIFF-FORMING DOLOSTONE.
	CAMBRIAN		GALLATIN, GROS VENTRE, FLATHEAD	1000-1200'	POORLY RESISTANT LIMESTONES, SANDSTONES, AND SHALES. GENERALLY HELD UP BY THE OVERLYING RESISTANT BIG HORN DOLOMITE.
PRECAMB.					ARCHEAN AMPHIBOLITE, GNEISS, AND SCHIST INTRUDED BY ARCHEAN AND PROTEROZOIC GRANITE, MAFIC AND FELSIC DIKES.

kinematic linkage between it and thrusts in the southern Washakie Range. Regional tectonic models proposed by Sales (1968) and Stone (1969) also depicted the North Owl Creek fault as left slip; the inferred regional boundary conditions in these models are simple shear and pure shear, respectively.

In contrast to the aforementioned models, Gries (1983b) proposed that the North Owl Creek fault and the Mud Creek thrust are a single back thrust, accommodating dip-slip displacement, in the hanging wall of a northeast-dipping, blind, sole thrust (Shotgun Butte thrust in Fig. 2) bounding the southwest flank of the mountain range. The inferred transport direction of the range in this model is to the south-southwest. A similar interpretation was proposed by Blackstone (1990). Murphy and others (1956), Long (1959), and Gries (1983b) also suggested that the North Owl Creek fault and other east-west–striking faults in this region resulted from a north-south compression that occurred after a northeast-southwest compression produced the northwest-trending structures.

STRUCTURE OF THE NORTH OWL CREEK FAULT SYSTEM

The North Owl Creek fault system is exposed over a distance of ~30 km in the mapped area (Fig. 4, Plate 1). Topographic relief along the east-trending North Owl Creek fault, a major component of the system, is ~400 m. The exposed faults in the system are not individual dislocation surfaces, but are shear zones. The width of each shear zone varies along strike, from 2 to ~10 m. For the following discussion, we divide the North Owl Creek fault system into the eastern and central segments based on fault geometry and characteristics of associated mesoscopic- and macroscopic-scale structures. An extension of this fault system to the west is suggested, but is only described briefly in the discussion section of this paper because we have not yet examined it specifically for kinematic indicators.

Eastern segment

The eastern segment of the North Owl Creek fault system extends approximately from locations A to D in Figure 4. The North Owl Creek fault and the Mud Creek thrust zone join in this segment. The Mud Creek thrust consists of a zone of reverse faults dipping 30°–60° to the southwest (Figs. 4 and 5A, A-A′, B-B′). Lower Paleozoic strata in the hanging wall are folded into a tight anticline. Bedding in the fault zone and footwall is generally overturned to subparallel with the thrusts (Plate 1). Most of the incompetent stratigraphic units are missing in the overturned limb due to attenuation during thrusting. A tight overturned syncline is present in the Triassic Chugwater Formation in the footwall of the thrust; its hinge is parallel to the thrusts. Striations plunging ~48°, S75W (location A, Fig. 4), tension gashes, and fold hinges measured in and near the thrust zone indicate that the slip direction is N70°–80°E along the Mud Creek thrust. Restoration of the Precambrian-Cambrian contact in cross-sections A-A′ and B-B′ yields 0.9–1.1 km of shortening associated with this northern segment of the Mud Creek thrust.

The North Owl Creek fault and the Mud Creek thrust zone join near location B (Figs. 4 and 5A, C-C′). It is important to note that neither fault cuts the other, implying that they were coeval. The North Owl Creek fault is a single fault dipping ~65° to the south-southwest at this location. One slickensided shear surface with striations oriented 32°, S84°W indicates oblique slip along this curved segment of the fault. This slip direction is consistent with that determined for the Mud Creek thrust zone. Thus, this segment of the North Owl Creek fault may be a lateral ramp (e.g., Boyer and Elliot, 1982) linked with the Mud Creek thrust.

The overturned syncline in the footwall of the Mud Creek thrust dies out at location B (Fig. 4). In addition, folds in the hanging wall of the Mud Creek thrust are terminated at the North Owl Creek fault and cannot be identified north of the fault. Unlike bedding adjacent to the Mud Creek thrust, bedding west of location B is generally not subparallel to the trace of the North Owl Creek fault (Plate 1). Bedding contacts on the south side and adjacent to the fault at location C (Plate 1) appear to be rotated counterclockwise between faults, interpreted to be caused by drag due to left slip along the fault. Steeply-dipping slickensided shear surfaces in the Precambrian basement immediately adjacent to the fault at location D have a variable strike but indicate dominantly strike-slip displacement, compatible with other measurements.

North of the North Owl Creek fault, between locations D and E (Fig. 4), an open anticline plunges gently north-northwest. The anticline terminates southeastward at the North Owl Creek fault.

Central segment

The central segment of the North Owl Creek fault extends approximately from location E to N (Fig. 4). Beginning near location G, there are two main faults (referred to here as the northern and southern faults) that join near location N. The northern fault dies out eastward, east of location G, near several northwest-trending mesoscopic-scale folds. The southern fault is continuous from the eastern segment and continues into the western segment (west of location N). Both faults generally dip steeply to the south; locally, however, the faults dip steeply to the north. The southern fault exhibits the greatest and most variable vertical stratigraphic separation (measured by the offset of the Precambrian-Cambrian contact), ~1800 m up to the south, as shown in cross-section D-D′ (Precambrian-Cambrian contact is projected into the cross section on the south side of the fault) (Fig. 5A), and only 180 m up to the north, as shown in cross-section H-H′ (Fig.

Figure 3. Generalized stratigraphic column for the Owl Creek Mountains region, central Wyoming (from Paylor and Lang, 1990).

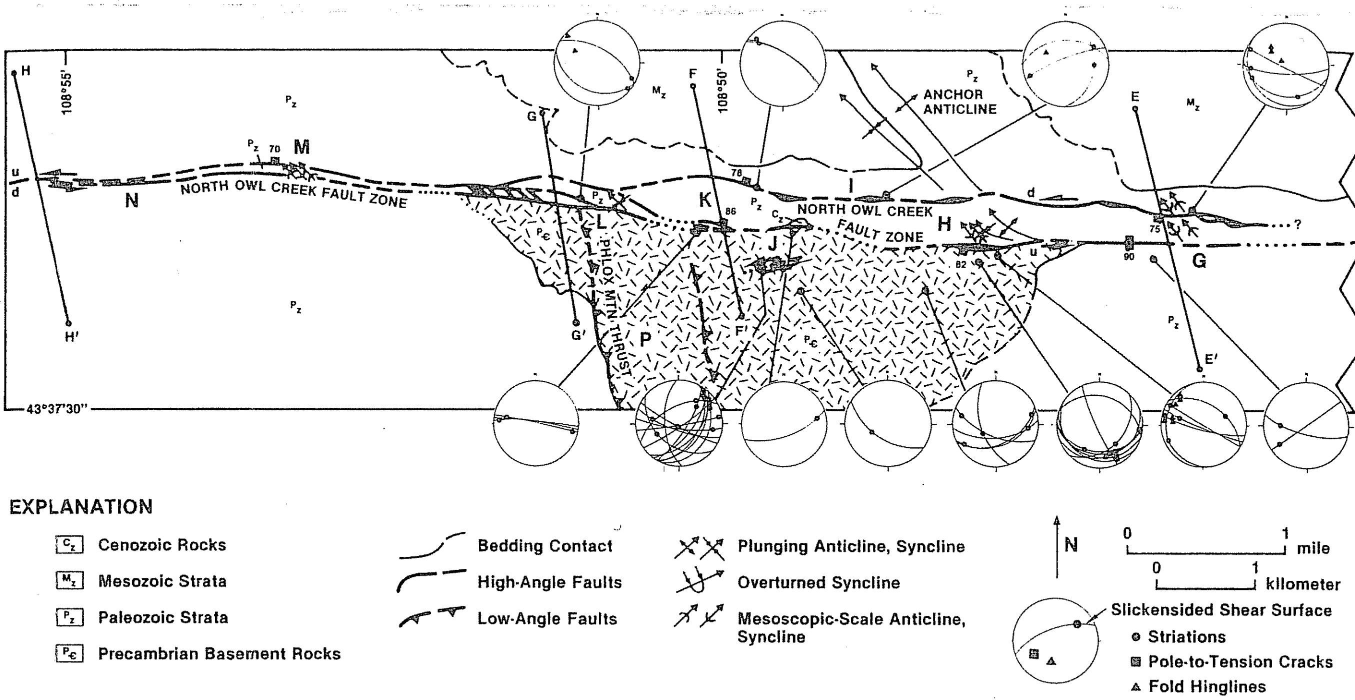


Figure 4. Simplified tectonic map of the North Owl Creek fault system, which includes the North Owl Creek fault, the Mud Creek thrust, and mesoscopic and larger-scale structures adjacent to the main faults. Equal-area, lower-hemisphere projections of kinematic data measured along the fault zones are included. Large letters refer to locations discussed in text. Plate 1 provides additional geologic information for this area, including stratigraphic contacts, dike locations, and strike/dip and foliation measurements.

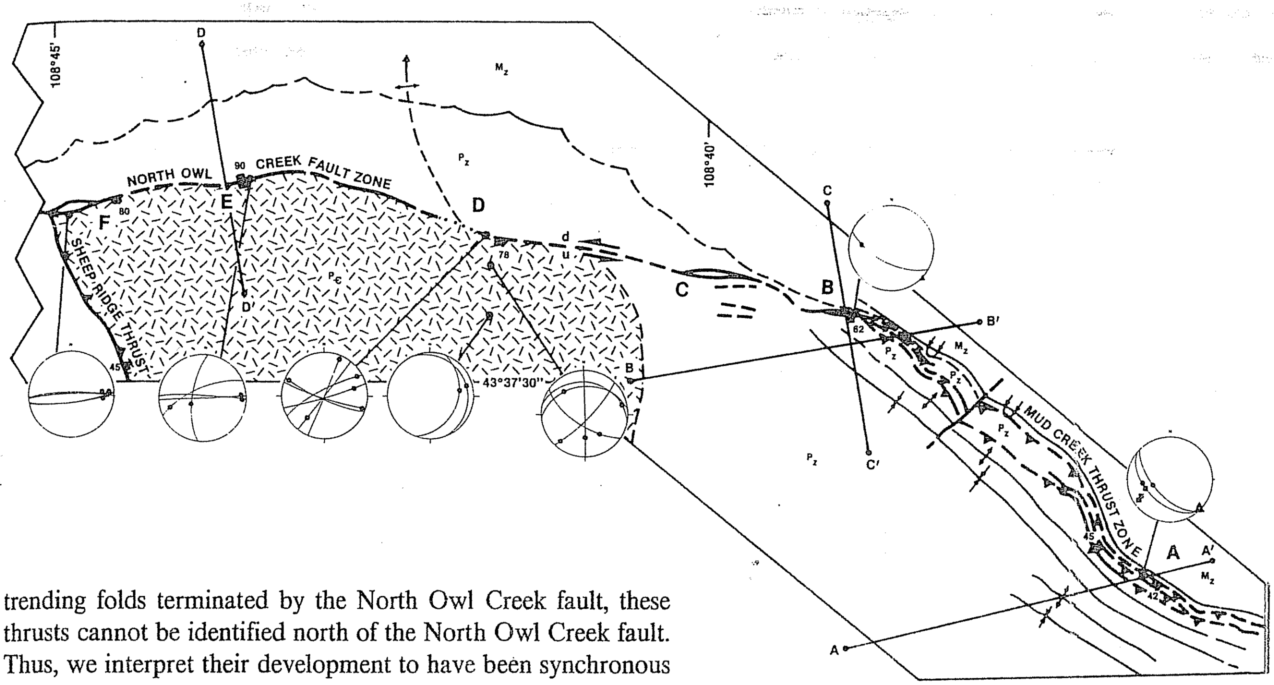
5B). Vertical separation on the northern fault is typically less than 300 m (Fig. 5, A and B). The above relations indicate that the southern fault is the main North Owl Creek fault.

Striations measured at locations E, F, H, and J on the southernmost fault plunge both westward and eastward. Because the plunge angle is typically less than 30°, subhorizontal or strike-slip motion along the fault is implied. South of location H, south of the fault in the Precambrian basement the striations on slickensided shear surfaces indicate north-northwest–south-southeast normal displacement. Striations measured at locations G, I, and K, on the northern fault plunge less than 30° westward and eastward, indicating that it also is dominantly a strike-slip fault.

Bedding between the two faults exhibits variable dip directions (Plate 1). Locally, bedding is upturned steeply or overturned adjacent to the faults. North of the northern fault, and south of the southern fault, however, the regional dip of bedding is northeastward and gentle.

Unlike folding associated with the Mud Creek thrust, folds associated with the central segment are oriented obliquely to, and are typically terminated by, the North Owl Creek fault (Fig. 4, Plate 1). These folds include mesoscopic-scale folds (1 to 30 m wavelengths) adjacent to the faults at locations G, H, I, L, and M, as well as larger-scale folds (hundreds to thousands of meters wavelengths) at locations D, H, O (Sheep Ridge anticline-syncline), and P (Phlox Mountain anticline-syncline) (see Fig. 2). Hinges of both the mesoscopic- and larger-scale folds trend northwest. Fold hinges southeast of location H appear to be rotated counterclockwise to subparallel with the southern fault. All folds are interpreted to have developed coevally with the North Owl Creek fault because the folds are not cut and offset by the fault (i.e., they cannot be found on both sides of the fault). The orientations of these fold hinges thus suggest left slip along the North Owl Creek fault.

Two major thrusts are terminated to the northwest by the North Owl Creek fault: the Phlox Mountain thrust on the southwest limb of the Phlox Mountain anticline (location P, Fig. 4) and the Sheep Ridge thrust on the southwest flank of Sheep Ridge anticline (location O). A third, the Jenkins Mountain thrust on the southwest flank of the Jenkins Mountain anticline, may also extend northward and terminate against the North Owl Creek fault (Fig. 2). These thrusts dip between 40° and 50° to the northeast. Striations, tension gashes, and fold hinges measured in the thrust zones indicate a west-southwest transport direction (Paylor, 1989; Paylor and Lang, 1990), which is consistent with the slip direction reported here for the North Owl Creek fault and Mud Creek thrust. Similar to the northwest-



trending folds terminated by the North Owl Creek fault, these thrusts cannot be identified north of the North Owl Creek fault. Thus, we interpret their development to have been synchronous with movement along the North Owl Creek fault.

Numerous minor faults are also present in the central segment near locations K and L between the northern and southern faults (Fig. 4). These minor faults strike west to northwest. Striations measured at locations K and L plunge between 10° and 30° to the west-northwest or east-southeast. These faults branch off the southern fault and link to the northern fault obliquely and resemble P shears in a simple-shear system (e.g., Tchalenko, 1970; Swanson, 1990).

In the Precambrian basement, ~400 to 500 m south of the southern fault (south of locations J and H), several outcrops of faulted basement were encountered. Like other outcrops of Precambrian basement near faults, the orientation of striations and the attitude of slickensided shear surfaces are highly variable; however, many are consistent with those measured on the northern and southern segments of the North Owl Creek fault. The map alignment of these outcrops is coincident with a curious break in topography and is parallel with the southern fault, suggesting that there may be a third strand of the North Owl Creek fault near this location.

Volcaniclastic rocks belonging to the Absaroka volcanic group are cut by the North Owl Creek fault at location J (Fig. 4) (see also Masursky, 1952; Paylor and Lang, 1990). This outcrop helps delimit the timing of latest fault motion at this location to be approximately post–middle Eocene (Love, 1939; Sundell, 1982). These rocks are currently being dated.

Relation to preexisting structures in the Precambrian basement

Structures in Precambrian basement rocks south of the North Owl Creek fault are shown mainly in the central segment (Plate 1, Fig. 4). Foliation is defined by compositional banding of dominantly quartz-rich and feldspar-rich layers, and a few biotite-rich layers. On average, foliation dips to the northeast (see also Long, 1959). Northeast-dipping Precambrian mylonitic shear zones, presumably Precambrian in age, are mapped near location J and south of location H. East-plunging stretching lineations and rotated feldspar porphyroclasts indicate dominantly top-to-the east sense of shear for these zones. Precambrian mafic dikes that trend west-northwest are abundant in the basement (Long, 1959; Blundell and Marrs, 1991) and cut the foliation. Locally, however, foliations immediately adjacent to the dikes are rotated parallel to the dikes.

Directly south of the North Owl Creek fault, the strike of the foliation is dominantly west-northwest. Elsewhere, except where effected by minor faults and/or dikes, the strike is generally northwest (see also south of location D in the eastern segment). Paleozoic rocks exhibit a similar change in strike southward away from the North Owl Creek fault (i.e., beds strike parallel or subparallel to the fault immediately south of the fault, and strike more northerly, southward) (Plate 1). We have observed that: (1) the intensity of microfaulting (with shear surfaces of variable attitudes) increases near faults causing disruption and/or rotation of foliations from their regional northwest trend; and (2) foliations sometimes appear rotated in rigid blocks between two faults (much like the Paleozoic stratigraphic contacts near location C).

Blundell and Marrs (1991) demonstrated that the dominant trend of fractures in the basement of the Sheep Ridge anticline (Fig. 2) is east-west. They suggested that these fractures were responsible for transferring shortening strain from northwest-

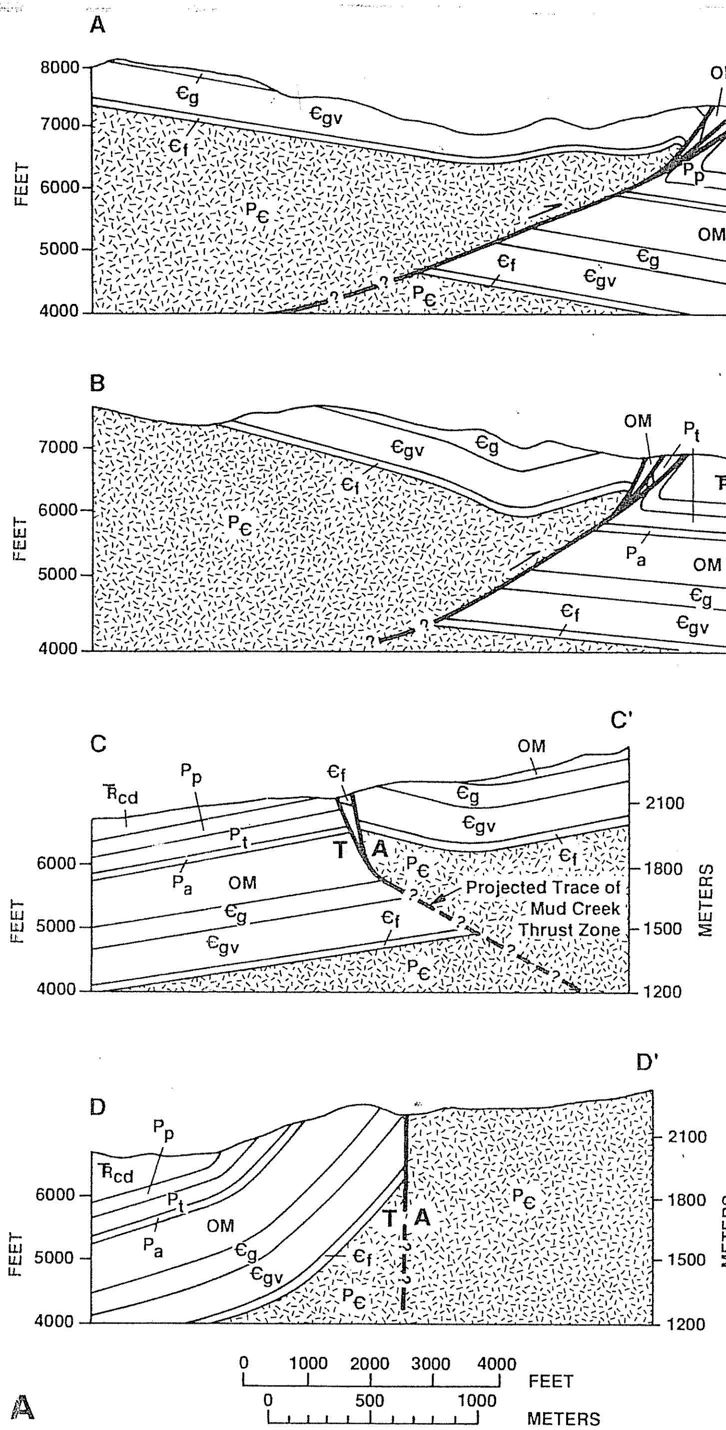
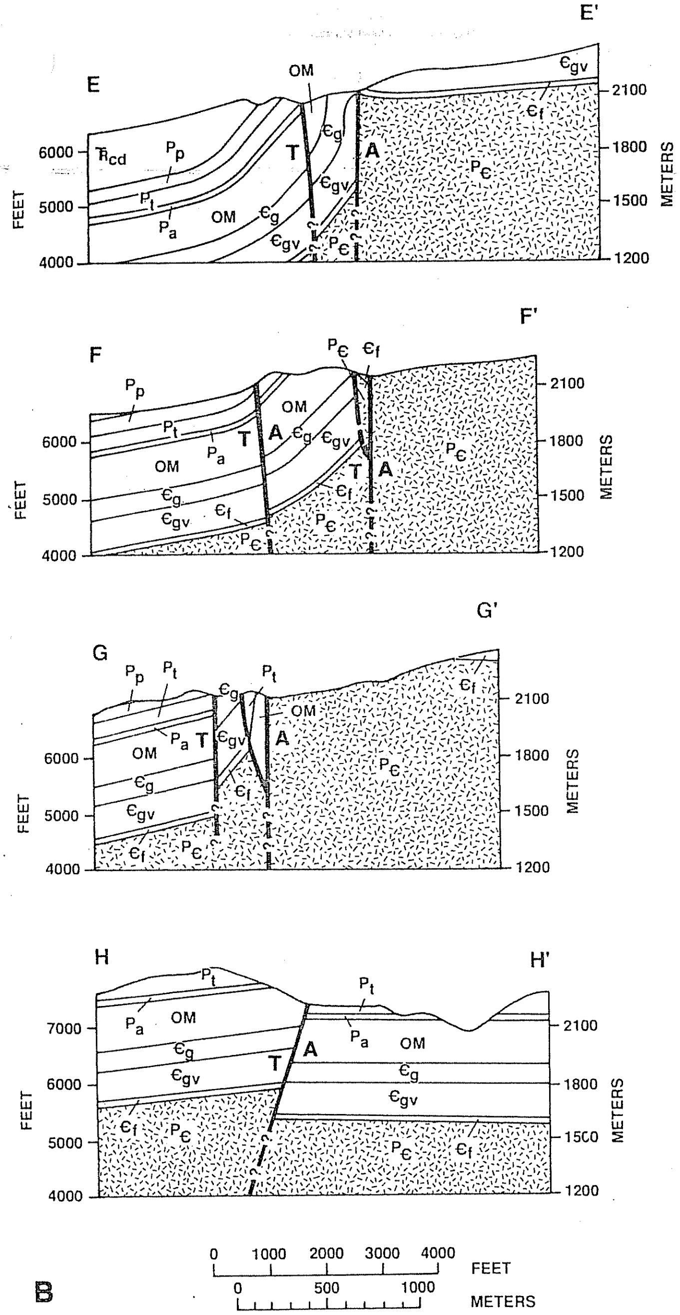


Figure 5. Geologic cross sections of the North Owl Creek fault system. See Figure 4 for location of section lines, and Plate 1 for explanation of symbols. T indicates fault motion toward viewer, A indicates fault motion away from viewer. Horizontal scale equals vertical scale. A: Cross sections A-A′ and B-B′ across the Mud Creek thrust, and C-C′ across the eastern segment of the North Owl Creek fault. Cross section D-D′ is across the central segment of the North Owl Creek fault. B: Cross sections E-E′, F-F′, G-G′, and H-H′ are across the central segment of the North Owl Creek fault.



striking thrusts to themselves, thereby initiating development of east-striking faults, such as the North Owl Creek fault. The age of these east-striking fractures, however, is unknown.

On the basis of our mapping, preexisting structural elements in the basement rocks, including foliations, dikes, and ductile shear zones, are cut by the North Owl Creek fault. In fact, as described above, foliation in the basement appears to be rotated adjacent to and between faults. This interpretation implies that the present orientation of structures in the Precambrian basement may be controlled by, but does not necessarily control, the younger Laramide structural trends in this area.

DISCUSSION

Western extension of the North Owl Creek fault system

We interpret the North Owl Creek fault system to extend farther west than previously described, and to include the area west of location N (Fig. 4) to the southern end of the Washakie Range. Although this segment of the fault system has not yet been studied kinematically, it is important because we interpret it to be linked kinematically with faults in the southeastern Washakie Range (Fig. 1). At the western edge of the area shown in Figure 4, the dip of the North Owl Creek fault is to the north and the sense of vertical separation is up to the north, opposite to that in the eastern and central segments. West of the area of Figure 4, large-scale folds are oriented obliquely to, and are terminated by, the North Owl Creek fault (Masursky, 1952; Blackstone, 1990), similar to folding in the central segment.

Love (1939) mapped a north-dipping fault approximately bounding the southern end of basement exposures in the Mountain Meadows anticline, southeastern Washakie thrust system (Fig. 6). Evans (1987) also mapped the fault and called it the Trail Ridge fault. Blackstone (1990, Fig. 2) formally named this the Red Creek fault and depicted it terminating into a series of northwest-trending folds a few kilometers west of the western end of our mapped area (Fig. 4, Plate 1). Blackstone (1990) interpreted the Red Creek fault to be en echelon with, not continuous with, the North Owl Creek fault, and the North Owl Creek fault and the Red Creek fault to be south- and north-dipping reverse faults, respectively. He suggested, however, that because of its east-west strike in relation to the inferred Laramide northeast-southwest compression direction, there may be some left-oblique motion on the Red Creek fault. In contrast, Masursky (1952) connected the Red Creek and North Owl Creek faults. In addition, he mapped several parallel, east-striking faults and northwest-striking faults that appear to link the east-striking faults in the area where Blackstone (1990) depicted the faults overlapping (near the dashed segment of the North Owl Creek fault in Fig. 6).

Our geometric interpretation is similar to that of Masursky (1952), that the North Owl Creek and Red Creek faults are connected. Our kinematic interpretation is similar to that suggested by Blackstone (1990), that left slip is likely along the Red Creek fault. As such, the geometric problem of linking the North Owl Creek and Red Creek faults does not exist because reversals in dip direction and stratigraphic separation are expected along strike-slip faults (e.g., Stone, 1969; Naylor and others, 1986; Sylvester, 1988). However, even if these two faults are not linked physically, we interpret them as being part of the same North Owl Creek fault system, exhibiting compatible left-slip displacements, and, therefore, they are linked kinematically.

Shortening direction along the North Owl Creek fault system

Observations along the North Owl Creek fault system, including its western extension, the Red Creek fault, indicate that

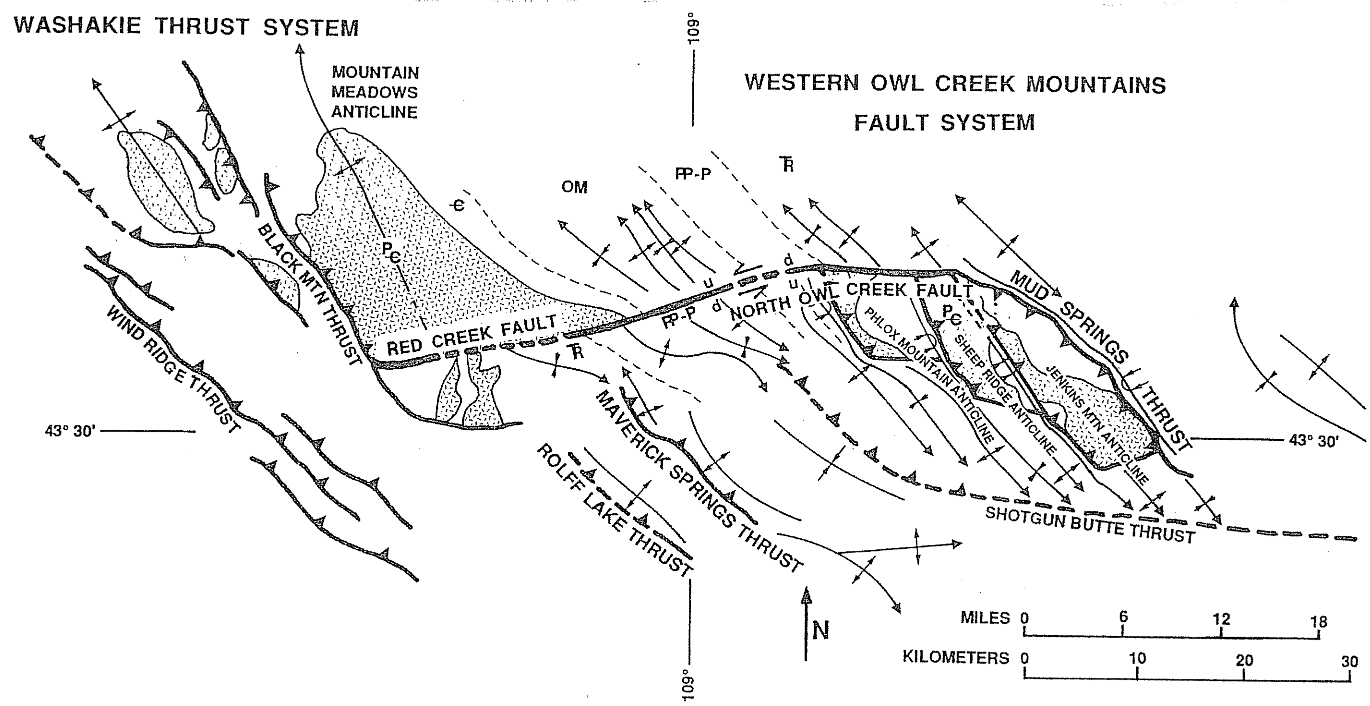


Figure 6. Simplified tectonic map of the Washakie thrust system and western Owl Creek Mountains fault system, Wyoming. Approximate location of Precambrian through Triassic stratigraphic contacts along the North Owl Creek fault are shown with dashed line. The North Owl Creek and Red Creek faults are interpreted to be linked kinematically. See text for discussion. (Modified from Blackstone, 1990.)

the evolution of the system is a consequence of regional contractional deformation. Slip directions on thrusts, together with the northwest to north-northwest trend of fold hinges and vergence of folds, indicate that the direction of maximum shortening was west-southwest–east-northeast. This direction is compatible with the slip direction determined for the North Owl Creek fault (approximately parallel to strike of the fault), not north-south as suggested by Long (1959), Gries (1983b), and Blackstone (1990). This direction is also consistent with measured shortening directions in the eastern Owl Creek Mountains (Molzer and Erslev, 1991), Gros Ventre Range (Lageson, 1987), and the northern Wind River thrust system (Mitra and others, 1988). Furthermore, as also pointed out by Brown (1988), the relation of mesoscopic- and macroscopic-scale structures with the North Owl Creek fault is consistent with structural relations observed along strike-slip and in particular transpressional faults (see Harland, 1971; Wilcox and others, 1973; Christie-Blick and Biddle, 1985; Naylor and others, 1986). The North Owl Creek fault system thus is interpreted to be a type of transfer zone (e.g., Dahlstrom, 1970) that exhibits strike-slip displacement and accommodates differential shortening between two evolving northwest-striking contractional fault systems, the Washakie thrust system and the west Owl Creek Mountains fault system.

Magnitude of displacement along the North Owl Creek fault

The structural relations discussed above constrain the direction of displacement along the North Owl Creek fault. The magnitude of displacement is, however, poorly constrained due to the lack of piercing points across the fault. By assuming that deformation north and south of the fault was coeval with fault slip and the contractional direction is everywhere the same along the fault, an estimate of differential shortening across the fault is possible by using the shortening direction inferred from kinematic data and magnitude of shortening along contractional structures north and south of the fault. Differential shortening can then be used as an estimate of the magnitude of left slip along the North Owl Creek fault.

According to Blackstone (1990), most shortening strain in the southern end of the Washakie thrust system was accommodated by the northwest-striking Black Mountain thrust (Fig. 6). Although the slip direction along this fault is not known precisely (see also Winterfeld and Conrad, 1983; Evans, 1986), we assume that it is compatible with that determined for northwest-striking thrusts (Paylor, 1989) and the east-striking North Owl Creek fault in the North Owl Creek fault system (i.e., west-southwest–east-northeast). The Black Mountain thrust is linked to the east-striking Red Creek fault, the western extension of the North Owl Creek fault. East of the Black Mountain thrust and north of the North Owl Creek fault, shortening is minimal because no major faults are present (see Masursky, 1952; Blackstone, 1990). Shortening south of the North Owl Creek fault includes ~1 km on the northern end of the Mud Creek thrust, ~2 km total on the northern ends of the Jenkins Mountain and Sheep Ridge thrusts, and 1 km on the northern end of the Phlox Mountain thrust, based on reconstruction of the Precambrian-Cambrian contact. Other structures, including the Shotgun Butte, Maverick Springs, and Rolff Lake thrusts of Blackstone (1990) (see Fig. 6) that may contribute to the total shortening south of the North Owl Creek fault are not accounted for because their structural relation to the North Owl Creek fault is not well known. If it is assumed that approximately the same amount of shortening strain is accommodated by folding and layer-parallel shortening mechanisms (e.g., cleavage formation) north and south of the fault, it is excluded from this estimation. Thus, as illustrated in Figure 7, we estimate a minimum of 4 km of left-slip along the North Owl Creek fault. Sundell (1990) estimated a minimum of ~10 km of left slip based on the discovery of Precambrian granitic lithic fragments in a loosely consolidated sandstone penetrated by borehole near the North Owl Creek fault, ~20 km west of Phlox Mountain, which was thought to be derived from the western Owl Creek Mountains. Due to the geometric relation between the North Owl Creek fault and the northwest-striking thrusts located to the south, the magnitude of left slip should decrease eastward, east of each major northwest-striking thrust (Fig. 7).

Kinematic evolution of the North Owl Creek fault system

A kinematic model for the development of the North Owl Creek fault system is illustrated in Figure 8. The Black Mountain and Mud Creek thrusts initiated as a consequence of regional Laramide east-northeast–west-southwest contraction (Fig. 8A). As displacement across the two thrusts increased, east-striking high-angle strike-slip faults developed as lateral ramps at the southern and northern tips of the two thrusts (Fig. 8B). As the two high-angle faults propagated toward each other, mesoscopic- and macroscopic-scale folds and faults developed to accommodate some of the shortening strain. The relative timing of these structures is currently not known, but is inferred to have been

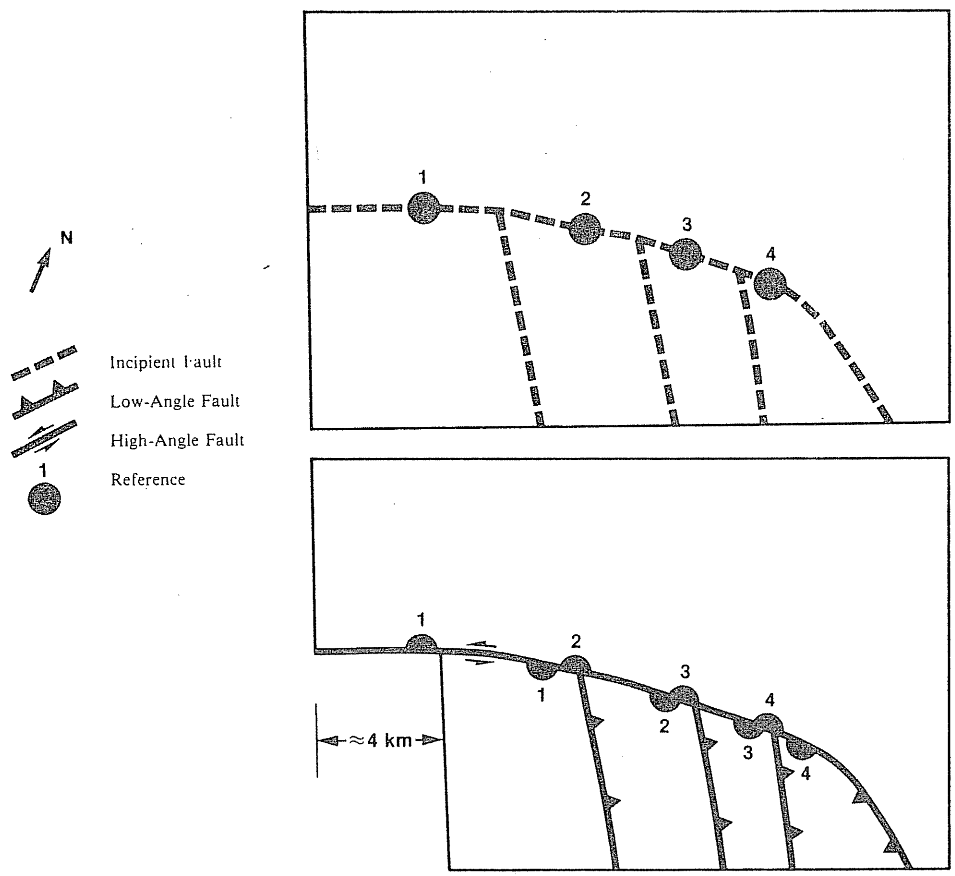


Figure 7. Schematic diagram illustrating shortening south of the high-angle North Owl Creek fault in the central segment. Low-angle faults are, from left to right, Phlox Mountain thrust, Sheep Ridge thrust, Jenkins Mountain thrust, and Mud Creek thrust. Reference dots indicate displacement along several parts of the North Owl Creek fault. Fault spacing not drawn to scale. See text for discussion.

coeval with displacement along the North Owl Creek fault zone. The two high-angle faults probably overlapped (Fig. 8C). Further regional shortening caused increased displacement along the thrusts and the east-striking high-angle faults, the development of additional northwest-trending structures to accommodate regional shortening strain, and the development of minor northwest-striking faults between the two high-angle faults (Fig. 8C). These minor faults serve as links to transfer displacement across the two high-angle faults, and are analogous to P-shears from simple shear (Swanson, 1990) in the zone of overlap between the two faults. Drag-related counterclockwise rotation of foliation, Paleozoic strata, and structures adjacent to and between faults would have resulted from continued left-slip displacement along the North Owl Creek fault.

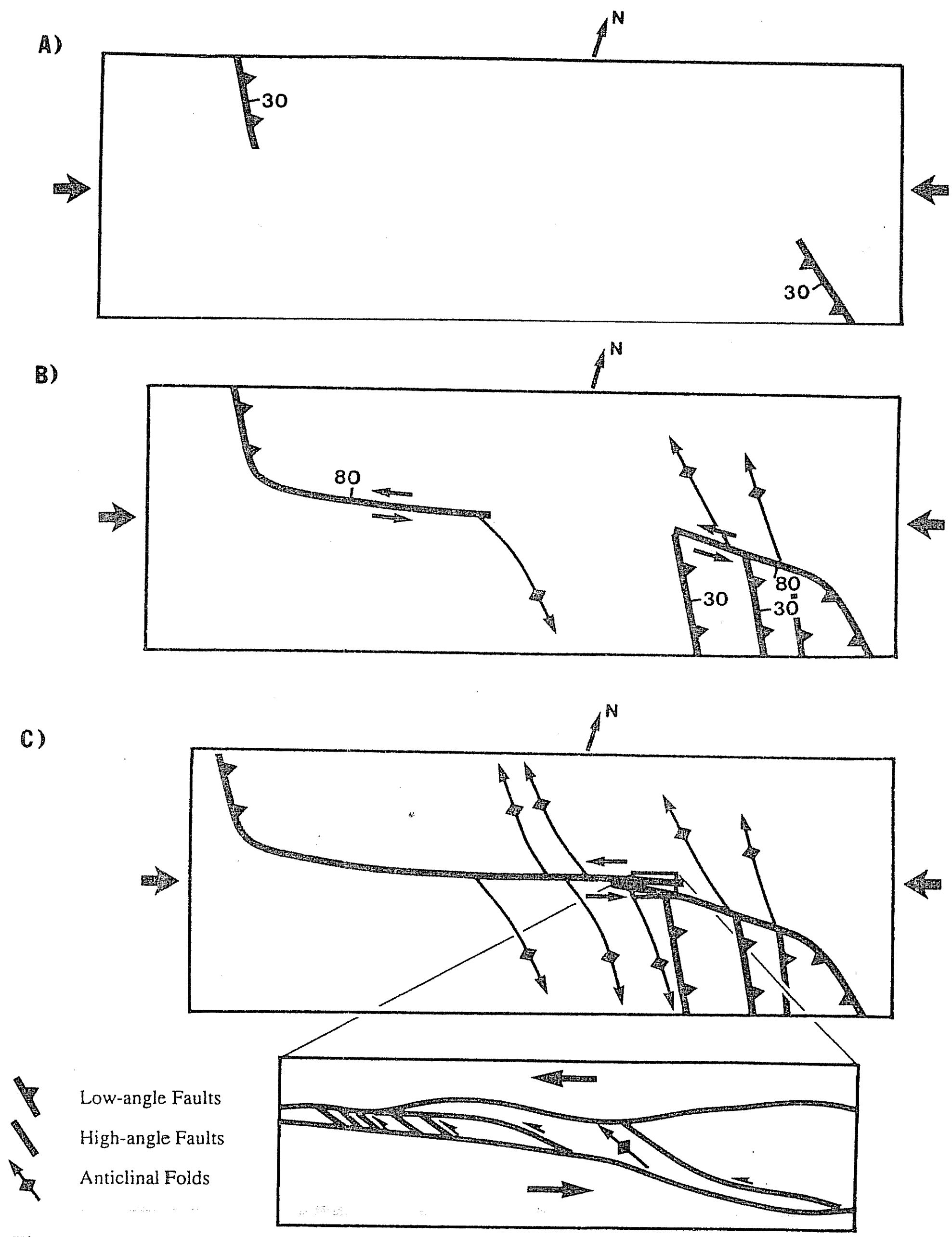


Figure 8. Kinematic model for the development of the North Owl Creek fault system. A: Mud Creek and Black Mountain thrusts initiated as a consequence of east-northeast–west-southwest regional Laramide compression. B: East-striking high-angle faults developed as lateral ramps at the southern end of the Black Mountain thrust and the northern end of the Mud Creek thrust. C: East-striking high-angle faults propagated toward each other and overlapped in a zone of simple shear. Simultaneous development of folds and thrusts north and south of the North Owl Creek fault with the North Owl Creek fault is implied.

We believe that the kinematic model proposed here may be applicable to other east-striking faults developed during the Laramide orogeny. These include the south Owl Creek Mountain thrust, the northern Laramie–Casper Mountain fault, the Granite Mountains fault system, and the Tensleep fault. Except for the Tensleep fault and south Owl Creek Mountains fault systems, for which left-slip displacement during the Laramide has been documented (Allison, 1983; Molzer and Erslev, 1991), consistent with this model, constraints on the kinematics of these faults have not been established.

CONCLUSIONS

Results of this study in the western Owl Creek Mountains indicate the following.

1. The North Owl Creek fault system is the ultimate result of contractional deformation during the Laramide orogeny. The main component of this system, the east-striking North Owl Creek fault, is left slip and links kinematically the northwest-striking Washakie thrust system to the west Owl Creek Mountains fault system. The role of the North Owl Creek fault system was to transfer regional east-northeast–west-southwest shortening from the Black Mountain thrust in the Washakie system to the Mud Creek thrust in the western Owl Creek system. The North Owl Creek fault may have formed by propagation of two lateral ramps, one linking the Mud Creek thrust at its eastern end, and the other linking the Black Mountain thrust at its western end. A protracted deformation history with unidirectional compression is required to explain the development of the North Owl Creek fault system.

2. The initiation of the North Owl Creek fault does not appear to be controlled by any known preexisting Precambrian shear zones, foliations, or dikes. Instead, field relations suggest that the present orientation of these Precambrian structures and the Paleozoic strata are the result of rotation adjacent to faults in the North Owl Creek fault system during left-slip displacement.

3. The observations made along the North Owl Creek fault system do not support previous hypotheses that: (1) northwest-trending structures in the area formed first and were later cut by east-trending structures; or (2) the Laramide compression direction was reoriented to north-south in order to form the east-trending fault system.

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