

# Paleomagnetic study of thrust-sheet motion along the Rocky Mountain front in Montana



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## ABSTRACT

Near Wolf Creek, Montana, the fold and thrust belt intersects the central Montana trough at the northern edge of the Helena salient. Remanent magnetizations from 18 of 31 paleomagnetic sites in the Late Cretaceous Two Medicine Formation (~79 Ma) document counterclockwise rotations of thrust-bound rocks along the margin of the salient. Results from 12 reliable sites in the upper of two thrust sheets gives a mean direction of Dec = 328.4°, Inc = 67.9°,  $\alpha_{95} = 5.63^\circ$ . Results from 6 reliable sites in the underlying thrust sheet yield Dec = 321.9°, Inc = 69.3°,  $\alpha_{95} = 11.87^\circ$ . The difference in these directions is not significant at the 95% confidence level. The thrust sheets show no relative rotation. Combining all 18 sites gives an average direction of Dec = 326.3°, Inc = 68.4°,  $\alpha_{95} = 4.94^\circ$ . This average direction is  $25.2^\circ \pm 14.0^\circ$  counterclockwise from a Late Cretaceous reference direction (Dec = 351.5°, Inc = 69.3°) established from the adjacent Adel Mountain volcanic rocks (~76 Ma). Comparison to an older (~88 Ma) pole established from the Niobrara Formation indicates  $11.7^\circ \pm 11.4^\circ$  of counterclockwise rotation. The paleomagnetic results, with other geologic evidence, show that both thrust sheets interacted with an oblique, lateral foreland ramp.

## INTRODUCTION

Near Wolf Creek, Montana, closely spaced thrust faults carry deformed sedimentary and volcanic rocks of the Late Cretaceous Two Medicine Formation. The thrusts strike northwest-southeast and dip moderately to the southwest. To the east, these thrust faults coalesce and show left-lateral movement (Birkholz, 1967; Woodward, 1981). Local fault planes and slickensides show that left-lateral movement extends into the Wolf Creek area. Similar allochthons exist to the south in the Helena salient (Fig. 1). There, interactions with crystalline blocks of the Rocky Mountain foreland rotated the allochthons about nearby vertical axes. Eldredge and Van der Voo (1988) showed that deflection of paleomagnetic declinations records those rotations. North of the Helena salient, crystalline foreland blocks are less obvious than in southwestern Montana. Rotations of thrust sheets may, however, mark underlying lateral ramps and foreland buttresses in the thrust system. We began this paleomagnetic study to learn about the motion of thrust sheets over lateral ramps and foreland blocks.

The rocks near Wolf Creek furnish an excellent opportunity to study the relative motion of thrust sheets. Two superimposed thrust sheets coalesce in the area. Both contain nearly complete sections of the Late Cretaceous Two Medicine Formation. The stratigraphic sections, composed of a thick sequence of welded tuffs, lava flows, and volcanoclastic sedimentary rocks, are well exposed and accessible. Ample geologic evidence

suggests that these thrust sheets interacted with the foreland (Bregman, 1976; Schmidt, 1972a, 1972b, 1972c, 1977a; Swenson, 1988). The nearby and contemporaneous Adel Mountain volcanic rocks (Gunderson and Sheriff, 1991) and the Fort Hays limestone (~88 Ma) in Colorado and Kansas (Acton and Gordon, 1990) provide reliable paleomagnetic directions for comparison. Thus, the Two Medicine Formation presents the opportunity to measure relative rotation between two sheets that passed over the same subsurface features.

## THE TWO MEDICINE FORMATION

The Two Medicine Formation is a Late Cretaceous (Campanian) volcanic and sedimentary sequence deposited in a foreland basin. The regional environment was near shore to lagoonal (Viele and Harris, 1965) and extended laterally more than 1,000 km. Two facies of the Two Medicine Formation occur near Wolf Creek. The eastern facies consists predominantly of sedimentary rocks with nonvolcanic clasts. The western facies is thrust bounded and consists of both volcanic rocks and volcanoclastic sedimentary rocks.

The age of the Two Medicine Formation and its relationship to thrusting is unequivocal. Lyons (1944) defined the Two Medicine Formation as the basal section of the Adel Mountain volcanic field. He assigned a Late Cretaceous age based on plant fossils in a conglomerate at the base of the volcanic pile. Later, detailed mapping (Schmidt, 1972a, 1972b, 1972c, 1977a, 1977b; Schmidt and Strong, 1972) and stratigraphic correlations (Viele and Harris, 1965) showed that the Two Medicine Formation and Adel Mountain volcanic rocks are distinct units. Obradovich and Cobban (1975) determined a K-Ar isotopic age of ~79 Ma for the Two Medicine Formation.

The age of the Two Medicine Formation is similar to the nearby Elkhorn Mountain volcanic rocks (~80 Ma; Robinson and others, 1968). Two radiometric dates ( $81.1 \pm 3.5$  and  $71.2 \pm 2.7$  Ma) from the Adel Mountain volcanic rocks (Gunderson and Sheriff, 1991) suggest that Two Medicine and Adel volcanism are also coeval. Stratigraphic relationships determined by Schmidt (1972a, 1972b, 1972c, 1977a) place the Adel Mountain volcanic field over the Two Medicine Formation. New  $\text{Ar}^{40}$ - $\text{Ar}^{39}$  dates from the Adel Mountain volcanic rocks (Harlan and others, 1991) confirm the ~76 Ma average for the Adel Mountain volcanic rocks. The average agrees well with age and stratigraphic relationships in the area.

If the Two Medicine Formation, Elkhorn Mountain volcanic rocks, and Adel Mountain volcanic rocks were all autochthonous, they would have the same paleomagnetic direction. The Adel Mountain volcanic rocks, in the footwall beneath the Two Medicine Formation and Elkhorn Mountains volcanic rocks, are relatively undisturbed. Thus, the Adel