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Abstract. It is highly probable that in the synclinal formation of the Cañon City Embayment, the east side, at least, developed as a monocline. Its west limb was downwarped to form half of the syncline, and its east limb was upwarped as Cooper Mountain was elevated. The developing monocline was steep with high westward dips. Tensional forces must have developed in the upper bend and westward compressional forces in the lower bend. In some portions of the monocline the compression exceeded the tensile strength of the rocks; thus the Fourmile Creek Thrust Fault and associated tear faults were formed as the more mobile and active upper parts of the fold slid over the lower. The effects of thrusting are now seen as thinned and overturned beds adjacent to the faults, and characterized by the products of dislocation metamorphism that developed in the zone of intense deformation and dislocation along the sole of the overthrust fault, and in the zones of the tear faults.

This paper is an outgrowth of a summer project done along the eastern half of the Cañon City Embayment. The embayment is a southward plunging (5°-15°), triangular shaped re-entrant that lies between the southern limits of the Front Range and the Wet Mountains, in eastern Fremont County, Colorado, as illustrated in Figure 1. The embayment begins about four miles southwest of the town of Cripple Creek and extends about 15 miles south-southeast, where it is about eight miles wide. Boos and Boos (1957, p. 2668) considered the embayment as a graben since both of its sides are more or less bounded by faults. In the simpliest sense, however, the embayment apparently began as, and is, a synclinal tectonic unit with a relatively flat and southerly plunging floor but with steeply dipping limbs on either side. During its Laramide development lateral compressive forces developed on the east side, at least, and parts of the monocline here became overfolded and thrust-faulted to the west. The fault zones have since been exposed by erosion.

Description

There are a number of faults in this area, but only those related to the overthrusting are discussed in this paper. These are the Fourmile Creek Thrust Fault and several tear faults generally striking at near right angles to the thrust as illustrated in Figure 1. The trace of the thrust fault describes a sinuous pattern as it meanders back and forth faulting out first the Manitou limestone,

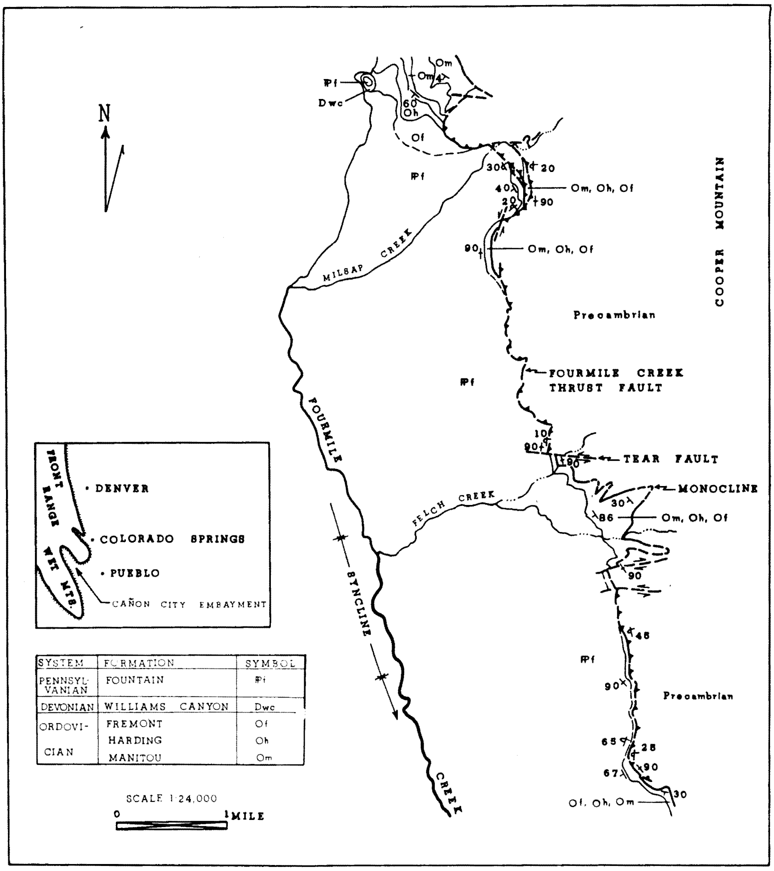

Figure 1. Geologic sketch map of the central east side of the Cañon City Embayment showing the Fourmile Creek Thrust Fault and related tear faults. Inset adapted from Lovering, 1933, plate 3.

then the shales and siltstones of the Harding, and finally through the Fremont dolomite and into the Fountain arkose. Much of the fault plane is exposed and consequently eroded, however, it appears to dip at approximately 10° in an easterly direction, with a maximum heave of 500 feet. The thrust fault fades into monoclines at either end and at two places in between.

The tear faults are found where the overthrust fades into the monoclines. They generally strike at near right angles to the thrust fault and have a more or less vertical fault plane. They thus occur between the weaker and stronger units of the fold, where the more active region of folding broke away from the less active and slid over the lower portion of the monocline(Figure 2). Thus the tear faults are found in nearly vertical shear zones with their steeply dipping walls having moved past one another almost horizontally. According to Lovering (1932, p. 652), the tear faults formed in response to the shearing stresses that caused the thrust faulting in the region of more active folding, and so they strike approximately parallel to the direction of thrust force, which was from the east and more or less at right angles to the axis of the monocline.

The tear faults are not extensively devoloped and rapidly die out to the west in the less resistant Fountain arkose. They extend into the mobile Precambrian unit to the east but are commonly obscured by talus.

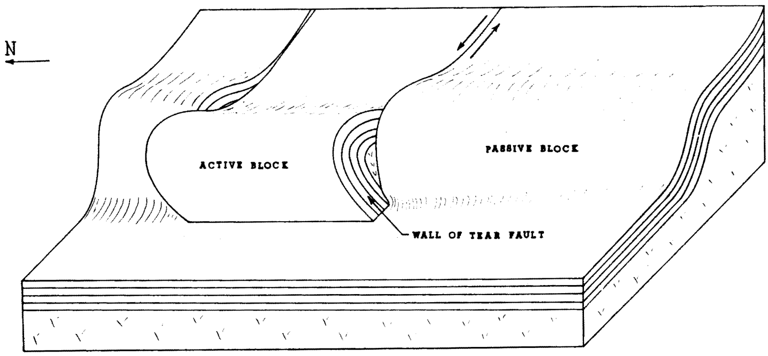

Figure 2. Idealized diagram showing the method of development of the Fourmile Creek Thrust Fault and related tear faults. Adapted from Lovering, 1932, page 652.

The Milsap Creek Fault Complex

Outcropping on a bifurcating ridge immediately south of Milsap Creek are three related thrust faults. They are a part of, and thus contemporaneous with, the Fourmile Creek Thrust Fault. Field study indicated that their probable order of development was as follows. First the monocline became over-folded with subsequent overthrusting and formation of the westernmost fault. Thrusting continued as a second segment of the upper portion of the overfold was thrust over the lower portion and the middle fault was formed. Associated thrusting developed the easternmost fault (Figure 3), and subsequent erosion exposed the faults as they are today.

Evidence of Thrusting

Most common evidence of overthrusting is the expression of the dip of the associated sedimentary rocks, which ranged from vertical (Figure 4) to 155° to the east. This is best shown in an area just north of the north end of the flat-iron monocline unit at Felch Creek where Fountain strata, exposed on stream valley walls, are vertical at the base of the wall and overturned 10° to the west at the top of the wall.

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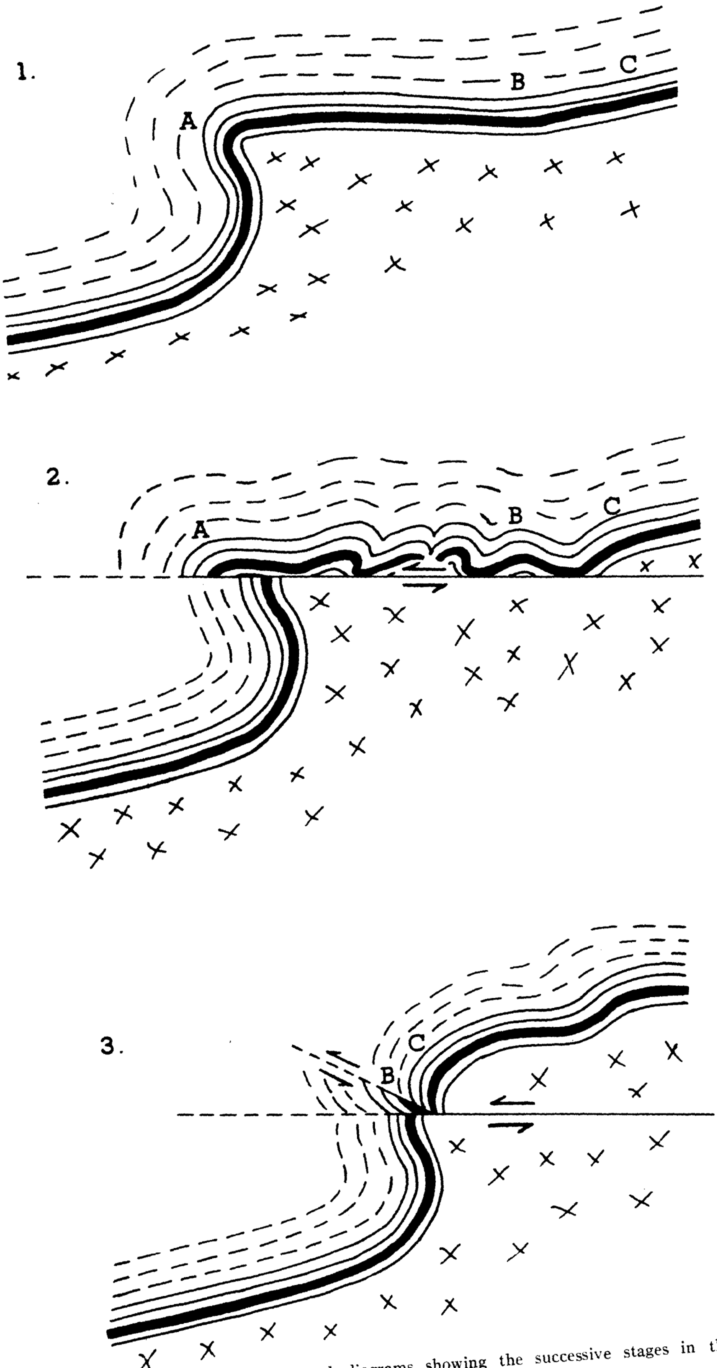

Figure 3. Idealized cross sectional diagrams showing the successive stages in the development of the Milsap Creek Fault Complex.

Equally impressing are beds of Harding, Fremont, and Fountain rocks (the Manitou was faulted out) overturned 65° to the west near the southern end of the overthrust. Also in the areas of the overturned beds the formations are considerably thinner than normal. For example, the less resistant Harding shales and siltstones normally measure about 90 feet thick, but in the area of the south end of the overthrust they thin to about 40 feet. In cross section the beds may have a fan-like appearance with decreased overturning towards the west. Thus the Manitou strata may be overturned and Fountain beds vertical. The best evidence is in the tear fault zones where Precambrian rocks of granite or schist lie adjacent to Paleozoic sediments.

Figure 4. Remnants of vertical strata of the steeply dipping monocline, about one-half mile south of Milsap Creek. Om: Manitou limestone; Oh: Harding siltstones and shales: Of Fremont dolomite; ℙf: Fountain arkose.

Fault Zone Metamorphism

The fault zones of the Fourmile Creek Thrust Fault and associated tear faults contain dislocation (kinematic) cataclastic metamorphic products. These products may be found under conditions of low to moderate confining pressures and temperatures in which directed stress was dominant.

Ferruginous slickensides are abundant and generally well developed in the fault zones as well as in the bedding planes of the adjacent sediments. The largest surface of slickensides measured was about 10 square feet. Fault gouge is another but less common product and not as well exposed as the slickensides.

Less prominent, but well developed, at the south end of the thrust fault are friction breccias. These generally consist of variegated, coarse to very coarse, heterogeneous, angular fragments firmly cemented by a siliceous binder, and which are always ferruginous and generally calcareous. The fragments dominantly consist of decomposed feldspars and mica plates, quartz, and occasional limestone or dolomite fragments. Epidote is also a contituent, though not common, filling the interstices and coating the fragments.

The most pronounced and abundant effects of metamorphism are seen in the sediments that are a part of the exposed sole of the overthrust. Here the sediments are generally highly siliceous, ferruginous, and indurated, and consequently have a "baked" appearance. These sediments may also show incomplete granitization in the areas of most intense dislocation, and here the contact between the sediments and the Precambrian rocks is not always sharp or obvious. The metamorphic exchange of materials between the Precambrian and Paleozoic rocks is generally shown by "calcareous granites" with defined zones of calcite, or by "baked" Manitou with a few small biotite or muscovite mica flakes in a matrix of ferruginous and fine to coarse crystalline limestone; or the Manitou may be finely crystalline, highly ferruginous and very siliceous, indurated and brittle. In this same environment the Harding may be a quartzite or quartzite-like, as is the Fountain arkose.

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