PS Thrust Faults in the Alcova Limestone: Nature's Sand-Table Experiment*

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Abstract

The two-meter thick Triassic Alcova Limestone, a heterogeneous, thin-bedded carbonate, forms a stiff strut within a thicker shale sequence. Small, complex thrust faults in the Alcova Limestone near Beer Mug Anticline in southeastern Wyoming record a bedding-parallel compressive stress that exceeded the weight of the overburden.

Structures characteristic of the Alcova thrust system include standard thrust planes, back-thrusts, bedding-parallel decollement zones, bed-parallel shear in the folds, folds, and fold-core voids. Local stylolites suggest that dissolution also played a role. The main thrusts in the Alcova Limestone form meter-scale en echelon planes that step back at each offset when traced up section, and that have offsets of 1-20 centimeters. The thrusts cut ductile lithologies, where the beds thickened plastically, and brittle lithologies where the beds fractured. These thrust planes can be traced from down-dip initiation at bed-parallel slip planes up-dip to where they steepen and terminate blindly in folded duplex structures. Smaller, centimeter-scale synthetic and antithetic thrusts are also pervasive in the formation. Most of the main thrusts are relatively small, and none seems to have developed into a larger structure that localized meters or tens of meters of offset, suggesting a self-limiting feedback mechanism that locked each fault after at most a few tens of centimeters of displacement.

These thrusts allow a unique interpretation of the local stress system that produced the kilometer-scale thrust faults in the area. Only horizontal compressive stresses in excess of the overburden could have produced the Alcova thrust system, and those stresses rather than drape over a basement fault likely produced the local dramatic and tightly folded Beer Mug Anticline, which is analogous at a larger scale.

More importantly, the small Alcova thrusts mimic the geometry of kilometer-scale thrusts seen in seismic lines in thin-skinned fold and thrust belts, and can be used as analogs to study the characteristics of deformation in these systems.

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ABSTRACT

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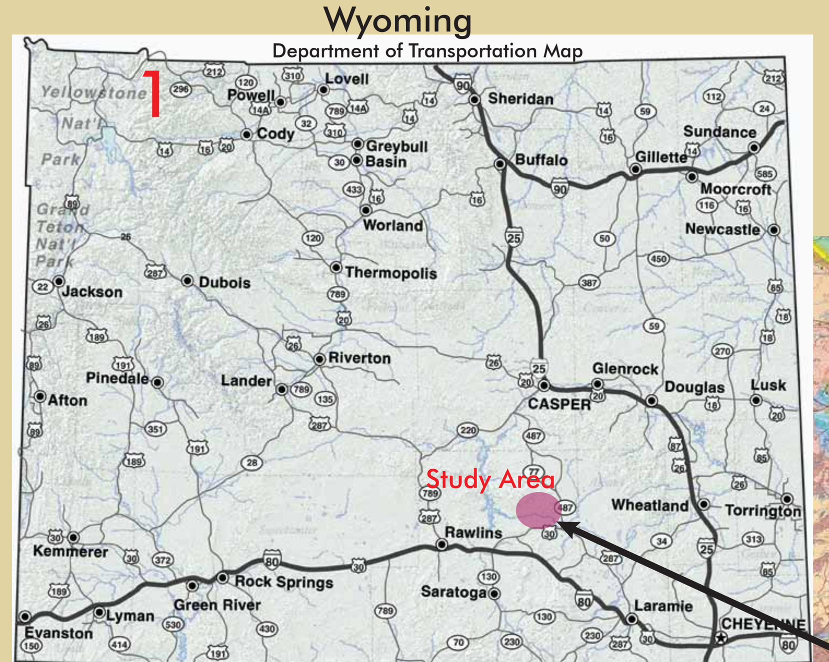
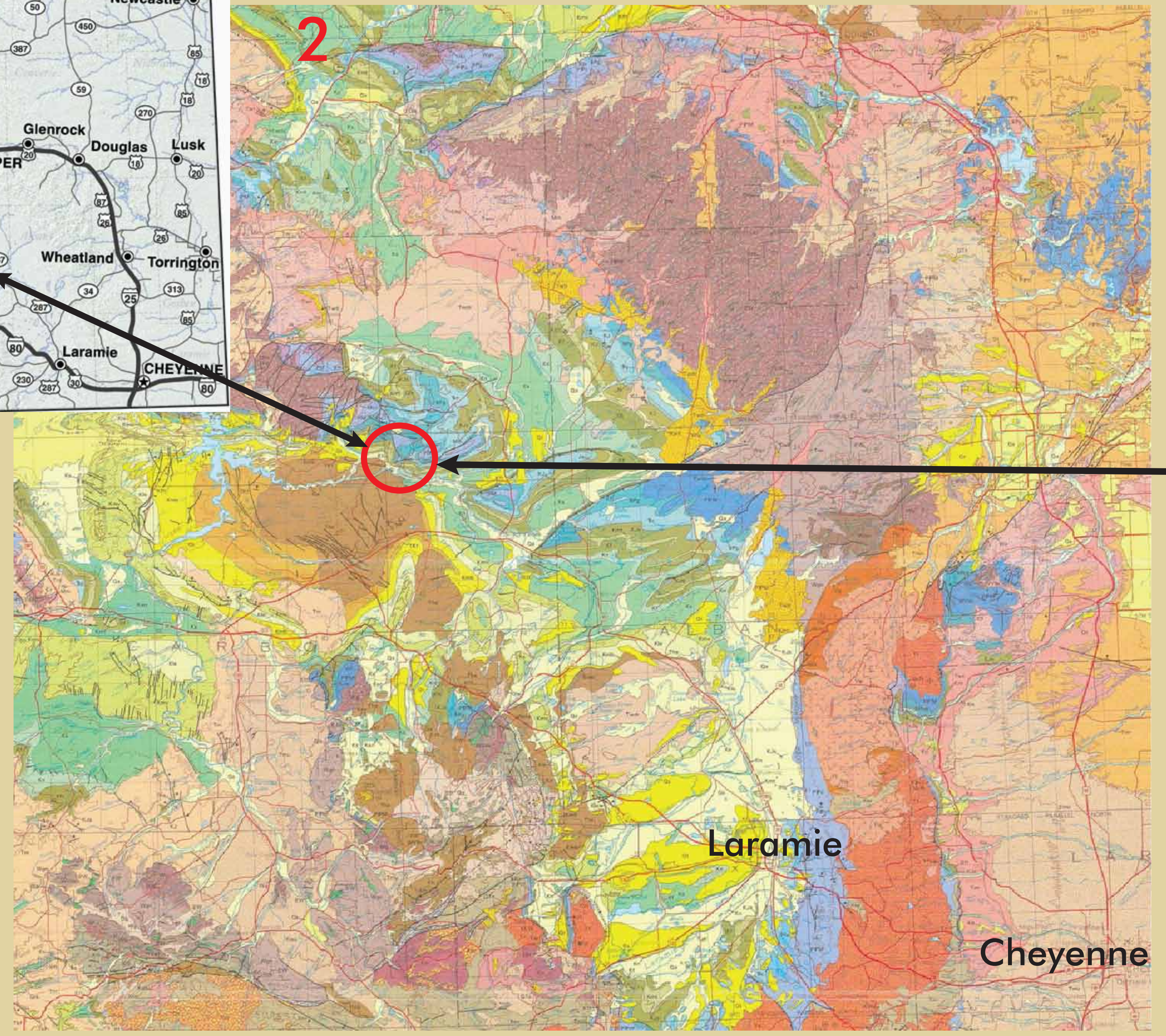


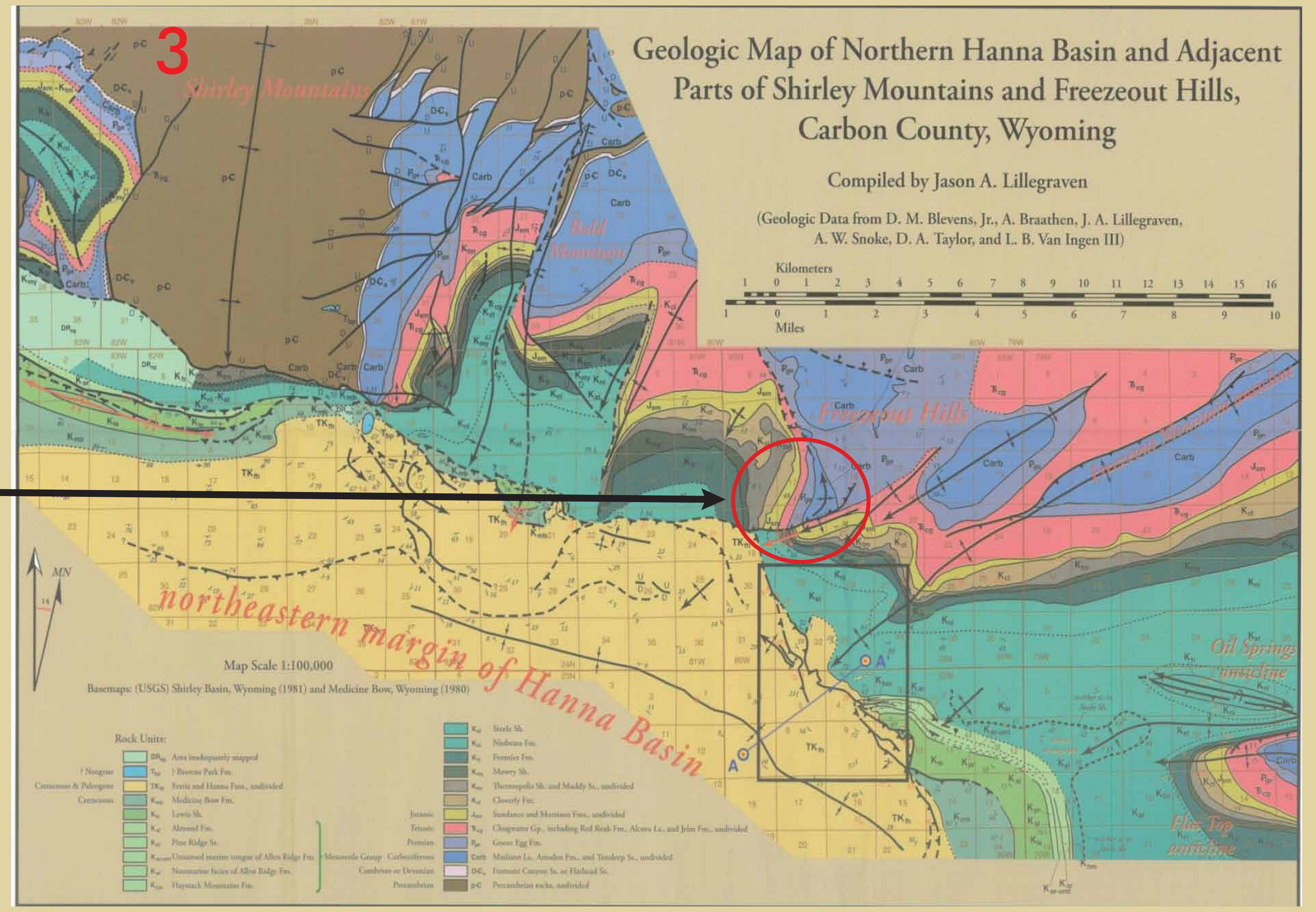


Location Maps of the Study Area.

Wyoming Department of Transportation Highway map.

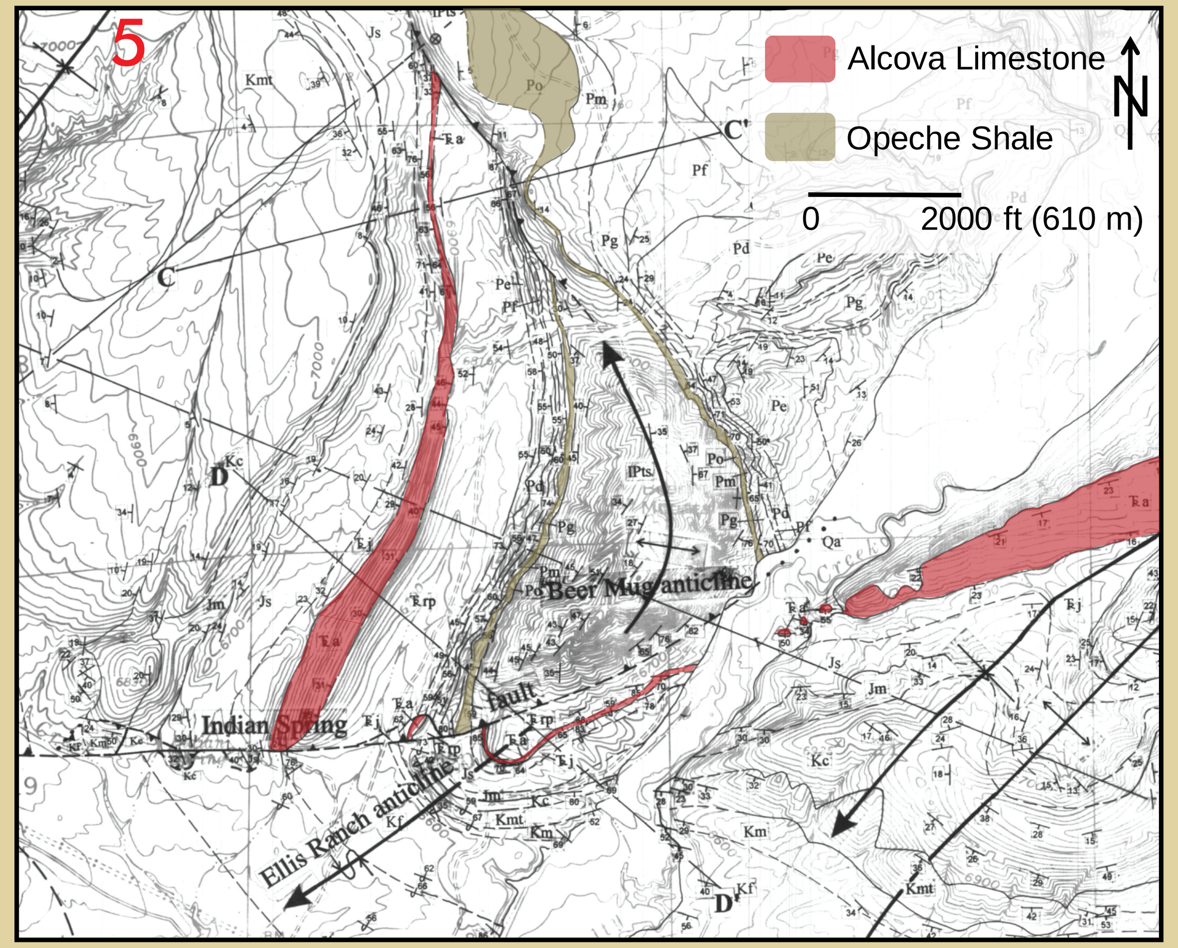
and

Southeastern section of the Wyoming state geologic map (Love and Christiansen, 1985).

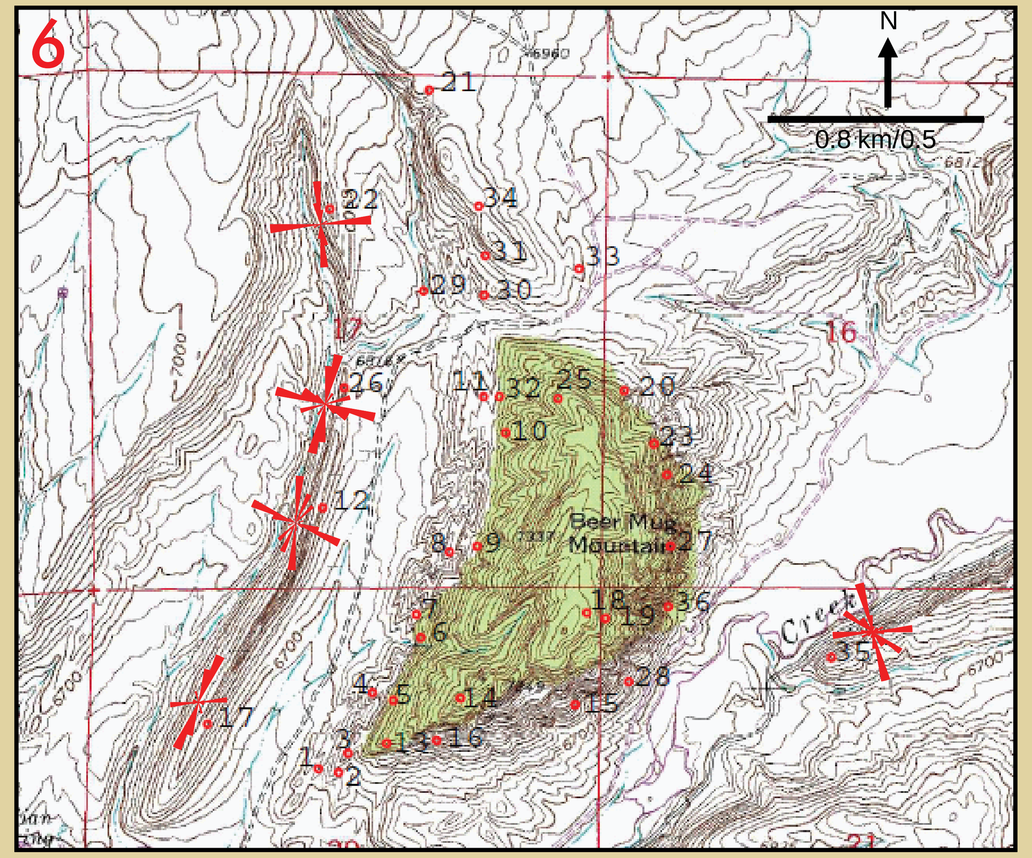


Geologic map of the northern Hanna Basin. Beer Mug anticline study area is highlighted in the red circle near the center of the map (Lillegraven, Snoke and McKenna, 2004).

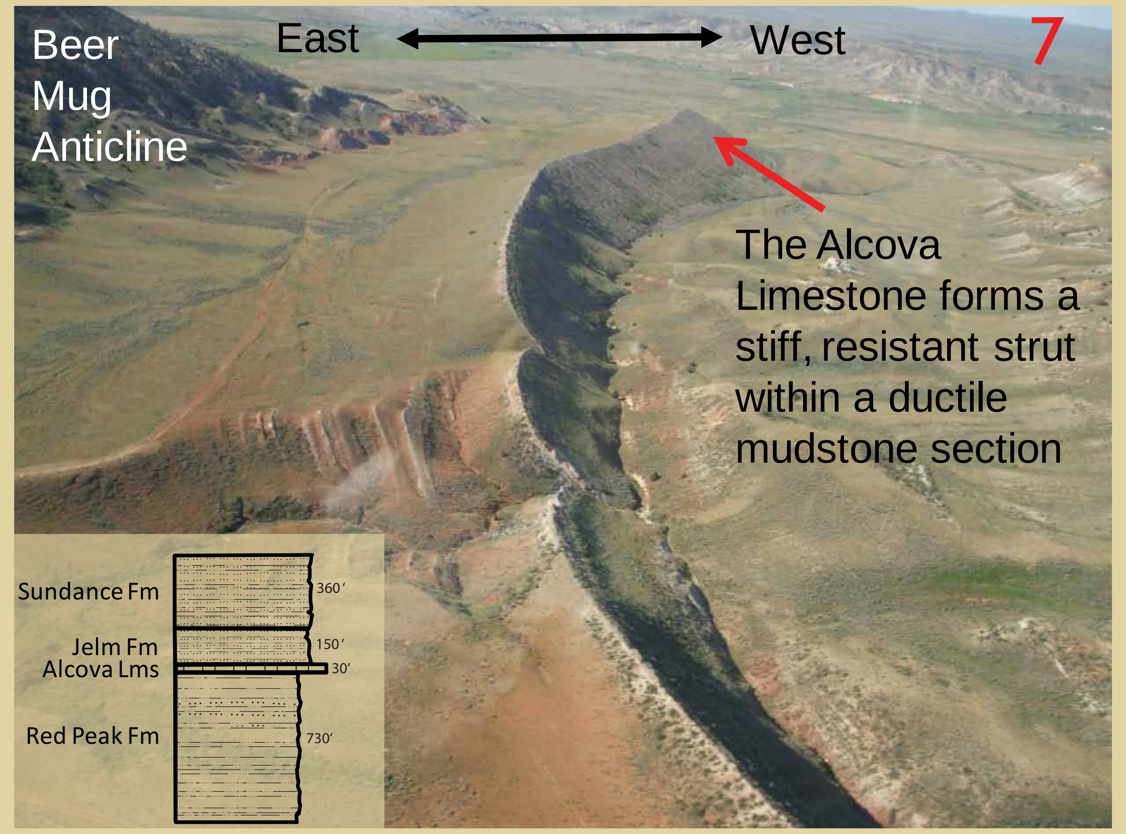
Aerial view (Google Earth) of Beer Mug anticline and surrounding area with fault and fold interpretation on image.



Geologic map of Beer Mug anticline and surrounding area (Taylor, 1996).



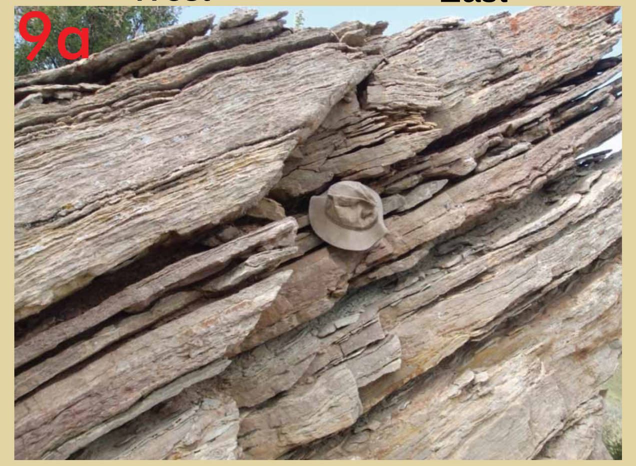
All fractures in the Alcova Limestone east and west of Beer Mug Anticline.



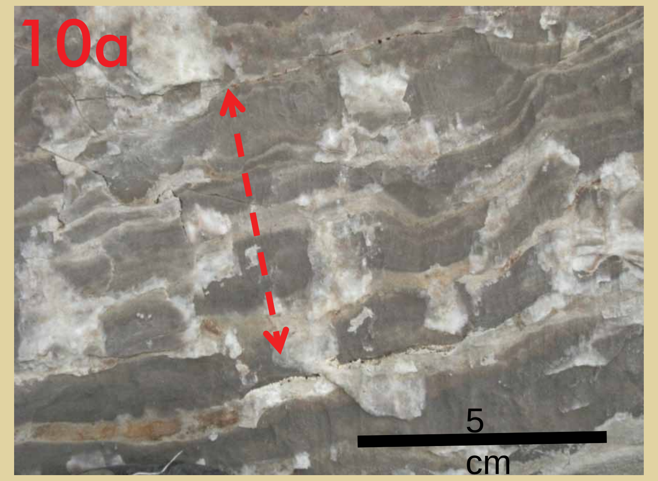
The Alcova Limestone currently forms a west-dipping hogback on the west side of Beer Mug Anticline. Stratigraphic section after Taylor (1996).

The Alcova Limestone Member of the Chugwater Formation is two to three meters thick. It consists of a thin, hard, fine-bedded, pinkish to light-gray limestone with thinner interbedded shaley units. Fossils from the Alcova place it in Middle or Upper Triassic.

West ⟵⟶ East



The Alcova is cut by numerous oblique-to-bedding, strike-parallel, en echelon shear planes, most dipping to the west but also locally to the east.



Surfaces of the shear planes are marked by slickenlines, and by asymmetric calcite slickencrysts indicating dip-parallel, reverse offset.

West ⟵⟶ East

Offset bedding shows a reverse sense of motion on all shear planes. Calcite was deposited in the hollows formed between asperities.

Intersection of opposite-dipping, calcite-mineralized thrust planes with the upper Alcova bedding surface in outcrops east of the Beer Mug Anticline. More irregular thrust orientations at this location suggest a more complex stress history.

The largest observed shear plane extends across approximately four square meters

14

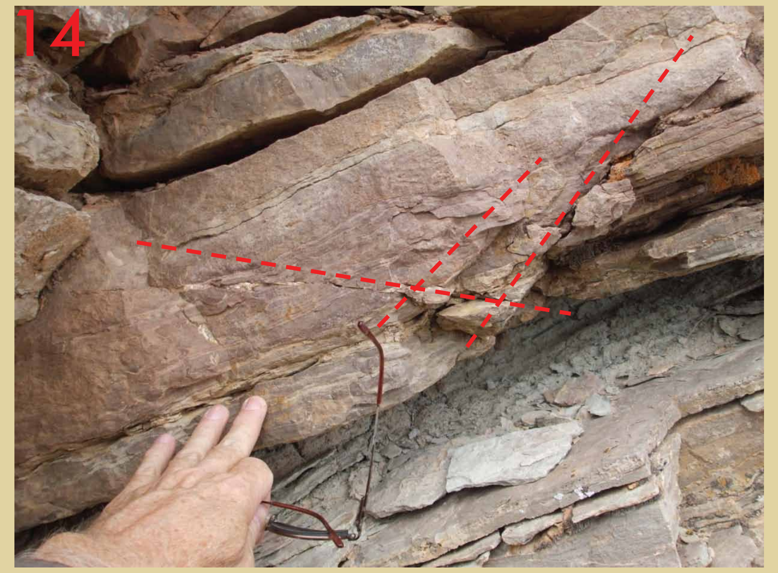
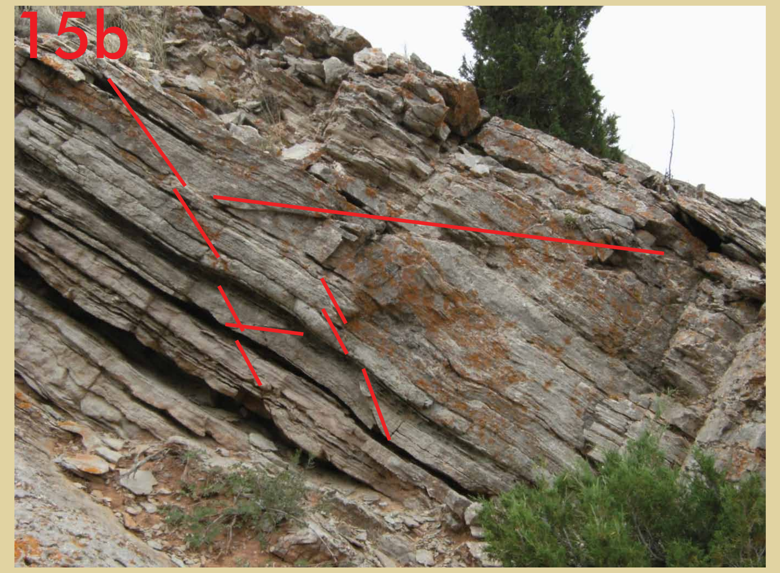


Photo of shears in both directions forming a conjugate pair.

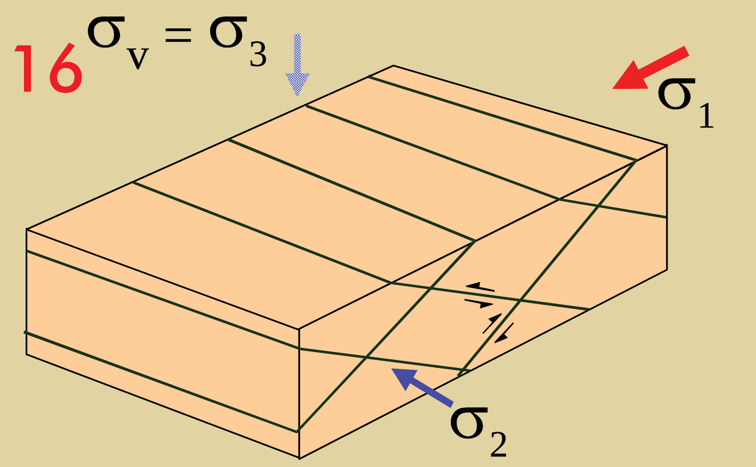
15a

15b



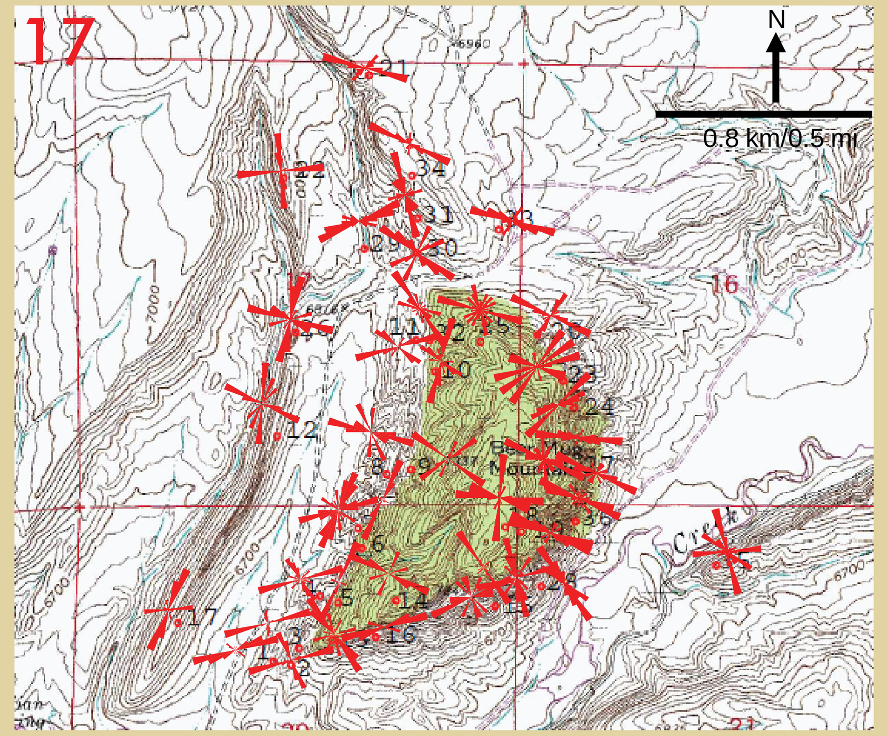
Intersecting inclined shear planes.

16



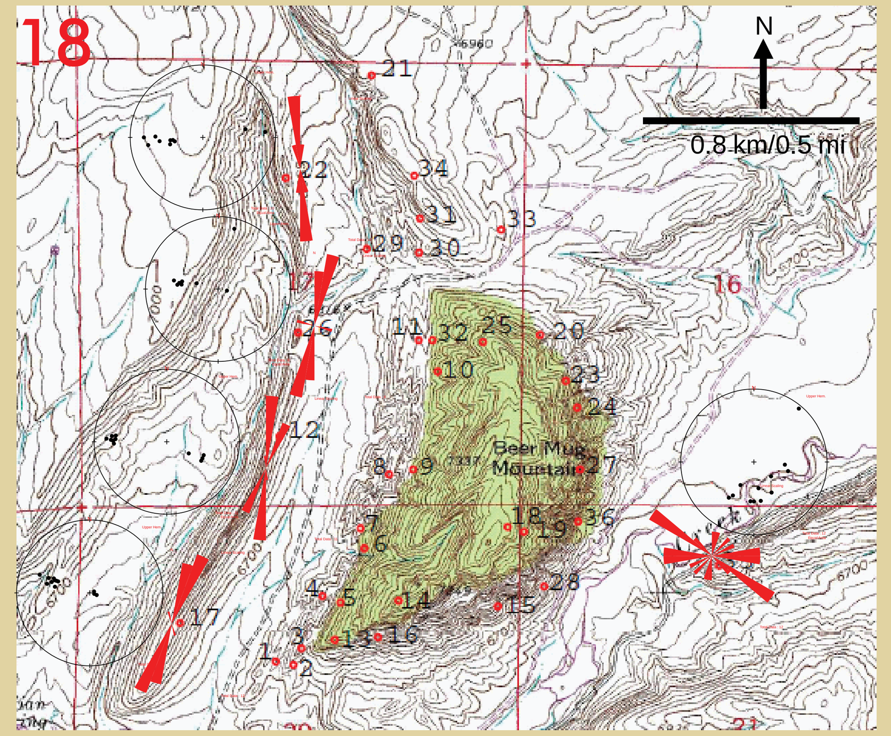
Conjugate thrust faults/shear fractures indicate that the maximum compressive stress, bisecting the acute angle, was parallel to bedding and in the horizontal plane before folding of the strata.

17



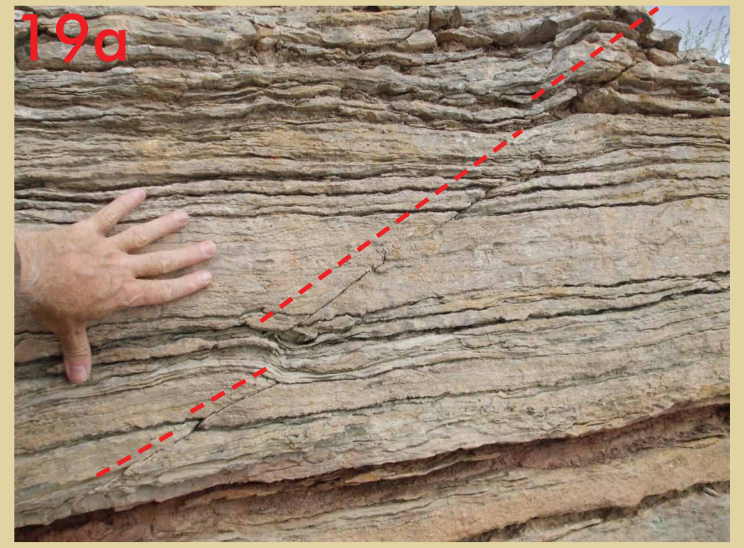
Rose diagrams on topographic base map of all fractures in all lithologies near and on Beer Mug anticline.

18



Strikes of the shear planes parallel the strike of the Alcova bedding, indicate that the maximum compressive stress was generally east-west and parallel to bedding.

19a



En echelon shear segments step back up-section (see close-up below).

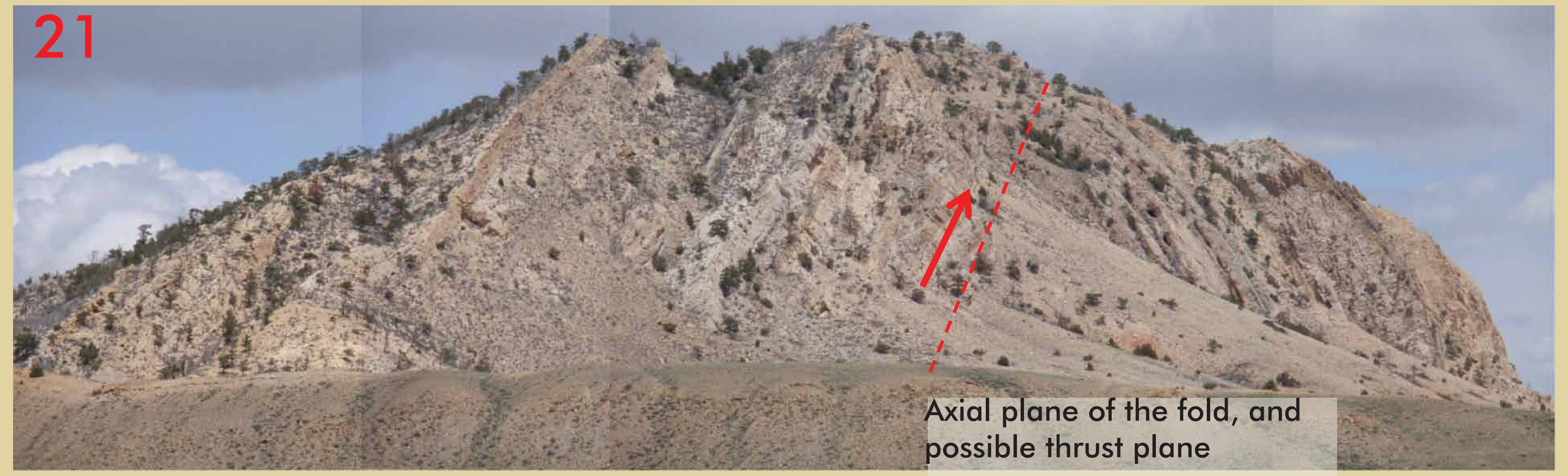
19b

Close-up of upper photo showing that en echelon offsets step up-section section, and that they commonly step where propagation was interrupted by more ductile shaley beds.

West ⟷ East

Planar, west-dipping backlimb — Curved, steep, east-dipping forelimb

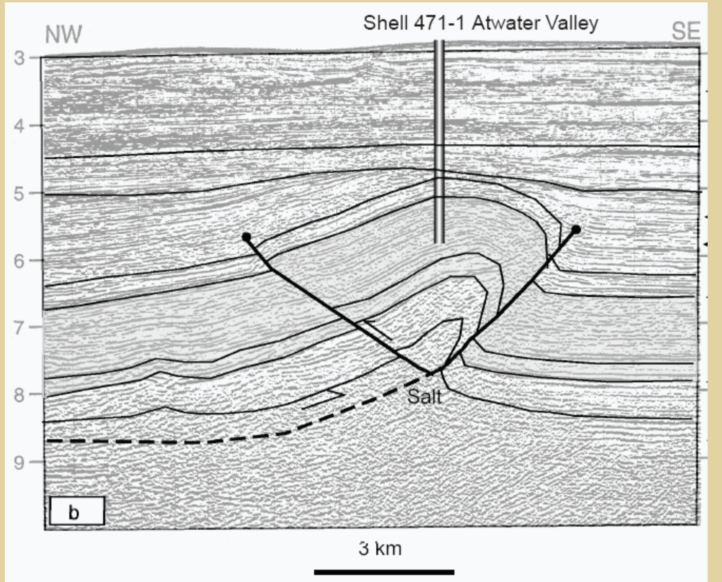
21



Shear fractures/thrust faults in the Alcova Limestone indicate that Beer Mug Anticline was formed primarily by E-W horizontal compressive stress as a detached fold.

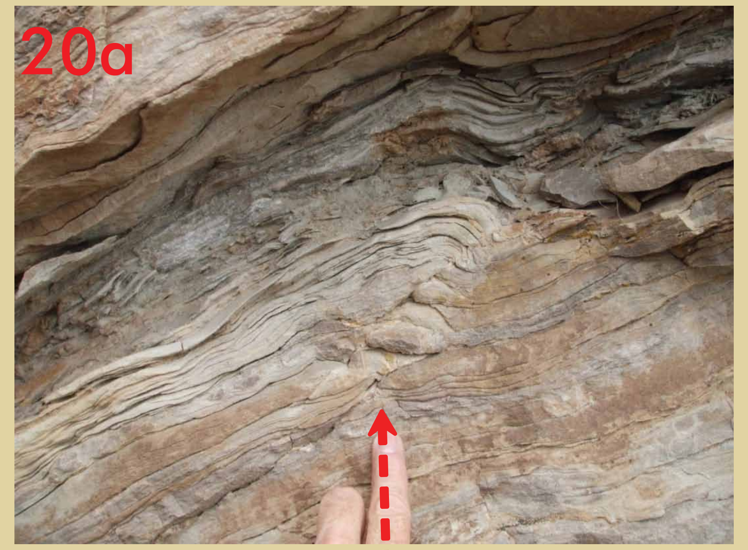
22 Sand Box

The Alcova shear fractures have similarities to both small-scale sand-box experiments and to large-scale thrust systems.

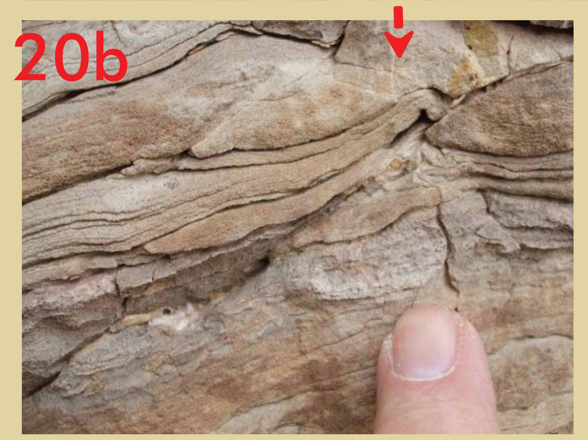


Seismic section showing folded forelimb and backthrust, analogous to the much smaller Alcova thrust system. From Mitra, 2002

20a



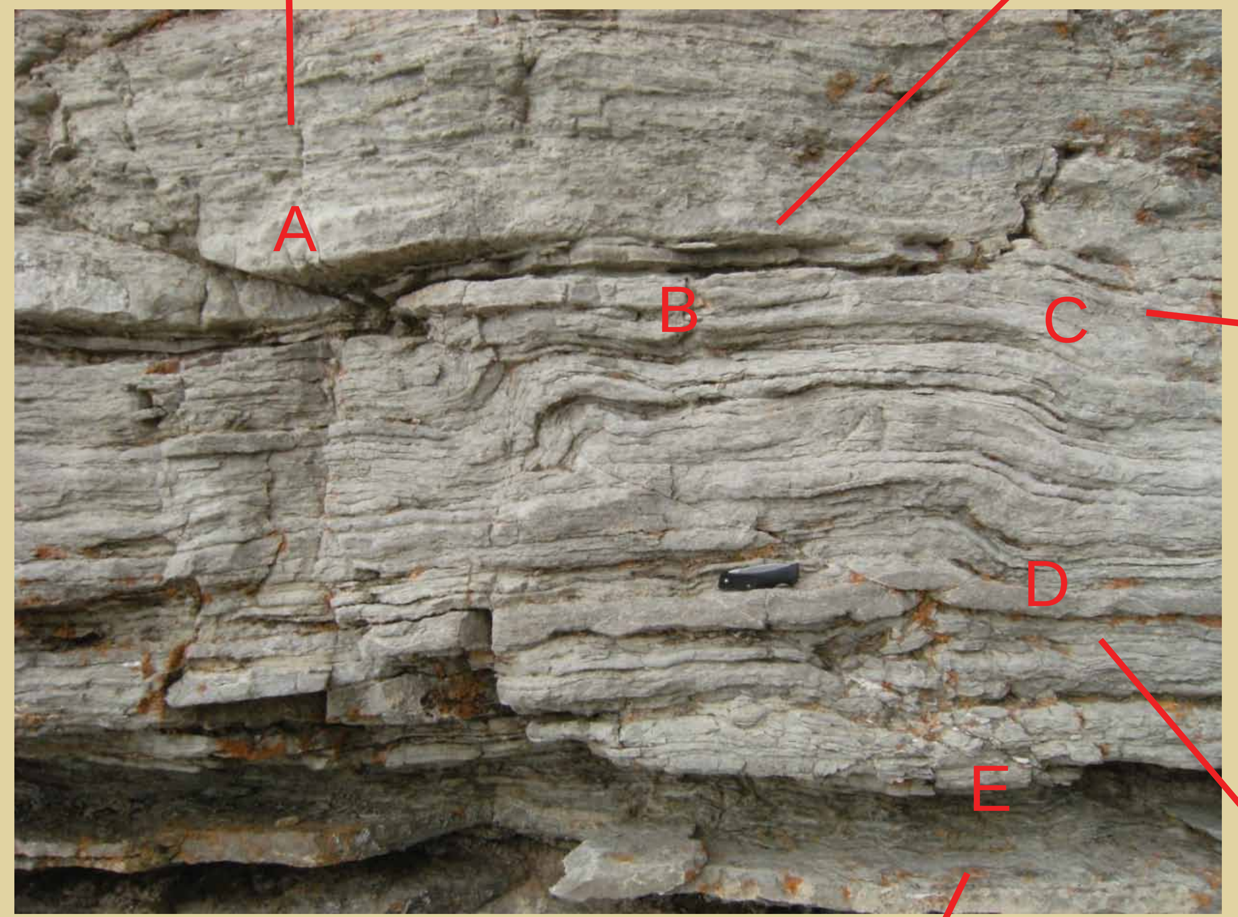
20b



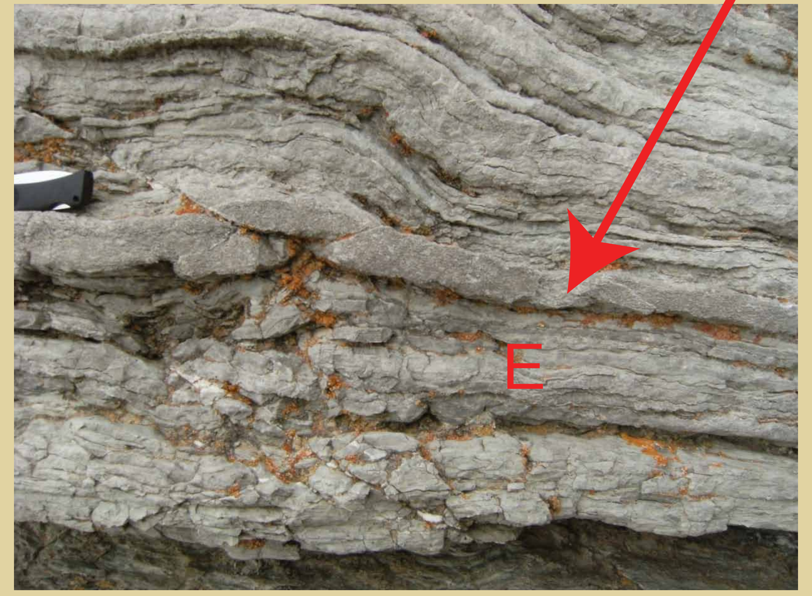
20c

Shear planes commonly die out in folds. Geometry mimics that of the larger-scale Beer Mug Anticline - see photo to left.

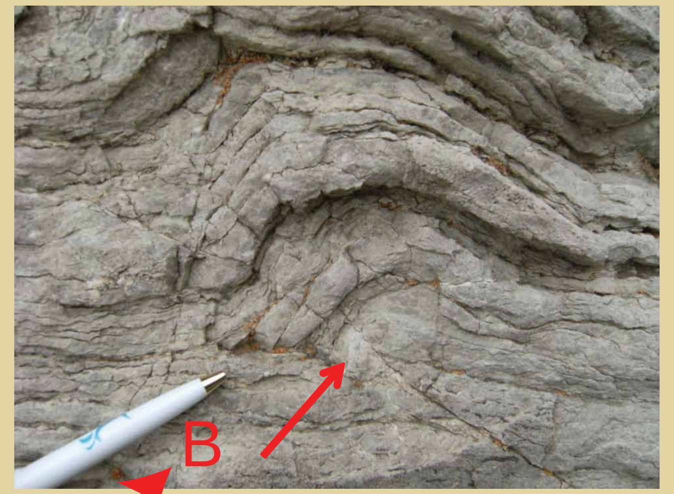
New thrust above the fold is backstepped, originates at volume constraints associated with the fold.

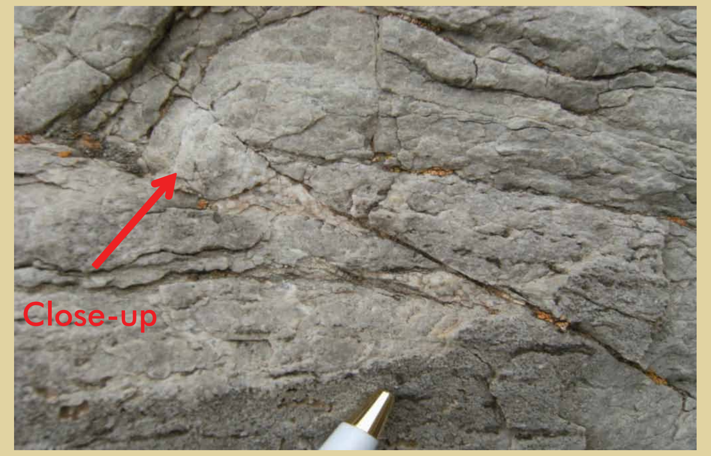


Reverse-offset en echelon shear planes with different characteristics in different lithologies, blind fold terminations, and back thrusts. Pocket knife for scale. This and the associated photos of this outcrop have been rotated 20° ccw so that the inclined bedding appears horizontal.



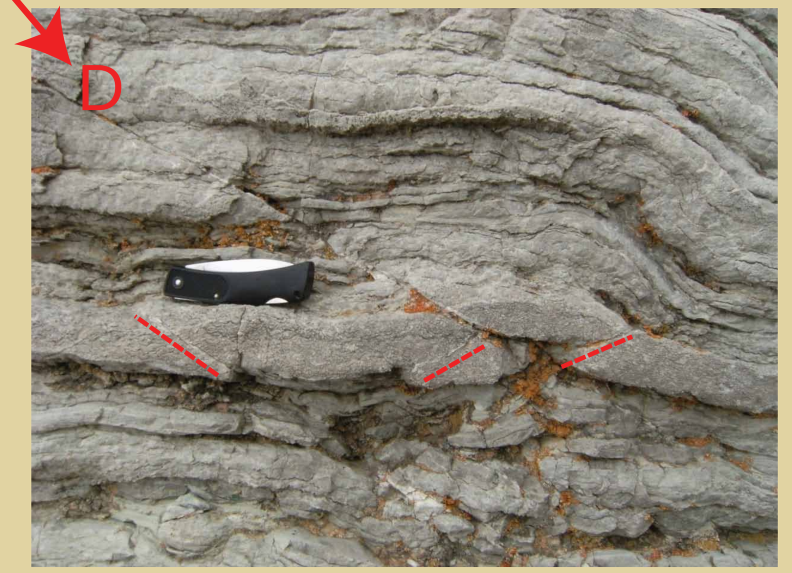
Thrust initiated above a volume-constrained crush zone defined by breccia and irregular intersecting shears.





Thrust fault tips out upward in a splayed fault and overlying fold. Sparry calcite (arrow) fills a void under the fold. Beds thicken and thin due to pressure solution, overlap, and ductility.

Poorly defined back thrust is accommodated primarily by folding.



Back thrust (upward to the right) and associated fold lift a keystone wedge of rock in a more competent, grainstone unit (A) with several smaller subsidiary shears along the dotted lines. Less competent units above the wedge are folded, doubled, overlap, and locally dissolved.

Summary

Implications for the Kinematic Origin of Beer Mug Anticline

1. Maximum horizontal compression E-W
2. Beer Mug is likely a thin-skinned, crumpled-rug fold rather than a passive drape over a basement fault
3. Bedding folded during and after formation of conjugate thrust faults

Conclusions

1. Shear fractures in the Alcova Limestone are small-scale intersecting thrust faults
2. They have mm to cm scale reverse offset
3. They step back up section, in en echelon segments
4. They commonly terminate upward blindly in folds
5. Deformation depends in part on lithology
6. Thrust faults in the Alcova indicate that the maximum stress was parallel to bedding, and E-W during folding of the associated Beer Mug Anticline.

Acknowledgements

Enhanced Oil Recovery Institute at the University of Wyoming and the Landowners.

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