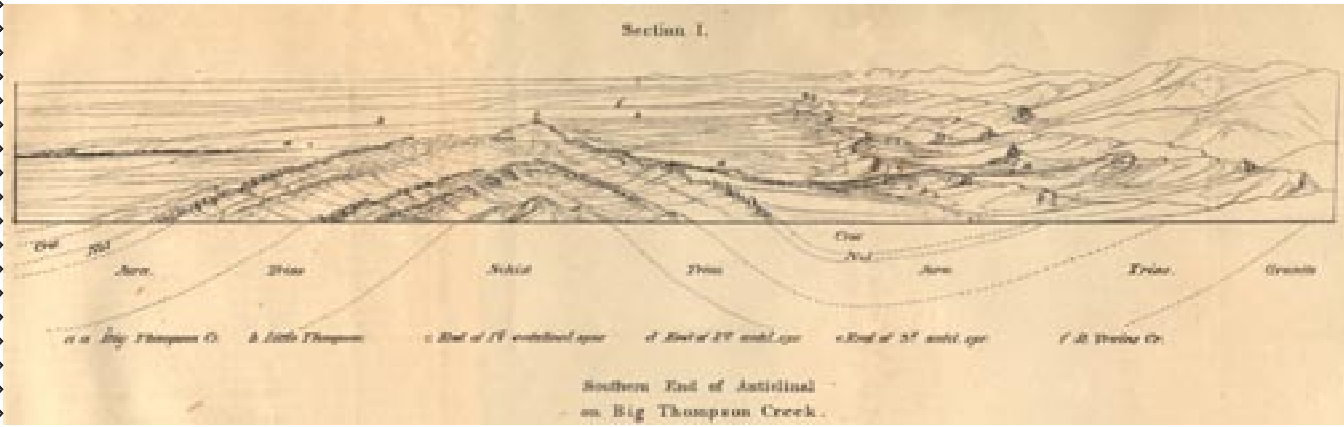
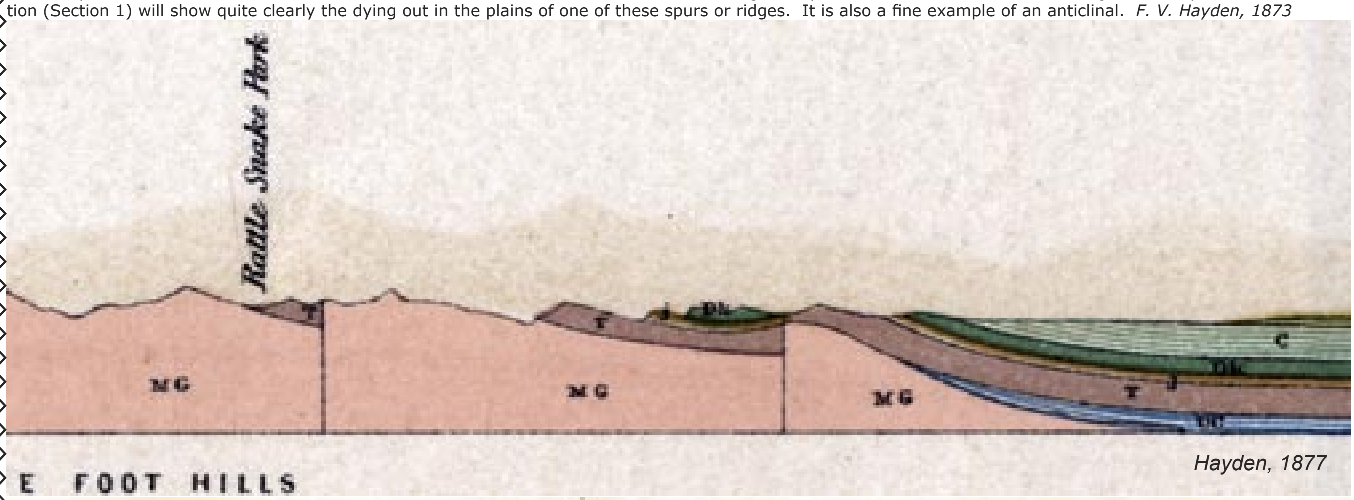
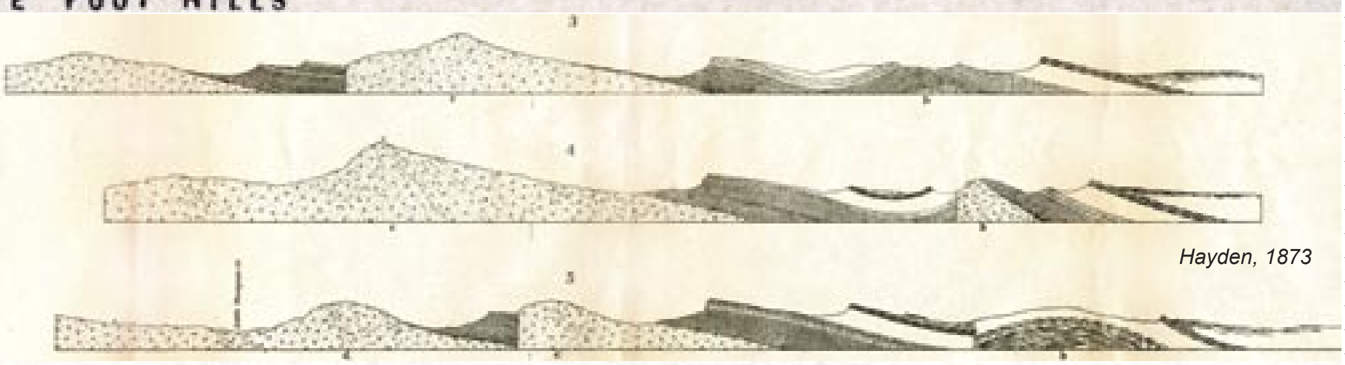
LARAMIDE STRUCTURES ALONG THE NORTHEASTERN FLANK OF THE COLORADO FRONT RANGE



"If we examine the eastern flanks of the range we shall find, from point to point, smaller ranges or spurs extending down from the main mass toward the plains, with a trend about northwest and southeast, and soon dying out, leaving between the end of the spur or minor range a broad open valley, which forms the source of many of the important streams. Most excellent illustrations of this structure are seen where the Big Thompson and Saint Vrain's Creeks emerge into the plains. The illustration (Section 1) will show quite clearly the dying out in the plains of one of these spurs or ridges. It is also a fine example of an anticlinal. *F. V. Hayden, 1873*



Hayden, 1877



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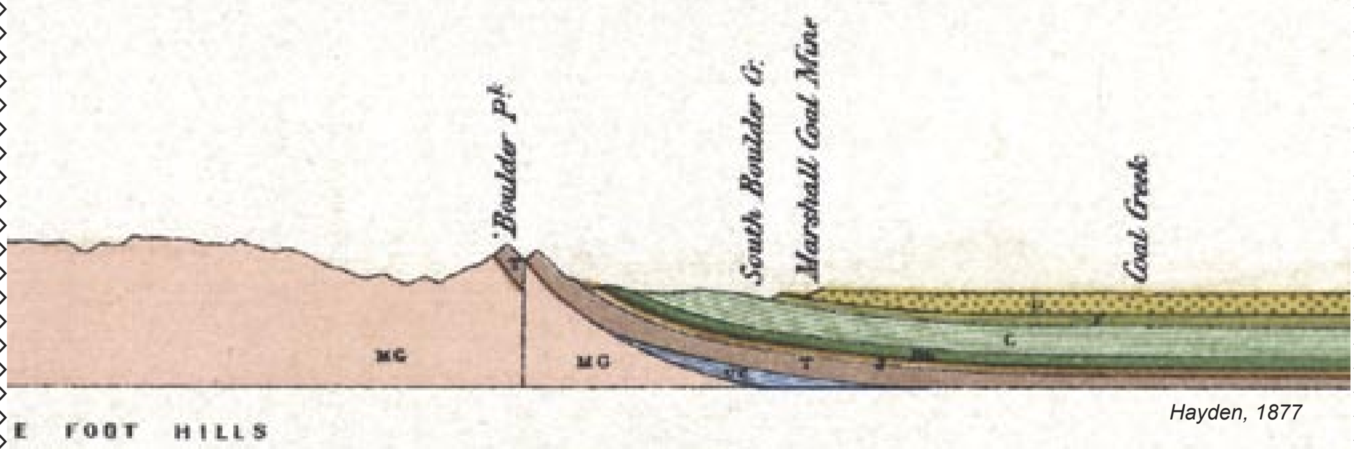
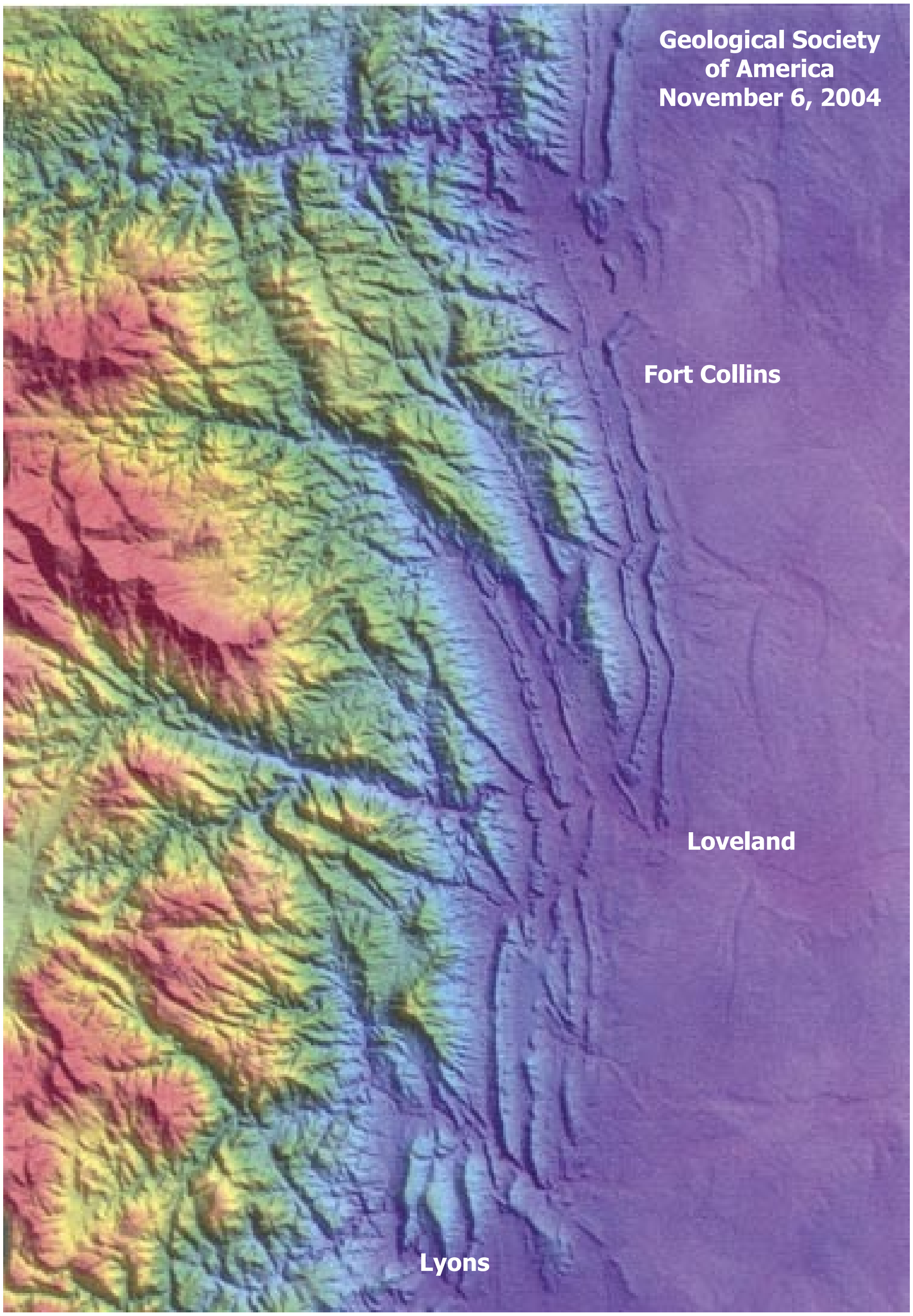


Hayden, 1877


FORT COLLINS
DENVER
THE COLORADO
FRONT RANGE
COLORADO
SPRINGS

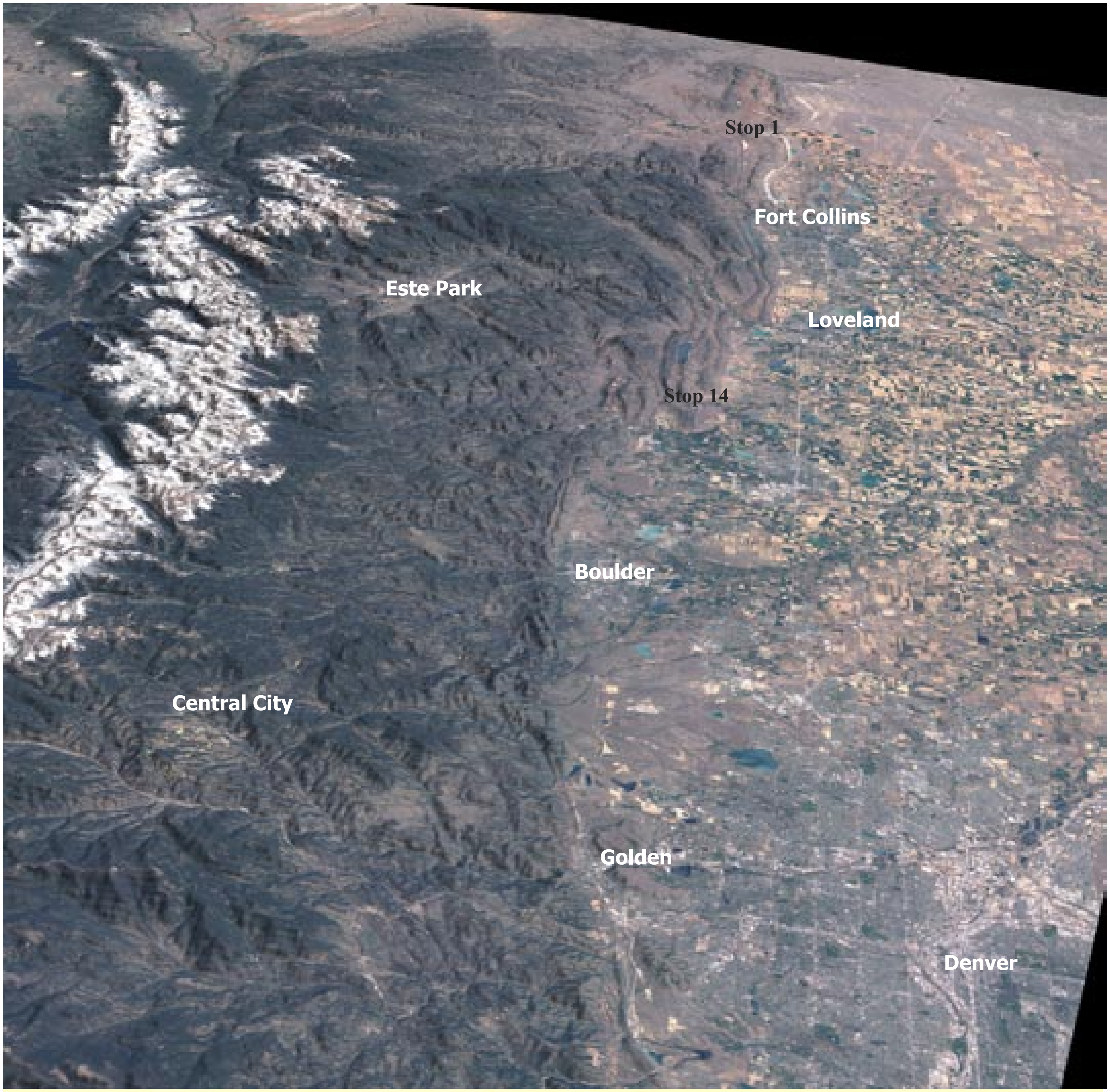
Guide to Laramide Structures Along the Northeastern Flank of the Front Range

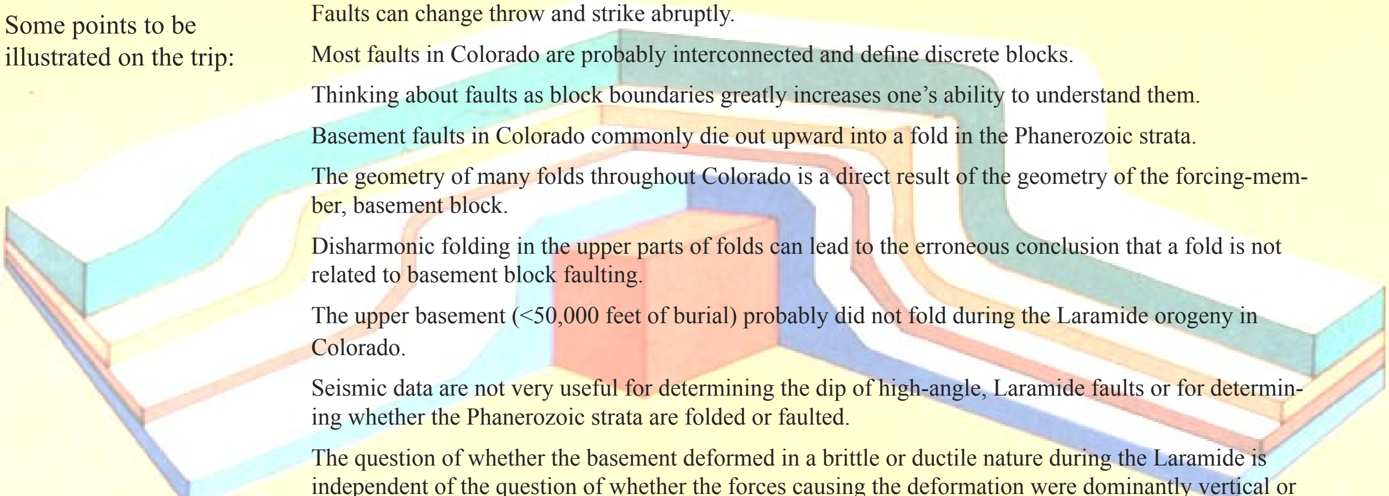


Led by

Vince Matthews

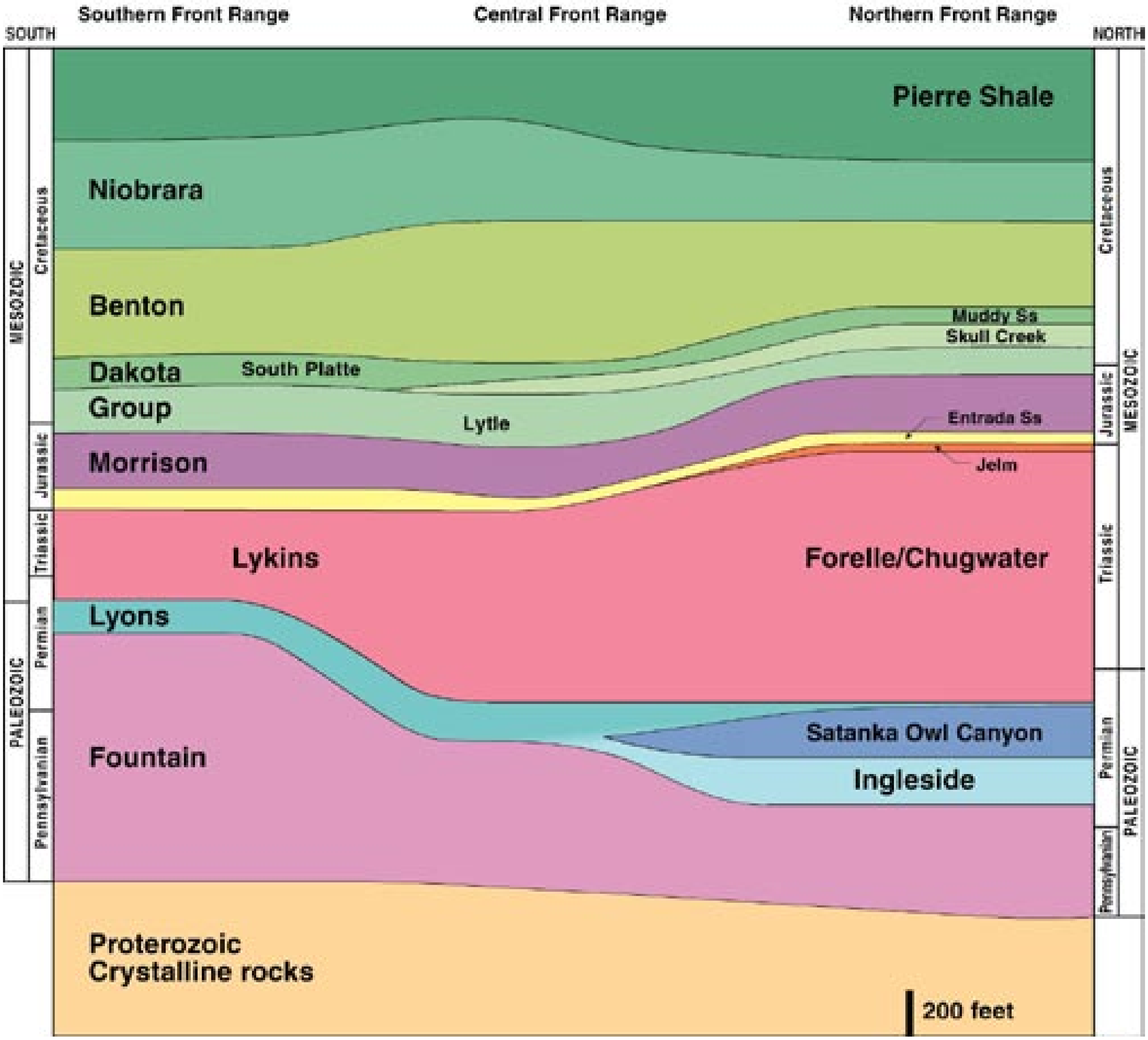
DEM Courtesy of K. Mueller





Some points to be illustrated on the trip:

- Faults can change throw and strike abruptly.
- Most faults in Colorado are probably interconnected and define discrete blocks.
- Thinking about faults as block boundaries greatly increases one's ability to understand them.
- Basement faults in Colorado commonly die out upward into a fold in the Phanerozoic strata.
- The geometry of many folds throughout Colorado is a direct result of the geometry of the forcing-member, basement block.
- Disharmonic folding in the upper parts of folds can lead to the erroneous conclusion that a fold is not related to basement block faulting.
- The upper basement (<50,000 feet of burial) probably did not fold during the Laramide orogeny in Colorado.
- Seismic data are not very useful for determining the dip of high-angle, Laramide faults or for determining whether the Phanerozoic strata are folded or faulted.
- The question of whether the basement deformed in a brittle or ductile nature during the Laramide is independent of the question of whether the forces causing the deformation were dominantly vertical or dominantly horizontal.



Constructed by Berman, 1980

Stratigraphic Variation along the Northeastern Flank of the Front Range

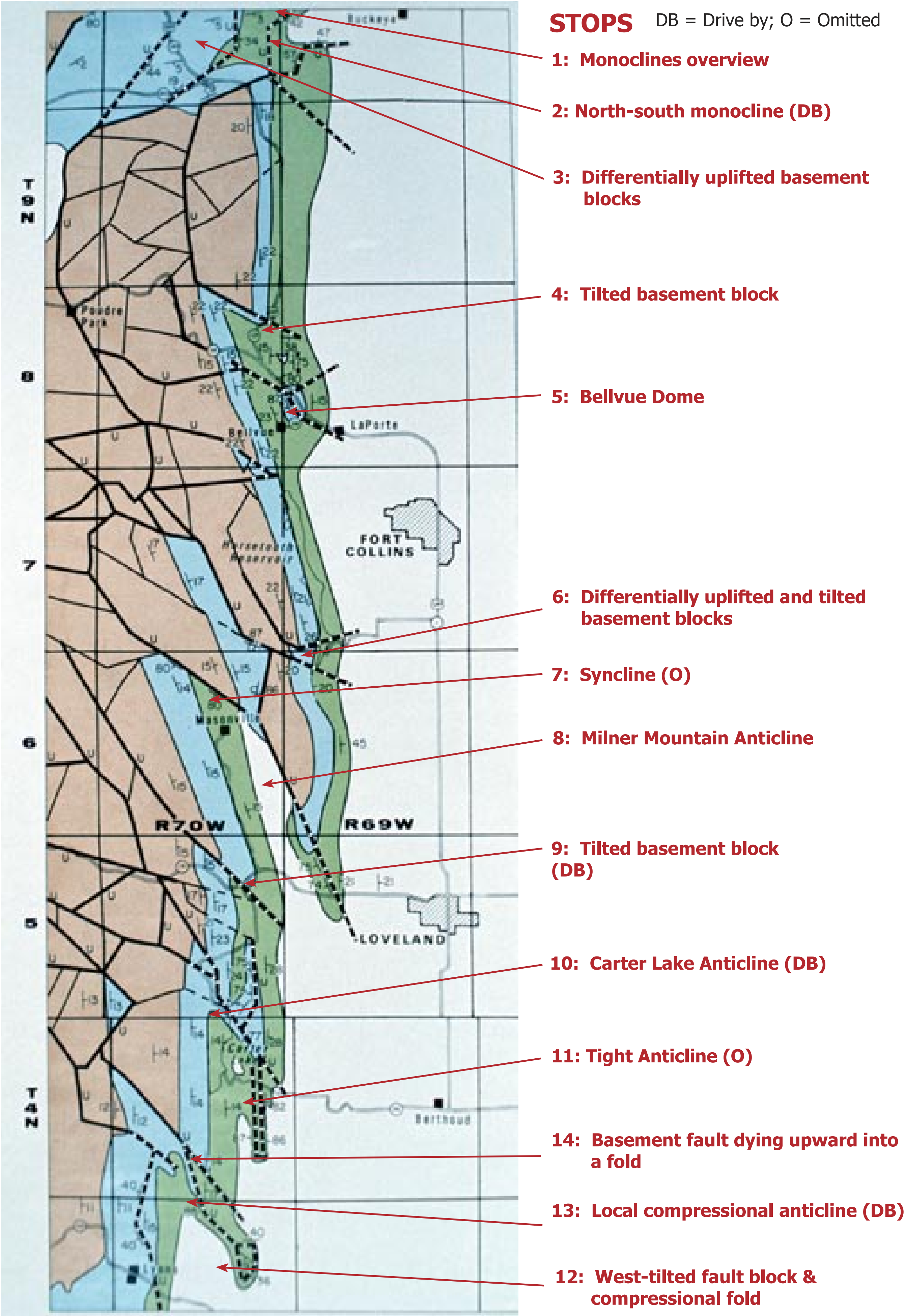
The stratigraphy relevant to the structures seen on this trip includes Proterozoic crystalline rocks and Phanerozoic strata ranging from the Fountain through the Dakota. Several marked stratigraphic changes occur along our route from the Northern Front Range to the Central Front Range:

1. The Fountain Formation thickens toward the south.

2. The Ingleside Formation thins and changes from dominantly carbonate in the north to dominantly siliclastic in the south.

3. The Satanka shales thin southward and pinch out just before Stop 14.

4. The Lyons formation thickens dramatically southward and merges with the upper Ingleside when the Satanka pinches out.



Simplified geologic map of the northeastern flank of the Front Range. Tan is Proterozoic, blue is Paleozoic, and green is Mesozoic. Strike and dip symbols in the Proterozoic rocks represent the attitude of the pre-Fountain erosion surface. (*from* Matthews and Work, 1978)

Summary

Laramide folds in the sedimentary rocks along the northeastern flank of the Front Range uplift are quite varied, including both symmetrical and asymmetrical anticlines and synclines; as well as domes, basins, and monoclines. These structures are a microcosm of the Wyoming Province of the Rocky Mountain Foreland. Exceptional exposures along the flank of the Front Range make it possible to observe the relations of the brittle deformation of the Proterozoic crystalline rocks to the ductile deformation of the Phanerozoic strata.

Figure 1: Wellington Oil Field with the Gangplank on the horizon. The Gangplank is underlain by the Mio-Pliocene Ogalla Formation which grades onto the Laramie Range and buries the flanking structures. Ogallala strata are generally considered to also have graded onto the Front Range. The South Platte River system has removed the Ogallala from the area of the field trip and exhumed the pristine Laramide structures.

Mileage

0.0 Begin at east end of bridge over I-25 at Owl Canyon Road exit. (40° 45.297′, 104° 59.470′) Proceed west on Owl Canyon Road, (Larimer Cty. 70).

2.7 Wellington oil field (Figure 1). A structural trap similar in size and geometry to Owl Canyon block.

4.5 Right turn on Larimer CR-15.

8.5 Turn left on Larimer CR- 78.

9.5 Turn right on Larimer CR-17.

10.5 Turn left on Larimer CR- 80.

11.5 Paved road turns right, continue straight on gravel road.

13.5 Passing through limb of monocline. Beds of Dakota Group at 3:00 are dipping southeast at 74°. Beds of Dakota capping hill at 2:00 are dipping 4° south.

13.9 Beds of Morrison formation exposed in spillway of dam.

14.3 **STOP 1** View to northwest of monocline (figs. 2 & 3). Pink and grey beds in monocline are in the Ingleside formation (Pennsylvanian/Permian). Red and white flatirons are Permian Satanka formation. Wide valley to north is in beds of Chugwater formation (TR) that are dipping 4° south. Crossbedded sandstone below road is the Entrada formation (Je). Roadcut exposes strata of Morrison formation (Jm). (40° 50.242′, 105° 09.798′)

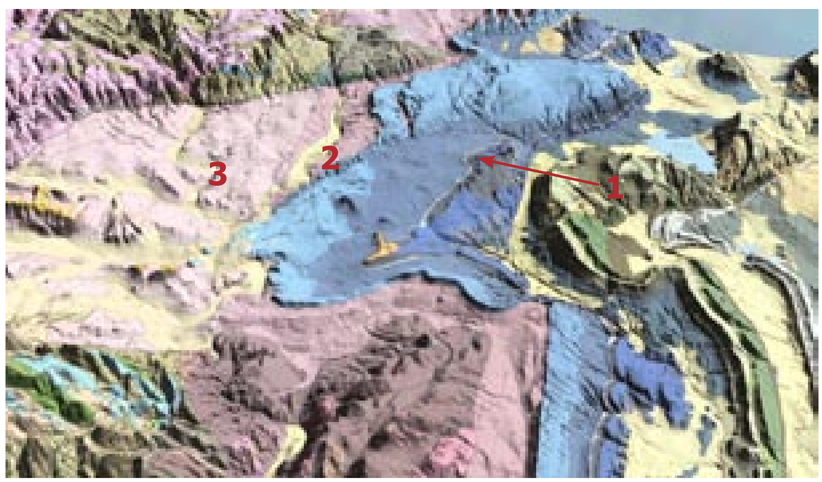


Figure 2: Overview of monoclines and exposed basement blocks. (Draped geology from Braddock and Connor, 1998; Braddock, et al, 1988)

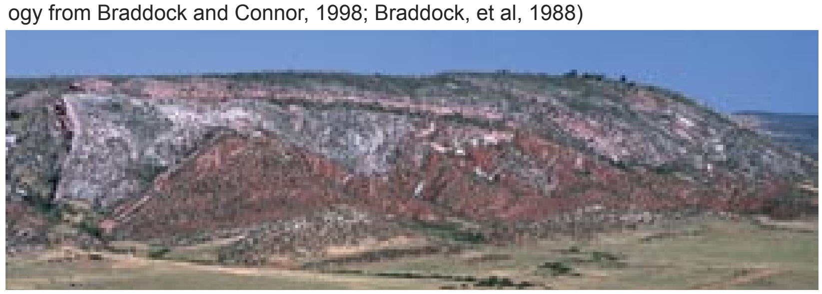


Figure 3: View of monocline from Stop 1. Pink and gray beds are Ingleside Formation, redbeds are Satanka Formation.

14.7 Excellent exposure of crossbedded sandstones of the Entrada formation at 10:00.
16.3 **STOP 2** A N9°E monocline, crosses the road here, and intersects a N75°W monocline poorly exposed north of the road. These two smaller monoclines merge and form a third, larger monocline trending N55°E (Figures 4 & 5). These monoclines are interpreted as forced folds over the edges of three differentially-uplifted basement blocks (Matthews and Sherman, 1976). (40° 50.055′, 105° 11.716′).

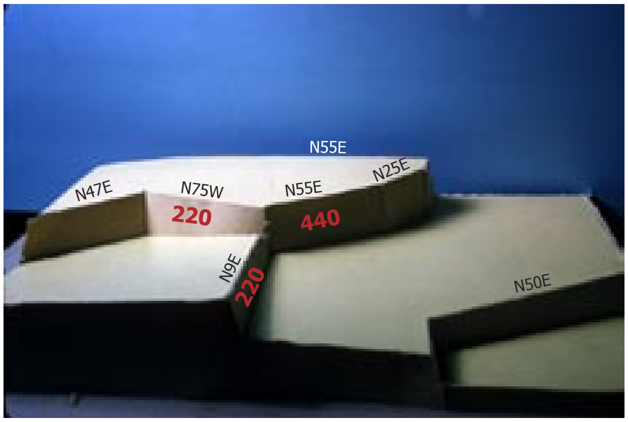


Figure 4. Block model of the basement blocks creating the monoclines at Stops 1-3. Same view direction as Figure 5. Red numbers are the throw on each fault in meters.

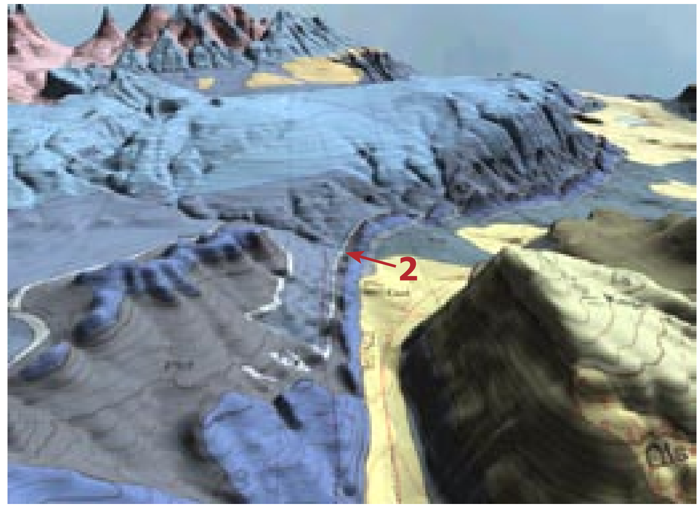


Figure 5. Overview of Stop 2 showing intersection of N9E monocline with N55E and N75W monoclines. (Draped geology from Braddock and Connor, 1988; Braddock, et al, 1988)

Continue west.
17.3 Driving parallel to Grayback Ridge Monocline (N45°E) on right (Figure 6).
18.1 **STOP 3**—Straight ahead are flat-lying Triassic strata in Deadman Butte. To the north is the limb of Grayback Ridge monocline (N.45°E.) dipping 45°SE. Horizontal Triassic strata north of Grayback Ridge monocline are 220 m higher than flat-lying strata in Deadman Butte. To the west, the sedimentary cover has been removed from the underlying Proterozoic basement. There, the pre-Fountain erosion surface can be seen differentially uplifted to different levels.
19.9 Intersection with U.S. Hwy. 287. View to north across Grayback monocline. In the distance, on the skyline, are two differentially uplifted blocks of Proterozoic crystalline rocks (Figure 7). View to

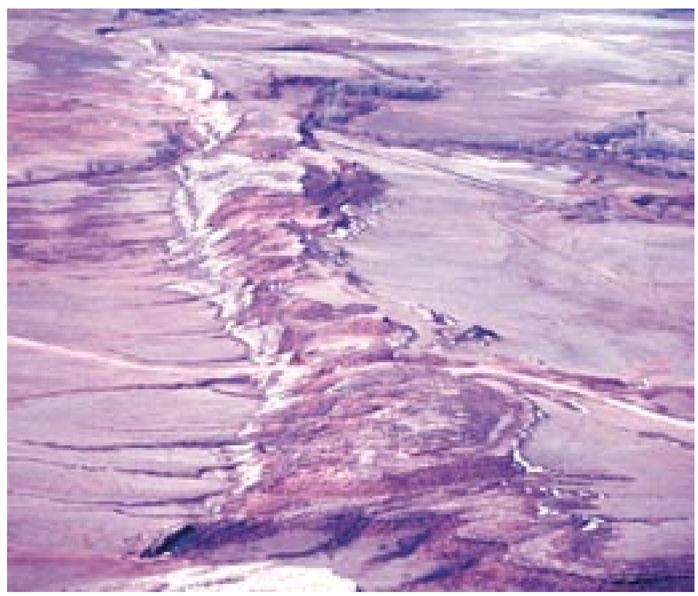


Figure 6. View of Grayback Ridge monocline looking southwest. US-287 cuts through the limb of the monocline.

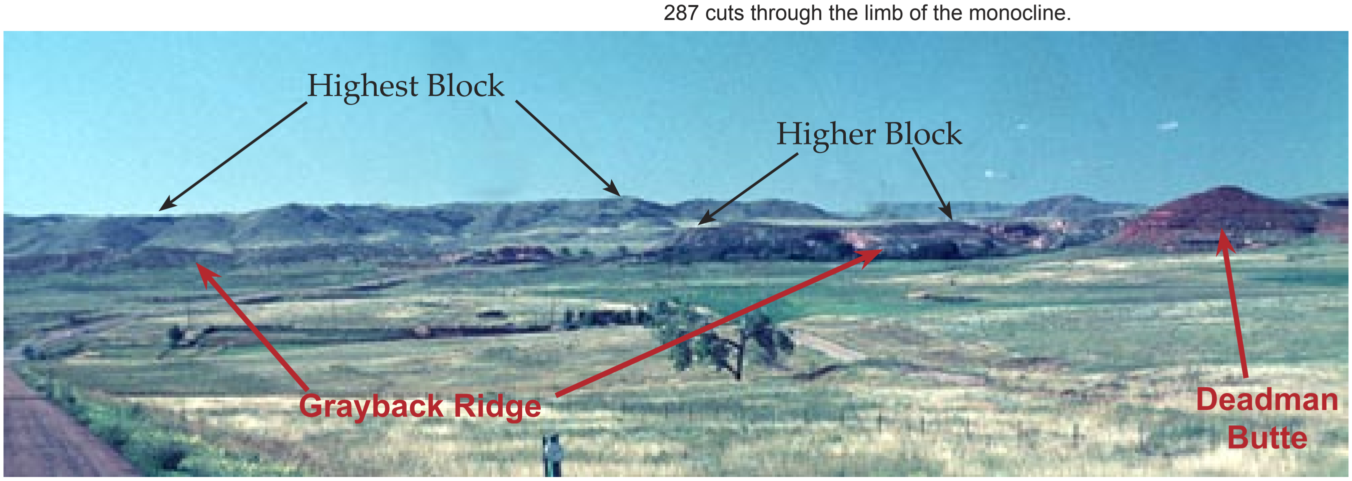


Figure 7. View of Grayback Ridge monocline from intersection with US-287. Black arrows point to two differentially uplifted blocks of Proterozoic rock north
same in si
and horizontal Triassic strata in Deadman Butte.

the south at 10:00, down the valley over the North Fork fault. Fault separates two large, deeply dissected, fault blocks of Proterozoic crystalline rocks which are differentially uplifted and tilted toward the east (Figure 8). Throw on the fault is approximately 300 m. Road log follows along north, east, and south side of easternmost tilted block (fig 9).

Figure 8. View south of two, tilted fault blocks with North Fork fault in between (arrow). Note the gentle dips to the east and steeper dips to the west.

Turn left.

20.3 Limb of small monocline exposed in roadcuts.

21.4 Strata of Ingleside formation on left are folded over north edge of tilted block of Proterozoic rock on right.

21.8 Beds of Ingleside abruptly change strike from EW to NS as corner of tilted fault block passes underneath.

22.1 Riding on poorly exposed beds of Fountain formation. Limestone quarry on left is in Ingleside formation. Proterozoic Sherman granite is on right. Sedimentary strata are resting passively on east-dipping, Owl Canyon fault block (Figure 9).

24.1 Owl Canyon roadcut. Sandy limestone beds of Ingleside formation are dipping 17° east.

25.6 Dakota sandstone is capping ridge on left. Slope is poorly-exposed Morrison, Entrada, Jelm, and Lykins Formations. First hogback to right is Lyons Formation. Second hogback is Ingleside Formation.

29.1 View at 12:00 of south-dipping Dakota sandstone which forms north rim of four-sided, structural basin.

30.6 Cross railroad tracks.

30.9 **STOP 4** Pull off road onto wide shoulder. View north shows beds of Fountain and Ingleside Formation on east side of valley dipping 22° east. Tilted block of Proterozoic crystalline rocks on west side of valley (figs. 9 –12). Pre-fountain erosion surface is dipping 22° east. View to northeast shows beds of Ingleside abruptly changing strike as they fold over south edge of tilted fault block. To the west, the low red ridges are resistant strata of the Ingleside formation, passively resting on another tilted block of Proterozoic crystalline rocks forming grassy slopes farther west. In roadcut to the south are east-dipping beds of Morrison Formation forming the west flank of the structural basin. 40° 40.460', 105° 11.228'.

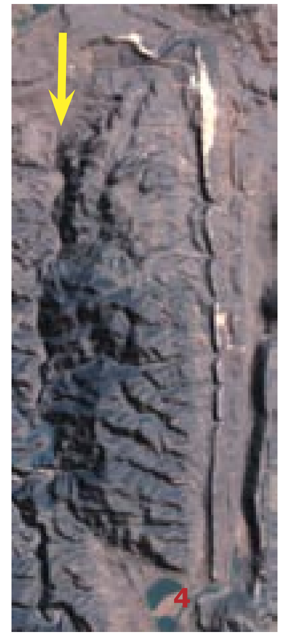


Figure 9. Draped Landsat 7 view of Owl Canyon block. Yellow arrow points to north end of North Fork fault.

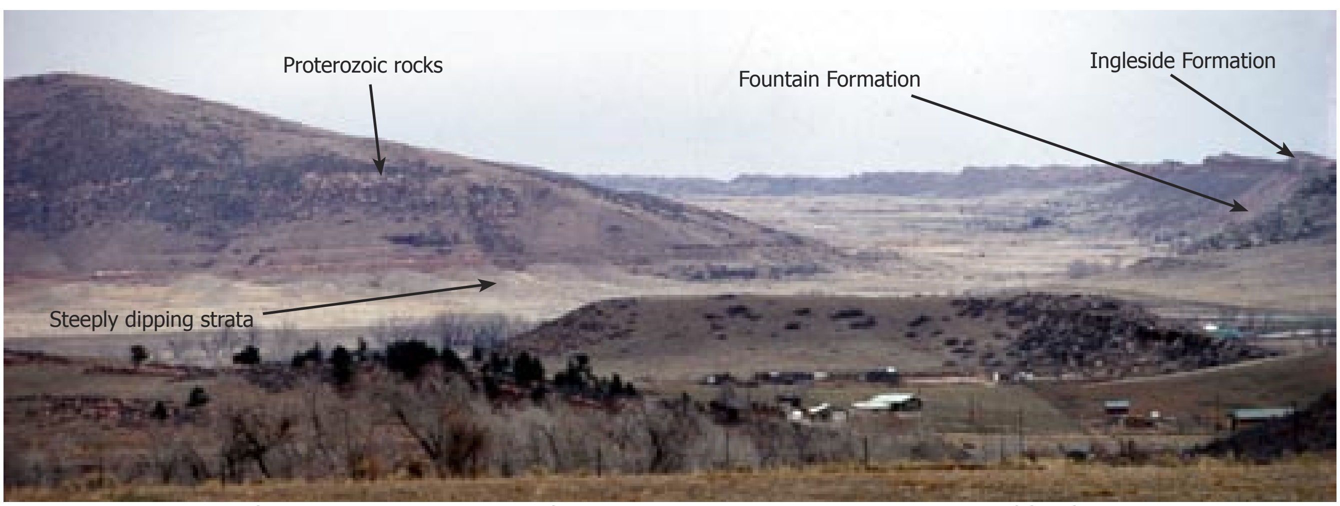


Figure10. View northward of tilted pre-Fountain erosion surface developed on Proterozoic crystalline rocks of Owl Canyon block. Arrow points to horizontal pegmatite.

32.7 Turn right on CR-54E.

33.2 Turn left on CR-25E.

33.7 View at 10:00 of north-dipping, Paleozoic strata forming north flank of Bellvue dome (fig. 13). View at 8:00 of north-dipping Mesozoic rocks forming north flank of Bellvue dome and south flank of basin. Beds of Dakota sandstone are dipping north at 80°.

34.6 Turn left on CR-52E.

34.8 View to the northeast of core and south flank of Bellvue dome. Strata in central part have an apparent south dip of 4°; true dip is 17° east. 40° 37.774, 105° 10.664.

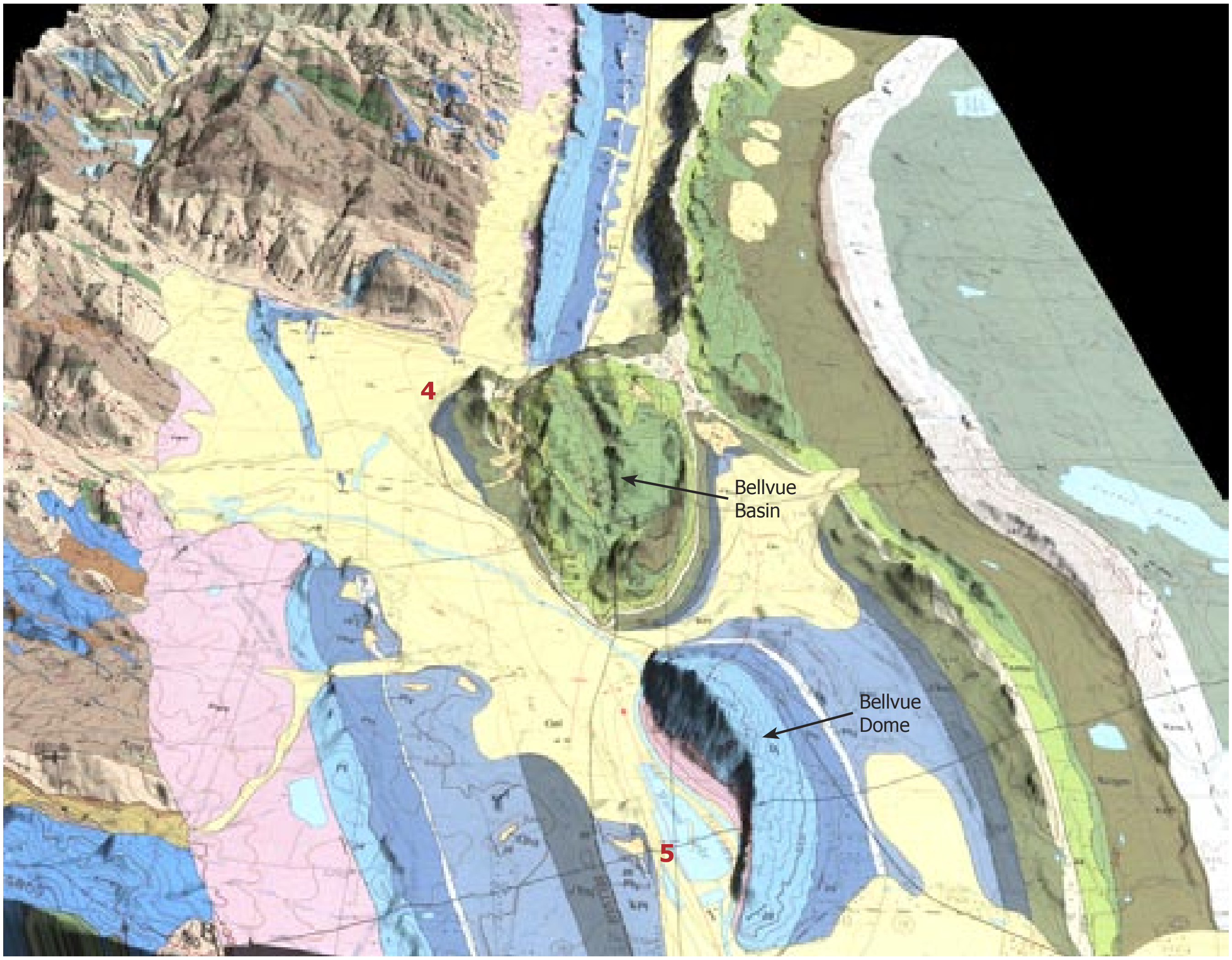


Figure 11. Overview showing draped geology of Stops 4 and 5.

Geology from Braddock, et al, 1988

35.3 Turn left into State Fish Rearing Unit (Watson Lake). Proceed to picnic area.

STOP 5 Picnic area is in core of Bellvue dome. Dome is four-sided with three steeply-dipping flanks and a planar, gently- dipping east flank. Massive beds of Ingleside Formation cap ridge across lake. Slopes are in Fountain Formation. Outcrop west of picnic area exposes steeply-dipping strata of Ingleside, Satanka, and Lyons Formation. Most workers show a north-south fault associated with this west flank of the dome. However, the fault's location is debatable. Some place it west of the steeply dipping beds (Braddock and others 1973), some place it under the lake (Boos and Boos 1957), and others consider it to be present only in the basement and

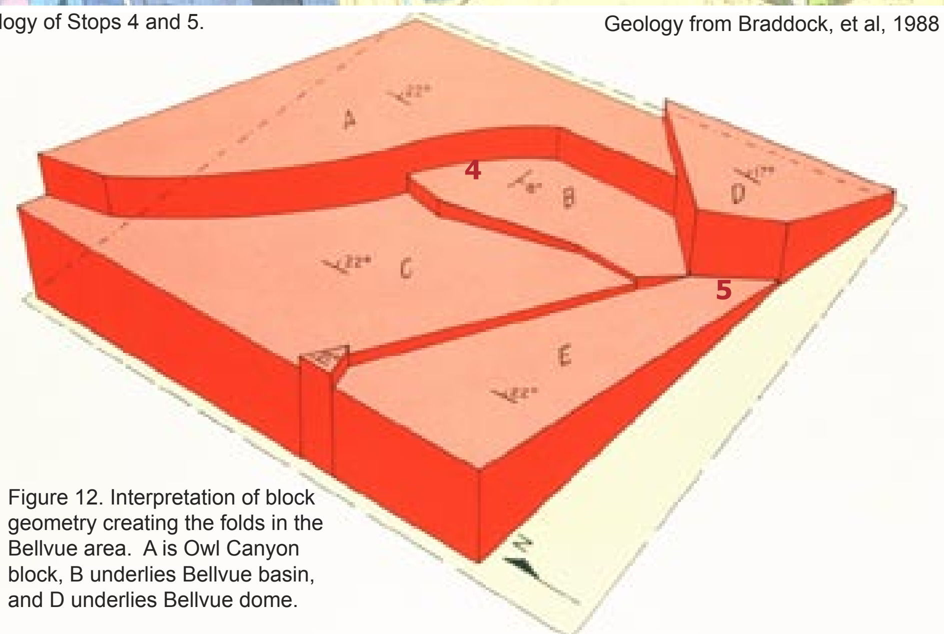


Figure 12. Interpretation of block geometry creating the folds in the Bellvue area. A is Owl Canyon block, B underlies Bellvue basin, and D underlies Bellvue dome.

Figure 13. Overview of Bellvue Dome

not to cut the sedimentary strata (Matthews and Work 1978). The dome is interpreted by Matthews and Work (1978) to be a forced fold over a buried block of Precambrian basement (Block D, fig. 12).

36.1 Return to CR-52E. Turn right.

36.2 Turn left on 23 Road toward Horsetooth Reservoir.

38.3 Horsetooth Reservoir Dam on right. Dam is built on Triassic redbeds prone to karsting. The reservoir was drained for several years in this century in order to stop leakage under the dam.

40.3 Note that the Dakota hogback on the left is at a much lower elevation in this area. This is the head of a block glide landslide. Numerous block-glide landslides have moved down the east slope of the hogback. These glide blocks slid on the weak shale unit which separates the two resistant sandstone units of the Dakota Group (Braddock and Eicher, 1962).

42.1 Bear right.

43.7 Turn right on 38E Road. Contact between Dakota and Morrison formations.

46.3 Climbing hogback of Lyons sandstone.

Figure 14a. View of three differentially-uplifted and tilted fault blocks (A, B, & C) of Proterozoic crystalline rocks seen from Stop 6.

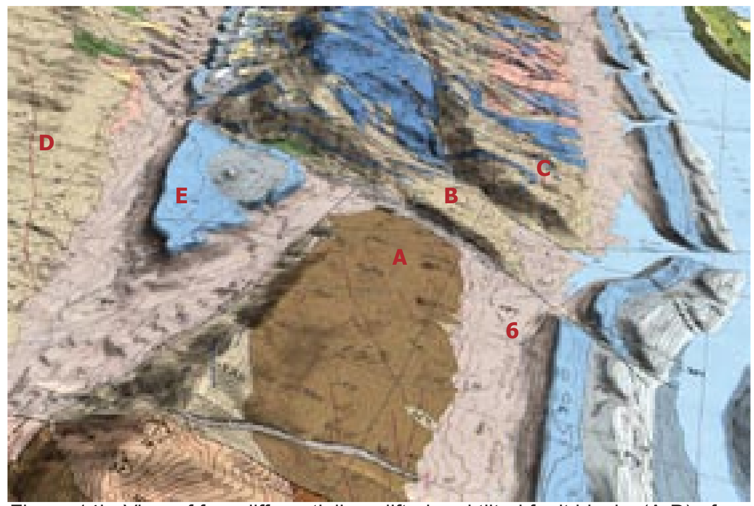


Figure 14b. View of four differentially-uplifted and tilted fault blocks (A-D) of Proterozoic crystalline rocks and "Bishop's Hat" syncline (E). Stop 6 in red. (Draped geology from Braddock, et al, 14989; Braddock, et al, 1970.

46.8 **STOP 6** . The view to the north shows the dip slopes and fault line scarps of three differentially uplifted blocks of Proterozoic rocks (fig. 14). Strong zones of shearing are evident at the boundary of each block. The easternmost block (C) dips 26° to the east and the strata to the east have a similar attitude. The block on which we are standing (A) dips 20° east, and the sedimentary strata to the east of this block dip 20° to the east. The sedimentary strata to the east pass over the edges of these three blocks in a relatively continuous fashion. The Fountain formation is faulted; however, the Lyons and Dakota pass over the block edges in continuous folds. After leaving this stop we climb a short hill which is directly over the shear zone bounding two of these differentially uplifted blocks. 40° 31.025, 105° 09.772′.

47.5 Bear left. Road follows shear zone in Precambrian rocks which marks boundary between two differentially-uplifted fault blocks.

49.1 After cresting the hill we will be riding over a down-dropped block where the overlying Phanerozoic strata form a triangular-shaped basin. This is one of the areas described by Prucha and others (1965) in their classic paper on basement-controlled deformation in the Rockies. Prucha described this "Bishop's Hat" syncline (Fig. 15) as forming from "differential, principally vertical, movement of three discrete basement fault blocks". Unfortunately, it is difficult to view all of the geometrical relationships in this area from the highway. But overviews are possible from the development south of the County Park.

51.6 Masonville. Continue straight ahead.

53.0 Flagstone quarries in Lyons sandstone forming hogback on left.

53.5 **STOP 7** Obtain permission from white farmhouse to the south before entering gate. Well exposed syncline in Lyons Sandstone. The syncline is interpreted as a drag fold by some workers and an eroded through forced fold by others. Cross creek and walk east to Proterozoic/Fountain contact. Contact is interpreted as fault by most workers, yet examination of contact yields little evidence supporting either depositional or fault interpretation. Return to Masonville. 40° 30.496, 105° 13.775′.

55.5 Masonville. Continue straight.

57.8 Pullout. East-dipping Dakota hogback at 3:00. At 12:00 is east dipping Fountain Formation. Looming above and behind the Fountain is an uplifted block of Proterozoic rock that cores the Milner Mtn. anticline.

58.05 View north up valley containing fault separating Proterozoic rocks on the east and Dakota strata on the west.

58.2 Turn right on CR-25E. View at 11:00 of anticlinal nose in Fountain Formation. View at 2:00 of east-dipping Dakota Formation.

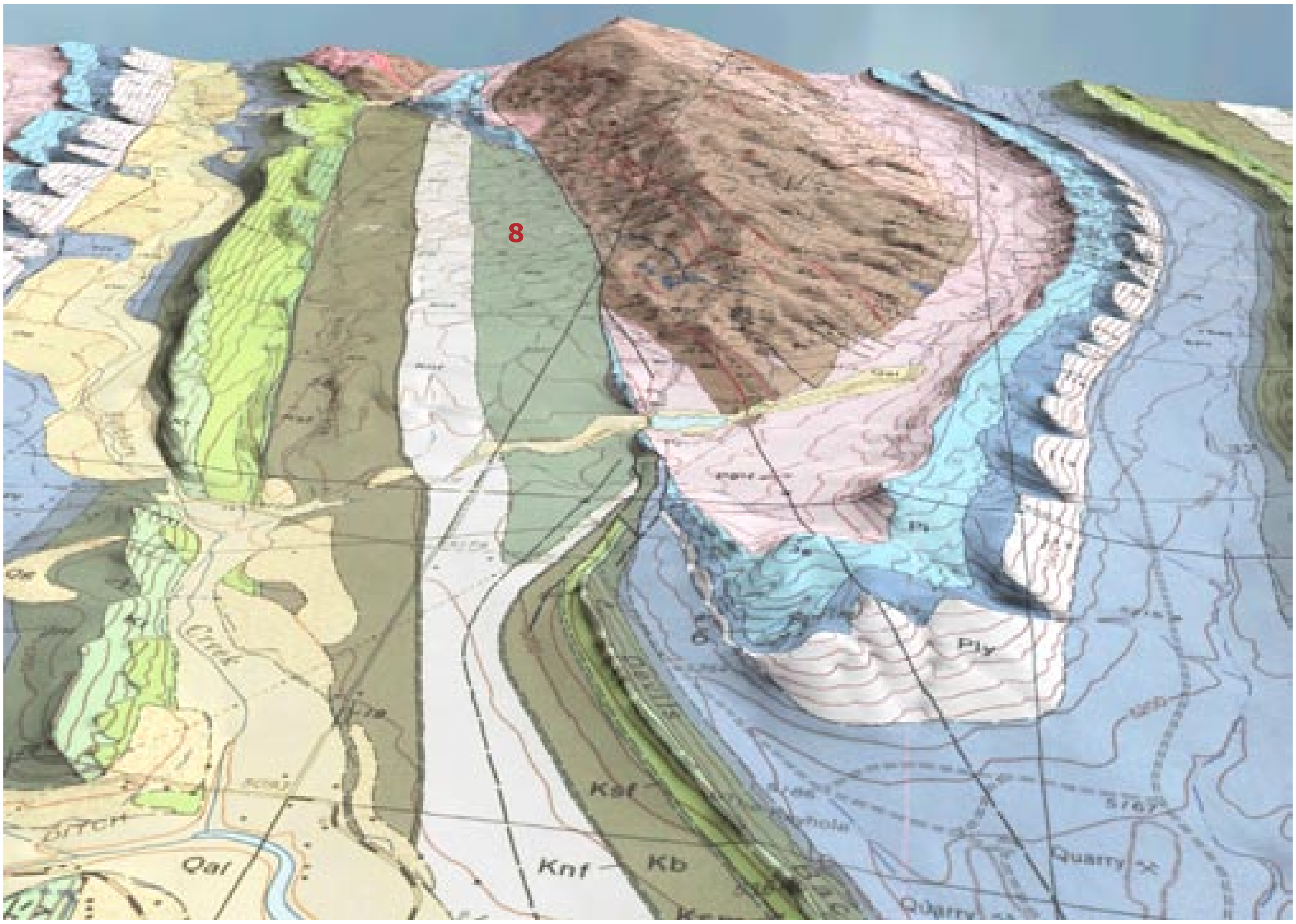


Figure 16. Draped geology showing Milner Mountain fold and location of Stop 8. (Geology from Braddock, et al, 1970.

59.4 **STOP 8** View to the east of the core of Milner Mt. anticline. To the southeast can be seen Devil's Backbone which is composed of steeply-dipping Dakota conglomerate. LeMasurier (1970) interprets the Proterozoic rocks to be arched into the core of the fold, as a result of compressive stresses. Studies of dikes in the core of the fold show that the basement has not folded. Matthews & Work (1978) interpret the geometry of the Milner Mountain structure to be the result of a large basement block which has been tilted toward the east and has been broken into smaller secondary blocks (fig. 16 & 17). The geometry of the gently-dipping, east limb of this anticline can be related to the differential uplift of the secondary blocks (Figure 17). The steeply-dipping west limb is interpreted to be folded over the west edge of the large uplifted block.

The question of how much displacement can occur in the basement before the sedimentary package along the Front Range will fault can't be precisely answered yet. The Dakota is faulted through at the north end of the Milner Mountain structure. That displacement of 1,500^{+} m is clearly sufficient to fault through the entire sedimentary package. There are places along the Front Range where 200 m of displacement in the basement is covered by a continuous fold at the Lyons level. We have been unable to narrow these limits. By comparison the carbonate package in the Big Horn basin of Wyoming (which is much different than the clastic package here) is able to withstand as much as 2000 m of displacement on the basement block without faulting the sedimentary section.

Disharmonic folding between the Mesozoic and Paleozoic strata is well illustrated at Milner Mountain. Similar disharmonic folding is recognized in many structures in the foreland province and must be dealt with in a successful exploration program. The origin of this disharmonic folding is discussed by Weinberg (1979). As we leave this stop, we will have a good view of Devil's Backbone out of the left windows. 40° 28.377.377, 105° 11.733′.

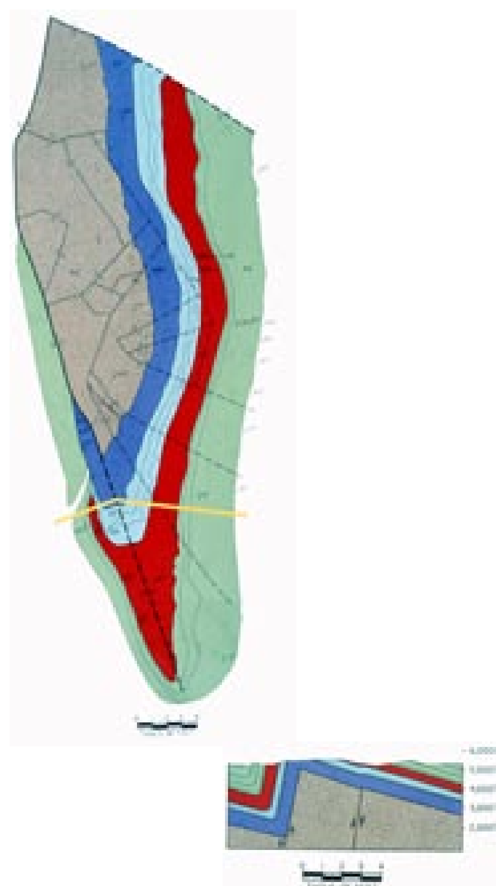


Figure 17. Map and cross section of Milner Mountain (modified from Braddock et al, 1970.)

66.0 CR-24H. Turn left. Excellent view of Devil's Backbone (Steeply dipping Dakota Sandstone which forms west limb of southeast plunging anticline.)
67.2 CR-24. Turn right.
68.1 RD-27. Turn left.
68.3 US-34. Turn right.
68.4 Exposure of Lykins Formation.
68.5 Good exposure on right of large scale, cross bedding in Lyons sandstone.
69.4 Intersection of US-34 and CR-29.

STOP 9 View to northeast of Green Ridge fault block (fig. 18 & 19). Formations exposed in hill to northeast are Fountain, Ingleside, Satanka and Lyons which are resting passively on Green Ridge block. Green Ridge block is tilted 16° east. Hogback of Lyons Sandstone to west is resting on another Precambrian block. Strata in small knoll to northeast are dipping 18° west. Hill to south is nose of plunging anticline. This structure is interpreted as drag fold by some workers and a forced fold by Matthews and Work (1978).

69.4 Turn left (south) on North Carter Lake Road. (CR-29)
71.5 Turn right on CR-18E.
71.8 Small rollover in Lyons Sandstone at

Figure 18. Draped geology showing Green Mountain Block (Stop 8) and Milner Mountain fold (Stop 7). Geology from Braddock, et al, 1970.

Figure 19. Aerial view of Green Mountain block. Buckhorn and Horsetooth blocks in the background.

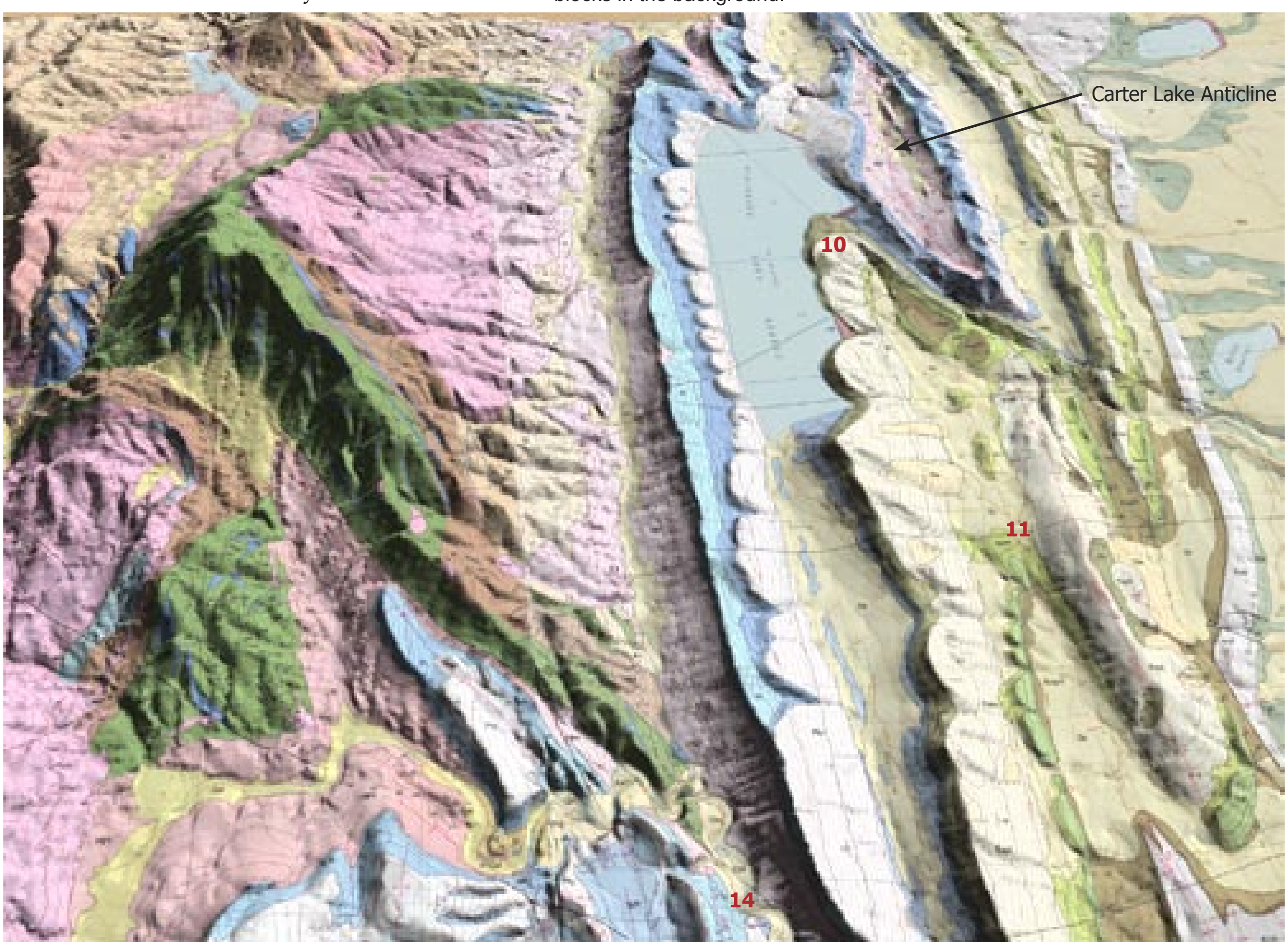


Figure 20. Overview of Blue Mountain block showing Stops 10, 11, & 14. Geology from Braddock, et al, 1988; Braddock, et al, 1989.

northernmost end of Carter Lake anticline.

72.0 View at 9:00 of synclinal valley. Lyons on west side of valley is east-dipping at 24°. Steeply dipping (74°) Lyons and Lykins strata on east side of valley form west limb of Carter Lake anticline (fig. 21).

73.1 View north of fault block of Proterozoic crystalline rocks rotated 24° east.

73.3 View north of fault-line scarp marking west face of rotated bloc of Proterozoic crystalline rocks.

73.6 Turn left to Carter Lake on CR-31.

74.0 View at 7:00 of tilted block of Proterozoic rocks.

76.0 View across lake of hogbacks formed by planar strata of the Lyons Formation (Figure 20). Strata rest on Blue Mountain block which is tilted 14° east. The Blue Mountain block is one of the largest blocks along the mountain front. Final stop (14) in road log is 3D view of fold over south edge of this block.

76.3 Quarry on left in cross-bedded, west-dipping, Lyons Sandstone that forms west limb of Carter Lake anticline.

77.1 Turn right into picnic area loop.

STOP 10 View to the southwest of planar beds of Dakota Formation reflecting 14° eastward tilt of Blue Mountain block. View to southeast of synclinal valley and steep, west limb of Carter Lake anticline. Carter Lake anticline is interpreted by Matthews and Work (1978) as a forced fold over three, differentially uplifted basement blocks (fig. 22). Follow loop around and turn right on paved road. 40° 20.315, 105° 12.634'.

78.0 Contact between Dakota and Morrison Formations.

78.6 Turn left on 8E. View across valley of steep southwest limb of Carter Lake anticline.

79.4 Right turn on gravel CR-27E.

80.6 **STOP 11** View looking down synclinal valley to the distant Rabbit Mountain structure which is a west-tilted block. Strata on right of valley are east-dipping (14°), planar beds of Dakota resting on Blue Mountain block. Strata on left are steeply-dipping to overturned beds of Dakota Formation which form the west limb of small, flat-topped anticline (Figure 20). 40° 17.808, 105° 11.965'.

82.7 South-dipping Dakota strata on left.

83.1 View at 9:00 of east-dipping Dakota strata.

84.4 Turn right on CR-23E.

84.7 Flat-topped hills at 1:00 and 2:00 are Quaternary pediment surfaces.

87.5 Turn right on Woodland road. (CR-4)

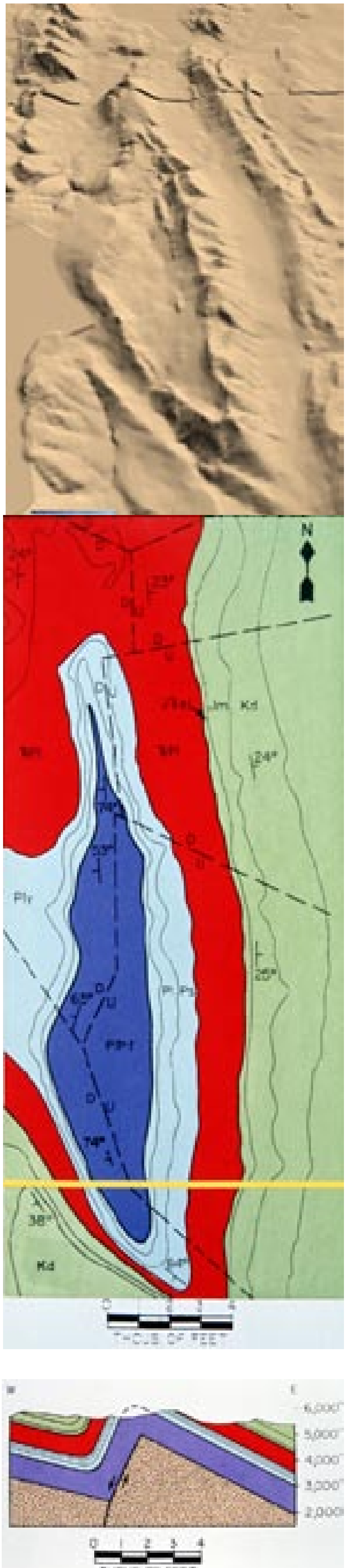


Figure 21. DEM, map, and cross section of Carter Lake anticline (modified from Braddock et al, 1988)

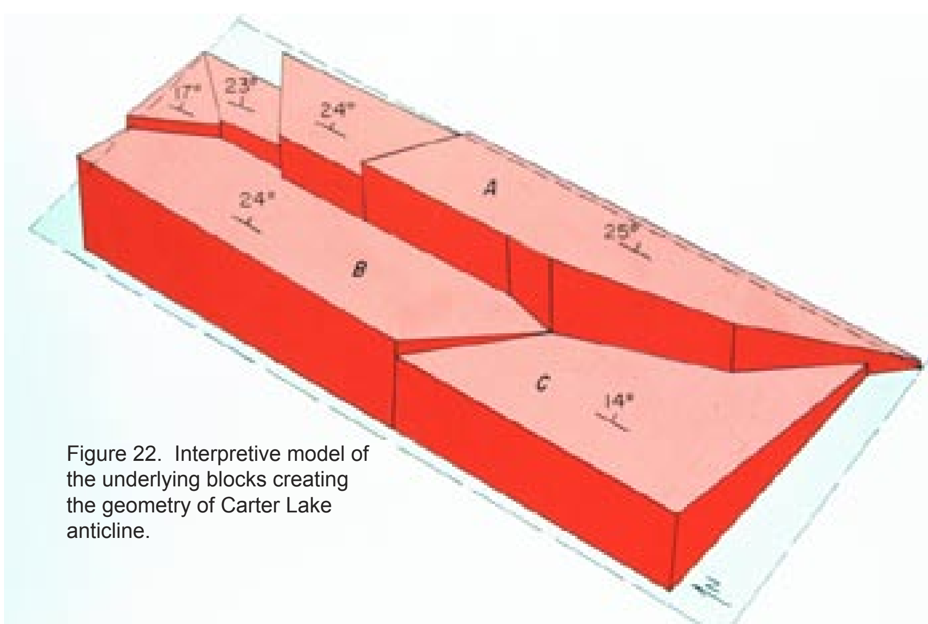


Figure 22. Interpretive model of the underlying blocks creating the geometry of Carter Lake anticline.

Figure 23. View northward of Rabbit Mountain showing steep east limb and gentle, planar southwest limb. Steep dip is also along the south, north, and west sides of block.

87.6 View straight ahead of Rabbit Mountain. Beds of Dakota sandstone on top of mountain have a planar dip of 9° SW. Dakota strata in foreground are dipping 74° east; Dakota at north end of mountain is dipping 55° northeast.
89.5 Turn right on Colo. Hwy. 66.
90.2 View at 2:00 of Rabbit Mountain, showing southwest-dipping, planar strata of Dakota on top of mountain (fig. 23) and steep, east-dipping Dakota to the right of mountain.
92.4 Turn right on CR-47 just west of large water storage tank.
94.2 **STOP 12** View to the east of Rabbit Mountain. The small symmetrical anticline along the west side of Rabbit Mountain is interpreted by Matthews and Work (1978) as compressional fold caused by westward tilting of Rabbit Mountain block (figs. 23 & 24) View north-northeast of thrust fault mapped by Masters (1957). He interprets this as a compressional thrust moving from east to west. Matthews and Work (1978) interpret the thrust to have slid eastward off the steep, east limb of Dowe Pass anticline.
Continue north on CR-47 to top of hill in steeply-dipping limb of Dakota Formation. Stop at four way intersection. Rest of road log requires permission from Spring Garden Ranch.
0 **STOP 13** View north of Dowe Pass anticline. The anticline does not have the geometry typical of other folds in Paleozoic strata along the mountain front, rather it looks like a typical compressional fold with a round crest and symmetrical, steeply-dipping limbs (55°). Exposed strata forming the anticline are Lyons sandstone. The local compression was apparently generated by a room problem in a small graben which appears to have caused the strata on either side to "pop up" over the edges of the adjacent blocks. Where the graben widens to the south, the compressional anticlines change into normal forced folds. The three symmetrical anticlines visible from this stop are considered to be atypical of the Front Range folds. Matthews and others (1975) interpret them as compressional folds existing only in the sedimentary veneer and resulting from basement block faulting.
Proceed on dirt road to right.

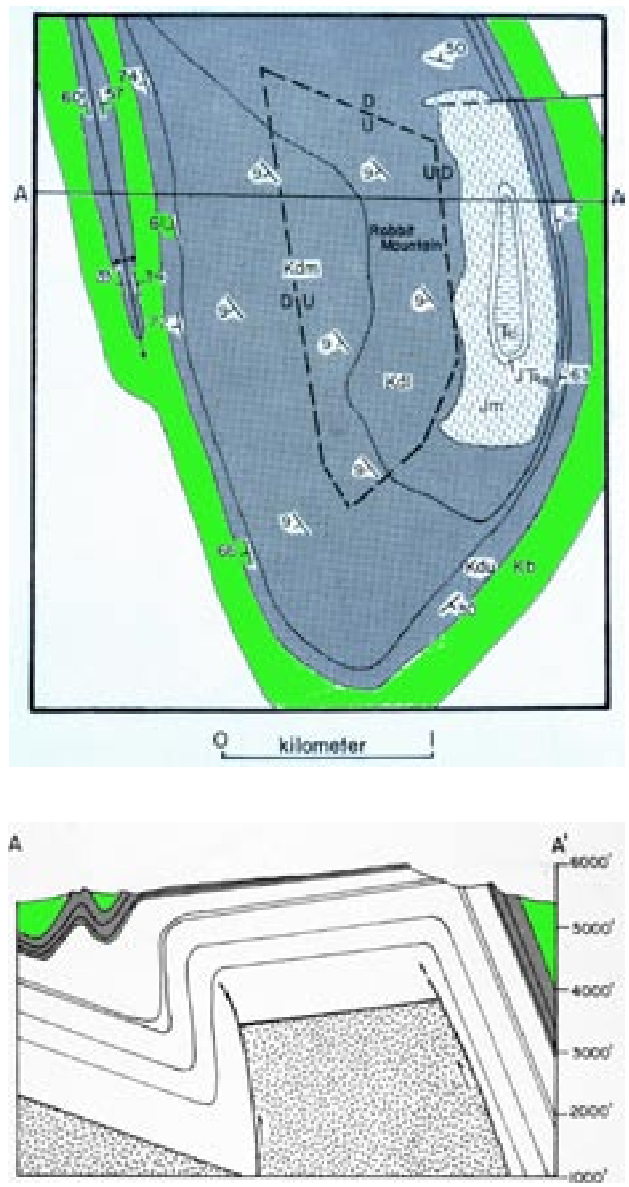


Figure 24. Map and cross section of Rabbit Mountain. Modified from Masters, 1957.

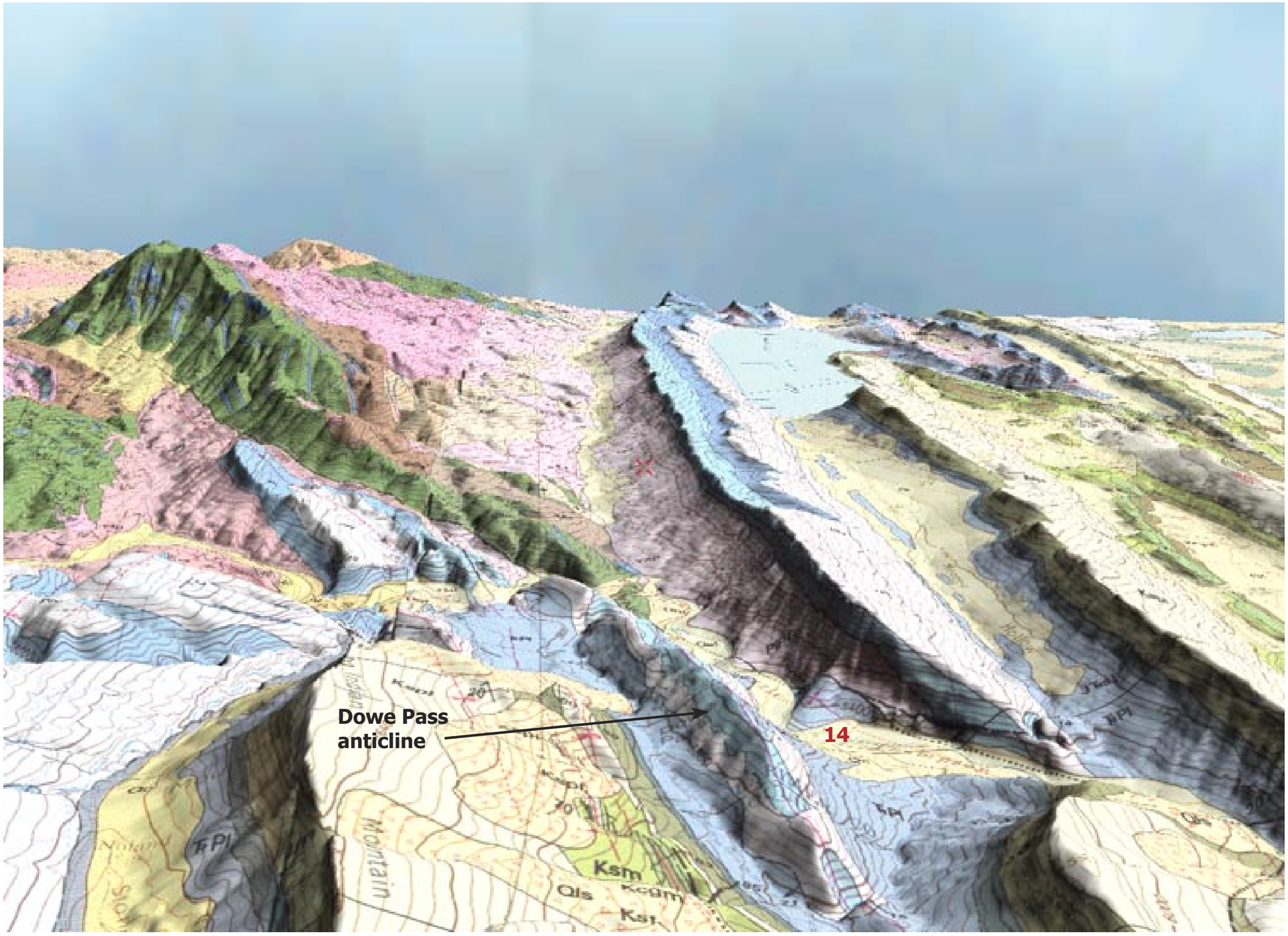


Figure 25. Overview of Dowe Pass anticline and south edge of Blue Mountain block.

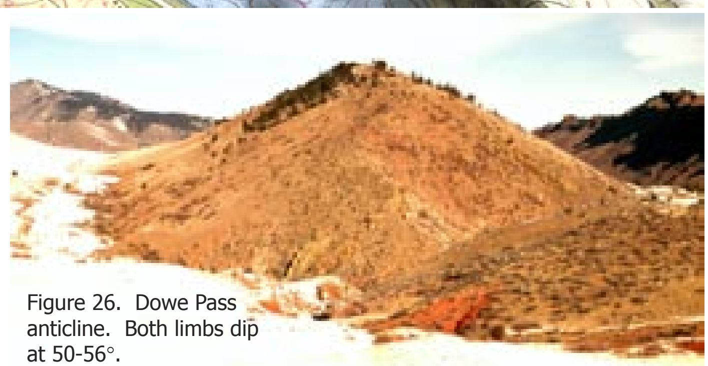


Figure 26. Dowe Pass anticline. Both limbs dip at 50-56°.

0.5 View of east limb of Dowe Pass anticline. Notice how abruptly strata change dip from 55°E to 14°E.

1.1 **STOP 14** View of south end of Blue Mountain block (fig. 25 & 27). Fountain Formation is faulted in same manner as underlying basement, whereas, Lyons Sandstone is folded with only minor faulting. Displacement here is approximately 200 m.

End Road Log.

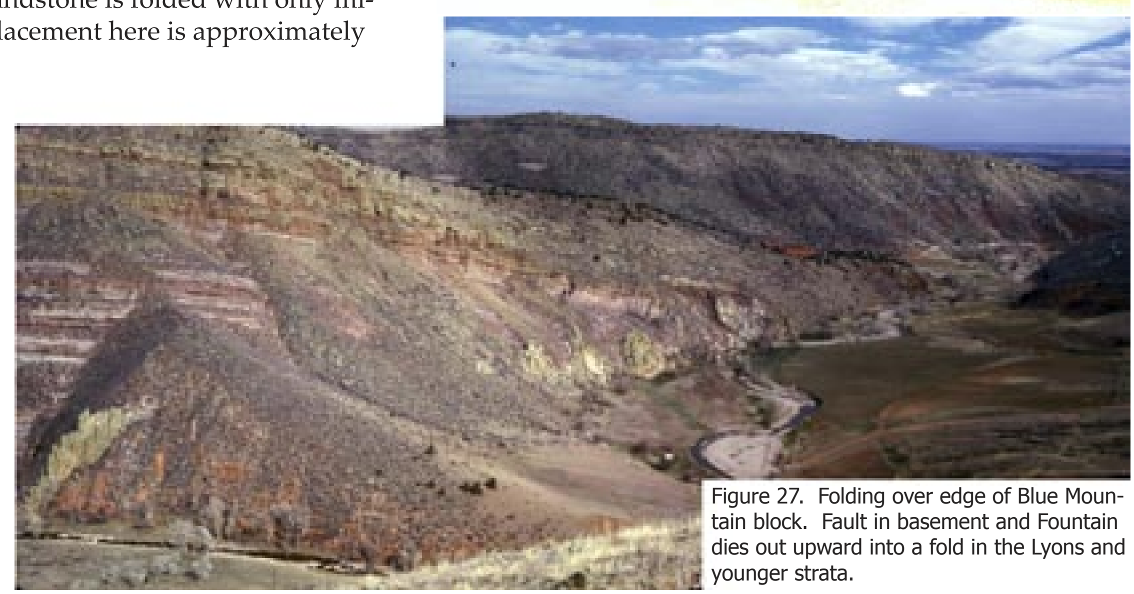


Figure 27. Folding over edge of Blue Mountain block. Fault in basement and Fountain dies out upward into a fold in the Lyons and younger strata.

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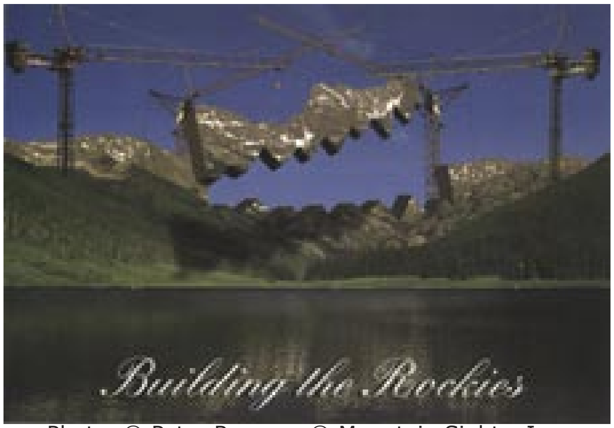
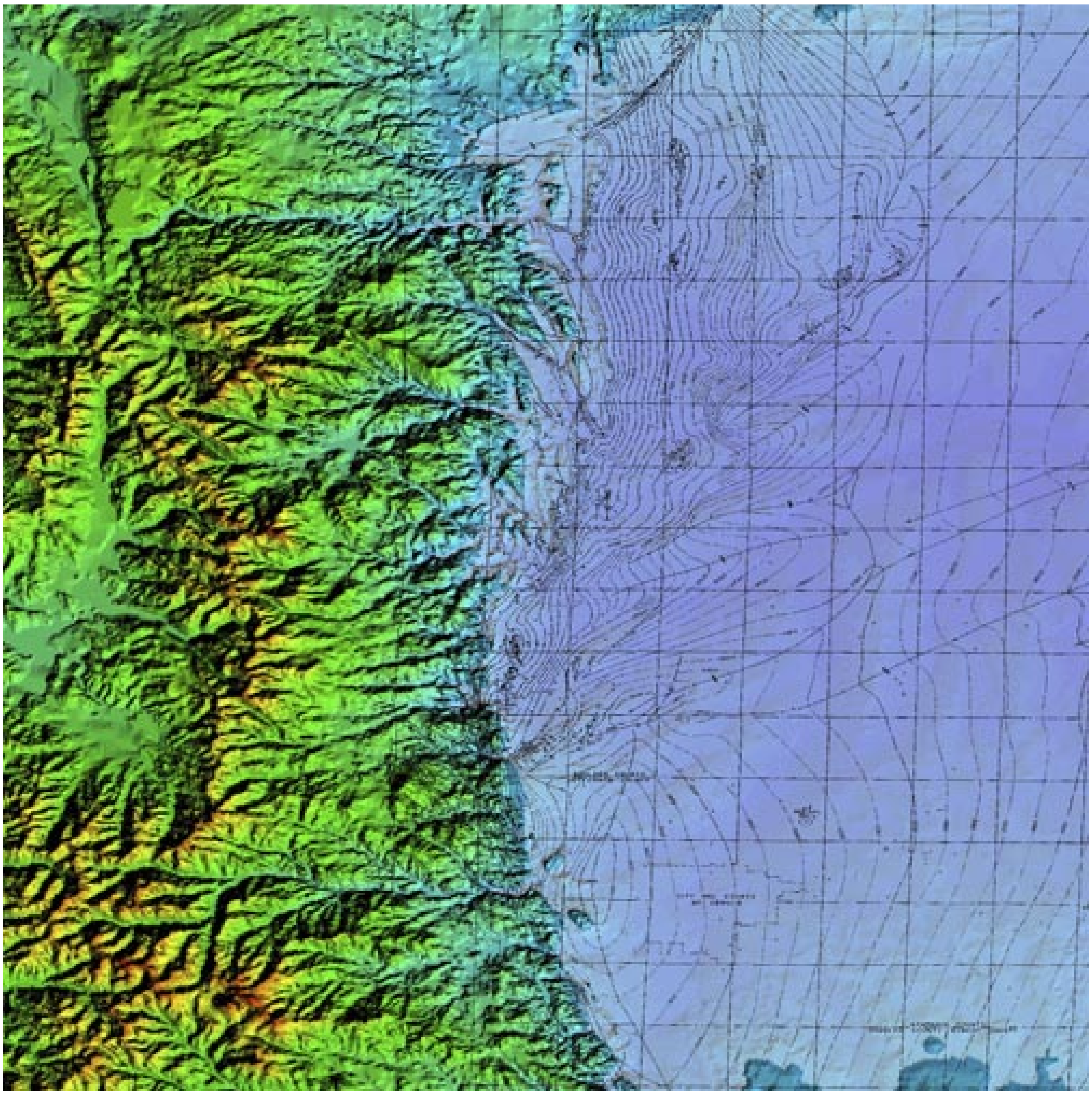


The northeastern flank of the Front Range uplift has three distinct styles of Laramide deformation: a northern area characterized by differential uplift of basement blocks with associated monoclinal folding in the overlying sedimentary strata; a central area characterized by differential uplift and rotation of basement blocks with asymmetrical anticlines and synclines developed in the overlying sedimentary strata; and a southern area characterized by major, high-angle frontal faults.

The upper crust underlying the Front Range and Denver Basin appears to be broken into three major blocks separated by two northeast-striking lineaments that are interpreted as scissor faults. The differences in style of the second-order structural features along the flank of the uplift are caused by differences in vertical rotation of the three first-order blocks. The amount of rotation is reflected in the structural gradient between the Front Range uplift and the Denver Basin. The structural gradient on the northern block is low (50 m/km), the gradient on the central block is moderate (90 m/km), and the gradient on the southern block is steep (415 m/km). These different gradients probably reflect differences at the brittle/ductile transition.

— Matthews, 2004



Digital elevation model of the Front Range coupled with a structural contour map on the top of the Muddy J sandstone (from Haun, 1968).

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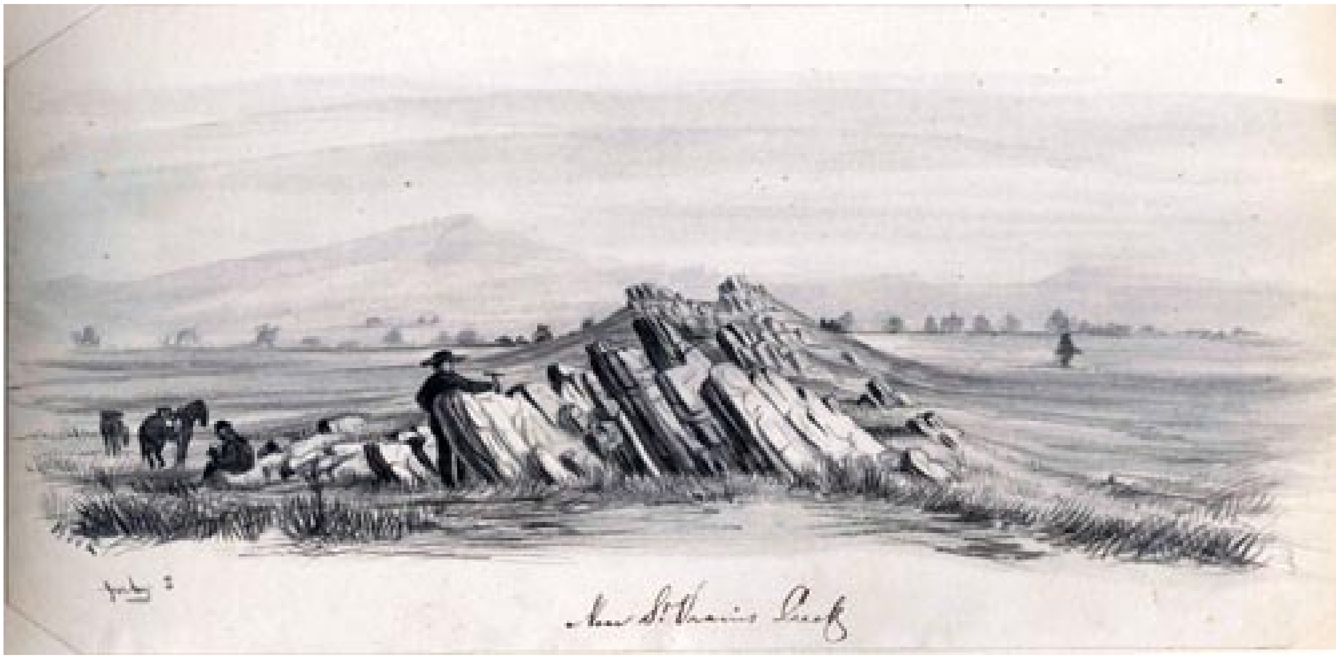
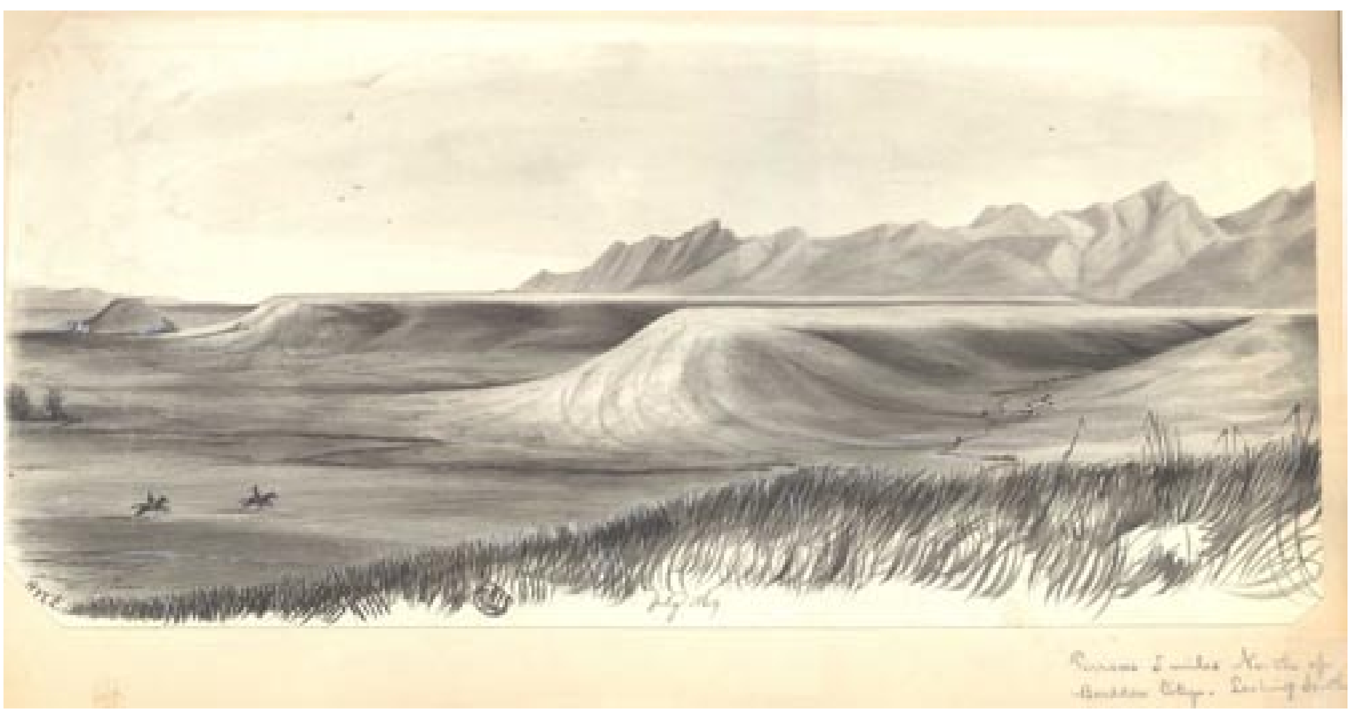


Geologists from the Hayden Survey studying outrop of Cretaceous strata in July of 1869. Rabbit Mountain in background.



View from southern end of field trip toward the Boulder Flatirons. Quaternary terraces in foreground. July, 1869.

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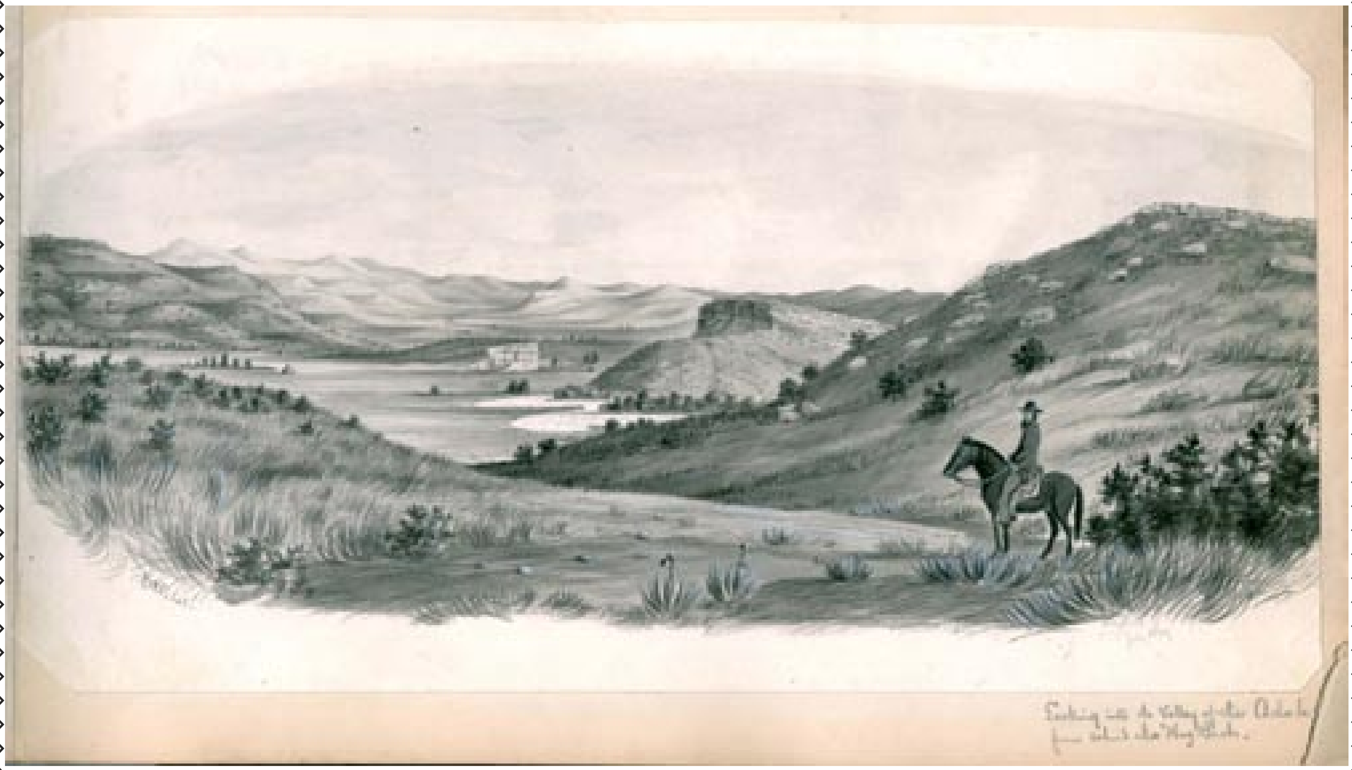

Geologist from the Hayden Survey admiring Bellvue Dome in July of 1869.

A party from the Hayden Survey working in the valley that is now flooded by Horsetooth Reservoir, July of 1869.