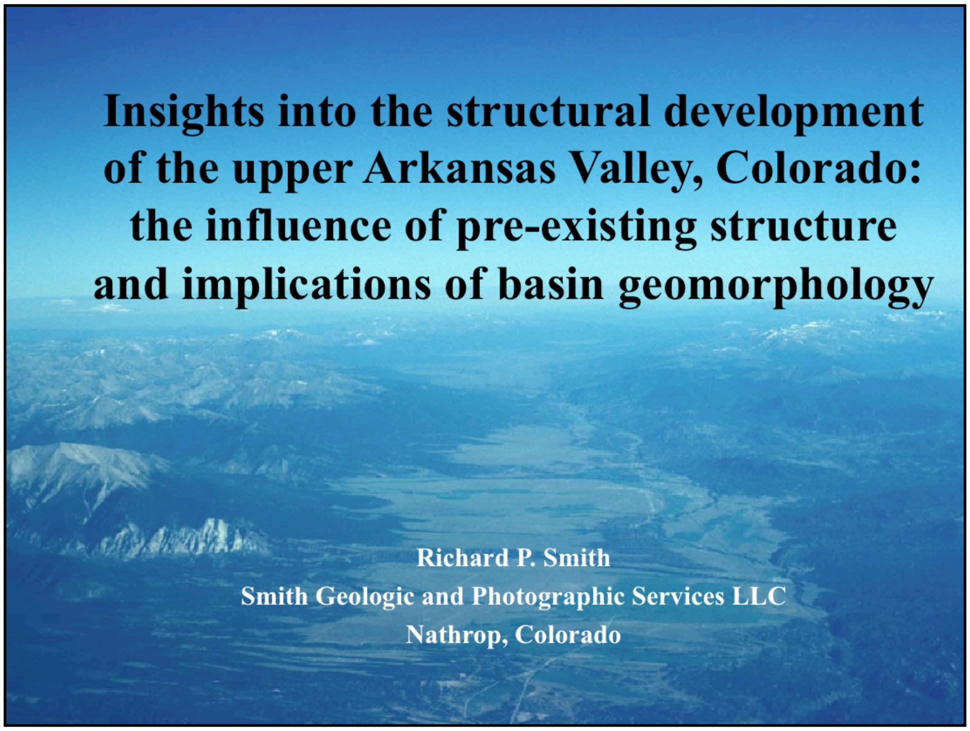
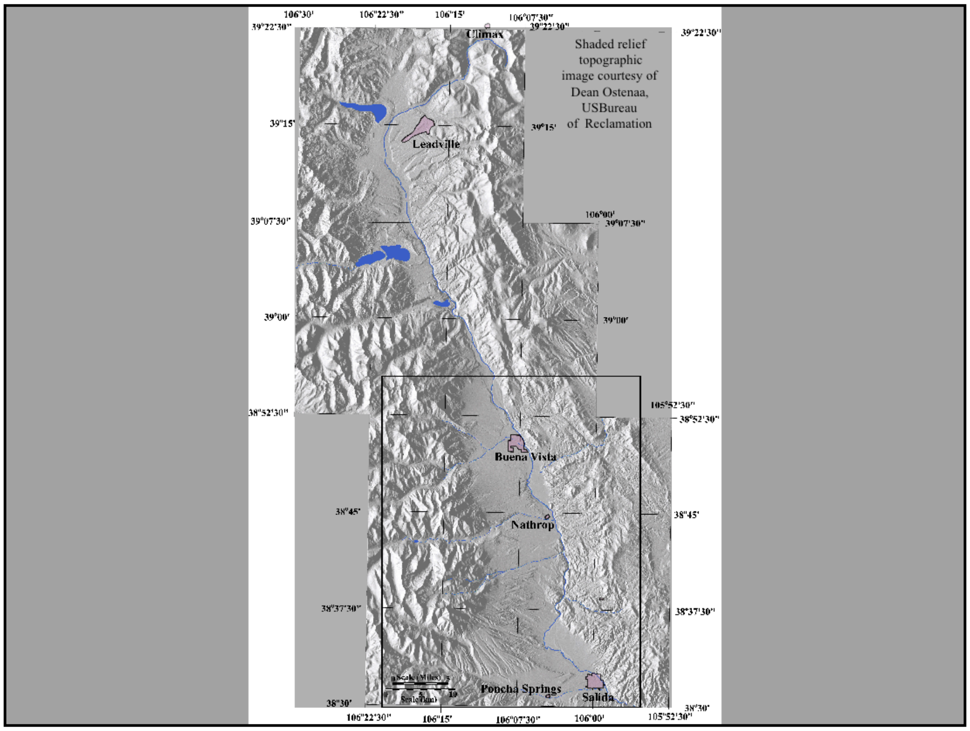
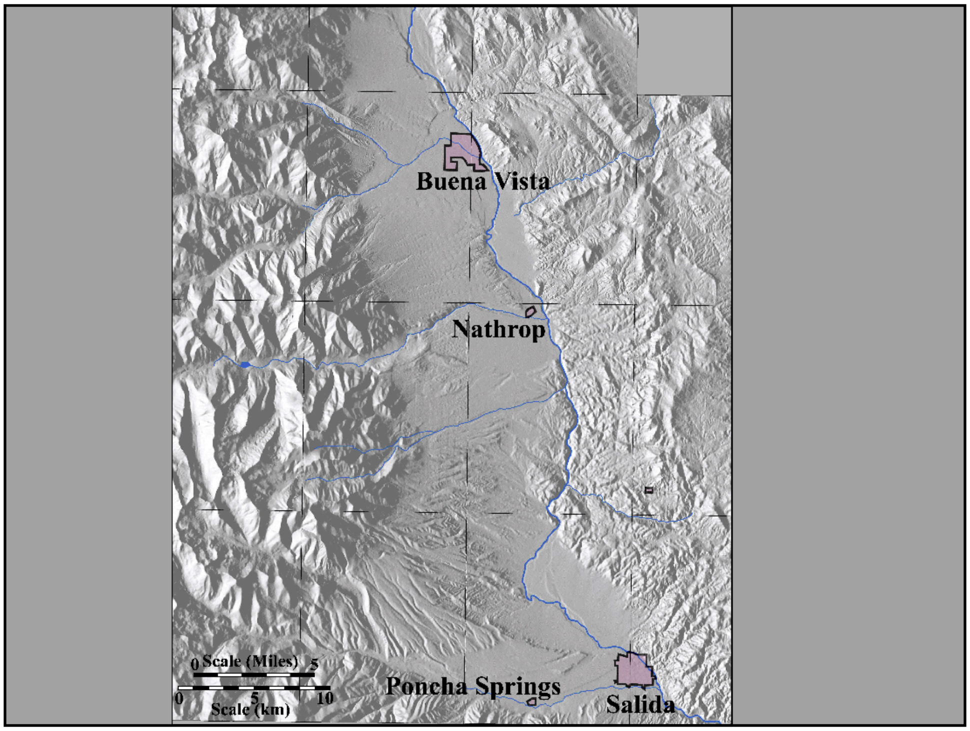


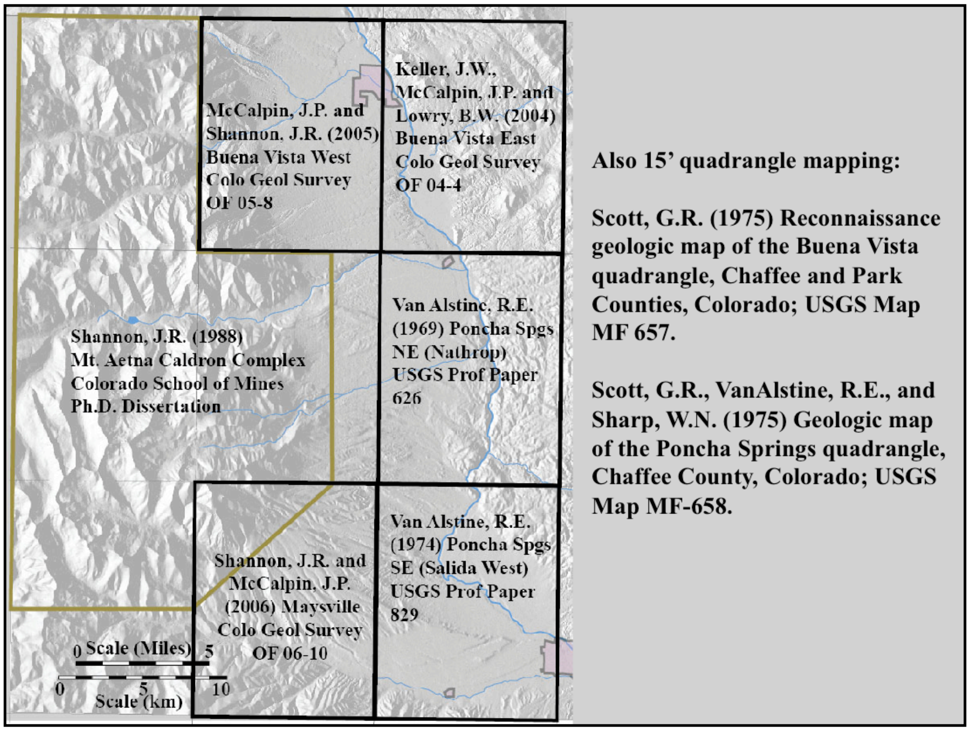
Background image: Looking north along upper Arkansas Valley from 25,000 ft. Sawatch Range on left (Chalk Cliffs and Mt. Princeton at lower left). Arkansas Hills and Mosquito/Tenmile Range on right (Browns Canyon at lower right).



Upper Arkansas Valley extends from headwaters near Climax to Salida. The focus of this presentation is the southern part, from the Buena Vista area to Salida.



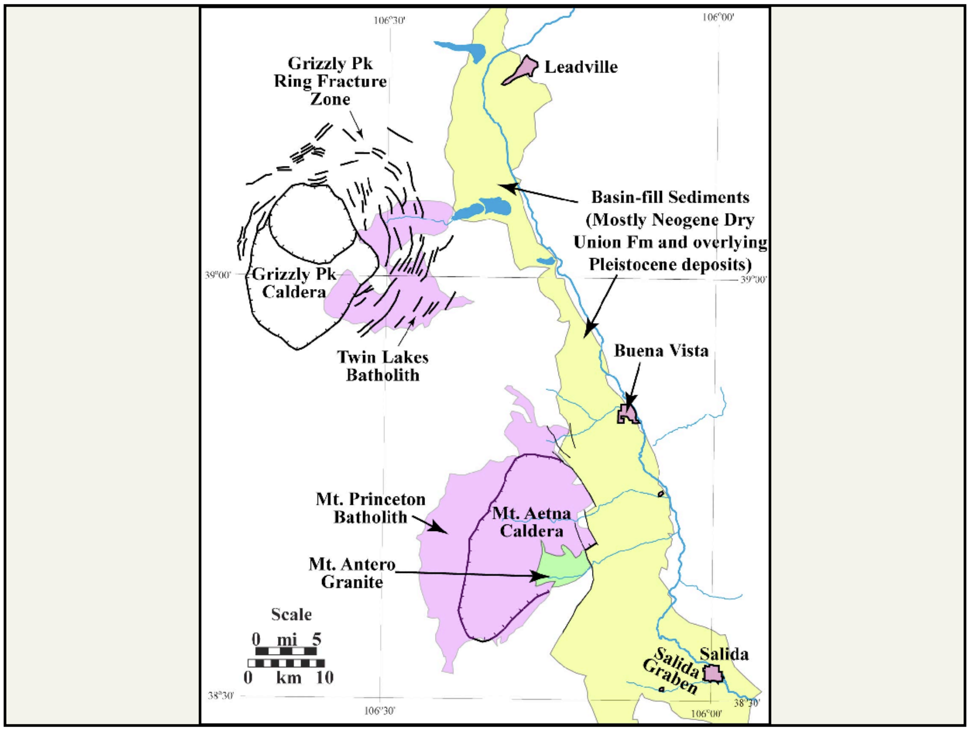
Here, the structural basin (graben) is bounded on the west by the 14,000 ft peaks of the Sawatch Range (Collegiate Peaks) and on the east by the low hills of the southern end of the Mosquito/Tenmile Range (sometimes called the Arkansas Hills). The basin is filled by several thousand feet of Neogene clastic sediments. The Arkansas River flows in the basin-fill sediments along the east edge of the basin from Buena Vista to just south of Nathrop, were it enters Browns Canyon, which is cut into Precambrian granitic rocks. It then exits the canyon, back into basin-fill sediments, and flows southeastward to Salida.



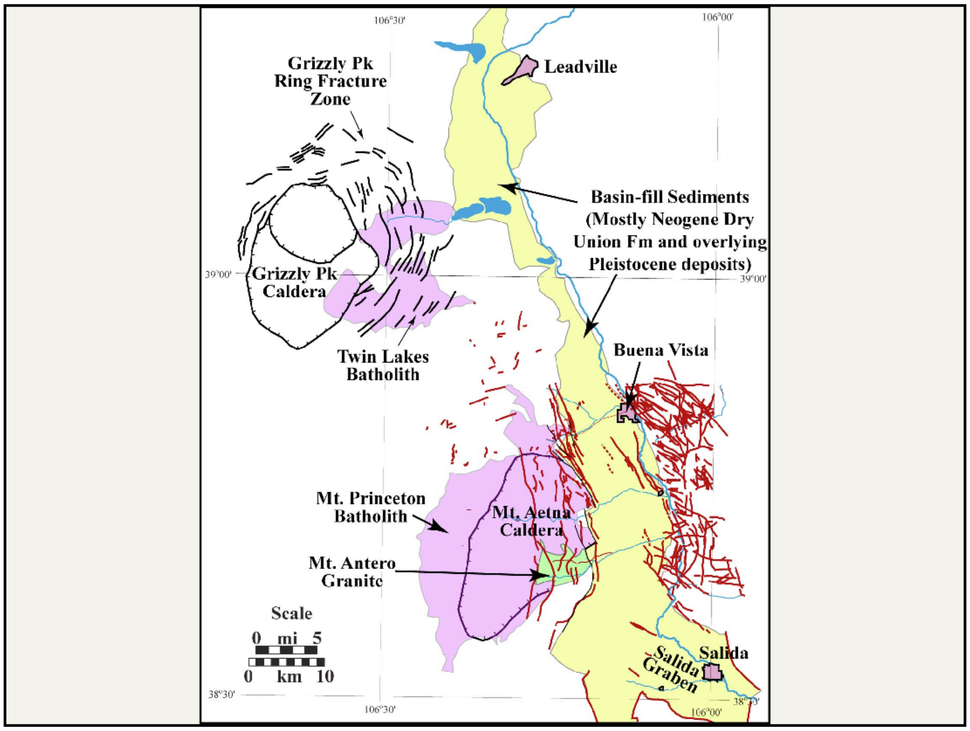
Compilation of structure from these references onto different map layers helps to synthesize existing work. Despite mapping by Van Alstine, 1969 and Scott et al., 1975, there was very sparse structural information for the area just east of Browns Canyon in the Precambrian basement rocks.

Examination of aerial photographs of the area shows a system of curving faults, concave to the west.

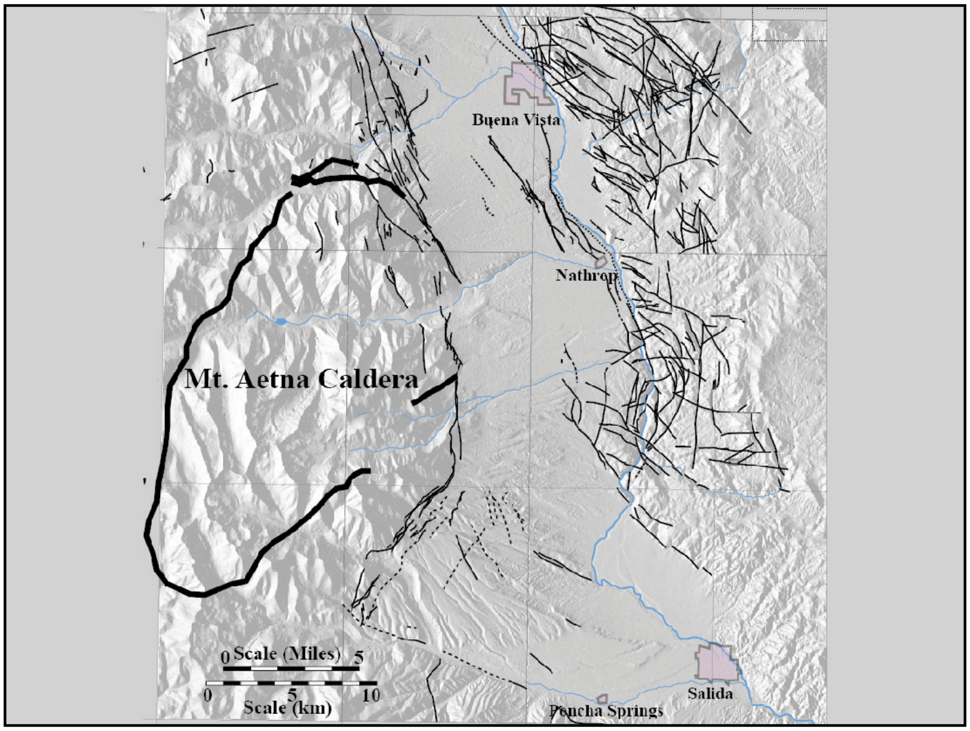
This fault pattern is at first puzzling until the Cenozoic history of the Sawatch Range on the other side of the basin is considered.



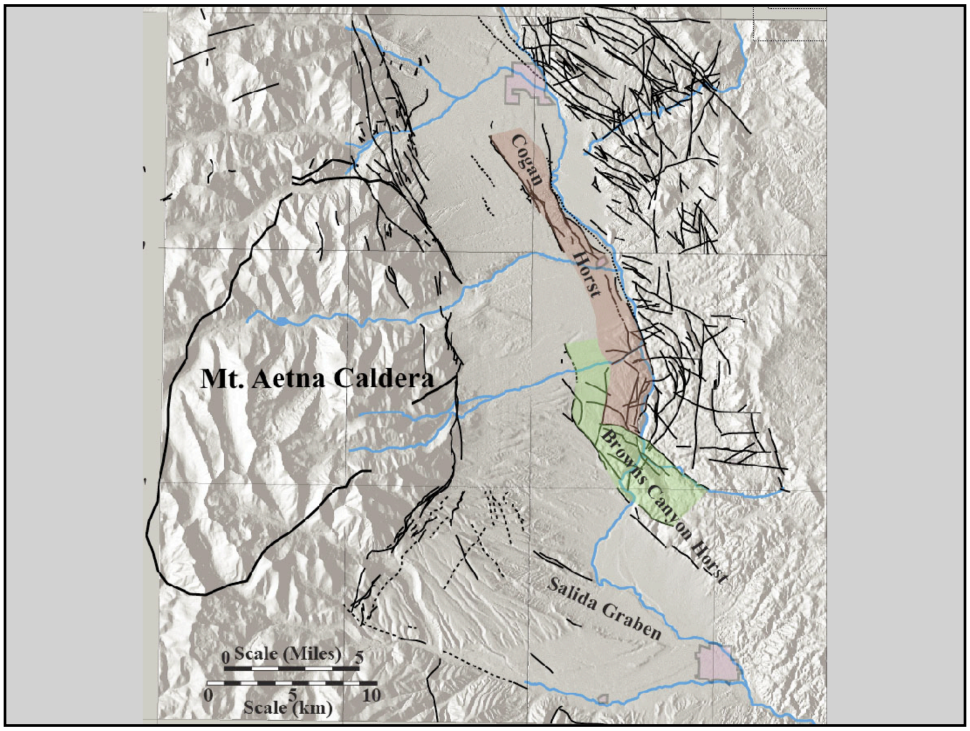
On the west side of the upper Arkansas Valley, two Paleogene calderas (~mid-30's million years) occur, each of which produced large outflow sheets of welded tuffs and other volcanic products. To the north, the Grizzly Peak caldera and its ring fracture system was mapped in the late 1970's and early 80's (Fridrich et al., 1985).



When the compiled and mapped faults in and adjacent to the southern part of the valley are plotted, they show a pattern similar to that surrounding the Grizzly Peak caldera, and probably represent a ring fracture zone around the Mt. Aetna caldera, directly to the west of the valley. That fracture pattern has influenced the shape of the southern end of the upper Arkansas Valley graben.

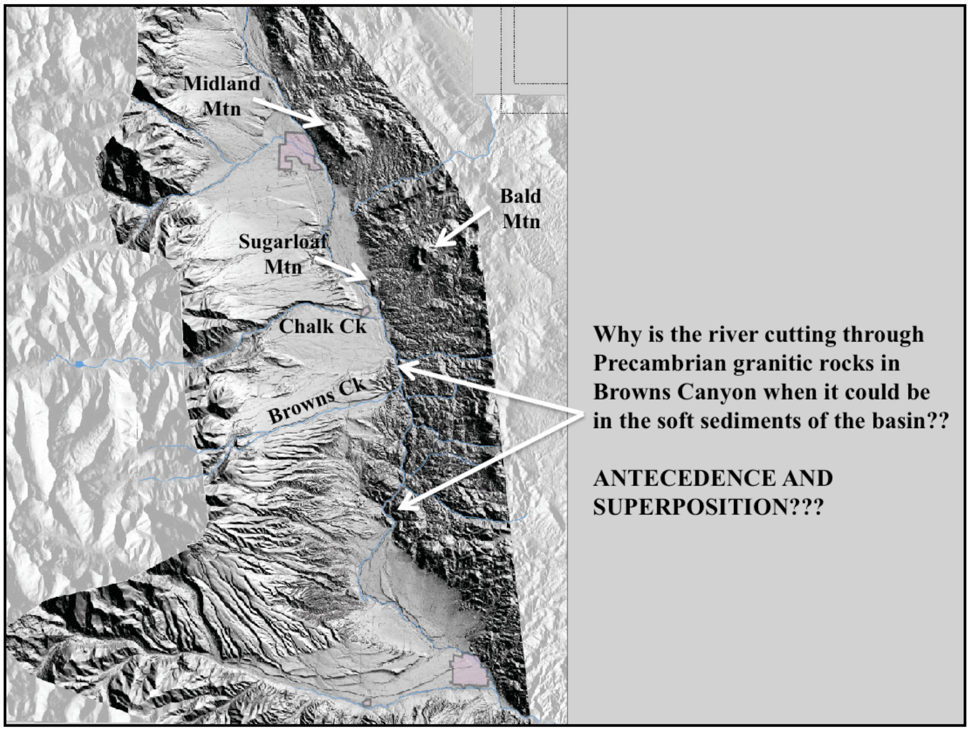


The basin, which trends uniformly NNW north of Buena Vista (see slides #7 and 8) curves to a NNE trend south of Buena Vista. The bounding faults on both sides of the graben and the intra-basin faults make the curve. In addition, the Arkansas River through Browns Canyon follows the same curving trend, exploiting the curving fault system to carve it's canyon.



Because much of the ring fracture system underlies the basin-fill sediments in the graben, the trend of intra-basin horsts is also strongly influenced by this pre-existing structure. In fact, the Browns Canyon horst (mapped by Van Alstine, 1969 and by Scott et al, 1975) could not maintain it's NW trend as it enters the basin, curving abruptly to the NNE trend as it encounters the ring fracture system beneath the valley-fill sediments.

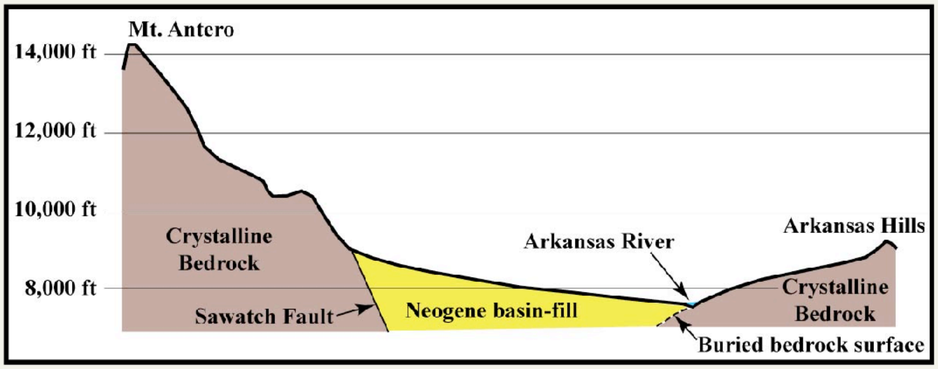
Photo of the Cogan horst from the west, showing the pinion-covered hills along its crest, and a line of cottonwood trees and other vegetation along the western boundary fault, where eastward-flowing groundwater is forced to the surface.



Is the river's course through Browns Canyon due to imprint of an antecedent stream channel (superposition), a common cause for such a geometry? An alternative interpretation, based on processes operating in the basin today and likely to have operated throughout most of the history of development of the upper Arkansas Valley, is presented in the following slides.

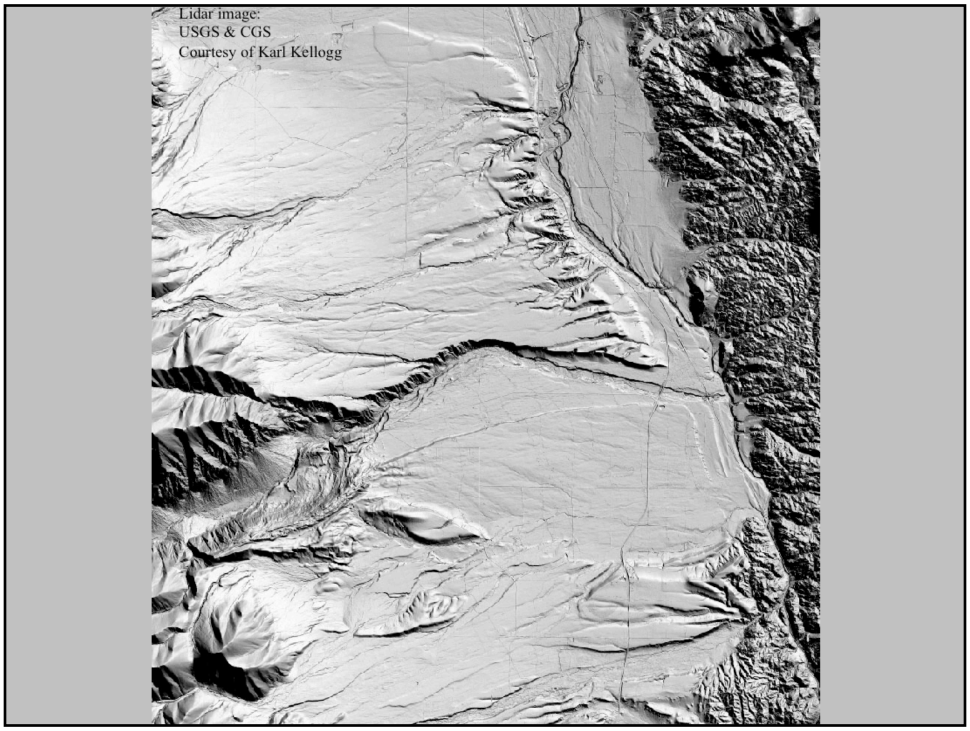
On this map, rocks east of the river are mostly Precambrian granitic rocks. Bald Mountain and Sugarloaf/Ruby Mountain are ~30-million-year-old rhyolite domes resting on Precambrian granitic rocks. Rocks west of the river are mostly basin-fill sediments to the east front of the Sawatch Range [along the western edge of the LiDAR imagery]. An exception is the Precambrian basement rocks brought to the surface in the southern part of the Cogan horst, forming the highlands west of the river in Browns Canyon (see slide #10).

(Topography from the recent USGS and CGS LiDAR survey of the area is used for the base map here. Notice the LiDAR map's dramatic increase in resolution and detail from the shaded-relief topography generated by existing 7.5minute topo maps).

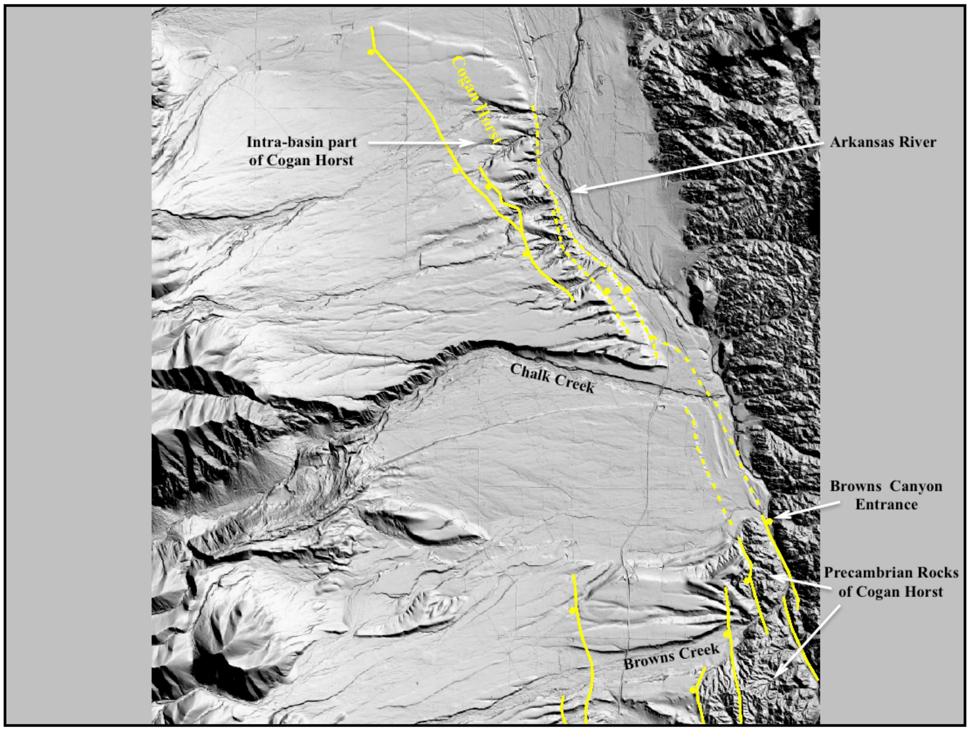


Cross-section across the upper Arkansas Valley to illustrate the premise that the course of the Arkansas River is continually forced to the east side of the valley.

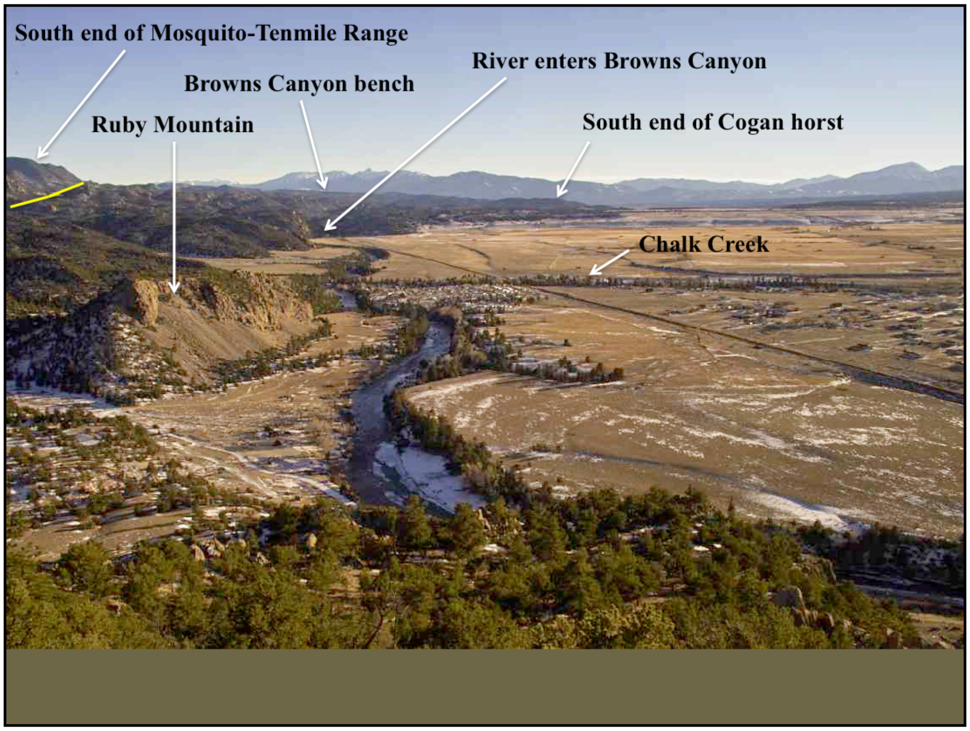
Premise 1: The river is continually forced to the eastern margin of the graben, flowing near the contact of the basin-fill sediments with the Precambrian granitic rocks east of the basin. This is because the uplift rate, elevation, and deposition rate of sediments shed from the Sawatch Range has been much greater than that from the Arkansas Hills to the east throughout the history of structural development of the graben. Thus, the basin floor has always sloped eastward, away from the Sawatch rangefront, to the east side of the valley. This makes it unlikely that the river's course could have ever been centrally located in the valley; specifically, it could not have been in a position that it would have allowed superposition on the bedrock in the Browns Canyon area.



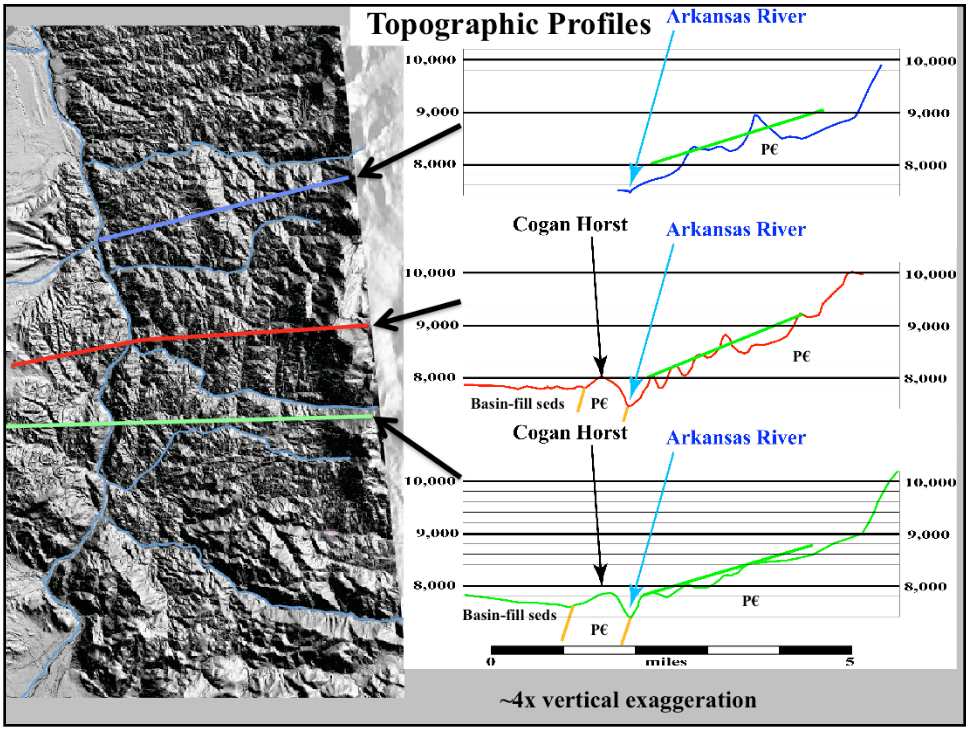
A notable exception to Premise 1 is in the area just east of the intra-basin Cogan Horst.



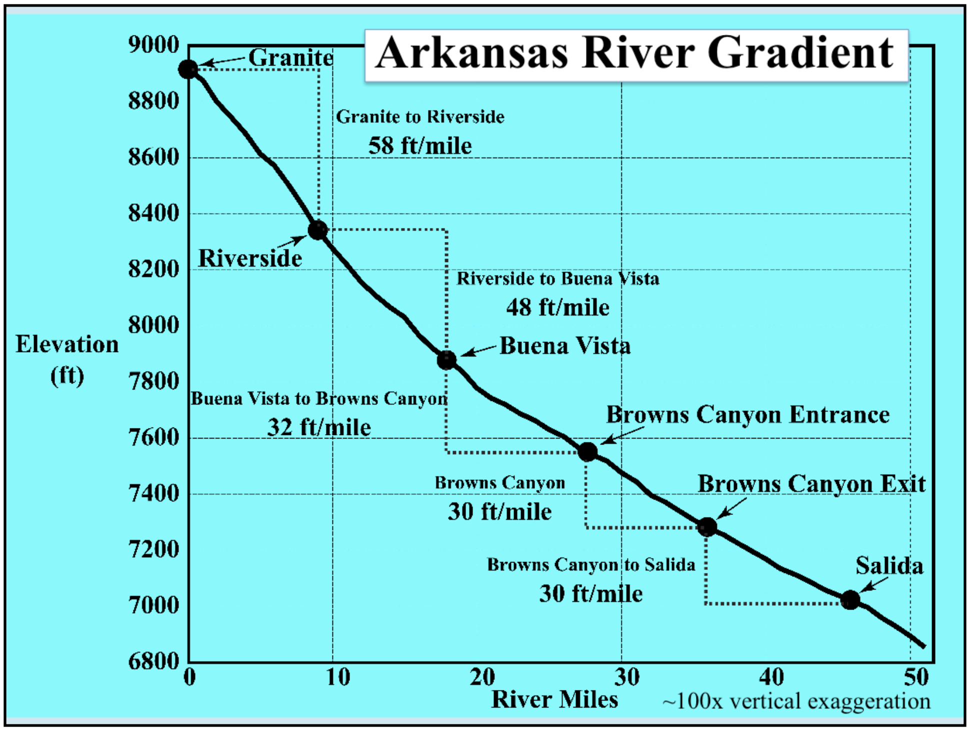
Here, the rising horst (which brings Dry Union sediments to the surface in this area) has blocked the eastward transport of sediments from the Sawatch Range, allowing Trout Creek and smaller streams entering the valley from the east to build alluvial fans east of the river, forcing its channel westward against the east edge of the horst. Note also, that the river exploits the eastern boundary fault(s) of the horst as it enters Browns Canyon, and follows their curving path through the canyon.



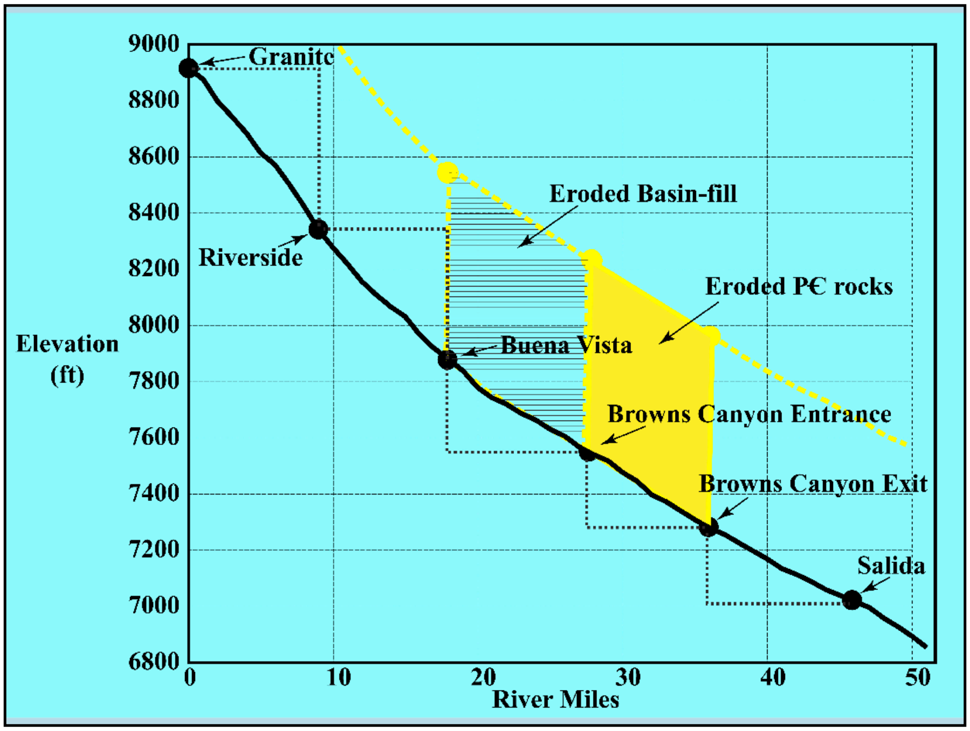
View to the south from Sugarloaf Mountain, showing the river flowing south (away from the camera) past Ruby Mountain, and entering Browns Canyon. Chalk Creek enters from the west (right) near the town of Nathrop. Also shown is the south end of the Cogan Horst, which uplifts Precambrian basement rocks above the level of the Browns Canyon bench. The bench is the deeply dissected and westward-tilted erosion surface east of Browns Canyon. It's elevation, between 8000 and 9000 ft, is intermediate between that of the Arkansas Hills to the east, and the basin floor to the west. The bench is most likely a pre-rift beveled surface (see Epis and Chapin, 1975; especially their Figure 10) that has been structurally downdropped and tilted into the basin during the early history of rifting. North-trending faults at the eastern edge of the bench (approximated by yellow line above; also see slides 9 and 10) would have been the early faults that accommodated the downward displacement into the early rift system. Both the Bald Mountain and the Sugarloaf/Ruby Mountain rhyolite domes (~30 Ma) rest on the beveled surface. Because their age is very close to the onset of extension and rift formation, it is not clear whether the rhyolite domes were emplaced before, during, or after the bench was downdropped into the rift. The occurrence of fragments of flow-banded rhyolite (similar to that present in both the rhyolite domes) in the Wagontongue Formation of South Park to the northeast of Browns Canyon (Keller et al., 2004) suggests that they were emplaced slightly before rift formation began and have subsequently been downdropped and tilted into the rift.



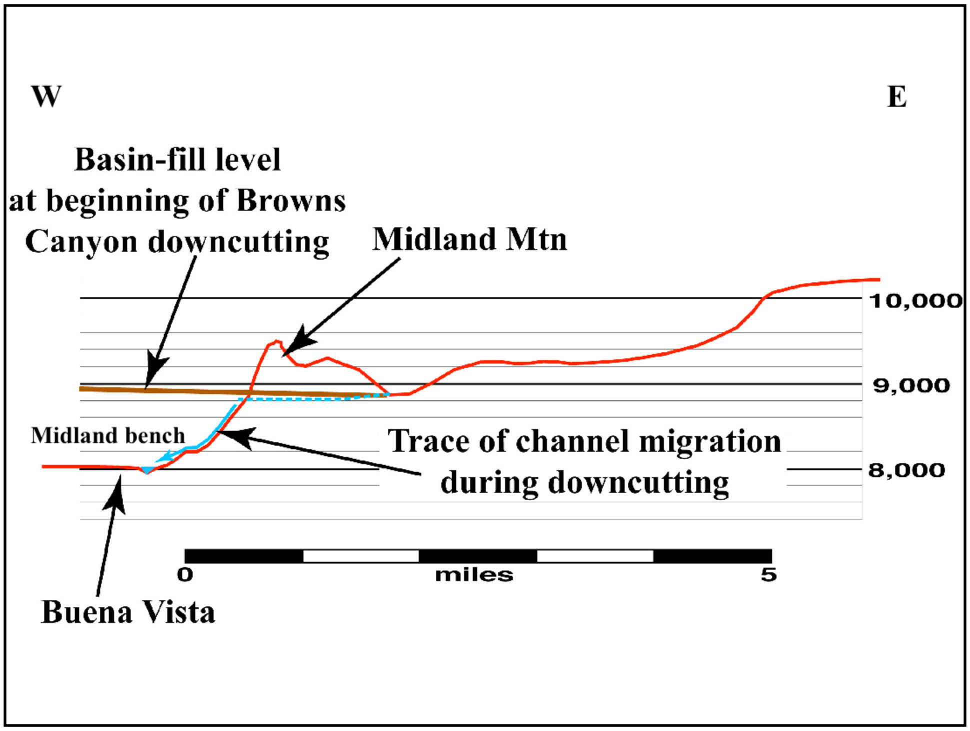
Topographic profiles show that the high areas of the bench define a westward-sloping surface, and that there are some outlier peaks that stand above the surface. Note especially that the elevation of the Precambrian basement rocks in the Cogan Horst, west of the river, stands 100 to 200 ft above the elevation of the bench, and that the river has carved Browns Canyon to a depth of ~600 feet beneath the elevation of the bench.



The constant gradient of the river from Buena Vista through Browns Canyon to Salida shows that the river's course has been established here long enough for an equilibrium gradient to be established, consistent with the realization that it would have taken at least several million years to carve a 600-ft-deep canyon into the granitic rocks.

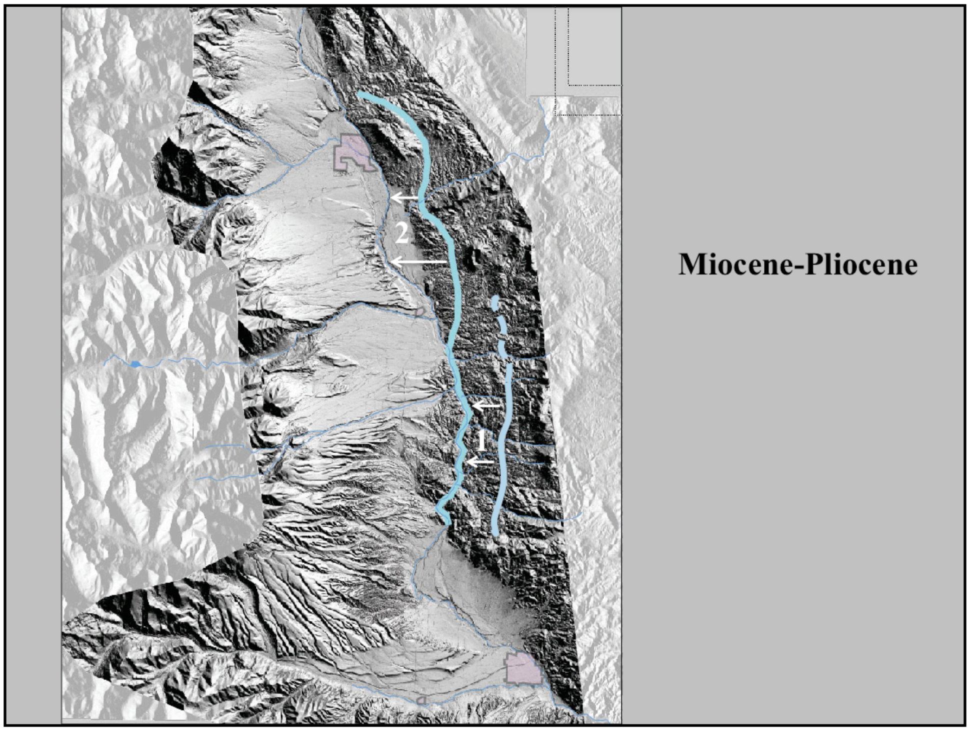


Reconstructing the river's gradient at the beginning of Browns Canyon downcutting requires adding at least 600 ft to the elevation of today's gradient, and leads to the conclusion that during downcutting of the canyon, an equivalent depth of basin-fill sediments were removed by erosion both upstream and downstream of the canyon. The erosion rate in the granitic rocks would have controlled the rate of removal of sediments.



Assuming up to 800 feet of canyon downcutting, a cross-section of the eastern edge of the valley at Buena Vista is constructed here to examine the potential position of the river at the beginning of canyon downcutting. Adding 800 feet of basin-fill sediment (brown line), and remembering Premise 1, the river's course would have been forced against the bedrock, high on Midland Mountain east of Buena Vista. As Browns Canyon downcutting progressed, it would have migrated westward, down the west face of Midland Mountain (solid blue line). A pause in canyon downcutting may have allowed carving of the Midland bench at about 200 feet above the current river level, a bench used by the Colorado Midland Railroad for its route north from Trout Creek.

An interesting possibility is presented by the broad, north-trending underfit valley east of Midland Mountain. At about the time of beginning of downcutting of Browns Canyon, the Arkansas River could have flowed east of Midland Mountain, through this valley. If so, it would have eventually escaped from that course (dashed blue line) and migrated westward down the face of Midland Mountain, as described above.



Premise 2: Early in the history of development of the upper Arkansas Valley, the graben was filled to a much higher level than that at present by clastic sediments shed mostly from the Sawatch Range. Since then (through Miocene and Pliocene times - ~25 million years to 2 million years) the river's course has migrated westward, down the sloping bedrock face of the eastern side of the valley, as erosion slowly removed sediment from the valley. The beginning of sediment removal may have coincided with the Miocene or early Pliocene eastward escape of the river at Salida (see p. 334 and Figure 9 of Epis et al., 1976), and the gradual downcutting of the baselevel at that escape point. This makes the river's course vulnerable to irregularities in the underlying bedrock surface.

Given Premises 1 and 2, we can envision a history of river channel migration beginning east of Browns Canyon, migration westward to Browns Canyon (migration path 1), followed by downcutting of Browns Canyon accompanied by westward migration of the river upstream of Browns Canyon to the river's course today (migration path 2). The westward migration of the river's course in path 1 was arrested by the uplifted basement rocks in the southern part of the Cogan horst – a case of structural entrapment. Structural entrapment is akin to, but distinctly different from, antecedence and superposition. Akin because it involves removal of soft sediment overlying hard bedrock, but different because it entails arrest of lateral river channel migration instead of lowering of the channel onto the underlying bedrock.

The river could not escape around the north and west side of the uplifted basement of the Cogan horst because of Premise 1, and could not move farther west because it was blocked by the higher bedrock ridge to the west. This case of structural entrapment left the river with no recourse but to begin downcutting along the faults defining the eastern boundary of the Cogan horst. These curving ring faults related to the Mt. Aetna caldera provided less -resistant zones for river erosion and controlled the curving course of the river through the canyon.

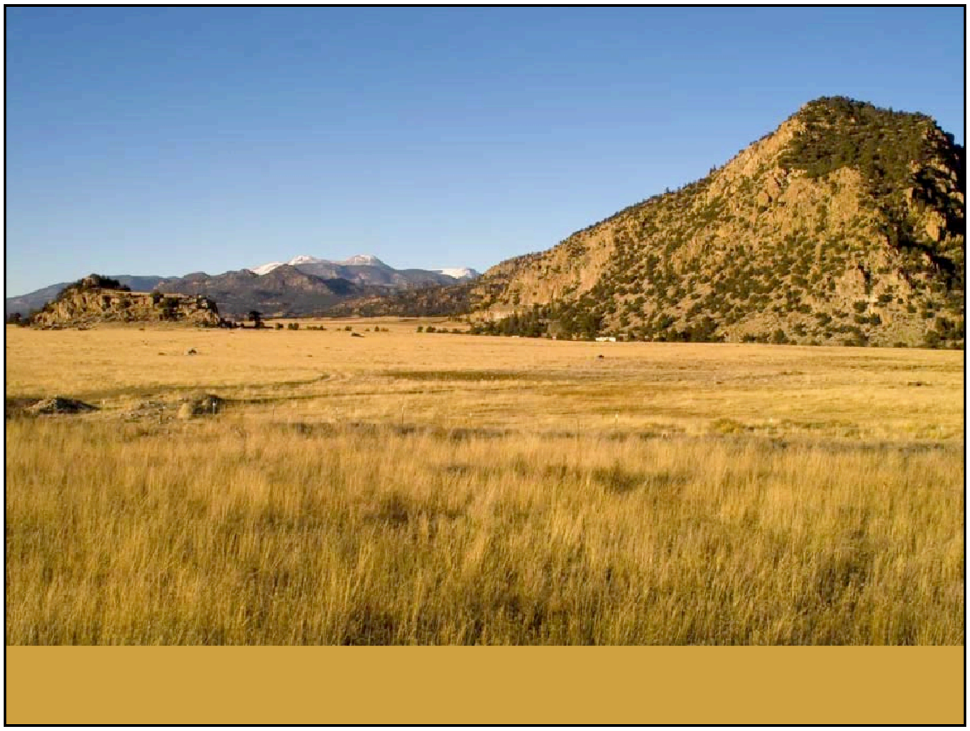
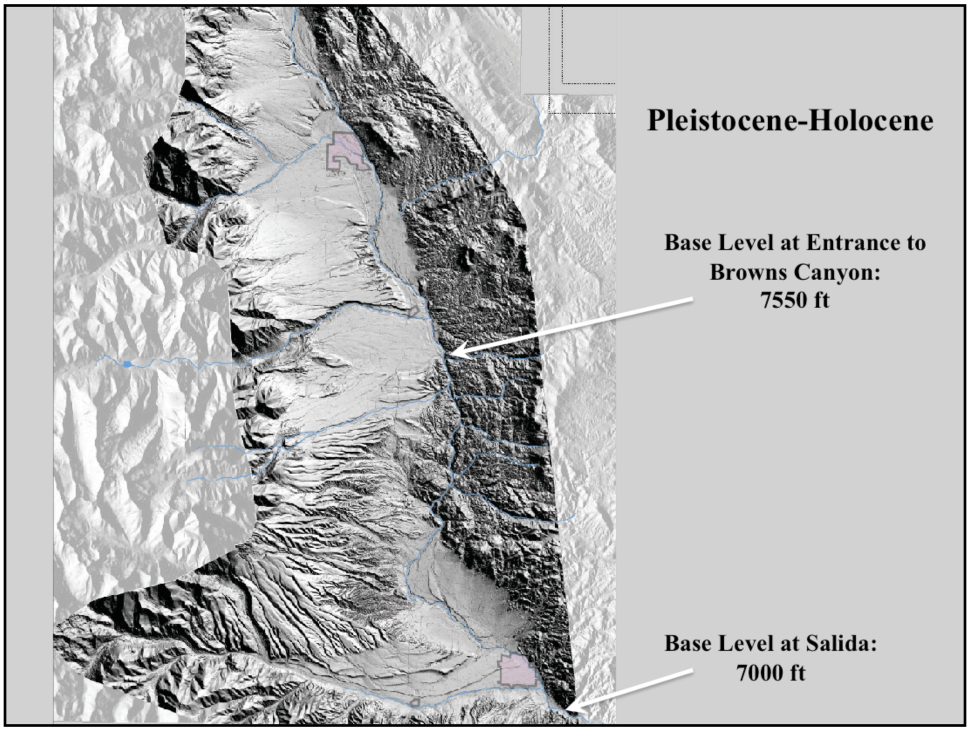
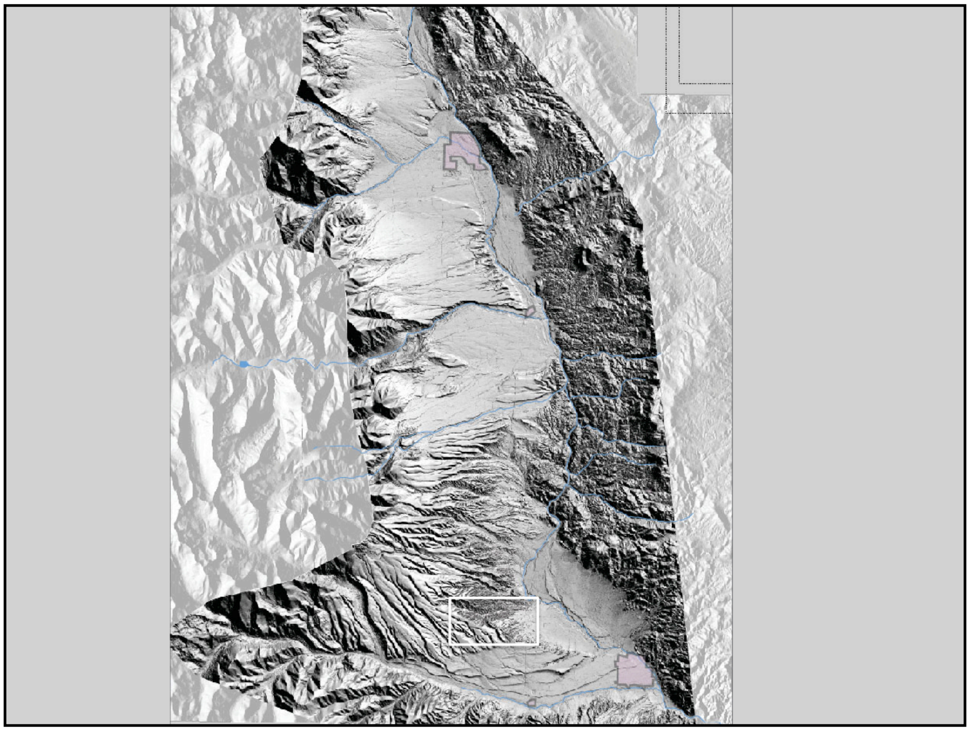


Photo looking north at the south end of Sugarloaf Mountain (a ~30 million-year-old rhyolite dome emplaced near the beginning of upper Arkansas Valley rifting). During Browns Canyon downcutting, the river probably cut the bench in the south end of the mountain about 400 ft above the current channel, and definitely beveled the horizontal surface on the rhyolite outcrop at left center.

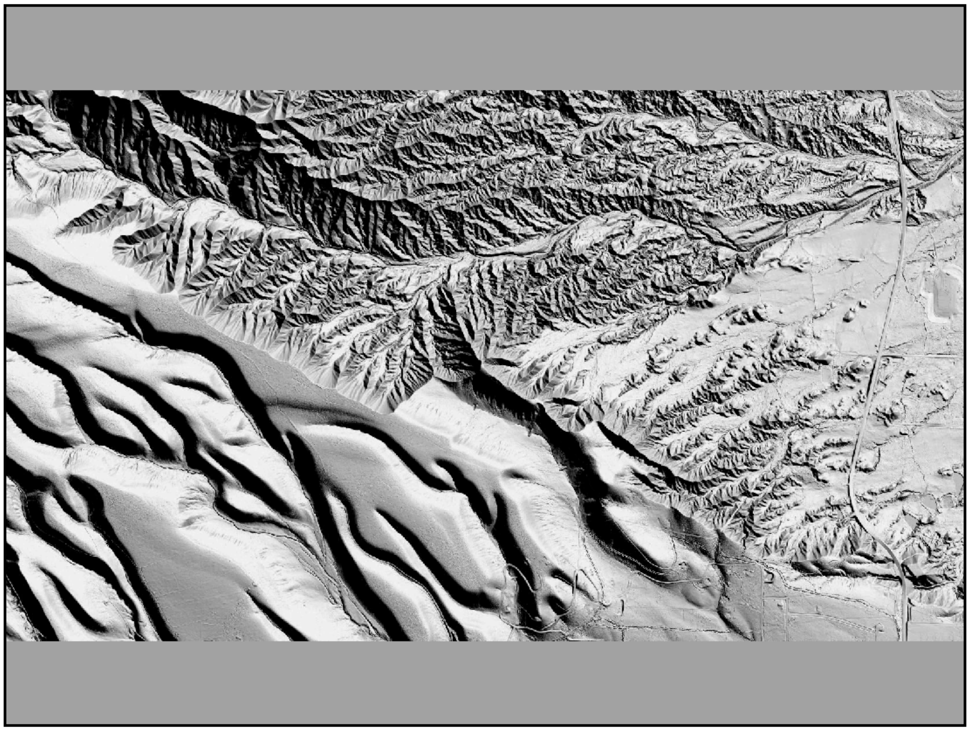


During Pleistocene time extensive mountain glaciation in the Sawatch Range renewed, and dramatically changed the character of, deposition of basin-fill material, mantling the eroded surface of the Dry Union formation with varying thickness of glacial outwash and alluvial deposits. The several glacial cycles, from earliest (Nebraskan, Nussbaum) to latest (Pinedale) Pleistocene, each left characteristic surfaces and deposits graded eastward from the range-front to the river on the east side of the valley. Those deposits and surfaces are still largely intact in the northern end of the valley (Buena Vista to Browns Creek; see Slide 11), but are deeply dissected to the south. Even in the dissected area west and south of Browns Canyon, remnants of those surfaces (seen in the LiDAR image above) define a continuous pediment that was graded to elevations considerably above the current river level below Browns Canyon. They are preserved in the northern part of the valley because the base level for that area is controlled by the bedrock elevation at the entrance to Browns Canyon (~7550 ft). The 550ft lower elevation of bedrock at the river's exit from the basin at Salida has allowed tributary streams from the west to incise deeply into those surfaces, exposing underlying Dry Union Formation sands, silts, and gravels in classic "badlands" topography.

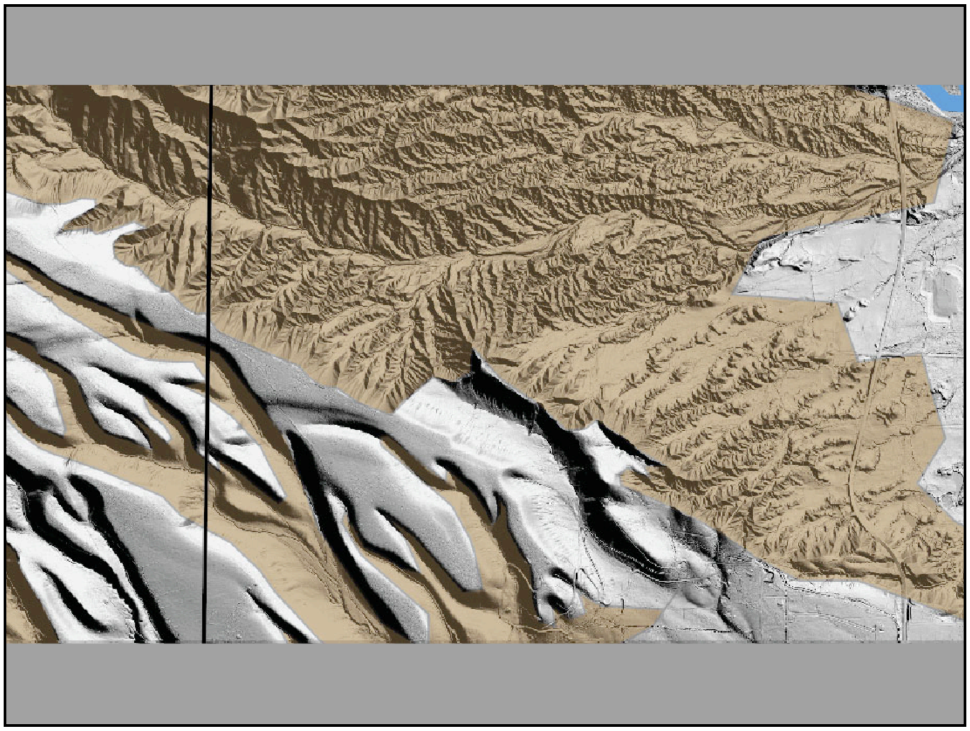
This photograph, looking southwest from the south end of Browns Canyon, shows the remnants of the oldest of those Pleistocene surfaces, and two lower (and younger?) surfaces at right center. Also, the badlands topography in the underlying Dry Union formation is apparent.



Attention is directed here to the topography in the area of the white rectangle, where one of the Pleistocene drainages has been beheaded by incision of Holocene drainages graded to the current river level.



The LiDAR image shows the dramatic difference in topography between the older Pleistocene surfaces (lower left) and the Holocene badlands (upper right). This beheaded Pleistocene drainage was also noted and described in detail by VanAlstine (1974).



Adding the outcrop area of Dry Union formation (brown) to the image emphasizes the difference in topography between the Pleistocene surfaces and the badlands.

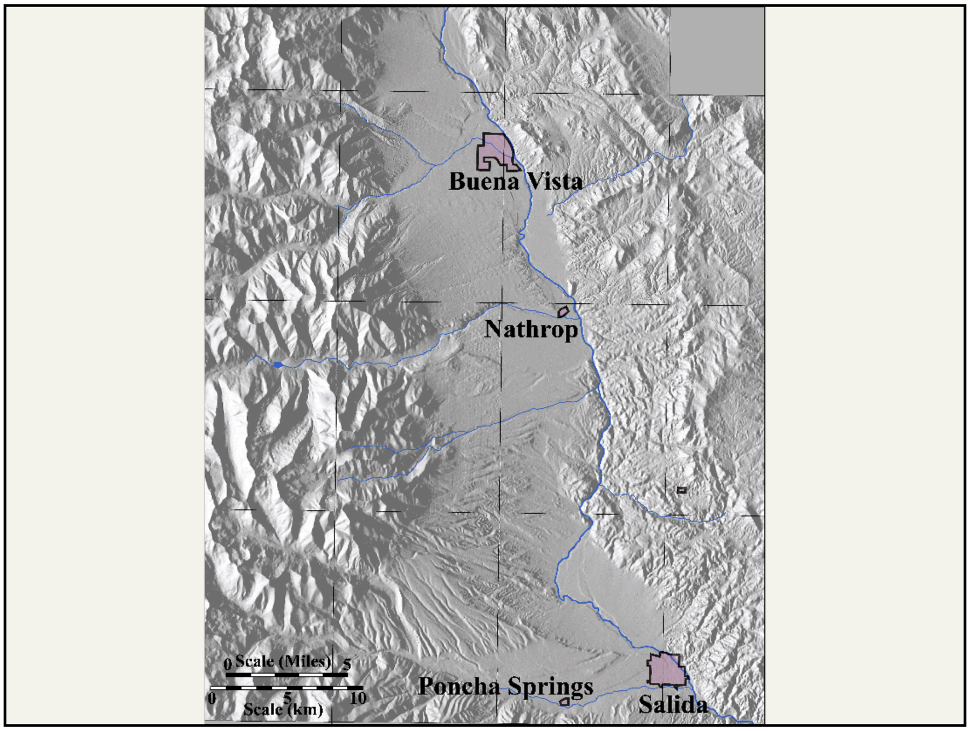
To Develop Understanding of Basin Structure and Evolution:

- ☑ Detailed mapping of Neogene and Quaternary rocks, seds, faults, surfaces; Dry Union; Mt.Ant.Q.
- ☑ Lidar (intra-basin & regional structure); done
- ❑ Basin-wide geophysical surveys (high-res. aeromag, detailed gravity, seismic, electrical); local/partial
- ❑ Absolute age determinations (sediments, surfaces, faults, dikes); partial for Tert. igneous, much left
- ❑ Paleoseismic and tectonic geomorphologic studies; partial for Sawatch fault, much left to do
- ❑ Deep drilling; one 1000' well, no driver for others
- ❑ Synthesis

The upper Arkansas Valley is perhaps the most understudied basin in the Rio Grande Rift system. This is probably because there are few drivers for the work necessary to develop an understanding of the structure and evolution of the basin. There are no large cities to place demands on groundwater supplies, no prospects for petroleum exploration, no critical infrastructure demanding geologic hazards assessment, and no major ore exploration activity. Recent interest in geothermal resources has resulted in some geophysical surveys, mostly by students in several Colorado School of Mines and Boise State University field camps in the area, but the comprehensive, basin-wide surveys needed have not been done.

Comments specifically directed at the points in the slide above.

1. Detailed mapping has been done for most of the basin by Colorado Geological Survey and USGS mapping campaigns (see Slide 4). Still needed are mapping in the Mt. Antero quadrangle and detailed stratigraphic studies of the Dry Union formation, especially in the area just west of Browns Canyon (Nathrop quadrangle).
2. The recent LiDAR map of the valley (joint project of USGS and CGS) is a valuable resource. See slides 29 and 30 for a comparison of a shaded relief map made from existing 7.5 minute topographic quadrangles (Slide 29) and a relief map made from the LiDAR data (Slide 30). Also, keep in mind that the LiDAR data is extremely high-resolution and can be enlarged without loss of detail (see Slides 14, 15, 17, 26, and 27).
3. The comprehensive basin-wide geophysical surveys needed are largely unavailable. High-resolution aeromag would be a valuable aid in defining the locations of intrabasin faults, especially in large areas covered by Holocene and latest Pleistocene alluvium. A regional gravity map is available, but station density is not sufficient for definition of major faults beneath the basin-fill sediments. Some seismic and electrical surveys have been done, but more are needed.
4. Absolute age determinations are available for some of the igneous rocks but many more are needed for sediments, ash beds within Dry Union formation, pediment surfaces, faults, and the set of dikes subparallel to the ring fracture system on the east side of the valley (Keller et al., 2004).
5. Additional paleoseismic and tectonic geomorphologic studies would be a great help in defining the Neogene and Quaternary evolution of the basin.
6. One USGS research drill hole to a depth of 1000' has been drilled (about 3 miles south of Buena Vista). No information other than geophysical modeling provides any control on estimates of basin depth and rocks present below the basin-fill sediments.
7. Synthesis of existing data (some of which has been attempted here) and new data obtained in the future is the final step that is needed.



Shaded relief map generated from 7.5 minute topographic maps.

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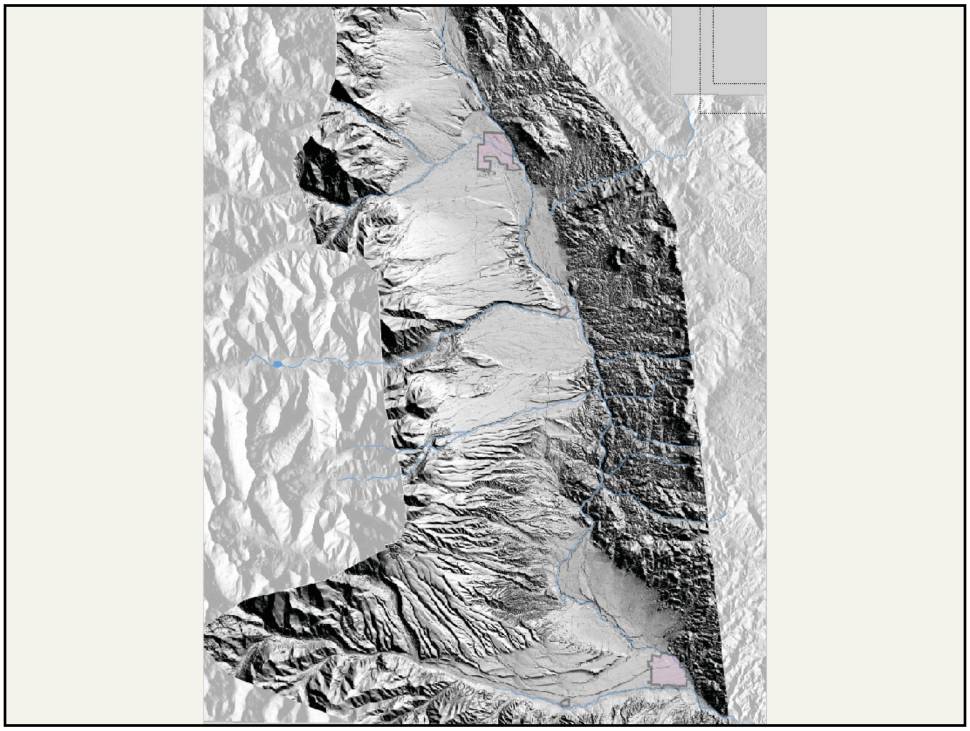

Shaded relief map generated from LiDAR data, showing greatly increased resolution over shaded relief generated from 7.5 minute topography.