# *Moab salt-intruded anticline, east-central Utah*

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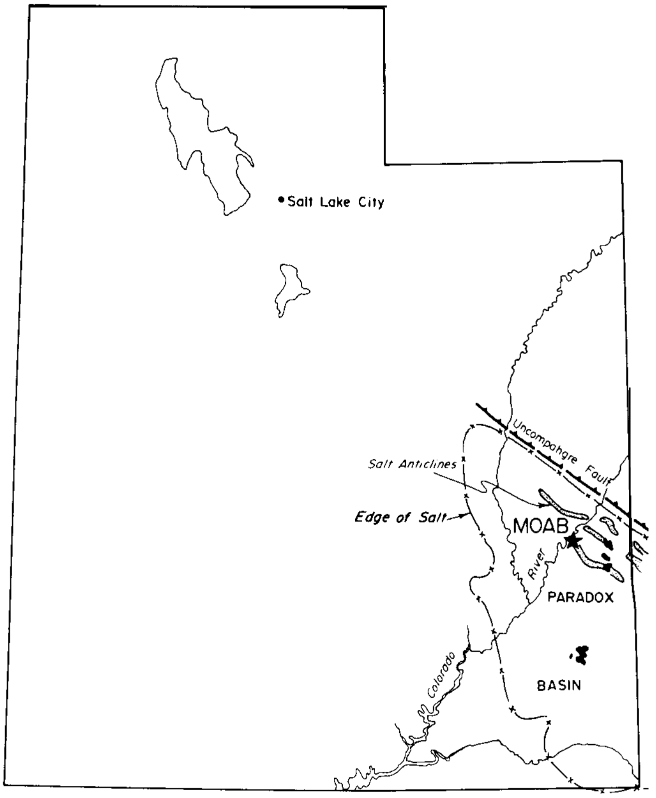


Figure 1. Index map of Moab and vicinity, Utah.

## LOCATION AND ACCESS

Moab, Utah, lies on the northwestern end of the Moab Valley salt-intruded anticline on the banks of the Colorado River in east-central Utah, in T.25 and 26S., R.21 E. (38°36′N., 109°32′W.), on the Moab 15′ Quadrangle, in southern Grand County, Utah (Fig. 1). U.S. 163 passes through Moab and along the length of Moab Valley. The elevation at Moab is 4,000 ft (1,467 m). The area is readily accessible with any vehicle, but off-pavement lands are almost entirely privately owned and permission should be secured for specific locality access.

## SIGNIFICANCE

Moab Valley (Fig. 2) lies in the eastern and deepest part of the Paradox evaporite basin of Pennsylvanian age. That basin area is a unique part of the Colorado Plateau's physiographic province in which structures and stratigraphy have been influenced by salt tectonics. The Moab salt anticline and fault are good examples and provide some of the better, accessible exposures that demonstrate intimate relationships between salt flowage and related sedimentation. Salt diapirism occurred from Middle Pennsylvanian through Jurassic time, and sedimentary accumulations detail growth history of the folds, local angular unconformities and thickness variations within the stratigraphic column of those geologic periods.

## GEOLOGY

The Paradox Basin was formed as the pre-Pennsylvanian "basement" collapsed, mainly along pre-existing northwest-trending faults. The most active period of subsidence extended from mid-Pennsylvanian to Late Triassic time. Thick cyclic accumulations of salt were deposited early and were influenced by irregular and episodic movements of the faults. Zones of least confining pressure developed along the active faults, and the salt migrated toward them, assisted in part by differential thickness variations in the overburden, thus forming northwest-trending bulges—"salt anticlines"—overlying the faulted basement fabric. Succeeding formations were deposited more thinly over the growing structures, some were never deposited, and others were deposited only to be later removed by erosion. The salt-bearing Pennsylvanian Paradox Formation was locally thickened to more than 10,000 ft (3,667 m) along these zones. The salt adjacent to the "salt anticlines" migrated to supply the growing structures, and troughs in adjacent areas were filled with "thicker than normal" amounts of sediment.

Along the Moab Valley salt anticline much of the Pennsylvanian Honaker Trail Formation, all of the Permian Cutler and Lower Triassic Moenkopi Formations, and the lower part of the Upper Triassic Chinle Formation are missing in outcrop (Fig. 3). North of the Colorado River, along the southwest flank of the anticline, these units begin to reappear and demonstrate the irregular deposition and erosion that occurred along the "salt anticlines."

Migration of the salt continued after Chinle time, but gradually diminished. Sedimentary units of Jurassic age thin over the core of the neighboring Salt Valley anticline, but it is difficult to prove continued growth into Cretaceus time. There are few indications that angular unconformities developed over the anticlines after Chinle time. Eventually the Upper Cretaceus Mancos sea covered the entire region, and a thick section of marine dark-gray shale was deposited. Collapsed sections of the lower Mancos Shale and Ferron Member, in the southern extension of the Moab Valley anticline (Pack Creek syncline), are of normal thickness.

At some later time, probably during the Laramide orogeny of Late Cretaceus or Early Tertiary age, the area was submitted to a west-to-east compressional tectonic event. The northwest-trending zones of thick salt were reshaped into true anticlines,

Figure 2. Aerial view toward the southeast of the Moab fault in the foreground, Moab Valley salt-intruded anticline in the middle distance, and the Tertiary igneous-intrusive La Sal Mountains in the distance. The broad valley resulted from salt intrusion in Paleozoic-Mesozoic time and subsequent collapse caused by groundwater solution of the salt cap (photo by D. L. Baars).

while adjacent areas became synclines. Salt movement into the anticlines may have been rejuvenated for a short time. The Moab salt-intruded anticline was complete by Early Tertiary time, and the Moab fault, an apparently normal fault, formed parallel to the present southwest escarpment of the valley. If the Moab fault is normal, then a relaxation of compression had to have occurred some time later. The relative displacement on the fault north of Moab, near the Arches National Park visitors center, is about 2600 ft (953 m), down to the northeast (Fig. 3).

## STRATIGRAPHY

The sedimentary column exposed in and near Moab Valley ranges from the leached evaporates of the Middle Pennsylvanian Paradox Formation upward to the Jurassic Entrada Sandstone. All of the formations are in some way distorted by paleo-growth of the Moab salt-intruded anticline and/or later dissolution-induced collapse of the structure. Pre-Pennsylvanian sedimentary rocks are known only in the subsurface of the Moab region and are variously thinned and otherwise affected by early penecontemporaneous movement of the basement structure. The older rocks are diagrammatically illustrated on Figure 4.

Jumbled masses of gypsum, black shale, and some dolomite of the leached cap of the Paradox evaporates, contorted by diapiric intrusion and later dissolution and collapse, are exposed along the lower margins of Moab Valley. The true nature of such caprock is more evident along Onion Creek, a few miles east of Moab. Some 800 ft (293 m) of this caprock underlie Moab Valley (Fig. 4). Drilling has revealed that over 4198 ft (1540 m) of allochthonous evaporates, including salt, occur beneath the valley, and about 15,000 ft (5,500 m) of Paradox evaporates were penetrated in another salt structure nearby (Paradox Valley). The probable thickness in Moab Valley is estimated in Figure 5.

The Honaker Trail Formation of Middle to Late Pennsyl-

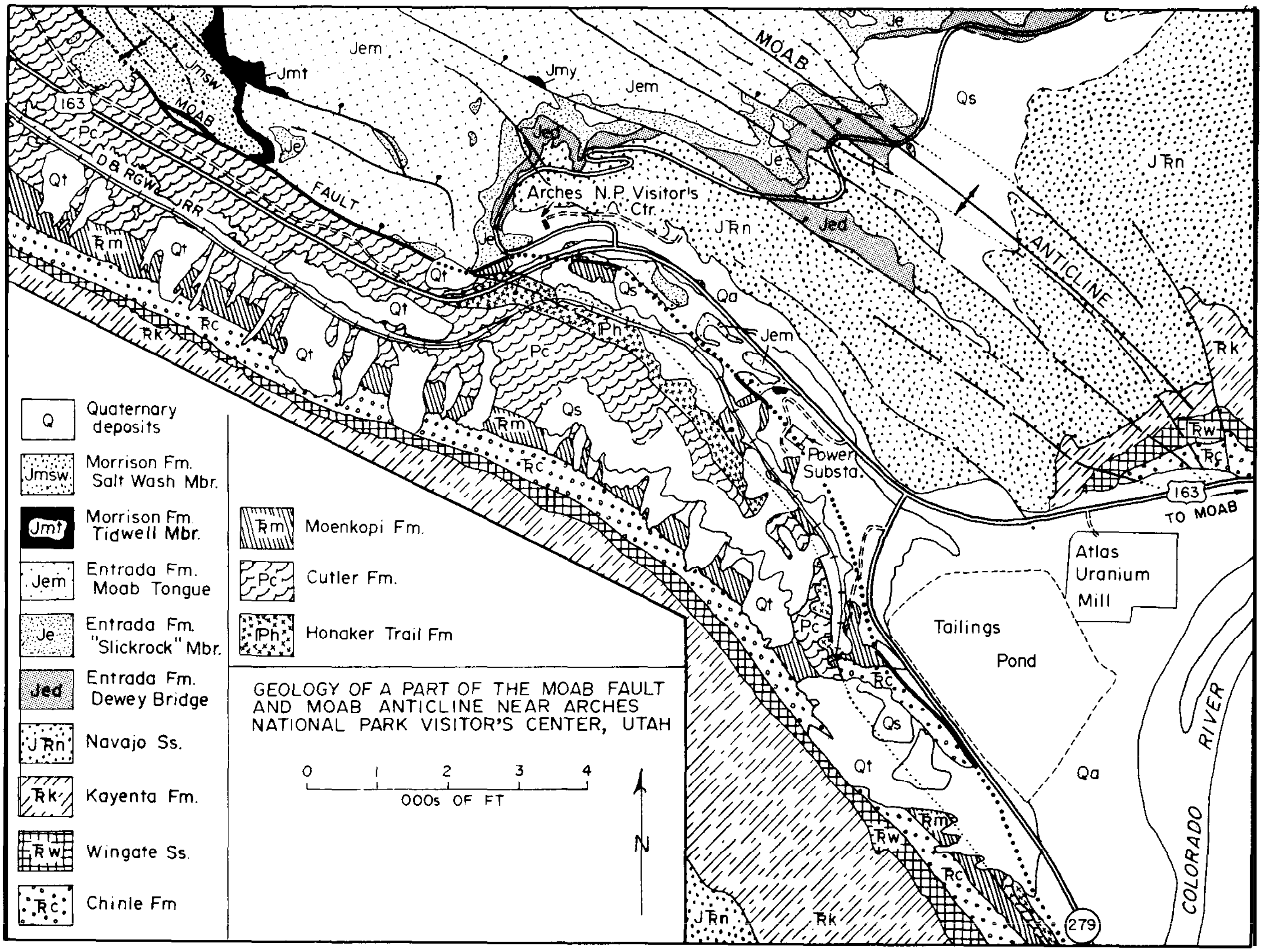


Figure 3. Geologic map of northwestern Moab Valley salt-intruded structure and the related Moab fault in the vicinity of Arches National Park Visitor's Center.

vanian age stratigraphically overlies the Paradox Formation. Only the upper few feet of the formation are exposed in the flanks of Moab Valley. The best exposures occur along U.S. Highway 163 near the Arches National Park visitors center, where the formation consists of interbedded fossiliferous, marine, gray limestone and brown Cutler-like arkoses. Here the limestones are highly fossiliferous and contain abundant brachiopods, bryozoa, rugose corals and crinoids. Rare fusulinids, trilobites, and crinoid calyces date the limestones as Virgilian (latest Pennsylvanian) age. Similar strata of Lower Permian age, the Elephant Canyon Formation, may be seen on the Cane Creek anticline, west of Moab, but were either not deposited or were removed by erosion from the Moab anticline.

The overlying Permian Cutler Formation is a coarse-grained arkosic sandstone in the Moab area. The clasts were derived from the "Ancestral Rockies" Uncompahgre uplift, to the east, and were distributed by fluvial processes. The formation thickens northward from a wedge-edge north of the Colorado River at the "West Portal" to more-than-l ,100 ft (357 m) in about 4 mi (6.5 km). It also thickens markedly in the subsurface on both flanks of the Moab structure.

Rocks of Triassic age are mainly mudstones, siltstones, and sandstones of the Moenkopi and Chinle Formations in the Moab area. The section is best displayed along the high cliffs bordering the Moab fault north of the Colorado River and in synclines, both upstream and downstream, along the river. The Moenkopi Formation is a dark brown, slope-forming unit that contains abundant ripples, mudcracks, and compactional structures. The Chinle Formation is a varicolored slope-forming shaly and ledgy unit directly beneath the massive Wingate Sandstone. A basal member, the Moss Back, is not well developed, but its stratigraphic position at the base of the Chinle slopes is marked by a thin white layer and numerous bulldozer scars, made in the search for uranium in the 1950s.

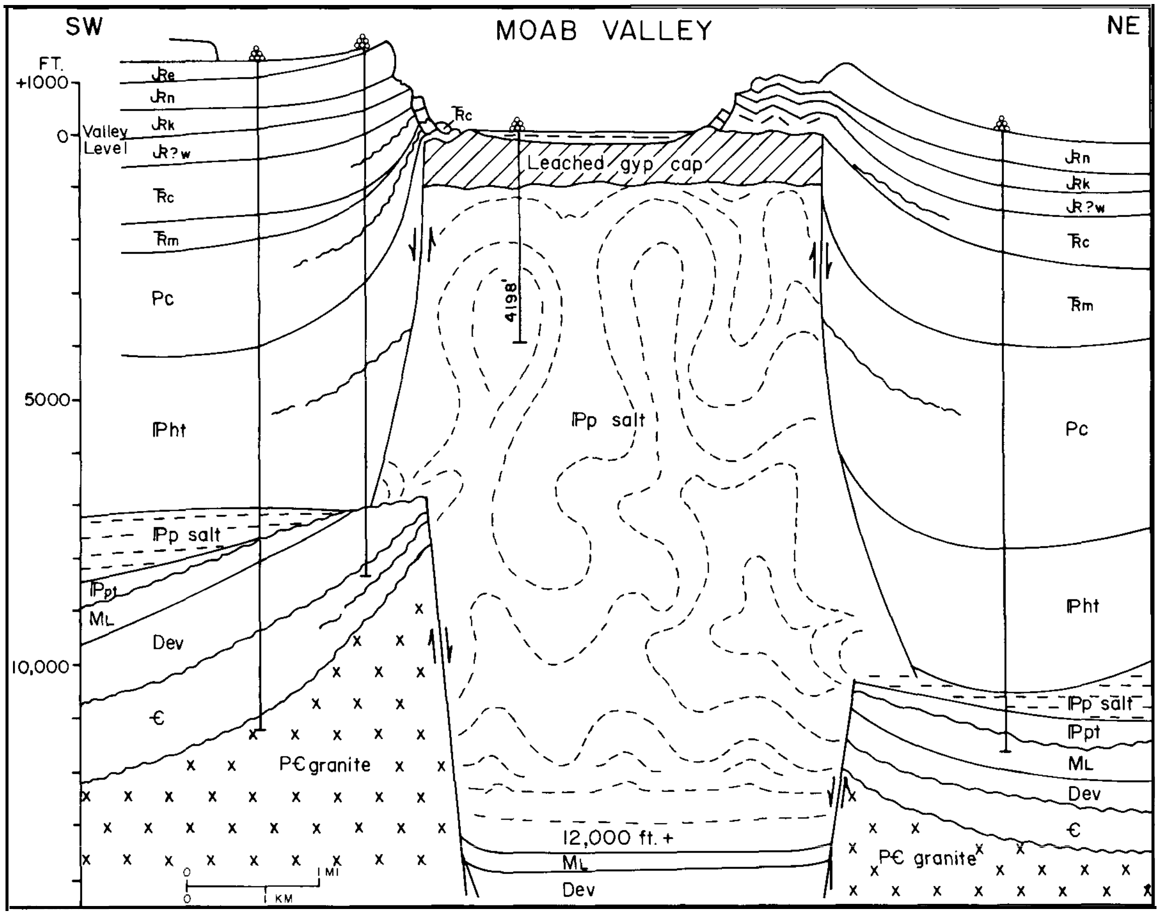


Figure 4. Highly generalized cross section of the Moab salt-intruded anticline. Deep-seated faults originated in Late Precambrian time and were episodically rejuvenated throughout the Phanerozoic. Cambrian through Mississippian strata thin locally and display fault-related facies changes near the faults. Middle Pennsylvanian evaporates, including salt, were deposited within the paleograben and buried the structure as salt flowage was initiated. Upward growth of the salt bulge continued through late Paleozoic and Mesozoic time, causing excess thicknesses of elastic sediments to accumulate in synclines and thinning by deposition and local unconformities to occur along the rising salt core. Tertiary to Recent near-surface groundwater dissolution of salt created a residual "leached gypsum cap" and subsequent collapse of overlying strata. The valley surface is now largely covered by fluvial and eolian Recent deposits. Flowed salt thickness may exceed 15,000 ft (5,500 m).

The Triassic-Jurassic boundary is not well defined on the eastern Colorado Plateaus province, as fossil data are meager at best. Some workers now place it at the base of the Wingate Sandstone rather than in the middle of the Navajo Sandstone on the basis of palynomorphs. Wherever it maybe, the rocks overlying the Triassic Chinle Formation maybe summarized as follows:

***Wingate Sandstone.*** Vertical cliff-forming brown sandstone, highly cross-bedded, forms the lower massive cliffs high on the southwestern walls of Moab Valley, along the Moab fault north of Moab and in the Colorado River canyons above and below Moab. Most workers consider it to be eolian in origin.

***Kayenta Formation.*** Ledgy sandstone cliffs at the top of the Wingate Sandstone. It displays small-to medium-scale cross-stratification in channels and irregular lenticular beds; fluvial in origin.

***Navajo Sandstone.*** Light brown to white, massive cliff-forming unit, with well-developed large-scale cross-stratification of an eolian origin; forms rounded cliffs and knobs above the Wingate-Kayenta cliffs. Best seen in Arches National Park, but widely exposed along the margins of Moab Valley, high above the Moab fault north of the Colorado River, and in the Colorado River canyons.

***Entrada Sandstone.*** Best known as the massive sandstone cliffs containing the arches in Arches National Park and elsewhere; now subdivded into the reddish basal, crinkly-bedded mudstones, siltstones, and silty sandstones of the Dewey Bridge Member that forms the notch at the top of the Navajo Sandstone; the Slick Rock Member of massive cliffs containing many of the archey and the highest massive sandstone cliffs of the Moab Tongue.

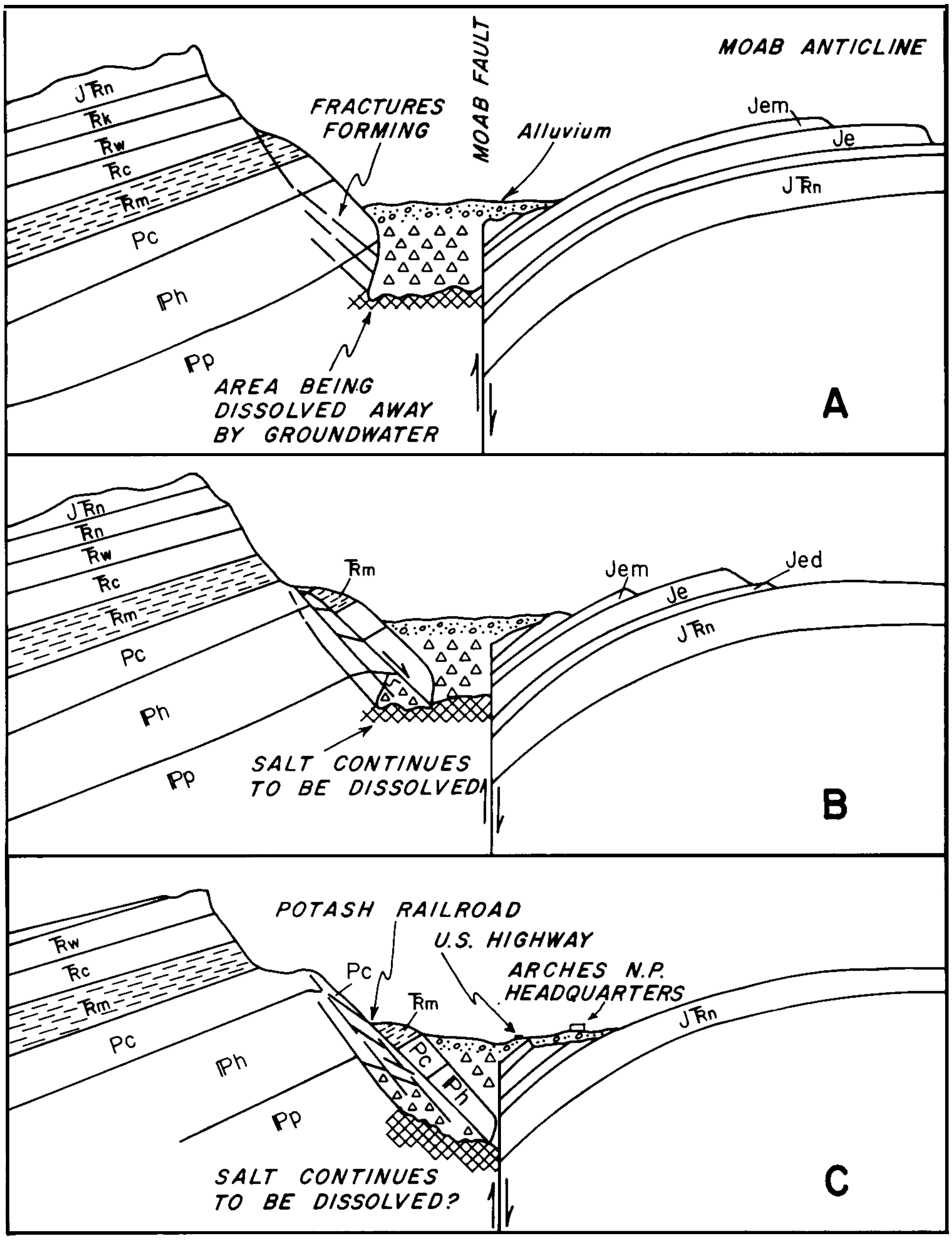


Figure 5. In more recent geologic time some of the salt of the Paradox Formation has been dissolved away by ground water, causing collapse of the top of Moab Valley salt-intruded anticline. The above series of diagrams illustrates how this may have occurred in the vicinity of the D&RGW railroad tunnel and Arches National Park visitors center.

***Morrison Formation.*** Consists of the basal thin reddish siltstone and sandstone of the Tidwell Member that contains large, white, siliceous concretions; the medium-bedded, fluvial sandstones of the Salt Wash Member, forming ledgy cliffs above the reddish-orange Entrada cliffs and containing vanadium-uranium deposits in the general Moab region; and an upper mudstone-siltstone Brushy Basin Shale Member, widely exposed along U.S. Highway 163 north of Moab, where it is mainly a bright green.

***Cretaceus Formations.*** Seen only in and along the Book Cliffs near Crescent Junction north of Moab and in the southern extension of Moab Valley. Best recognized by the dark gray shaly badlands exposures of the Mancos Shale. Consist of the Lower Cretaceus Burro Canyon-Cedar Mountain Formation and the Upper Cretaceus Dakota Formation and Mancos Shale. Cretaceous strata occur in well-developed dissolution collapse structures in the southern part of Moab Valley (Pack Creek syncline) and in Salt Valley in Arches National Park.

## DISSOLUTION COLLAPSE STRUCTURES

In more recent geologic time, since about the mid-Tertiary, the Colorado Plateaus were elevated and are currently being eroded by the Colorado River and its tributaries. The erosional regime includes groundwater activity, and wherever natural conduits to the salt are available, dissolution of salt can and does occur. The removal of the salt has resulted in the massive collapse of overlying strata, some of which have been removed at the surface by normal erosion and some of which are now buried under a veneer of alluvium. The overall result has been the formation of elongate, northwest-trending valleys above the salt-intruded anticlines. Superimposed stream courses, such as that of the Colorado River, cross the salt anticlines and their collapsed valleys nearly at right angles, rather than running along the valleys. These valleys, essentially unrelated to the river courses, were considered to be "paradoxical" by early pioneers of the region, and therefore the names of "Paradox Valley," "Paradox Formation," and finally "Paradox Basin" were originated.

Gypsum plug outcrops of Paradox Formation are exposed along the flanks of Moab Valley south of the Colorado River, the associated salt having long been dissolved away. North of the river, near the tunnel portal of the Potash spur of the D&RGW Railway, a relatively thin sandstone slab of Cutler Formation, dipping 35° to the NE, is faulted against oppositely dipping edges of Honaker Trail Formation (Fig. 5C). This peculiar structure was probably produced by dissolution collapse. In this case, the Moab fault provided the conduit for the surface water to move underground to the salt. North of the tunnel, opposite the Arches National Park visitors center, an unrotated downdropped block of Moenkopi Formation is faulted against the Entrada Sandstone by the Moab fault. In this case, collapse may have been essentially vertical, at least at depth.

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