GEOLOGIC STUDIES OF THE SALT VALLEY ANTICLINE-
PROGRESS REPORT

by Hellmut H. Doelling

October 1982

Utah Geological and Mineral Survey
Open-file Report No. 30

GEOLOGIC STUDIES OF THE SALT VALLEY ANTICLINE--PROGRESS REPORT

Hellmut H. Doelling, October, 1982

INTRODUCTION:

Utah's Paradox Basin, located in the southeastern part of the State, is underlain with thick salt deposits in the Pennsylvanian Paradox Formation that may be favorable for the storage of nuclear wastes. The Utah Geological and Mineral Survey began geologic studies of the Basin with respect to such storage early in 1980 and prepared a preliminary report, "Stratigraphic investigations of Paradox Basin structures as a means of determining the rates and geologic age of salt-induced deformation" (UGMS Open-file Report 29).

That study served to identify what types of further information were needed and found that much information was still lacking in the understanding of the region's geologic history. It also pinpointed the Salt Valley anticline area as an excellent place for intensive study because it exposes the entire stratigraphic column in an area where salt deformation has taken place. It also is an area of well exposed and abundant geologic structures that have developed because of the presence and movement of the salt. A detailed stratigraphic and structural study of the anticline should provide information to refine the understanding of the geologic history of the region. Most of the events that shaped the Salt Valley anticline most probably have affected the whole Paradox Basin region as well and many of the geologic processes found to be active in the Salt Valley anticline have also been active in similar areas within the Basin.

METHODS OF INVESTIGATION:

The Salt Valley anticlinal area (figure 1) is being mapped geologically at a scale of 1:24,000. Included are surrounding areas covered by the Crescent Junction SE, Thompson SW, Thompson SE, Moab NW, Moab NE, and Castle Valley NW topographic quadrangles. Structurally complex areas, especially within the core area of the anticline, are being mapped at a scale of 1:12,000. Collapse structures and Tertiary-Quaternary unconsolidated deposits are being examined in detail. When the mapping is complete many additional stratigraphic sections will be measured and numerous structural cross-sections will be constructed. Results and conclusions will be prepared in a final report that will refine our understanding of the region's geologic and geomorphic history.

LOCATION AND EXTENT OF STUDY AREA:

The Salt Valley anticline is a segment in a chain of salt structures extending 70 miles from the Book Cliffs to the northwest to Montrose County, Colorado, at the southwest end of Sinbad Valley. The study area is limited to the 25 mile portion of the chain extending northwestward from the Colorado River to where the structure crosses U. S. Highway 163 (figure 1). For cross-sectional purposes the southwest boundary is placed slightly southwest of U. S. Highway 163 and the Moab fault zone. A northern boundary has tentatively been placed along the lower outcrop contact of the Cretaceous Mancos Shale and the eastern boundary has been placed along the eastern edge of Township 22 East, Salt Lake Base & Meridian.

GENERAL GEOLOGY:

Stratigraphy:

Consolidated rocks ranging in age from Pennsylvanian to Cretaceous are exposed in the Salt Valley anticline area. In addition various unconsolidated deposits give clues to the more recent geologic history. These units have been described in numerous publications, the most complete coming from the work of Baker (1933) and Dane (1935). Brief descriptions and comments are presented here. A general stratigraphic column is given as figure 2.

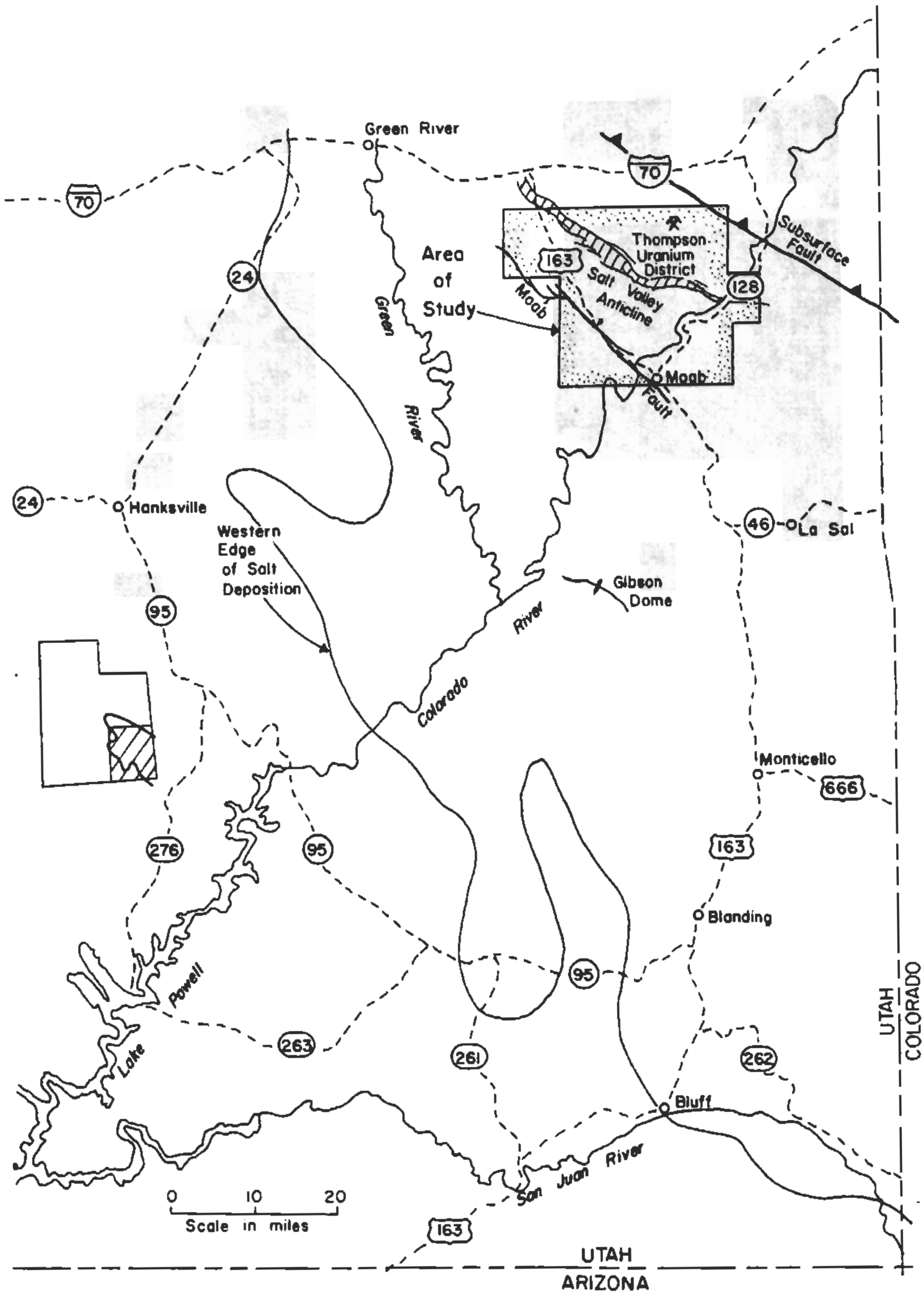


Figure 1. Index map of Paradox Basin (Utah) and Salt Valley Anticline Area.

Photo 1: View looking northerly across the north end of the Salt Valley anticline graben. The Moab Tongue of the Entrada Sandstone in the foreground is dipping toward the graben. The low ridges in the graben are exposures of the Lower Cretaceous Cedar Mountain Fm., which have collapsed into the graben.

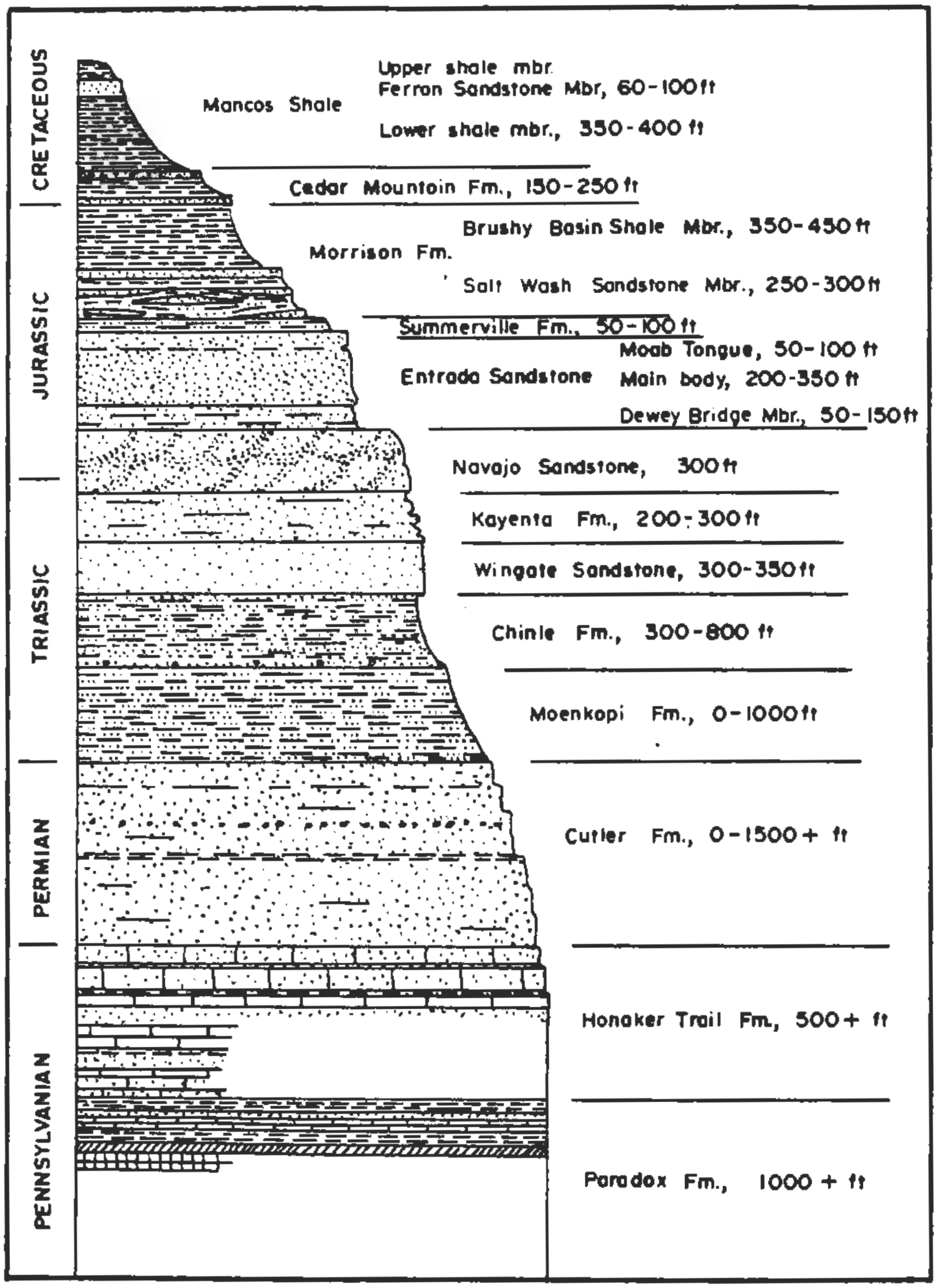


Figure 2. Generalized stratigraphic section of units exposed in the Salt Valley anticline area, Grand County, Utah.

The oldest rocks exposed in the Salt Valley anticline area are Pennsylvanian in age and include the Paradox Formation and the Honaker Trail Formation. The oldest unit is the salt-bearing Paradox Formation. Rather large areas of gray and black shale, sandstone, limestone, and gypsum are found in the anticlinal valley and in two small exposures at the southeast end of Cache Valley. Other exposures are found in Moab Valley, along the Moab fault, just south of the Colorado River. The Paradox Formation exposures are all complexly folded, faulted or brecciated so that it becomes difficult to estimate the exposed thickness. Perhaps 1000 ft of the unit is exposed in Salt Valley. Wells drilled for petroleum indicate the presence of thick salt beds in the subsurface, some of which contain valuable potash and magnesium minerals. Ground and surface waters have dissolved away all the rock salt that was once incorporated in the exposed parts of the Paradox Formation and the remaining rock now represents a compressed view of the unit.

Some brecciated Honaker Trail Formation, which normally overlies the Paradox, may be present in Salt Valley in a small outcrop. Incomplete sections of the unit are present along the Moab fault, adjacent to Arches National Park Visitors Center and just south of the Colorado River. The unit is a gray marine sandy limestone interbedded with subordinate calcareous greenish-gray sandstone and variecolored sandy shale. Less than 500 ft is exposed.

The Permian period in the Paradox Basin is represented by a single formation, the Cutler. The Cutler is not present across the entire area due to a post-Permian erosional interval which affected the anticlinal areas. The Cutler is probably completely missing in the Salt Valley anticline area, but probably underlies the Cache Valley area even though it is not exposed there. The unit consists of red and maroon cross-bedded arkoses, sandstones and conglomerates with subordinate sandy shales. A few thin fossiliferous limestone beds are found near its base in western exposures which increase in number westerly where they are called the "Rico" or Elephant Canyon Formation. The Cutler Formation is well exposed on the floor of the Richardson Amphitheatre to the east (incomplete exposures) and just southwest of the Moab fault where perhaps 1500 ft are exposed. The Cutler Formation is known to thin regionally in a southwesterly direction. One drill hole on the Moab anticline indicates the formation to be present and not thinned over that structure.

The Moenkopi Formation unconformably overlies the Cutler Formation and is the oldest Triassic unit. It, too, was thinned or removed over some of the anticlinal areas, but locally it is exceptionally thick over them. It is unconformably overlain by the Chinle Formation. There are no confirmable outcrops of the Moenkopi Formation in Salt Valley or Cache Valley, but at least part of Cache Valley must be underlain by it. Drill holes indicate it thickened under the Courthouse syncline (between Moab and Salt Valley anticlines) and to the northwest of the Salt Valley anticline (exceeding 1000 ft). The formation is exposed to the southwest of the Moab fault on the southwest flank of the Moab anticline. At the Colorado River it is missing, but it appears a short distance to the north and thickens rapidly to 459 ft at a point opposite the Arches National Park Visitors Center. Thereafter it thins gradually and is only a few feet thick where the exposure is cut off by the Moab fault. It is also exposed in the Richardson Amphitheater east of Cache Valley. The unit thickens rapidly from the east and about 1,000 ft are exposed adjacent to the faults emerging from Cache Valley. In the Richardson Amphitheater the Moenkopi Formation is an evenly bedded series of brown to reddish brown sandy shales and micaceous silty sandstones. Many of the sandstones are ripplemarked and the unit contains a few gypsum beds. It forms a steep slope in contrast to a more ledgy Cutler outcrop below. It is further distinguished from the Cutler exhibiting a more uniform brown color than the more red and occasional lavender hues of the lower unit. The outcrops to the

Photo 2: View looking northerly along the escarpment immediately southwest of the Moab fault. The base of the escarpment exposes the Cutler Formation (Pc) which has a reddish appearance. It is overlain by the brownish Moenkopi Formation (Trm) and the Chinle Formation (Trc), the base of which consists of greenish outcrops. Capping the Chinle Formation is the Wingate Sandstone (Trw), an imposing cliff-former.

southwest of the Moab fault are thinner and the slopes are not as uniform, being broken by an occasional ledgy sandstone. There are no gypsum beds in these exposures as well.

The Chinle Formation is interbedded siltstone, sandstone, conglomerate and mudstone, mostly of a pale reddish brown, brown, or grayish red color. Maroon, reddish orange and gray green are other colors exhibited by the unit. The outcrop pattern is generally a slope with an occasional, but sometimes significant ledge. Ledges tend to be more common toward the top, except for a single basal unit. In western exposures the base of the Chinle Formation is a distinctive greenish-gray weathering unit of conglomerate, sandstone and gritstone (Moss Back Member) that locally contains uranium mineralization. Eastward this changes to a gritty mottled siltstone unit which thins to a very thin green line between the Moenkopi and Chinle in the Richardson Amphitheater. The upper part of the unit changes little across the area. The Chinle Formation is exposed just southwest of the Moab fault where it is about 325 ft thick. Well logs from drill holes in the Courthouse syncline area indicate the unit to exceed 800 ft in thickness. It is incompletely exposed along the south escarpments of Salt Valley and Cache Valley and wells show the unit to be 300 to 500 ft thick to the northeast of the anticline. It is exposed above the Moenkopi in the Richardson Amphitheater as well. The Chinle is also poorly exposed in the collapsed central part of Salt Valley. Here it laps directly onto the Pennsylvanian Paradox Formation. The Chinle was probably the first unit to be deposited to blanket the anticlinal area (except perhaps over a few local areas) and indicates that the Paradox Formation surface had developed some relief. As the Chinle Formation is considered to be a continental unit, some dissolution of salt may have already begun in the Paradox Formation.

The Wingate Sandstone overlies the Chinle Formation and is regionally more uniform in thickness, usually 300 to 350 ft. Only locally is it thinned over the anticlines. Generally, it forms a vertical cliff of reddish orange color irregularly masked by a dark brown to black surficial stain in outcrop. These cliffs erode along joints that extend through the full thickness of the fine-grained, well sorted and poorly cemented unit. Crossbedding is evident upon closer examination in the massive unit. The typical cliffy exposures are found southwest of the Moab fault and rimming the Richardson amphitheatre and along the canyon of the Colorado River. The Wingate Sandstone is also discontinuously found along the rims of Salt Valley and Cache Valley; however, the rims represent knick-points of collapse and the unit is shattered into a coarse blocky outcrop. Only a few exposures of the Wingate are found in the anticlinal valley areas, protruding through the unconsolidated units that blanket large areas of the floor.

The Kayenta Formation is regarded as the youngest unit completely Triassic in age. It crops out as an alternation of benches and ledges 200 to 300 ft thick above the Wingate Cliff. It is irregularly bedded (mostly thickbedded to massive), brown, lavender, gray and white micaceous sandstone, with interbeds of red sandy shale, limestone and intraformational (pebble) conglomerate. It is found capping many of the mesas across the southern part of the study area and is found on the upper dip-slopes on both sides of the Salt Valley anticline. There are only minor exposures of the Kayenta Formation in the valley areas between the rims along Salt Valley and Cache Valley.

The Navajo Sandstone is an aeolian crossbedded unit of fine-grained quartz sand, massive and of light yellow or tan color. Locally, there are thin beds of very dense gray limestone. The unit is about 300 ft thick, although some well logs indicate thicknesses exceeding 500 ft. In outcrop it forms a rough, bare rock surface of "frozen" dune sand, with protrusions of rounded domes and monuments. The lower parts are not as massive and exhibit irregular horizontal partings.

The formation is mostly Lower Jurassic in age and its exposures are widespread in the area, although little is found exposed in the anticlinal valleys. Jointing is quite prevalent in the Navajo, generally trending northwesterly, even adjacent to the east-west trending Cache Valley.

The Entrada Sandstone overlies the Navajo in the Salt Valley anticline region. The unit consists of three parts: a lower Dewey Bridge Member, 50 to 150 ft thick; a main body of sandstone, 200 to 350 ft thick; and an upper Moab Tongue, 50 to 100 ft thick. The lower Dewey Bridge Member was formerly known as the Carmel Formation, and it is a reddish muddy sandstone with interbeds of sandy mudstone. It is thinbedded to massive and contains an occasional light colored bed. Its bedding is contorted and irregular and this deformation extends into the lower part of the main body of the Entrada Sandstone. Thin erosional remnants of the main body break up easily over the Dewey Bridge Member to form extensive sandy areas. The Dewey Bridge Member is an excellent marker to separate the Navajo Sandstone from the Entrada Sandstone.

The main body of the Entrada Sandstone is orange-tan to reddish, massive "slickrock" sandstone that weathers into vertical or rounded cliffs, locally jointed from bottom to top. The massive sandstone is often color-banded in lighter and darker shades. Many of the scenic landforms of Arches National Park are in the Entrada Sandstone which has been influenced by salt-related deformation, notably dissolution collapse. As collapse occurs at the edges of the anticlines, the joints in the Entrada open and widen and sand falls into the cracks. Damp sand serves to dissolve the cement and weaken the formation, producing more sand. If the jointing is deep, the upper parts of the "fins" that are formed are less subjected to loss of cement and become more stable, hence arches and monuments. The softer, underlying Dewey Bridge Member enhances the arch producing process. If the loose sand is kept away from the bases of the monuments, such as it is

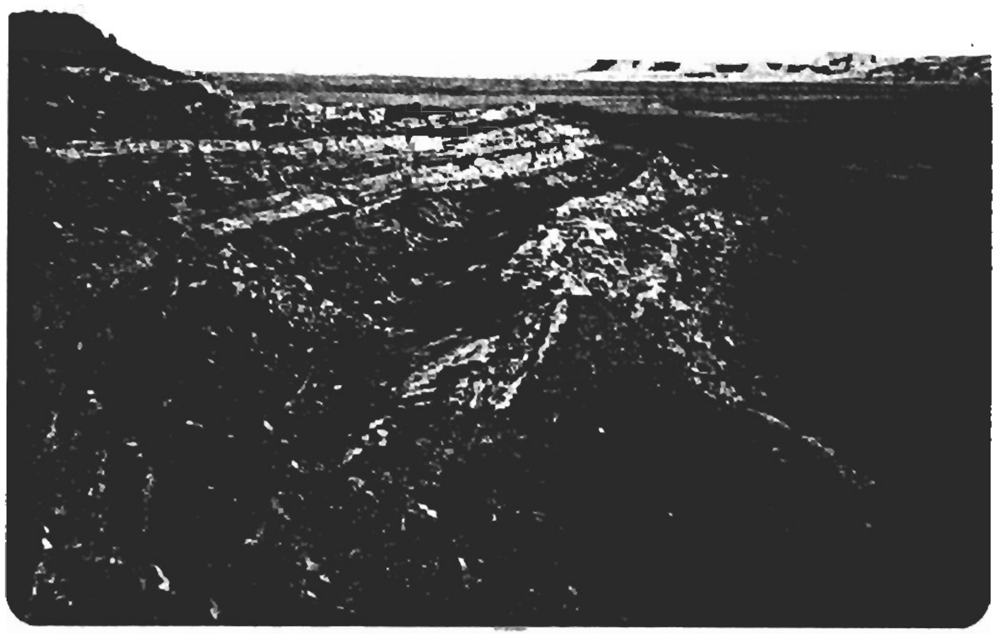


Photo 3: View looking northerly along the southwestern escarpment of Salt Valley near its northwestern end. Exposed are the Navajo Sandstone (Jn), Dewey Bridge Member of the Entrada Sandstone (Jed), the main body of the Entrada Sandstone (Je), and the Moab Tongue of the Entrada Sandstone (Jem).

along Elephant Buttes (fig. 3), these will be preserved for a longer length of time.

The Moab Tongue is the upper member of the Entrada Sandstone. It is a very hard, resistant caprock to the main body and forms many bare rock dip slope surfaces in the region. It is a lighter-colored, highly jointed sandstone. Faults, along which collapse occurs, usually follow the Moab Tongue jointing. The contact between the main body of the Entrada and the Moab Tongue is a strongly developed and indented bedding plane, along which numerous springs are found and many seepage lines. In the northwestern part of the area the parting thickens to several feet of reddish micaceous silty shale. It is of interest to note that the dominant joint patterns found in the Moab Tongue are not always parallel to those in the main body of the Entrada Sandstone. Generally, the direction of jointing in the Entrada is not as predictable as that in the Navajo Sandstone, but are generally subparallel to the trends of the anticlines or other structural elements of the region.

The Summerville Formation consists of 50 to 100 ft of reddish micaceous siltstone shale with a few interbeds of purplish gray limestone and red sandstone. Often accompanying the limestone beds are large concretions of white-weathering chert. It makes an excellent marker horizon between the Moab Tongue and the overlying Salt Wash Member of the Morrison Formation and forms a slope between them. The sandstones and siltstones are often ripple-marked.

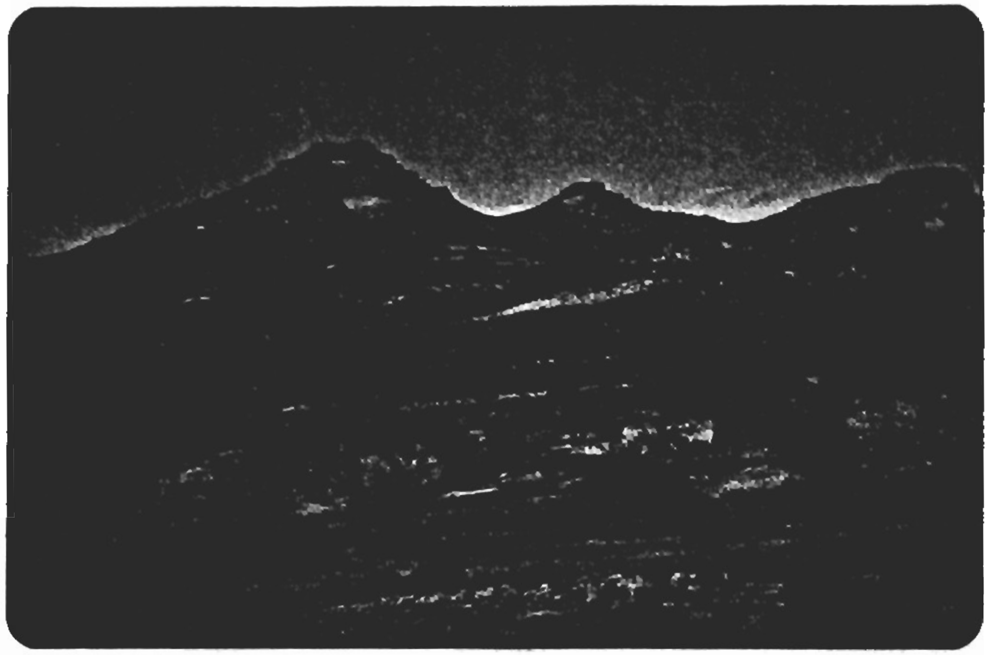
The Morrison Formation is the youngest Jurassic unit and consists of two members: a lower Salt Wash Member, 250 to 300 ft thick and an upper Brushy Basin Member, 350 to 450 ft thick. The Morrison Formation is exposed along a generally east-west band across the northern part of the area and along a north south band along the west edge of the area. In addition there are considerable exposures in faulted blocks in Cache Valley and eastern Salt Valley. The lower Salt Wash

Photo 4. View looking westerly down the dip-slope on the southwest flank of Salt Valley anticline. There are large areas of the bare rock upper surface of the Moab Tongue of the Entrada Sandstone (Jem). These are overlain by the thin, but easily recognized red siltstones of the Summerville Formation (Js) and the rough lenticular sandstones of the Salt Wash Member of the Morrison Formation (Jmsw). Note the pronounced jointing in the Moab Tongue as marked by the lines of vegetation. These generally parallel the trend of the anticline.

Member consists of lenticular channels of white and gray conglomeratic and cross-bedded sandstone interbedded with red and gray sandy mudstone. The red interbeds are often quite similar in appearance to the Summerville Formation. In many areas the channel sandstones are mineralized with vanadium and uranium. The unit usually forms rough, broken-appearing outcrops with alternating ledges and slopes. In many areas the Salt Wash has a tendency to be covered by large areas of sandy colluvium.

The upper Brushy Basin Member forms a steep slope of silty and limy mudstone, with occasional interbeds of sandstone, gritstone or conglomerate. The mudstones are brilliantly color-banded, especially green, white, gray, maroon, red, orange, yellow and purple. There is a noticable and gradual overall color change in the Brushy Basin slope from north to south. In the north maroon, red and lavender colors dominate the slope and in the south the greens and white dominate. In Cache Valley the Brushy Basin Member is mostly a bright green or greenish blue.

Overlying the Brushy Basin Member and usually formaing a dip-slope, is the Cedar Mountain Formation of Lower Cretaceous age. The unit consists of ledges of conglomerate and sandstone divided by slopes of siltstone, shale or mudstone. Limy brown concretions are common in the slope-formers. The slope-formers are similar in appearance to the Brushy Basin Member of the Morrison, but are less bright in color, less variegated, much thinner, and more rubble strewn. The uppermost ledge-former is a discontinuous layer of yellow-tan conglomeratic sandstone and gray shale, termed the Dakota(?) Sandstone. It becomes thicker and more continuous to the east. The Cedar Mountain Formation, including the Dakota(?) ledge, ranges from 150 to 250 ft in thickness. The Dakota(?) portion can be found to be up to 100 ft thick. Except for the faulted exposures in Cache Valley (which have the Dakota(?) present), exposures of the Cedar Mountain Formation are limited to the northern half of the study area.



Photos 5 and 6. Two views of the Brushy Basin Member of the Morrison Formation. The variegated shales and siltstones become more greenish in overall appearance to the south and southeast.

The Mancos Shale of Upper Cretaceous age is the youngest consolidated unit of the area, but most has been stripped from the area by erosion. It is preserved along the north margin of the area and in the Courthouse syncline in the northern part of the area. Some has also been preserved in the collapsed zone in Cache Valley and Salt Valley and indicates the Mancos was once deposited across the entire region. Three divisions can be recognized, a lower gray marine shale, a middle sandy and carbonaceous shale zone known as the Ferron Sandstone Member, and an upper light-gray weathering marine shale. The lower shale member is uniformly 350 to 400 ft thick across the area, the Ferron Member is 60 to 100 ft thick, and the upper shaly member is incomplete in the area and very thick. The upper and lower shale members are soft and not resistant to erosion, the Ferron Sandstone Member is more resistant and usually forms a cuesta or hogback.

Unconsolidated Deposits:

There are several types of unconsolidated deposits in the Salt Valley anticline region. These are believed to be mostly Quaternary in age, but a few may be Late Tertiary in age.

Alluvium is found in the valleys of washes and the more important drainages, usually as a thin veneer, but occasionally to a hundred ft in thickness, such as in the valley of Salt Wash north of Cache Valley and Salt Valley. All sizes of detrital material are found in the alluvium, but the most prevalent material is sand. The detritus reflects the nature of the source rocks, principally sandstone, but clasts of all consolidated hard materials can be found; conglomerate, siltstone, limestone and chert.

Sandy deposits, usually as coverings of irregular thicknesses, develop on nearly flat surfaces, especially in protected places on sandstone formations. They are particularly extensive over the outcrops of the Entrada Sandstone. Locally, the sand blows and collects along cliffs or on the leeward side of obstructions. Larger dune areas are relatively rare in the Salt Valley area.

Residual soil deposits develop on relatively flat or nearly flat formations, especially where the bedrock is a softer siltstone or sandy shale. The color of the soil reflects the color of the unit from which it developed. Partings in the Kayenta, Navajo, or mudstone in the Salt Wash Sandstone are especially favorable. The vegetation that grows on these, usually small patches stabilizes them and offers resistance to erosion.

Colluvial deposits, mixtures of alluvial, residual and slope-wash deposits are common in the Salt Valley anticline region. Of especial interest are those covering the floor of a large part of Salt Valley. These are deeply weathered and a caliche zone has developed beneath the surface. The presence of caliche and the thickness of the weathered zone in the colluvial deposits indicate that they are older than most of the unconsolidated deposits found in the region. The colluvial deposits are currently being eroded headward by tributary washes (Salt Valley Wash) of Salt Wash. The deposit is mostly removed from Cache Valley, which receives a more copious supply of flood waters from the relatively high Dome Plateau, a few remnants still persist, however. Similar colluvial deposits are also found on top of the south escarpment of Salt Valley-Cache Valley on Dry Mesa and around Panorama Point, at least 100 ft above the surface of the valley deposit. At one location on Dry Mesa, the deposit appears to have been cut by fault movement.

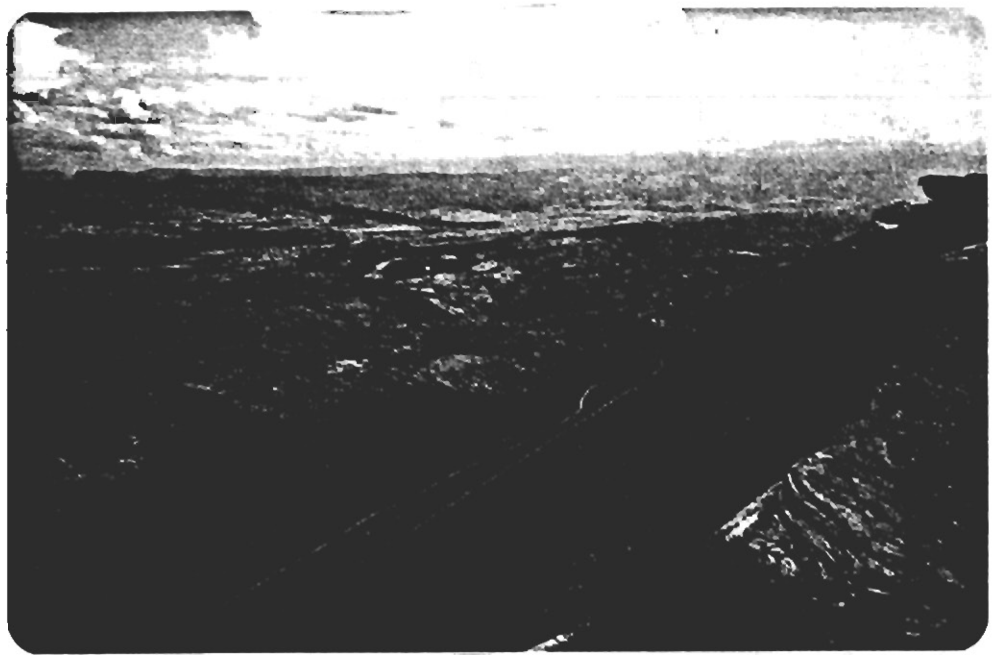
Although accumulations of landslide or talus debris are rarely of large areal extent, they are found everywhere on the sides of the many cliffs, escarpments and canyon walls. Occasional piles of landslide materials have been found miles from their source. Large boulders and rubble, usually from the Morrison or Cedar Mountain Formations are found as pointed hills on top of older units. They are especially common between Panorama Point and the Eye of the Whale resting on members of the Entrada Sandstone.

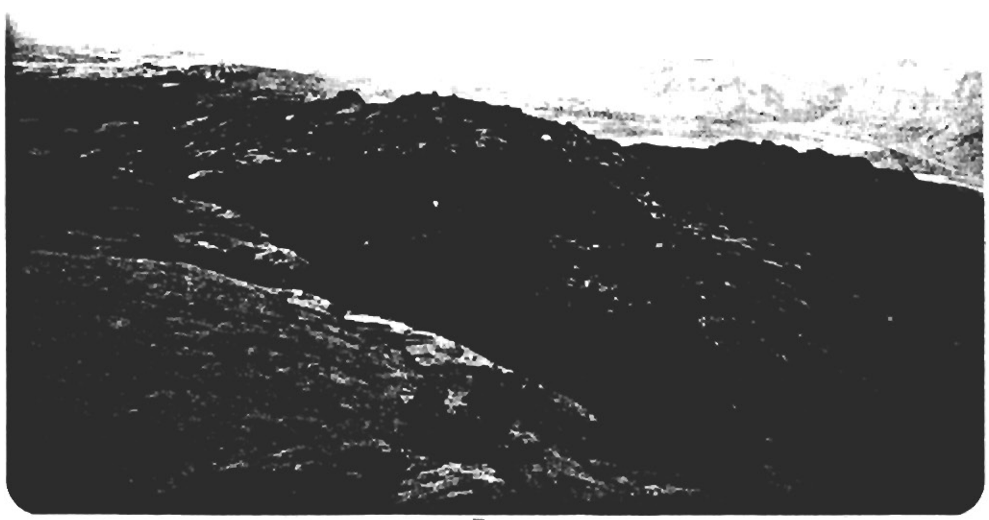
Structure:

The principal structural elements of the Salt Valley anticline region (figure 3), include the Salt Valley anticline (with Salt Valley and Cache Valley grabens), Courthouse syncline, Salt Wash syncline, Moab anticline, Yellowcat dome and Moab fault. Starting from the southwest the Moab fault is a northwesterly trending fault which cuts the southwest flank of the Moab anticline. The down-dropped block is on the northeast side and the displacement increases southeasterly. The maximum displacement may be as much as 3,000 ft. The strata, southwest of the fault, continue to dip southwesterly into the Kings Bottom syncline (not shown). The dip slope strata are mostly of the Kayenta Formation at the higher elevations and the Navajo Sandstone at lower elevations. A steep escarpment is present a bit to the southwest of the fault line which places the Cutler Formation adjacent to the Salt Wash Member of the Morrison Formation along much of its length.

The Moab anticline is 6-7 miles long, extending northwesterly from the Colorado River at the north end of Moab Valley. Farther to the northwest the anticlinal bulge flattens out and disappears. The Morrison Formation rocks rise onto the anticlinal crest from the southwest, but are eroded on the northeast flank where the hard Moab Tongue of the Entrada Sandstone forms the dip slope. The northeast flank dips are usually gentler than those on the southwest flank. Several small displacement faults parallel the anticline where the bulge is at a maximum, near its southeast end. There is an interesting subsidiary structural feature on the southwest flank of the anticline adjacent to the Moab fault. A v-fault, doubly-plunging syncline, scarcely a mile in length, parallels the fault, causing a local dip reversal on the southwest side. The structure is certainly suggestive of collapse, and dips approach 30 degrees on the flanks.

The Courthouse Wash drainage closely follows the axis of the Courthouse syncline. The syncline plunges northwesterly, but the wash flows southeasterly.





Photos 7 and 8. Upper is view looking southeasterly across the Moab fault which places the Permian Cutler Formation against the Salt Wash Member of the Morrison Formation. Lower is view looking south toward Moab Valley and along the Moab anticline. The anticline dips easterly into the Courthouse syncline. Note the adjustment fault a short distance to the west (right) of the anticlinal axis.

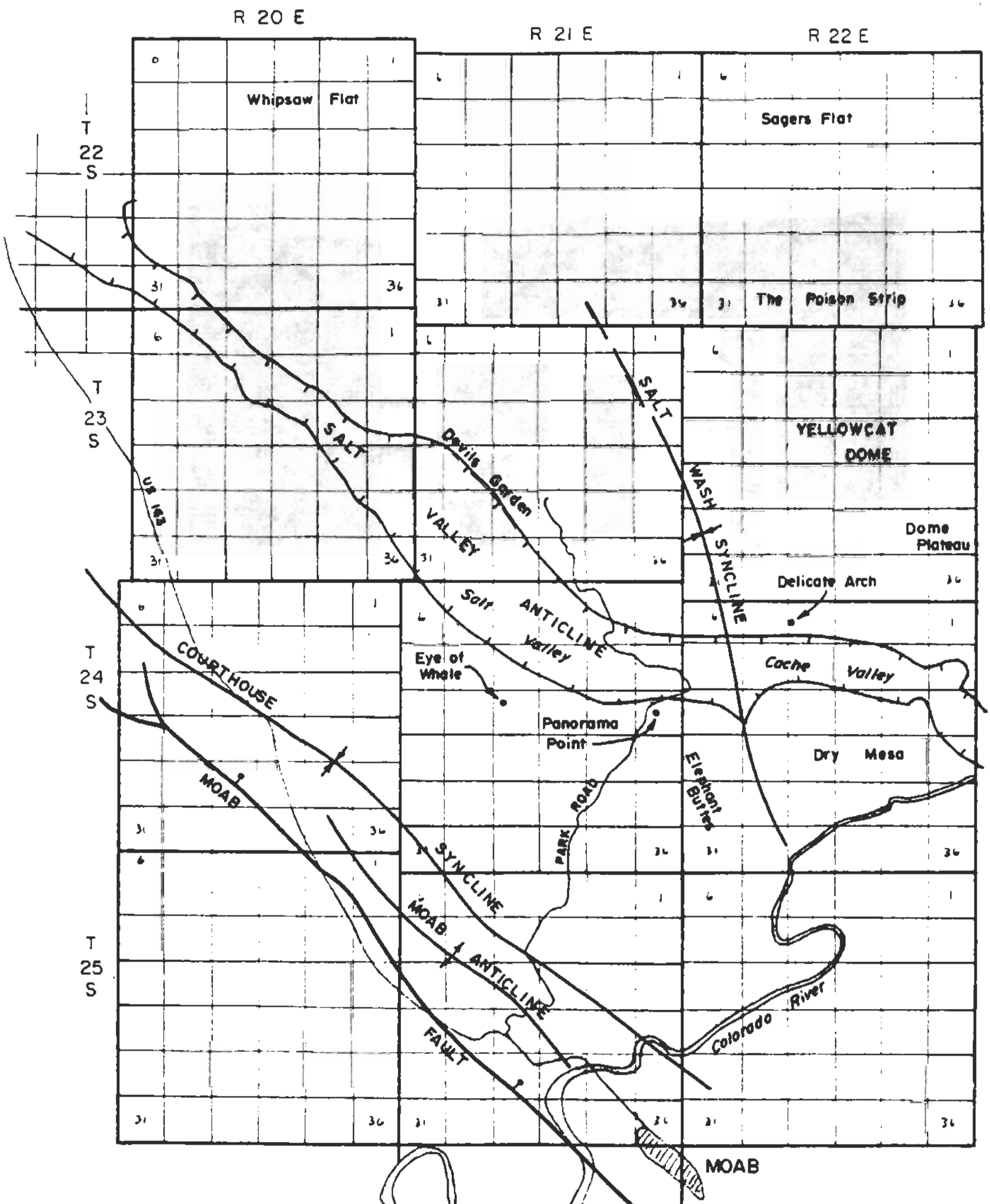


Figure 3. Principal structural elements of the Salt Valley anticline region.

Photo 9. View looking northerly along the west flank of the Moab anticline showing a doubly plunging knick-line collapse syncline adjacent to and parallel to the Moab fault.

The wash flows across the Cretaceous units to the northwest, then crosses units stratigraphically downward, just reaching the top of the Triassic Chinle Formation before flowing into the Colorado River at the north end of Moab Valley.

A salt anticline, such as the Salt Valley anticline, is a very complex structure and the Salt Valley anticline exhibits some additional complexities as well. In the northwestern part of the area it is a characteristic salt anticline. The flanks dip gently away from the axial area, which has collapsed as a graben. Within the graben areas are exposures of collapsed units down to the Chinle Formation. These collapsed units are present as faulted blocks, some of which dip quite steeply. In addition, there are exposures of contorted and folded Paradox Formation, which was probably intruded into the anticlinal areas along a narrow (fault?) zone early in the history of the region. The graben has widened considerably as dissolution of salt continued left and right of the narrow intruded zone. As the units break and fold over into the graben an anticlinal axis is formed paralleling the escarpments on each side of the graben.

The graben aligns itself east-west in the eastern part of the area and is crossed by the Salt Wash synclinal axis. In this area the north flank of the anticline is quite different from the south flank. It appears as if the Salt Valley anticlinal axis continues directly southeastward instead of paralleling the graben and that the axis continues along Elephant Buttes, which indeed it seems to do and then to the east, allows the Salt Wash synclinal axis to cross the graben at right angles. The north flank escarpment of the graben is not as well defined as that of the south flank. Collapse occurs along faults that parallel the graben, which becomes progressively deeper as the graben is approached. All of the collapsing blocks dip into the Salt Wash syncline as well as into the graben. There is a master fault along the south rim, which dips northward, placing the Triassic Chinle against the Cretaceous Mancos Shale for 3,000 ft of displacement. South of the south escarpment, "above" the graben are a series of east-west trending synclines that have less collapsed shallow anticlines between them, known as the Elephant Butte folds. These plunge toward the Salt Wash syncline. The anticlines are often sharp and marked by an axial fault. In addition, there are also a few very short doubly plunging synclines a few miles east and west of the Salt Wash syncline that parallel the Elephant Butte folds.

As the strata dip from Devils Garden into the Salt Wash syncline they are occasionally cut by northwest trending short faults with minor displacement. To the east the beds rise gradually onto Yellowcat dome and the Dome Plateau. The dip of strata north of the Poison Strip is gently northward into the Uinta Basin.

STRUCTURAL FEATURES OF THE SALT VALLEY ANTICLINE REGION:

Hydrologic Features:

Most of the folds and faults associated with the Salt Valley anticline and Cache Valley are associated with collapse as uppermost salt beds in the Paradox Formation are dissolved by ground water. These features are best developed in the graben areas, but extend for a mile or two on the flanks. Dissolution of salt is dependent on ground water flow which is quite uneven. The unevenness indicates that avenues, by which the ground water reaches the top of the salt is related to structural breaks in the aquicludes, such as fault zones and prominent fracture zones. The deepest collapse has occurred along the principal drainages. There are only two such drainages, the most important of which is Salt Wash. The presence of Salt Wash is controlled by the Salt Wash syncline which channeled the drainage across the old narrow belt of disturbed rock along which the local plugs of the Paradox Formation had emerged in pre-Chinle time. Some of the water from the through-going stream found subsurface avenues to the salt, beginning the dissolution (or re-establishing it). The collapsing area channeled other drainages to it, usually paralleling the old salt structures, and these in turn provided water for the dissolution process. Collapse then proceeded headward along the tributary streams. To the northwest, Thompson Wash and its tributaries cross the Salt Valley anticline and evidence is present for a complex collapsed zone, but presently most of the structures are buried by colluvium.

The thick colluvial cover in and around Thompson Wash shows no evidence of recent collapse and none has been observed in historical times in the area of Salt Wash and its tributaries. This suggests that today's climate, which is dry, does not provide enough water to actively keep the process going. Indeed most washes are dry except after a torrential desert rain. The torrential rains are quite effective in eroding the land, but the resultant runoff is too short-lived to maintain an active ground water flow. Most of the active collapse occurred in Late Tertiary and Pleistocene times when wetter climatic conditions prevailed.

Structural Features:

The structural features along a salt anticline cannot be adequately described without some reference to the geologic history in which they were created. All of the details of the history are not yet clear, but the following postulated series of events will help in understanding the region's structural features. Briefly, the position of the northwest-trending salt structures was fixed by faults of tectonic origin, along which subsidence occurred to produce the Paradox Basin. The greatest subsidence occurred in the northeastern part of the basin adjacent to the emerging Uncompahgre Uplift. Somewhat thicker accumulations of sediment and evaporites probably collected along faults (downdropped sides)where greater subsidence was occurring. These linear belts of somewhat increased deposition became focal points of anticlinal formation for the intermittent tectonic activity that followed.

From Late Pennsylvanian to Triassic time there were intermittent rejuvenations of the faulting that had created the basin. The faults were often absorbed in the thick salt and anticlines formed over them with broad synclines being formed between them. That the movement was intermittent is attested by the truncation of formations (not decreased sedimentation) over the anticlinal areas. The same truncated units are complete and often thicker (increased sedimentation) in the synclinal areas. It is believed that during such tectonic events the salt in the anticlinal area was thickened while the salt in the synclinal areas was thinned. The forces are attributed to either compression related to tectonic activity or differential loading of the accumulating body of sediments. The salt was probably mostly moved by recrystallization, since the extensive deformation of "toothpaste-squeezed" salt is only present along very narrow zones along the anticlines. An exception to the idea that post-salt formations are thick in the synclinal areas and truncated or thin in the anticlinal areas is present in the Salt Valley anticline region, notably at the east end of Cache Valley. The Moenkopi and Chinle Formations are usually thinned or missing over the salt anticlines, but are overly thick where Cache Valley joins Professor Valley. An answer may be that the paleo-anticlines were not always aligned exactly the way the modern ones are. The thicker sections occur where the salt structure trends east-west, rather than northwesterly.

Late Triassic and post-Triassic units were generally deposited over the entire area and not removed over the anticlines. Only locally, along the narrow zones where the Paradox had been domed upward to form some relief,were they not deposited. Generally, the overlying units lap onto these domes, and show little or no deformation. Some of the units were deposited terrestrially and local dissolution of salt may have occurred, involved sediments may have been deformed by collapse.

All of the units were regionally folded and faulted after deposition of the Late Cretaceous Mancos Shale, perhaps as late as Eocene time (Early Tertiary).

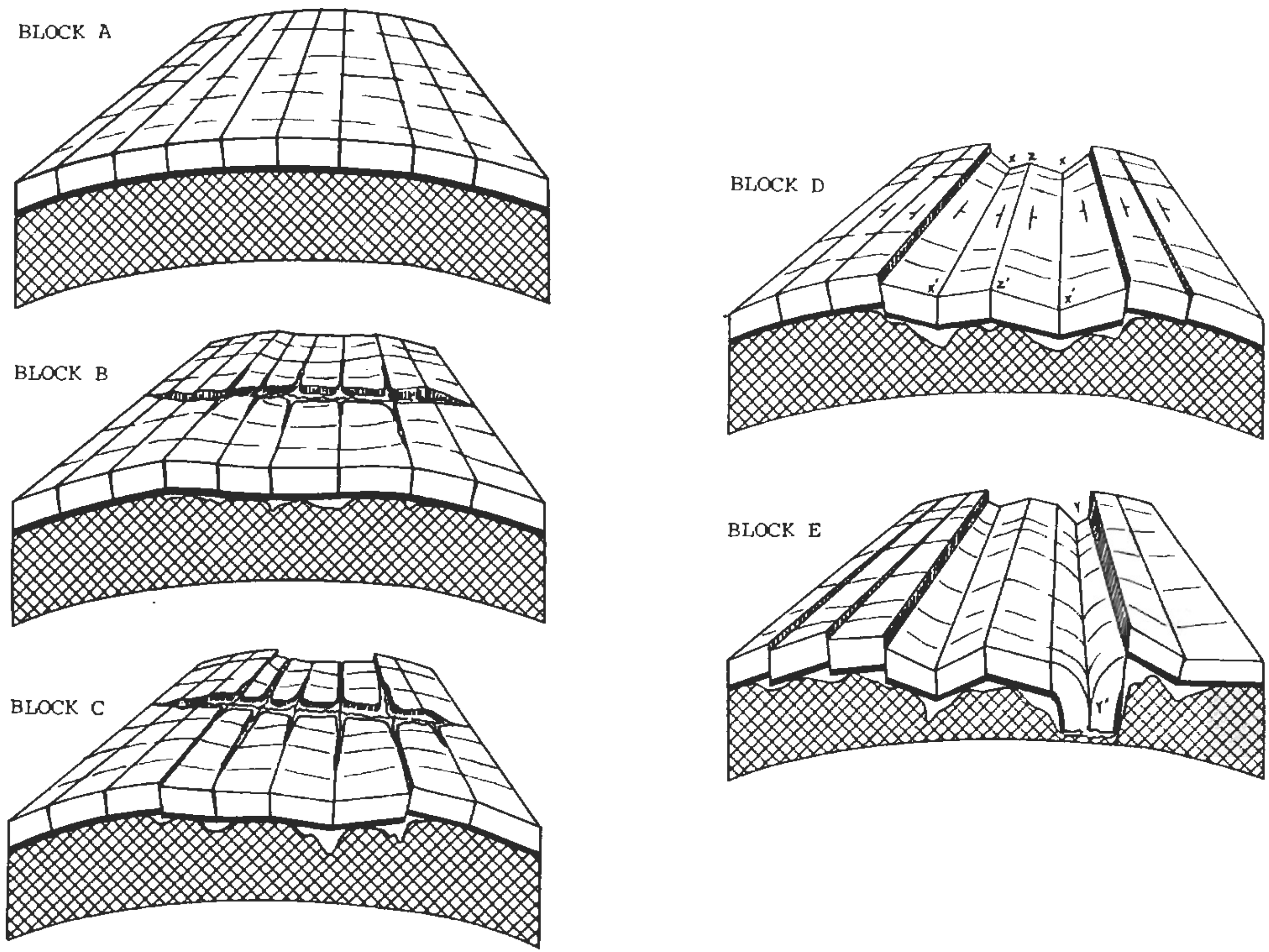
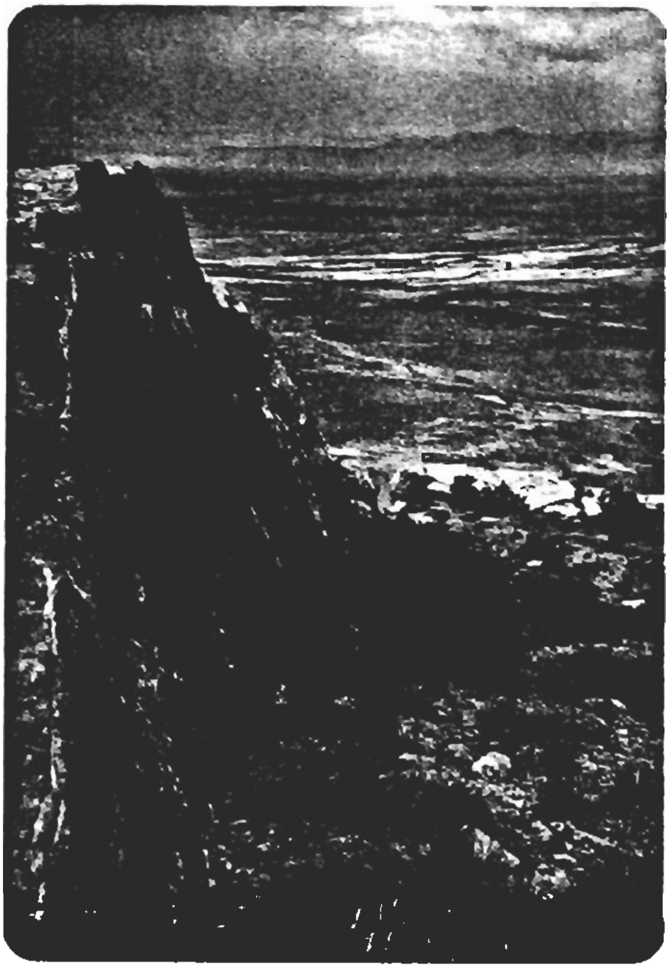


Figure 4. Diagrammatic block diagrams across the axial portion of a salt anticline (see text for explanation).

The deformation deepened the old synclines and elevated the old anticlines and faulting caused considerable displacement of all involved units (Moab fault). In Late Tertiary time the Colorado Plateau region was epeirogenically uplifted and the ancestral Colorado River system began to carve out the topography, attacking differentially the hard and soft stratigraphic units and the old lines of weakness. During wet climatic periods, ground water found many natural conduits to the upper salt units causing its dissolution, which was then marked by collapse, especially in the faulted anticlinal areas.

During dissolution, salt is removed from the top of the salt sequence by the ground water and subterranean voids are created. As the voids increase in size the overlying strata begin to sag into them, to fill the open spaces. Figure 4 shows five diagrammatic blocks, each representing a segment across the axial part of a salt anticline (one underlain by thick salt). In the diagrams the strata are represented as a single fractured prism with a heavy dark line at the base overlying massive salt (cross-hatched). In reality the strata overlying the salt are quite varied in their properties (competency) and the salt itself is found in several cyclical beds separated by layers of anhydrite and shale. Detail was omitted to maintain simplicity. Fractures created during the uplift of the anticline generally parallel its axis (blocks A and B) and can act as conduits for ground water, especially if a through-going permanent stream (superposed) cuts the structure perpendicularly (blocks B and C). The stream feeds the ground water system as it erodes the strata above the salt, so that local collapse can ensue. Subsequent drainages then develop laterally and parallel to the anticline drawing additional tributary water to it along the lines of weakness (fractures).

As the collapse deepens, some of the fractures become faults (block C). At first the movement along these faults is slight. Rather than each side of the fault moving relative to the other, it is more of a bending fault or knick-line. Down-



Photos 10 and 11. Views of two faults in the Salt Valley anticline region, both downthrown on the right. The left photo fault exhibits slickensides, the polished surface left after one block slides adjacent to the other.

ward bending knick-lines become synclinal knick-faults (x-x', block D). If the area between two such synclinal knick-faults (z-z', block D) experiences considerably less dissolution it becomes an anticline, which can also be faulted, creating an anticlinal knick-fault. If this linear dissolution progresses deeply, the strata tilt more and more, and as they do so, can drop nearly vertically into the void (y-y', block E). As the strata become very steeply tilted, bedding faults develop allowing the individual beds to slide into the void as a deck of cards. An example of shallow dissolution is found south of Cache Valley (Elephant Buttes-Dry Mesa area) and an example of deep dissolution is found in the graben of Cache Valley itself.

GEOLOGY OF THE ELEPHANT BUTTES-DRY MESA AREA

The Elephant Buttes-Dry Mesa area is located between Cache Valley on the north and the Colorado River canyon on the south, east of Panorama Point or Elephant Buttes from Panorama Point for a distance of 6 or 7 miles. The maximum north-south dimension is about four miles. The Salt Wash drainage flows southerly across the area into the Colorado River.

Exposed stratigraphic units are mostly Triassic and Jurassic in age ranging from the Moenkopi Formation to the Entrada Sandstone (figure 5). As expected, the older units are exposed in the deep canyons and adjacent valleys, and the younger units are exposed on the high mesas. The Entrada Sandstone is found making up the Elephant Buttes, at the highest elevation of the area. Although many of the units have not yet been measured, these formations appear to be of normal or greater than normal thicknesses. A partial measurement of the Moenkopi Formation in the SW¼ of Section 19, Twp. 24 South, Rge. 23 East, indicates the presence of at least 840 ft, which is overlain by 670 ft of Chinle Formation (east edge of area). In the NW¼, NW¼ of Sec. 4, Twp. 25 South, Range 22 E., just south of the mapped area, an incomplete Chinle exposure was 694 ft thick. Both of these units are

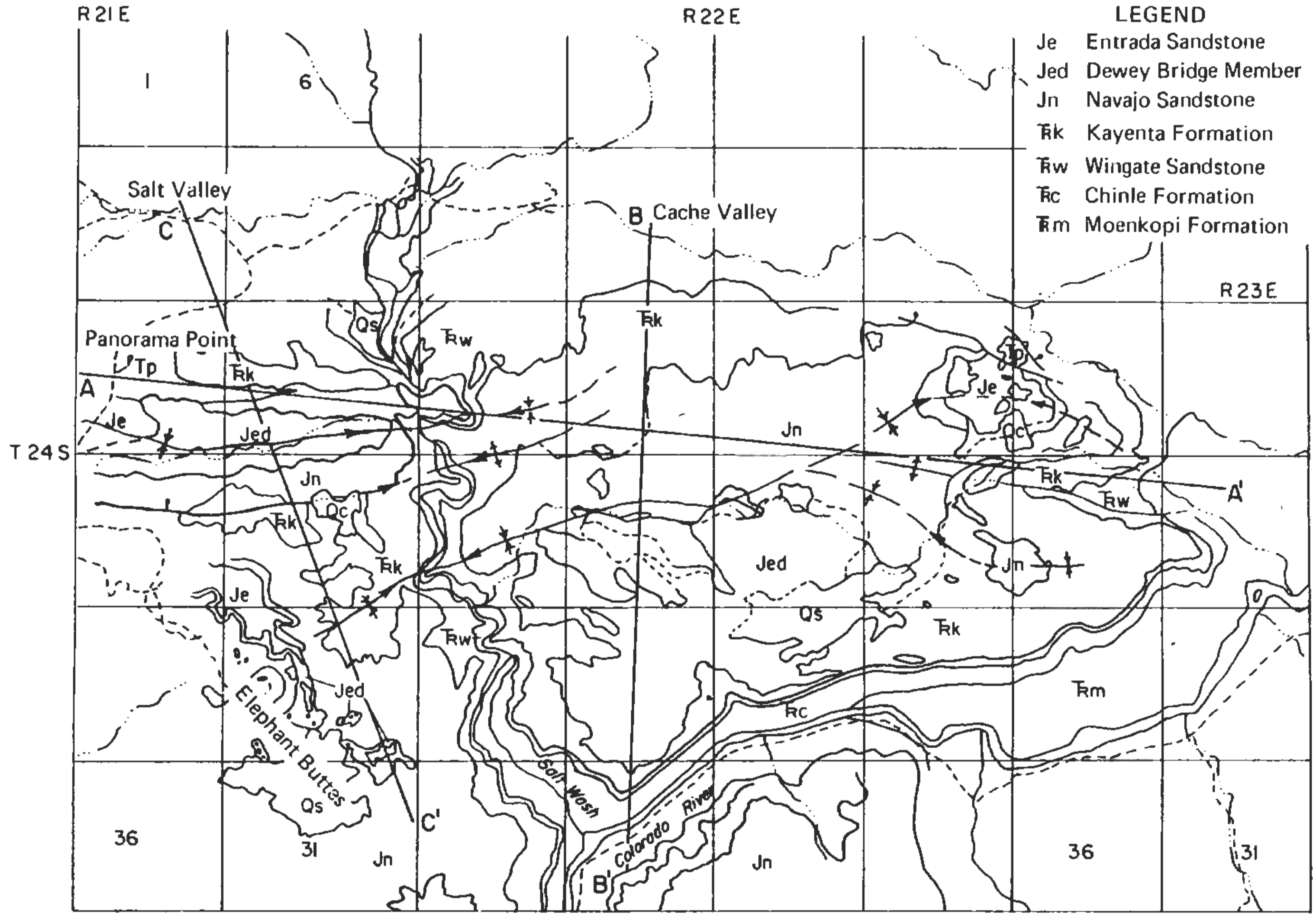


Figure 5. Preliminary geologic sketch map of Elephant Buttes-Dry Mesa Area.

considered to be thicker than expected. Stratigraphic sections of all units are to be measured as part of future studies.

The principal structural elements of the area trend roughly east-west, paralleling the Cache Valley graben to the north. These consist of three folds or knick-lines known as the Elephant Butte folds, first described by Dane(1935). Except for one small place to the northeast on Dry Mesa, all of these folds plunge toward the Salt Wash canyon and the steepest plunge occurs from the eastern, Dry Mesa side (cross-section A-A', figure 6. Each of the two synclines and intervening anticline cross the canyon. The northernmost fold is a syncline with a steep northern flank and a gentle southern flank. The fold flattens out only a mile east of Salt Wash along with the anticline to its south. The syncline continues westerly out of the area. Between Panorama Point and Salt Wash a tributary wash marks the synclinal axis. The youngest unit exposed in the syncline is the Entrada Sandstone.

The medial anticline develops quickly and plunges steeply from a point one mile east of Salt Wash westwardly across the Salt Wash canyon, from whence it continues westwardly out of the area after reversing its direction of plunge. Between Panorama Point and Elephant Buttes it is a knick-line fault (cross-section C-C', figure 6). Both flanks are normally quite gentle, except just north of Elephant Buttes where the north flank exhibits dips up to 15 degrees while the south flank probably does not exceed a dip of 3 degrees. On Dry Mesa (cross-section B-B'), the longer and steeper dip is to the south. On the Elephant Buttes side of Salt Wash, where the fold is a knick-line fault, there has been some downward displacement on the north-side as well. Erosion on the axis has proceeded down as far as the Kayenta Formation.

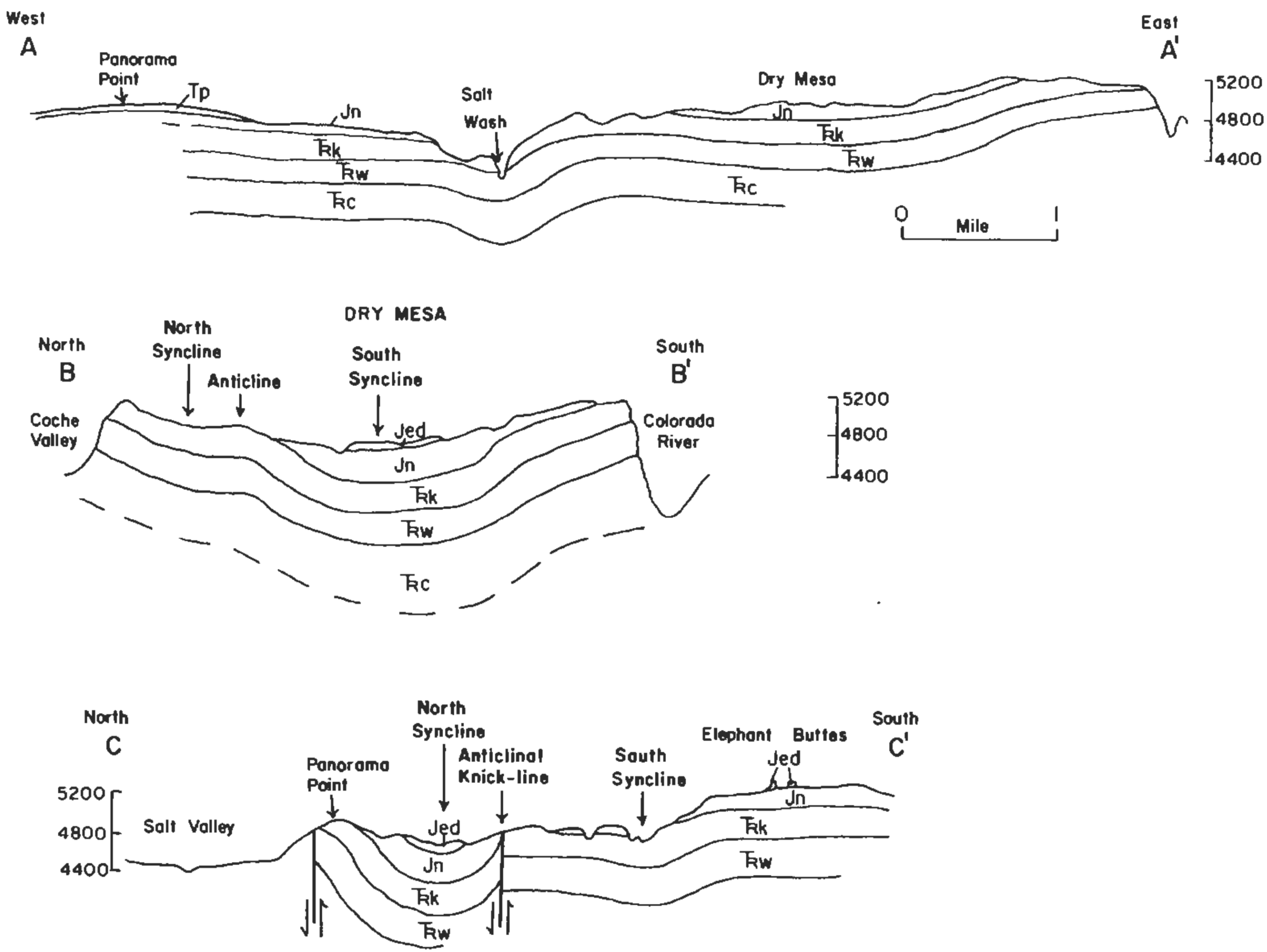


Figure 6. Structural cross-sections of the Elephant Buttes-Dry Mesa Area.

Whereas the north syncline and medial anticline are better developed west of Salt Wash, the south syncline is better developed on the eastern, Dry Mesa side. The axis develops just east of Elephant Buttes and extends eastward across Salt Wash canyon, and after reversing its plunge, continues across the full extent of Dry Mesa. After about 2½ miles on Dry Mesa, the axis bifurcates into a north and south branch and a new, intermediate anticline forms between them. The Dry Mesa principal drainage marks the synclinal axis and where the axis bifurcates the drainage branches as well. The dips are mostly gentle and symmetrical on both flanks, but the trough is broad and easily noticeable. There is a pronounced sag along the north branch axis, which extends for about a mile, which locally reverses the plunge direction. Some Entrada Sandstone is preserved in the sag. The anticlinal fold between the branches has developed into another knick-line fault, with a steeper north flank. Diagrammatically the Elephant Buttes-Dry Mesa area is best exemplified by block C of figure 4.

GEOLOGY OF A SMALL PART OF CACHE VALLEY

Cache Valley is defined as that part of the salt graben located east of Salt Wash or the Salt Wash syncline (figure 3). The valley is about 6 miles in length (east-west) and about a mile wide. The principal drainage is by Cache Valley Wash, which drains westerly along the entire length of the valley into Salt Wash. Winter Camp Wash flows into Cache Valley from the northeast about a mile before it also flows into Salt Wash. In the mapped part of the valley or graben, a north escarpment is not clearly defined, the elevations are lowered through a series of smaller cliffs. East-west trending ridges are found in the valley floor and the well-developed south escarpment has a maximum relief of about 700 ft.

All of the formations younger than the Moenkopi are exposed in the valley or graben and all have participated in the folding and faulting accompanying rather deep collapse. The thickest exposures of each unit appear to be of normal thickness for the region. There are many thin exposures, however, but these can best be explained by the presence of bedding faults (figure 7) or deep knick-line faults. The strata strike east-west and essentially the exposures pass from older to younger from north to south until just before the south escarpment is reached. Thus the Triassic Kayenta and Jurassic Navajo and Entrada formations are exposed along the north edge of the valley, the Morrison Formation members are exposed in the middle of the valley, and the Cretaceous units are found along and just north of the south escarpment. The base of the south escarpment, in the mapped area, exposes the Chinle Formation (and perhaps some Moenkopi Formation) above which the Wingate and Kayenta formations are to be seen.

The structure of Cache Valley is complex considering the degree of faulting and folding brought upon by the deep dissolution of salt. Beds are found from horizontal to vertical position. Faults and fold axes generally parallel the valley or graben. The deepest collapse occurred beneath or near the present position of Cache Valley Wash and Salt Valley Wash. In its westerly flow toward Salt Wash, Cache Valley Wash first flows along the north edge of the graben (area not shown on geologic map, figure 7), then flows diagonally across the graben to the south edge. Since the principal fractures or weakness zones occur along the edges, these places exhibit the deepest collapse. Figure 8 illustrates the structural features of Cache Valley in simplified form and shows the locations of the more deeply collapsed areas. As the deeply collapsed zone along the south edge of the graben draws nearer to Salt Wash it appears to move into the middle of the valley. Exposures of colluvium are found between the escarpment and the known collapsed area, but this colluvium is believed underlain with Moenkopi or


Jem
Je
Js
Jmsw
Cabin Wash
Winter
Qa
Qc
Jmbb
Kbc
Kd
Kml
Kmf
Kmu
Salt Wash
Cache Valley Wash
Wash
Salt

la-

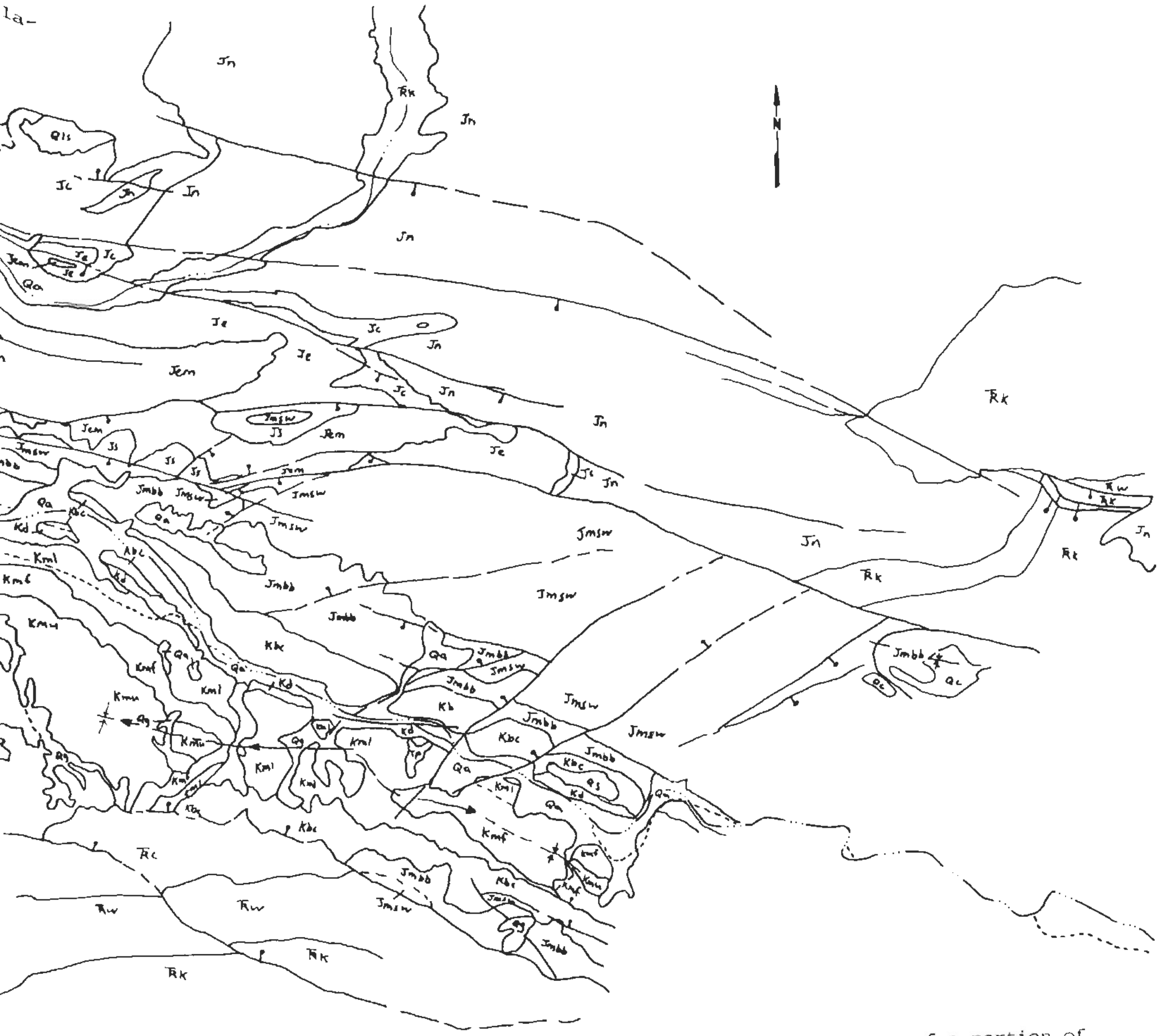


Figure 7. Geologic map of a portion of Cache Valley, scale approximately 1:12,000 (1"=1000 ft).

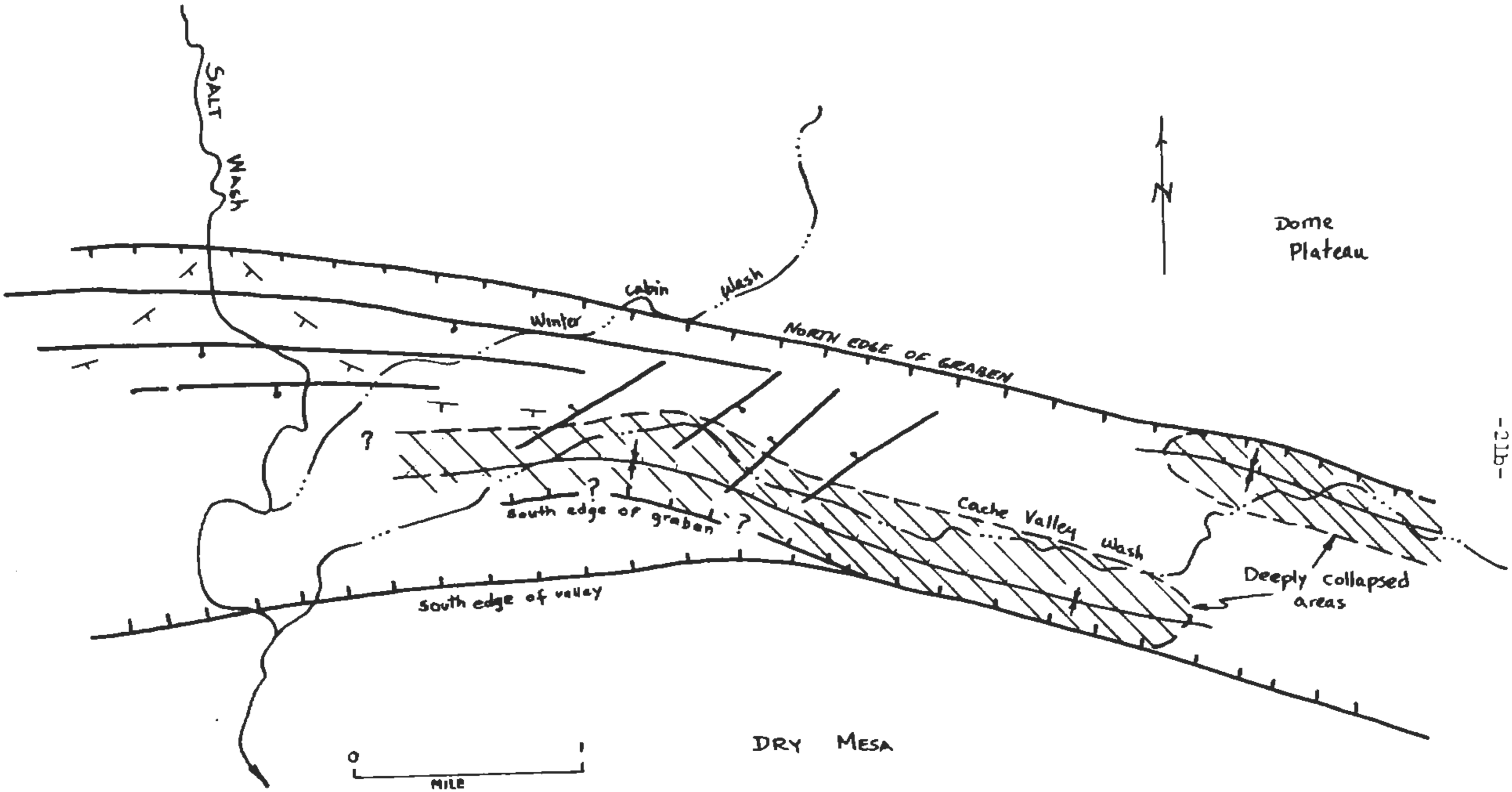


Figure 8. Simplified structural features of Cache Valley.

Chinle Formation. The escarpment at this location is thus probably eroded back from the zone of weakness or major fault. Numerous bedding faults accompany the deeply collapsed zones and in many places there is a synclinal knick-line fault running through the middle along strike.

A series of east-west faults are crossed by the Salt Wash drainage immediate: after entering the graben area. Each one lowers the strata toward the deeply collapsed zone. The amount of displacement often increases in the direction of the wash. The blocks between the faults dip southward, but have a component towa: the drainage. Another series of faults, somewhat to the east of Salt Wash have a northeasterly trend and exhibit comparatively small displacements, mostly down to the northwest.

GEOMORPHOLOGY OF SALT WASH

Salt Wash is a drainage with a complex geomorphological history. The wash has its beginnings with a number of tributaries heading on the Mancos Plain just beneath the Book Cliffs. None of these tributaries head in the high Book Cliffs area. Most of the tributaries are joined near the Yellow Cat area of the Thompson uranium district where the wash cuts into the Entrada Sandstone and enters an alluvium-filled valley, which widens to as much as a half-mile. At present the wash is cutting through this alluvium. This wide valley narrows to a gorge just before entering the Cache Valley-Salt Valley graben as the hard Moab Tongue of the Entrada Sandstone dips down to drainage level in response to salt dissolution collapse. In the graben area the wash meanders across a broad alluvial area and then cuts a narrow and deep canyon across the Elephant Buttes-Dry Mesa area to the Colorado River. The narrow and deep canyon is complete with incised meanders as if it had been a major through-going superposed stream (figure 9).

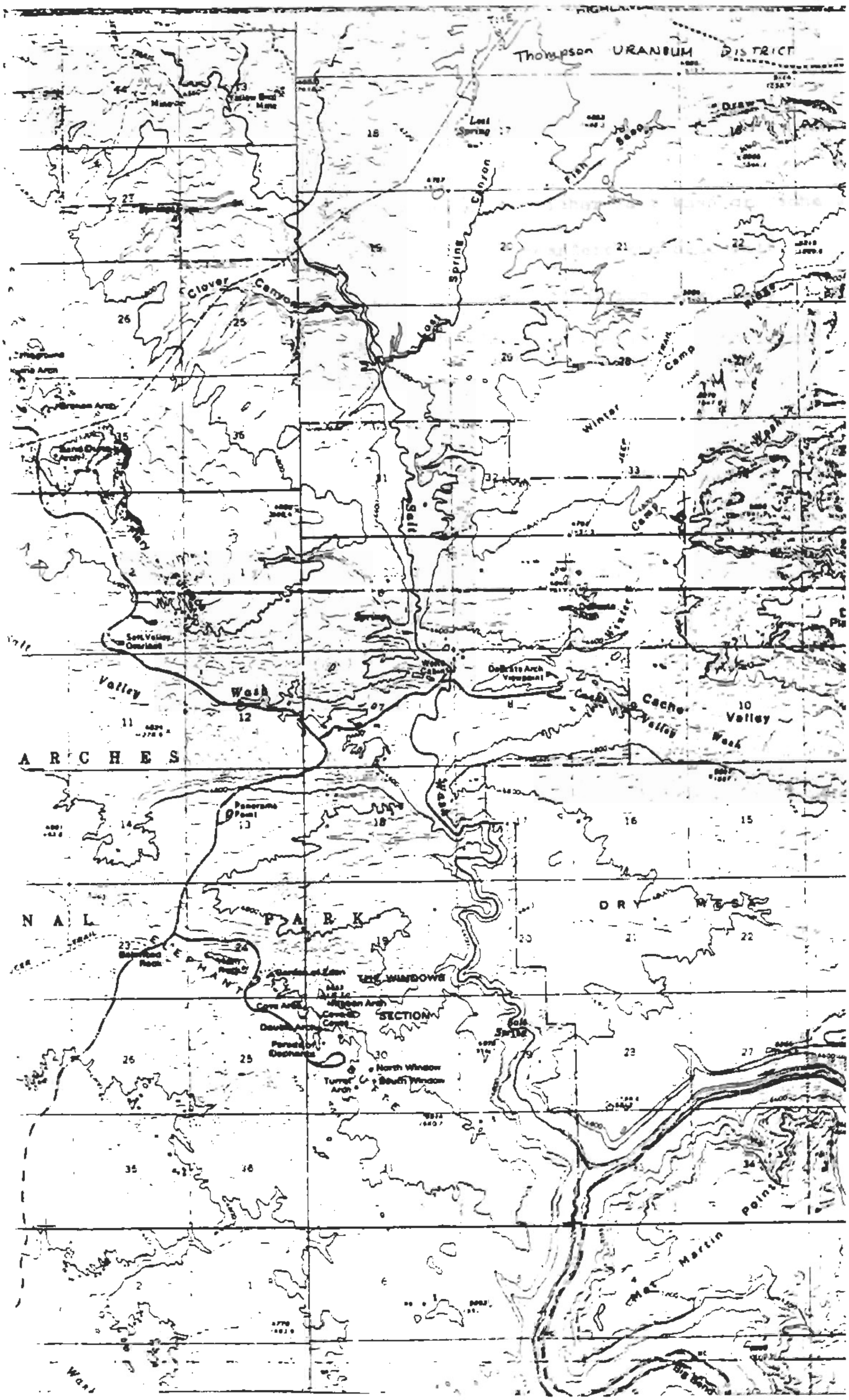


Figure 9. Topographic map of the Salt Wash showing its drainage course to the Colorado River from the Thompson uranium district (just to the north). See text for discussion of geomorphology. Scale is 1:50,000, from U. S. Geol. Survey Arches National Park special topographic map, 1974.

At present there is not enough water in either Salt Wash or Cache Valley Wash to cause the erosion of the entrenched meanders and deep salt dissolution collapse. At some time in the past, climatic conditions must have been much wetter than now, or the drainages must have been connected with lengthier ones capable of providing larger amounts of water.

GEOLOGIC PROCESSES OF THE SALT VALLEY REGION:

Geologic mapping in the Salt Valley-Cache Valley area has revealed that various geologic processes have been operative at various times during the geologic history of the area. The area was first subjected to tectonic forces which created the Paradox Basin along northwesterly trending faults some 300 million years ago. Continued working of these faults occurred intermittently in succeeding geologic time. This activity caused the development of northwest trending anticlines and synclines in the region and caused the salt to be thickened in the anticlinal areas, either by causing differential depositional loading on the salt or by tectonic compression. The last recognized tectonic activity that deepened the synclines and elevated the anticlines occurred in Eocene time (40-60 million years ago) and was accompanied by faulting. There is no field evidence that such activities took place thereafter or are active now.

Geologic investigations of surrounding areas indicate that the Salt Valley anticline region was probably being blanketed with sediments well into Early Tertiary time, but that the area was elevated thereafter. This, of course, caused sedimentary deposition to cease and instigated a regimen of erosion which persists to the present. The Salt Valley anticline region is being deeply incised and actively eroded even under the present relatively dry climate. The few rains are usually torrential and local in nature and the washes quickly fill with water only to dry out again after a few hours. But while they flow they clear out much accumulated debris and widen or deepen channels. These torrential intermittent floods are not very effective in recharging subsurface aquifers, however, so that their effectiveness in providing water to dissolve subsurface salt is probably negligible.

Surface mapping of the salt structure appears to substantiate the fact that little or no collapsing of strata is presently occurring. At various levels throughout the region are remnants of colluvial deposits, now being actively destroyed by erosion. Most of these relatively recent deposits show little sign of having participated in collapse. On Dry Mesa, at the south edge of Cache Valley, one such patch of colluvial material appears to have been broken by a collapse fault. Thus it is assumed that dissolution of salt can occur locally wherever a sufficient amount of ground water finds conduits to it.

CITED REFERENCES:

BAKER, A. A., 1933, Geology and oil possibilities of the Moab district, Grand and San Juan Counties, Utah: U. S. Geological Survey Bulletin 841, 84p.

DANE, C. H., 1935, Geology of the Salt Valley anticline and adjacent areas, Grand County, Utah: U. S. Geological Survey Bulletin 863.

DOELLING, H. H., 1981, Stratigraphic investigations of Paradox Basin structures as a means of determining the rates and geologic age of salt-induced deformation-a preliminary study: Utah Geological and Mineral Survey Open-file Rept. No. 29.