GEOLOGY OF ARCHES NATIONAL PARK

by
Hellmut H. Doelling

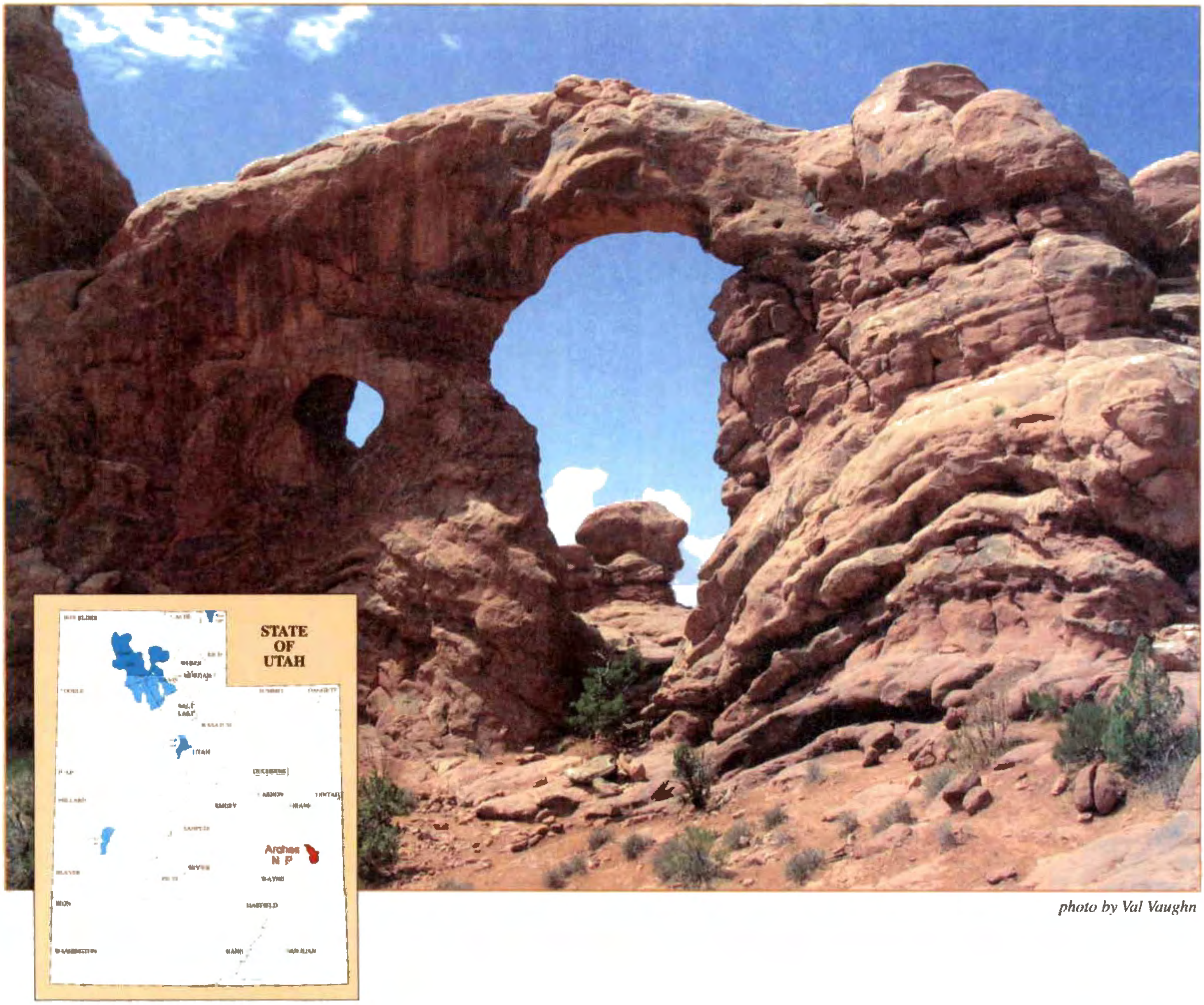

photo by Val Vaughn

MAP 74
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UTAH GEOLOGICAL SURVEY

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UTAH GEOLOGICAL AND MINERAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
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UTAH GEOLOGICAL AND MINERAL SURVEY

606 Black Hawk Way
Salt Lake City, Utah 84108-1280

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GEOLOGY OF ARCHES NATIONAL PARK

By Hellmut H. Doelling[1]

INTRODUCTION

Arches National Park has an unique variety of well-exposed and colorful rock formations. It is located in the Paradox Basin of the Colorado Plateau Physiographic Province which lies in parts of four western states: Utah, Colorado, Arizona, and New Mexico. The Paradox Basin straddles the Utah-Colorado State line in the north central part of the physiographic province and is an area in which thick beds of rock salt were deposited some 300 million years ago (mid-Pennsylvanian time). This salt is older than the rocks exposed in the park.

Rock salt has many unique properties. Unlike other rock materials, for example, it is both plastic and soluble. These properties have greatly influenced the subsequent geologic history of the area, especially in the deep part of the basin in which Arches National Park is found (fig. 3). This area is characterized by northwest-trending "salt anticlines" which appear at the surface as valleys bounded by escarpments or cliffs. Examples of such valleys include Salt Valley and Cache Valley inside the park and the valley in which the town of Moab is found (Moab Valley-Spanish Valley). The arches and fins of the national park are mostly located on the cliffs adjacent to Salt Valley and Cache Valley. These, and the other landforms of the area, are mostly reflections of the effect of subterranean salt flowage and dissolution on the surface rocks. Arches National Park has the greatest concentration of natural rock arches in the world (Lohman, 1975, p. 40), but this would not have been possible without the presence of salt.

GEOLOGY AND ARCHES NATIONAL PARK

The attractions of Arches National Park are based on geologic phenomena and an increased understanding of its geology can significantly add to the visitor's enjoyment. The geologic map is designed to assist in identifying and locating the rock formations, the axes of anticlines and synclines, and the alignments of faults. Because these rock units and structural features are so well exposed in the park, the visitor can graphically visualize what has transpired in the geologic past. Arches National Park has not only a great accumulation of arches and fins but, more than in any other park, it displays the features of salt dissolution and flowage on a grand scale. Many of the rock units found at Arches are also present in the other Utah national parks and monuments. Additional geologic information about Arches National Park can be obtained from the books and pamphlets listed under the references.

GEOLOGIC HISTORY AND ROCK FORMATIONS

The descriptions of the individual rock formations found in Arches National Park are given on the map and the geologic events that have left their mark on the area are summarized in figure 4. The rock formations are classed as sedimentary rocks by geologists and represent accumulations of sediments (clay, silt, sand and gravel) and chemicals (salt, gypsum, limestone and dolomite) that were deposited by water, wind, and gravity. As the sediments and chemicals piled up they were, in time, cemented together as hard rock by geologic processes. The thickness of this accumulation of sediments, including the salt, amounted to more than 15,000 ft. and was deposited in a period of time spanning 210 million years, ending about 80 million years ago (Late Cretaceous). The deposition of sediments was intermittent, and during non-depositional periods some erosion probably occurred.

LATE PALEOZOIC TIME, 360-245 MILLION YEARS AGO

The Paradox Basin was created 300 million years ago when long northwest-trending faults appeared and downdropped rock surfaces. Faults are ruptures or fractures in the earth's crust along which one side moves relative to the other (figs. 5, upper block, and 6). This formed an asymmetrical depression, deepest to the northeast, where it ended sharply against the

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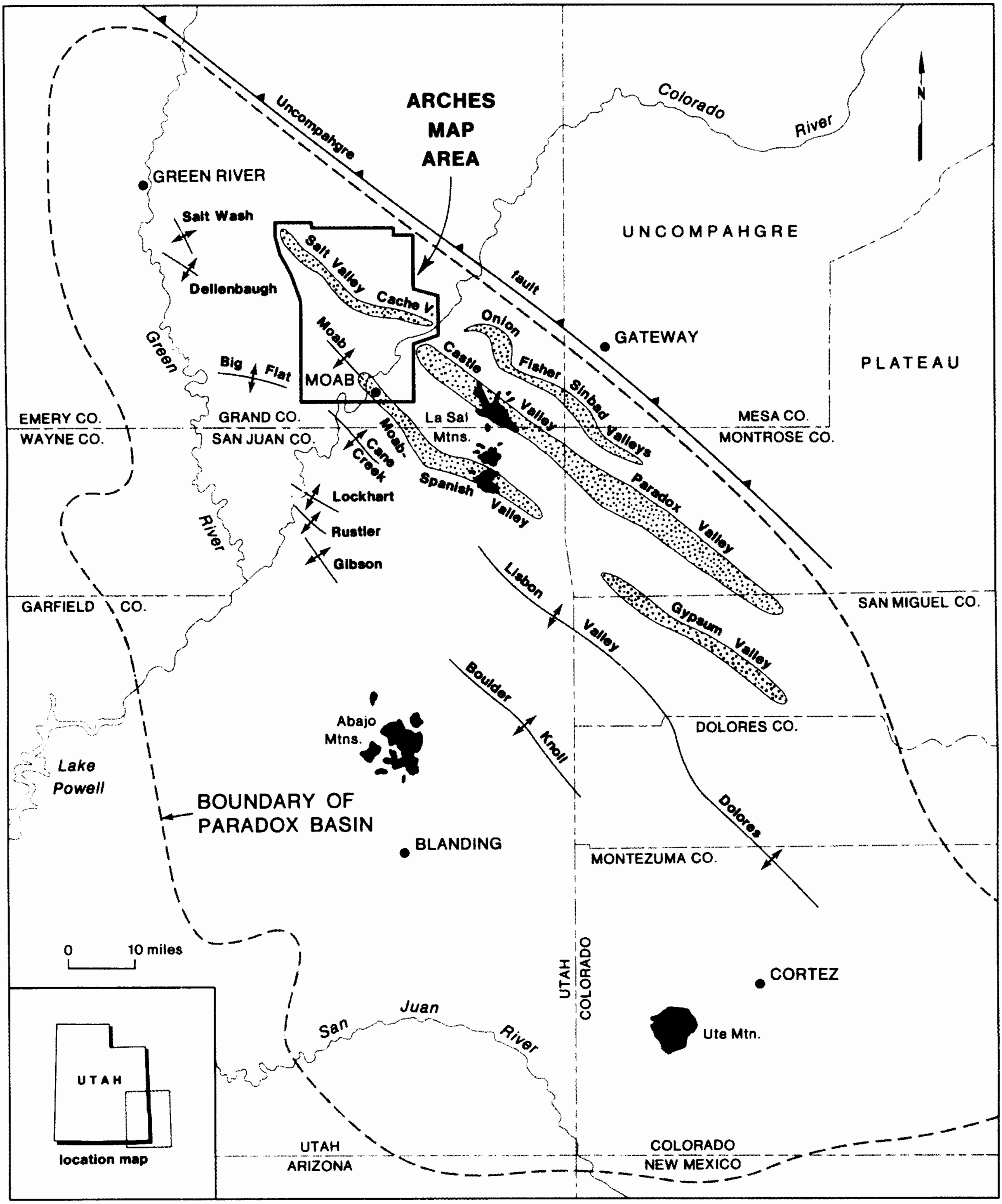

FIGURE 3. *Location of Arches National Park geologic map and the Paradox Basin in Utah and Colorado. Stippled areas show locations of salt anticlines with collapsed crests (salt valleys). The axes of uncollapsed salt anticlines are simply shown with standard anticlinal symbols (see map legend). Paradox Formation salt underlies the entire area within the boundary of the Paradox Basin.*

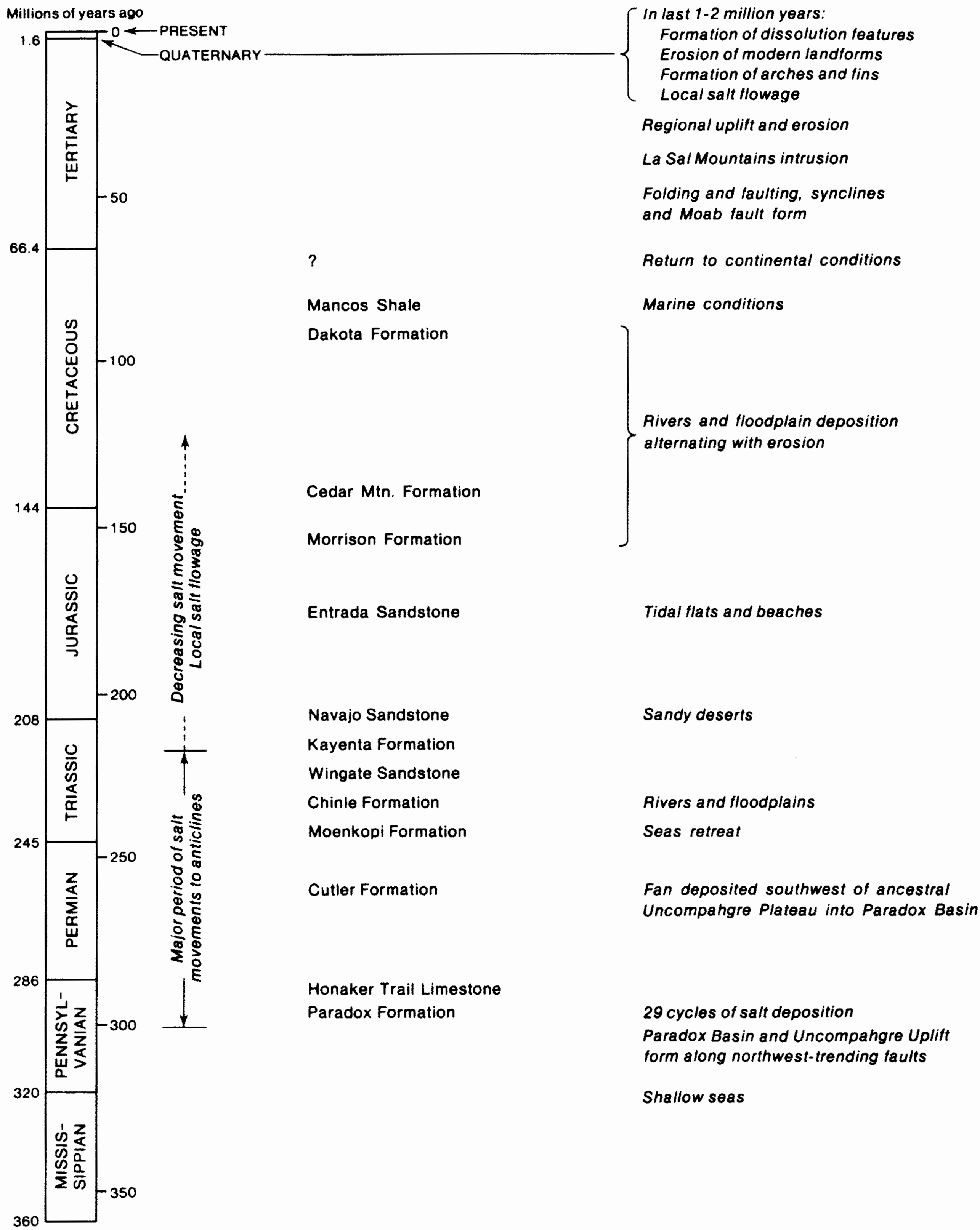

FIGURE 4. *Table relating rock formations and important geologic events of Arches National Park with geologic ages and time.*

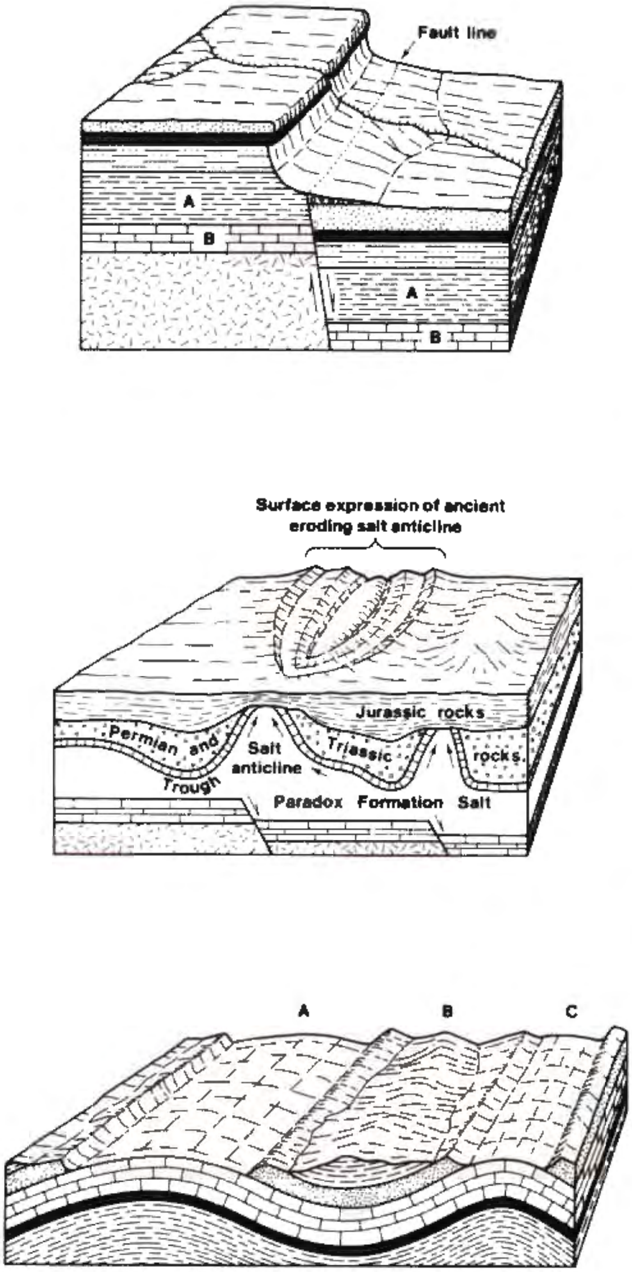

FIGURE 5. *Block diagrams of folded and faulted rock strata. The* ***upper block*** *illustrates a simple (normal) fault. Rock strata, identified by patterns and by the letters A and B, are downdropped on the right hand side of the fault. The* ***middle block*** *shows the formation of early salt anticlines and adjacent troughs and explains why some geologic formations are locally thick, thin, or missing. The* ***lower block*** *shows rock strata folded into two anticlines (upfolds A and C) and a syncline (downfold B). Synclines do not necessarily form valleys and often preserve younger rocks that are eroded from the anticlines.*

FIGURE 6. *Rock fault along Utah Highway 191 opposite the Arches National Park Visitor Center. The dark layer left of the fault has been displaced downward about 10 ft to the right. This is a branch fault of the more important Moab fault which parallels the highway at this location. The Moab fault displaces rocks as much as 2,600 ft.*

Uncompahgre Uplift, being simultaneously elevated along another set of faults.

Before the basin was formed, the area was covered by a shallow marine sea which precipitated carbonates (limestone and dolomite) to the sea floor. As the floor of the basin was lowered, the margins were elevated so that the sea within the basin was restricted or cut off from the ocean. At first the sea continued to precipitate carbonates, but the warm climate caused rapid evaporation and the salt in the seawater became concentrated. Eventually the sea water became so saturated that salt and gypsum (calcium sulfate) were precipitated to the sea floor. Fresh seawater periodically drained into the restricted body of water. Then a new cycle of chemical precipitation began, first depositing carbonates, then gypsum, then salt. At least 29 cycles of seawater evaporation have been recognized by scientists (Hite, 1960).

The rock formation which contains the salt is known as the Paradox Formation (Ppg and/or Php). It contains 75 to 90 percent sodium chloride (table salt) and the total thickness deposited was originally about 5,000 ft. In the salt anticlines the maximum known thickness is nearly 14,000 ft. (Hite and Lohman, 1973, p. 15). The thickness of salt under Salt Valley in Arches National Park is at least 10,000 ft. In some cases potash salts (valuable as fertilizer) and magnesium salts were deposited as well. The non-salt beds of the Paradox Formation are called "marker beds" because they divide the salt cycles. Salt is nowhere exposed at the surface in the Salt Valley and Moab Valley anticlines, but the marker beds (caprock) are. Caprock is formed as the salt in the upper part of the Paradox Formation dissolves, leaving behind a residue comprised of impurities, especially gypsum, shale, and limestone. The gypsum occurs in contorted masses and is exposed on each side of Moab Valley near the town of Moab and in the middle of Salt Valley along the road to Klondike Bluffs.

As the weight of accumulating sediments over the salt beds increased, the salt flowed to areas of less confining pressure much the same as squeezing toothpaste from a tube. Displacements along the northwest-trending faults created paralleling zones of lower confining pressure to which the salt migrated and thickened. At the same time the salt was thinned in the adjacent areas. This shifting of salt was reflected at the surface as changes in relief, arching the rocks over the thickened salt zones to form anticlines (fig. 5, middle block), and forming troughs in the adjacent areas. As new sedimentary layers were deposited over the region they were thinner over the arched areas and thicker over the subsiding troughs. Consequently these younger formations vary considerably in thickness. At certain times the arching was pronounced enough to elevate the rocks and subject them to erosion. This happened intermittently from the time the salt began to be deposited 300 million years ago (mid-Pennsylvanian time) until about 220 million years ago (Late Triassic time).

After the 29 cycles of salt were deposited, the basin became more stable and it filled up with sediment. The area had a better connection with the open sea to the west, and limestone and dolomite were deposited to form the Honaker Trail Formation (part of Php). Its thickness varies considerably from one locality to another in the Arches National Park area because of salt flowage while it was being deposited. The Honaker Trail Formation is missing in outcrop along much of Salt Valley and Moab Valley. In boreholes between the salt anticlines it is 1000 to 2000 ft. thick and is composed of fossiliferous gray limestone, cherty limestone, and brown and lavender siltstone and sandstone. The best exposures of the Honaker Trail Formation are located opposite the Arches National Park Visitor Center above and below the Denver & Rio Grande Railway tracks. These rocks are at highway level at the bend in U.S. Highway 191 north of the visitor center. Some of the limestones are full of corals, bryozoans, brachiopods, crinoid stems and, in smaller numbers, fusulinids and trilobites.

The Uncompahgre Uplift, located near the present Uncompahgre Plateau (fig. 3), was elevated as the Paradox Basin was downdropped. Large quantities of gravel, arkosic sand, and silt were eroded from the uplift and transported by streams into the sea in which the Honaker Trail limestones were being deposited. Coalescing alluvial fans formed along the margin of the ancient mountains in Pennsylvanian and Permian time. Along the northeast margin of the basin (near the Uncompahgre Plateau), arkosic sandstone, purple and brown siltstone and shale are interbedded with the Honaker Trail limestones.

Eventually the alluvial fan spread out over the whole region to form a large coastal plain with beaches and tidal flats. The rivers that crossed the coastal plain were often diverted from their courses as hills formed by salt flowage formed in their paths, all the while dumping more sediments on the plain. The ancient Uncompahgre mountain mass that was being eroded to supply the sediment consisted mostly of a reddish granite. This deposit is known as the Cutler Formation (Pc) and exceeds 5,000 ft. in thickness adjacent to the highland. It is missing in the cliffs bordering Salt Valley, Cache Valley and Moab Valley, because these were the salt-induced hills during the time it was being deposited in the surrounding low areas. Sand and gravel of the Cutler Formation may have been deposited over the anticlines when the salt was less active, but these sediments were later eroded as the salt activity increased. The red rocks of the Cutler Formation are well exposed in the cliffs on the southwest side of the highway between Seven Mile Canyon and the Arches National Park Visitor Center. The formation reaches a thickness of over 1100 ft. along these cliffs, but the whole unit thins rapidly to zero in outcrops between the visitor center and Moab Valley. The Cutler Formation rocks were deposited about 260 million years ago.

TRIASSIC PERIOD, 245-206 MILLION YEARS AGO

The next geologic formations deposited were the Moenkopi (Trm) and Chinle Formations (Trc). The lower (older) Moenkopi Formation consists mostly of brown fine sands and silts that were deposited on tidal flats. The thin beds of these rocks are commonly ripple marked. The Chinle Formation rock materials were deposited on the flood plains of streams, the sea by this time having retreated westward. Sands and gritty materials filled channels of the ancient streams and rivers between which reddish finer-grained sands, silts, and clays were deposited when the streams flooded their banks. As with the Cutler Formation, salt movements affected the deposition and thickness of the Chinle Formation, but the Chinle sediments finally completely covered the salt.

The Moenkopi Formation is mostly missing above the Paradox Formation in the Salt Valley anticline and is completely missing in the outcrops along the flanks of Moab Valley. At least the thin upper part of the Chinle is exposed along the flanks of both Salt Valley and Moab Valley. The steep slope of the Chinle rises from the valley floor and underlies an impressive sandstone cliff (Wingate Fm.) that forms the valley escarpments. Good exposures of both the Moenkopi and Chinle Formations are found along parts of the canyon of the Colorado River. The basal part of the Chinle Formation, where it consists mostly of gritty channel sandstones, is often mineralized with uranium and has been mined in a few areas around the park.

After Chinle time salt movement in the Paradox Formation slowed down considerably and each of the succeeding stratigraphic units completely covered the salt anticlines as they were deposited. Only locally did hills arise because of subterranean salt movement. However, the overlying Glen Canyon Group of formations is thinner over the salt anticlines and boreholes indicate that it thickens in adjacent areas. The Glen Canyon Group of formations was deposited next and consists of the Wingate Sandstone (Trw), the Kayenta Formation (Trk) and Navajo Sandstone (JTrn). These are the hard rocks that make up the cliffs and the tops of plateaus in a large part of the region. The lower Wingate Sandstone, in particular, forms a prominent cliff throughout the Canyonlands region. These formations are mostly sandstones, the upper and lower units were largely deposited by the wind, either in Sahara-like deserts or on wide coastal areas adjacent to and along beaches. The high-angle sweeping crossbeds in the Navajo Sandstone suggest that the sand was deposited in dunes. The erosional surface of this unit has fascinated viewers, not only at Arches National Park, but at Zion, Capitol Reef, and Canyonlands National Parks. The hummocky, often dome-shaped, cross-bedded outcrops are commonly called frozen or petrified sand dunes. The Kayenta Formation forms a ledgy slope between the Wingate and Navajo and consists of thick lavender or reddish channel sandstones. Occasionally dinosaur footprints are found preserved in these rocks. Shallow lakes or ponds appeared occasionally during the deposition of the upper two units, leaving deposits of thin gray limestones or dolomites. These can be seen on the jeep roads near Klondike Bluffs on the rim of Salt Valley.

JURASSIC PERIOD, 208-144 MILLION YEARS AGO

The upper part of the Navajo Sandstone and two other formations were deposited during the Jurassic period. The two formations, the Entrada Sandstone and the Morrison Formation, each have three distinctive members. The Entrada is perhaps the most important formation in Arches National Park (figs. 1 and 2 - on map), since it is the unit in which most of the arches have formed. An arm of the sea inundated central Utah from the north and the sands of the Entrada represent deposits of tidal flats, beaches, and beach sand dunes. The three members consist of the dark reddish brown and often contorted Dewey Bridge Member (Jed) at the bottom, the orange-brown, sometimes banded, smooth-appearing cliffy Slick Rock Member (Je), and the whitish cliffy rimrock of the Moab Member or Tongue (Jem). The upper surface of the Moab Member forms dipslopes on each flank of the Salt Valley anticline which are prominently marked by joints that parallel the axis of the anticline. The joints are most noticeable from the air or on aerial photographs. The Entrada Sandstone is the cliffy unit exposed on the left side of the main National Park road from the visitor center to Balanced Rock.

Overlying the Entrada Sandstone is the Morrison Formation, an interesting unit which is likely to be overlooked by the casual visitor to Arches National Park. The lower Tidwell Member (Jmt) is a thin, dark red siltstone unit containing large white siliceous concretions. Most of the exposures are on the periphery of the park, but some are found in tilted blocks in Cache Valley and Salt Valley, especially along the trail to Delicate Arch. The remainder of the Morrison Formation was deposited in stream channels and on broad flood plains. The middle Salt Wash Member (Jmsw) is dominated by channel sandstones separated by thin varicolored siltstones and claystones, the whole unit making very rough outcrops. The streams of Salt Wash time were lined with trees, some of which were undermined and felled as meandering and flooding took place. As a result, petrified and carbonized wood fragments are quite common in the channel sandstones. There are even occasional petrified dinosaur bones. Northeast of the park, the Salt Wash Member is mineralized with uranium and vanadium minerals. The upper Brushy Basin Member (Jmbb) consists of varicolored shales, mudstones, sandstones, conglomerates and limestones that form a slope. In the northern map area the maroon shades dominate and to the south a green or aquamarine color dominates the outcrops. The greenish slopes south of the Moab airport and north of Seven Mile Canyon along U.S. Highway 191 are of the Brushy Basin Member. Other good exposures are found in the Yellow Cat mining area, northeast of the park, and in Cache Valley around the Delicate Arch trail and viewpoint parking lots.

CRETACEOUS PERIOD, 144-66 MILLION YEARS AGO

Except for the thin unconsolidated recent deposits, the youngest rocks were probably deposited in Cretaceous time. A thin unit, the Cedar Mountain Formation (Kcm), was the only unit deposited during the first 45 million years. The formation resembles the Brushy Basin Member of the Morrison Formation, but its slope-forming mudstones and shales are generally lighter in color. The Cedar Mountain Formation is separated from the Brushy Basin Member by a prominent ledge of sandstone and conglomerate. There were several times when previously deposited materials were eroded only to have new sediments brought in by the streams. In Late Cretaceous time another arm of the sea transgressed into Utah, this time from the east. The last terrestrial deposit, the Dakota Formation (Kd), was laid down by streams along the coastal regions. Yellow sandstone, conglomerate, gray shale and dark coaly shales are found in this discontinuous unit. It forms a rimrock on the softer mudstones and shales of the Cedar Mountain Formation. Overlying these rocks are the gray muds of the Mancos Shale (Kml and Kmu), well exposed along Interstate Highway 70 to the north, and in parts of Salt Valley and Cache Valley. During 10-13 million years the Mancos sea deposited over 3,000 ft. of gray mud which covered everything. At one time a surge of sand entered the sea from the west and was deposited over the area (Ferron Sandstone Member, Kmf). This sand now forms a slight ridge that can be followed on the west side of U.S. Highway 191 between Crescent Junction and the Moab airport. Fossils are abundant in places along this ridge and include oysters and cephalopods.

The Mancos Sea, in northeastern Utah, retreated about 80 million years ago and additional rocks were subsequently deposited in beach, coastal plain, fluvial, and finally lake environments. These younger rocks are exposed in the Book Cliffs north of Arches National Park. Some of these rocks may also have been deposited on parts of the Arches National Park area but, if so, were eroded away long ago.

TERTIARY PERIOD, 66-1.6 MILLION YEARS AGO

Some of the rocks deposited in the Book Cliffs after the retreat of the Mancos Sea were deposited during the first 20 million years of the Tertiary Period. Sometime thereafter the the rocks were gently warped into synclines and anticlines (fig. 5, lower block) and then faulted by forces originating deep in the earth. For the most part the folding followed the old northwest trends (the trends of the salt anticlines), but in a few places new folds formed across them. The new anticlines were generally aligned over the salt anticlines of the past and the layers of rock between were downfolded into synclines. The most prominent of these synclines is the Courthouse syncline, the axis of which follows Courthouse Wash. The park highway crosses the Courthouse syncline north of the visitor center. After making the turn at Park Avenue (Courthouse Towers), the road drops in elevation down the dipslope of the Navajo Sandstone, crosses the wash, and then rises on the opposite dipslope to Balanced Rock.

The Moab fault is the most obvious of the Tertiary faults and parallels U.S. Highway 191 from the Colorado River northward almost to the Moab airport. At Seven Mile Wash rocks of the Cutler Formation abut against rocks of the Salt Wash Member of the Morrison Formation, indicating a vertical movement of about 2,600 ft.

About 35 million years ago the granitic rocks making up the core of the La Sal Mountains were intruded into the Earth's crust. Granitic rocks are formed within the Earth's crust by the cooling of molten rocks called magmas. Molten rocks reaching and cooling at the surface are called lavas. The La Sal Mountain magma pushed its way up through the thousands of feet of salt and pushed aside the overlying rock layers, but little reached the surface.

After the folding and faulting were over, the entire region was uplifted to a high altitude and the area was subjected to erosion. Our landscape began to form about 5 million years ago, and most of what we see today was created in the Quaternary Period.

QUATERNARY PERIOD, 1.6 MILLION YEARS AGO-PRESENT

The unconsolidated thin deposits of sand, stream gravels and silt that cover the older rocks are merely in transit in their voyage to the sea, but they give clues that help interpret the more recent geologic history. These recent deposits probably have been in the area less than 1.5 million years and have been weathered, broken, scraped, plucked, abraded, rubbed, or dissolved from the pre-existing rocks by the action of water, ice, and wind.

Talus deposits (Qmt) consist of blocks, boulders and smaller angular fragments of rock which fall by gravity from the cliffy units and accumulate on the slopes below. Soils developing by weathering slowly move toward the drainages by a process known as creep. Eventually these materials reach the drainages and the flowing waters continue the work by breaking down the larger particles and moving the smaller ones downstream. If the drainage is a dry wash, it gradually becomes choked with rock materials, eventually to be moved by flash floods.

Alluvium (Qa_1 and Qa_2) is the sediment deposited by the rivers, streams, and intermittent streams of the area. The sediment includes particles of all sizes: clay, silt, sand, gravel, and even large boulders. The Colorado River, a through-flowing stream, has introduced much sediment from outside the area, including many granitic and metamorphic cobbles and pebbles from the very old rocks of the Uncompahgre Plateau in western Colorado. As the river erodes its deep canyon, it often fails to remove its temporarily deposited materials (Qat) for a relatively lengthy period of time and some of these gravels remain in terraces high above the river level. The processes that deepen and widen the canyons will eventually return these sediments to the river.

Most of the more recent unconsolidated sediments of the area consist of sand and reflect the dominant hard rock types of the area. The occasional torrential summer rains first dissolve the cementing material of the hard (consolidated) rocks and release the sand grains, and then carry them downslope as sheetwash. This loose sand is particularly vulnerable to the prevailing winds which blow the sand into dunes or sand sheets (eolian sand). The dunes and sheets (Qes) are generally aligned northeast-southwest along the direction of the prevailing wind. They commonly accumulate on the northeast-facing slopes of escarpments, such as opposite the Arches National Park Visitor Center.

SALT TECTONIC STRUCTURES

Salt tectonic structures are features formed by salt movement or salt dissolution. Such features have been forming continuously since the deposition of the salt beds. The earlier events are recorded by local angular unconformities, either at the tops or within the formations. Examples of angular unconformities (figs. 7 and 8) can be observed in the Chinle Formation in Moab Valley at the west portal of the Colorado River (along the south bank road), and along the canyon of the Colorado River between Castle Valley

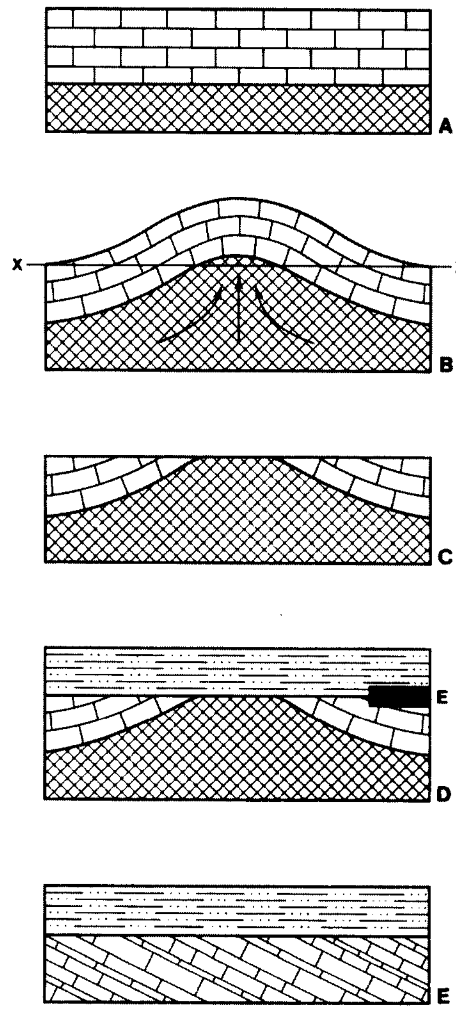

FIGURE 7. *Diagrams showing the development of an angular unconformity in the salt anticline region. Diagram A shows limestone strata (brick pattern) deposited over salt (small checked pattern). Salt flowage arches the overlying limestone (diagram B) which is then eroded to a flat plain (x-x' and diagram C). A siltstone bed is then deposited over this erosional plain. The part covered in black (E), is shown enlarged as diagram E. Angular unconformities indicate when the salt has moved, in this case after the deposition of the limestone and before the deposition of the siltstone.*

FIGURE 8. *Angular unconformity in the Chinle Formation on the southeast side of Moab Valley. Such unconformities indicate when the salt flowed (see fig. 7).*

and Big Bend. Excepting these, most of the salt structures we see were probably formed during the last 10 million years, older features having long ago been destroyed by erosion. In these more recent salt structures there is evidence for both plastic salt movement and the dissolution of salt.

SALT DISSOLUTION FEATURES

The salt features most easily recognized are those that form when the underlying beds of salt are dissolved. They are manifested by tilted and broken blocks of strata which parallel the salt valley. Dissolution occurs when a flow of fresh water reaches the salt through open fractures and faults. Such faults are often present along the bordering escarpments or extend down the middle of the salt valleys. The latter are usually buried by overlying alluvium (fig. 9). The thick salt under Salt Valley extends well under the flanks, and salt dissolution is likely where the overlying rocks are thin. The fresh water attacks the salt on a dissolution surface and dissolves deepest along and around the open faults. Several hundred feet of caprock usually lie above the dissolution surface of the Paradox Formation (Ppg).

A series of diagrammatic blocks (fig. 10) shows how the crest of a salt anticline collapses through salt dissolution. All of the recent unconsolidated deposits are omitted for simplification. The strata overlying the salt are represented by a single fractured prism with a heavy dark line at the base for reference. This overlies the salt-bearing Paradox Formation, which is cross-hatched. Open spaces between the salt and the heavy dark line are either actual voids or caprock. The strata represented by the single overlying prism are quite varied in their properties (competency), and the salt of the cross-hatched area is found in several "cyclical" or repeated beds separated by layers of anhydrite and shale (marker beds). In block A the whole system is folded into an anticline. Extensional joints or fractures form parallel to the axis of the anticlinal fold because of the folding . In blocks B and C the structure is eroded by a through-going stream, such as Salt Wash. The stream supplies the fresh water which circulates to the salt through some

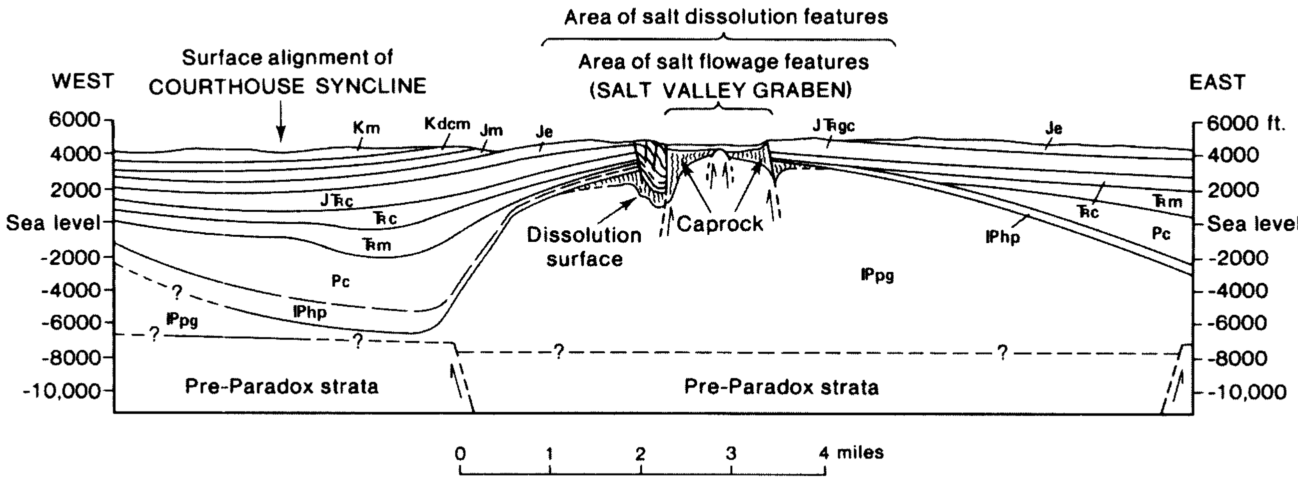

FIGURE 9. *Cross-section across north end of Salt Valley (modified from Lohman, 1975, p. 28-29). Salt dissolution features can develop over the salt formation (Paradox Formation—Ppg) where overlying rocks are thin. Ridges and hills formed by salt flowage usually appear where the caprock is close to the surface and not where hard consolidated units cover it. The salt beds adjacent to and to the west of the "salt anticline" are very thin but the overlying beds are thicker. The salt anticline "grew" at the expense of the salt originally deposited in the thin area.*

of the open joints and dissolves it. The dissolution is followed by the collapse (tilting) of the overlying units in the crestal part of the anticline. The Moab anticline, north of the Colorado River, north of Moab Valley, is a good example of this early phase. Tributary streams develop that parallel the prominent joints, faults or fractures (block C). The blocks between the fractures tilt in zigzag fashion in response to greater or lesser dissolution along these fractures (block D). Synclines (downfolds) develop where the fractures have transmitted the greater amount of fresh water to the salt (x-x') and anticlines form between the synclines (z-z'), or where less fresh water reaches the salt. The stream has been removed in this block to simplify the drawing. The fracture traces (axial planes of the anticlines and synclines) are generally sharp, the blocks remain uniformly tilted as dipslopes to form V-shaped rather than U-shaped synclines (figs. 11 and 12). This sharp dip change is best exhibited in the brittle formations; more ductile units tend to produce U-shaped synclines and anticlines. In some cases the dissolution along a favored fracture might proceed to the point where blocks drop vertically in the void (y-y', block E). In this case the original length of the strata can increase as individual beds slip relative to another like slipping one card over another in a deck. Cache Valley and the Elephant Butte fold belt are good examples of the dissolution described by the diagrammatic blocks in figure 10.

Valley development along a salt anticline is illustrated by another set of block diagrams (fig. 13). The explanations for the rock units are the same as in figure 10, except that recent alluvium and unconsolidated deposits are shown with a stippled pattern on blocks B, C, and D. In this case there is a crestal fault on the anticline (block A). The fault escarpment erodes and retreats laterally down the flank of the anticline. Tributaries develop on the downthrown block and start dissolution in the same manner as described in the figure 10 block diagrams. The collapsing and tilting of the blocks helps to preserve them from early erosion. The process continues and the valley widens. Later, the edge of the erosional escarpment can tilt inward toward the valley if dissolution activity proceeds downdip faster than the erosion can cause the cliff to retreat downdip (blocks C and D). Very narrow-spaced extensional fractures appear along the edge of the cliff to form fins (see Arches and Fins section). Such is the condition of the valley along parts of Salt Valley (Fiery Furnace). Erosion can sometimes remove all the overlying strata so that only caprock and alluvium lie above the salt formations (block D), as is the case in Moab Valley.

Even the unconsolidated alluvium has been involved in the tilting caused by the dissolution of the underlying salt and gives an idea of how recent this activity is. Two volcanic ashes have been identified in the sediments immediately west of the intersection of the main park highway and the road to Delicate

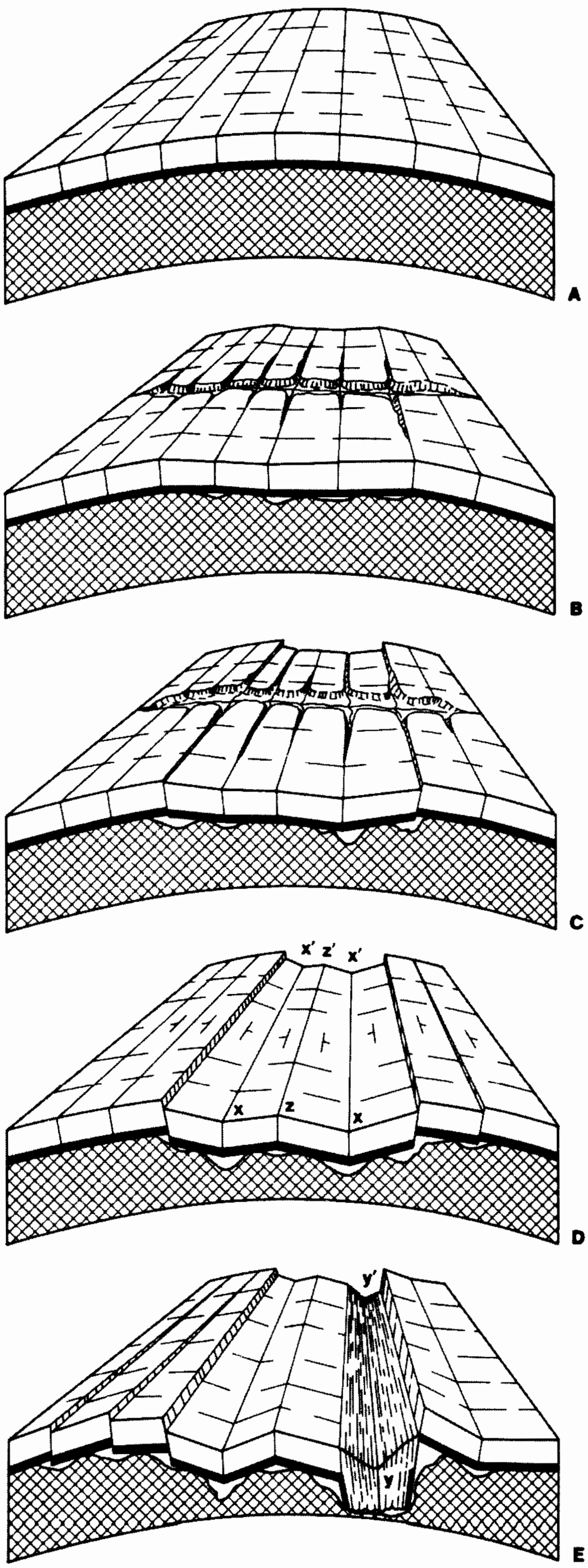

FIGURE 10. *Block diagrams illustrating sequentially how collapse features may form over salt anticlines as the salt below is slowly dissolved away. An explanation is carried in the text under "Salt Dissolution Features."*

Arch. The eruptions which produced the ashes have been precisely dated by radioactive methods. The eruptions took place 620 and 740 thousand years ago and the tilting occurred both during and after the ash beds were deposited. Dissolution of salt was quite rapid during the humid Ice Age glacial cycles occurring 1.6 million to 10,000 years ago. It continues today at a somewhat diminished rate, but a new ice age would re-accelerate the process.

RECENT SALT FLOWAGE

Salt flowage (diapirism) is caused by unequal loading on the salt beds. The weight of the rocks on the flanks exceeds the load carried by the salt in the valley where there is only 500-600 ft of relatively lighter alluvium and cavernous caprock. The salt flowage can "heal" fault planes, mend fractures, fill in places where dissolution has occurred, or cause bulges to appear at the surface. Rock salt, however, is not exposed at the surface in Salt Valley or Moab Valley. Plastic movement is slow and salt is usually dissolved by groundwater before it can reach the surface. Only the caprock gypsum and marker beds emerge to the surface as hills, domes, and ridges (fig. 14). Such domes are marked by an x on blocks B and C (fig. 13). These most often appear adjacent to mid-valley faults or along the valley margins (block D) adjacent to the cliffs. It is improbable that salt diapirism can push up or dome very thick prisms of rocks. Examples of mid-valley gypsum hills can be found in central Salt Valley, and examples of hills marginal to the escarpments and cliffs are found in Moab Valley. The diapiric hills and ridges all exhibit highly contorted Paradox Formation strata, never simply tilted as in the dissolution features. The pushed up rocks dip away from the domes or ridges in all directions.

ARCHES AND FINS

How arches and fins form is an interesting question. Arches can form in many ways, but most in the park are the result of a combination of three peculiar features: the nature of the Entrada Sandstone sand grains, the susceptibility of the sandstone to weathering and erosion, and fractures in the sandstone that were created during the formation of anticlines. Most arches and fins at Arches National Park have formed wherever the Entrada Sandstone is arched over an anticline on which closely spaced paralleling fractures have developed. This anticline is usually partially dissolution induced and parallels the valley escarpments. Good examples are at Klondike Bluffs, Devils Garden, Fiery Furnace and Herdina Park. In the Windows Section a thin remnant of

FIGURE 11. *V-shaped syncline in Cache Valley. Dissolution of salt underlying Arches National Park causes the overlying strata to collapse and tilt sharply.*

FIGURE 12. *A syncline of the Elephant Butte folds just east of Salt Wash. The strata dip sharply along an axis under which the salt has dissolved.*

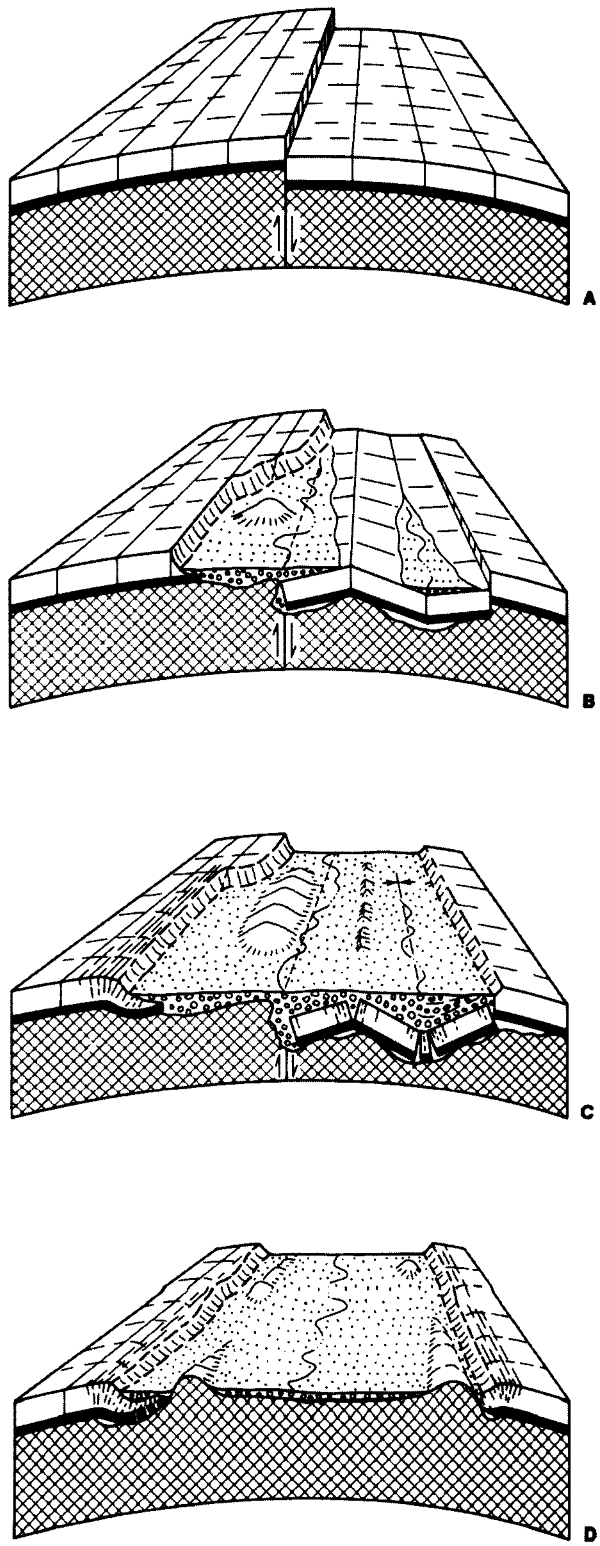

FIGURE 13. *Block diagrams illustrating valley development over salt anticlines. An explanation is carried in the text under "Salt Dissolution Features."*

Entrada Sandstone stands as Elephant Butte, arched over an anticline formed many millions of years ago and probably not formed by dissolution.

The Slick Rock Member of the Entrada Sandstone (Je) is composed mostly of quartz grains cemented by calcium carbonate ($CaCO3$). Rain water, charged with atmospheric carbon dioxide ($CO2$), forms weak carbonic acid, which can dissolve the cement. Many other sandstone units are also cemented with calcium carbonate, but the individual Slick Rock sand grains remain and accumulate on the surface of the parent rock after they are released. The reasons are not fully understood; the grain size, angularity, and degree of grain frosting may or may not have something to do with it. Nevertheless, large irregular patches of sand cover a significant percentage of the outcrop area of the Slick Rock Member. The slightly acidic rainwater passes through the sand veneer and attacks the unweathered rock beneath, forming more sand. This precipitation-derived groundwater is protected by the sand from quick evaporation by the wind or hot sun, as it might occur on bare rock surfaces, and is given the time to dissolve the rock cement. Therefore the sandstone under the sandy fields is more quickly broken down than the bare surface rock. The sand accumulating on the Entrada Sandstone, behind the Great Wall where there are few fractures, is illustrated in figure 15, diagram l.

Fractures open to form the fins (fig. 15, diagram 2) across the top of the bent Entrada Sandstone as the anticline forms. Where thin fins form, little upper surface is left on which the sand may collect to help weather the rock. The sand collects between the fins (fig. 16) and the slightly acidic waters attack the sides as well as the floor (fig. 15, diagram 3), thinning the fins even more. The softer, less well-cemented partings in the otherwise massive Slick Rock are especially prone to the sideward attack of the groundwater. The contacts between the Slick Rock Member (Je) and the Moab Tongue (Jem) or Dewey Bridge Member (Jed) also act as prominent partings. The water seeps into the partings at favorable places and dissolves out the surrounding sand grains at a faster rate than at the unfractured adjacent rocks, creating a thin opening (diagram A). Gravity stresses (indicated by the long arrows on diagram A) then appear in the overlying rock. The strain ellipsoids (egg-shaped figures) in the diagram indicate the direction of the tensional stresses (short arrows) and the lines along which fractures would be expected to develop (those which cut the ellipsoid in half). The fractures (diagram B) propagate upward into the

FIGURE 14. *Domed caprock (mostly gypsum) near The Portal of the Colorado River southwest of Moab. These domes and ridges are squeezed up from under the weight of the adjacent cliffs.*

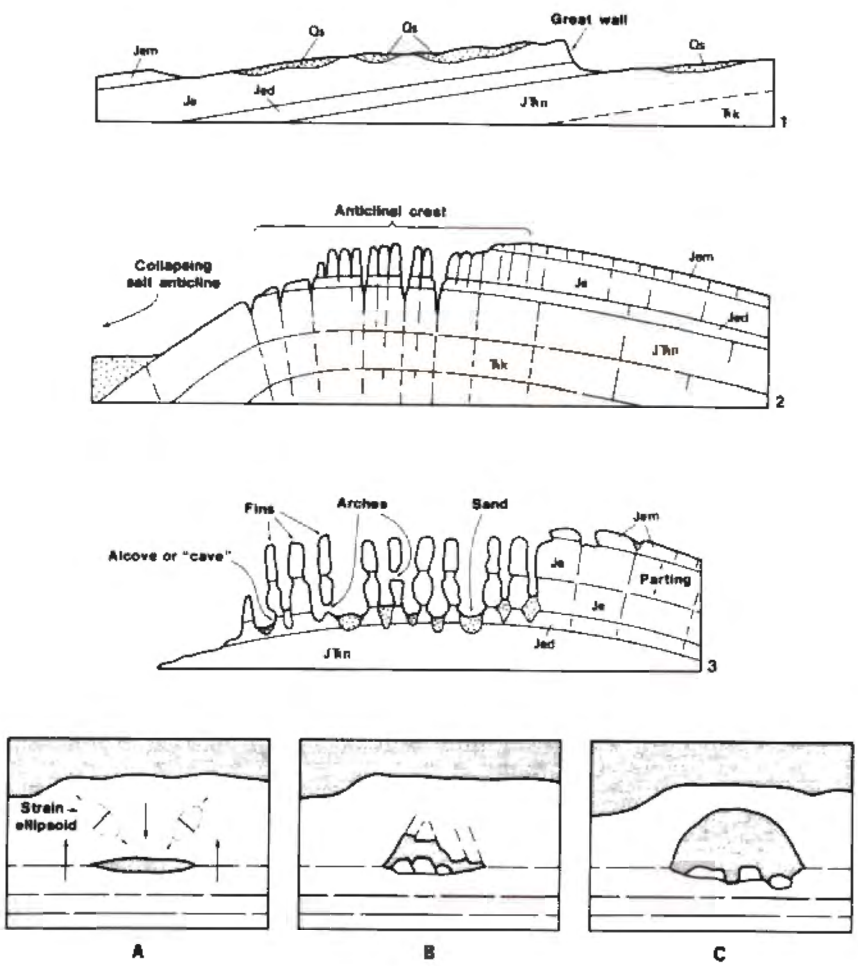

FIGURE 15. *Diagrams illustrating the development of some of the fins and arches in Arches National Park. An explanation is in the text under "Arches and Fins," last two paragraphs.*

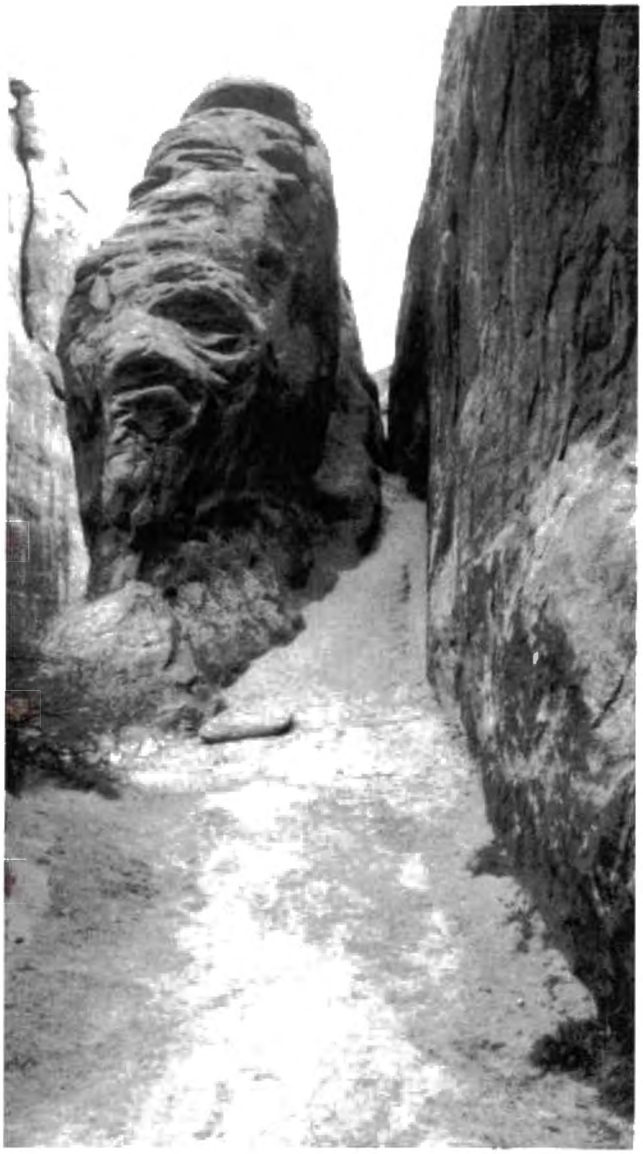

FIGURE 16. *Fins with sand between on the trail to Landscape arch. The sand assists in forming arches (fig. 15, diagram 3) and the fractures which open to form the fins develop as rock strata are arched over an anticline.*

overlying rock. As in mines with unbolted poor roofs, the back collapses until it creates the typical stable arch form, which neutralizes the stress and inhibits further collapse (diagram C). Delicate Arch has formed along the parting formed by the contact of the Moab Member with the Slick Rock Member. Skyline Arch is formed along a parting entirely within the Slick Rock Member The Windows arches occur along the Dewey Bridge-Slick Rock contact. Erosion of the soft Dewey Bridge Member often enlarges the arch. Thick-walled fins are not as favorable for arch development as the thin ones, but alcoves and "caves" can form on their sides.

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STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES
UTAH GEOLOGICAL AND MINERAL SURVEY

MAP 74

GEOLOGIC MAP OF ARCHES NATIONAL PARK AND VICINITY, GRAND COUNTY, UTAH

1985

By Hellmut H. Doelling

Klaus D. Gurgel, Cartographic Editor
Kent D. Brown, Cartographer

Scale 1:50,000
1 inch equals approximately .8 mile
Contour intervals 40 feet and 80 feet

Base from U.S. Geological Survey Arches National Park, 1:50,000, 1974; topographic quadrangles: Crescent Junction, 1958; Thompson, 1958; Cisco, 1958; Castle Valley, 1954.

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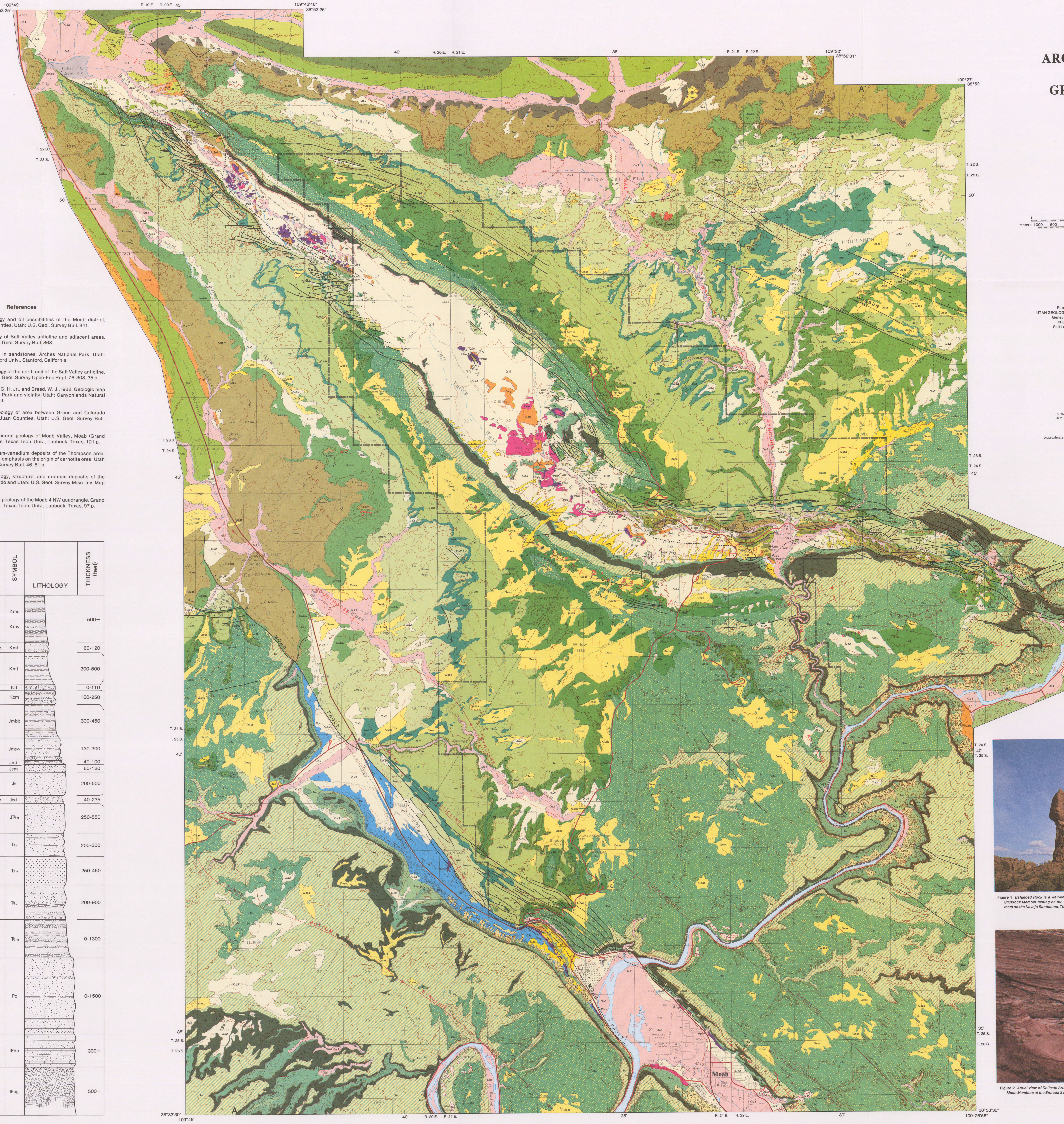

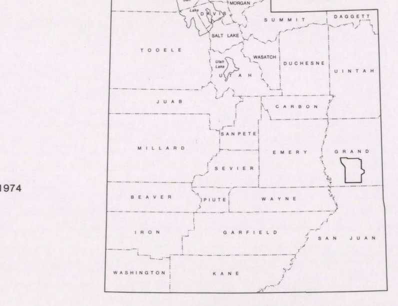
LOCATION MAP

EXPLANATION

CENOZOIC ERA — QUATERNARY

- **Qf** Man-made fill.
- **Qa1** Alluvium—*Clay, silt, sand and gravel deposits along the more important active rivers, streams and washes.*
- **Qa2** Alluvium and older alluvium, mixed with varying amounts of colluvial, lacustrine, and aeolian deposits—*Mostly sand, but contains considerable gravel, silt, and clay. Interbedded volcanic ashes dated at 620,000 and 740,000 years before present.*
- **Qag** Gravel deposits of mostly alluvial origin—*Larger mappable areas.*
- **Qat** Terrace gravel deposits located along the Colorado River and its more important tributaries—*These deposits have mostly been transported to the depositional site from a considerable distance and are locally auriferous.*
- **Qeas** Sand deposits—*Mostly of aeolian origin, mixed or interlayered with various amounts of alluvial, eluvial, and colluvial sand.*
- **Qes** Aeolian sand deposits-*In dunes or sheets.*
- **Qms** Landslide deposits—*Mostly larger coherent to partly broken up masses of consolidated units that have moved downslope a considerable distance.*
- **Qmt** Talus deposits—*Mostly rockfall blocks, boulders, and smaller angular fragments lying on slopes immediately below the parent outcrop. Mapped only where they completely cover the units beneath.*

MESOZOIC ERA — CRETACEOUS

Mancos Shale

- **Kmu / Kms** Upper Mancos Shale—*Light to dark gray marine shale, slope-former, containing occasional sandy beds (Kms) which are slightly more resistant. Locally fossiliferous. Youngest consolidated unit found involved in dissolution collapse along Salt Valley anticline. Incompletely exposed in mapped area, thickness 500+ ft.*
- **Kmf** Ferron Sandstone Member of Mancos Shale—*Thin-bedded sandstone, sandy shale, marine shale, carbonaceous shale, forms a double cuesta, being more resistant than Mancos Shale members above and below. The member can be subdivided into three units—upper and lower sandy units which are brown gray to yellow gray and fossiliferous and a medial dark shale unit, which is locally coaly. Thickness 60 to 120 ft.*
- **Kml** Lower Mancos Shale—*Light to dark gray marine shale, slope-former containing occasional sandy beds, especially near the top. The sandy beds are slightly more resistant and have yellow gray to brown gray color. Thickness 300 to 500 ft.*
- **Kd** Dakota Sandstone—*Sandstone, conglomeratic sandstone, conglomerate, with subordinate gray sandy shale, carbonaceous shale, and marl beds. Thin and discontinuous to the west, it forms well marked dip slopes on the northeast flank of the Salt Valley anticline. Thickness 0 to 110 ft.*

Unconformity

- **Kcm / Kdcm** Cedar Mountain Formation—*Silty variegated nonresistant mudstones interbedded with ledgeforming quartzites, conglomerates, and gritstones. Mudstones are mostly light green, gray, lavender and white. Kdcm indicates areas of undifferentiated Cedar Mountain Formation and Dakota Sandstone. Cedar Mountain Formation thickness is 100 to 250 ft.*

Unconformity

JURASSIC

Morrison Formation

- **Jmbb** Brushy Basin Member of Morrison Formation—*Mostly variegated slope-forming mudstone with thin ledges of conglomeratic sandstone, conglomerate, nodular weathering limestone, and gritstone, containing varicolored chert. These ledge-formers are more abundant near the base of the unit. Purplish and lavender hues dominate to the north, but bright greens dominate in Cache Valley and the southern part of Salt Valley anticline. Thickness 300 to 450 ft.*
- **Jmsw** Salt Wash Member of Morrison Formation—*Light yellow gray crossbedded lenticular sandstone interbedded with red and gray mudstone and siltstone. Some conglomeratic sandstone, gritstone and thin limestone beds are also present. The thickest sandstone beds are often mineralized with vanadium-uranium (Yellow Cat area), or with copper (northern part of SW flank, Salt Valley anticline). Thickness 130 to 300 ft.*
- **Jmt** Tidwell Member of Morrison Formation—*Reddish silty shale, with interbeds of fine-grained yellow sandstone and gray limestone. Eastern exposures exhibit large white siliceous concretionary bodies. This excellent marker bed was formerly known as the Summerville Formation, but shown by O'Sullivan (1980) to be a lower member of the Morrison Formation. Thickness 40 to 100 ft.*

Unconformity

San Rafael Group

- **Jem** Moab Tongue of Entrada Sandstone—*Light yellow gray fine- to medium-grained resistant and massive sandstone, forming an impressive barerock dipslope on both flanks of the Salt Valley anticline. Exposures to northwest have a slope and ledge-forming unit beneath the main cliff of medium-grained sandstone up to 25 ft thick. Thickness of entire unit is variable, 60 to 120 ft.*
- **Je** "Slickrock" or Main Body of Entrada Sandstone—*Mostly orange-red fine-grained sandstone, massive, often covered with self-derived sand. Not as resistant as Moab Tongue above, but more resistant than Dewey Bridge Member below. Thickness 200 to 500 ft.*
- **Jed** Dewey Bridge Member of Entrada Sandstone—*Dark reddish fine-grained silty sandstone, with occasional white bands. Exhibits contorted bedding which often affects the lower part of the "Slickrock" Member above. Formerly known as the Carmel Formation. Thickness 40 to 235 ft.*

Unconformity

TRIASSIC

Glen Canyon Group

- **JTRn** Navajo Sandstone—*Mostly massive light-hued aeolian sandstone, cropping out as vertical cliffs in deep canyons and as domes and rounded knolls elsewhere. Contains local thin, hard, gray carbonate beds. Thickness in outcrop 250 to 550 ft.*
- **TRk** Kayenta Formation—*Mostly sandstone of lavender-gray color with local white and dark brown beds. Some beds are micaceous and there are occasional intraformational conglomerates. Forms thick step-like ledges between the more massive Navajo and Wingate Formations. Thickness in outcrop 200 to 300 ft.*
- **TRw** Wingate Sandstone—*Massive fine-grained, well-sorted sandstone, usually forming a dark brown cliff in outcrop. Where shattered by salt tectonics forms a fine-terraced orange or orange-brown cliff. Thickness in outcrop 250 to 450 ft.*
- **TRc** Chinle Formation—*Mostly reddish-brown silty fine-grained sandstone, forming slopes, interbedded with considerable mudstone and some gritty beds. Toward the base is a member of poorly cemented gritstone, conglomerate, mottled gritty siltstone and mudstone which is quite variable in thickness. Upper part exhibits local angular unconformities. Lower member is often mineralized with uranium and copper. Thickness in outcrop varies from 200 to 900 ft.*

Unconformity

- **TRm** Moenkopi Formation—*Brown, evenly-bedded sandy shale and micaceous silty sandstone forming smooth slopes interrupted by occasional thin ledges. Sandstones are often ripple marked. Thickness 0 to 1300 ft.*

Unconformity

PALEOZOIC ERA — PERMIAN

- **Pc** Cutler Formation—*Red and maroon crossbedded sandstones and conglomerates with subordinate sandy shales. Lower part contains thin fossiliferous limestone beds. Thickness 0 to 1500 ft.*

Unconformity

PENNSYLVANIAN

- **IPhp** Pennsylvanian rocks—*Non-gypsiferous rocks Mostly Honaker Trail Formation outcrops, but may include some non-gypsiferous Paradox Formation outcrops at some Salt Valley locations. Mostly limestones, shales, sandstones, and arkosic sandstones. Limestones are often fossiliferous. In mid-valley knolls the outcrops are highly deformed and faulted consisting of poor exposures of mostly sandstone and sandy limestone chips. Maximum thickness of exposures is 300+ ft.*
- **IPpg** Paradox Formation gypsiferous exposures—*Mostly contorted gypsum with interbeds of black shale, thin chippy limestone and sandstone. Surface thicknesses probably do not exceed 500+ ft.*

LITHOLOGIC CONTACT

FAULT
Approximate trace of fault at surface, dotted where concealed, bar and ball on downthrown side.

STRIKE AND DIP OF INCLINED BEDS

ANTICLINE SYNCLINE
Approximate trace of anticlinal or synclinal axis and direction of plunge. These folds are thought to be formed during Early Tertiary compressional event. Dotted where concealed.

ANTICLINE SYNCLINE
Approximate trace of anticlinal or synclinal axis and direction of plunge. Most of these folds are due to salt tectonics, either through collapse by dissolution of salt, or by salt movement. Dotted where concealed.

ARCHES NATIONAL PARK BOUNDARY

MINE TAILINGS

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SYSTEM	FORMATION		SYMBOL	THICKNESS (feet)
CRETACEOUS	MANCOS SHALE	Upper Member	Kmu	500+
		(Sandy Beds)	Kms	
		Ferron Ss. Mbr.	Kmf	60-120
		Lower Member	Kml	300-500
	DAKOTA Ss.		Kd	0-110
	CEDAR MOUNTAIN FORMATION		Kcm	100-250
JURASSIC	MORRISON FORMATION	Brushy Basin Member	Jmbb	300-450
		Salt Wash Member	Jmsw	130-300
		Tidwell Mbr.	Jmt	40-100
	ENTRADA SANDSTONE	Moab Tongue	Jem	60-120
		"Slickrock" Member	Je	200-500
		Dewey Bridge	Jed	40-235
	NAVAJO SANDSTONE		JTRn	250-550
TRIASSIC	KAYENTA FORMATION		TRk	200-300
	WINGATE SANDSTONE		TRw	250-450
	CHINLE FORMATION		TRc	200-900
	MOENKOPI FORMATION		TRm	0-1300
PERMIAN	CUTLER FORMATION		Pc	0-1500
PENNSYLVANIAN	HONAKER TRAIL FORMATION		IPhp	300+
	PARADOX FORMATION		IPpg	500+

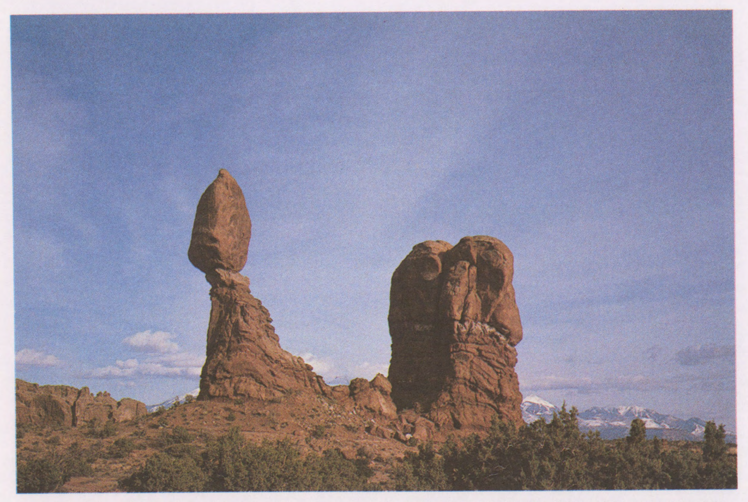

Figure 1. *Balanced Rock is a well-known and central landmark in Arches National Park. The Balanced Rock consists of the Slickrock Member resting on the narrow pedestal of the Dewey Bridge Member of the Entrada Sandstone. Balanced Rock rests on the Navajo Sandstone. The La Sal Mountains form a beautiful backdrop to many of the park features.*

Figure 2. *Aerial view of Delicate Arch. Delicate Arch is the park's trademark and is formed at the contact of the Slickrock and Moab Members of the Entrada Sandstone.*