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# QUATERNARY FAULTING IN SALT BASIN GRABEN, WEST TEXAS

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## INTRODUCTION

The Salt Basin graben is the easternmost limit of modern Basin and Range tectonism in Texas and is the easternmost structure related to the Rio Grande rift in the United States. Quaternary faulting in Salt Basin appears to be controlled by pre-existing structural zones of weakness. Over one hundred Quaternary fault scarps and photolineaments were mapped in Salt Basin (Goetz, 1977; fig. 1). Three types of fault scarps were recognized: lakeshore scarps, mid-fan breaks, and bedrock boundary faults. The faults, particularly the mid-fan breaks, frequently act as semipervious barriers separating fresh water on the mountain side from saline water on the playa side.

A tectonic origin is suggested by the orientation of the scarps and the proximity of the Mayfield fault scarps to the estimated epicenters of the 1931 Valentine earthquakes (intensity VIII on the modified Mercalli scale). It is suggested that these fault scarps have been produced and maintained by intermittent activity rather than by a single event. A Holocene age for some of the scarps is strongly suggested by a comparison of the erosion rate there with that on the 1968 Borrego Mountain, California, scarps (Clark and others, 1972) and by interpolation using the caliche development scale developed by Giles and others (1970) for southern New Mexico.

The frequency of small earth tremors felt by the residents of the basin and recorded by temporary seismograph stations indicate that tectonic adjustments are presently occurring (Dorman and others, 1976; *see also* Dumas, this volume).

I suggest that the basement blocks of the graben floor are being actively downdropped to the west-southwest along the eastern hinge of the half-graben. Evidence for this includes the preferential alignment of Quaternary and Holocene fault scarps along the western side of the graben. The westward shifting of the playa lakes and the preferred orientation of giant desiccation polygons also were probably induced by this movement (*see* second paper by Goetz, this volume).

The basement blocks are broken by four transverse structural lineaments crossing the Salt Basin graben mapped by King (1948, 1965) and Wiley (1970). A fifth zone trending east-west between the Babb flexure and Bitterwell Mountain has been proposed by the author (Goetz, 1977).

## STRUCTURAL SETTING

Salt Basin graben is a block-faulted half-graben composed of four segments (fig. 2). Each segment is offset to the west of its adjacent southern segment along faults that parallel Late Paleozoic fault trends. The two southernmost segments form Salt Flat. The southernmost section bifurcates to the south at the latitude of Van Horn. The northern Salt Flat section also bifurcates at its southern end. The basin arm west of the Baylor Mountains is much less significant than the basin arm that widens to become Wildhorse Flat. The two northern sections of the area form the Salt Basin and are essentially rectangular and parallel in outline.

The graben floor appears to be formed by a series of southwest-west-dipping basement blocks. From the New Mexico–Texas border, south to the latitude of Van Horn, there are at least five major structural breaks.

The northernmost structure line shown in Figure 2, a map of Salt Basin, was dashed in by King (1948) and bears southeast from the faulted limestone south of Dell City to the south side of Bitterwell Mountain. The next apparent break in the basement blocks is postulated by the author to bear east-west between the Babb Flexure and the south side of Bitterwell Mountain. This structural zone has not been mapped before and will be discussed later. The Babb Flexure may continue beneath the Salt Basin and intersect the Apache Mountain trend, thus forming the northern side of the Scott Canyon fan embayment.

The Victorio Flexure strikes in a more easterly direction than does the Babb Flexure. Movement on the flexure apparently downdropped the basement block to the north along an east-west trend beginning in Victoria (sic) Canyon, crossing the north side of the Baylor Mountains and intersecting the Apache Mountains on the south side of the Scott Canyon fan embayment. Both the Babb and Victorio flexures are Early Paleozoic, north-dipping faulted monoclines.

The southern limit of the Wildhorse sub-basin, the southernmost basement block in the study area, is formed by the Hillside Fault and the Wylie Mountain Fault. These two faults and the faults that separate the grabens of Lobo Valley and Michigan Draw from the Salt Flat graben and have downdropped the sub-basin of Salt Flat and the toe of the Wylie Mountains (Hood & Scalapino, 1951, Baker, 1952 and Hay-Roe, 1958). These faults lie in the northwest-trending zone of structural transition known as the Texas Lineament (Wiley and Muehlberger, 1970; *see* Muehlberger, this volume). This regional anomaly forms a 100- to 150-m-wide zone extending from the Transverse Ranges of California along the southern edge of the Colorado Plateau to Trans-Pecos Texas. Locally it separates the stable Diablo Plateau from the mobile Chihuahua Trough.

The approximate depth of the alluvium and the general tilt of the bedrock blocks beneath Salt Basin are indicated in figure 3, constructed from the resistivity and well log data assembled by White and others (1977). With the exception of the block or zone adjacent to Bitterwell Mountain, all the bedrock blocks appear to be downdropped to the west and have increasing displacements to the south.

The graben as a whole is asymmetric, with the eastern horst elevated higher than the western horst in the Salt Basin section of the graben. The reverse is true for the Salt Flat section. The difference in elevations is approximately 1400 m at the north end of Salt Basin and decreases to approximately 180 m at the southern end. The relief between El Capitan Mountain in the Guadalupe Mountains (2624 m) and the adjacent basin floor (1080 m) is the most extreme found in the state of Texas.

The steep slope and high elevation on the eastern side of the graben at its north end is similar to the slope and asymmetry of the Rio Grande rift. This characteristic shape is used by Chapin and Seager (1975) as the basis for including this basin as part of the rift (fig. 3).

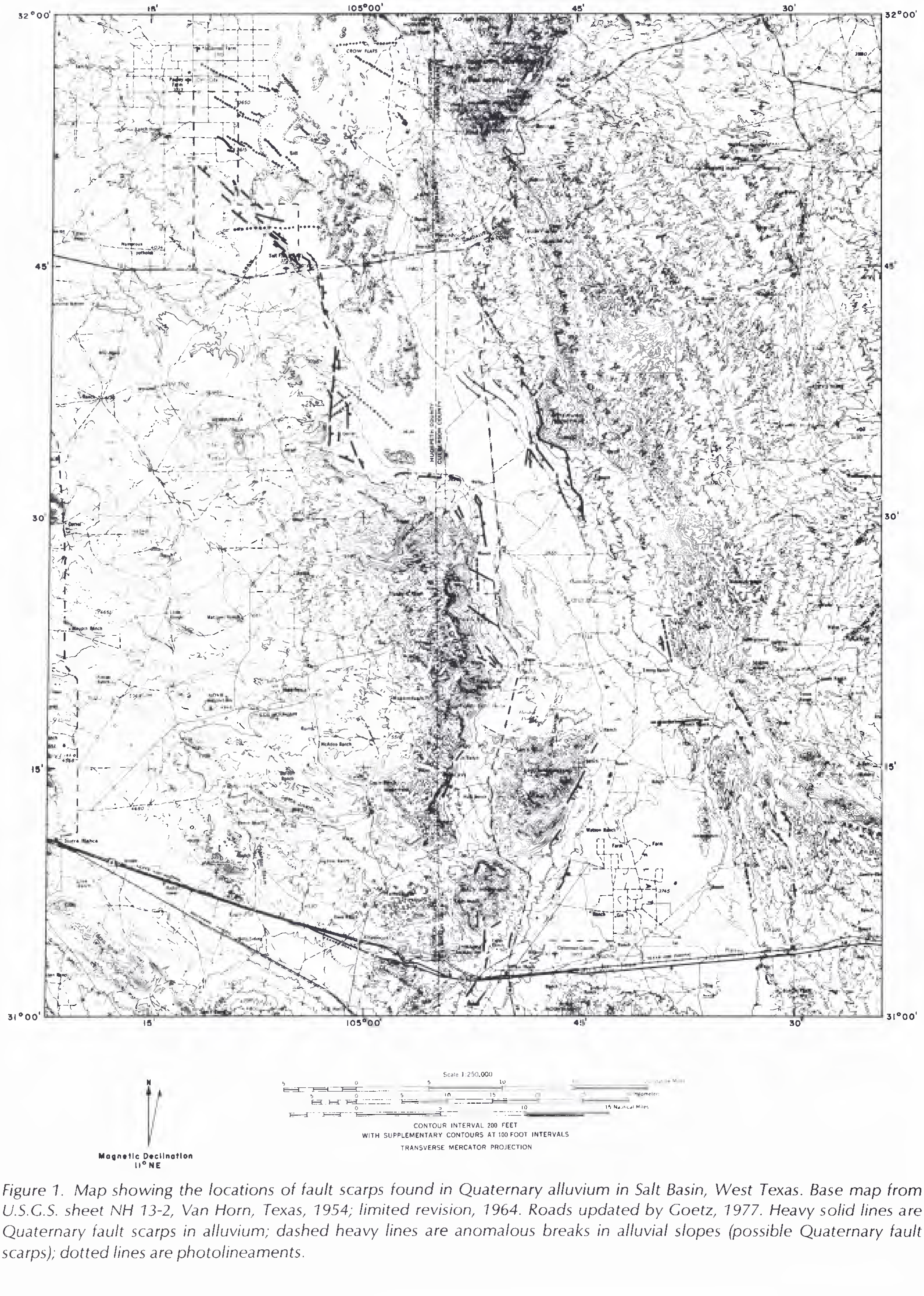


*Figure 1. Map showing the locations of fault scarps found in Quaternary alluvium in Salt Basin, West Texas. Base map from U.S.G.S. sheet NH 13-2, Van Horn, Texas, 1954; limited revision, 1964. Roads updated by Goetz, 1977. Heavy solid lines are Quaternary fault scarps in alluvium; dashed heavy lines are anomalous breaks in alluvial slopes (possible Quaternary fault scarps); dotted lines are photolineaments.*

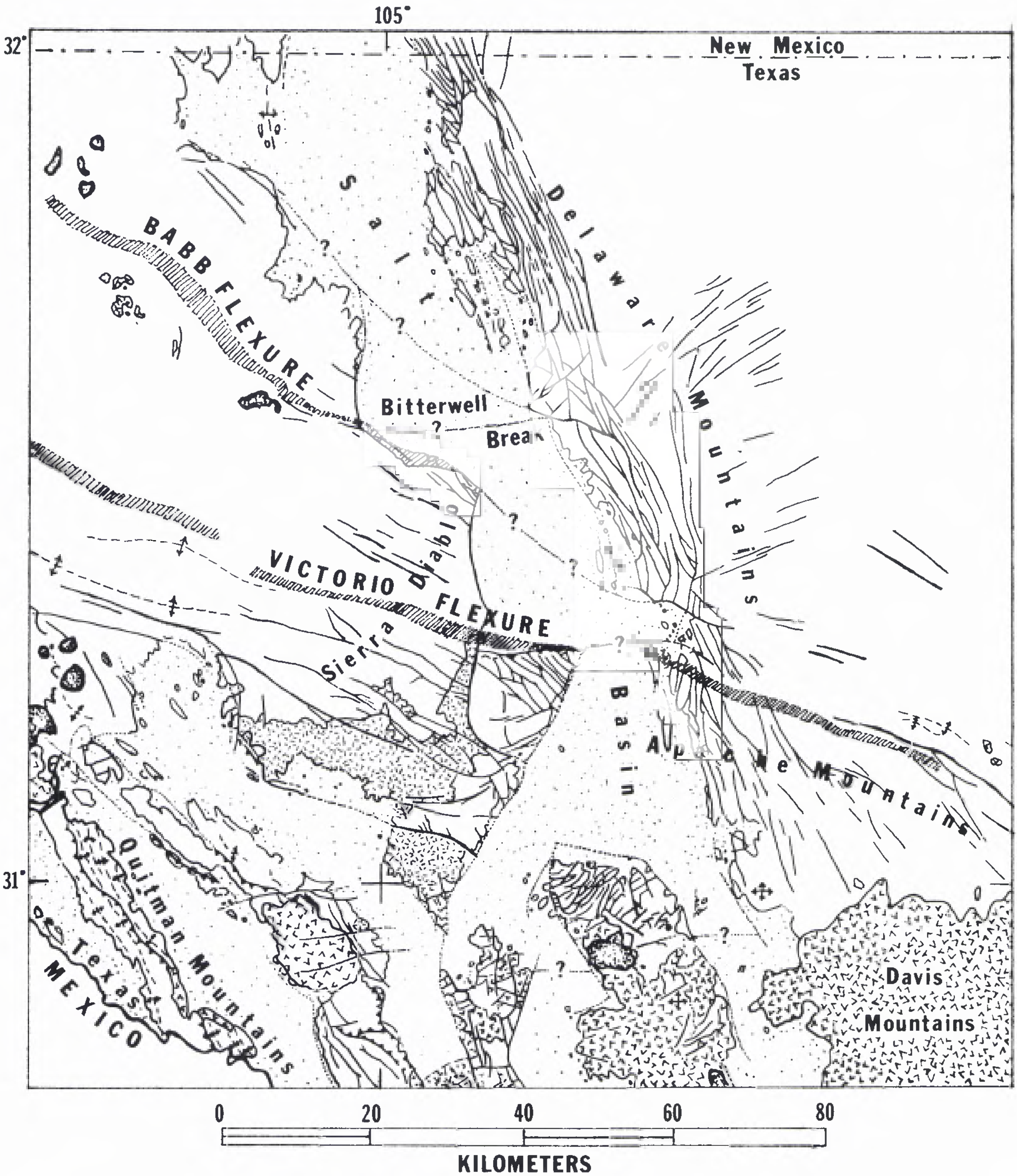


*Figure 2. Structural map of the area about and including Salt Basin, adapted from King, 1965.*

The Rio Grande rift or depression is a series of structurally aligned basins which lacked a master integrated drainage system until sometime in the late Pliocene (Strain, 1958). The southern section of the Rift is distinguished by parallel basins and intra-graben horsts. The Salt Basin graben includes several horst blocks and parallels the Hueco, Tularosa, Mimbres and Mesilla basins of the southern Rio Grande rift. As with other basins of the rift, the shoulders of Salt Basin graben are sharply uplifted and tilted outward from the basin, which has a width varying between 17 and 50 km.

Gravity and heat flow data aid in delineating the major, steeply dipping, normal en echelon faults that outline the Rio Grande rift (Cordell and Kottlowski, 1975), which closely resemble the faults similarly defined in Salt Basin graben (Wiley, 1970; Decker and Smithson, 1975).

There are some major differences between the Rio Grande rift and Salt Basin graben, the most important of which is the lack of recent volcanism and thermal activity in Salt Basin graben. This may be related to the lack of major northeast-trending faults in Salt Basin graben. It has been noted by several workers that the most recent rift volcanism has occurred at the junction of major northeast trending faults and the rift valleys (Kelley, 1956; Chapin and Seager, 1975; Cordell and Kottlowski, 1975).

A second difference is that, from south to north, the Salt Basin

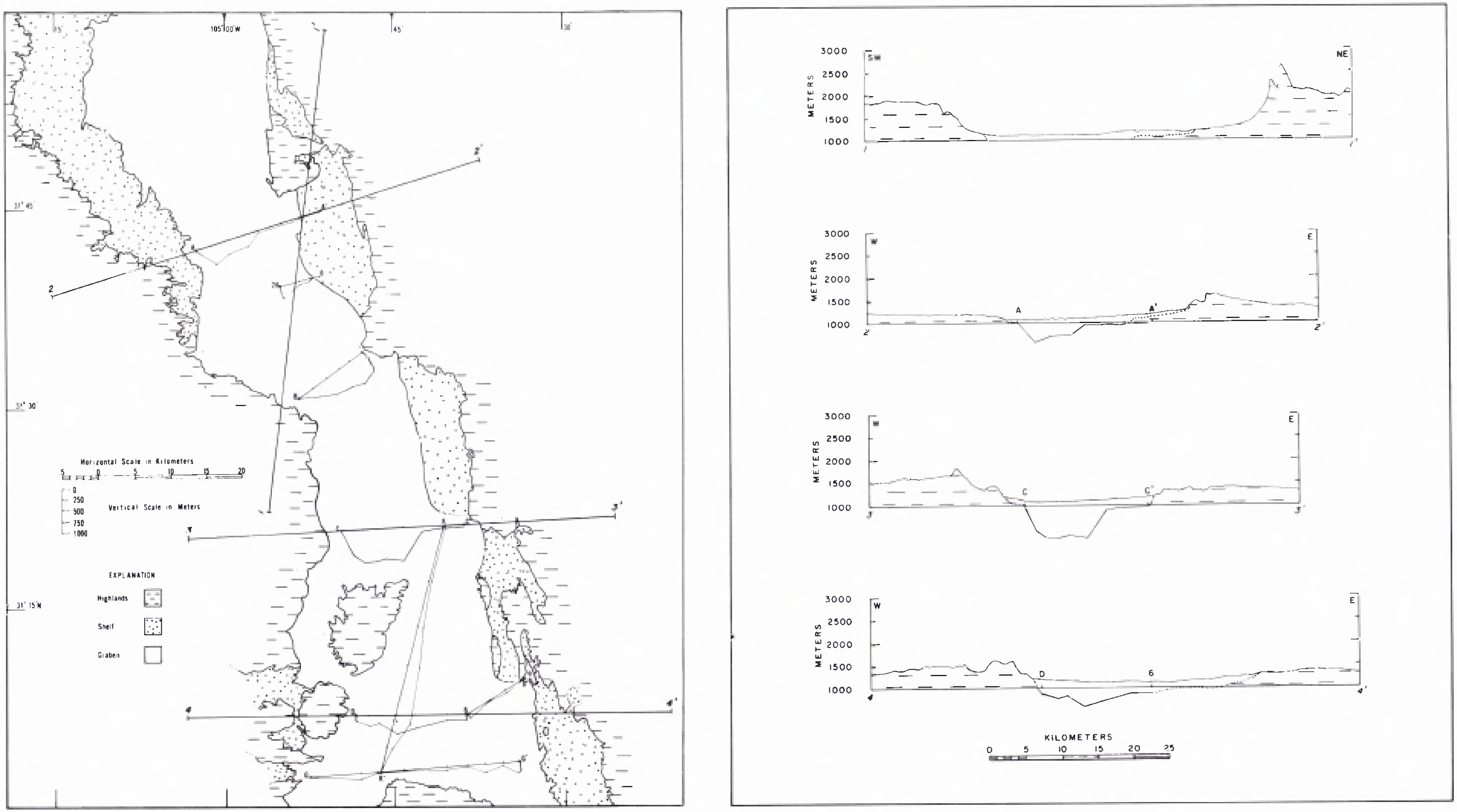


*Figure 3. Schematic diagram of Salt Basin showing the limestone highlands (dashed), the shelves where alluvium is immediately underlain by bedrock (dotted), and the basin area proper (no pattern). Lines identified by numbers 1 through 4 show topographic relief. Lines identified by letters show the inferred depth of alluvial fill, as determined by White and others (1972).*

graben is repeatedly offset to the west. The Rio Grande rift is frequently offset to the east, although there are some southern basins with a geometry similar to that of Salt Basin graben.

Finally, Salt Basin graben has no through drainage, while the Rio Grande rift is drained by the Rio Grande. However, integration of some of the basins in the Rio Grande rift is a relatively recent phenomenon (Strain, 1958). Barring another major structural change, the drainage of Salt Basin will be captured by the Rio Grande when deposition raises the basin level a few tens of meters higher.

## INTERPRETATION OF AERIAL PHOTOGRAPHS

Before any fault scarps could be recognized, it was necessary to determine the geomorphology of an undisturbed arid basin system. A bolson is characterized by semi-circular alluvial fans which radiate from the narrow canyon mouths at the bases of the surrounding mountains. Both the steepness of the fan dip and the size of the fanglomerate particles quickly decrease as the fans spread and coalesce basinward. Lakeshores at the bases of the fans may be expected to have minor beach deposits, and wave-cut benches would be scarce as standing water is ponded only briefly. Lakebeds in Salt Basin are rarely water-covered for more than a few weeks each year. Once the lakes are filled, the water rapidly recedes as the intense heat during the rainy period and the low slope of the lakebed (less than one percent) combine to create optimum evaporation conditions. The outline of the playa lakes should be highly irregular due to transgression of windblown sands and the eccentricities of the nearly level basin floor. Where alluvial fans have built out into the lakes, the shoreline should be correspondently concave.

The most obvious appearance of a fault scarp in an aerial photograph is that of a dark lineament high on the fan flank bearing orthogonally to the fan slope (fig. 4). The darkness may be due to the scarp shadow, a change in soil type and hence a change in its albedo, or, most commonly, the preferential growth of brush along the normally better irrigated fracture.

Unusual topographic shapes, particularly straight edges, may indicate fault activity. Many aerial photographs show alluvial fans terminating in straight sharp "benches." These "benches" are almost all orthogonal to the slope of the fans (fig. 4). Normally, alluvial fans develop broadly arcuate fronts (Cooke and Warren, 1973). The possible effect of wave action cutting these 'benches' when water reaches the fan edges may be discounted due to the short duration of the floods. By the same token, straight edges on the playa lakes should be regarded with suspicion. Several of the salt lakes near Dell City have straight shores that trend in the same direction as nearby faults.

Exceptionally sharp and straight boundaries between mountain fronts and alluvial fans observed in conjunction with the appearance of smaller fans resting atop the larger well developed fan surfaces suggest recent movement along this sort of interface. An example of this may be seen at Bitterwell Mountain, which suggests that the basin has been downdropped relative to the Mountain (fig. 5).

A more subtle change in topography indicating recent faulting is a change or disruption is the stream patterns (fig. 5). These drainage anomalies may also suggest the relative youthfulness of a fault. Streams may be offset across the fault (northwest corner of Bitterwell Mountain), or the depth of incision may change abruptly as the streams cross a fault (southwest corner of Bitterwell Mountain). In both cases, the anomalies have occurred on several streams and are closely aligned over a kilometer and a half distance. The streams on the mountain side of the lineaments appear to be more deeply incised. This suggests that the lineaments are faults and that the relative movement was down to the basin. This in turn would lower the stream base level and thereby cause the "upthrown" reach of the stream to become more deeply entrenched.

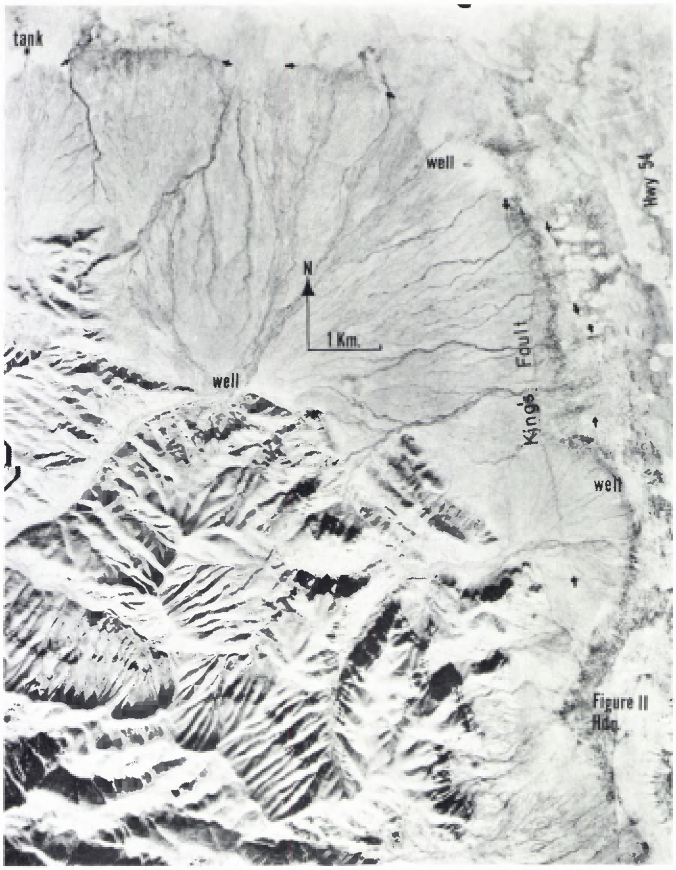


*Figure 4. Fault scarps bounding and cutting Apache Canyon fan, off the Diablo Platform, along the Babb Flexure and "Bitterwell break." The long north-south scarp was mapped by King (1948) and is named King's Fault in this paper.*

The youthfulness of the faults southeast of Dell City is suggested by lineaments found on the aerial photographs. The photographs show the mouth of Eightmile Draw to be cut by several northwest-bearing lineaments which are now known to be faults. These scarps, usually less than a kilometer long and two meters high, have formed an en echelon pattern that has remained sharp and distinct despite having been crossed by frequent and severe flash floods.

## FIELD IDENTIFICATION OF FAULT SCARPS

### Mid-Fan Scarps

The fault scarps rarely exceed two meters in relief and are readily confused with stream levees and apparent alignment of fan lobes. The scarps are nearly impossible to discern when viewed from upslope, as displacements were universally down to the basin. The fault scarps are most easily seen from a distance of a kilometer or more downslope. At this distance the abrupt change in fan slopes is obvious. However, as one proceeds up the fan toward the scarp, its features become obscure. The linearity of a scarp, easily seen over its total length of a kilometer or more is camou-

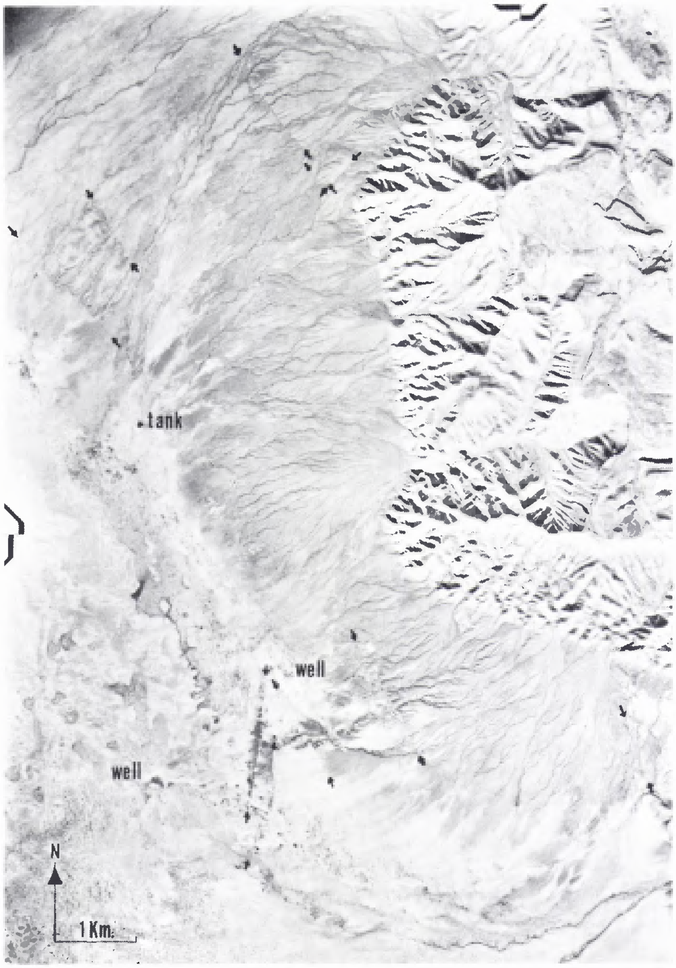


*Figure 5. Fault scarps in the alluvial fans west of Bitterwell Mountain. A bedrock outcrop is bounded by fault scarps north of the tank. Notice the unusually sharp linear boundary between Bitterwell Mountain and the fan surrounding it. See text for further comment. View in Figure 5 is northeast of that in Figure 4.*

A

B

*Figure 6. A) Looking southwestward at King's Fault and Apache Peak, along the east face of Sierra Diablo. B) Sketch made from the above photograph exaggerates the geomorphology. The white lineament in both views is the fault scarp face. Relief along the fault is 2 to 3 m.*

flaged by the fan curvature and smaller scale irregularities of the fracture. Occasionally, the scarp has a lobate appearance when viewed at close range. This appearance is enhanced by the rounded slope of the fanglomerates forming the scarp face.

Presumably, when faulting suddenly removed the basinward support from the top of the unconsolidated fan detritus, the exposed footwall responded by slumping forward. Post-faulting erosion has rounded and dissected some of the scarps giving them a bight-and-cusp expression. Often a scarp may be hidden by scrub brush that is taller than the scarp.

The north-striking fault scarp on the northeast corner of the Apache Peak fan was mapped (King, 1948) and is the longest scarp in the Salt Flat area (fig. 4). This fault, previously unnamed, will be referred to as "King's Fault" throughout the remaining text. The scarp dies out abruptly at its southern end. Four kilometers to the north the fault bifurcates. Each of these branches may be traced another kilometer to the north. The exact position of the northern terminus is unknown as both branches cross into silty lakebed deposits where erosion could have quickly effaced the scarps.

This fault served as a model used in recognizing faults within alluvial fans. Figure 6A is a view to the south along King's Fault. Figure 6B is a sketch done from the photograph simplifying the geomorphology. Notice the characteristic break in the slope of fan along the horizon. The white lineament in both illustrations is the fault scarp which has a displacement of one to two meters.

The break in slope is shown even more clearly in Figure 7. In this picture, an oblique view along the strike of King's Fault, one can see the coarse gravel cover on the face of the scarp. The increased slope of the scarp, relative to the fan, enables the periodic sheet floods to carry off larger sized particles from the scarp face than they normally could from the fan. The result of this sudden and short increase in erosion capability is that the fault scarp becomes armored with a coarser pavement than that on either the upper or lower fan surfaces. Frequently, the upper fan surface is covered by desert pavement with individual cobbles of three to ten centimeters in diameter. Deposits on the lower fan surface tends to be less well sorted. The winnowed silt and clay from the upper surface and from the face of the fault scarp are deposited at the base of the scarp, where the fine sediment is often protected from the wind.

The youth of King's Fault is indicated by the poorly developed nick points along its length. Except for the arroyos cut by major fan streams, the nick points were an average of eleven meters upslope from the main scarp. Many of the stream channels had multiple terraces, a phenomenon which could be produced by either variation in local climate or by multiple movements along the fault trace.

*Figure 7. An oblique view to the north along King's Fault scarp. El Capitan peak is in the center background. Notice the armor of caliche and limestone cobbles on the face of the scarp.*

Clark (1972 a, b) described the 1967 Borrego Mountain, California, earthquake of intensity VII (modified Mercalli scale). Like the Valentine earthquakes, it too occurred in a desert basin area. However, in contrast with the probable normal dip-slip movement of the Valentine earthquake, the movement during and immediately after the Borrego Mountain earthquake was predominantly oblique strike-slip. The major fault scarps were frequently accompanied by smaller parallel fractures, usually on the downslope side of the fault trace. Smaller linear features, such as aligned vegetation and smaller fan breaks are parallel and downslope from King's Fault (fig. 4). These may be the remnants of subsidiary fractures similar to those formed during the Borrego Mountain earthquake.

### Lakeshore Scarps

Lakeshore faults form another classification of normal fault scarps in Salt Basin. These faults cut the toes of the alluvial fans and form linear scarps which act as lakeshores when the playa lakes flood beyond capacity. The contrast of the geomorphic surfaces on either side of the lakeshore scarps is more distinct than that of the mid-fan scarps. Like the mid-fan scarps, lakeshore scarps are mantled with a coarser gravel than is either of the two adjacent surfaces. However, the basinward surface, or the downthrown surface, is frequently covered with very fine evaporite-rich playa deposits. A recently developed feature related to these scarps is a network of unimproved ranch roads built along the edge of the upthrown surface. It seems these surfaces are the most basinward stretches that can be maintained with a minimum of repair after flooding.

### Bedrock Boundary Scarps

The fault boundary between bedrock and alluvial deposits is a third type of recent fault scarp, which is distinguished by a change in geomorphic surfaces across the scarp. South of Dell City, where the fault scarps strike northwest, stream channels draining off the Bone Spring Limestone plateau are displaced down-to-the-basin at least three times along northwest-striking faults. West of Bitterwell Mountain a kilometer-square block of limestone is bounded on the east and the west by northwest-trending faults (fig. 5). The easternmost fault may be the only recent east-dipping normal fault on the east side of Salt Basin. Zones of caliche-cemented fanglomerate and limestone breccia were found along the faults. The largest of these bedrock-bounding faults in the Salt Basin is along the base of Bitterwell Mountain.

Similar relationships between alluvium and bedrock valley walls may be seen in the north-northwest-trending valleys of the Apache Mountains. The vertical adjustments within the western Apache Mountains appear to be related to the tectonics of Salt Basin graben.

The most obvious of these active bedrock-bounding faults is a north-south-striking fault just west of Van Horn on the McVay Ranch (Yates Ranch on topographic map). In Figure 8 the sharp boundary between Precambrian Van Horn Sandstone and the Holocene alluvial fill is obvious. The scarp is nearly continuous from a normal fault in the Beach Mountains to the eastern front of Threemile Mountain. The three-meter-wide massive caliche deposit that marks the fault trace is breached only once, at Hackberry Creek. The creek has flooded Van Horn to a depth of a meter or more several times in the past (Wiley, 1973). Apparent vertical displacement on this fault is down to the east and increases from two meters at the north end to six meters at the south end. Mapping (Muehlberger and others, 1978) indicates that the McVay scarp is the northern section of a series of fault scarps which cut the western alluvial fans of Lobo Valley and continue southward to become the Mayfield Fault scarps.

The Mayfield Fault extends over 80 km southward from Van Horn through the alluvial fans of the Van Horn Mountains and the Sierra Vieja. It forms the longest continuous fault scarp (35 km) in the Salt Basin graben area. R. Belcher (Muehlberger and others, 1978) mapped the largest displacement on any recent fault scarp in the graben, an apparent down-to-the-east displacement of 7 m. This scarp is located where the Mayfield Fault breaks into a series of en echelon fault scarps on the Miller Ranch, west-southwest of Valentine, Texas. This same segment was also shown to demonstrate the only evidence of recurrent movement known in Salt Basin graben.

The majority of the recent fault scarps in Salt Basin trend to the north or northwest and occur singly or in en echelon patterns. The fractures about the Baylor Mountains are the only linear features in Salt Basin bearing northeast, and the faults parallel to the northern boundary of Sierra Diablo are the only fault scarps to strike east-west.

King's Fault, which diverges to the north, and the southward-diverging faults in the fans adjacent to the southwestern corner of Bitterwell Mountain are the only fractures which have splayed into

*Figure 8. Looking northeastward across Wildhorse Flat toward the Apache Mountains and the Scott Canyon fan. Beach Mountain is to the far left. The tonal lineament is the scarp between the Precambrian Van Horn Sandstone (light color on left) and the Holocene alluvium (dark color on right).*

two distinct arms (fig. 5). However, some linear fault traces appear to be the result of several parallel fractures such as the northwest-trending fault near the northwest corner of Bitterwell Mountain (fig. 9.).

One of the most unusual deviations from the regional fault trends is the bend found in the fault swarm southeast of Dell City. The trend changes from north in the area south of U.S. Highway 62-180 to the northwest in the area north of the highway at the longitude of Salt Flat. Individual fault scarps exhibit almost rectilinear bends to the northwest and maintain their en echelon relationships all the way through the deflection.

## FAULTS AND HYDROLOGY

Lineaments of thicker, more verdant vegetation frequently result from the concentration of moisture and finer soils in the fracture zone of a fault. During the summer months, when the field work was done, most of the vegetation appeared to be brown and parched. However, the vegetation along fracture zones formed distinctive green lineaments that were easily mapped. The thickened growth of brush at the base of King's Fault and on the trace of a fault 14 km north of Van Horn in the Beach Mountain fan (fig. 10) are examples of this.

A

B

*Figure 9. A) View to the southwest of a fault scarp northwest of Bitterwell Mountain. Notice the abrupt change in the stream channel pattern where it crosses the fault toward the basin in the upper portion of the photograph. B) View to the northwest along the strike of the same fault. This scarp was either produced by normal down-to-the-basin movement on en echelon faults or by recurrent movement along a single fault.*

*Figure 10. Looking southward along the north-south-striking fault trace in the Beach Mountain fan (vegetated lineament). The Wylie Mountains are in the haze in the distance. Notice the depression in the alluvial fan parallel to the fault.*

Linear depressions formed by the collapse or compaction of the basin fill within the fracture zones may capture streams and divert the flow along the fault traces. Examples of this may be seen at the base of the cliffs north of the Babb Flexure, at the head of the Apache Canyon fan and in the Beach Mountain fan.

More subtle indications of alluvial faulting are found in changes of the water table and in the salinity of the groundwater. Alluvial faults can behave as semipervious barriers (Williams, 1971; Clark and others, 1972; Castle and Youd, 1972; Waanamen and Myle, 1972; Kreitler, 1976; Holzer, 1976). Pumpage on one side of the fault causes pressure declines and aquifer or reservoir compaction on that side of the fault and not on the other. Tension on the ground surface may be produced by differential sediment compaction caused by the elastic expansion and shrinkage of the aquifer. This is translated to the surface as differential land subsidence or fault movement along a pre-existing plane (Kreitler, 1976).

Hood and Scalapino (1951) describe a water table barrier separating Lobo Valley from the Wildhorse subbasin of Salt Basin. The displacement along the east-west barrier is down to the north. The water table was found to drop from 27 m below the surface at Lobo to 120 m below the surface at Van Horn. The average slope of the water table exceeded that of the valley floor and increased from a uniform 2.3 m/km to 4.1 m/km at the latitude of the southern Wylie border fault. Hay-Roe (1958) suggested a water table break, down to the south, parallel to the south Wylie border fault. Twiss (1959) found evidence for this fault in the Van Horn Mountains at latitude 30°49′W: "at this point a north-flowing stream makes a right-angle turn and drains eastward into Lobo Flat." He described this feature as a down-to-the-south normal fault which divides Lobo Valley and acts as a boundary between a half-graben in the south and a full graben in the north.

B. G. Baker (1952) described a distinct difference in the groundwater in the northern and southern parts of Michigan Draw: south of 30°56′N the mineral content is comparatively low but north of this line the water contains such quantities of gypsum and other minerals as to be potable only to livestock. Although Baker postulated a transverse anticline blocking the groundwater flow, Hay-Roe (1958) suggested a fault.

Resistivity lines run by White and others (1977) suggest that the basin is unusually shallow in the vicinity of Wylie Mountain. This and the data of Hood and Scalapino suggests that the fault or faults that bound the north side of Wylie Mountain continue across Lobo Valley and possibly Michigan Draw and that the groundwater flow from the south is partially blocked by a horst block which includes Wylie Mountain.

The alluvial faults of Salt Basin serve an important economic function by forming semipermeable barriers. The gouge zones of the faults apparently separate the fresh water on the mountain side from saline water on the playa side. Mr. J. Garlick, Manager of the Figure Two Ranch, reported locating sweet water above the "chalk line" (King's Fault and other faults) and salty water below. Most of the older wells below the faults yielded brackish water, while the six new wells drilled into the mountain side of the fault produce sweet water (Garlick, oral commun., 1976). In one case the well was relocated less than half a kilometer above the old well. A survey about Salt Basin will show that most of the wells presently in use for cattle ranching are located above the fault scarps.

## A MODEL OF THE GRABEN

Salt Basin graben was initiated and continuously deformed by east-west crustal extension. Tensional experiments done with clay cakes have produced grabens with outlines and fracture patterns very similar to those of Salt Basin graben (H. Cloos, 1939, and E. Cloos, 1955).

The downdropped blocks underlying the basin deposits are settling unevenly but differentially to the west and southwest. Older evidence for this supposition is shown by the presence of a highly faulted flexure along the eastern border of the east side of the Basin. The Patterson Hills, Black Jack Mountain, and the western Apache Mountains are the highest standing remnants of the continuation of this flexure beneath the basin. The Baylor Mountains are the only surficial evidence of a large downdropped block on the western side, and it may be outside of the currently active portion of the graben. The bight-and-cusp outline of the western Sierra Diablo may have been produced by the more sudden and more extreme downdropping along the western side of Salt Basin graben.

The preferential development of the Salt Lakes along the western side is recent evidence of a westward tilting of the basement blocks. The resistivity lines run by White and others (1977; fig. 3 this paper) show that Salt Lakes are almost invariably located over the deepest basin fill. The lakes have remained on the west side and in many cases have apparently shifted westward despite the active deposition by a preponderance of eastward-flowing streams draining into the graben. As almost all the rain received in the drainage basin falls on the west side of the graben, these streams would normally develop larger fans, forcing the lakes eastward.

The preferential development of normal down-to-the-basin fault scarps in the Quaternary alluvium along the west side of the graben is the strongest evidence of continued tilting. The orientation of these scarps suggests that the forces acting now are in the same general direction as those which originally formed the graben.

The bolson deposits may have behaved brittley where caliche cementation was well developed or plastically where unconsolidated fanglomerates and high water tables were present. Sharp fault scarps in the unconsolidated basin fill could have been produced by sudden shock, i.e., an earthquake producing momentarily brittle conditions. In apparent contradiction to the preceding statement, no fault scarps were reported to have formed in Salt Basin graben during the 1931 Valentine earthquakes; movement may have been minor and along pre-existing scarps.

King (1948; 1965) constructed a map of the faults and structural features that surround Salt Basin graben. By extending and interpreting the surrounding geology, three major breaks in the floor of the graben were suggested (fig. 2). The unnamed northernmost postulated break trends southeastward. Field mapping shows that Quaternary fault scarps and photolineaments have courses parallel to this trend. The Babb and Victorio Flexures form the next two breaks to the south. Faults related to the Texas Lineament strike nearly east-west, north and south [latitude 30°56′N (Michigan Draw) and latitude 30°54′N (Lobo Valley)] of Wylie Mountain. Each of these breaks or zones of topographic change is related to a possible down-to-the-north fault zone.

The presence of an additional east-west striking fault zone is suggested by several anomalies between the Babb Flexure and Bitterwell Mountain. The only known eastward-dipping portion of the graben floor was located by White and others (1977) on the northeast-striking resistivity line (B-B′) between Doublewells on the Apache Peak fan and the southwestern corner of Bitterwell Mountain (fig. 3). The east-west orientation of this feature, which may resemble the Babb and Victorio flexures, is suggested by the strikes of the Quaternary fault scarps (fig. 4). The scarps north of the Babb Flexure strike due east rather than southwest as do the pre-existing bedrock faults. King's Fault, the longest fault in Salt Basin, bifurcates and abruptly dies out at the latitude of the east-striking Quaternary scarps (fig. 4). On the east side of the bolson the fault pattern changes strike from southeast, north of this latitude, to north-south, south of this line. The basinward faults immediately above the east-west "Bitterwell break" are also bifurcated, opening toward this zone (fig. 5).

A long salt lake trending east-west is located just north of the Quaternary scarps along the Babb Flexure (fig. 4). The relationship between basin depth and Salt Lake formation and the resistivity data near Bitterwell Mountain suggests that the displacement along the Bitterwell break, as with the other fault zones in the floor of Salt Basin and Salt Flat, is down to the north. The band of faults that continues northeastward from Bitterwell Mountain and the faults of Sierra Diablo related to the Babb Flexure are all down-to-the-north as well (Barnes and others, 1975).

The most easily seen feature of the "Bitterwell break" is the reversal of topography and structure that occurs across this zone. As described earlier, the east side is high for the northern segment and the west side is high for the southern segment (fig. 3).

## CONCLUSIONS

Basin and Range deformation in West Texas produced several fault-bounded basins between elongate mountain ranges. The fronts of the mountain ranges forming the walls of Salt Basin and Salt Flat were examined, and fault scarps that were present in the Quaternary basin fill were mapped. By restricting the mapping to fault scarps in active alluvial fans, it was possible to establish a minimum of age for most of the deformation.

The fault scarps cutting alluvial deposits define the present-day eastern boundary of Basin and Range faulting in Trans-Pecos Texas. These faults are found in the Salt Basin graben north of Van Horn, Texas, and in its southerly extensions along Lobo Valley and Michigan Draw. Discontinuous and en echelon Quaternary fault scarps quickly die out to the south on the eastern side of the graben but become more continuous and develop larger displacements (up to 6 meters) along the west side of Salt Basin at the base of Sierra Diablo.

The orientation of the more than one hundred Quaternary down-to-the-basin fault scarps and photolineaments appears to be controlled by pre-existing structural zones of weakness.

The preferential alignment of Quaternary (Holocene?) fault scarps along the western side of the graben, the westward shifting of playa lakes and the preferred orientation of giant desiccation polygons show that the graben floor is subsiding more rapidly along the western margin. These faults also separate fresh from saline ground water.

A tectonic origin is suggested by the orientation of the scarps and the proximity of the Mayfield fault scarps to the estimated epicenters of the 1931 Valentine earthquakes. The frequency of small earth tremors felt by the residents of the basin and recorded by temporary seismograph stations indicate tectonic adjustments are presently occurring.

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