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Structural Development of the Toquerville-Pintura Segment of the Hurricane Cliffs, Utah

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ABSTRACT.—The section of the Hurricane Cliffs north of Toquerville, Utah, is structurally an asymmetrical anticline which plunges to the north and is truncated on the south by the eastward bend of the Hurricane fault trace.

Minor structures within the anticline include thrust faults and related compressional folds, antithetic faults, normal faults, and drag folding into the west-dipping Hurricane fault zone. The east flank of the fold dips eastward at about 40°. Dips on the west flank range from 25° to 30° but increase abruptly to nearly 65° where the limb is flexed into the Hurricane fault zone

Asymmetry of this fold and the associated minor structures indicate that the overall structure is the result of several periods of deformation beginning in the Cretaceous period. The first disturbance resulted in a long north-trending anticline, subsequently faulted along its axis north of Toquerville by a succession of later periods of normal faulting which modified the structure to its present configuration. It is concluded that the east flank of the structure represents the remnant Late Cretaceous-Early Tertiary (Laramide) fold whereas the steeper west limb is interpreted as a later drag flexure.

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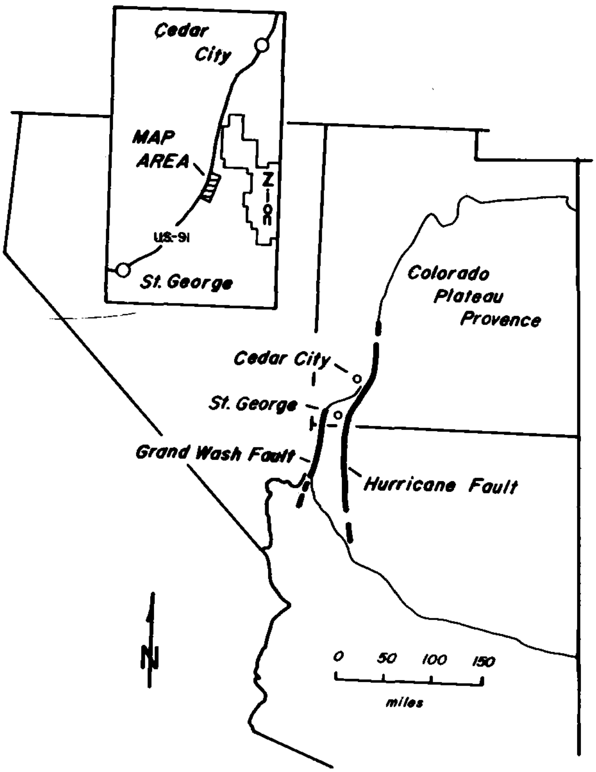
INTRODUCTION

The southwestern quarter of the Colorado Plateau is characterized by vast expanses of nearly horizontal strata broken by large north-south trending fault-flexures, well known for their extensive length. Dutton (1882, p. 19) described these features as "the Great Faults and Flexures which traverse lengthwise the district of the high plateaus and the Grand Canyon . . ."

The Grand Wash Fault, the westernmost of these large fault zones, marks the southwest boundary of the province from the Grand Canyon to the Utah-Arizona border. Near St. George, Utah, this fault dies out and the province boundary is located several miles to the east along the prominent escarpment associated with the Hurricane Fault zone (Dutton, 1880, p. 7) (Text-fig. 1).



TEXT-FIGURE 1.—Index map of Toquerville-Pintura segment of the Hurricane Fault, near Cedar City, in southwestern Utah.

This escarpment can be traced from south of the Grand Canyon in Arizona north into Utah for over 160 miles. Near Toquerville, Utah, the escarpment, the Hurricane Cliffs, attains a vertical relief of slightly over 2,000 feet and overlooks the northern end of the St. George Basin. The Hurricane Cliffs is a composite fault escarpment which owes its relief primarily to vertical displacement along the Hurricane Fault zone. The section of the cliffs immediately north of Toquerville, Utah, is anticlinal (Text-fig. 2). The east limb of the anticline tends to dip more steeply than the west limb. Along the fault zone, where recent drag has accentuated flexure of an older structure, the westward flexure increases to nearly 70° locally. A history of at least four major periods of deformation since deposition of the oldest rocks, the Permian Pakoon Limestone, is evident from structural and stratigraphic relationships in this area.

ACKNOWLEDGMENTS

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STRATIGRAPHY

The stratigraphic units present in the Toquerville-Pintura segment of the Hurricane Cliffs include sedimentary rocks of Wolfcampian, Leonardian, Guadalupian, and Early Triassic ages. These older sediments are partially covered by Quaternary basalts, alluvium and colluvium.

The following discussion of these units is based on the investigations of Averitt (1962), Bissell (1963), Stokes (1963), and Watson (1967).

PERMIAN SYSTEM

Pakoon Limestone

The Pakoon Limestone is a Lower Permian (Wolfcampian) thin- to thick-bedded dolomitic limestone. Upper zones contain interbedded gypsiferous siltstones. Thicknesses in the mapped area exceed 300 feet. One thousand and forty feet were measured in the Pan American Petroleum Company No. 1 Pintura Well near Pintura, Utah (Bissell, 1963, p. 43).

Undivided Quantoweap Sandstone-Coconino Sandstones

The Quantoweap-Coconino Sandstone is a subrounded, fine- to medium-grained, light buff, cross-bedded, calcareous to dolomitic quartzose sandstone and is Late Wolfcampian to Leonardian. The upper portion of the formation is better sorted, lacks dolomite in the cement, and is thought to represent the Coconino Sandstone facies. Thicknesses are estimated to be in excess of 1,100 feet.

Toroweap Formation

The Toroweap Formation disconformably overlies the Quantoweap Sandstone-Coconino Sandstone (Bissell, 1963, p. 55). This formation is divided into four members: (1) a lower or basal, tan to buff, quartz sandstone similar to the Coconino Sandstone but without conspicuous cross-bedding, (2) a lower gypsiferous member, (3) a middle limestone member, and (4) an upper gypsiferous member. For mapping convenience the two lower members were mapped as the Alpha Toroweap and the two upper members as the Beta Toroweap. In the mapped area about 400 feet of Toroweap Formation is present.

Kaibab Limestone

The Kaibab Limestone consists of a lower massive, light to medium gray, fossiliferous, marine limestone and an upper gypsiferous, thin-bedded, argillaceous limestone with interbedded calcareous, red mudstones. Fossils collected from this formation are Late Leonardian. Thicknesses in the mapped area are in excess of 300 feet.

TRIASSIC SYSTEM

Moenkopi Formation

The Moenkopi Formation disconformably overlies the Kaibab Formation and marks the base of the regional sequence of Triassic continental red beds. Only the two lower members of this formation are present along the west face of the cliffs in the mapped area. These members are not everywhere present, having been removed by recent erosion except where preserved in slices along the Hurricane Fault zone or preserved beneath Quaternary basalt remnants. The basal or Timpoweap Member is conglomeratic with interbedded sandy limestones and red shales. Pebbles consist of subrounded chert, limestone, and quartzite, less than one inch in diameter. Above the Timpoweap Member is the Lower Red Member which consists predominantly of dark red, gypsiferous shales with thin interbedded lenses of selenite, alabaster, and satin spar. Only about 25 to 30 feet of the Moenkopi Formation is exposed in the mapped area.

QUATERNARY SYSTEM

Basalt Flows

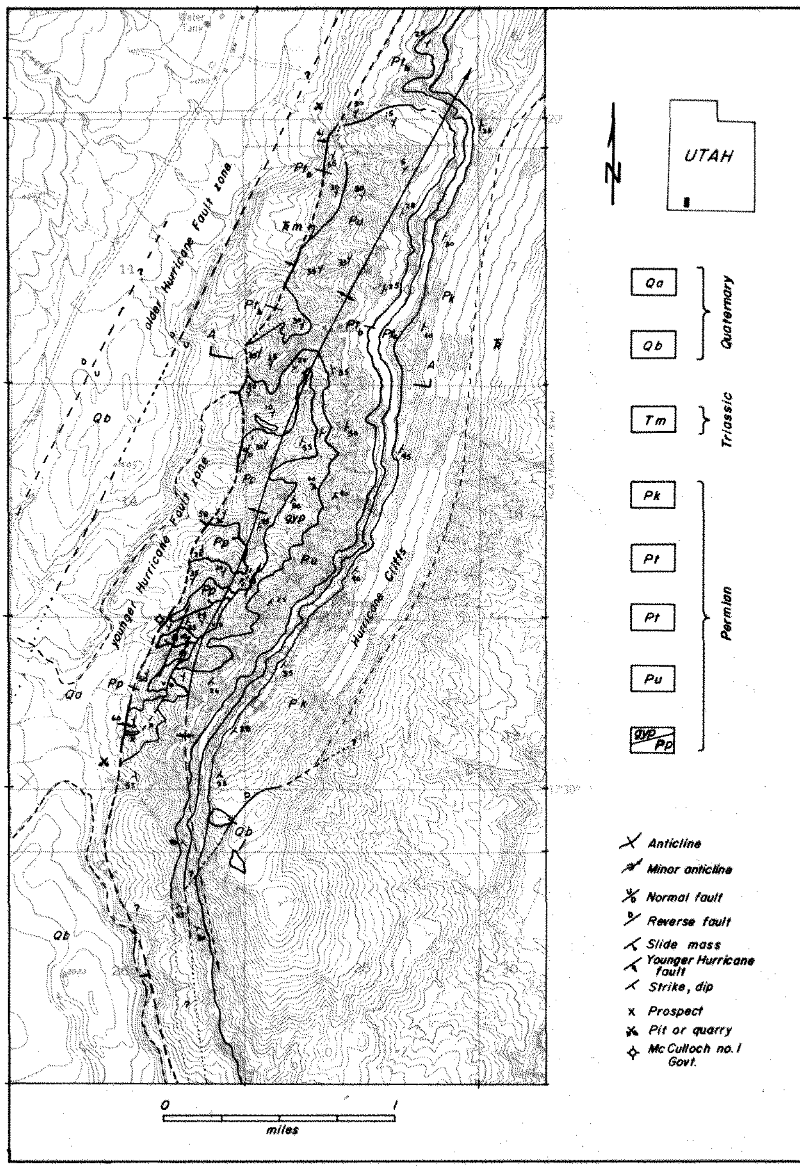
Basalt flows in the mapped area were extruded onto an older erosion surface preserved in several inverted valleys and erosional plateaus. They are described as stage II-c by Hamblin (1963). Remnants of the flows are found overlying former stream channels and terraces along Ash Creek and at the top of the escarpment.

Unconsolidated Debris

Many of the slopes and ravines are choked wih colluvium and alluvium derived from the Permian and Triassic sediments and basalt debris derived from Quaternary flows along the fault zone. Debris consisting of Jurassic and younger sediments and Tertiary intrusive and extrusive rocks are brought into Ash Creek from the west by streams draining from the Pine Valley Mountains.

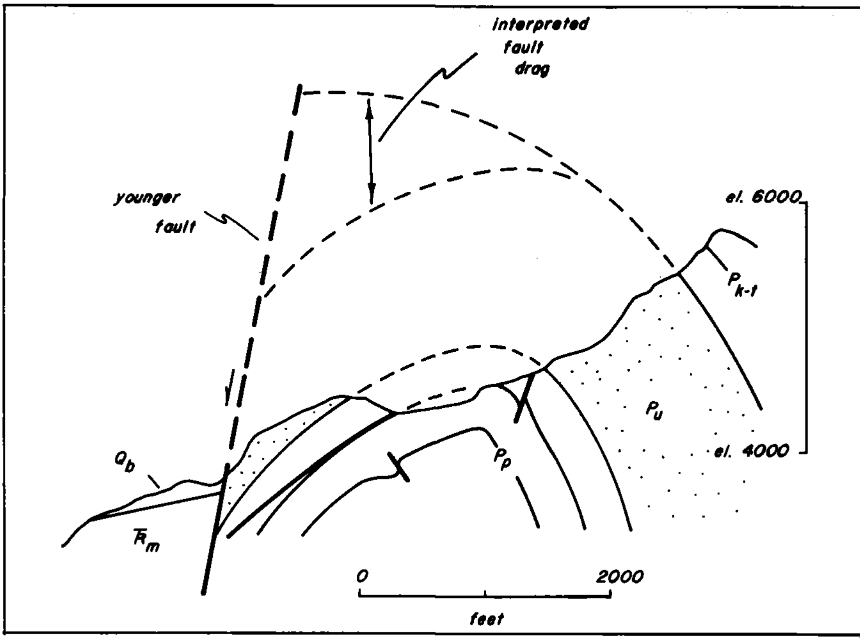
STRUCTURE

North of Toquerville, Utah, the Hurricane fault zone is approximately a mile in width (Text-fig. 2) and is characterized by two major periods of faulting. An older fault zone lies west of Ash Creek and is evident from offset of limited exposures of Paleozoic, Mesozoic and Tertiary sedimentary rocks and Tertiary and Quaternary extrusives. A younger period of faulting is restricted primarily to a large fault scarp, the Hurricane Cliffs. Several of the arroyos dissecting the west escarpment of the cliffs afford good exposures of the younger fault surface. Measurements taken on these exposures show that, at the present level of erosion, this fault is a high-angle normal fault which strikes N. 30° to 35° E. with a westward dip of 58° to 60°. Examination of exposures of the fault surface indicates only a dip-slip movement. Where exposed, the fault plane appears to be planar. However, logs from the McCulloch I Govt.-Wolf Well in Sec. 23, T. 40 S., R. 13 W., indicate that the fault plane may not be consistently planar and may be locally flexed eastward at depth (Kurie, 1966, p. 869). Such phenomena seem to be relatively common to many high-angle faults and usually represent a nonplanar nature of the fault surface. Kurie (1966) suggested that the well may have wandered from the vertical, intersecting the fault plane twice.



TEXT-FIGURE 2.—Geologic map of the Toquerville-Pintura segment of the Hurricane Cliffs. Base from the La Verkin 2 SE, Utah preliminary quadrangee sheet.

Cross section A-A (Text-fig. 3) shows the internal structure of this section of the cliffs to be an asymmetrical anticline. Dips on the east flank of this fold approach 40°, while those of the west flank range from 20° west near the axis, to 65° west approaching the Hurricane fault zone. Beds in the lower Pakoon



TEXT-FIGURE 3.—Geologic cross section through the Hurricane Fault zone and the northern part of the asymmetrical anticline north of Toquerville, along line A-A′. The amount of interpreted fault drag along the Hurricane Fault is shown by divergence of the projected basal contact of the Toroweap Formation on the undifferentiated sandstones below. P_{k-t}, Kaibab and Toroweap formations; P_u, undifferentiated Quantoweap and Coconino sandstones; P_p, Pakoon Limestone; Tr_m, Moenkopi Formation; Q_b, Quaternary basalt flows.

Formation (Permian) near the axis of the fold are crumpled and broken by minor faulting. Bedding thrusts were observed in the upper portion of the formation (Text-fig. 3). Much of this deformation is thought to be associated with drag folding on the younger fault.

Near the younger fault (Text-fig. 2), tensional deformation predominates. Bedding faults, slide masses, en echelon subsidiary faults, and drag folding into the major fault plane are present (Text-fig. 4). One mile north of Toquerville the younger fault truncates the anticlinal structure (Text-fig. 4). In this area the Kaibab Limestone and Toroweap Formation are folded sharply into the fault line (Text-fig. 2). As the result of this drag folding, bedding in the Kaibab Limestone and the Moenkopi Formation veer east and dip steeply south into the fault zone. East of the McCulloch I Govt.-Wolf Well (Text-fig. 2), a small east dipping normal fault parallels the axial plane of the main fold and displaces the lower Permian formations approximately 50 feet, faulting the Quantoweap-Coconino Sandstone against Pakoon Limestone. At the southern end of the structure a high angle reverse fault (Text-fig. 2), located between two basalt remnants, displaces the Permian strata exposed in the cliffs. Basalt remnants at the top of the cliffs (Text-fig. 2) can be correlated stratigraphically with lavas to the west at the base of the cliffs. Dislocation of these remnants by the Hurricane fault is approximately 1,500 feet and represents a major portion of the post-basalt displacement along the Hurricane Fault zone. Basalt remnants on the up-thrown block lie on the Kaibab Limestone, while those on the down-thrown side of the fault are underlain at many places by the Lower Red Member of the Moenkopi Formation. This relationship would indicate that some displacement had occurred along the younger fault prior to emplacement of the basalts.

GEOLOGIC HISTORY AND TECTONIC DEVELOPMENT

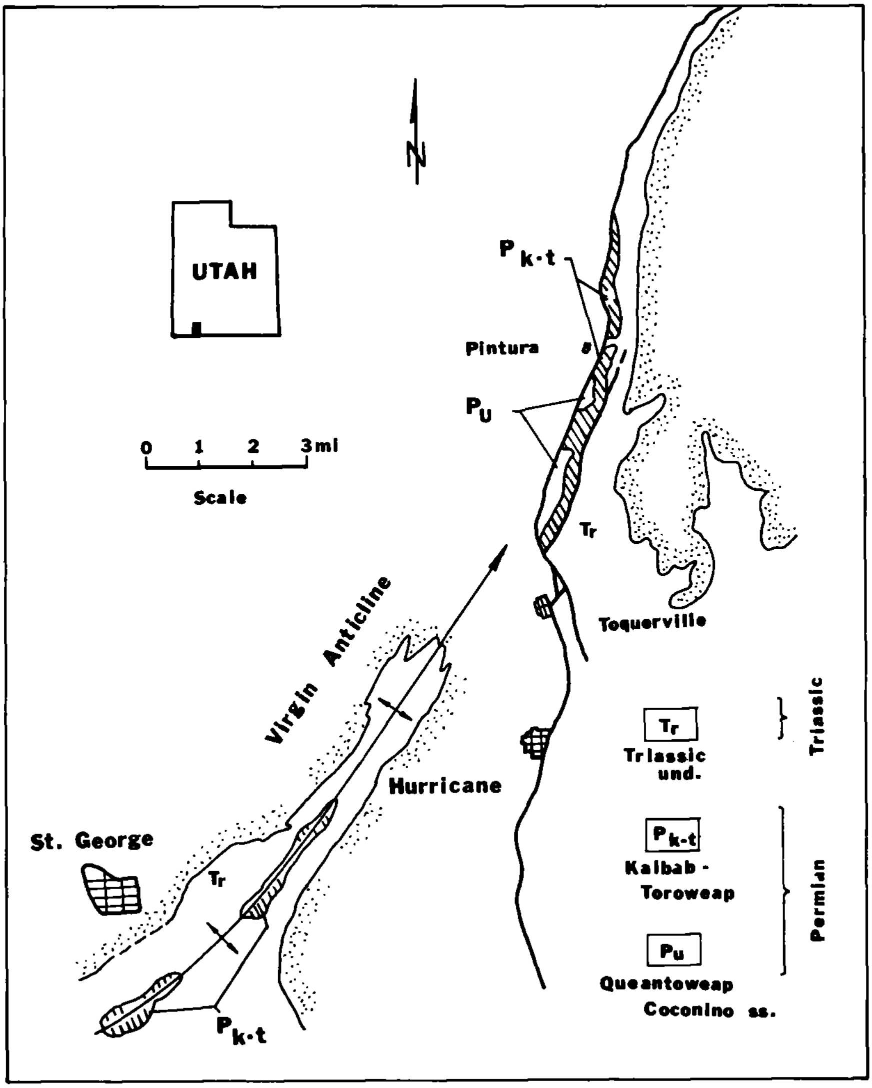
Structure of the Toquerville-Pintura segment of the Hurricane Cliffs exhibits evidence for at least four periods of structural deformation. During Late Cretaceous and Early Tertiary (Laramide), prior to deposition of the Claron or Wasatch Formation (Paleocene), several long, north-trending folds were developed in the Paleozoic and Mesozoic strata. Remnants of these folds strongly influence the present structure of the plateau margin from Cedar City south to St. George, Utah. The Kanarra Anticline north of the mapped area and the Virgin Anticline to the south are such remnants. Their alignment with the structure in the Toquerville-Pintura segment (Text-fig. 4) of the Hurricane Cliffs suggests that these three structural remnants are in fact the same fold.

This folding (Laramide) probably produced moderate topographic relief which resulted in nondeposition or in the removal by erosion of much of the Cretaceous and early Tertiary sediments (Text-fig. 5a). Erosion reduced the topography to a surface of low relief upon which the Wasatch Formation was subsequently deposited.

A second period of deformation, characterized by normal faulting, is described by Dutton (1880) as the relaxation of Laramide stresses. Dislocation, west of the present location of Ash Creek, resulted in several hundred feet of offset near Pintura, Utah (Gardner, 1941) (Text-fig. 5b). This period of normal faulting is thought to be associated with the beginning of Tertiary Basin and Range block faulting (late Eocene). Another erosional interval followed this second disturbance and bevelled the major escarpments, again reducing the topography to one of low relief. Extrusion of Miocene (?) (Averitt, 1964) latitic lavas related to the Pine Valley Mountain laccolith (Cook, 1960) filled existing stream channels and locally covered much of the pre-Miocene surface.

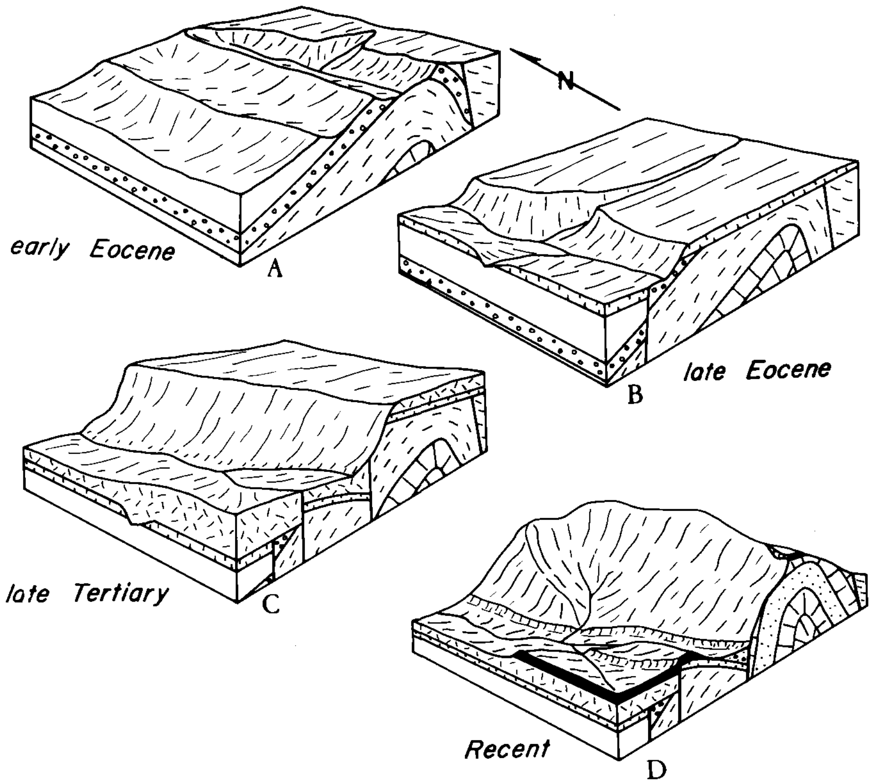
Following these Miocene eruptions, a third period of disturbance (thought by Gardner [1941] to represent the greatest amount of displacement in the region) began along the Hurricane fault zone. This disturbance resulted in nearly 8,000 feet of displacement and established a second major fault line to the east (Text-fig. 5c). Gardner postulated that this dislocation accounted for nearly 75 percent of the total displacement. He also stated that much of this dislocation may be the result of "down bending" or reverse drag along the down-thrown side of the fault zone. Reverse drag on the Hurricane fault zone is discussed in detail by Hamblin (1965). Kurie (1966) indicates evidence for only 2,500 feet of displacement in this region which is considerably less than Gardner's estimate.

The absence of post-Miocene deposits in this area suggests that a major period of erosion, probably extending into the Quaternary period, followed this second period of faulting. Much of the Miocene volcanics was removed



TEXT-FIGURE 4.—Geologic map showing relationships of the Virgin Anticline, west of Hurricane, to the anticline near Pintura and Toquerville, to the north. The Hurricane Fault cuts the anticlinal trend north of Toquerville.

along with large quantities of pre-Miocene sediments. The erosion resulted in the development of a broad pediment extending eastward from the Pine Valley Mountains. This surface is described by Huntington and Goldthwait (1903) as the "Mojave Peneplain." Topographic irregularities toward the end of this interval were probably restricted to structurally controlled ridges and valleys of alternating resistant and nonresistant strata. During the early



TEXT-FIGURE 5.—Block diagrams of structural development of the mapped area from Early Tertiary to Recent. Early Tertiary folding and moderate relief are shown in block A. Normal faulting along the Hurricane Fault zone cut Late Eocene sedimentary rocks which had been deposited over the folded older rocks, as shown in block B. Major movement along the Hurricane Fault zone during Late Tertiary time, following eruption of Miocene (?) latitic lavas, is shown in block C. Later basalt flows are shown as interrupted by recurrent movement along the Hurricane Fault in block D, to produce the Recent appearance of the region.

Quaternary, a second period of volcanism began, in which basaltic lavas were extruded from several centers onto the pediment surface. These flows inundated many of the former stream channels and lowlands. Several stages of extrusion are evidenced by the relations of various basalt remnants and flows to the drainage of the region (Hamblin, 1963). The flows in the vicinity of Ash Creek are regarded as stage II-c flows. Due to their occurrence as juvenile inverted valleys, they are thought to have flowed down the tributaries and channels of the ancestral Ash Creek.

Near the end of this period of vulcanism, renewed movement along the Hurricane fault gave rise to the fourth period of structural disturbance (Text-fig. 5d). The major portion of this fourth disturbance occurred along the younger fault line east of the original fault zone. This renewed movement gave rise to the escarpment now called the Hurricane Cliffs. In the Toquerville-

Pintura area, displacements along this younger fault exceed 2,000 feet. Conclusive evidence for displacement of this magnitude can be obtained from the offset of the Quaternary basalt flows. Lava remnants on the upthrown side of the fault are nearly 1,500 feet above those west of the cliffs. Additional dislocations of 30 to 50 feet in the older fault zone are apparent from dislocation of the basalt flows west of the younger fault line. These offsets are probably the result of renewed movement along the older shears.

Much of the drag folding evident along the cliffs can be attributed to this fourth period of disturbance. Dips on the Permian formations increase from 25° west to 68° west near the fault. In addition, where the younger fault truncates the axis of the original structure, the Permian carbonates capping the cliffs are dragged steeply downward into the fault zone. Drag folding of this magnitude is also evident near Pintura, Utah, where nearly horizontal beds are flexed westward with marked abruptness from 20° west to 60° west. It must be noted that some of this westward flexing may reflect relict dip from the older faulting and earlier Laramide folding. However, the abundance of tensional deformation along the west flank of the structure seems to indicate that the major portion of deformation or flexing of the west flank of the structure is due to the fault flexure of the younger Hurricane fault, while dips on the east flank are remnants of the Laramide disturbances.

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