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STRUCTURAL FRAMEWORK AND TECTONIC EVOLUTION OF THE FOUR CORNERS REGION OF THE COLORADO PLATEAU

by

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INTRODUCTION

The Colorado Plateau is an area that is structurally unique in the western United States insofar as it has been only moderately deformed compared to the more intensely deformed regions that surround it. Monoclines appear to be the most distinctive structural features of the plateau and most of the deformation has occurred along them (Kelley, 1955a). The geographically widespread uplifts and structural basins, however, are the main features that define the major tectonic divisions of the Colorado Plateau. Each of the uplifts in this report is bounded on one side by a major monocline (fig. 1).

This report is a generalized summary and synthesis of existing work and is an attempt to relate the structural evolution of this region to current concepts of plate tectonics.

TECTONIC SETTING

The Cordilleran foldbelt (fig. 2) which lies to the west and to the south of the Colorado Plateau (King, 1969) is characterized by flat-lying thrust faults that have yielded toward the foreland to the east and the northeast. Mostly, the zone of frontal breakthrough of the thrusts parallels and nearly coincides with the older zone of transition between the Cordilleran geosyncline and the platform along the western edge of the craton. Locally, the overthrust belt truncates the older geosynclinal margin and involves cratonic basement as in southern Nevada and southeastern California (Burchfiel and Davis, 1972). The traces of the thrusts appear to bend eastward into Arizona and may connect with a zone of thrusting in southern New Mexico (Corbitt and Woodward, 1973).

East and north of the Colorado Plateau lie typical uplifts and basins of the Rocky Mountain foreland. Many of the uplifts are bounded by range-marginal upthrusts (Woodward and others, 1972) and commonly have tens of thousands of feet of structural relief.

The intensely deformed regions noted above contrast markedly with the vast expanses of gently dipping strata and the scattered monoclines of the Colorado Plateau.

After development of the Cordilleran foldbelt, Rocky Mountain foreland and the basins and uplifts of the Colorado Plateau in the Late Cretaceous and early Tertiary, the Basin and Range structures were superimposed on the area to the west, south and southeast of the plateau. Epeirogenic uplift of the entire plateau apparently occurred late in Cenozoic time (Longwell, 1946) and may be related to the synchronous development of the Basin and Range structures. Lovejoy (1973) has suggested that much of the uplift of the plateau took place during early Cenozoic time. Regardless of the exact timing of uplift, it apparently occurred after the Laramide structures were formed.

STRUCTURE

Descriptions of the structures of the Colorado Plateau are based principally upon regional maps by Baker (1935), Luedke and Shoemaker (1952), Shoemaker (1954) and Kelley (1955b, 1960, 1967). Names and boundaries of the major tectonic elements of the plateau (fig. 1) are those proposed by Kelley (1955b, 1960).

Zuni Uplift

The Zuni uplift is about 70 miles long and up to 35 miles wide. It trends northwesterly and is markedly asymmetrical with a steep southwestern flank and a gently dipping northeastern flank (Dayton, 1928). There is over 8,000 feet of structural relief between the highest part of the uplift and the Gallup sag near the town of Gallup; maximum structural relief between the uplift and the deepest part of the San Juan basin far to the north is over 13,000 feet (Kelley, 1955b).

The western margin of the uplift is defined by the Nutria monocline which dips as much as 80° and has up to 4,600 feet of structural relief (Edmonds, 1961). Locally, there are minor monoclines along the northeast flank, but mostly the uplift merges with the Chaco slope along beds dipping 3°-10° (Kelley, 1967). High-angle faults having various strikes occur within the uplift and are common in the Precambrian rocks (Goddard, 1966) and reverse faults having up to 2,000 feet of stratigraphic separation have been noted by Edmonds (1961).

Defiance Uplift

The Defiance uplift trends north, is about 95 miles long and 35 miles wide, and is asymmetrical with a steep eastern limb (Gregory, 1917). There is at least 7,000 feet of structural relief between the highest part of the uplift and the adjacent Gallup sag.

The eastern boundary of the uplift is defined by the sinuous Defiance monocline which dips 20°-90° and has 3,000 to 6,000 feet of structural relief (Kelley, 1967). Sinuosity is caused by a number of southeast-plunging folds that cross the monocline. The western boundary of the uplift is marked locally by three monoclines having mostly moderate dips and a few hundred feet of structural relief. Elsewhere the western flank dips 2°-3° into the Black Mesa basin along a broad regional homocline. Northward the uplift merges with the Red Rock bench which, in terms of structural height, is intermediate between the Defiance uplift and the Four Corners platform.

The crest of the uplift is crossed by several northwest-trending, en echelon folds, including the Lukachukai monocline. Faults are not common, but two areas of high-angle faulting reported are the northeast-trending Tsaile graben in the

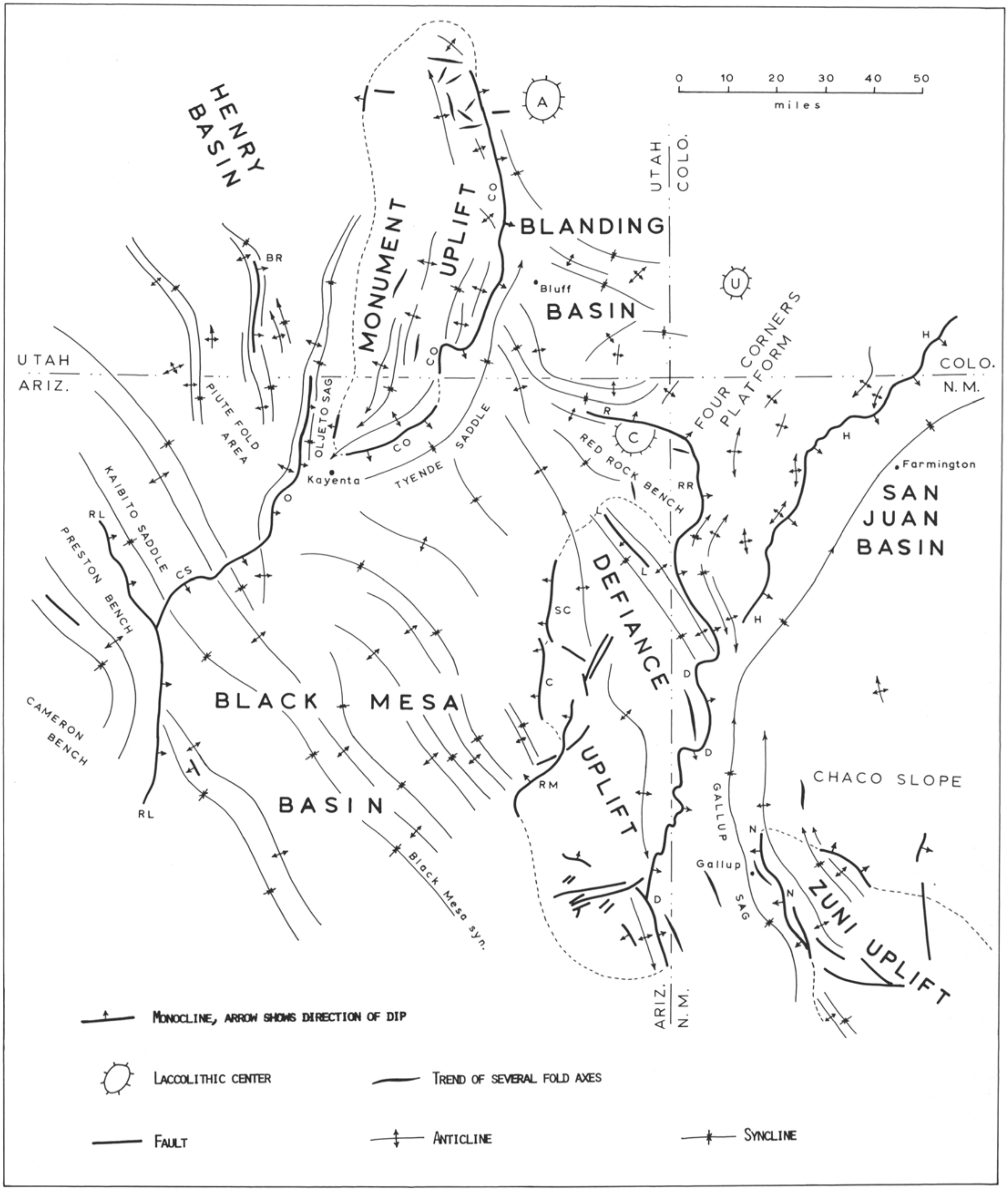

Figure 1.

Generalized tectonic map of Four Corners region of Colorado Plateau (modified from Kelley, 1955b). Abbreviations for monoclines are: BR, Balanced Rock; C, Chinle; CO, Comb; CS, Cow Springs; D, Defiance; H, Hogback; L, Lukachukai; N, Nutria; O, Organ Rock; R, Rattlesnake; RL, Red Lake; RM, Rock Mesa; RR, Red Rock; SC, Sheep Creek. Abbreviations for laccolithic centers are: A, Abajo; C, Carrizo; U, Ute. Dashed lines indicate boundaries of uplifts.

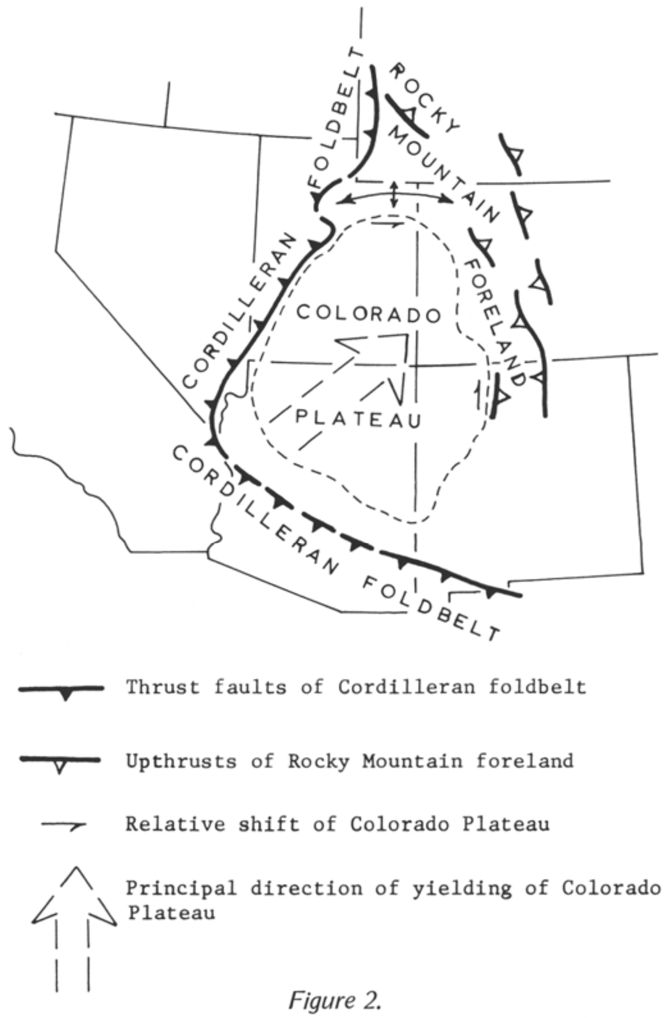

Figure 2.

Generalized tectonic map showing Cordilleran foldbelt, Colorado Plateau and Rocky Mountain foreland.

northern half of the uplift and the east-northeasterly trending Wide Ruins fault zone near the southern end of the uplift (Kelley, 1967).

San Juan Basin

Only the western part of the San Juan basin is shown in Figure 1; in its entirety it is nearly circular and about 100 miles in diameter (Kelley, 1957). It is strongly asymmetrical with the axial trace forming an arc near the northern edge of the basin. There is at least 6,000 feet of structural relief between the deeper part of the basin and the Four Corners platform to the west. Only a few gentle folds occur within the basin.

The northwestern boundary of the basin is marked by the Hogback monocline which dips as much as 60° and has up to 4,000 feet of structural relief within the area of this report. The trace of the monocline is sinuous because of many small, southeast-plunging, cross folds. The southern boundary grades into the gently dipping Chaco slope. The Gallup sag extends from the San Juan basin and separates the Zuni and Defiance uplifts.

Four Corners Platform

The Four Corners platform is intermediate in structural height between the surrounding uplifts and basins. Overall trend of the platform is northeast, but only the southwestern part is present in the area of this report. Here the platform has a maximum width of about 32 miles. There is only a few hundred feet of structural relief between the platform and the deepest part of the Blanding basin to the northwest.

The eastern boundary is defined by the Hogback monocline. To the southwest the Red Rock and Defiance monoclines mark the boundary, but farther north the platform merges westward with the Blanding basin.

Several domes and other anticlines occur within the platform. Axial traces of the folds tend to be arcuate and mostly trend north and northeast.

Blanding Basin

The Blanding basin is fairly shallow, having less than 500 feet of closure (Kelley, 1960). It is asymmetrical with the trough occurring near Bluff. There is at least 5,000 feet of structural relief between the basin and the top of the Monument uplift to the west.

Boundaries of the basin are clearly marked by the Comb monocline on the west, which has up to 3,000 feet of structural relief and dips moderately eastward, and by the Rattlesnake monocline on the southeast. This latter monocline dips gently northward and has about 500 feet of structural relief. Elsewhere, the Blanding basin merges through gently dipping strata with the adjoining structural divisions of the plateau. The Tyende saddle connects the Blanding and Black Mesa basins. A number of broad, open folds having various trends occur within the Blanding basin.

Monument Uplift

The Monument uplift is about 90 miles long, 30 miles wide, and trends slightly east of north. It is markedly asymmetrical with the steep eastern side formed by the Comb monocline. This monocline is somewhat sinuous in its southern part where it is crossed by south-plunging folds. The western flank of the uplift merges with the White Canyon slope which dips very gently into the Henry basin. The southwestern edge of the uplift is bounded by the Oljeto sag which connects the Black Mesa basin with the White Canyon slope.

Domes occur near the north end of the uplift and along the southeast edge. Parallel anticlines are present in the southern part of the uplift and numerous minor folds having various trends occur at the north end of the uplift.

Black Mesa Basin

The Black Mesa basin is shallow, nearly symmetrical, and is about 80 miles across. There is about 6,000 feet of structural relief between the deepest part of the basin and the top of the Defiance uplift (Elston, 1960).

Boundaries of the basin are gradational except on the northwest where the Red Lake, Cow Springs and Organ Rock monoclines define the limits of the basin and on the east where the Rock Mesa, Chinle and Sheep Creek monoclines mark the boundary with the Defiance uplift. The monoclines to the northwest dip moderately and mostly have a few hundred feet of structural relief (Kelley, 1955a). The Cameron and Preston benches that border the basin are intermediate in structural height between the basin and the Echo Cliffs uplift farther west. The Piute fold area consists of several north-trending, asymmetric folds.

Structural features within the Black Mesa basin consist of very gentle folds that trend northwesterly (Doeringsfeld and others, 1958). The Black Mesa syncline forms the deepest part of the basin and extends northwest through the Kaibito saddle (Kelley, 1958).

Laccolithic Centers

The three major laccolithic centers shown on Figure 1 are the Abajo (Witkind, 1958), Carrizo (Strobell, 1958) and Ute (Ekren and Houser, 1958) areas. These centers are characterized by complex, multiple domal structures that appear to be younger than the Laramide monoclines, basins and uplifts (Hunt, 1956) and have slightly modified the older structures.

TECTONIC EVOLUTION

Monoclines and related structures of the Colorado Plateau developed principally during Late Cretaceous to early Tertiary (Laramide) time, whereas epeirogenic uplift of the plateau as a whole probably took place later during Tertiary time. Minor doming related to injection of laccoliths and other intrusions occurred after Laramide time and modified some of the older structures.

A compressional origin for the monoclines has been proposed by Baker (1935) and by Kelley (1955a, 1955b) on the basis of geometry of the monoclines and the regional distribution of thrust faults of similar age in surrounding regions. Earlier workers, however, thought that vertically oriented forces had produced vertical faults in the basement with draping of overlying beds to form the monoclines (Powell, 1873; Dutton, 1880). It seems likely that primary horizontal compression deep within the crust beneath the Colorado Plateau resulted in local secondary stress fields near the surface having strong vertical components, perhaps similar to a mechanism proposed by Thom (1955) for wedge uplifts in the northern Rocky Mountain region. This implies a strong crust that was able to transmit horizontal stresses over long distances without intense deformation.

Kelley (1955b) suggested that en echelon folds along the eastern and northern regions of the plateau indicate that the plateau was pushed northeast relative to its surroundings (fig. 2). He has also pointed out that the small, diagonal, cross folds that cause the sinuosity of the Defiance monocline (fig. 1) are indicative of right shift along the monocline (Kelley, 1967), which is the same sense of shift as along the eastern margin of the Colorado Plateau (fig. 2).

Thus, northeasterly oriented compression during Laramide time resulted in shift of the plateau toward the north and the east and caused the monoclines and zone of right shift along the Defiance monocline to form within the plateau. This compression probably formed in response to westward drift of the North American plate over an eastward-dipping subduction zone, or possibly imbricate subduction zones (Lipman and others, 1972), along the eastern edge of the oceanic Farallon plate (Atwater, 1970). Lateral movement of large amounts of sialic crustal material by metamorphic flowage from the west to beneath the Colorado Plateau may have occurred during this time (Gilluly, 1963, 1973). This may account for the fact that the sialic crust beneath the Colorado Plateau is now much thicker than beneath the Basin and Range province to the west (Pakiser, 1963).

Northeastward yielding of the Colorado Plateau appears to be related to the sharp bend in the Cordilleran foldbelt in southeastern California (fig. 2) where the foldbelt structures cut into the crystalline basement rocks (Burchfiel and Davis, 1972). East-west compression in the Nevada segment of the Cordilleran foldbelt and nearly north-south compression in the foldbelt in Arizona and New Mexico give a resultant vector that trends northeast; thus, crowding and compression of the Colorado Plateau structural block by the forces in the foldbelt to the south and to the west resulted in pushing the plateau toward the northeast.

Transmittal of compressional stresses for long distances through the basement rock beneath the Colorado Plateau was probably facilitated by low thermal gradients, whereas the basement rocks in the foldbelt to the southwest were more easily deformed because of heat derived from the nearby subduction zone along the margin of the continental plate.

With continued westward drift of the North American plate and eventual overriding of the East Pacific rise (Menard, 1964), the subduction zone, or zones, were dissipated and movement along the western edge of North America began to be dominated by a strike-slip regime (Atwater, 1970). Resistance to Basin and Range-type faulting by the Colorado Plateau could be related to the thicker crust beneath the plateau and to its physical state.

When the currents in the mantle beneath the continental crust of the Colorado Plateau were dissipated after overriding of the East Pacific rise, the thick sialic crust that had been formed beneath the plateau by lateral transfer from the area to the west was free to rise isostatically. Thus, the Cenozoic epeirogenic uplift of the Colorado Plateau was probably an isostatic adjustment of the thick sialic crust (Gilluly, 1963) that had been derived laterally during the compressional deformation of the Laramide orogeny.

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