Lisenbee, A.L., 1988. "Tectonic History of the Black Hills Uplift" in Thirty-ninth Field Conference Guidebook, Eastern Powder River Basin – Black Hills. Casper, Wyoming: Wyoming Geological Association.

TECTONIC HISTORY OF THE BLACK HILLS UPLIFT

ALVIS L. LISENBEE[1]

ABSTRACT

Synchronous development of the intra-cratonic Powder River Basin and Black Hills uplift was initiated in the Paleocene as Laramide crustal stresses affected the coastal plain region of a retreating foredeep basin. Sediments stripped from the growing uplift helped fill the adjoining Powder River Basin through the Eocene, and were probably also transported northeast to the Williston Basin.

The Black Hills uplift, which joins the Chadron Arch on the south and the Miles City Arch on the northwest, has the gross character of a broad, doubly-plunging anticline with a maximum structural relief of 9000 ft. In detail, however, it consists of two north-trending structural blocks, the mutual boundary of which marks a zone of recurrent movement, at least in the Phanerozoic. A proterozoic core is exposed in the eastern block due to greater structural relief. On the west, abrupt (up to 5000 ft of structural relief), westerly facing monoclines separate gently west-dipping strata of the basin and uplift for a strike length of 150 mi. They are probably underlain by reverse faults. In contrast, the broadly arched eastern margin contains local, superimposed monoclines with 200 ft or less of structural relief. Three large, west-facing anticlines plunge from both the north and south ends of the eastern block.

A 20 Ma episode of alkalic magmatism associated with the Laramide orogenic event formed dikes, sills, stocks, laccolithic domes, diatremes and ring complexes; composite intrusions formed laccolithic clusters or doming of the basement. These occur in a westerly trending band which crosses the uplift, possibly along a deep basement fault which offsets the boundary of the Archean and Proterozoic provinces.

Oligocene strata of the White River Group covered most of the eroded roots of the uplift as well as the basin. Epeirogenic uplift in the Oligocene, and probably in the Miocene, and Pliocene, resulted in removal of most of these strata.

INTRODUCTION

The Black Hills uplift is the easternmost Laramide uplift with topographic expression. It extends from southeastern Montana to the South Dakota-Nebraska border (Figure 1), although the topographic expression is restricted to the smaller Black Hills and Bear Lodge Mountains.

The geometry and geologic character of the uplift has been described in numerous studies (e.g., Darton and Paige, 1925; Noble, 1952a; Lisenbee, 1981, 1985). The timing of the uplift, however, is less well defined, but decipherable from an examination of the sedimentation patterns formed before, during, and after growth of the elevated mass. These patterns indicate that this Laramide uplift results from early Tertiary tectogenesis with deformation underway in the Paleocene and Eocene: Erosion accompanied uplift, as indicated by sediment patterns in the adjoining Powder RIver Basin, and had exposed the Precambrian core before continental Oligocene White River Group sediments were deposited with angular unconformity across the uplift.

The uplift consists of two northerly-trending blocks with an en echelon pattern. Pre-Oligocene erosion cut to the Precambrian core in the more elevated eastern block and to Paleozoic strata on the western block.

PRE-UPLIFT PHASE

As the Cretaceous Period drew to a close the seas of the Interior Seaway were in retreat. In the area of the future Powder River Basin and Black Hills uplift, offshore deposits of the Pierre Shale (see Stratigraphic Chart, this volume) were succeeded by coarse-grained sediment of the nearshore Fox Hills Formation and these, in turn, by fluvio-deltaic deposits of the Lance Formation (Buswell, 1982). This depositional basin was a foredeep to deformation underway in the Wyoming thrust belt and to initial Laramide foreland uplifts to the west.

Cherven and Jacob (1985) have interpreted the latest Cretaceous deposits as resulting from the growth of a large delta extending eastward across central

[1]Department of Geology and Geological Engineering, South Dakota School of Mines and Technology, Rapid City, SD 57701

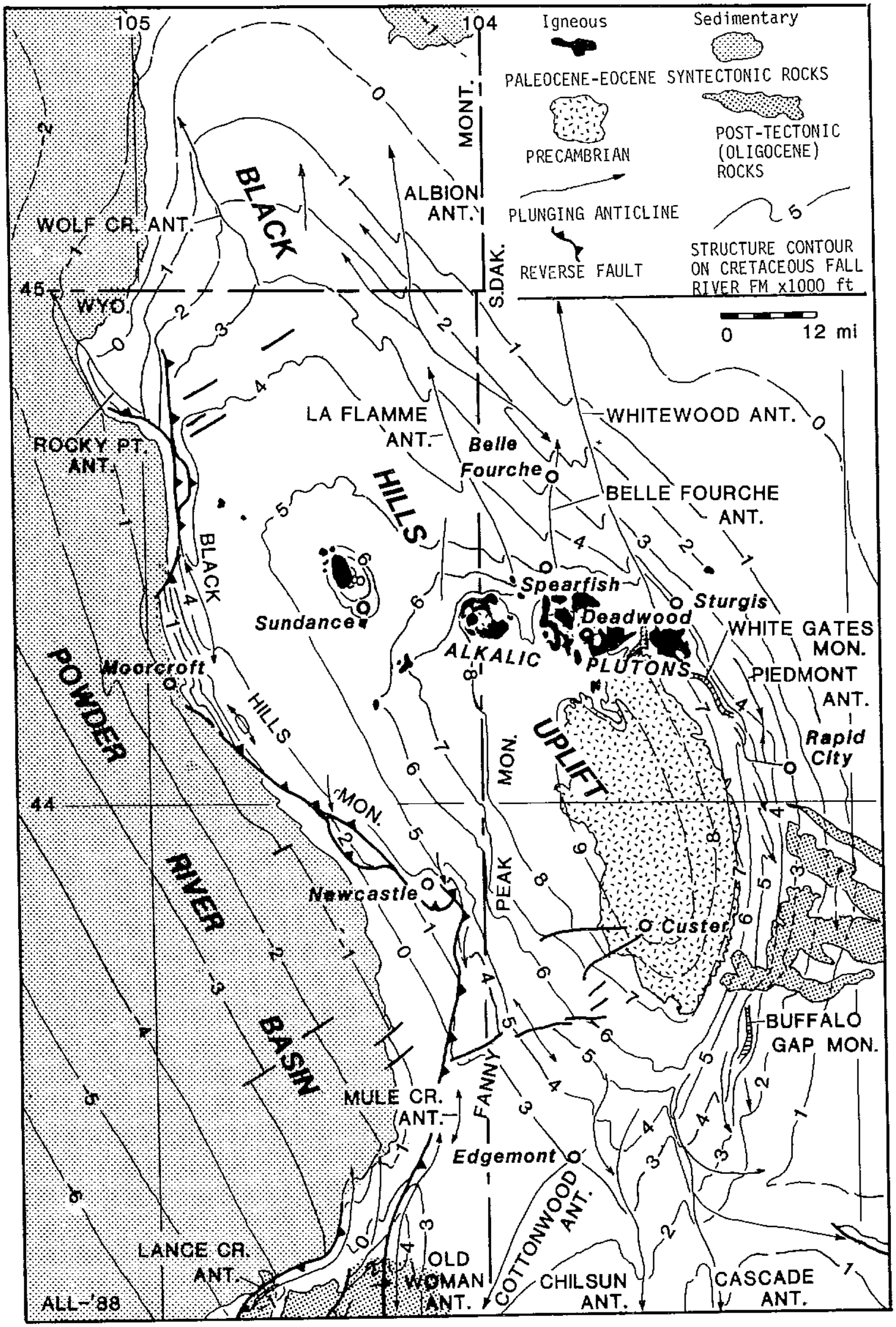

Figure 1 — Tectonic map of the Black Hills uplift and eastern Powder River Basin.

Montana. Fossil evidence presented by Gill and Cobban (1973) shows that as the seas retreated southward, an easterly-trending shoreline crossed the area of the future uplift. This indicates that the region was, therefore, essentially at sea level at the end of the Cretaceous. The latest Cretaceous sedimentary record remaining on, and near to, the uplift gives no indication of the existence of an early phase of growth at about 65 Ma.

UPLIFT PHASE

Sedimentation

Synchronous development of the intra-cratonic Powder River Basin and Black Hills uplift was initiated in the Paleocene as Laramide crustal stresses affected the low-lying region. The uplift is indicated as one of the source terrains feeding the Powder River Basin in lithofacies maps (Lewis and Hotchkiss, 1981) of the Tullock Member of the Fort Union Formation (sand percentage increases toward the uplift) and by paleocurrent directions based on cross-bedding orientations indicating a westerly flow (Flores and Ethridge, 1985).

By the time of deposition of the uppermost, Tongue River Member of the Fort Union Formation a major trunk stream flowed northward out of the Powder RIver Basin and turned eastward into North Dakota (Winczewski, 1982; Winczewski and Groenewold, 1982; Cherven and Jacob, 1985; Flores and Ethridge, 1985) toward the Cannonball Sea. Based on the presence of metamorphic fragments in the Tongue River Member of the northern Powder RIver Basin, Merin and Lindholm (1986) postulate that unroofing of the adjacent uplifts had reached the Precambrian cores by Late Paleocene. They suggest that the Black Hills uplift is the probable source for the micaceous fragments of this group. Redden (1988, written communication), however, notes that Precambrian clasts in Tongue River channels in the Cave Hills of extreme northwestern South Dakota do not have a Black Hills source. This may mean either that the micaceous fragments were destroyed before reaching the Cave Hills area, or that Merin and Lindholm were incorrect in their interpretation of the source.

The record preserved in the sedimentary strata show that during at least the early stages of uplift, the sea was present not more than 60 mi northeast of the Black Hills uplift (Goodrun, 1983; Best, in prep.). The surface of the Powder River Basin, from which a stream system flowed to this sea, must have been at an elevation near sea level. Based on an interpreted fluvio-deltaic model for upper Paleocene strata in western North Dakota, Daly et al (1985) suggest that the Cannonball Sea may have existed as far south as north-central South Dakota in the Late Paleocene.

The Black Hills uplift continued to be a source of sediments for the Powder River Basin during deposition of the Eocene Wasatch Formation (Seeland, 1976). A north-flowing trunk stream followed the general path of its Paleocene predecessor.

Tectonic Patterns

In gross form the uplift is a doubly-plunging anticline, or a markedly elongate dome, approximately 180 mi long and 75 mi wide (Figure 1) extending from the Chadron Arch on the south to the Miles City Arch on the northwest. In detail, however, the uplift is not a simple fold, but rather consists of an eastern and a western block separated by a west-facing monocline whose dips locally reach 85°W. This structure marks a zone of recurrent movement, at least in the Phanerozoic (Weimer et al, 1982; Shurr et al, this volume). Over large areas of both uplifted blocks strata display dips of two degrees or less and in much of the remainder dips of less than 10 degrees dominate. Such gentle inclinations are disrupted locally by small, linear folds related to uplift and by superimposed domes related to the Tertiary plutons. As shown diagrammatically in Figure 2, the flanks of the uplift display different general characteristics (Lisenbee, 1981) with a sharp monoclinal break on the west and a broad arch on the east.

The structurally highest part of the uplift is on the eastern block centered on the exposed Precambrian core (Figure 1). The block consists of a broad fold which plunges gently northwest and somewhat more steeply southward from the apex. As shown by structural contours in Figure 1, the crest of this fold is 9000 ft above the margin of both the Powder River Basin to the west and the southern end of the Williston Basin to the east.

Figure 2 — Diagrammatic cross-section of the Black Hills uplift. Suspected Archean granitic basement shown in stippled pattern: Proterozoic metamorphic basement in anastomosing pattern. Black indicates Tertiary intrusions in the Deadwood-Lead dome. Kfr is restored contact of the Cretaceous Fall River Formation and GS the ground surface. Vertical scale x 1000 ft and vertical exaggeration approximately 6 x.

Figure 3 — Flat-irons of upper Minnelusa Formation sandstone in the Fanny Peak monocline northeast of Newcastle, Wyoming. Structural relief is approximately 1100 ft. Meadow on left in middle distance is on near-flat-lying Minnekahta Limestone. Aerial view looking north near LAK reservoir.

The uplift is bounded on the west by abrupt (up to 5000 ft of structural relief), westerly-facing monoclines separating gently west-dipping strata of the basin from the uplift for a strike length of 150 mi. The maximum values of westerly dips in the rotated limb range from 15°W to vertical along strike. The western block is bounded on the west by the Black Hills monocline. The eastern block, which extends further to the south, is separated from the basin by the Fanny Peak monocline. Northward from Newcastle, Wyoming, this latter feature (Figure 3) continues onto the uplift, separating the eastern and western blocks (Figure 1). Due to a decrease in structural relief in this segment, however, faulting did not reach the level of the Cretaceous and, therefore, no fault is shown on Figure 1 affecting this segment. Although proof is not presently available, the author suspects that this monocline may mark the eastern margin of the Wyoming Archean Province with a granitic basement to the west and a Proterozoic metamorphic basement to the east.

Unlike the western margin of the Powder River Basin, where resistant Paleozoic strata are dramatically exposed in the monoclines and form an impressive topographic front approximately coincident with the uplift margin, the eastern basin margin is undistinguished topographically. As shown in Figure 4, the Cretaceous units are only rarely reflected in the topography, so the uplift and basin are at the same elevation for much of their shared length.

Although major faults cutting monoclinal limbs along the margin of the basin are not mapped at the surface, there are suggestions that such faults are present at depth. Two such indications are from the Fanny Peak monocline. On the basis of gravity modeling, Black and Roller (1961) interpreted the segment of the fold east of Newcastle, Wyoming, to be underlain by two faults which they show as high angle and normal in character. Along the monocline to the south, exposures of Cretaceous strata along the west flank of the Old Woman anticline (Figure 1) are cut by a fault which Stock (1981) interprets as having reverse movement. Unpublished cross sections (Kelley, 1986) controlled by abundant drill data along the Black Hills monocline north of Moorcroft also suggest the need for a reverse fault to explain the diminished thickness of the Cretaceous section there. As a result of these interpretations Figure 1 indicates that the monoclines bounding the Powder River Basin are cored by some type of reverse fault.

The boundary monoclines are modified by local terraces and splays (Lisenbee, 1981) and by several anticlines on the uplifted side. These folds have two distinct orientations. Several parallel the monoclines, such as the oil productive Mule Creek structure (Figure 1) along the Fanny Peak monocline. Others, west of Newcastle, are oblique to them. Shurr et al (this volume) have interpreted these patterns to indicate a limited component of strike-slip along the monoclines, although the dominant movement is clearly vertical. In their interpretation, the en echelon pattern of fold axes oblique to the monoclinal trend are suggested to result from strike slip and the folds parallel to the monocline may represent compressive features such as flower structures. Alternatively, these latter folds may be "rabbit ear" structures formed by out-of-syncline movement of strata from lower in the monocline.

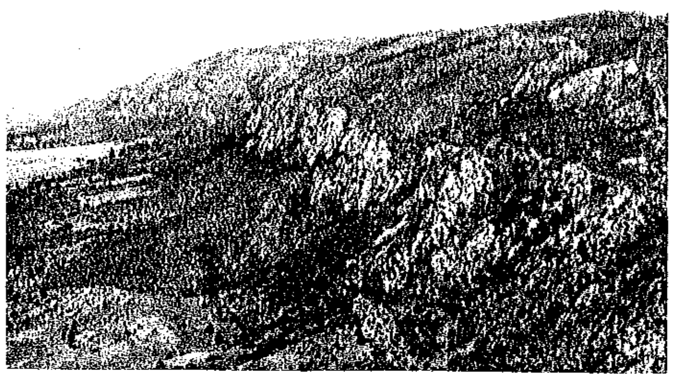

Figure 4 — View from Powder River Basin across Black Hills monocline onto Black Hills uplift illustrating lack of topographic expression at boundary. Location north of Moorcroft, Wyoming looking east toward the Missouri Buttes and Devils' Tower (small bump on horizon at right).

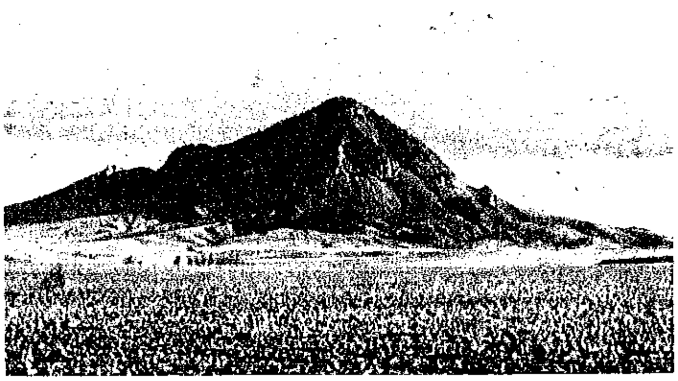

Figure 5 — Bear Butte, the easternmost pluton of the Tertiary alkalic igneous province seen, from the northwest. A collar of upturned strata surrounds the base of the stock.

In contrast to the abrupt boundary at the western margin of the Black Hills uplift, the eastern flank is a broad arch modified by small, superimposed monoclines, each of which is interpreted to be cored by basement faults. These folds generally parallel regional strike and the steep limbs dip both with and opposed to regional dip. In the former case they form monoclines such as the White Gates and Buffalo Gap structures (Figure 1) and in the latter case asymmetric anticlines such as that at Piedmont. Structural relief on these features does not exceed 1650 ft. The Paleozoic strata may locally be rotated to vertical in the fold cores (White Gates monocline).

West-facing anticlines with as much as 2000 ft of structural relief and dips to 60°, plunge from the crest of the eastern block for many miles to both the north and south. These include the La Flamme, Belle Fource, and Whitewood folds on the north and the Cascade and Chilsun on the south. Whitewood anticline continues northward from the Vanocker igneous complex near Sturgis, South Dakota, for more than 75 mi. These features are interpreted as basement fault-controlled structures whose downthrown sides are opposed to regional dip and appear to have formed at the same time as other folds on the uplift. Although the presently favored model for such folds of Laramide origin is by association with basement reverse faults, none of the faults have cut upward sufficiently far to be exposed, nor is the actual dip of the fault known.

Igneous Activity

A west-northwesterly-trending band containing dikes, sills, stocks, laccoliths, diatremes and ring complexes is continuous across both blocks of the uplift, extending from Bear Butte (Figure 5) in South Dakota to Devils Tower and Missouri Buttes in Wyoming. A wide variety of alkalic rocks in the several igneous centers include rhyolite, trachyte, dacite, phonolite, pyroxenite, carbonatite and many types of breccia and tuff.

These intrusions formed domes of two types and scales. In the first category are laccoliths in the Phanerozoic section. These may arch the strata into near perfect domes, such as the excellent example at Green Mountain near the eastern suburbs of Sundance, Wyoming, or produce structures resulting from a combination of bending and marginal faulting. Individual structures are approximately one mi in diameter and clusters, such as the Vanocker complex south of Sturgis, South Dakota, are as much as 8 mi across. The igneous cores are generally less than 1500 ft thick.

In the second category, the doming is of greater dimensions and involves the Precambrian basement as well as the overlying strata. Noble (1952b) recognized the composite intrusion known as the Cutting stock near Deadwood/Lead (Figure 2) as having forcefully invaded, and swelled the enclosing Precambrian basement. This stock, and probably several unexposed igneous masses in the subsurface, produced a dome approximately 10 mi in diameter. Similar domes are located in the Tinton area (the intrusive complex north of the word "Alkalic" in Figure 1) and in the Bear Lodge Mountains north of Sundance. Due to unroofing by erosion it is difficult to estimate the exact structural relief of these features, but it is on the order of 3000 ft.

The magmatic activity was strongest during the period 50 to 60 Ma (McDowell, 1971) although ages as young as 39 Ma (Staatz, 1983) are reported. This timing coincides with growth of the uplift indicated in the sedimentary patterns previously described and suggests a relationship between magmatic and tectonic activity. The petrogenesis of the magma within the broader tectonic scheme, however, is not well understood. Isotopic studies by Olson (1976) and Beintema and Montgomery (1986) indicate a mantle parentage for the phonolite and probable crustal contamination of such magma to form the rhyolite. On the basis of gravity and magnetic geophysical data, Roggenthen and Lisenbee (1986) postulated an offset of the Archean and Proterozoic basement along a deep basement fault zone generally coincident with the belt of plutons. Such a deeply penetrating zone of anisotropy might have acted to channel magma ascent in the deeper crustal levels.

POST-UPLIFT PHASE

Oligocene strata of the White River Group covered most of the eroded roots of the uplift as well as the syntectonic sedimentary rocks in the Powder River and Williston basins. In the Powder River Basin Oligocene strata are nearly completely removed by erosion and only a small remnant is preserved.

In the White River Badlands east of the uplift, flat-lying mauve and tan siltstone, sandstone and tuff rest on the Interior Paleosol. The paleosol formed by pre-Oligocene weathering of the Cretaceous Pierre Shale. Westward toward the uplift, channels of the White River Group have an angular relationship to progressively older, tilted strata. in the higher levels of the Black Hills they are in a nonconformable relationship with the metamorphic Precambrian basement.

The basal units of these strata are Lower Chadronian (P. Bjork, oral comm., 1985) and approximately 37 Ma in age. This time would be the younger limit on structural activity, although growth likely ended prior to this date as the White River strata do not appear to be deformed by the uplift.

LATE TERTIARY EPEIROGENIC UPLIFT

As previously noted, Oligocene strata are almost completely removed from the Powder River Basin and this is true for the Black Hills uplift and much of the region north and northeast of it as well. Stripping of Tertiary and older deposits is a widespread aspect of the evolution of the entire Rocky Mountains and Plains regions (Cook, 1960; Love, 1960; Trimble, 1980; Swinehart et al, 1985) and is interpreted to be a response to one or more pulses of regional uplift.

Several terrace levels are present along streams in and near the Black Hills. The highest of these is the Mountain Meadow surface, with levels as great as 500 ft above Rapid Creek. In a review of the evolution of these terraces, Martin (in Wayne et al, in press) give a probable Blancan age for this highest terrace based on the presence of a fragment of the camel *Gigantocamelus* in terrace gravel deposits. Compatable with this is the interpretation of Harksen (1969) that erosion during the past 4.5 m.y. has produced down-cutting of as much as 1200 ft in western South Dakota. In any case, the terraces clearly indicate degradation as the dominant process in the last stages of the history of the uplift.

Further understanding of the late history of the Black hills uplift may be gained from nearby, as well as regional, interpretations. A stratigraphic study by Swinehart et al (1985) along the Chadron Arch in northwestern Nebraska gives a detailed view of tectonic activities in the region. Their work suggests three periods of probable uplift. The first, at about 28 Ma, is a time of epiclastic deposition which indicates to them "Uplift in the Rocky Mountains and Great Plains..." A second period of uplift followed cessation of Arikaree deposition at about 19 Ma, suggesting local uplift. Regional uplift in the past 5 Ma represents the third uplift phase and is dominated by downcutting so that streams flow in canyons cut 1000 ft lower than Miocene Ogallala Group strata on the nearby tablelands. Trimble (1980) believed post-Ogallala uplift to have affected the entire western craton. He postulated uplift of as much as 7000 ft in the western Great Plains region of Colorado and 1000 ft in the eastern Great Plains. For Wyoming, Love (1960) noted the Pliocene as a time of degradation including superposition of rivers across mountains and basins, excavation of basins filled in Early Tertiary, and the exhumation of buried uplifts. Erosion continued through the Pleistocene.

It is likely, therefore, that the Black Hills uplift underwent similar exhumation in the late Tertiary removing the Oligocene, and possibly younger, cover. Prior to this event the Black Hills may have been represented only by the higher reaches of Harney Peak, standing above a broad plain (J. Redden, oral commun., 1974) which extended outward into the surrounding basins. If so, the Black Hills physiography may have been little different from the present Rawhide Butte just south of Lusk, Wyoming.

DISCUSSION AND SUMMARY

The history of the uplift may be interpreted from sedimentary deposits formed before, during and following uplift. They reveal no evidence of a positive feature in the Black Hills region during deposition of the Latest Cretaceous Lance Formation. By the early Paleocene, however, during deposition of the Tullock Member of the Fort Union Formation, streams carried detritus westward into the nascent Powder River Basin and possibly northward as well. This continued through the time of deposition of the Eocene Wasatch Formation. At 347 Ma, Oligocene White River Group deposition was underway across the truncated layers surrounding the eroded uplift. Studies of Tertiary deposits of the Rockies and Northern Great Plains suggest several periods of late Tertiary uplift and a strong period of erosion and exhumation of uplifts such as the Black Hills during the past 5 Ma.

The general anticlinal character of the uplift, combined with the interpretation that many (all?) of the monoclines and asymmetric anticlines form by the draping of the Phanerozoic section over upthrust basement blocks, indicates an origin of the uplift by regional compression. The orientation of the maximum compressive stress causing such features is less clear, however. Use of the simplest assumption, that maximum horizontal stress is perpendicular to the trends of large folds, is jeopardized in at least two ways. First, due to the extremely complex structural, metamorphic and igneous development of the Precambrian basement underlying the uplift (Redden et al, in press) it is likely that Laramide features follow preexisting trends. At least on the local scale, therefore, structural trends need not match those predicted on a theoretical basis. The second is the presence of both northerly-and northwesterly-trending monoclines such as those which separate the uplift and the Powder River Basin. The mutual relationship of the Fanny Peak and Black hills monoclines indicates that they share a common timing of formation even thought they have differing trends. In its gross form, however, the overall northwesterly trend of the combined blocks of the uplift is compatable with the direction proposed by Gries (1983) for Paleocene age Laramide features of the northern Rockies. Models of tectonic development proposed by Gries (1983) and Chapin and Cather (1983), suggest more than one period of deformation for the Laramide Rockies. Although there may have been more than one tectonic pulse during development of the Black Hills uplift, an understanding of the sedimentary record is insufficient to test this concept.

The interpretation of reverse faults beneath the surface monoclines at the margin of the Powder River Basin has potential significance to petroleum exploration in Paleozoic rocks there. Such thrusts, combined with regional westerly dips, may produce small overhangs and potential traps in the footwall layers. Alternatively, they may have acted to shatter original sedimentary traps, such as those in the Minnelusa Formation, and provided paths for the escape of petroleum.

ACKNOWLEDGMENTS

The thoughts expressed here are aided by discussions with many colleagues including Paul Gries, Jim Fox, Jim Martin, Phil Bjork, Jack Redden and Fred Rich. The critical review of the manuscript by Jack Redden, in his minute handwriting, is must appreciated and added to both the substance and the clarity of the final product as did those of Chuck Chapin and George Shurr. My thanks, as well, to the editors of this guidebook for their helpful critique of the manuscript and their patience.

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