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GEOMORPHOLOGY OF THE NAVAJO COUNTRY*

by

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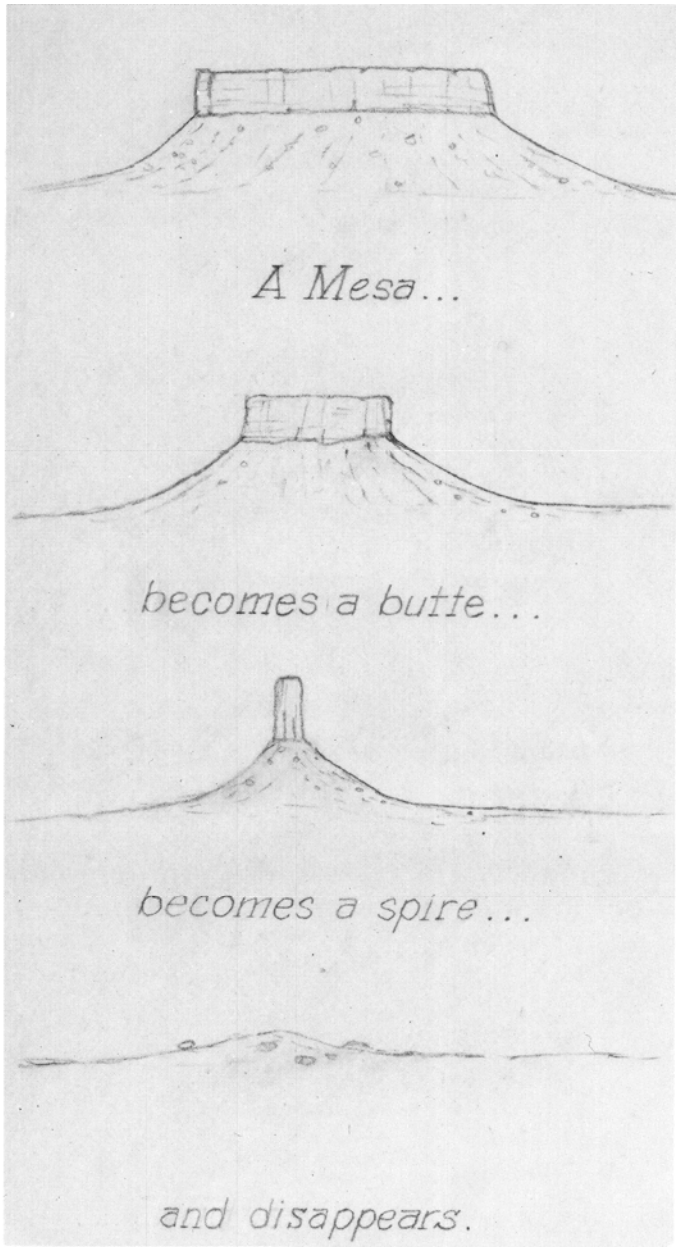
INTRODUCTION

Those who have not beheld it in actual reality have surely "seen it in the movies." I refer to the Navajo country with its famous mesas, buttes, spires, canyons, dunes and badlands. This photogenic land and its people have been painted and photographed with increasing ardor ever since the explorations of Newberry and Dutton. Many are the movies that show glimpses of the monuments of Monument Valley and the walls of Canyon de Chelly. Even the precocious roadrunner and bedraggled coyote of the animated cartoons perform in a setting that is obviously stylized "red rock country."



*Pencil sketches by the author. Reproduced from Scenes of the Plateau Lands, 1969.

While these commercialized shadows pay homage to the colorful and moody scenery, they fall far short of capturing the true essence of the landscape. Geologists are not unappreciative of the superficial view; they are as avid in their picture taking as the passing tourist. But, as with all things geologic, the serious geomorphologist sees a landscape in transition from what has been to what will be. The task of tracing the evolution of the landforms back to Tennyson's "stillness of the central sea" is a difficult but rewarding one. Those who have contributed have laid a descriptive background that will be built upon with increasing perception by students armed with the tools of the quantitative geomorphologist. But even their revelations will not dull the charm or solve all the mysteries of this colorful land.

PHYSIOGRAPHIC SUBDIVISIONS

Harshbarger (et al., 1953) has subdivided the Navajo country of northeastern Arizona and southeastern Utah into eight physiographic units (fig. 1).

1. Painted Desert: The Painted Desert is a broad semi-circular tract surrounding the Navajo country on the west, southwest and south. Where it is widest along the southern margin it includes the Hopi Buttes as a distinctive subregion. The bedrock is chiefly the varicolored formations of the Glen Canyon, Chinle and Moenkopi groups of Triassic and Early Jurassic age. With the exception of the sandstone units of the Glen Canyon Group the sediments are relatively soft and non resistant. Elevations range between 4,000 and 6,000 feet. Precipitation is low and vegetation and soil covers are sparse. This combination of influences has produced mainly badlands and barren bed-rock surfaces. Drainage is into the Little Colorado River which traverses the southwestern portion of the region and into the Colorado River which forms the western margin.

2. Navajo Uplands: The Navajo uplands occupies much of the northwestern corner of the region with a tapering wedge curving southward and southeastward almost to the Hopi Buttes. There is also an irregular arm to the north of the Black Mesa subdivision which takes in the valley of Laguna Creek and the lower reaches of Chinle Valley. As a practical matter the inner border of the cresent-shaped Navajo uplands is the base of the slope which leads up to Black Mesa.

The bedrock of this tract is chiefly the Glen Canyon Group of which the Navajo Sandstone is the most widespread and conspicuous component. Much of the area is mantled by thin deposits of sand or sandy soil which is supplied in abundance by weathering of the bedrock.

The elevation is generally between 4,000 and 6,500 feet.

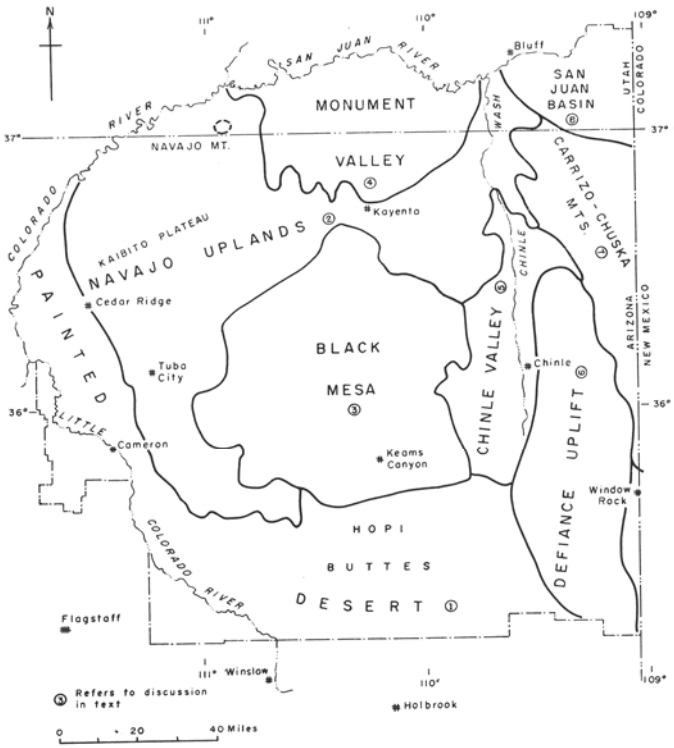


Figure 1.

Physiographic subdivisions of the Navajo country, Arizona and Utah. Reproduced from Mineral Resources of Navajo-Hopi Reservations, Arizona-Utah, Vol. II, by George A. Kiersch, University of Arizona Press, 1955.

Navajo Mountain, reaching 10,388 feet, is the high point of the entire region. Except for Navajo Mountain the precipitation ranges between 6 and 14 inches. Reactions between the prevailingly sandy formations and the agents of weathering and erosion has produced a combination of barren "slickrock" surfaces laced with deep gorges eroded below the general level of the terraced surface. The famous ruins of Inscription House, Betatakin and Keet Seel are found in secluded canyons of the Navajo Sandstone. Drainage is chiefly northward into the Colorado River but large tracts are essentially undrained because the meager run-off is absorbed into the prevailing sandy regolith.

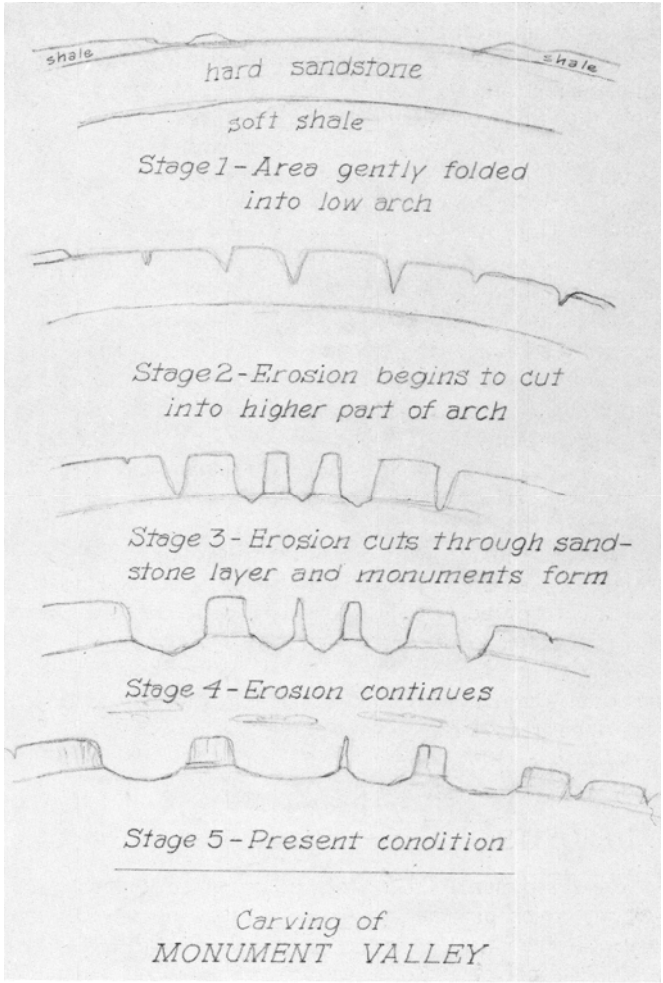
3. Black Mesa: Black Mesa is the central and dominating topographic and physiographic subdivision of the Navajo country. It is a roughly circular plateau-remnant bounded by steep retreating cliffs of Upper Cretaceous sandstone formations of the Mesaverde Group. The bedrock is almost entirely Upper Cretaceous sandstone and shale. The name is a translation of a Navajo term meaning "black streak mountain" referring to the coal seams.

Elevation ranges from 6,500 on the southern escarpment to 8,000 feet on the north. Precipitation is 8 to 14 inches and the higher surfaces are well vegetated with pine forests.

An unusual feature of Black Mesa is the prevailing northeasterly trending, regularly spaced drainage ways. Many of these washes continue southwesterly well beyond the mesa front. This stream pattern shows evidence of having been inherited from a higher surface. The orientation seems to be a direct response to the prevailing dip, but wind action could also have been influential in directing the formation of the drainage ways. It appears to be more than mere coincidence that the orientation of dunes as reported by Hack (1941) for the entire Navajo country is essentially the same as the orientation of major washes on Black Mesa.

4. Monument Valley: Monument Valley, most widely known subdivision of the Navajo country, occupies a north-central position with regard to the region as a whole. It is essentially a great breached anticline enclosed on the east, south and west by the Navajo uplands. The so-called "valley" is in reality the broad summit area of the Monument upwarp; a major feature which continues northward into Utah. Erosion has cut below the Mesozoic rocks which make up most of the Navajo uplands into continental Permian red beds and sandstones. Ongoing erosion has created a fantastic array of mesas, buttes, spires and pinnacles, some of which reach an elevation of 5,000 feet and stand 800 feet above the general level of the valley. Preservation of many of the monuments seems to have been due to protection by local thicker channel deposits of the Triassic Shinarump Conglomerate which still remains as a caprock on many of the monoliths.

5. Chinle Valley: The relatively low-lying open valley between Black Mesa and the Defiance uplift takes its name from Chinle Wash—the most important stream that is entirely within the Navajo country. Average elevation is about 5,500 feet. The rocks of this subdivision are predominantly the softer Triassic Moenkopi and Chinle formations. Although the discharge of water from Chinle Wash is small and variable, a number of permanent towns and villages are found along its course.



Chinle Wash is a good example of a strike valley which is working headward along a belt of soft rocks. Inasmuch as the rocks on the east side are generally harder than those of the west there has been a downdip migration of Chinle Wash from a higher position on the flanks of the Defiance uplift. As a consequence of this westward shift the west-flowing tributaries have been lengthened and superimposed upon the older rocks. Spectacular Canyon de Chelly and its tributaries record the results of downcutting into the resistant DeChelly Sandstone. The headwaters of Canyon de Chelly are at elevations of 8,500-9,500 feet in the Chuska Mountains and have apparently been capable of supplying runoff to keep pace with the downcutting of the master stream.

6. Defiance Uplift: The Defiance uplift forms a natural topographic and structural divide between the Black Mesa basin of Arizona and the San Juan basin of New Mexico. Structurally the uplift is a broad, elongate anticline about 100 miles in length and 40 to 60 miles wide. The summit area has been stripped to the general level of the resistant DeChelly Sandstone with elevations ranging between 7,000 to 9,000 feet. Topographically, the area is generally referred to as a plateau.

Remnants of the relatively soft Bidahochi Formation (Pliocene) lie upon the western and southeastern flanks in what must be their approximate original attitudes. Westward-flowing tributaries of Chinle Wash cross the uplift in deep canyons incised in the DeChelly Sandstone.

7. Carrizo-Chuska Mountains: The Carrizo-Chuska Mountains subdivision lies partly in New Mexico and partly in Arizona with an over-all trend of about N. 20° W. The two mountains are quite dissimilar in origin but together form an imposing highland up to 9,000 feet in elevation and 3,500 feet above the valleys on either side.

The Carrizo Mountains consist of a complex aggregation of Tertiary intrusive rocks and Mesozoic sediments. The summit areas are noticeably flattened in contrast with the laccolithic ranges of Utah. Differential erosion has etched many of the igneous bodies into relief and several domical uplifts on the flanks suggest others at shallow depths.

The Chuska Mountains are capped by the horizontal Chuska Sandstone of Pliocene(?) age and by volcanic flows which rest unconformably upon the Mesozoic formations of the Defiance monocline. The range is about 60 miles long and 9 miles wide; the highest point is 9,784 feet in elevation. Important tributaries of Chinle Wash arise on the west flanks of the range and the upland surface supports stands of ponderosa pine interspaced with many clear lakes.

The Lukachukai Mountains constitute a narrow curving bridge between the Carrizo and Chuska mountains. Here spectacular cliffs of red Triassic and Jurassic rocks are seen beneath retreating softer sediments of the Morrison Formation.

8. The San Juan Basin: A small slice of Arizona adjacent to the Four Corners intersection is included in the San Juan basin. The area is a rocky badland draining into the nearby San Juan River.

DEPOSITS OF GEOMORPHIC SIGNIFICANCE

Several sedimentary remnants are preserved in northeastern Arizona which provide important clues to the late Cenozoic history of the Four Corners region and the Colorado Plateau as a whole. Chief of these deposits is the Bidahochi Formation which lies in the headwaters area of the Little Colorado River with present outcrops bounded by Black Mesa on the north, the Defiance Plateau to the east, the Zuni Plateau to the southeast and the Little Colorado River to the south and southwest. A probable time correlative of the early part of the Bidahochi is the Chuska Sandstone which caps the Chuska Mountains partly in New Mexico and partly in Arizona. These formations are obviously erosional remnants of once extensive deposits. Their preservation is due to their relative thickness, resistance to erosion and to their location at comparatively great distances from the Colorado River and its larger more vigorous tributaries. An excellent discussion of Tertiary stratigraphy of the Navajo country is that of Repenning, Lance and Irwin (1958).

A few small isolated high level patches of river gravel lying between the Colorado River and Black Mesa are of paramount significance as clues to evolution of a major drainage. The chief remnant is at an elevation of 6,800 feet on White Mesa. The constituents include types of rocks that could have come only from the east and northeast, specifically from the southern slopes of the San Juan Range. The cross-bedding dips to the southwest confirm the direction of flow of the river which delivered the material to this site. Cooley estimates the age as being about middle Miocene, that is, older than the Bidahochi. These gravels are considered by Cooley (1960) as being fortituous remnants of the former course of the San Juan River. As emphasized by Hunt (1969) it is difficult to escape the conclusion that this major stream was already flowing southwestward from the San Juan Mountains between the Carrizo and Abajo mountains and south of Navajo Mountain in Miocene time.

PHYSIOGRAPHIC DEVELOPMENT

The physiography of the Navajo country has evolved chiefly by a process of general denudation. Differential erosion of the varied sedimentary formations which range from weakly to moderately resistant has proceeded with little hinderance from soil or vegetation for a long period of time. Nevertheless, there have been subtle changes of climate that introduce complications not fully understood. The tectonic history is likewise known only in broad outlines. The area has obviously been elevated over a mile above sea level since the Cretaceous, but whether this has been a steady or intermittent process it is unknown. The task of sorting out and evaluating the climatic and tectonic influences is progressing, but final solutions are obviously not yet agreed upon.

THE CONCEPT OF CYCLES

The idea that the landscape of the Colorado Plateau bears the impress of cyclic processes dates back to Dutton who introduced the concept of an older cycle of widespread erosion, the "Great Denudation," followed by a cycle of canyon cutting which produced details of the present landscape.

Recent students have followed Dutton's general concepts and have recognized a number of lesser cycles within his greater ones. These lesser cycles are based on the recognition of surfaces that have been graded to local base levels such as through-flowing streams during periods of relative geologic quiet. The termination of one cycle is considered as being due to diastrophism that has generally expressed itself by acceler-

ated downcutting of master streams such as the Colorado River. This in turn upset the behavior of the tributary systems and initiated the cutting of new surfaces. Needless to say the various cycles differ in the magnitude of the surfaces attributed to them. The cycles and associated events recognized by Cooley and others is briefly summarized in Table 1.

The information of Table 1 may be clarified by quoting from the excellent summary of Cooley, Harshbarger, Akers and Hardt (1969).

> The streams that flowed on the Valencia surface began the Colorado River system. The Valencia surface is usually higher than 7,000 feet and predates the cutting of the Grand Canyon. It is preserved below the basalt caprock on Red Butte on the Coconino Plateau, perhaps below some of the lava flows on the Chuska Mountains, and in several places south of the reservations. The summit on Black Mesa and the Kaiparowits Plateau probably represent dissected segments of the Valencia surface.
>
> Accelerated downcutting during the early part of the Hopi Buttes-Zuni cycle entrenched the ancestral Colorado and Little Colorado River systems 1000-1500 feet below the Valencia surface. The amount of downcutting was determined from the contouring of the Hopi Buttes and Zuni surfaces near the Little Colorado River ... and by reconstruction of the old valley profiles preserved in other parts of the Navajo Country. The ancestral Colorado River during the Hopi Buttes-Zuni cycle flowed in an open valley south of Navajo Mountain, and its confluence with the ancestral Little Colorado River probably was in the western part of the Navajo Country. The fluvial and lacustrine Bidahochi Formation was deposited on the Hopi Buttes and Zuni surfaces in the ancestral valley of the Little Colorado River.
>
> Vigorous downcutting caused by uplift of the Colorado Plateau during late Cenozoic time ended the Hopi Buttes-Zuni cycle, and during the following Black Point and Wupatki cycles, the present Colorado River drainage system was outlined and entrenched. Excavation of the major valleys of the Navajo Country and Glen, San Juan and Navajo canyons and Canyon de Chelly, probably began during the Black Point Cycle. Regional downcutting continued intermittently throughout the Wupatki cycle and is recorded by the several terraces preserved along the large streams.
>
> The deposits capping terraces of the Wupatki cycle along the Colorado, Little Colorado and San Juan rivers and the lower reaches of their tributaries are contempor-

Table 1.

Late Cenozoic erosional and depositional events in the Navajo Country. Reproduced from Regional Hydrology of the Navajo and Hopi Indian Reservations, Arizona, New Mexico and Utah; U.S. Geol. Survey Prof. Paper 521-A (1969), p. A35.

Age			Cycle	Erosional and depositional events	Height of terraces above river level (feet): Confluence of the Colorado and San Juan Rivers	Height of terraces above river level (feet): Little Colorado River in the Cameron-Winslow area	Approximate age of cutting of principal canyons: Eastern Grand Canyon	Marble Canyon	Glen Canyon	San Juan Canyon	Canyon de Chelly
Quaternary	Pleistocene	Middle and late	Wupatki	Downcutting and terracing.	Five terraces at 30–50, 50–100, 100–200, 200–300, and 400–500.	Five terraces at 30, 50, 75–100, 150–200, and 200–300.					
Quaternary	Pleistocene	Early	Black Point	Downcutting and terracing.	Two prominent terraces at 800–1,200 and 1,400–1,800.	Two prominent terraces at 400–500 and 600–800.					
Tertiary	Pliocene	Late									
Tertiary	Pliocene	Middle	Hopi Buttes-Zuni	Formation of Zuni surface and deposition of the upper member of the Bidahochi Formation in valley of the Little Colorado River.	About 2,500.	1,000–1,500.					
Tertiary	Pliocene	Early	Hopi Buttes-Zuni	Formation of Hopi Buttes surface and deposition of the lower member of the Bidahochi Formation and equivalents.	About 2,500.	1,000–1,500.					
Tertiary	Pliocene	Early	Valencia	Few deposits(?)	About 4,000.	2,000–2,500.					
Tertiary	Miocene										

aneous with the alluvial deposits of Pleistocene age laid down in the upper reaches of streams in the Navajo Country and with glacial outwash deposits in some of the nearby mountainous areas. Terrace deposits along the Little Colorado River are contiguous with alluvium referred to as the Jeddito Formation by Hack (1942, p. 48-50), along Jeddito, Polacca and Orabi washes, and with the Gamerco Formation in the Gallup area. Similarly, the alluvium in the upper part of Chinle Wash and the Chaco River drainages is a lateral equivalent of the terrace deposits along the San Juan River.

Deposits of the three lowest terraces in the Shiprock-Farmington area, 30-200 feet above the San Juan River, are continuous upstream along the Animas River to Durango, Colo. The highest of these deposits merges with the outwash sediments of the Durango glaciation. The deposits of the two remaining terraces are correlative with the younger outwash sediments of the Wisconsin glaciation of Atwood and Mather. Field mapping and lithologic studies indicate that the deposits of the three lowermost Wupatki surfaces along the Little Colorado River downstream from Grand Falls are lateral equivalents of the outwash of the three glaciations on San Francisco Mountain described by Sharp. The relation of the terrace deposits in the Navajo Country to the outwash in the San Juan Mountains and San Francisco Mountains suggest that deposition occurred during the glaciation when the streams were overloaded and that the intervening periods of downcutting and formation of the terraces are correlative with the drier interglaciations. (Cooley, Harshbarger, Akers and Hardt, 1969, p. A34-A35.)

It is noted that the major cycles are thought to have bees initiated by tectonic events while the later minor perturbation are correlated with climatic influences of the Pleistocene.

NON-CYCLIC PHYSIOGRAPHIC DEVELOPMENT—AN ALTERNATE VIEW

Although the reality of remnants of ancient erosion surface is not to be doubted, there may be more than one explanatioi for them. The lateral expansion of level tracts such as pedi ments need not necessarily result during pauses between up lifts, and reasons for the destruction of these surfaces can b imagined which have nothing to do with sudden uplift.

Chief proponent of this new way of interpreting the histor of the Colorado Plateau is C. B. Hunt. He writes: In th absence of evidence for a sudden jarring uplift, I assume au Rocky Mountains and Colorado Plateau were raised graduall during the last 35 million years, a rate of uplift of 150 feet pe million years, less than 6 inches since the time of Christ.' (1969, p. 125.)

It may be instructive to apply the concept of non-cycli denudation to the Navajo country.

That the area was once covered by a fairly uniform am continuous blanket of Cretaceous sediment may be accepter as a basic fact on which to base a simplified analysis of th geomorphology. The Cretaceous Period is divisible into a lowe thick shale sequence typified by the Mancos Shale and ai overlying more resistant aggregation of sandstone formation designated as the Mesaverde Group. Almost everywhere thi sedimentary couple maintains its separate integrity appearing as a steep slope or pediment surmounted by a steep cliff. The escarpment erodes and retreats by a process of sapping and collapse of the cliff and a consequent rapid removal of the unprotected shale. The retreat of the Cretaceous escarpment commences along fault lines, at monoclinal flexures, at deeply incised canyons and from the summits of anticlinal structures. It is usually a relatively simple matter to restore the escarpment at any stage from its present position back to an initial position at a canyon, fault, or flexure.

Applying this line of reasoning to the past history of Black Mesa it seems justifiable to suppose that the bounding cliff has retreated from a position along the Echo monocline on the west, the Little Colorado River on the south, the East Defiance monocline on the east and the San Juan and Colorado rivers on the north. The distance and rate of retreat has varied from place to place but a certain symmetry of features has nevertheless resulted. After the removal of the Cretaceous cover the agents of erosion have encountered the more varied continental Jurassic and Triassic formations. Where these are predominantly less resistant shale, as they are on the east, south and southeast of Black Mesa, the tendency has been to produce a wide band of modified badland topography, pediments and wide stream valleys. Thus Chinle Wash and the Little Colorado River occupy the more shaly zones along the margins of the central highlands and depending on local conditions the master streams and their tributaries have been working headward along the strike into adjacent territory. These streams probably did not exist before the removal of the Cretaceous blanket. They have lengthened and deepened their courses and shifted down dip as conditions permitted. They have occasionally reached positions of stability so that wide floodplains or fringing pediments have had time to form.

Where rocks of the Jurassic and Triassic level are more resis-

Figure 2.
Exposure map of the Mesaverde Group which caps Black Mesa showing its relation to surrounding river systems. Adapted from Ground water in Black Mesa Basin and adjacent areas, by Akers and Harshbarger in New Mexico Geol. Soc. 9th Field Conf., 1959, Guidebook of the Black Mesa Basin (fig. 3), p. 176.

tant, homogeneous and sandy as they are to the north and northwest of Black Mesa, erosion has produced deeply incised vertical-walled canyons with intervening barren "slick rock" surfaces mantled with patches of transient soil or dune material. Drainage of such areas is poorly integrated and no really major streams analogous to those occupying the shale valleys have been produced.

The presence of a resistant cliff-former above a softer slope-making foundation sets the stage for the process of cliff retreat. Notable cliff-slope pairs, in addition to the Mancos-Mesaverde, exist in the form of the Glen Canyon Group upon the Chinle, the Shinarump upon the Moenkopi and the DeChelly upon the Organ Rock. These provide multitudes of mesas, buttes and spires of which Monument Valley displays the best examples. As long as climatic conditions are right the process of cliff retreat can go on at any elevation regardless of tectonic movements. This seemingly inexorable process probably has had more to do with shaping the scenery than is usually supposed.

Erosion in the Navajo country has reached the Paleozoic in only a few places, particularly on the Defiance uplift and in Monument Valley. The result has been either the production of stripped surfaces such as the Defiance Plateau or deeply incised drainage ways such as Canyon de Chelly.

WIND ACTIVITY

The Navajo country bears the impress of wind action to a degree unmatched by any other region of the United States. This is well illustrated by Figure 3 borrowed from USGS Professional Paper 521-A (Cooley et al., 1969, p. A31). Evidences range from currently forming dunes backward through arrested dunes, through various types of older aligned topographic features, including parallel stream courses which which the initial surficial material has disappeared, to deposits of increasing antiquity in which the internal cross-bedding and not the superficial form reveals an aeolian origin.

This evidence indicates that wind action has been a powerful influence since at least Miocene time. Remnants of ancient wind-deposited sand remain in the Bidahochi and Chuska formations and these are obviously remnants of once extensive sheets. The total effects of wind in removing loose material can never be known, but, considering that winds may have been more powerful and erosion products more plentiful during various periods of the past, the amount removed may have been roughly comparable to that carried out by water. This strong possibility must be taken into account in any reconstruction of the Cenozoic history of the Navajo country and the Colorado Plateau as a whole.

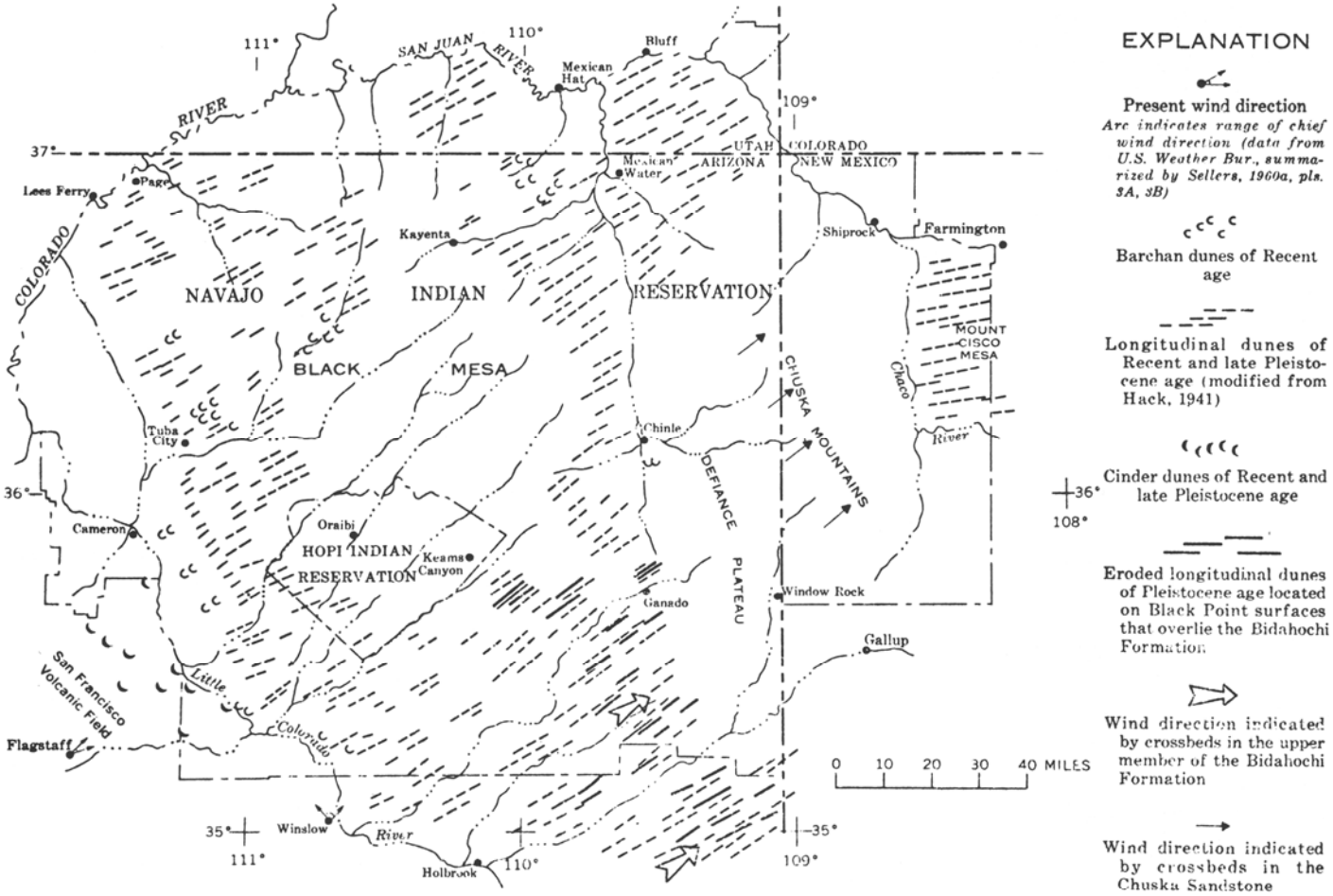
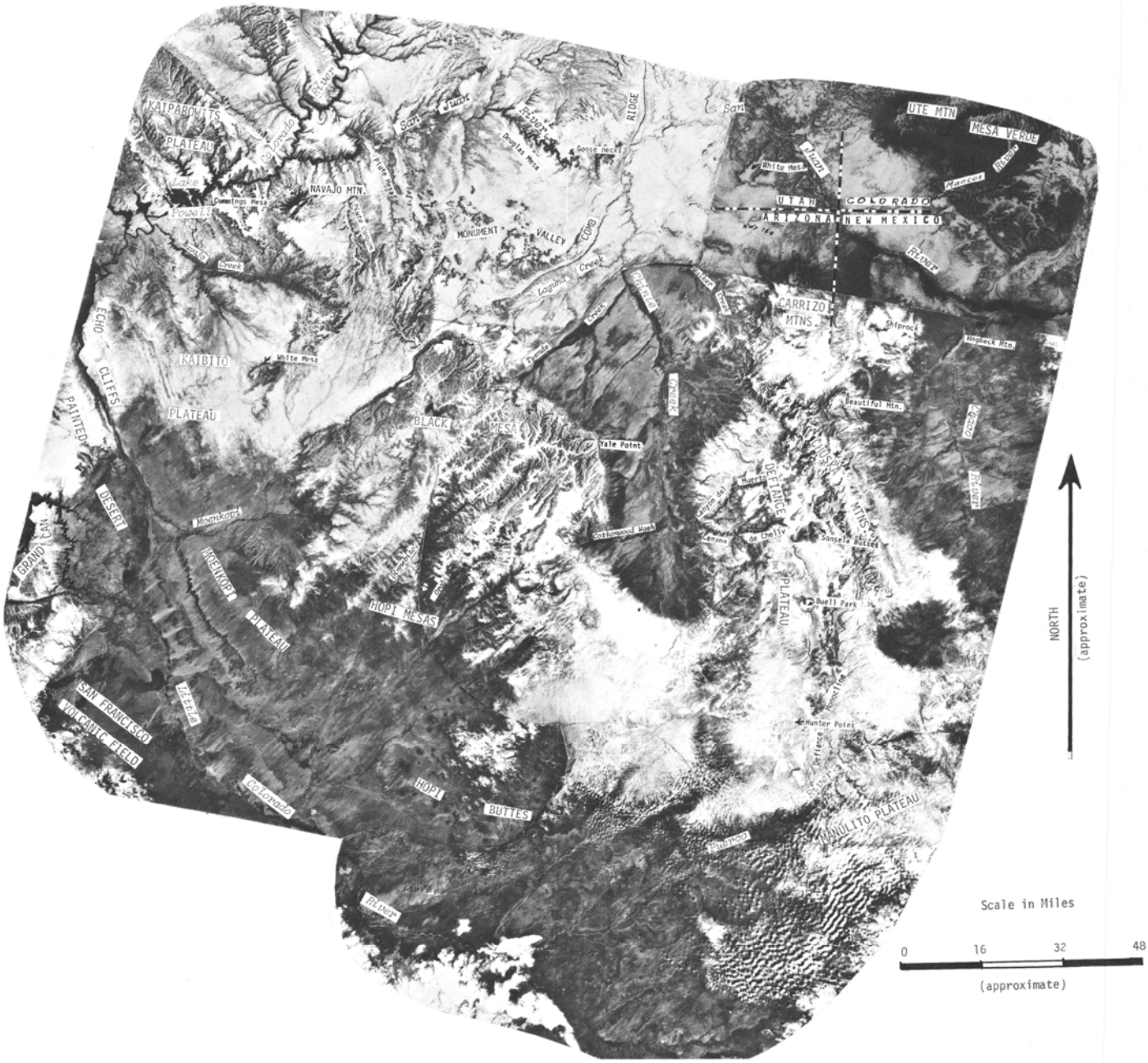


Figure 3.

Map showing past and present prevailing wind directions in the Navajo country. Reproduced from U.S. Geol. Survey Prof. Paper 521-A (fig. 14), p. A31.



PHOTOMOSAIC MAP OF THE NAVAJO COUNTRY:

Assembled from photos taken by the Earth Resources Technology Satellite (ERTS). Compilation July, 1973, by W. Lee Stokes, University of Utah.

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