• 13 •

Mesozoic and Cenozoic Strata of the Colorado Plateau Near the Grand Canyon

Michael Morales

INTRODUCTION

If you stand on either the north or south rim of the Grand Canyon, the soles of your shoes will rest on the cracked and weathered limestone of the Kaibab Formation. This topmost rock unit of the canyon was deposited near the end of the Paleozoic Era. As you peer into the deep chasm below, you will see a mile (1.6-km)-thick section of strata that accumulated during the Proterozoic Eon and Paleozoic Era. Now turn your gaze skyward and imagine a section of rocks extending *above* your feet for approximately another mile, about the same distance above the rim as the bottom of the canyon is below the rim. This exercise will give you an idea of the great thickness of marine and terrestrial rock layers that were deposited on the top of the Kaibab Formation in several intervals during the Mesozoic Era (Hintze 1988). These sediments once covered the entire southwestern portion of the Colorado Plateau Physiographic Province (Fig. 13.1), an area that includes the Grand Canyon (Billingsley 1989).

In the vicinity of the canyon, denudation stripped away the Mesozoic strata during the Late Cretaceous in a major episode of erosion associated with the uplift of the southwestern Colorado Plateau (Lucchitta, Chapter 15, this volume). During the early Cenozoic Era (Paleocene and Eocene epochs), one-half mile (0.8 km) or more of terrestrial sediments and volcanics accumulated, only to be removed almost entirely in another episode of erosion during the Oligocene (Elston and Young 1989). Widely dispersed remnants of these deposits, primarily unnamed gravels and interbedded freshwater limestones, still crop out in the southwestern part of the Grand Canyon area (Elston and Young 1989; Young 1989). Thus, nearly all Cenozoic and Mesozoic sedimentary rocks have been removed from the Grand Canyon area, leaving mainly strata of middle and late Paleozoic age (Kaibab, Toroweap, Coconino, Redwall, Supai) as the topmost bedrock units surrounding the canyon. Scattered patches of Pleistocene volcanic rocks cover sedimentary units in and near the western Grand Canyon (Hamblin, Chapter 17, this volume). South of the canyon, Tertiary and Quaternary volcanic rocks of the Mount Floyd, San Francisco, and Mormon Mountain volcanic fields (Fig. 13.2) cover the Paleozoic strata (Chronic 1983). These fields include a multitude of cinder cones (e.g., Sunset Crater), volcanic domes (e.g., Bill Williams

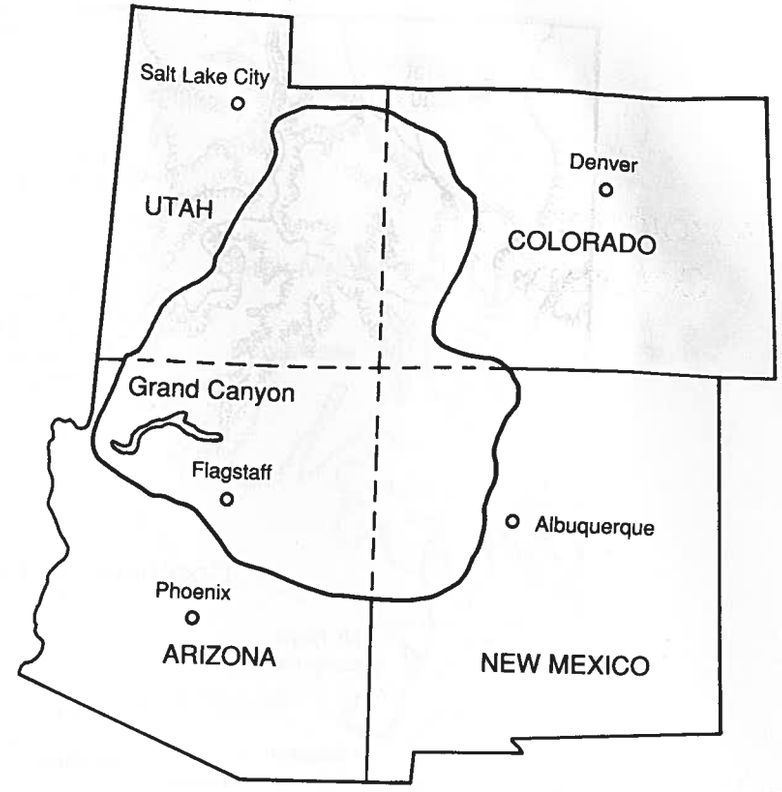

Figure 13.1. The Colorado Plateau Physiographic Province.

Mountain), composite volcanoes (e.g., San Francisco Mountain or Peaks), and many lava flows (Holm 1987; Holm and Moore 1987).

North and east of the Grand Canyon, where less erosion has occurred, Mesozoic and Cenozoic strata of the southwestern Colorado Plateau are preserved in vast badland outcrops of cliffs, canyons, and plateaus. These rocks are especially visible in two regions: north of the canyon, in the area of northern Arizona and southern Utah that Clarence E. Dutton named the Grand Staircase, and east of the canyon to Black Mesa, Arizona. This chapter summarizes the main aspects of rock units, excluding surficial Quaternary deposits, that rest on top of the Kaibab Formation in areas of the Colorado Plateau near the Grand Canyon (Table 13.1).

THE GRAND STAIRCASE

The topography north of the Grand Canyon is made up of alternating cliffs and flatlands that form a series of erosional steps of increasing elevation through Mesozoic and Cenozoic deposits. The Grand Staircase section of this region (Stokes 1986) includes the Uinkaret, Kanab, Kaibab, Markagunt, and Paunsaugunt

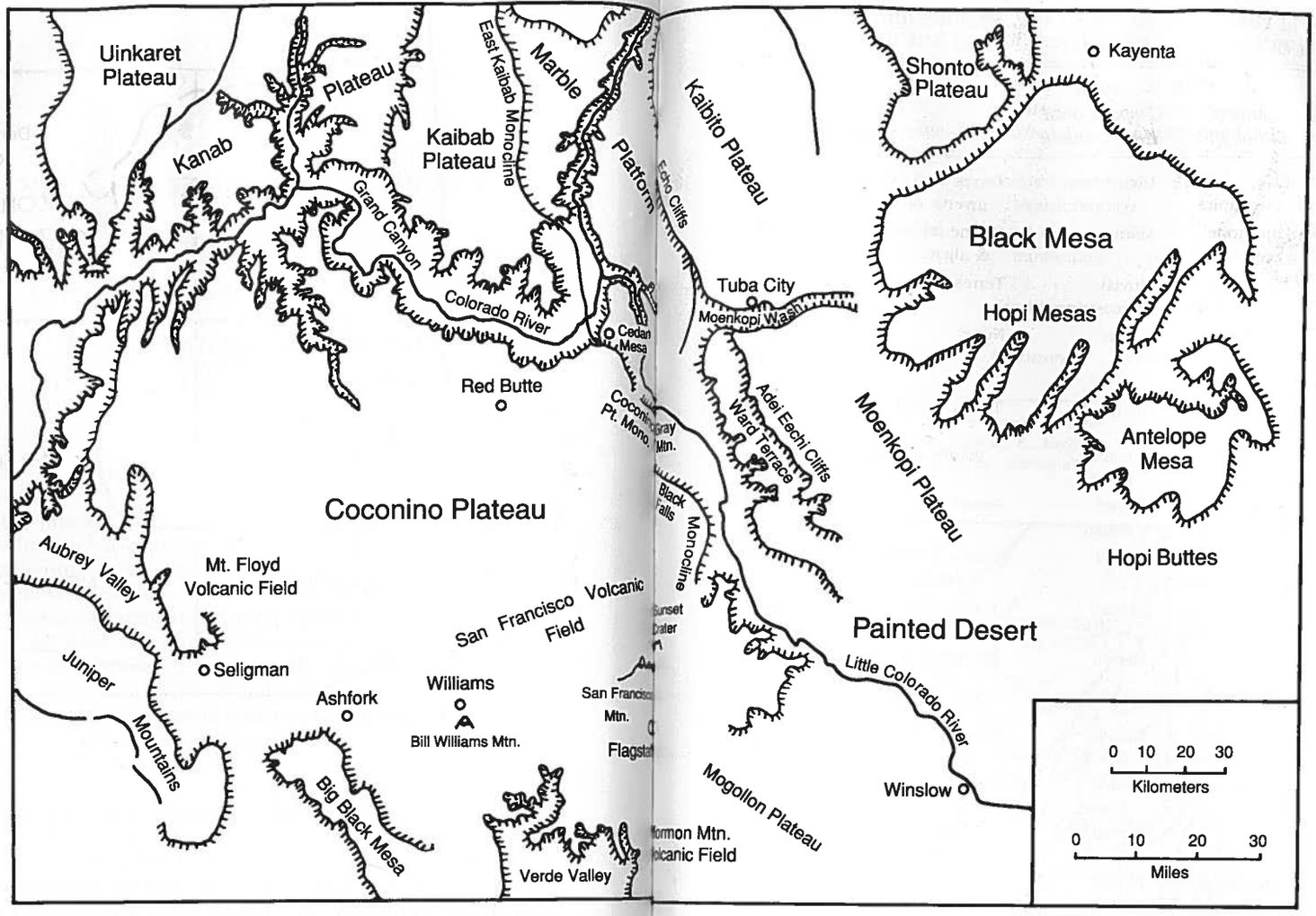

FIGURE 13.2. Physiographic map of the central and eastern Grand Canyon and surrounding areas. (After Gregory 1950, Cooley et al. 1969, King 1977, and Billingsley and Hendricks 1989.)

plateaus; Antelope Valley; Telegraph Flat; the Little Creek, Wygaret, Kolob, and Skutumpah terraces and their equivalents to the east; the Block Mesas region; and the Moccasin Terrace (Fig. 13.3). The plateaus and terraces are bordered on their west and east sides by the major north/south-trending Hurricane, Toroweap–Sevier, and West Kaibab–Paunsaugunt faults (and associated monoclines and cliffs) and by the East Kaibab monocline (and related faults). In three areas, Zion and Bryce national parks and Cedar Breaks National Monument, deep canyons and extensive badlands have been carved into the rocks. Figure 13.4 illustrates the slightly north-dipping strata and stepped topography of the Grand Staircase.

The first line of cliffs north of the Grand Canyon is the Chocolate Cliffs. The name is derived from the red-brown mudstone of the Lower and Middle Triassic Moenkopi Formation that forms the majority of the cliff profile. This escarpment sometimes is called the Shinarump Cliffs after sandstones and conglomerates of the Shinarump Member of the Upper Triassic Chinle Formation that cap the cliffs. Although the Chocolate Cliffs officially terminate at the northern end of Kaibab Plateau, the same rock units form a cliff and slope line along the southern margin of Paria Plateau. There, however, the Moenkopi–Shinarump cliffs are not as well developed as the true Chocolate Cliffs. Erosional unconformities, which represent gaps in the rock/time record, separate the Moenkopi from the underlying Kaibab and overlying Chinle formations. The Moenkopi contains both marine and nonmarine sediments, whereas the Shinarump member of the Chinle is composed primarily of fluvial channel deposits. The flatlands and slopes above

TABLE 13.1. Alphabetical List of Formations of the Southwestern Colorado Plateau North and East of the Grand Canyon[a]

Formation Name	*Age*	*Major Lithologies*	*Main Depositional Environment*	*Fossil Groups*
Bidahochi	Mio-Plioc.	Clay, volcanics	Lacustrine, volcanic	Terres. and fresh. verts; inverts; & plants
Carmel	M. Jur.	Limestone, mudstone	Marine	Marine inverts., verts., & algae
Chinle Claron	Lt. Tri.	Mudstone, sandstone	Fluvial, lacustrine	Terres. plants; fresh. inverts.
Cow Springs Sandstone	M. Jur.	Sandstone	Eolian	None?
Dakota inverts;	Lt. Cret.	Sandstone, mudstone, coal	Marginal marine, fluvial	Terres. plants, verts., & marine inverts.
Entrada Sandstone	M. Jur.	Sandstone, mudstone	Fluvial, eolian	None?
Kaiparowits	Lt. Cret.	Mudstone, sandstone	Fluvial	Terres. & fresh. verts., inverts., & plants
Kayenta	E. Jur.	Siltstone, sandstone	Fluvial, eolian	Terres. plants, verts.; dinosaur tracks
Mancos inverts. Shale	Lt. Cret.	Shale	Marine	Marine plants, verts., &
Moenave	E. Jur.	Sandstone, mudstone	Eolian, fluvial	Fresh. fish, crocodiles, dinosaurs, & reptile tracks
Moenkopi	E-M Tri.	Mudstone	Marine, fluvial, tidal flat	Marine inverts.; terres. & fresh. verts., inverts., & plants; vert. & invert. trace fossils
Morrison	Lt. Jur.	Mudstone, sandstone	Fluvial	Terres. & fresh. plants, verts. (esp. dinosaurs), inverts., & trace fossils
Navajo Sandstone	E. Jur.	Sandstone, limestone	Eolian lacustrine	Terres. reptiles, plants, & invert. trace fossils; dinosaur tracks
Summerville	M. Jur.	Sandstone	Eolian	None?
Straight Cliffs	Lt. Cret.	Sandstone, mudstone	Fluvial, marginal	Marine & fresh. inverts. fresh. marine & terres. verts.
Temple Cap	E-M. Jur.	Mudstone, sandstone	Fluvial	None?
Toreva	Lt. Cret.	Mudstone, sandstone,	Littoral, fluvial, coal	Vert. fragments?
Tropic Shale	Lr. Cret.	Shale	Marine	Marine plants, verts., & inverts.

(*continued*)

TABLE 13.1. Alphabetical List of Formations of the Southwestern Colorado Plateau North and East of the Grand Canyon[a] (*Continued*)

Formation Name	*Age*	*Major Lithologies*	*Main Depositional Environment*	*Fossil Groups*
Wahweap	Lt. Cret.	Sandstone, mudstone	Fluvial	Fresh. & terres. verts. & inverts.
Wepo	Lt. Cret.	Sandstone, mudstone,	Fluvial, paludal, coal	None?
Wingate Sandstone	E. Jur.	Sandstone	Eolian	Dinosaur tracks
Yale Point Sandstone	Lt. Cret.	Sandstone	Littoral	None?

[a]Data compiled from many sources. Mio-Plioc., miocence-Pliocene; Paleoc.?, Paleocene; Cret., Cretaceous; Tri., Triassic; Jur., Jurassic; E., Early; M., Middle; Lt., Late; inverts., invertebrates; fresh., freshwater; verts., vertebrates; terres., terrestrial.

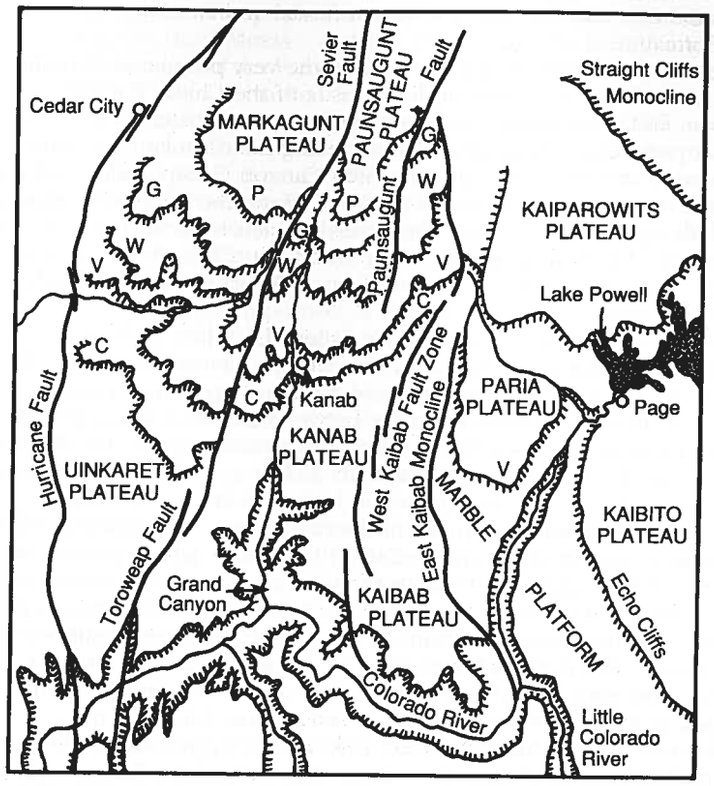

FIGURE 13.3. Physiologic map of the Grand Staircase section of the Colorado Plateau. C, Chocolate Cliffs; V, Vermilion Cliffs; W, White Cliffs; G, Gray Cliffs; P, Pink Cliffs. (After King 1977, Stokes 1986, and Billingsley and Hendricks 1989.)

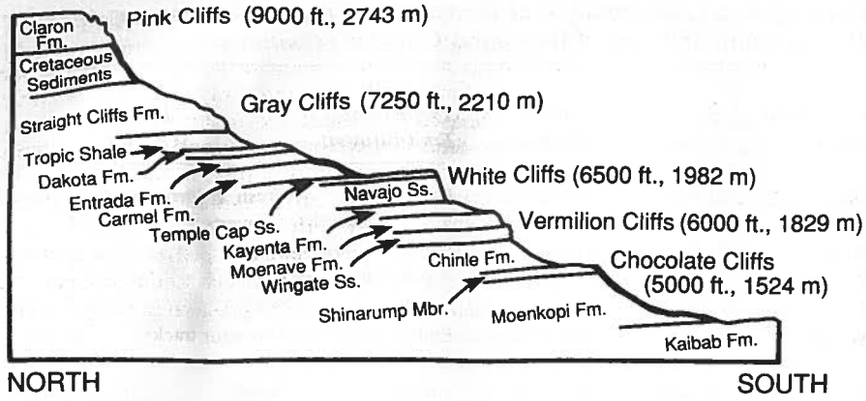

FIGURE 13.4. Diagrammatic cross section of the Grand Staircase—vertical scale greatly exaggerated. (After King 1977, Stokes 1986, Hintze 1988, and Clemmensen et al. 1989.)

the Chocolate Cliffs, including Little Creek Terrace, Telegraph Flat, and related areas to the east, are formed by different fluvial and lacustrine members of the Chinle Formation.

The next step up the Grand Staircase is the very prominent Vermilion Cliffs. Starting at the base, red and purple deposits of the Chinle Formation, Wingate Sandstone, and the Moenave and Kayenta formations make up these cliffs, with the lower part of the Navajo Sandstone forming the caprock. The latter four formations comprise the Lower Jurassic Glen Canyon Group and are of primarily eolian and fluvial origin. An unconformity separates the Wingate Sandstone from the underlying Chinle Formation; however, contacts between the other units are gradational to intertonguing. Above the Vermilion Cliffs, the Navajo Sandstone forms the bench that includes Mocassin Terrace, Wygaret Terrace, and their equivalents to the east.

The next escarpment northward is called the White Cliffs; it is composed primarily of the prominent buff-to-white colored Navajo Sandstone. Fluvial deposits of the Lower and Middle Jurassic Temple Cap Formation cap the cliffs, and there is an erosional unconformity between the two formations. The White Cliffs terminate on the west side of the Kaiparowits Plateau. The flatlands and slopes above the White Cliffs include the Kolob and Skutumpah terraces and their equivalents. Zion Canyon is carved into southern Kolob Terrace along the White Cliffs. The southern portions of the two terraces are made up primarily of the Dakota Formation overlying the Carmel Formation, which rests on the Navajo Sandstone. To the east, the Entrada Formation is present between the Carmel and the Dakota. The contact between each of the four formations is unconformable. Both the Carmel and Entrada are Middle Jurassic formations of the San Rafael Group. The former, however, is of marine origin, whereas the latter is predominantly tidal flat and eolian. Depositional environments of the Dakota Formation range from terrestrial to marginal marine.

The Gray Cliffs form a relatively low line that runs across the Kolob and Skutumpah terraces and extends to the eastern side of the Kaiparowits Plateau. They are formed by the gray Tropic Shale capped by the Straight Cliffs Formation. The Tropic Shale disconformably overlies and interfingers with the Dakota Formation. The Tropic Shale and the Straights Cliffs Formation have an intertonguing contact. Deposits of the Tropic Shale are marine, while those of the Straight Cliffs Formation are terrestrial to marine.

The northern portions of Kolob and Skutumpah terraces, formed by the Straight Cliffs Formation, continue northward from the Gray Cliffs to the final step up the Grand Staircase, the Pink Cliffs. These are made of Upper Cretaceous rocks of uncertain affinities (called Wahweap and Kaiparowits formations in early literature) that are capped by light pink and orange lacustrine and fluvial deposits of the lower Cenozoic (Paleocene?) Claron Formation (Hintze 1988). An unconformity separates the Claron from underlying strata. The Pink Cliffs form the southern escarpment of the Markagunt Plateau on the west and the Paunsaugunt Plateau on the east (Fig. 13.3). The badlands of Cedar Breaks and Bryce Canyon are carved into the Pink Cliffs on the southwestern Markagunt and southeastern Paunsaugunt plateaus, respectively.

SOUTH RIM TO BLACK MESA

The topography east of the Grand Canyon includes cliffs, terraces, plateaus, and generally north/south-trending fault zones and monoclines that cross a transect from the south rim eastward to Black Mesa. Unlike the Grand Staircase, this region of the southern Colorado Plateau has no general name. It includes the Coconino, Kaibito, and Moenkopi plateaus; Marble Platform; Ward Terrace; Black Mesa (including the Hopi Mesas); and the Little Colorado River Valley, which contains the western part of the Painted Desert (Fig. 13.2). The northeastern edge of the Coconino Plateau is marked by the East Kaibab, Coconino Point, and Black Point monoclines (and their associated faults). The Echo Cliffs, a result of erosion along the Echo Cliffs monocline, form the western border of Kaibito Plateau. The related Adei Eechii Cliffs comprise the western boundary of Moenkopi Plateau. Between the Kaibito and Moenkopi plateaus runs Moenkopi Wash, which extends eastward to Black Mesa. Figure 13.5 illustrates the stratigraphy and topography along the transect from the eastern part of the canyon's south rim to Black Mesa.

In the central and eastern portion of the Grand Canyon, the south rim represents the northern border of the Coconino Plateau. The Kaibab Formation caps the plateau here, except in rare places where remnants of Triassic rocks are preserved. At Cedar Mesa, slightly east of the south rim's Desert View overlook, the Moenkopi Formation overlies the Kaibab Formation; it, in turn, is capped by a resistant layer of Cenozoic volcanic rock. At Red Butte, south of Grand Canyon Village, the Moenkopi is covered by Shinarump deposits, which also are overlain by a younger lava flow.

On its northeastern border, the Coconino Plateau folds downward along the east to northeast-dipping East Kaibab, Coconino Point, and Black Point monoclines. This folding is especially noticeable at Gray Mountain, southeast of Desert View (Barnes 1987). Tidal-flat, fluvial, and eolian deposits of the Lower and Middle Triassic Moenkopi Formation border the edge of the plateau and extend to the middle of the Little Colorado River Valley and Marble Platform. Farther eastward, overlying red and purple deposits of the fluvial lower members of the Upper Triassic Chinle Formation make up the Painted Desert. A step up and to the east of the Painted Desert in the Little Colorado River Valley is Ward Terrace. This flat area is composed of the mainly gray lacustrine sediments of the Chinle's upper members.

East of Marble Platform and Ward Terrace, the topography includes two erosional steps upward (Fig. 13.5). The first is formed by the Echo and Adei Eechii

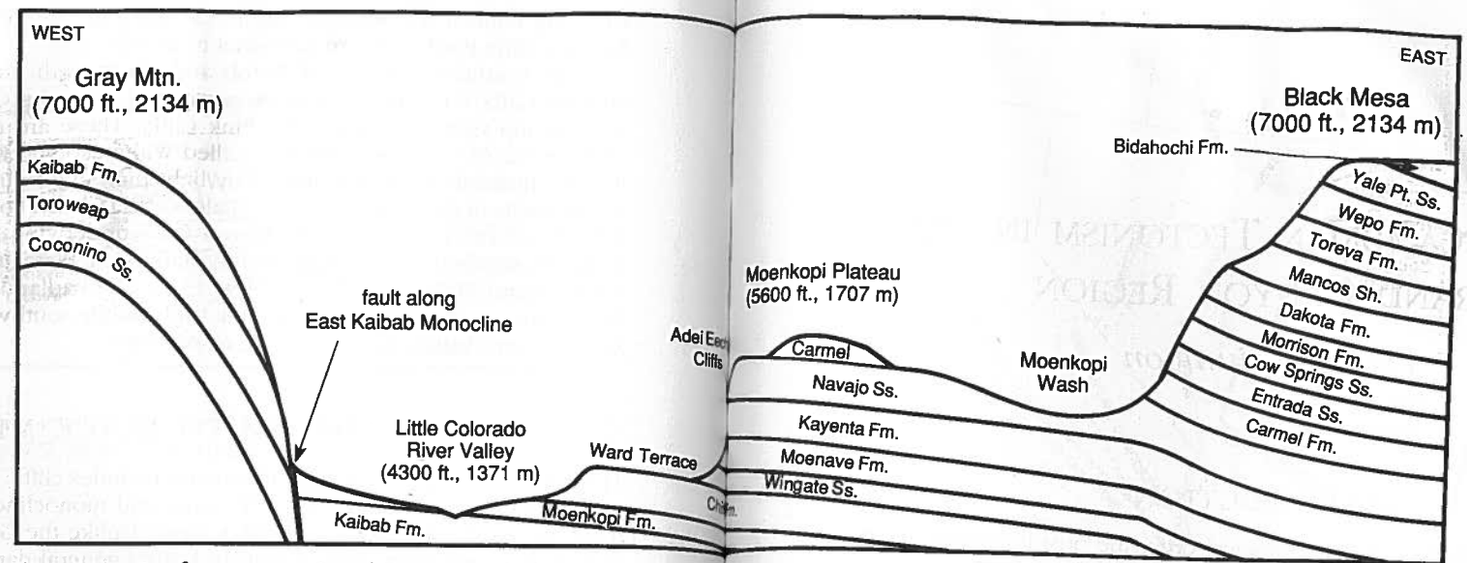

FIGURE 13.5. Diagrammatic cross section from eastern Grand Canyon to Black Mesa—vertical scale greatly exaggerated. (After Brown and Lauth 1958, Cooley et al. 1969, and Chronic 1983.)

cliffs, which border the Kaibito and Moenkopi plateaus, respectively. The second step includes the cliffs and top of Black Mesa. Units of the Upper Jurassic Glen Canyon Group form the Echo and Adei Eechii cliffs, which are capped by the Navajo Sandstone. The Wingate Sandstone is present only in the southern part of the Adei Eechii Cliffs; it thins northward to an erosional pinchout south of Moenkopi Wash. Strata of the Echo Cliffs dip steeply to the east because of the Echo Cliffs monocline. However, the beds of the Adei Eechii Cliffs dip only slightly in the same direction because the monocline does not extend that far south. Most of the surface of the Kaibito and Moenkopi plateaus is formed by the Navajo Sandstone, except in places where less intense erosion has left younger strata, such as the unconformably overlying Carmel Formation.

The lower flatlands and slopes of Black Mesa are composed of, in ascending order, the Carmel Formation, Entrada Sandstone, Cow Springs Sandstone (west side) or Summerville Formation (east side), and Morrison Formation—all part of the Middle and Upper Jurassic San Rafael Group (Cooley et al. 1969). The Entrada has conformable contacts with units below and above it, whereas the Cow Springs and Summerville, which laterally intergrade and interfinger, have an uncomformable contact with the overlying Morrison. The upper slopes and cliffs of Black Mesa are made of Upper Cretaceous deposits of the Dakota Formation, Mancos Shale (correlative with the Tropic Shale), Toreva and Wepo formations, and Yale Point Sandstone. The latter three units comprise the Mesaverde Group. An unconformity separates the Dakota from the underlying Morrison. The Mancos has gradational boundaries with the Dakota below and Toreva above. The lower and upper contacts of the Wepo are intertonguing. Deposits of the San Rafael Group, except the marine Carmel Formation, are terrestrial in origin, as are parts of the Dakota, Toreva, and Wepo formations. Other portions of the latter three formations represent nearshore environments (Harshbarger et al. 1957; Wilson 1974). Sediments of the Mancos Shale are of marine origin.

Most of Black Mesa's top surface is formed by the Wepo Formation, but the Yale Point Sandstone caps it to the northeast. In the extreme southern portion of Black Mesa, in the area of the Hopi Mesas, the Miocene–Pliocene Bidahochi Formation unconformably overlies the Mesaverde Group (Cooley et al. 1969). Lacustrine sediments dominate the Bidahochi, but fluvial and volcanic deposits are also present.

SUMMARY

Although the Proterozoic and Paleozoic rocks of the Grand Canyon record ancient environments, prehistoric life, and geologic events over hundreds of millions of years, they do not provide a complete picture of the area's geologic history. For the rest of the story, we must look to strata resting on top of the Kaibab Formation in and near the canyon.