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Kaibab Formation

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INTRODUCTION

The Kaibab Formation comprises the caprock of the Grand Canyon and forms the surface of the Kaibab and Coconino plateaus, which is the area through which the deepest part of the canyon has been carved. When visitors view the Kaibab Formation from scenic points and trailheads within the national park, they can recognize it easily as the gray, stepped cliff directly above the vegetated slope of the Toroweap Formation (Fig. 12.1). The Kaibab, the youngest Paleozoic rock unit on the southern Colorado Plateau, is composed of a variety of lithologic types that were deposited within a complex shallow-marine setting during the Permian. It represents the final chapter in the geologic story recorded by the sedimentary layers of the Grand Canyon.

Because it is at the top of the Grand Canyon stratigraphic section (and, therefore, is easy to see), geologists have studied the Kaibab Formation extensively. This chapter summarizes the cumulative knowledge gained through decades of observations by numerous geologists and is dedicated to Edwin D. McKee, in whose footsteps we all have followed.

NOMENCLATURE

The detailed description and naming of strata included within the Kaibab Formation has a long and interesting history. The earliest recorded observations of Permian rocks in northern Arizona were made by Jules Marcou (1856). Originally, geologists considered the units represented by the present-day Kaibab and Toroweap Formations a single formation, the Aubrey limestone (G.K. Gilbert 1875). Walcott (1880) placed these strata within the Upper Aubrey Group. The name "Kaibab" first was applied by Darton (1910) for exposures on the Kaibab Plateau north of the Grand Canyon. Noble (1914, 1922), along with Longwell (1921), provided the initial description and correlation of Kaibab strata across the Grand Canyon region. Geologists then subdivided these strata into five basic topographic and lithologic units. Reeside and Bassler (1922) named the uppermost beds the Harrisburg Gypsiferous Member for exposures at Harrisburg Dome in Utah. Noble (1928) proposed a type section for the Kaibab Limestone in Kaibab Gulch (in Utah, along the East Kaibab Monocline).

It was not until the classic work by McKee (1938) that the Kaibab Limestone was split into two formations. McKee proposed that the term Kaibab be applied only to the massive upper limestone and the unit directly above it, suggesting

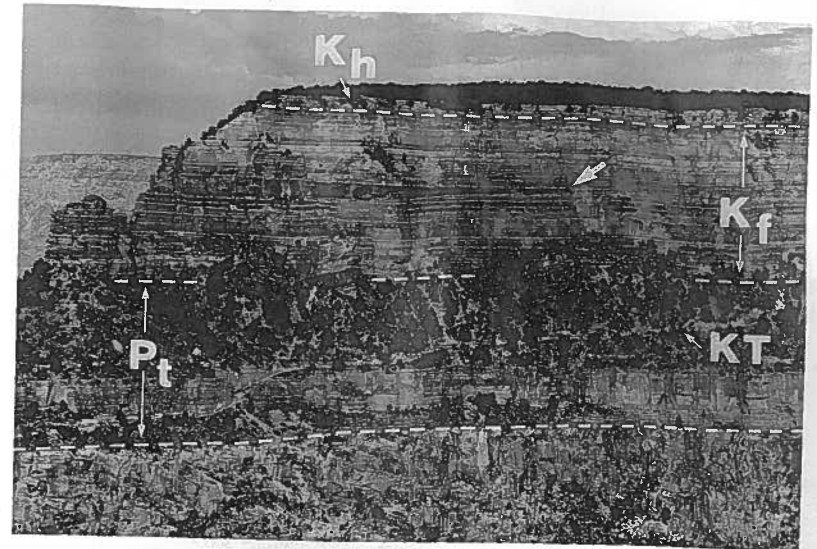

Figure 12.1. View of precipitous Kaibab cliff along the south rim near the South Kaibab Trail (KT) showing Fossil Mountain (K_f) and Harrisburg (K_h) members. Note pinch out of sandstone until laterally within the Fossil Mountain member (*arrow*). Slope-forming Woods Ranch Member of the Toroweap Formation (P_t) everywhere underlies the Kaibab Formation in the walls of the Grand Canyon. Photograph looking east from Mather Point.

that these rocks be called the "Kaibab Formation" because they are composed of a variety of lithologic types. The lower limestone unit and adjacent slope-forming units became the Toroweap Formation (Turner, Chapter 11, this volume). McKee's scheme recognized three members within each formation and named them "alpha," "beta," and "gamma" in descending order.

In an attempt to establish more formal rock units, Sorauf (1962) proposed a change in terminology for both the Kaibab and the Toroweap Formations. He suggested that the rocks included with the alpha (or upper) member be called the Harrisburg Member. The beta (or middle) member of the Kaibab became the Fossil Mountain Member, named for Fossil Mountain along the south rim near the Bass Trail. Rocks included within the gamma (or lower) member, confined by McKee to the Mogollon Plateau south of the Grand Canyon, were not present in Sorauf's field area. Geologists interpret the gamma member as a facies within the Fossil Mountain Member (Lapinski 1976; Cheevers and Rawson 1979). Most subsequent workers have utilized the revisions in nomenclature suggested by Sorauf (1962), and the designation was formalized by Sorauf and Billingsley (1991).

DISTRIBUTION

Rocks of the Kaibab Formation form a continuous layer across the Grand Canyon and the surrounding region. The best exposures in cross section occur along the cliffs of the canyon and its tributaries. Although recent exposure and erosion of Kaibab rocks beneath the Permo-Triassic unconformity obscure thickness trends,

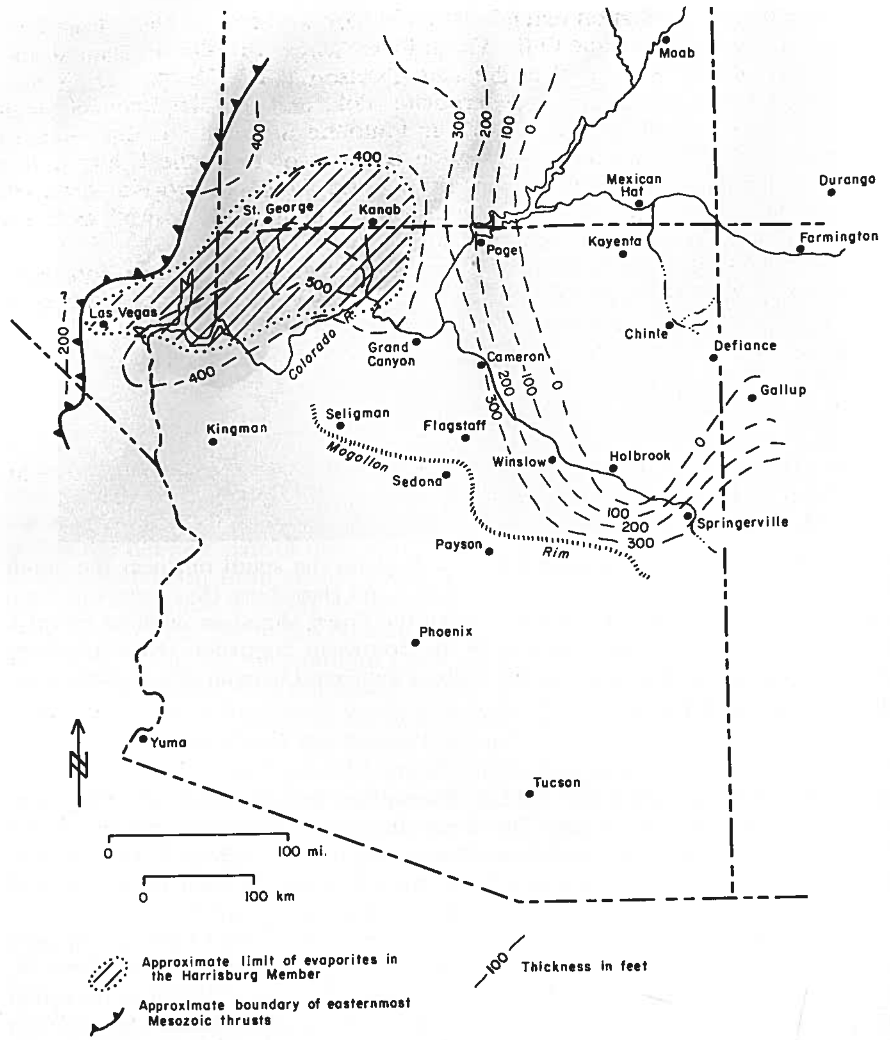

FIGURE 12.2. Isopach map of the Kaibab Formation illustrating total thickness trends across the Grand Canyon and surrounding regions. Maximum thickness of the Kaibab occurs in northwestern Arizona, where the Harrisburg Member contains significant evaporites. Data are compiled from many sources.

we know that the formation gradually thickens to the west (Fig. 12.2). Along the rim of the canyon, it generally ranges between 300 and 400 feet (90–120 m) in total thickness. Geologists have measured the greatest thickness in northwestern Arizona, in an area west of Kanab Creek, and northwest of the Colorado River. Here it exceeds 500 feet (150 m). East of the Grand Canyon, the Kaibab thins dramatically and is absent along the Defiance and Monument upwarps. Outcrops southeast of Winslow and south of Holbrook clearly show stratigraphic thinning (McKee 1938; Mather 1970; Cheevers 1980).

To the south, the Mogollon Rim, or escarpment, defines the limit of Kaibab exposure. This area represents the southern edge of the Colorado Plateau. Northward, the Kaibab Formation extends into southern and central Utah. It is well-exposed along the Hurricane Cliffs, Virgin River Gorge, and Beaver Dam Mountains in the southwestern part of the state (Nielson 1981). The formation continues on into the Circle Cliffs–Waterpocket Fold and the San Raphael Swell regions in central Utah (Davidson 1967) and into the subsurface across southern Utah (Irwin 1971). Some of this formation contains oil (e.g., the Upper Valley Field near Escalante, Utah). Geologists have found Kaibab outcrops as far north as the Deep Creek Mountains and Confusion Range in Utah, as well as in the isolated mountains of northeastern Nevada.

In southern Nevada, westernmost outcrops of the Kaibab Formation occur in a number of scattered mountain ranges in the Las Vegas area (Longwell 1921; Bissell 1969). The formation appears to thin westward (Fig. 12.2).

STRATIGRAPHY

Facies changes within the Kaibab Formation and in adjacent units complicate internal and regional stratigraphic relations.

Lower Contact

At the Grand Canyon, the Kaibab Formation is underlain everywhere by gypsum and/or contorted sandstones of the Woods Ranch Member of the Toroweap Formation (Fig. 12.1). Originally, geologists believed that the Kaibab–Toroweap contact was unconformable. They based this impression primarily on the presence of local intraformational breccias and erosional surfaces (McKee 1938). Further study has shown that these features are related to collapse following the dissolution of evaporitic facies within the underlying Woods Ranch Member, indicating that the contact is conformable or only locally disconformable. The basal Kaibab is the first cherty carbonate or sandstone unit located above the *Schizodus* bed (Hurricane Cliffs tongue) of the Woods Ranch Member.

To the south and east of the Grand Canyon, the evaporites and contorted sandstones (sabkha complex) of the underlying Woods Ranch Member are transitional and interstratified with cross-bedded sandstone facies (eolian dune complex). These rocks ultimately become indistinguishable from the Coconino Sandstone (Turner, Chapter 11 this volume). As a result, the Kaibab Formation in the Mogollon Rim region directly overlies the Coconino Sandstone. In northeastern Arizona and southeastern Utah, the White Rim Sandstone underlies the Kaibab.

Fossil Mountain–Harrisburg Contact

The contact between the Fossil Mountain and Harrisburg members of the Kaibab Formation is conformable, though different workers have placed it at slightly different stratigraphic levels. The similarity in the facies of both members at eastern localities has made it difficult to establish the contact. At the Grand Canyon, however, there are distinct textural, mineralogical, and faunal changes within the upper portion of the Kaibab sequence. Typically, a distinctive white, butterscotch, or red nodular-to-bedded chert horizon marks the base of the Harrisburg Member. This "marker-chert" most often is coincident with the disappearance of the normal-marine fauna and limestone mineralogy that is most characteristic of the cliff-forming Fossil Mountain Member (Sorauf 1962; Clark 1980; Hopkins 1986). In areas of southwestern Utah where the marker-chert is absent, geologists place the contact at the obvious change to slope-forming gypsiferous beds in the basal part of the Harrisburg Member.

East and south of the Grand Canyon, the contact between members is less obvious. It is easy to distinguish the Fossil Mountain Member in this region because it contains fauna of normal-marine affinity—particularly the productid brachiopod *Peniculauris bassi* (McKee 1938). At its eastern and southeasternmost extent, the lithology and fauna within the Fossil Mountain and Harrisburg members are similar. In this area, geologists place the contact at a distinct change from the thick-bedded sandstones and sandy carbonates of the Fossil Mountain Member to thinner-bedded units of the Harrisburg. The latter contain a more abundant molluscan fauna. Along its depositional edge, for example, southeast of Winslow and south of Holbrook, the Kaibab sequence is difficult to subdivide into members (Cheevers and Rawson 1979). Because the Harrisburg Member has disappeared from this area, only the shoreward facies of the Fossil Mountain Member have been preserved.

Upper Contact

In northern Arizona and southern Utah, the Triassic Moenkopi Formation occurs above the Kaibab Formation. Because of their less resistant nature, however, Moenkopi redbeds at the Grand Canyon have been removed almost entirely by erosion. One consequence of this erosion is that the Kaibab Formation caps many of the vast plateaus that border the Grand Canyon. Only rarely are the uppermost beds of the Kaibab preserved.

In northwestern Arizona, southeastern Nevada, and southwestern Utah, discontinuous conglomerate-filled channels and breccia deposits occur between the Kaibab Formation and Timpoweap Member of the Moenkopi Formation. Reeside and Bassler (1922) termed these deposits the Rock Canyon conglomerate for a channel 250 feet (75 m) deep and 700 feet (210 m) wide in Rock Canyon, which is north of Antelope Spring, Arizona. At several localities (e.g., in the Beaver Dam Mountains), channels of the Rock Canyon conglomerate have scoured completely through the Harrisburg Member and into the underlying Fossil Mountain Member (Nielson 1981). The tectonic significance of the Rock Canyon conglomerate is unresolved, though associated features may represent paleokarst depressions.

In areas of southwestern Utah and southern Nevada where carbonates of the Timpoweap Member of the Moenkopi Formation overlie uppermost carbonates of the Harrisburg Member, the formational contact can be difficult to determine (Bissell 1969; Nielson 1981). Geologists also have trouble distinguishing the contact when gypsiferous beds of the Lower Red Member of the Moenkopi Formation occur directly above gypsiferous beds of the Harrisburg Member (Bissell 1969; Cheevers 1980). To the north, in the mountains of western Utah and eastern Nevada, the Kaibab Formation is overlain conformably by the Permian Plympton Formation and Gerster Limestone of the Park City Group.

LITHOLOGY AND COMPOSITION

The Kaibab Formation is a complex sedimentary package composed of a variety of rock types. Due in part to mixing between carbonate siliciclastic sediment and intense post-depositional (diagenetic) changes in composition [in particular, silicification (chert formation) and dolomitization], rock ledges of the Kaibab appear similar at first glance. A number of detailed studies have delineated internal facies characteristics and distribution, providing resolution with respect to major changes in lithology, mineral composition, and faunal constituents.

Fossil Mountain Member

The Fossil Mountain Member of the Kaibab Formation is a prominent cliff that weathers to form distinctive pinnacles, or "hoodoos," below the rim of the canyon. The member thickens gradually westward and typically ranges between 250 and 300 feet (75–105 m). At Fossil Mountain along the south rim, where it is over 200 feet (60 m) thick, cherty limestones that contain abundant whole fossils characterize the member (McKee 1938; Cheevers 1980; Hopkins 1986).

As observed in outcrop along both rims of the canyon, the Fossil Mountain Member exhibits a pronounced change in lithology, mineralogy, and faunal constituents from west to east (Fig. 12.3). In western Grand Canyon, for example (in an area west of Fossil Mountain on the south rim and North Bass Trail on the north rim), the member contains a characteristic cherty, fossiliferous limestone with an abundant and diverse normal-marine fauna. This fauna includes brachiopods, bryozoans, crinoids, sponges, and solitary corals. Carbonate textures are dominated by skeletal wackestone (matrix-supported texture), with only minor amounts of admixed detrital quartz. Packstone intervals (grain-supported texture) are common locally, but typically form an insignificant percentage of the sequence. Sandstone comprises less than 10 percent of total lithofacies and commonly occurs near the base. Dolomite occurs only as scattered rhombs replacing a micrite matrix (carbonate mud).

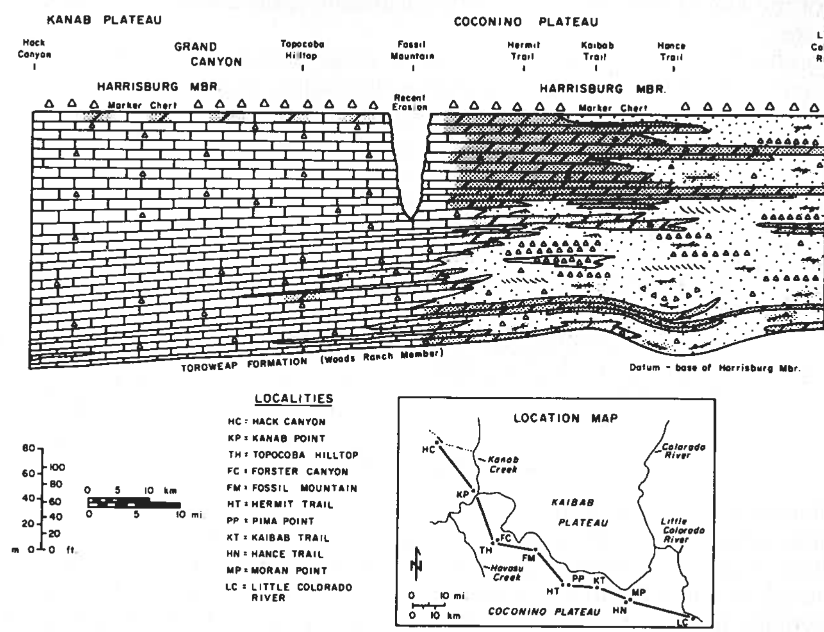

FIGURE 12.3. Diagrammatic cross section of the Fossil Mountain Member illustrating the west-to-east change in lithology and mineral composition at the Grand Canyon. See Fig. 12.4 for list of symbols. (Modified from Hopkins 1986.)

In contrast, the Fossil Mountain Member becomes increasingly siliciclastic to the east. Here, dolomite is the predominant mineralogy, and a restricted-marine fauna is most characteristic (Fig. 12.3). Within the zone of most pronounced lithologic transition, at Hermit Trail, for example, sandstone and sandy carbonate comprise nearly 50 percent of the member.

Carbonate lithofacies consist of skeletal wackestone and mudstone textures that have been altered to dolostone. We can see a similar change on the north rim near Point Sublime. In the basal portion of the sequence, sandstone beds occur in close association with relatively siliciclastic-free, skeletal carbonate units, though mixing between lithologies near unit contacts is common. Scouring along basal contacts occurs locally, and in some cases, siliciclastic units pinch out laterally (Fig. 12.1). Preserved sedimentary structures are scarce because units typically are bioturbated intensely. We can recognize horizontal, ripple, and low-angle laminations within certain sandstone intervals. To the east along both rims, the percentage of sandstone increases significantly. Ultimately, the Fossil Mountain Member consists of approximately 75 percent sandstone or sandy dolostone (e.g., at Desert View on the south rim and Cape Royal on the north rim).

An obvious lithologic characteristic of the Fossil Mountain Member is the amount and variety of chert (McKee 1938; Hopkins 1986). Chert is common as spherical nodules associated with siliceous sponges, which are most abundant in normal-marine carbonate facies in the western portions of the Grand Canyon. Irregular and branching chert forms also are typical within these facies. Many form by the selective replacement of burrow structures. Closely spaced nodular-to-bedded chert occurs as thin, laterally continuous intervals within sandstone facies. Petrographic study reveals that these chert horizons contain abundant relict sponge spicules and apparently formed by the recrystallization of biogenic silica during shallow burial. These horizons are most common in the eastern portions of the Grand Canyon, where they weather to form distinct recesses along cliff faces.

Another important chert type is a small, white nodule of cauliflower shape that occurs in both carbonate and sandstone lithologies, primarily where dolomitization has been pervasive within the member. These nodules represent silicified evaporites and suggest that a major portion of dolomitization in the Fossil Mountain Member was associated with the migration of hypersaline pore fluids in the shallow subsurface. The selective silicification of skeletal material represents an additional chert type. This silicification results in excellent preservation of many fossils. Chert also is common as lenses and irregular nodules within sandstone units. The fundamental control on the origin of chert in the Fossil Mountain Member, and in the Kaibab Formation as a whole, is attributed to the primary distribution and abundance of siliceous sponges and spicules within the depositional environment (Hopkins 1986).

Harrisburg Member

The Harrisburg Member of the Kaibab Formation forms the uppermost cliffs and receding ledges along both rims of the canyon. This member consists of an assemblage of gypsum, dolostone, sandstone, redbeds, chert, and minor limestone. It generally is thinner than the underlying Fossil Mountain Member. It is difficult to determine its true thickness and extent, however, because of removal associated with the Permo-Triassic unconformity, evaporite dissolution, and recent erosion. Complete sections range from 80 feet (25 m) at eastern exposures along the Little Colorado River (Blakey and Middleton, unpublished data) to 300 feet (90 m) near Whitmore Wash (Sorauf 1962). The member thickens dramatically west and northwest of Kanab Creek and is thickest in northwestern Arizona, southwestern Utah, and southern Nevada, where gypsum comprises a considerable portion of the sequence (Fig. 12.2). In fact, gypsum currently is mined from the Harrisburg Member at Blue Diamond Hill, west of Las Vegas, Nevada. At its type section at Harrisburg Dome east of St. George, Utah, it is about 280 feet (85 m) thick (Reeside and Bassler 1922).

Despite considerable change in lithology and thickness, we can recognize at least six informal stratigraphic units within the Harrisburg Member (Figs. 12.4 and 12.5; Clark 1980; Blakey and Middleton, unpublished data). It is possible that a seventh unit is present is some areas. If this is the case, erosion has removed most of the evidence of this unit (Clark 1980).

The basal unit (unit 1) appears gradational with fossiliferous beds of the underlying Fossil Mountain Member. It is marked by a ragged cliff or site recess 20–40 feet (6–12 m) thick. The unit consists of bedded, nodular, and lenticular chert (marker-chert) that is gradationally overlain by sandstone and sandy dolostone. Locally, silicified evaporite nodules are abundant. Horizontal, ripple, low-angle, and hummocky cross-stratification, preserved in places within the chert, occurs on a local basis. Petrographic study reveals the chert to contain abundant sponge spicules, varying amounts of detrital quartz, and scattered peloids, but only sparse skeletal fragments.

A carbonate ledge 5–12 feet (1.5–3.5 m) thick constitutes a second unit. At western localities, this unit has a limestone mineralogy and is characterized by packstone and wackestone textures containing a variety of fossil fragments that include pelecypods, gastropods, crinoids, bryozoans, foraminifera (forams), and ostracods. At sections along Kanab Canyon and to the northwest, this unit has an oncolite-bearing cap and is locally brecciated. Sections to the east become increasingly dolomitic. They are dominated by mudstone textures that show cryptalgal laminations and contain intraclasts and calcite-filled vugs.

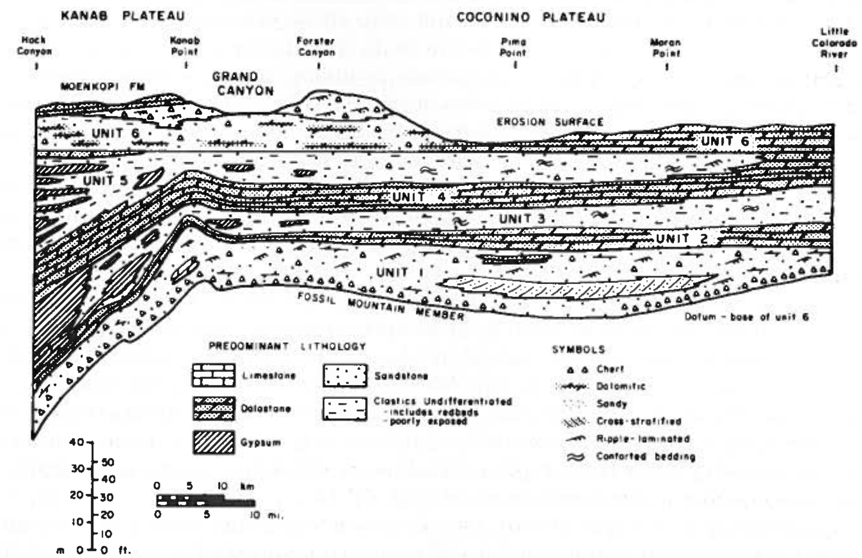

Figure 12.4. Diagrammatic cross section of the Harrisburg Member illustrating change in thickness and lithology laterally across the Grand Canyon. See Figure 12.3 for line of section. (Modified from Blakey and Middleton, unpublished data).

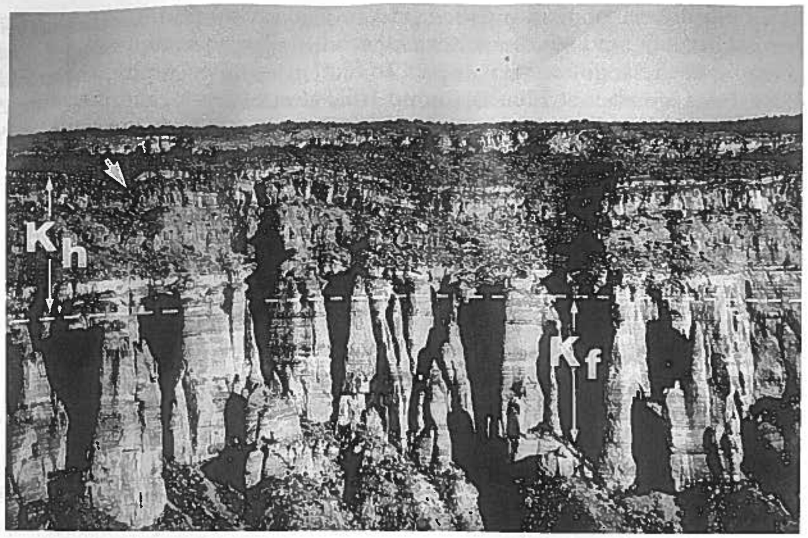

Figure 12.5. View of receding ledges of the Harrisburg Member above cliff-forming Fossil Mountain Member. Note warping of beds (*arrow*) related to evaporite dissolution. Photograph by R.C. Blakey looks northwest from Kanab Point.

Unit 3 is a poorly exposed, slope-forming sequence that is lithologically variable and undergoes extreme changes in thickness. At eastern localities, this unit is about 20 feet (6 m) thick. Sandstone, sandy dolomitic mudstone, and local cryptalgal-laminated, dolomitic mudstone characterize unit 3. To the west and northwest of Kanab Creek, however, portions of the sequence that contain considerable bedded gypsum and contorted red sandstone can exceed 100 feet (30 m) in thickness. In this region, this unit may show dramatic local changes in thickness and some warping of adjacent beds (Fig. 12.5).

A persistent medial ledge corresponds to unit 4, which averages 20 feet (6 m) in thickness and ranges from 10 to 40 feet (3–12 m). This unit consists predominantly of sandy dolomitic mudstone that locally contains thin lenses of fossil hash, intraclastics, and cryptalgal-laminated horizons. Fossil fragments include pelecypods, gastropods, and ostracods—with crinoids, bryozoans, and brachiopods occurring less commonly. The unit generally contains less sand to the west and toward the top. Local brecciation and warping is related to the dissolution of gypsum within unit 3 below.

Unit 5, which forms the upper slope, exhibits lithologic and thickness trends that are similar to those of unit 3. At eastern localities, this unit is poorly exposed, generally less than 20 feet (6 m) thick, and consists of ripple-laminated sandstone that contains chert locally. West and northwest of Kanab Creek, however, this unit approaches 80 feet (24 m) in thickness and consists of gypsum and interstratified siliciclastic redbeds. Unlike unit 3, this unit contains a number of thin, laterally persistent cryptalgal-laminated dolostone beds. Apparently, it pinches out east of the Grand Canyon (Fig. 12.4).

Uppermost beds (unit 6) form the chert-rubble erosion surface across much of the Grand Canyon region. Only locally is the unconformable contact with the Moenkopi Formation preserved. Where nearly complete, as in Robinson Wash south of Hacks Canyon (Blakey and Middleton, unpublished data), this interval approaches 50 feet (15 m) in thickness and consists of a lower ledge-forming, sandy, fossiliferous dolostone; middle slope and ledge-forming, cherty, ripple-laminated sandstone; and upper slope and ledge-forming cryptalgal-laminated and peloidal dolostone. West and northwest of Kanab Creek, the member contains a prominent molluscan fauna, which includes whole *Bellerophon* gastropods that are spectacularly jasperized locally. To the east, this unit is composed predominantly of dolostone containing increasing numbers of pelecypods, gastropods, and peloids that form packstone textures.

PALEONTOLOGY

Marine invertebrate and vertebrate fossils have been studied by many authors. The paleontology of the Fossil Mountain Member includes work done on the following organisms: brachiopods (McKee 1938; Beus 1964, 1990); bryozoans (Keppel 1932; Condra and Elias 1945a,b; McKinney 1983); conodonts (Thompson 1995); ctenacanthoid sharks (Thompson 1995); nautiloids (Miller and Unklesbay 1942); paleoniscid fish (Thompson 1995); petalodont sharks (David 1944; Ossian 1976; Hansen 1978); sponges (Griffen 1966); and trilobites (Cisne 1971, 1977; Brezinski 1991); the work of DeCourten (1976) on trace fossils should also be noted. Studies by Batten (1964), Beus (1965), Brady (1955, 1959, 1962), Chronic (1953), Mather (1970), Nicol (1944), and Snow (1945) were limited to fossils found within the Harrisburg Member. Many of the fossil forms in the Kaibab Formation (e.g., trilobites) became extinct toward the end of the Permian.

Fossil Mountain Member

In western sections of the Grand Canyon, skeletal limestones in the Fossil Mountain Member contain a diverse macrofaunal assemblage that includes a variety of brachiopods, fenestrate and ramose bryozoans, crinoids, siliceous sponges, and solitary corals (Fig. 12.6). Fossils often are whole and unabraded—indicating little or no transport.

Two types of macrofossils are most characteristic of the Fossil Mountain Member at western localities: (1) large productid brachiopods (*Peniculauris bassi*), which are often silicified and found along bedding plane exposures in life position (concave up)—sometimes with delicate spines still attached; and (2) siliceous sponges (*Actinocoelia maeandrina*; Finks 1960), which commonly occur in the center of spherical chert nodules. Typically, brachiopods and sponges decrease in abundance toward the top of the member, whereas the number of fenestrate and ramose bryozoans and associated crinoid debris significantly increases.

Recent work reveals several different kinds of microfossils (Fig. 12.7), which include: (1) gnathodid, hindeodid, and sweetinid conodonts; (2) seven groups of chondrichthyan dermal denticles (placoid scales); (3) seven types of chondrichthyan teeth; (4) two types of osteichthyan teeth; (5) two orders of ostracods; and (6) two kinds of sponge spicules (Thompson 1995). All are helpful in determining the paleoenvironment at the time the Fossil Mountain Member was deposited; this is especially the case for the conodont fossils, because the morphologic characteristics of all three conodont genera indicate a shallow, warm water environment. Additionally, the association of these genera, along with the marked absence of neogondolellid conodonts, is consistent with nearshore to intermediate marine environments.

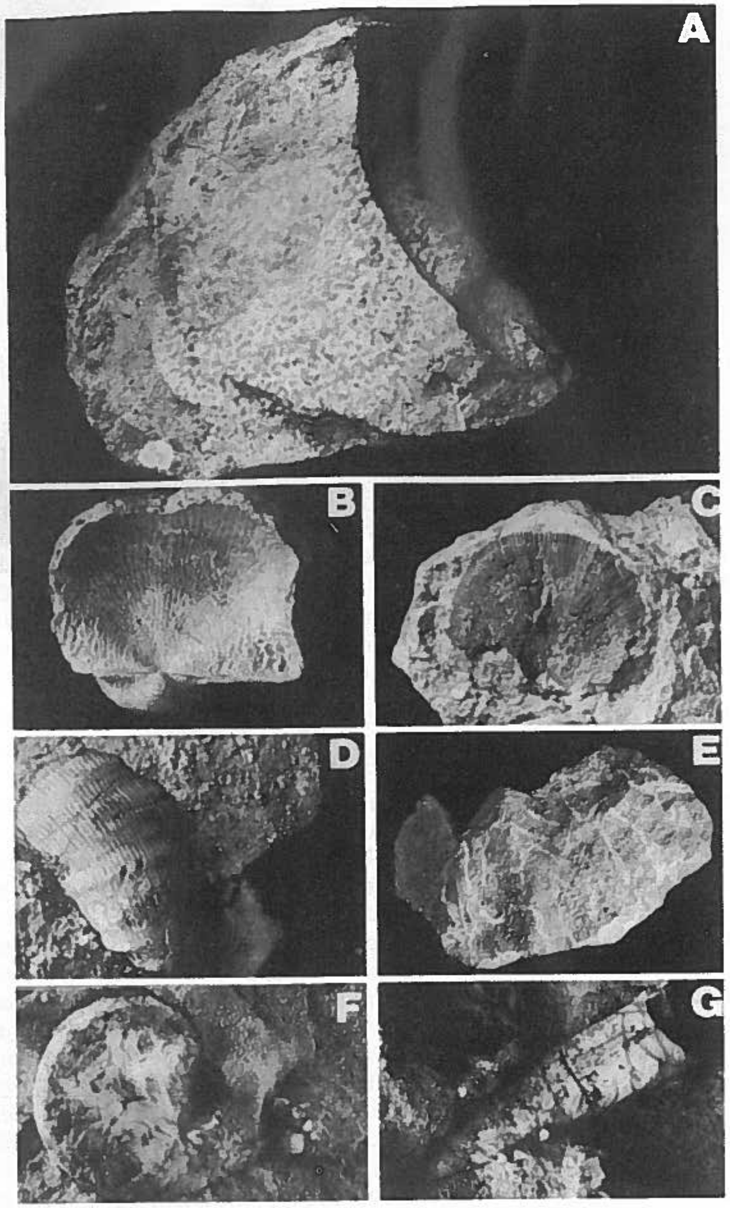

FIGURE 12.6. Fossil types representative of the Kaibab Formation at the Grand Canyon. Examples from the Fossil Mountain Member: (a) Siliceous sponge (*Actincoelia maendrina*) within chert nodule; (b) propductid brachiopod (*Penciculauris bassi*); (c) strophomenid brachiopod (*Derbyia*); (d) solitary or rugose coral; (e) limestone composed of branching or ramose bryozoans and crinoid debris. Examples from Harrisburg Member: (f) coiled gastropod (Bellerophontid); (g) scaphopod (*Prodentalium*). (Photographs by Ted Melis.)

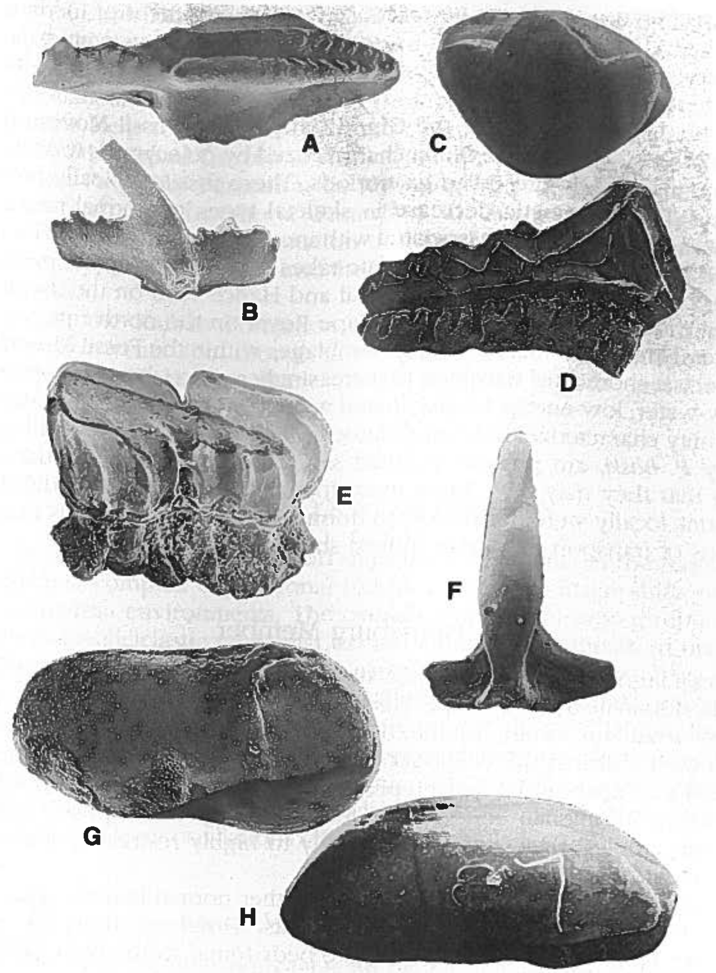

FIGURE 12.7. SEM microphotographs of selected microfossils from the Kaibab Formation, 50× magnification (all specimen numbers refer to the Museum of Northern Arizona, Flagstaff, Geology Collection). Conodont elements: (a) *Neostreptognathodus newelli* (MNA · X 137); (b) *Sweetina festiva* (MNA-X 138). Chondrichthyan teeth: (c) *Cooleyella peculiaris* (MNA · X 135); (d) Hybodont tooth (MNA · X 136). Chondrichthyan dermal denticles: (e) *Cooperella striatulata* (MNA · X 133); (f) *Moreyella typicalis* (MNA · X 134). Ostracod steinkerns: (g) Cavellinid ostracod (MNA · X 139); (h) Bairdeacean ostracod (MNA · X 140). (Microphotographs by Kelcy Thompson.)

Macrofaunal and microfaunal assemblages in the western portion suggest unrestricted, open-marine conditions characterized by seawater of normal-marine salinity, with deposition below a fair-weather wavebase. Numerous branched, horizontal, and irregularly inclined burrow traces characteristic of low-energy, offshore environments indicate a homogenization of sediment by biogenic reworking. Hopkins (1986) proposed that the apparent vertical transition in macrofossils, from abundant brachiopods and sponges to an assemblage dominated by bryozoans and crinoids, may have reflected an environment of increasing water depth from a few tens of meters to nearly 100 meters. However, paleoecological interpretations based on the conodont assemblage suggest that shallow marine conditions prevailed.

In the eastern sections of the Grand Canyon, the Fossil Mountain Member is dominated by a molluscan fauna characterized by pelecypods (*Schizodus* most common) and poorly preserved gastropods. These fossils typically occur as fossil molds. This systematic decrease in skeletal types of normal-marine affinity within a carbonate facies is associated with increasing siliciclastics. The most pronounced faunal transition found to date takes place in the upper portion of the member between the South Kaibab Trail and Hance Trail on the south rim, and between the North Kaibab Trail and Cape Royal on the north rim.

Lateral change in macrofaunal assemblages within the Fossil Mountain Member reflects a shoreward transition to increasingly restricted-marine environments. Shallow-water, low-energy levels, limited water circulation, elevated temperature, and salinity characterize these environments. Whole productid brachiopods, particularly *P. bassi*, are present in some sandy dolomitic units to the east, suggesting that they may have been more tolerant to changing conditions or that conditions locally were transitional to normal-marine. Brachiopods that show indications of transport may have moved shoreward during storms.

Harrisburg Member

Molluscan faunal assemblages characterized by a variety of pelecypods and gastropods dominate fossils in the Harrisburg Member. In addition, scaphopods are very abundant locally. Nautiloid cephalopods and trilobites are present but vary in their distribution. Geologists can identify ostracods and foraminifera in thin section. These faunal types represent hardy individuals tolerant of a greater range in environmental conditions. Along with gypsum deposits and silicified evaporite nodules, they indicate a partially to highly restricted, shallow-marine environment.

Brachiopods, bryozoans, crinoids, and other normal-marine organisms typically are rare, occurring as small fragments. However, they are present in increasing numbers within the carbonate beds found to the west. This suggests a possibility that seawater of normal or near normal salinity may have returned from time to time to the western Grand Canyon region during Harrisburg deposition.

AGE AND CORRELATION

Geologists have debated the age of the Kaibab Formation until relatively recently. While most agree that the Kaibab was Leonardian in age, based on comparisons of brachiopod faunas (McKee 1938; Fisher 1961; McKee and Breed 1969; Welsh et al. 1979; Kues and Lucas 1989) and the distribution of the siliceous sponge *A. maeandrina* Finks (Finks et al. 1961; Griffen 1966), the question remained as to whether part of the formation was slightly younger or in part Wordian (Guadalupian) in age (Cooper and Newell 1948; Newell 1948; Sorauf 1962).

The conodont assemblage obtained from the western portion is extremely useful in precisely dating the age of the Fossil Mountain Member; the presence of the gnathodid species *Neostreptognathodus newelli*, along with the brachiopod *P. bassi*, correlates well with Wardlaw and Collinson's Zone 3 in the Park City Group in eastern Nevada and western Utah (Wardlaw and Collinson 1978).

The absence of other indicator fossils from lower zones (*P. ivesi*, Zone 1; *N. sulcoplicatus*, Zone 2) and higher zones (*Thamnosia depressa*, Zone 4; *Neogondolella bitteri*, Zone 5) helps to further constrain the time range to be Roadian (latest Early Permian, latest Leonardian) age (Thompson 1995). This brachiopod and conodont fauna help to establish correlation with other Permian sequences in regions beyond the Grand Canyon, including the uppermost part of the Grandeur Member of the Park City Formation in Wyoming, the Meade Peak Phosphatic Shale Member of the Phosphoria Formation in eastern Idaho and western Wyoming, the Garden Valley Formation in central Nevada, the Plympton Formation (Park City Group) in Utah, and the Road Canyon Formation in west Texas (Thompson 1995).

In general, the Kaibab Formation records widespread marine deposition about 260 million years ago, though in western Utah the Kaibab is, at least in part, older than the Kaibab in southern Utah, southern Nevada, and the Grand Canyon (Wardlaw 1986).

DEPOSITIONAL HISTORY

The close association of carbonate and siliciclastic sediments in the Kaibab Formation reflects a complex depositional history marked by major shifts of subtidal, shallow-marine environments. The overall depositional setting represents a mixed carbonate-siliciclastic ramp that existed along the southeastern margin of the Cordilleran miogeocline during the early Roadian (Fig. 12.8). The Kaibab ramp extended across northern Arizona and into southern Nevada, at times exceeding 200 miles (125 km) in width. In this setting, minor fluctuations in the relative position of sea level resulted in abrupt changes in depositional environments. Considering the quiescent tectonic setting of the Grand Canyon region during the Permian, it is most likely that these cycles were caused by glacial–eustatic sea-level oscillations (Kendall and Schlager 1981).

Fossil Mountain Member

The Fossil Mountain Member represents an overall transgressive phase of sedimentation punctuated by repeated regressive events of varying regional extent. Significant eastward shifts in carbonate facies across the Grand Canyon region record a relative rise in sea level. The westward distribution of siliciclastic facies, on the other hand, reflects seaward progradation of nearshore environments during a relative fall in sea level. The abrupt lateral and vertical lithofacies changes within the sequence (Fig. 12.4) reflect these lateral facies migrations.

Beyond the westward limit of siliciclastic progradation, carbonate sedimentation in the Fossil Mountain Member generally was continuous. These outer-ramp carbonate environments consisted of a diverse normal-marine faunal association that effectively baffled, trapped, and stabilized sediment, resulting in widespread limestone units dominated by wackestone textures. Discrete organic buildups, such as sponge patch reefs, have not been documented. Local packstone textures reflect higher-energy conditions that may represent localized shoals, transgressive lag deposits, or storm events. Dissipation of wave, tidal, and current energy across the broad, gently dipping seafloor was sufficient to restrict circulation in nearshores siliciclastic-dominated environments without the development of distinct physical barriers (Irwin 1965). Because there was no exchange with seawater of normal-marine salinity, and the rate of evaporation was high, the salt content of water within inner-ramp environments increased. We see this

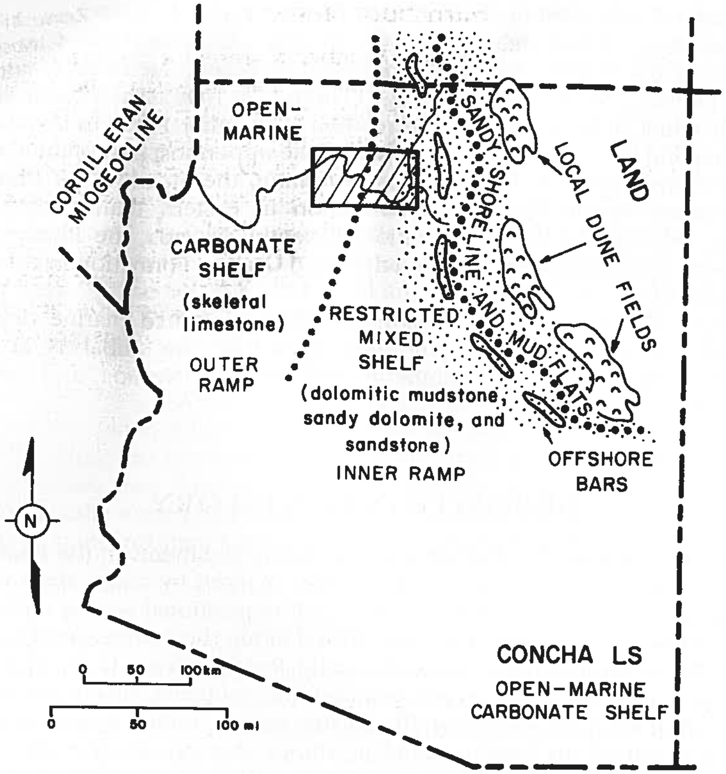

Figure 12.8. Hypothetical paleogeographic map of northern Arizona illustrating generalized environments and facies relationships during Fossil Mountain deposition. (After Blakey and Knepp 1988).

from an eastward decrease in skeletal types of normal-marine affinity and the presence of molluscan faunas. The occurrence of silicified evaporite nodules within dolomitized facies also supports this thesis.

The sedimentary characteristics of sandstone units and their relationship with carbonate facies suggest deposition within inner-ramp, nearshore environments. Deposition may have occurred as relatively featureless sand sheets, lower shoreface deposits, or low-relief bars and sandwaves. A variety of processes may have created the currents necessary for sediment transport—including longshore processes, local wind regimes, and episodic storm events. Much of the sediment, however, experienced an intense biogenic reworking that resulted in structureless facies. The most probable source of siliciclastic detritus is coastal eolian complexes thought to border the Kaibab sea to the east (Fig. 12.8). Unlike the underlying Toroweap Formation, however, geologists have not documented any intertonguing between marine and eolian deposits in the Kaibab Formation.

Thin, laterally continuous chert horizons, most common as interbeds within siliciclastic facies at eastern localities, could have formed by suspension settling of sponge spicules and carbonate mud within slight topographic depressions. These spicules may have moved shoreward as a suspension cloud during storm events, or they may have been winnowed by gentle fair weather and/or tidal currents.

Harrisburg Member

Sedimentary strata of the Harrisburg Member represent a distinct change from the diversely fossiliferous, skeletal carbonates characteristic of the Fossil Mountain Member. The six informal, sedimentary units that comprise the Harrisburg sequence reflect deposition within predominantly restricted-marine environments during cyclic westward retreat of the Kaibab sea. Repeated shifts in depositional environments are recorded by the alternation between carbonate, siliciclastic, and evaporite deposits across the Grand Canyon region (Fig. 12.4).

The Harrisburg sequence developed as a result of repeated transgressive–regressive cycles, with lower-order oscillations indicated by minor lithologic and textural variations within individual units. Carbonate deposition generally occurred within shallow, subtidal environments. Molluscan faunas, mudstone textures, and cryptalgal laminations suggest a low-energy, restricted setting, though local fossil hash, intraclastic, and oncolite horizons indicate periodic higher-energy conditions. The occurrence of brachiopods, bryozoans, and crinoids within carbonate units at western localities documents brief pulses of normal-marine conditions.

Sandstone intervals correspond to relative falls in sea level and result in a net transport of sediment derived from nearshore and coastal dune environments. Stratification is a product of the migration of small-scale bedforms, such as ripples and perhaps sand waves, generated by a combination of wave, tidal, and storm currents.

Thick accumulations of evaporites in the Harrisburg document at least two periods of extreme restriction associated with major regressive phases. The intense evaporation associated with an arid climate favored chemical sedimentation. Deposition of massive and bedded gypsum deposits probably occurred within localized hypersaline basins or lagoons bordered by a coastal mudflat–sabkha complex. The considerable thickness of the evaporite deposits suggests that seawater of normal-marine salinity replenished these restricted areas periodically.

Rapid change in the lithology and thickness west of Kanab Creek reflects periods of increased differential subsidence in this portion of the Kaibab ramp. The relationship, if any, of Harrisburg evaporite basins to recurrent movement along basement faults is uncertain. Other, more local thickness variations, along with warping and brecciation of adjacent carbonate units, are more likely related to post-depositional dissolution. Contorted beds in the upper part of the Harrisburg to the east suggest that the evaporites originally were more widely distributed and have been removed from much of this area.

SUMMARY

Rocks of the Kaibab Formation are testimony to the ancient seaway that covered most of the Grand Canyon region approximately 260 million years ago. The cyclic interbedding of carbonate and siliciclastic sediments documents a complex depositional history characterized by repeated shifts of subtidal, shallow-marine environments. Rocks of the Fossil Mountain Member record a west-to-east transition from fossiliferous open-marine limestone to restricted-marine sandy dolostone. The overlying Harrisburg Member reflects deposition during the cyclic retreat of the Kaibab sea. A short walk down any of the canyon rim trails allows visitors to easily examine the great variety of rocks and fossils that comprise the Kaibab Formation.