Stratigraphy, Lithology, and Depositional Environments of the Lower Permian Kaibab Formation, Northwestern Arizona

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ABSTRACT

Geological studies of the Early Permian Kaibab Formation in northwestern Arizona have been conducted for over 150 years, but details of its stratigraphy and environmental setting have not been thoroughly evaluated. This paper describes the stratigraphy, elucidates the diagenetic history and provides a revised interpretation of the environments of deposition of the Kaibab Formation throughout the central Grand Canyon. The two members of the Kaibab Formation record significant variations in lithologic and faunal characteristics on a regional scale; therefore, multi-unit subdivisions are proposed for each member based on stratigraphic marker beds. The two subdivisions of the Fossil Mountain Member are characterized by a distinct sequence of chert. A six-unit subdivision of the Harrisburg Member is correlated by distinct outcrop characteristics, lateral changes in lithology, and indigenous fossil assemblages. Within each member, a normal marine fauna found at western locations transitions to an impoverished molluscan fauna toward an eastern shoreline.

Lime mud forms the matrix of both members; its origin is thought to be the breakdown of calcareous algae, direct precipitation from seawater, and particle abrasion of calcareous bioclasts. Thick beds of gypsum are characteristic of the Harrisburg Member and formed in a highly restricted marine basin. Dolomitization and silicification had a profound effect on these rocks; their possible origins provide a framework of paleoenvironments that lack relevant modern-day analogues. Dolomite formed in two contrasting settings; one in the subsurface platform sediments and the other within arid supratidal areas. Pervasive post-depositional dolomitization of subsurface carbonate sediments in the Fossil Mountain Member formed by refluxing of dense, Mg-rich brines in a highly restricted marine basin. Penecontemporaneous dolomite within the Harrisburg Member was produced by evaporative concentration of pore water in supratidal sabkhas. Chert is a primary constituent of both members and was derived from siliceous organisms, mainly sponges that served as the primary source although seawater reacting with terrestrial groundwater may have contributed.

Two new models representing the formation of thick beds of gypstone for the Harrisburg Member are presented and draw on platform tectonics and eustatic sea-level fluctuations. These beds formed when minor tectonic activity along the Las Vegas Line elevated the platform edge, essentially cutting off circulation of normal marine water. Accompanied by fluctuations in eustatic sea level, caused by glacial episodes in the southern hemisphere, produced cyclic sequences of evaporites and carbonates. The Fossil Mountain Member has lithologic and faunal characteristics of a regional marine transgression of an epeiric seaway over a broad carbonate platform. A regressive phase, formed the Harrisburg Member, when periodic lowering of sea level produced cyclic lithologies within restricted, highly saline basin, mudflat, lagoon and sabkha environments that are characterized by an impoverished molluscan fauna. These hypothetical reconstructions represent the paleoenvironments that existed across the Early Permian Kaibab sea, and record the last major advance and retreat of marine seawater to cover the Colorado Plateau at the close of the Paleozoic.
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INTRODUCTION

The Kaibab Formation, as discussed in this paper, is located within the Grand Canyon region of northwestern Arizona, north of the Colorado River to the Arizona/Utah border. Twenty-seven stratigraphic sections were described on the Shivwits, Uinkaret, Kanab, and Kaibab plateaus (Fig. 1). The maximum thickness of the Kaibab Formation is 150 m (500 ft) along the western Uinkaret Plateau; it thins toward the south extending at least to Holbrook, Arizona, and reaches a depositional edge along the Arizona/Utah border south of Lake Powell (Fig. 2). Regionally, the Kaibab extends north and west into Utah and Nevada, thins to the east, and although it undergoes significant lithologic changes south of the Grand Canyon, it is present along the Aubrey Cliffs of northwestern Arizona (McKee, 1938; Hopkins and Thompson, 2003).

Figure 1. Study Area
Landsat image of northwestern Arizona, showing the study area north of the Colorado River. Letter abbreviations represent the locations of the 27 measured sections (see Appendix A for location descriptions). Dashed lines labeled 1 and 2 indicate location of cross-sections (refer to Figures 4 and 5 respectively).
The Kaibab Formation includes two formal members: Fossil Mountain and overlying Harrisburg. McKee (1938) described a basal gamma ($\gamma$) member that is recognized only on the Mogollon Plateau south of Flagstaff, Arizona, so is not included in this paper. Lithologic variations of the members can be characterized on a regional scale because of nearly continuous outcrops throughout the study area. Stratigraphic correlation of the members is made by relative position with adjacent strata, weathering characteristics, lithology, and fossil assemblages. Member subdivisions based on these criteria are readily observed in the western and central parts of the Grand Canyon region, but less obvious east of the Kaibab Plateau where abrupt facies changes obscure their distinctive characteristics. Although lithologies change drastically within the region, stratigraphic, faunal, and petrologic analyses of individual units allow members to be correlated throughout northwestern Arizona. Within each member, a vertical sequence of repetitive lithologies has been established that allows detailed stratigraphic correlations.

**Previous Work**

Geological studies of the Grand Canyon region have been conducted for over 150 years (notably Marcou, 1856; Newberry, 1861; Gilbert 1875; Powell, 1875; Darton, 1910; Noble, 1914 and 1922; Reeside and Bassler, 1922; Bissell, 1969; Beus and Morales, 2003; Peak, et al., 2021). Many geologists (Reeside and Bassler, 1922; McKee, 1933, 1954; McKee, et al., 1967a and b; Hamblin and Best, 1970; Parsons, et al., 1996; Davis and Bump, 2009) have described and interpreted the regional structure and stratigraphy of the Colorado Plateau. Noble (1928) established the type locality for the Kaibab Formation in Kaibab Gulch, eight miles southwest of Paria, Utah. McKee (1938) published a monograph on the environment and history of the Toroweap and Kaibab formations in northern Arizona and southern Utah that remains the cornerstone in describing these two formations. Clark (1974) presented a thesis on the stratigraphy and carbonate petrology of the Harrisburg Member of the Kaibab Formation in Whitmore Wash (aka Whitmore Canyon in this paper) and a dissertation on the stratigraphy, depositional environments, and carbonate petrology of the Toroweap and Kaibab formations in the Grand Canyon region (Clark, 1980), and together, these form the framework of this paper. Hopkins (1986) described the depositional environments and diagenesis of the Fossil Mountain Member, and Hopkins and Thompson (2003) summarized the stratigraphy and paleontology of the Kaibab Formation, primarily along the Coconino Plateau south of the Colorado River. Sorauf and Billingsley (1991) established formal member names for the Toroweap and Kaibab formations, designating the Seligman, Brady Canyon and Woods Ranch for the Toroweap and Fossil Mountain and Harrisburg for the Kaibab. Hendrickson (2017) proposed a sequence stratigraphic model for the Harrisburg Member for northern Arizona and southern Utah. Santucci and Tweet (2021) prepared a paleontological resources inventory for the Grand Canyon.

**Purpose and Methods**

Much geological field work and research have focused on the Kaibab Formation. Nonetheless, because the Kaibab Formation within the current study area has not been thoroughly evaluated and our understanding of carbonates has advanced (cf. Bathurst, 1975; Wilson, 1975; Scholle and Ulmer-Scholle, 2006; James and Jones, 2016; SEPM STRATA, 2020), these rocks deserve reinterpretation. This paper provides details of the stratigraphy, lithology, and a revised environmental interpretation of these rocks in the northwestern part of the Grand Canyon. Field work was conducted from 1973 to 1975 and included describing and sampling the Toroweap and Kaibab formations where well exposed, complete and least deformed, or showed pronounced facies changes. Most outcrops were located in remote parts of the Grand Canyon region and required access via a high-clearance, 4-wheel drive vehicle capable of traveling over unimproved dirt roads, trails and dry stream beds. Twenty-seven stratigraphic sections were correlated and illustrate variation of lithologies throughout the region. Hand specimens and 740 thin sections (2x2”) revealed lithology, mineralogy and fossil content. A Scanning Electron Microscope (SEM) was used to evaluate high-resolution surface structure of individual grains and cements. X-ray
diffraction techniques were conducted on a few samples to determine molar percent Mg/Ca content. These analyses were used to form an interpretation of lithologic facies and paleoenvironmental models of deposition.

**REGIONAL SETTING**

During the Permian Period, southwestern United States was part of Pangea, situated a few degrees north of the equator (Zharkov and Chumakov, 2001). The climate was more arid than today, and sea level fluctuated in response to glaciation in the southern hemisphere. Throughout the Paleozoic Era, epeiric seas covered much of an embayment into a passive continental margin across the southwestern Colorado Plateau (Blakey and Ranney, 2008). Discrete cycles of carbonate, evaporite and siliciclastic sediments were deposited in response to glacio-eustatic sea-level oscillations across this relatively quiescent tectonic platform (Kendall and Schlager, 1981).

The Colorado Plateau includes parts of Colorado, Utah, Arizona and New Mexico encompassing 390,000 km² (150,580 mi², National Park Service, 2019). The study area is in the Grand Canyon region of the southwestern Colorado Plateau. The plateau has undergone relatively minor tectonic deformation since the Precambrian. A “tectonic hinge”, the Las Vegas Line (Fig. 2), extended from southern Nevada northeastward through southwestern Utah, and separated basin (west) from shelf (east) during Permian times (Bissell, 1969).

![Figure 2. Las Vegas Line](image)

Map location of the Las Vegas (Hinge) Line during the Permian Period with respect to the basin on the west and the shelf on the east (Modified from Bissell, 1969).

Four prominent structural blocks, the Shivwits, Uinkaret, Kanab and Kaibab plateaus (Fig. 3), were produced by crustal extension and folding during the Laramide orogeny, in Late Cretaceous through
Eocene (Hamblin, 1965; Huntoon, 2003). They resulted from three, north-south-trending normal faults with the upthrown, cliff-forming sides facing west, and a compressional fold, the East Kaibab Monocline.

The Lower Permian Kaibab Formation forms the rim rocks throughout most of the Grand Canyon. It is capped at isolated outcrops by the Triassic Moenkopi Formation and is underlain by the Lower Permian Toroweap Formation. It crops out throughout the region, extending to a few kilometers east of Page, Arizona, and south of Flagstaff, Arizona, along the Mogollon Rim, north into southern and central Utah (Hopkins and Thompson, 2003), and west to Las Vegas, Nevada (Longwell, 1921) where exposure ends abruptly in cliffs and mountain ranges (McKee, 1938). Stratigraphically it correlates with the Concha Limestone in southeastern Arizona, San Andreas Formation in New Mexico and the Phosphoria Formation in southeastern Idaho and southwestern Wyoming (Hopkins and Thompson, 2003).

The age of the Kaibab Formation is Leonardian (Cisuralian, Early Permian, 272 Ma) based primarily on brachiopod and fusulinid fauna and the siliceous sponge Actinocoelina maeandrina Finks (McKee, 1938; Vachard, et al., 2015; Finks, et al., 1961; Griffin, 1966). Studies of conodonts and Ctenantheniform shark teeth support this age (Clark, 1979; Thompson, 1995; Hodnett, et al., 2012), but indicate the upper part of the formation extends into the Guadalupian (Late Permian). That part is age equivalent to the Bone Springs Formation in the Delaware Basin of west Texas and southeastern New Mexico (Asmus and Grammer, 2013), the Black Box Dolomite of central Utah and the White Rim Sandstone of southeastern Utah (Welsh, et al., 1979; Condon, 1997).

**STRATIGRAPHY, LITHOLOGY AND PALEONTOLOGY**

Kaibab strata in northwestern Arizona are subdivided into members and various lithologic facies. Each member contains specific carbonate, siliciclastic and evaporite beds, fossils, textures and sedimentary features indicative of their environment of deposition.

**Fossil Mountain Member**

The Fossil Mountain Member, the lower portion of the Kaibab Formation, is a thick- and medium-bedded, resistant group of carbonates and siliciclastics that can be visibly correlated across the study area.
It undergoes noticeable changes in thickness, lithology and faunal assemblages from the west to the east (Shivwits to Kaibab plateaus).

**Stratigraphy**

The Fossil Mountain Member is typically thick bedded and forms prominent limestone cliffs or pillars at western locations and grades into less resistant, thinly bedded siltstones and sandstones to the east. Textures range from cherty, fossiliferous wackestones, packstones and grainstones at western locations to dolomitic wackestones, mudstones, siltstones and sandstones to the east.

The type locality of the Fossil Mountain Member is at Fossil Mountain, along the Bass Trail on the south rim of the east-central Grand Canyon (Fig. 1). There the member consists of 64.3 m of light-gray, cherty, thick-bedded, cliff-forming limestones and sandy limestones with Leonardian-age fossils. McKee (1938) initially referred to it as the beta (β) member, but it was formally named the Fossil Mountain Member by Sorauf and Billingsley (1991). It is a thick-bedded, cliff-forming limestone throughout most of the western Colorado Plateau, easily recognized by its tendency to form monolithic, cherty, iron-stained columns that McKee referred to as “pillars of erosion” (McKee, 1938, p. 207).

**Areal Variance in Unit Thickness**

The thickness of the Fossil Mountain Member averages 74 m at western locations along the Grand Wash and Hurricane cliffs and 61 m at central locations across the Kanab Plateau. The member is anomalously thin across the western Kanab Plateau, notably 57 m at Brady Canyon and 59 m in Paradise Valley. This local thinning may have resulted from the lower beds of the Fossil Mountain Member having slumped (possibly by dissolution) into the underlying gypstones of the Woods Ranch Member of the Toroweap Formation, or from erosion as indicated locally by lime-mudstone clasts and shell debris found along the Toroweap-Kaibab boundary. It thins over the Kaibab Plateau to 39 m within Marble Canyon.

**Stratigraphic Character of Unit Boundaries**

The Fossil Mountain Member is easily recognized throughout much of the Grand Canyon region because it forms relatively continuous cliffs above the slope-forming, bedded gypstones and contorted sandstones of the Woods Ranch Member. Along the Grand Wash and Hurricane cliffs, slumped beds of carbonates are present in the underlying gypstone and siltstone beds, or contain an erosional surface as indicated by channels or scattered carbonate clasts and broken shell debris contained within a dolomitic silt or micrite matrix. Fossil remnants are typically broken, disarticulated and abraded, forming an undifferentiated shelly lens. Locally, equivalent stratigraphic units along this boundary lack a mud matrix and formed as fossil hash or a lag deposit.

McKee (1938) interpreted this contact as an unconformity based on the presence of local intraformational breccias and erosional surfaces. Based on detailed studies in Whitmore Wash, Sorauf (1962, p. 140) suggested:

“brecciation and contortion of bedding appear to be the results of collapse and slumping, occurring at several times prior to and during deposition of the uppermost sandstones of the Woods Ranch resulting in disruption and erosion of the carbonate beds. Later, a more widespread, post-depositional brecciation of the lower Kaibab occurred, after lithification of these beds had progressed considerably, as evidenced by the angularity of the fragments. The explanation for this slumping and brecciation can be looked for in the underlying evaporite section. Solution of the underlying gypstone is thought to have produced submarine topographic irregularities that led to collapses and slumps. Unconsolidated sediments were probably displaced by slumping, whereas semi-lithified or lithified carbonates suffered brecciation. Minor erosion of diastemic proportion also occurred.”

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Additional research indicates that the intraformational breccias are associated with collapse after dissolution of evaporite deposits within the upper part of the Toroweap Formation (Rawson and Turner, 1974; Cheevers and Rawson, 1979; Clark, 1980; Hopkins and Thompson, 2003). Various authors have interpreted the transition from the Fossil Mountain Member to the Harrisburg Member as being persistently gradational throughout the Grand Canyon region. McKee (1938, p. 49) placed the contact at a thick bed of chert, that he interpreted as the last marine deposit, overlain by cross-bedded sandstones, limestones and magnesian limestones that contained a molluscan fauna. Sorauf and Billingsley (1991), similarly defined the upper contact of the Fossil Mountain Member at its reference section in Whitmore Canyon to be the top of the uppermost thick bed of cliff-forming limestone. The contact with the overlying Harrisburg Member is identified throughout much of the study area by the presence of a recessive, thin-bedded to laminated, brecciated mudstone lying on a prominent, densely mottled chert bed of the uppermost Fossil Mountain Member. Fossil remnants from the Fossil Mountain Member along this boundary are typically broken, disarticulated and abraded forming a shelly lens.

Lithology and Paleontology

The Fossil Mountain Member can be correlated and subdivided based on the variety of chert that weathers to produce distinctive beds, and on the relative stratigraphic position of the beds within the member (Fisher, 1961; Sorauf, 1962). The chert is found in four distinct types: nodular, spherical, mottled and bedded. The type of chert defines stratigraphic markers and forms distinct beds that aid in correlation throughout most of the study area. In the central and western locations, chert weathers to stand in relief providing stratigraphic marker beds, but loses its identity toward the east as noted across the Kaibab Plateau to Marble Canyon.

The most common forms of chert consist of white to light gray, spherical and elliptical nodules of varying sizes. The nodules (up to 20 cm) average 6 cm and are present throughout both members of the Kaibab Formation but are prevalent within the Fossil Mountain Member where they form a variety of marker beds. They are randomly distributed within the surrounding matrix with no particular affinity to bedding surfaces or spatial distribution. The interiors of chert nodules are typically unfossiliferous but sporadically contain fossil debris similar to the enclosing matrix or have a high concentration of elliptical-shaped cylinders averaging 0.25 to 1 mm in length, derived primarily from sponge spicules. Spicules can be seen sporadically in thin sections. Fossils in the limestone or cemented to the surface of chert nodules are commonly silicified providing excellent preservation and etched relief on the outcrop surface. The elliptical or discoid cherts are typically larger than the spheres (up to 10 to 20 cm in length) and are commonly elongated parallel to bedding.

Schlehl (1960) referred to large spherical masses of chert ranging in diameter from 6 to 23 cm as cannonballs (Pl. 1A). The cannonballs are discrete, circular masses compared to the typically smaller and nonsymmetric nodules. Cannonball cherts are characteristic of the upper part of the Fossil Mountain Member and are found along the face of outcrops or within the talus as large, circular, resistant masses. Their interiors are amorphous chert that commonly contain a high concentration of sponge spicules averaging 0.25 to 1 mm in length or whole sponges that McKee (1938) and McKee and Breed (1969) have identified as Actinocoelia maeandrina.

Densely mottled chert forms distinct beds that can be correlated between most outcrops. The irregularly shaped, coalesced chert nodules appear as a dark gray, oxidized, lacy, surface fabric referred to as chert tracery (Pl. 1B) in analogy to Gothic windows. Silicified crinoids and bryozoans are commonly found on the surface of the tracery.

 Beds of resistant, dense, laminated to thinly bedded chert are found in both members of the Kaibab Formation and form prominent chert bands that are traceable throughout the region. Many bedded cherts are observed in the central and western outcrops, but they are thinner or absent in the eastern locations.
Figure 4. Stratigraphic Section of the Fossil Mountain Member
West to east stratigraphic cross section of the Fossil Mountain Member from the Shivwits Plateau (Virgin River) to the Kaibab Plateau (Saddle Mt). Refer to Figure 1 for map location of measured sections. The member thins toward the east and the cherty limestone facies, characteristic of the western region, interfinger with sandy siltstones along the eastern-most extent of the study area.

**Lower Subdivision**

The Fossil Mountain Member is divided into lower and upper subdivisions based on the stratigraphic position of chert types (Fig. 4). The lower subdivision thins from west to east, ranging from 51 m at Virgin River, 48 m at Iverson Ranch in the western locations (Shivwits and Uinkaret plateaus), 41 m at Jumpup Canyon on the Kanab Plateau, 31 m at Ryan Canyon and 30 m at Saddle Mountain in Marble Canyon (Kaibab Plateau). It can be correlated over most of the study area by the presence of two intervals of nodular chert or irregularly shaped, coalesced chert, that appear on highly weathered outcrops as a lacy fabric, chert tracery. Throughout the western and central locations, the lower subdivision contains two distinct chert tracery beds. These two beds, separated by nodular, cherty limestone beds that lack the distinctive tracery, can be correlated from the Grand Wash Cliffs eastward to Hack Canyon on the Kanab Plateau. Most beds within the lower subdivision contain chert nodules that are not as abundant or coalesced as in the chert tracery units. Quartz silt is present in trace amounts, but becomes dominant east of the Kaibab Plateau (Pl. 2D). Horizontal, iron-stained stylolites with vertical amplitudes of up to 10 cm are found within thick limestone beds of the Shivwits and Uinkaret plateaus. Lithologies of the lower subdivision range from fossiliferous lime mudstones to packstones (Pl. 2B and 2C). Micrite content increases slightly toward the east although most textures are mud supported even at the westernmost locations. The productid brachiopod *Peniculauris bassi* (Pl. 1F) is the key index fossil of the Kaibab Formation and helps differentiate it from the underlying Toroweap Formation, which contains *Peniculauris ivesi*, a similar but smaller productid. Subtle lithologic and faunal variations occur within the lower subdivision from west to east. From the Grand Wash Cliffs to S.B. Point (Fig. 1), the lower subdivision is a thick-bedded, cliff-forming lime wackestone or packstone. Fossils are abundant and
include a normal marine fauna (Pls. 2 and 3) of productid brachiopods, crinoids, ramose and fenestrate bryozoans, solitary corals (Pl. 3A), trilobites, and molluscs. Productid spines, ostracods, trilobites, foraminifers (Pl. 4E) and sponge spicules are sporadically found in thin sections. Siliceous sponges and needle-shaped spicules, 1 to 2 mm long, are common in chert nodules. McKee (1938, p. 156) identified the echinoid Archaeocidaris in the Fossil Mountain Member. Some of the spines identified within the Fossil Mountain Member may be cylindrical-shaped echinoid or productid spines. Petrographically, unaltered echinoid spines can be distinguished by composition as single calcite crystals that show unit extinction under crossed-polarized light or by distinctive morphology. Productid spines are large curved hollow needles with calcite crystals oriented to produce a pseudo-uniaxial cross under crossed polars (Scholle and Ulmer-Scholle, 2006). In contrast, sponge spicules from Actinocoelia maeandrina are very fine, needle-size and were originally amorphous silica, but are commonly replaced by crystalline quartz or calcite.

Across the Kanab and Kaibab plateaus, marked facies changes occur between Jumpup Canyon and exposures at Nail and Ryan canyons (Fig. 1). Lithologies at Jumpup consist of highly fossiliferous, cherty lime packstones, mudstones and rarely grainstones and include a robust, diversified, normal-marine fauna like that further west. The equivalent stratigraphic units at Nail Canyon are silty, dolomitic mudstones and wackestones. Fossil abundance and diversity are greatly reduced, but include productids, crinoids, bivalves, and fenestrate and ramose bryozoans (Pl. 3B). Fossil abundance increases toward the top of the subdivision, but lacks diversity compared to western locations. Sponge skeletons and spicules are common within chert nodules. Most fossils are broken and disarticulated; some are abraded. Dolomitization has obscured possible remnants of algal laminations that are present in the mudstones. Bedding surfaces show moderate burrowing and breccia of mudstone clasts resulting from current reworking.

East of the Kanab Plateau, lithologies and fossil assemblages change significantly, and the chert tracery beds are no longer present as markers. Beds containing chert nodules are present but individual nodules are small and form minor constituents within the matrix. The limestones of the western locations have been replaced with dolomitic mudstones, siltstones and sandstones. Mudcracks, angular and subrounded breccia clasts, contorted beds, burrows and algal stromatolites are found in dolomitic mudstones. Lithologies range from crinoidal, productid wackestones to lime mudstones. Fossils decrease in diversity and abundance and are mostly molluscan. High-spired gastropods are common and a few foraminifers are noted in thin sections. Most textures are moderately burrowed and commonly contain micritic pellets. Quartz silt increases in abundance toward the top of the subdivision and constitutes up to 15% of some lime mudstones. A pronounced facies change is noted between Parisawampitts Point and Point Sublime, a distance of 25 km, oblique to depositional strike. At Point Sublime, the lower subdivision is predominantly medium- to thick-bedded dolomitic sandstones that are moderately to highly burrowed and locally contain wispy laminations and mudcracks. Fossils are fewer than in correlative units at Parisawampitts Point and include crinoids, brachiopods (especially Meekella), bivalves and gastropods. Spiculitic chert is found as nodules or lenses that are confined to individual beds.

Thirty kilometers further east at Saddle Mountain (east Kaibab Plateau, Fig. 1), the lower subdivision is composed predominantly of siliciclastics, including dolomitic quartz siltstones and sandstones. Most quartz grains are moderately to well sorted and rounded or subrounded. Chert and iron-stained mudstone clasts weather in relief along the outcrops. Spherical calcite nodules (1 to 2 cm in diameter) fill vugs or fossil molds. Chert nodules (average 10 cm) are found throughout the beds and are aligned along bedding surfaces. Large chert nodules with round to elongated shapes (up to 10 by 20 cm) are found sporadically. Iron-stained micritic nodules with an average diameter of 3 cm are common, and large, elongated nodules (up to 20 by 140 cm) are rarely found parallel to bedding. The weathered surface of most sandstone beds is pitted and vuggy; surface porosity amounts to over 15% in many rocks. Horizontal, iron-stained
stylolites are rare; average vertical amplitudes are 2 cm. A few beds contain wispy laminations, low-angle crossbedding, fractures, cut-and-fill scour features, and mudcracks. Fossils molds of small bivalves are confined to a few beds. Dolomitic mudstone clasts are common. Horizontal and vertical burrows commonly disrupt or obscure bedding surfaces and laminations.

**Upper Subdivision**

Recent erosion has removed the upper subdivision of the Fossil Mountain Member at many localities, although enough of the subdivision remains throughout the study area to allow stratigraphic correlation and an analysis of facies. It is characteristically thinner than the lower subdivision and ranges in thickness from 21 m at Mokiah Wash and 26 m at the Virgin River Gorge in northwestern Arizona to 34 m at Jumpup Canyon, and 36 m at Nail Canyon on the central Kaibab Plateau (Fig. 1). It is not present farther east at Saddle Mountain where it may have been removed by erosion or has merged with silty sandstones of the lower subdivision.

Two marker beds, the cannonball chert zone and the upper chert tracery (Fig. 4), can be traced throughout the study area. The more widespread is the cannonball chert zone. This zone is unique in that spherical chert nodules, averaging 13 cm in diameter, weather to produce distinctive concretionary balls in outcrop (Pl. 1A). These concretions are typically found randomly distributed throughout the fossiliferous matrix, but are locally aligned parallel to bedding planes. Fossils are often concentrated on their surfaces. Wispy laminations commonly bend around these chert concretions. The cannonball chert zone can be correlated from the Grand Wash Cliffs to Nail Canyon on the Kaibab Plateau, a distance of 120 km. The zone undergoes moderate thickness changes from west to east having a maximum thickness of 20 m at Whitmore Point and a minimum of 9 m at Point Sublime.

Another excellent marker bed, the upper chert tracery, overlays the cannonball chert zone and is composed of cherty, fossiliferous lime packstones and wackestones. It weathers to form a prominent thick-bedded, iron-stained band across the outcrop (Pl. 1B). The chert stands in relief forming dark gray to black masses that appear as lacy fabric similar to the chert tracery of the lower subdivision. The upper chert tracery is easily distinguished at exposures west of Kanab Plateau, but eastward the zone decreases in chert content and loses its identity. Dolomite content within this bed is less than 5% at Grand Wash Cliffs (e.g. Snap Point) and increases to over 90% on the Kaibab Plateau.

From west to east, lithologies of the upper chert tracery change from fossiliferous lime packstones and rare grainstones on the Shivwits and Uinkaret plateaus to cherty and silty lime mudstones on the Kaibab Plateau. Fossil assemblages are similar to those of the underlying cannonball chert zone, although fenestrate bryozoans are more prolific. Included are solitary corals, the productid brachiopods *Peniculauris bassi* and *Rugotia*, fenestrate and ramose bryozoans, crinoids, trilobites, and lesser numbers of the brachiopods *Meekella*, *Composita* and *Derbyia*, and bivalves and gastropods. Foraminifers are sporadically seen in thin sections.

Most upper-subdivision lithologies are fossiliferous lime wackestones and packstones. The fauna is more abundant and diversified than in the lower unit of the Fossil Mountain Member. Fossils are excellently preserved throughout this zone (Pl. 2A), and include the brachiopods *Peniculauris bassi*, *Derbyia*, *Meekella*, and *Composita*; crinoids, ramose and fenestrate bryozoans, and solitary corals (*Lophophyllum* sp.). Many foraminifers and a few trilobites and ostracods are observed in thin sections, as well as sponge spicules found in chert nodules and lenses. Griffin (1966) noted that many cannonball cherts contain sponges, identified as *Actinocyclus maenadrina* Finks. From Grand Wash Cliffs (e.g. Snap Point) eastward to Toroweap Valley, the most obvious trend in fauna, is a decrease in the number of solitary corals and a concomitant increase in molluscan (bivalve and gastropod) fossils. Along the western Kanab Plateau (Tuckup Canyon and S.B. Point), the fossiliferous lime wackestones replace dominant packstones.
farther west. Most fossils found at western locations are present, but less abundant. The abundance of bivalves and productid brachiopods (notably *Meekella*) increases slightly.

Dolomite and quartz content increases easterly from trace amounts along the Grand Wash Cliffs to be predominant across the Kaibab Plateau. Along the southwestern side of the Kaibab Plateau (Parisawampitts Point to Point Sublime), wackestones predominate and quartz silt increases to over 5% in some beds. West of Toroweap Valley, carbonates are less micritic and are predominantly packstones with trace amounts of quartz silt. Horizontal, iron-stained stylolites having average vertical amplitudes of 6 cm are confined to thick limestone beds of the Shivwits and Uinkaret plateaus. Sedimentary structures are rare, except for wispy laminations, common in most beds. Sporadically, laminations bend around chert and micritic nodules. Most lithologies are moderately burrowed and pellets are common.

**Harrisburg Member**

The Harrisburg Member is a sequence of nonresistant beds resting on the thick-bedded, cliff-forming Fossil Mountain Member. In northwestern Arizona and southwestern Utah, it consists of interbedded light-red to pale-gray limestone, gypstone, dolostone, siltstone, and sandstone strata. Weathering produces a series of carbonate and clastic ledges projecting from slope-forming, commonly talus-covered gypstone beds. This highly variable group of carbonate and clastic beds undergoes significant facies changes (Pl. 1C), some of which can be observed across laterally continuous outcrops.

**Stratigraphy**

Reeside and Bassler (1922) first named the Harrisburg Member the Harrisburg Gypsiferous Member for exposures at the Harrisburg Dome in southwestern Utah, about 13 km northeast of Saint George, Utah (Fig. 2). There the member is 85 m thick and consists of light-red and light-gray gypstone, limestone, dolostone, and lesser amounts of red and gray siltstone and sandstone. McKee (1938) referred to it as the alpha (α) member of the Kaibab Formation. Sorauf and Billingsley (1991), following the Code of Stratigraphic Nomenclature, formally named it the Harrisburg Member. Because the outcrop at the type locality is poorly preserved and supplies only limited stratigraphic information, they proposed a reference section in Whitmore Canyon where it is 53.1 m thick, well exposed, and consists of four distinct, ledge-forming carbonate units separated by slope-forming gypstone and siltstone units. It thins to the east and reaches a depositional edge within Marble Canyon. The predominant molluscan fauna in the Harrisburg Member versus the abundance of brachiopods in the Fossil Mountain Member helps differentiate the two members.

**Areal Variance in Unit Thickness**

The original stratigraphic thickness of the Harrisburg Member is difficult to estimate because locally it has been removed by erosion, either in the present cycle or before deposition of the overlying Moenkopi Formation. Of the 27 sections described, the uppermost beds have been removed at 11 sections. Sorauf (1962) measured a total thickness of 91 m at Hell's Hole, about 8 km north of Woods Ranch in Whitmore Wash and 53.1 m at the reference section, only 8 km distant. It is 70.6 m thick at Atkins Ranch along the central Hurricane Cliffs and 63.8 m at Seegmuller Mountain to the west on the northwest Shivwits Plateau. At eastern locations on the Kaibab Plateau, it thins to 17 m at Parisawampitts Point and 24 m at Point Sublime, ultimately reaching a depositional edge and pinching out at Saddle Mountain in Marble Canyon. Thick beds of gypstones interbedded with thin dolomitic mudstones comprise major parts of the member across the Uinkaret and Shivwits plateaus. Thick beds of gypstone within the Harrisburg Member are currently mined at Blue Diamond Hill, west of Las Vegas, Nevada (Ocano, 2014; Blue Diamond History Committee, 2020).
Stratigraphic Character of Unit Boundaries

The contact between the cliff-forming Fossil Mountain Member and the Harrisburg Member is interesting in the variety of lithologic features involved. McKee (1938, p. 49) described this contact in some detail and concluded:

"where the change from beta to alpha member in the Kaibab Formation [now Fossil Mountain and Harrisburg members respectively] is definite, any of three distinctive beds or horizons might be selected as the boundary. In nearly all Grand Canyon sections, a thick bed of chert, in many places brilliant red or yellow in color, was the last deposit in the sequence formed under normal marine conditions [Fossil Mountain Member]. Above this lies another distinctive bed, a cross-bedded sandstone or sandy limestone, that by the nature of its bedding and frequent occurrence of (nonmarine) trails in it heralds the departure of marine environments and the coming of brackish water and continental deposits. Next above the cross-bedded deposit, in most places, appears the first of the thin-bedded, magnesian limestones with molluscan fauna, indicating that the boundary lies beneath it. Where any of the three horizons referred to above persistent throughout the entire area of Kaibab deposition, an exact boundary could be easily assigned. As it is, inconsistencies arise in various sections, making it necessary to place the boundary not in relation to any one marker bed but wherever the environment of most extended sea seems to be replaced by that of a receding sea as reflected in the rocks."

McKee's dilemma in searching for a stratigraphic marker at the base of the Harrisburg Member was in part dictated by the vast area in which he studied this member. Exposures west of the Kaibab Plateau have a distinctive lithologic transition from thick-bedded, cliff-forming beds to recessive-weathering beds at this boundary. The unit lies directly upon the densely mottled upper chert tracery beds of the Fossil Mountain Member. As McKee noted, at a majority of outcrops, the rocks within this zone accurately reflect the transition from limestones containing a normal marine fossil assemblage to those of more restricted types. The two most definitive characteristics of this transition are related to lithology and fossils. The thick-bedded, densely mottled, chert tracery beds of the Fossil Mountain Member form a promontory followed by a group of less resistant cherty limestone and dolostone beds that weather to form step-like beds and recede from the cliff edge. Second, fenestrate bryozoans that are plentiful in the chert and carbonate beds of the chert tracery are much reduced in the overlying beds. Lithologies at the transition change from predominantly fossiliferous lime wackestones and packstones of the Fossil Mountain Member to dolomitic wackestones and siltstones.

The uppermost boundary of the Harrisburg Member is identified as the rocks forming the current surface or at the base of the Moenkopi Formation stream-channel deposits. Throughout isolated parts of the study area, rocks of the Timpoweap Member of the Triassic Moenkopi Formation have not been stripped from the plateau surface, so remain in contact with the Permian Kaibab Formation. This geologically significant boundary is the Permian/Triassic unconformity that represents much of Permian and part of Early Triassic. Typically, in northwestern Arizona it is a disconformity; erosional channels as much as several hundred feet deep are cut into the Kaibab Formation (McKee, 1938). However, in the eastern Grand Canyon, notably at Marble Canyon, recognizing the precise surface boundary is very difficult, if not impossible; the Kaibab-Moenkopi contact there is a paraconformity. It should be noted that the beds of the Harrisburg Member were probably considerably thicker after deposition but have been reduced in the current cycle of erosion or by dissolution and collapse during subaerial expose or scouring during deposition of Moenkopi stream channel conglomerates.

Lithology and Paleontology

Stratigraphic units within the Harrisburg Member can be correlated based on relative position within the
formation, relief along the face of the outcrop, and/or lithology and faunal assemblages. Clark (1974 and 1980) identified a recurrent sequence of lithologies at most outcrops, notably within the central and western parts of the study area. This sequence can be correlated across the study area; therefore, a six-unit subdivision is proposed for the Harrisburg Member. Each of these units shows distinct characteristics in both lateral change in lithology and fossil assemblage. Hopkins and Thompson (2003) also recognized this six-unit subdivision for the Harrisburg Member in their work, primarily south of the Colorado River, where lithologic characteristics are similar but vary from those in the current study area.

Fossils are found throughout most beds of the Harrisburg Member but lack diversity compared to the Fossil Mountain Member and are typically preserved as internal or external molds. Most fauna that is characteristic of the Fossil Mountain Member is present, although slightly dwarfed, most notably at eastern localities. The marked predominance of molluscan faunas of gastropods and bivalves, and rare occurrences of corals and sponges, is characteristic of the fossil assemblage.

Figure 5. Stratigraphic Section of the Harrisburg Member
West to east stratigraphic section of the Harrisburg Member from the Shivwits Plateau (Seegmuller Mt.) to the Kaibab Plateau (Point Sublume). Refer to Figure 1 for map location of measured sections. The thick gypstone beds found at the western locations thin and interfinger with dolomitic beds within the central part of the study area and pinch out between the eastern sandy shoreline facies.

Unit 1 Lower Fossiliferous Beds

Unit 1 rests on thick, cherty limestone beds of the Fossil Mountain Member and is composed of weakly resistant dolomitic mudstones, wackestones and packstones. Unit thickness remains relatively uniform throughout the central and western localities, but diminishes eastward toward the Kanab Plateau where it grades into, or interfingers with dolomitic siltstones of unit 2 as noted between Brady and Jumpup canyons (Fig. 5). The unit is 7.3 m thick at Mokiah Wash (Shivwits Plateau) and is a highly fossiliferous
wackestone containing a normal marine fauna of productids, crinoids, bivalves and fenestrate bryozoans. Along the southern Hurricane Cliffs, lithologies are medium- and thick-bedded, fossiliferous lime wackestones and, packstones and at Seegmuller Mountain they consist of few grainstones and medium-bedded, cherty dolostones. Unit 1 is highly fossiliferous compared to other units of the Harrisburg Member, but contains a less diverse faunal assemblage (Pl. 4A) than the underlying beds of the Fossil Mountain Member. Fenestrate and ramose bryozoans, crinoids, productid and other brachiopods, and molluscs are present in moderate amounts at southern outcrops but are noticeably fewer toward the north. Trilobites, ostracods and foraminifers are found sporadically in thin sections. Most fossils are broken, disarticulated and poorly preserved. Randomly distributed chert nodules are common throughout this unit. Quartz silt is present in trace amounts. Petrographically, lime mud is the primary interparticle matrix, but is replaced by fine-grained dolomite especially at eastern locations. Cloudy-center and clear-rim dolomite euhedra are noted in thin sections. SEM studies show individual dolomite euhedra range in size from 20 to 60 µ and form most of the matrix. Vuggy and fracture porosities increase slightly in the dolomitic siltstones and sandstones toward the east, visually forming up to 6% of most rocks.

Unit 2 Upper Fossiliferous Beds

Unit 2 is a group of thin- and thick-bedded dolomitic mudstones traceable from Atkins Ranch (Hurricane Cliffs) to Jumpup Canyon (Kaibab Plateau) where it interfingers with dolomitic, silty sandstones (Fig. 5). The abundance of mudstone textures and a notable reduction of fossils differentiates it from unit 1. The unit often contains discrete carbonate beds interlayered with gypseous beds of unit 3. The thinly bedded mudstones are mudcracked and slightly brecciated (e.g. at Atkins Ranch). A major facies change occurs to the west and north where mudstones grade into thick gypseous beds of unit 3. Local accumulations of these interbedded strata (up to 12 m) are found between Whitmore Canyon and the Cove, but noticeable thinning occurs both to the west and east. East of Tuckup Canyon, notably at S.B. Point, bedded cherts and dolomitic mudstones in the upper part of the unit interfinger with thick gypseous and bedded cherts. East of S.B. Point the unit thins and interfingers with siltstones and sandstones of unit 1 as noted at Point Sublime (western Kaibab Plateau). Both units 1 and 2 lose their identity across the Kaibab Plateau. A few silicified crinoid columnals, gastropods, productid brachiopods, bivalves, fenestrate and ramose bryozoans, trilobites and sporadic foraminifers are present locally. From Parashant Canyon to the Toroweap Valley, fossil molds, vugs and fractures average up to 5% porosity (Pl. 4B). Sedimentary structures are few and include laterally continuous laminations, cross laminations, cut-and-fill scour features and mudcracks. East of S.B. Point, silica commonly replaces halite molds (typically with length-slow chalcedony). Quartz silt increases from trace amounts at Whitmore Point to over 2% at Parisawampitts Point and eastward.

Unit 3 Interbedded Gypsstones

Abrupt lateral and vertical facies changes occur in unit 3 and are characterized by the variety of lithologies and thicknesses of beds. The presence of thick gypseous defines the unit boundaries. Thick beds of gypseous interbedded with thin dolomitic mudstones are the primary lithology of the unit. These strata are found primarily northwest of the Uinkaret Plateau, and the gypstones are found to become thinner eastward toward the Kanab Plateau, and pinch out along the Kaibab Plateau. Beds containing dolomitic lime mudstone and wackestone breccia and clasts of broken and disarticulated fossil debris separate the gypseous beds to the south and east. At Seegmuller Mountain and Atkins Ranch, this breccia zone is missing, leaving up to 50 m of interbedded gypseous. At Hobble Canyon (Grand Wash Cliffs), thinly bedded, burrowed, fossiliferous lime mudstones with sparse cephalopods are overlain by gypstones and interbedded, brecciated, dolomitic mudstones. Talus or sparsely vegetated soil conceals the unit at localities west of Toroweap Valley. Where equivalent intervals are exposed in Whitmore Canyon, thick beds of gypseous interfinger with brecciated lime mudstones forming a distinct facies change observable across the outcrop (Pl. 1C). Similar facies changes from brecciated and dolomitic lime mudstone beds to
gypstones are found at exposures a few kilometers north of Whitmore Canyon. Between Parashant Canyon and the Cove, unit 3 is a group of medium- and thick-bedded lime mudstones that forms blocky beds, traceable through continuous exposures. Lime mudstone clasts and broken and disarticulated fossils are found along bedding surfaces.

At Brady Canyon unit 3 is 47 m thick and includes 37 m of thick-bedded gypstone, separated by laminated and pelleted lime mudstone beds, each a few cm to 6 m thick. The carbonate beds contain mudcracks, vertical burrows, lime mudstone breccia and broken fossil debris. Silty lime mudstones and dolomitic crystalline carbonates are present along the Kaibab Plateau replacing the gypstone sequence found along the Hurricane Cliffs.

Fossils are generally absent in unit 3 although micritic fecal pellets, few beds of broken fossil debris, and subrounded lime mudstone clasts are found throughout in the mudstone beds, suggestive of reworking in a subaqueous environment. Other beds indicate subaerial exposure and contain sediment collapse breccia, silica-replaced halite casts, mudcracks and angular lime mudstone clasts (Pl. 4C).

**Unit 4 Round-Weathering Bed**

A prominent bed within unit 4 is a thick-bedded, dolomitic lime mudstone and wackestone that weathers to form one or more rounded beds that serve as a distinct marker (Pl. 1D). The unit can be correlated from the Shivwits to the Kaibab plateaus, maintaining a thickness of 3 to 7 m, with the only obvious lithologic change being an eastward increase in the amount of quartz sand and minor amounts of subrounded feldspar grains (Pl. 4D). Its surface is vuggy, pitted and has a characteristic sandy, abrasive texture. Molds of small molluscs and pellets, locally replaced with euhedral quartz, are visible in thin sections. Mudcracks and relic molds of evaporite crystals, crinoids and bivalves are rarely found on surface exposures. Some beds contain millimeter-size, dolomitic-lime mudstone clasts or gypsum that fills void spaces. Crinoids, bivalves, gastropods and bryozoans are rarely found within the unit although Hopkins and Thompson (2003) reported finding gastropods, bivalves and ostracods southwest of the study area within the same correlative unit.

**Unit 5 Sandy Mudstones and Rim Chert**

Unit 5 rests directly on top of the round-weathering bed. The lower beds are thin- to thick-bedded, sandy, cherty, dolomitic mudstones, wackestones, packstones and sandstones that weather to form a group of protruding ledges or a series of recessive beds that sit indented from the underlying thick beds of unit 4. These beds commonly contain desiccation features, including mudcracks and halite molds, and show signs of deformation including wavy and contorted beds and fractures. Lithologies are slightly fossiliferous on the Uinkaret Plateau and eastward across the Kanab Plateau. Silicified crinoids, gastropods, bivalves, and fenestrate and ramose bryozoans are randomly distributed throughout these beds and foraminifers and trilobites are found in a few thin sections. Along the Shivwits Plateau, textures are highly burrowed, moderately brecciated, mudcracked, and contain abundant pellets.

Immediately above these weakly resistant beds is a distinctive, laminated chert bed herein referred to as “rim chert” (Pl. 1E). It is the premier example of bedded chert in the Kaibab Formation and commonly forms the rim rock of plateaus west of the Kaibab Plateau. It is highly oxidized, very resistant, fractured, bench-forming and laterally continuous. Thicknesses range from 1 to 3.4 m (average 1.7 m) and because of its iron content, weathers to various shades of dark gray, yellow, red and orange. It rarely contains fossils or sedimentary structures other than thin, laterally continuous laminations (Pl. 4F).

**Unit 6 Dolomitic Sandstones and Gypstones**

Rocks extending from the “rim chert” of unit 5 to the base of the Triassic Moenkopi Formation constitute unit 6. The unit consists of red, orange and yellow, dolomitic-quartz sandstones, siltstones, terrigenous
mudstones, dolomitic mudstones and gypstones. Chert nodules with an average diameter of 2 cm are common in the sandstones and mudstones. Most beds have a sandy, friable texture and weather to produce a series of nonresistant ledges and covered intervals. Thick sequences of laminated gypstones and covered intervals are found at outcrops along the central and southern Hurricane Cliffs. Sandstone beds, locally containing a bimodal distribution of detrital quartz grains (Pl. 4G), are found within the gypstones. Well-rounded, sand-size quartz grains and detrital chert make up to 15% of the volume with subangular, well-sorted quartz silt serving as matrix. The larger grains average 0.5 mm and are slightly frosted and well rounded. Angular chert clasts are common within the sandstone beds, apparently derived from the upper chert beds of unit 5. Fossils are few within the unit and consist of an impoverished molluscan fauna of bivalves and gastropods plus crinoids and ramose and fenestrate bryozoans. Although most beds within the unit are unfossiliferous, an abundant molluscan fauna of Acanthopecten, disarticulated crinoids and scaphopods are found in Whitmore Canyon. Locally, laminated, dolomitic lime mudstone beds are mudcracked or contain cut-and-fill features, ripple marks, wavy beds or raindrop imprints. East of Whitmore Canyon, at Brady Canyon and S.B. Point, dolomitic mudstones within the unit have a notable increase in quartz sand and are moderately fractured or contain subrounded lime mudstone clasts within a dolomitic siltstone and sandstone matrix. Locally, thinly bedded, mudcracked, dolomitic lime mudstone and dolomitic, crystalline-carbonate beds are interbedded with the siltstones.

Regional erosion has typically removed most of unit 6 throughout the northern parts of the study area including the sandy mudstones and bedded cherts of unit 5, resulting in a residual breccia layer containing broken fragments of chert, or limestone and siliciclastic clasts. Remnants form isolated outcrops in the southern Shivwits, Uinkaret and Kanab plateaus and in Whitmore and Parashant canyons where it averages 9 m thick. Along the Hurricane Cliffs, Clark (1974) measured 36.4 m of unit 6, including 22.3 m of gyspstone. At Hell’s Hole in Whitmore Wash, Sorauf (1962) reported 43 m of strata above unit 5, including 30 m of gypstone and interbedded siltstones. Regionally, unit 6 may have originally been much thicker, but was eroded prior to, or during deposition of the basal Moenkopi Formation stream-channel deposits, or in the current cycle of erosion. Billingsley (1991 and 1997) indicates shallow sinkholes and karst caves in the Harrisburg Member have removed up to 49 m of gypsum in Sullivan Draw (due west of the northern Hurricane Cliffs). Triassic paleo-river valleys and associated tributaries as deep as 45 m have eroded through the Harrisburg Member, and even into the Fossil Mountain Member at Whitmore Point (Billingsley, 1997).

**ORIGIN OF LIME MUD AND GYPSUM**

Lime mud and gypsum are distinctive lithologies of the Kaibab Formation, and a review of their distribution and possible origins is important in reconstructing their environments of deposition.

**Lime Mud**

Most Kaibab lithologies contain marine fauna, lime-mud pellets and clasts, or breccia clasts encased in a lime (carbonate) mud matrix. The primary carbonate matrix of the Fossil Mountain and Harrisburg members is micrite and pseudospar (1-3 µ and >40 µ respectively, Folk, 1959). Therefore, a review of possible origin(s) of lime mud is relevant for an understanding of the environments of deposition.

Considerable research has been conducted on the origin of lime mud, yet it remains the subject of continued debate and uncertainty (Trower, et al., 2019). The most commonly accepted sources include decomposition of spiculitic calcareous organisms, precipitation from seawater, and physical abrasion of shells. Most lime mud in the Kaibab Formation probably formed from the decomposition of marine algae and by direct precipitation in the water column. Recent analogues for the formation of lime mud draw primarily on the breakdown of calcareous green algae. The Permian calcareous algae *Gymnocodium*
bellerophontis Rothpletz, as described by Johnson (1951) in the Apache Mountain of Texas and the Harbol Formation of Turkey by Elliott (1955), is commonly found in thin sections of the Toroweap and Kaibab formations. Sawin and West (2005) in their study of the Beattie Limestone in Kansas, proposed that the amount of lime mud produced by calcareous marine phylloid algae during the Permian could have been substantial and similar to sediment contributions of Holocene algae. Although Gymnocodium and phylloid algae decompose to sand-size particles or have ridged skeletons of centimeter scale, their possible sources to mud may have been by abrasion.

An additional contribution may have been by direct precipitation from seawater, similar to modern-day whittings found in the platform waters of the Bahamas and the Persian Gulf (Cloud, 1962; Wells and Illing, 1964; Larson and Mylroie, 2014). These milky clouds of mud-size carbonate needles form over vast areas of shallow platforms and are capable of generating large volumes of lime mud. They leave no geologic record except lime mud. The volumetric significance of mud generated by whittings in the past may have been substantial.

Recent laboratory results have shown that transport and abrasion of carbonate sand is also a significant source of carbonate mud (Trower, et al., 2019). The pulses of transgressive and regressive seas across the shallow Kaibab shelf disturbed bottom sediments producing discrete beds of broken and abraded shelly lenses in a mud matrix that probably included some abraded carbonate.

**Gypsum**

Gypsum is found in rocks of the Kaibab Formation filling interstitial pores and desiccation cracks, or as thin- and thick-bedded deposits that form much of the Harrisburg Member. These are found as intergranular, light- and medium-gray cement, 0.5 to 4 cm nodules or laterally extensive beds. The bedded gypstones range from a few centimeters to over 35 m thick and are prevalent in the central and northwestern parts of the study area. The thick gypstone strata are typically interbedded with thin beds of dolomitic mudstones. Anhydrite is found sporadically as nodules, void linings or thin beds as found on the Uinkaret Plateau. Nodules of gypsum and anhydrite or their molds are similar to nodular anhydrite found in modern supratidal sediments of the Persian Gulf (Kinsman, 1969).

The origin of gypsum as a precipitant from seawater has been researched for over a century (e.g. Usiglio, 1849; Kendall, 1984; Hardie, 1991; Babel and Schreiber, 2014) although specific details of its formation remain unclear. Gypsum is precipitated when seawater is evaporated to approximately 1/4 of its original volume. For gypsum to be the primary evaporite to precipitate, the seawater must be replenished as precipitation continues. Kendall (2010) noted that evaporating 1 km of seawater would produce slightly less than 13 m of evaporite minerals including less than 1m of gypsum. If this was the only means of producing up to 45 m of gypstone in the Harrisburg Member, the total seawater required would be over 45 km. This scenario would not fit our shallow-water model of gypsum formation in the Harrisburg Member. Rather, a periodic replenishment of seawater must have occurred concurrent with gypsum precipitation, probably in concert with basin subsidence, to form the thick gypstone beds within the Harrisburg Member. For gypsum saturation to be reached, the ratio of the surface area of the restricted basin to the cross-sectional area of the oceanic opening would be $10^6/1$ or greater; essentially the restriction from the open ocean would have to be nearly complete (Lucia, 1972). The origin of thick-bedded gypstone would ideally use a recent analogue but, according to Babel and Schreiber (2014), there are no depositional environments presently forming thick gypstone deposits, therefore a hypothetical model is developed and discussed in Environments of Deposition.
DIAGENESIS

Diagenetic alteration through dolomitization and silicification had a pronounced effect on lithologies of the Kaibab Formation and although considerable research has been conducted on these processes, their origins remain controversial. Although the primary intent of this paper is to describe the stratigraphy and depositional environments of the Kaibab Formation, the following summary describes the lithologic distribution and possible origins of these alterations and elucidates the original lithologies.

Dolomitization

The origin of dolomite and processes of dolomitization remains a mystery to carbonate petrologists (Zenger and Dunham, 1980; Shukla and Baker, 1988; Machel, 2004; Manche and Kaczmerek, 2018). Dolomite and dolomitized lithologies abound in the geologic record, but environments where dolomite is currently forming are few, therefore using modern-day analogs requires speculation. Dolomite is found within both members of the Kaibab Formation and its impact on these rocks is significant and has locally obscured their original lithology. It is present in the Fossil Mountain Member at eastern locations where lime wackestones and mudstones interfinger with dolomitic mudstones, siltstones and sandstones and is ubiquitous throughout the Harrisburg Member.

Carbonate strata in the Fossil Mountain Member are predominantly thick to medium bedded, light- and dark-gray lime mudstones, wackestones, packstones and few grainstones. Dolomite replaces the micritic textures primarily on the east side of the Kaibab Plateau, and is commonly found at the transition from the upper beds of the Toroweap Woods Ranch Member to the Kaibab Fossil Mountain Member. A distinctive bed is typically found at this transition and contains dolomitic, angular breccia clasts and rounded mud clasts derived from reworking of dolomitic beds of the underlying Toroweap Formation. Where these beds are not dolomitized, most fossils maintain their original mineralogy and are well preserved. Dolomite has altered original carbonate sediments and fossils, although it is typically fabric selective and not void filling. Murray (1964) maintains that such dolomite has grown by replacement of existing calcite or aragonite structures and fabrics and not as new crystals in existing void spaces. This is commonly reflected in dolomitized rocks of the Kaibab Formation where dolomitized fossils maintain excellent morphologic characteristics. Fossil-moldic and sediment-pore spaces remain empty or filled with calcite or quartz.

Dolomite is prevalent throughout the Harrisburg Member as light tan, yellow, orange and red dolomitic mudstones and wackestones locally interbedded with gypstones at western exposures, and quartz sandstones and siltstones to the east. The dolostone strata are typically thinner than the limestones of the Fossil Mountain Member, although individual beds can be correlated across laterally continuous outcrops and often terminate within thick-bedded gypstones. Depositional textures of these rocks are predominantly dolomitic mudstones and wackestones with few fossils or fossil molds. The abundance of fine-grained fabrics suggests most of the dolomite is a diageneric product of previous calcium carbonate mud (micrite). Dolomitization has obscured the remnants of possible algal laminations that are locally present in mudstones and siltstones.

Dolomite is found in the Kaibab Formation as discrete rhombohedra ranging in size from 2 to 2000 µ with mode close to 10 µ (0.01 mm) or as micrite. Texturally, most of the dolomite is sucrosic (after Murray, 1960) having uniform grain size (less than 25 µ) and subhedral crystal boundaries. The remaining dolomites have much larger crystals (100-2000 µ) that commonly have cloudy centers and clear rims. X-ray analyses of 37 randomly selected dolostones indicate a highly ordered molecular structure with a Mg/Ca ratio close to one (average molar Mg/Ca of 49/51).
Recent analogues provided primarily from carbonate research at large petroleum companies and universities during the 1960s and 70s (e.g. Illing et al., 1965; Kinsman, 1964 and 1969; Shinn et al., 1965; Deffeyes, et al., 1965; von der Borch et al., 1964) identified a few environments where dolomite is currently forming (e.g. Persian Gulf, Bahamas, South Florida, Bonaire, South Australia). Most modern-day analogues are characterized by their limited areal extent, small vertical thickness, and short time of formation. Recent dolomites lack ordering and stoichiometry, have crystals less than 3 µ with fuzzy euhedral boundaries, and are typically Ca rich with average Ca/Mg ratios of about 55/45 (Goldsmith et al., 1961). Many of these dolomites are found in arid, sabkha environments and on supratidal mudflats as surface crusts, filling pores of carbonate sediments, or a few centimeters below the surface as thin, discontinuous beds where they are commonly associated with anhydrite or gypsum. They formed as penecontemporaneous replacement of aragonite mud and are located a few centimeters above high-tide level (Illing et al., 1965) or as primary precipitates from hypersaline water in pore spaces (Shinn and Kendall, 2011). Sedimentary structures within these dolostones include mudcracks, teepee structures, evaporite nodules and sparse algal laminations. Zenger and Dunham (1980) warned that, although the discovery of Holocene penecontemporaneous supratidal dolomites illuminate processes that may have played a role in the geologic past, their volumetric significance probably has been magnified by researchers eager to apply these modern-day analogues. It is important to note that these early dolomites form relatively thin bands across supratidal areas, and at any given time, seldom exceed a few kilometers wide.

Adams and Rhodes (1960) proposed a model in which extensive beds of carbonate can be dolomitized in the subsurface. This model proposes refluxing brines through shallow subtidal and peritidal zones for the post-depositional formation of dolomite in laterally extensive beds. Rameil (2008), Fullmer and Lucia (2010), James and Jones (2016), and Dravis and Wanless (2018) have more recently applied this concept. Under this scenario, restriction of normal marine seawater circulation across a broad, relatively flat and shallow carbonate platform promotes evaporation and produces a highly saline, dense brine with an elevated Mg/Ca concentration. The brine, being denser than the pore water in the underlying sediments, flushes through the sediment, converting metastable carbonate minerals to dolomite. A primary requirement of this model is restriction of seawater. Lucia (1972) and Schreiber (1986) proposed a physical barrier, such as an offshore reef or shoal, is typically required to cause hypersalinity across a shallow platform.

Carbonate researchers still do not fully understand or agree upon the origin of dolomite, although it is generally accepted that the above-mentioned modes of formation seem reasonable. Those are penecontemporaneous diagenetic replacement of aragonitic mud in localized supratidal areas and reflux of hypersaline water to form laterally extensive, thick beds of dolomite. Laterally extensive, thin dolomitic mudstone and wackestone beds of the Harrisburg Member typically contain sedimentary features indicative of supratidal and intertidal environments characteristic of early penecontemporaneous dolomites. The pervasively dolomitized wackestones and packstones of the Fossil Mountain Member have features of subtidal environments and apparently formed adjacent to the shoreline as the result of early diagenetic alteration. Specific characteristics of these modes and their resultant facies are present in the Kaibab Formation as discussed later in Environments of Deposition.

Silicification

Silicification, primarily in the form of chert, is found throughout the Kaibab Formation and is prevalent in the Fossil Mountain Member as discrete circular nodules, disseminated lacy fabric, laminated beds, and fossil replacement or void-fillings. Nodular and bedded chert are present throughout the Harrisburg Member but not in the variety or abundance found in the Fossil Mountain Member.
The majority of chert consists of white- to light-gray silica typically in the shape of spherical to elliptical nodules or as a lacy fabric. Nodular chert is present as discrete nodules either randomly distributed throughout calcareous matrix or aligned parallel to bedding. Dense, thinly bedded chert forms distinct, continuous beds. Microcrystalline quartz and chalcedony are the primary constituents.

Chert replacement of original skeletal parts of fossils is typical of the Kaibab Formation. The original skeleton was composed of calcium carbonate (primarily high- and low-magnesium calcite or aragonite) that was replaced by silica that allows it to stand in relief on weathered surfaces. Chert, in the form of euhedral and microcrystalline quartz, and both length-fast and length-slow chalcedony are commonly observed in thin sections as fossil replacement and pore-filling fossil molds. Whidden and Bottjer (1989) in their studies of the Fossil Mountain Member in southwestern Utah, noted that trace fossils, specifically *Thalassinoides* and their characteristic Y-shaped branching burrows, are typically silicified. It is noteworthy that chert tracery described in the Fossil Mountain Member of the current study has the appearance of bifurcating burrows and may have had a similar origin.

Chert is also found filling voids and fractures. The voids have cubic or lath-like shapes, indicative of pre-existing halite or gypsum crystals, or appear as desiccation cracks. Chalcedony replaces evaporite crystals or lines desiccation cracks in some thin sections of Harrisburg Member carbonates. Although most chalcedony in the geologic record is optically length fast, the variety commonly observed in the Kaibab Formation is length slow, either as pore-filling or pseudomorphic replacement. Folk and Pittman (1971) have shown that length-slow chalcedony (luteceite and quartzine) routinely replaces evaporite minerals and is therefore an indicator of hypersaline environments. The source of silica for these cherts is uncertain, although it probably resulted from dissolution of sponge spicules, diatoms or radiolarians. McKee (1938) and Griffin (1966) found body parts of *Actinocoeilia maeandrina* and sponge spicules throughout the member in the central and western parts of the study area. Because of the relatively few numbers of silica-secreting organisms in the Permian versus the abundance of chert in the Kaibab Formation, it does not seem possible to attribute all chert to siliceous sponge spicules. Bustillo (2010) suggested that chert may be derived from siliciclastic grains, clays, and volcanic ash, perhaps transported from remote sites by phreatic or hydrothermal water. Butts (2014) similarly noted the close association of volcanic ash and silicified fossils in Permian fossils of West Texas. Knauth’s (1979) classic model of silification proposes that many nodular cherts in limestone have formed in the ground water of mixed meteoric-marine coastal systems.

**ENVIRONMENTS OF DEPOSITION**

Conceptual depositional models are necessary to establish the environmental framework for the members of the Kaibab Formation and are essential in developing details of the environments of deposition here during the Early Permian Period. The environmental setting consisted of an epeiric seaway that covered an extensive carbonate platform adjacent to a low-lying terrestrial shoreline. Located only a few degrees from the equator, temperatures and evaporation rates were high, and together with minimal precipitation produced an arid climate. Most models used to describe carbonate platforms draw on either a shelf or ramp, each having their unique environmental settings and resultant facies. Recent shelf analogues show the shelf to extend offshore for a few kilometers and include an elevated margin (e.g. Great Bahama Bank and South Florida), typically consisting of a sedimentary buildup of an organic reef, oolitic shoal or mound. The ramp model is a platform that may extend tens of kilometers from the shore and has a slope on the order of less than one meter per kilometer as found in the Persian Gulf. Unfortunately, both members of the Kaibab Formation have characteristics that do not align well with either of these models and would be best described using a shelf analogue but one lacking a documented elevated platform edge. Therefore, reconstruction of depositional models uses data presented in this study, application of current
advances in carbonate research, and speculation as viewed through a misty lens of what environments were like during the Early Permian Period.

The Kaibab Formation developed within an embayment along a passive continental margin that extended seaward from a low-lying coastal plain. An extensive epeiric sea covered the embayment creating a low-relief, shallow carbonate platform across most of northwestern Arizona (Blakey and Ranney, 2008). Tectonic activity throughout the region was minimal during the Paleozoic Era allowing continuous marine and near-shore carbonate and evaporite sediments to be deposited. A tectonic hinge, the Las Vegas Line, trending from Las Vegas, Nevada to St. George, Utah (Bissell, 1969), was located along the western edge of the platform and separated the platform and a deeper basin. Strata of the Fossil Mountain and Harrisburg members developed during cycles of marine transgression and regression that formed within two distinct environments of deposition. It is suggested these cycles were caused by minor tectonic movement along this hinge elevated the platform margin therefore restricting seawater circulation across the platform, and were accompanied by fluctuating sea levels associated with glacial episodes in the southern hemisphere. Marine, near-shore and supratidal lithologies with distinct fauna characterize the depositional environments and aid in the reconstruction of facies.

Fossil Mountain Member

An epeiric sea developed over this broad, flat platform, and in response to a rise in sea level, a regional transgression of normal marine seawater encroached from southeastern Nevada, over preexisting lagoonal, coastal sabkha, and aeolian deposits of the Woods Ranch Member of the Toroweap Formation (Fig. 6). Normal marine carbonates and fauna of the Fossil Mountain Member were deposited on this low-relief shelf during this last major continental invasion of the Kaibab Sea. An erosional, brecciated shelly lens formed as the sea encroached over the weakly resistant lagoonal and sabkha deposits and is documented from westernmost outcrops along the Grand Wash Cliffs eastward to Marble Canyon, a distance of 155 km (97 mi). Although the environmental setting across the platform was generally quiet during this gradual marine transgression, broken and disarticulated fossil-bearing zones are locally present and appear as lag deposits, and in conjunction with a general reduction of mud, indicate the sediment-water interface in at least some areas was well agitated. Discontinuous, wavy, cross-laminated beds with brecciated, dolomitic-lime mud clasts are sporadically found at the base of the member, indicating episodic wave or tidal energy across this boundary.
Figure 6. Depositional Model of the Fossil Mountain Member during the Early Permian Period (Leonardian)
Normal marine seas transgressed over lagoonal, sabkha and terrestrial (aeolian) deposits of the Woods Ranch Member (Toroweap Fm) producing an erosional, brecciated surface (Δ) and deposited normal marine carbonates on a broad, shallow platform. This environmental reconstruction represents the maximum continental invasion of the Kaibab Sea.

Lithologies and fauna of the Fossil Mountain Member are relatively uniform but areal variations represent deposition under various environmental settings. Facies gradients are consistent with more open seas to the west and shallower water encroaching on a shoreline to the east. Bedding is thick at western locations and thins toward the east. Packstones and few grainstones are found primarily at western locations, indicating a higher energy environment but do not show a notable thickening of strata that is characteristic at the edges of many modern-day carbonate platforms. The increase in packstones and grainstones at western locations may have resulted from minor tectonic movement elevated the western platform margin causing mud to be winnowed over this basin-to-shelf transition. The majority of textures are mud supported that become more prevalent toward the east, indicating life on the sea bottom was generally below wave base.

Desiccated surfaces formed during subaerial exposure of pre-existing evaporite deposits of the Toroweap Formation and resulted in sediment collapse prior to advancing of the seas. The paleoshoreline separating open marine from intertidal and supratidal environments was roughly north-south from Ryan and Nail canyons to Parisawampitts Point and Point Sublime in the easternmost Grand Canyon (Fig. 1). The location of this shoreline shifted periodically and at times the maximum transgressive surface may have been located much further to the east, outside of the study area. Marked vertical facies changes from terrestrial clastics to normal marine carbonates developed in response to changes in sea level. Fossiliferous lime packstones, wackestones and mudstones that formed on the carbonate platform graded into dolomitic mudstones, siltstones and sandstones along the shoreline. Cherty limestones containing a robust assemblage of normal marine fauna of brachiopods, crinoids, bryozoans, sponges and corals transition into lime mudstones and siliciclastics with a restricted molluscan fauna. Lithologies on the landward side of the shoreline are terrestrial siliciclastics and are brecciated, mudcracked, cross bedded, burrowed and locally contain algal stromatolites. The primary source of Permian terrestrial siliciclastics, was the Uncompahgre Uplift of the ancestral Rocky Mountains located to the northeast (Lessentine,
Cheevers and Rawson (1979) proposed that long-shore currents transported clastics into the area from an unnamed source to the north. The imported quartz silt may have mixed along the shoreline with the preexisting well-rounded sand grains from the underlying Coconino Formation that were exposed to the east at the end of Toroweap time, resulting in local accumulations of beds with a bimodal distribution of grain sizes. The bimodal size distribution may have resulted from saltation of well-rounded and frosted grains from the Coconino sands blowing over coastal areas from the east, mixed with the clastic sediments. A few ephemeral streams originating from the low-lying hinterland brought terrestrial siliciclastics into the shoreline through braided deltas, but their overall quantities were minor compared to the prograding carbonates of the offshore platform.

A diverse, normal-marine biota developed in the western and central areas, characteristic of warm, shallow seas with unrestricted circulation, agitation, oxygenation and normal-marine salinities. Productid brachiopods, notably *Peniculauris bassi*, are the distinguishing fossils in the Fossil Mountain Member. Other organisms include various brachiopods, ramose and fenestrate bryozoans, crinoids, solitary corals, sponges, echinoderms and a few ostracods, trilobites and foraminifers. Fossil abundance and diversity, notably solitary corals, decrease toward the eastern shoreline indicating a more restricted environment. A molluscan fauna became established close to the shoreline, with less abundance and diversity than in the overlying Harrisburg Member.

Diagenetic alteration, most notably dolomitization and silicification, affected the lithologies of the Fossil Mountain Member. Dolomite formed as a pervasive, early secondaryreplacement of carbonate sediments. Seepage refluxion of magnesium-rich sea water dolomitized the underlying sediments when highly saline, dense basin brines seeped into the underlying normal marine carbonate sediments, displacing pore waters as it moved seaward. Such pervasive zones of post-depositional dolomitization are found in the Fossil Mountain Member lithologies that formed along the shoreline and shallow intertidal areas.

Chert formed within the carbonate sediments as a diagenetic replacement although the timing of silicification, either as an early diagenetic phase or as a late-stage replacement is not certain. It is significant to note that wispy laminations are common in the carbonate matrix along with the chert, and laminae are typically found draping over chert nodules rather than passing from matrix into the nodules, suggest the laminations were present prior to the chert. The draping of laminae indicates that chert formed prior to compaction and lithification. Whidden and Bottjer (1989) also support an early diagenetic origin of chert in the Fossil Mountain Member and note that silicification appears to have occurred during early diagenesis because in some samples micrite is observed to be compacted around highly silicified nodules. This suggests the nodules were already harder than the surrounding sediment while the soft sediment was being compacted. Silicified fossils within the chert provide further evidence of a diagenetic origin. The origin of this chert remains speculative, but decomposition of siliceous organisms, primarily sponges, and reprecipitation of their spicules were the likely source. The burrow channels of intertidal and shallow-subtidal organisms may have served as conduit for the chert tracery beds. Laminated beds of chert are thought to have formed as a precipitant in shallow-intertidal zones where sea water mixed with terrestrial meteoric water.

**Harrisburg Member**

The model proposed for the environmental reconstruction of the Harrisburg Member (Fig. 7) contrasts with the Fossil Mountain Member as reflected in lithologies and fauna. A complex sequence of regressive and transgressive phases is identifiable across the study area and represents dramatic changes in the environments of deposition. The Fossil Mountain Member developed no apparent depositional relief (e.g. no reefs, algal banks or ooid shoals,) so the Harrisburg Member inherited a low-relief shelf, although the presence of grainstone and packstone textures at western locations indicates a higher energy environment, or possibly a topographic high in that direction that may have formed prior to the onset of a regressive phase.
Surface elevations between sea level and intertidal/supratidal surfaces were minimal, so minor changes of water depth or shifting areas of sediment accumulation would result in the redistribution of lithologies, interfingering of sediments, and pronounced lateral facies changes over relatively short distances. An erosional surface of broken and abraded fossils and carbonate clasts formed as vast areas of normal marine carbonate sediments became exposed in response to a westward retreat of the shallow sea water. High temperatures drove evaporation and sustained an arid setting where precipitation and terrestrial stream water were minimal. Few organisms lived in this hostile environment other than an impoverished molluscan fauna, burrowing organisms, and a few algal stromatolites that occupied intertidal areas.

Figure 7. Depositional Model of the Harrisburg Member during the Early Permian Period (Leonardian)

Lowering of seawater across the previous normal marine platform of the Fossil Mountain Member, produced a restricted basin and sabkha that formed during a regional marine regression, and represents the last recorded episode of marine seawater to cover the Colorado Plateau in the Paleozoic.

Periodic influxes of shallow seawater covered the platform during short-lived eastward transgressions. Medium and thinly bedded, fossiliferous mudstones, wackestones and few packstones were deposited and graded into medium and thinly bedded siltstones and sandstones toward the eastern shoreline. Lithologic textures along the supratidal areas were mud supported and sporadically contained gypsum nodules and thin, contorted and disrupted gypstone layers. These beds were commonly mudcracked, cross-bedded, brecciated, and locally contained teepee structures (Pl. 1G), reflecting deposition in a supratidal and coastal-dune setting.

As the shallow platform seas retreated, an intertidal mudflat complex formed over this supratidal deflation surface and included a series of ephemeral tidal channels, isolated ponds and lagoons that had limited connection with waters in the basin. Seawater became highly saline in these areas that were relatively isolated and had high evaporation rates. These environments were not static but shifted in response to minor fluctuations in sea level, sedimentation rates and distance from the shoreline as indicated by interfingering of interbedded, dolomitic, lenticular mudstones, wackestones, siltstones and sandstones. This highly saline mudflat complex was more extensive than those found in modern-day analogues and may have extended tens of kilometers from the shoreline. Most lithologies east of the Kaibab Plateau
have characteristics of intertidal mudflats, lagoons and sabkha deposits that grade into basin deposits to the west. Individual beds can be traced laterally over tens of kilometers and demonstrate lithologic facies changes, some abrupt and others gradual. Fossils are few and include an impoverished molluscan fauna of bivalves and gastropods. Closer to the shoreline, dolomitic siltstones and sandstones are relatively unfossiliferous, except for rare cephalopods and various other molluscs that are abraded and disarticulated. Similar intertidal complexes are analogous to the mudflats, lagoons and sabkhas in the present-day Persian Gulf (Purser, 1973).

Marine water circulation became restricted to nearly stagnant across the shallow platform as the seas continued to recede in this highly evaporative setting. Irwin (1965) suggested that seawater salinity across a vast, shallow platform would increase due to reduced circulation. This in itself could be the result of a “dampening affect” by friction along the water/sediment surface and would concentrate seawater sufficiently to allow thick beds of gypstone to form. However, Lucia (1972) demonstrated that regardless of the extent of a shallow sea, sea water connected to the open ocean could not remain sufficiently concentrated to produce the thick beds of gypstone as found in the Harrisburg Member. This paper provides two new concepts driven by tectonics and sea level fluctuations that would allow for the restriction of sea water and produce the thick bedded gypstones found in the Kaibab Formation.

Previous theories involving restriction rely on a physical barrier such as a reef or shoal at the shelf edge. Bissell and Chilingar (1968) and Bissell (1970) referred to an Upper Wolfcampian biohermal and reef limestone along the edge of a depocenter in southeastern Nevada as a barrier in the early Cisuralian (earliest Permian). No such barrier has been identified for the Kaibab platform. Although tectonic activity throughout the region was minimal during the Paleozoic, Bissell (1969) proposed that a “tectonic hinge”, the Las Vegas Line, extended from southern Nevada northeastward through southwestern Utah and separated basin (west) from shelf (east) during Permian times (Fig. 2). Periodic flexures along this structural hinge may have elevated the platform rim and restricted seawater circulation to the point of gypsum precipitation. Under this scenario, thick beds of gypstone formed in a shallow, restricted basin where rapid accumulation of thick evaporite deposits drove subsidence, thereby allowing basinal water depth to be substantially less than the final thickness of evaporite deposits. This would account for the accommodation space required for thick beds of gypstone to form in shallow water depths. Minor oscillations of eustatic sea-level in response to glacial episodes in the southern hemisphere, in concert with evaporative drawdown and episodic recharge, drove a very nervous sea level resulting in the deposition of alternating beds of carbonates and evaporites representing short-lived cycles of marine transgression and regression. Multiple cycles are documented in the Harrisburg Member, each beginning with shallow carbonate sediments being deposited during a transgression, followed by a quiescent period of evaporite precipitation. As sea level dropped, the platform sill was exposed, isolating the shelf and initiating gypsum precipitation prior to the onset of the next repetitive cycle. During low stands of sea level, a mosaic of distinct environmental settings coexisted across this warm, shallow, carbonate shelf: a restricted basin, mudflats, coastal sabkha and an alluvial plain (Fig. 7). The environments of deposition moved through time and space, depositing a complex distribution of lithologic facies in response to eustatic sea level changes.

An alternate depositional model of the Harrisburg Member is proposed where sea levels fluctuated primarily in response to Permian glaciation. During this period, sea level may have dropped well below the rimless Harrisburg shelf margin, preventing circulation of normal salinity sea water on the platform and allowing evaporation of the platform waters. Thin beds of carbonate platform mud would have become dolomitized in supratidal/mudflats as salinities and magnesium concentrations rose. Continued evaporation would have increased salinities further, such that a layer of gypsum would precipitate on top of the dolomitic mudstones completing one of the many dolomite/gypsum cycles that comprise the Harrisburg Member. As the next interglacial ice melted, sea level rose above the shelf margin and normal
salinity sea water would again gradually flood the platform area, beginning the next dolomite/gypsum depositional cycle. Thus, the building of thick gypstones interbedded with thin dolomitic mudstones could be the cumulative result of numerous evaporative cycles associated with sea level fluctuations during the Permian glaciation and associated increased accommodation space created by lime mud compaction. These models are based on the distribution of lithologies and fauna found in the Harrisburg Member. Either model is possible and currently data does not favor one or the other. The primary requirement is a restriction of seawater to the point of gypsum precipitation and a periodic influx of seawater to replenish the brine. This reconstruction forms the basis of the generalized model (Fig. 7) of the paleoenvironment that existed during a regional marine regression of the Kaibab Sea in the Early Permian Period and represents the last recorded event of marine seawater to cover the Colorado Plateau in the Paleozoic.

Basinal Gypstone

Thick regional deposits of Harrisburg Member gypstone formed in the central and northwestern parts of the study area and extended west to at least Las Vegas, Nevada, and at times may have extended over 100 km to the west. Based on the distribution of these gypstones, localized depo-centers may have been present and allowed thicker beds of gypsum to form within isolated basins. The thickest deposits of bedded gypstone are found along the Central Hurricane Cliffs extending westward to Seegmuller Mountain, although locally abrupt thickening of gypsum beds is found at Paradise Valley, Brady Canyon, and east to S.B. Point. This anomalous thickening may have resulted from dissolution and slumping of the Fossil Mountain Member into the gypstone beds of the Woods Ranch Member forming a localized depression prior to the deposition of the gypstone. Gypstone strata were originally thicker and more extensive, but have been removed during periods of subaerial exposure that resulted in solution collapse or from erosion and deposition of the Moenkopi Formation.

Supratidal Dolostone

A low-relief supratidal zone developed landward of the basin and mudflat complex. Lying slightly above normal high tide level, it was wetted only sporadically during lunar high tides and spray water from onshore winds. The environment was one of an arid coastal lowland with a salt-incrusted deflation surface that received minimal precipitation or terrestrial water from ephemeral streams. Small, isolated evaporative ponds may have been present but were ephemeral and only local in extent. Similar salt-flats or sabkhas are found in the Persian Gulf where high tides, accompanied by strong onshore winds, saturate marginal areas of islands, mudflats and sabkhas (Illing, et al., 1965; Bathurst, 1975). Interstitial pore waters of these salt flats evaporated to the point of gypsum (CaSO$_4$.2H$_2$O) precipitation forming nodular and thin, discontinuous layers. The ratio of magnesium to calcium (Mg/Ca) of the residual pore water increased in these lime muds producing penecontemporaneous dolomite to form prior to lithification. Similar features are found in the Harrisburg Member. Halite formed as ephemeral surface crusts on this deflation surface, but was dissolved by dew, occasional seawater spray, or exfoliated by on-shore winds. The presence of dolomite, halite pseudomorphs, gypsum nodules, mudcracks, algal stromatolites, laminated dolostones, and solution-collapse breccias in the lithologies of the Harrisburg Member support the hypothesis that they formed in supratidal areas similar to the present-day sabkha of the Persian Gulf.

The sabkha surface was only slightly above sea level which allowed groundwater to form within a few centimeters of the surface and served as a source of porewater to replace the evaporating water within the halite-incrusted surface crust. This upward movement of groundwater due to evaporative replacement is found within elevated areas of the Persian Gulf sabkha (Hsu and Schneider, 1973). This sabkha formed as a relatively narrow band in the supratidal areas of the Harrisburg Member and may have extended inland for a few kilometers. During the gradual regression of the Kaibab Sea, the sabkha lithologies moved
seaward and allowed thinly bedded dolomitic mudstones to extend over intertidal and shallow subtidal sediments.

The formation of dolostone beds within the Kaibab Formation therefore formed under two distinctly different environments; one within the Fossil Mountain Member caused by pervasive refluxing of dense, Mg-rich basin brines through pre-existing carbonate sediments in the subsurface, and the other along narrow supratidal sabkha surfaces caused by evaporation of seawater within the pores of penecontemporaneous muddy carbonate sediments. Strata of the sabkha graded landward into terrestrial lithologies of the interior alluvial plain that were laterally extensive and at times may have extended inland tens of kilometers or more from the shoreline.

**SUMMARY**

Shallow-water platform strata formed during the Early Permian Period and are exposed with near continuity within the Grand Canyon region of northwestern Arizona and can be subdivided into distinct lithologic units that characterize the Fossil Mountain and Harrisburg members of the Kaibab Formation. Each member contains specific carbonate, evaporite, and clastic lithologies, textures, sedimentary features, and indigenous fauna indicative of their environment of deposition.

The Fossil Mountain Member forms thick-bedded cliffs and prominent erosional pillars of fossiliferous, cherty-lime packstones and grainstones, found predominantly along the western Shivwits Plateau. These grade eastward into thick- and medium-bedded dolomitic wackestones and mudstones. The thickness of the member ranges from 77 m along the Grand Wash Cliffs on the Shivwits Plateau, to 40 m within Marble Canyon on the eastern side of the Kaibab Plateau. The member is correlated throughout the study area based on a two-unit subdivision; each is characterized with a distinct sequence of chert that serves as key marker beds consisting of four types: nodular, spherical masses, mottled lacy fabric, and bedded. A robust, normal-marine fauna became established across a vast, shallow-water platform in western locations and transitioned to an impoverished molluscan fauna toward the eastern paleoshoreline.

The Harrisburg Member consists of medium- and thin-bedded, dolomitic mudstones and wackestones, interbedded with thick beds of gypstones and siliciclastics. These weakly resistant beds, weather to form medium and thin protruding beds, receding ledges and talus-covered slopes. Its maximum thickness is 70 m found in the north-central part of the study area along the Hurricane Cliffs on the Uinkaret Plateau, and reaches a depositional edge on the eastern Kaibab Plateau within Marble Canyon. The original thickness of the Harrisburg Member was much thicker but is difficult to estimate because of recent localized erosion, or may have been removed during periods of subaerial exposure that resulted in solution collapse, or removed during deposition of the Triassic Moenkopi Formation stream-channel deposits. A recurrent sequence of lithologies can be identified at most outcrops, that allows for a six-unit subdivision of the member. Each unit shows distinct outcrop characteristics, lateral changes in lithology, specific fossil assemblages, and serves as a stratigraphic marker throughout the region. This highly variable group of carbonates, evaporites and siliciclastics undergoes significant facies changes, many of which can be traced across continuous outcrops. Fossils consist primarily of an impoverished marine fauna of molluscan bivalves and gastropods. Lithologic and faunal variations are notable from the basal units of the member to the top and indicate progressively shallower water conditions through time.

Lime mud is ubiquitous throughout the Kaibab Formation, forming mudstones and the interparticle matrix of wackestones and packstones. Its origin is thought to be the breakdown of calcareous marine algae that played a similar role as calcareous algae do today, accompanied by direct precipitation from seawater (analogous to modern-day whitings), or particle abrasion of calcareous marine fauna (Permian phylloid algae).
Thick regional deposits of gypstone are found in the Harrisburg Member in the central and northwestern parts of the study area and at times may have extended over 100 km to the west; their origin was a result of basin-wide evaporation of seawater accompanied by highly restricted circulation. Localized depocenters were present and allowed anomalously thicker beds of gypstone to form within isolated basins.

Diagenetic alteration through dolomitization and silicification had a profound effect on the Kaibab Formation. Dolomite formed in two contrasting settings, one in the subsurface platform sediments, and another on arid supratidal sabkhas. Pervasive post-depositional dolomitization of the Fossil Mountain Member subsurface carbonate sediments resulted from refluxing of dense, Mg-rich brine that formed in a highly restricted marine basin. Penecontemporaneous dolomite formed across narrow sabkhas of the Harrisburg Member by evaporation of Mg-rich seawater that periodically covered supratidal areas. As seas regressed, the supratidal environment migrated seaward and dolomitized locally continuous unfossiliferous mudstones and wackestones that contained sedimentary structures reflecting subaerial exposure.

Lithologies within both members contain significant amounts of chert as nodules, lacy fabric, laminated beds or as fossil replacement. The association of siliceous organisms, mainly sponges, served as the primary source although seawater reacting with terrestrial groundwater may have also contributed. Chert formed as an early diagenetic replacement within the carbonate sediments as evidenced by individual laminae in the carbonate matrix are often found draping over chert nodules rather than passing from matrix into the nodules, suggesting the laminations were present prior to the chert.

Rocks of the Kaibab Formation have lithologic and faunal characteristics of a regional marine transgression and regression as indicated within strata deposited across a broad carbonate platform. Lithologies of the transgression reflect deposition of normal marine carbonates and fossil assemblages of the Fossil Mountain Member prograding over preexisting coastal sabkha and aeolian deposits. The Harrisburg Member formed when fluctuating sea levels produced cyclic lithologies within restricted, highly saline basin, lagoon and sabkha environments that contained an impoverished molluscan fauna. Cyclicity of Harrisburg Member lithologies is one of its prominent characteristics but the cause of this remains uncertain. Two new Harrisburg Member models are presented of a restricted basin influenced by localized tectonics and accompanied by glacially enhanced, eustatic seal-level fluctuations that resulted in complex cycles of marine regression and transgression across this epeiric seaway. One model requires a physical sill-type barrier to create a restriction of seawater; the other is based on lowering of seawater below the platform in response to glaciation.

It is proposed that during the Permian a “tectonic hinge”, the Las Vegas Line, extended from southern Nevada northeastward through southwestern Utah and separated basin from shelf. Minor tectonic movement along this hinge may have elevated the platform rim, creating a sill-type barrier and restricted seawater circulation to the point of gypsum precipitation, and allowed thick beds of gypstone to form across the platform and in shallow basins. Oscillations of eustatic sea level in response to glacial episodes in the southern hemisphere, caused periodic mixing of the platform waters and in concert with evaporative drawdown and episodic recharge, drove a very nervous sea level and deposited alternating beds representing short-lived cycles of marine regression and transgression.

An alternate depositional model of the Harrisburg Member is proposed where sea levels fluctuated primarily in response to Permian glaciation. During this period, sea level may have dropped well below the rimless shelf margin, preventing circulation of normal salinity sea water on the platform. Carbonate platform mud would have become dolomitized in near-shore supratidal areas and mudflats as salinities and magnesium concentrations rose. Continued evaporation would have increased salinities further, such that a layer of gypsum would precipitate on top of the dolomitic mudstones. During the next glacial episode, seawater would again transgress over the platform completing one of the many dolomite/gypsum cycles that comprise the Harrisburg Member.
Currently there is limited data to confirm either concept. Hopefully future research will substantiate these or lead to an alternative interpretation.

These reconstructions form the basis of paleoenvironments that existed during regional fluctuations of the Kaibab Sea in the Early Permian Period, and record the last event of marine seawater to cover the Colorado Plateau in the Paleozoic. Excellent exposures of these rocks can be traced throughout the Grand Canyon and stand as paramount examples of lithologic facies and records of paleoenvironments.

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PLATES

Plate 1. Lithologies of the Kaibab Formation

A. “Cannonball” chert zone of Fossil Mountain Member along Hurricane Cliffs in Whitmore Canyon. Scale – rock hammer.

B. Densely mottled chert tracery along thick bedded cliffs in the upper chert tracery unit of the Fossil Mountain Member. These chert tracery zones form characteristic marker beds that are prominent at central and western outcrops within the study area. Scale – rock hammer.

C. Harrisburg Member exposed along Hurricane Cliffs in Whitmore Canyon. Thick and medium bedded dolomitic mudstones and wackestones on right pinch out between white gypsums on lower left (photograph courtesy of J.E. Sorauf).

D. Round-weathering bed along the Hurricane Cliffs in Whitmore Canyon. Highly weathered, abrasive surface texture created by relic molds of small molluscs and evaporite crystals. Note irregularly shaped chert lenses in lower beds of the outcrop. Scale – hammer in center left of photo.

E. Laminated, highly oxidized “rim chert” bed of the Harrisburg Member along the Hurricane Cliffs in Whitmore Canyon. Scale – Brunton compass.

F. Photograph of brachial valve of *Peniculauris bassi* (key index fossil of the Kaibab Formation) showing well preserved muscle scars and lophophore supports. Found in float from the Harrisburg Member in Toroweap Valley. Scale is in centimeters.

G. Teepee structure in uppermost bed (silty, dolomitic mudstone) of Harrisburg Member at Point Sublime. Scale-match pack.
Plate 2. Photomicrographs of the Fossil Mountain Member Lithologies

A. Fossiliferous packstone of “cannonball” chert zone from the upper subdivision at Jumpup Canyon. Fossils include crinoid (c), productid fragment (p), trilobite (t), and ramose bryozoa (r). Note micrite-filled burrow in upper left (b). Bar scale = 1 mm, Mag. 10x, sample KT 22-16.

B. Fossiliferous packstone from lower subdivision at Parashant Canyon. Note productid spines (ps), productid (p), crinoid (c), and molluscan fragment (m). Bar scale = 1 mm, Mag. 10x, sample KT 16-17.

C. Fossiliferous packstone from lower subdivision at Jumpup Canyon. Note brachiopod (b), crinoid (c), trilobites (t), fenestrate bryozoa (f), and mollusc (m). Bar scale = 1 mm, Mag. 10x, sample KT 22-14.

D. Subangular quartz silstone from lower subdivision at Marble Canyon (East Kaibab Monocline). Note silica overgrowths on silt grains. Bar scale = 0.25 mm, Mag 62x, sample KT 10-8.
Plate 3. Photomicrographs of the Fossil Mountain Member Fauna

A. Transverse section through a solitary rugose coral (Lophophyllum sp.) from lower subdivision at Atkins Ranch. Internal cement between individual septa is sparry calcite. Bar scale = 1 mm, Mag 10x, sample KT 25-12.

B. Transverse section through two ramose bryozoans from lower subdivision at Jumpup Canyon. Note: encrusting algae on lower bryozoan, intraparticle porosity and moderately high content of quartz silt (light-colored fragments). Bar scale = 1 mm, Mag. 10x, sample KT 22-13.

C. Longitudinal section through a fenestrate bryozoan from upper subdivision (“cannonball” chert zone) at Jumpup Canyon. Bar scale = 0.5 mm, Mag. 25x, sample KT 22-17.

D. Fossiliferous packstone from upper subdivision (“cannonball” chert zone) at Hack Canyon. Note: trilobite (t), ramose bryozoan (r), and encrusting bryozoan (e). Bar scale = 1 mm, Mag. 10x, sample KT 6-18.
Plate 4. Photomicrographs of the Fossil Mountain and Harrisburg Member Lithologies and Fauna

A. Fossiliferous wackestone from lower fossiliferous unit (unit 1) at Paradise Valley. Bar scale = 0.5 mm, Mag. 25x, sample KT 3-17.
B. Dolomitic mudstone from thinly bedded mudstones (unit 2) at Paradise Valley. Note: moderate amounts of vug porosity. Bar scale = 0.5 mm, Mag. 25x, sample KT 5-18.
C. Brecciated mudstone from breccia zone (unit 3) at Parashant Canyon. Cement is sparry calcite. Plane-polarized light. Bar scale = 1 mm, Mag 10x, sample KT 16-19.
D. Highly porous, vuggy, silty-dolomitic mudstone from round-weathering bed (unit 4) in Whitmore Canyon. Note: quartz grains (white specks) and twinned plagioclase feldspar (large gray grain) in upper right of center. Bar scale = 0.5 mm, Mag. 25x, sample KT 2-29.
E. Foraminifer (*Globivalvulina*? - S. Lucas, personal communication, December 1, 2021) from chert bed in lower subdivision of Fossil Mountain Member in Whitmore Canyon. Internal cement is sparry calcite. Mag. 63x, sample KT 2-19.
F. Laminated chert and crystalline carbonate (calcite) from rim chert (unit 5) at the Cove. Note: fracture porosity. Bar scale = 1 mm, Mag. 10x, sample KT 17-20.
G. Poorly sorted sandstone on infra-Kaibab unconformity (unit 6) at S.B. Point. Note: distinct bimodal distribution of grains. Bar scale = 0.5 mm, Mag. 25x, sample KT 12-19.
REFERENCES


Schleh, E.E., 1960, Toroweap and Kaibab Formations in a part of Parashant Canyon, Mohave County, Arizona [MS thesis]: Lawrence, University of Kansas.


**APPENDICES**

**Appendix A - Location of Measured Sections**

(Arranged by plateau and from north to south. Distances are approximated. See Fig. 1 for map location of stratigraphic sections.)

**Shivwits Plateau**

Virgin River (VR)

Section is in a gorge also referred to as Black Rock Gulch located 19.0 km west of St. George, Utah on route 15W. Section is on south side of highway on east facing cliffs in ravine designated Black Rock Canyon. Section is 3.2 km west on route 15 from Black Rock Canyon Road (dirt). Map location: northeast portion of T41N, R13W.

Mokiah Wash (MW)
Also referred to as North Seegmuller Mountain 16.4 km (road distance) south of Utah- Arizona border on Arizona Strip Road (toward Main Street Valley) and along cliffs on east side of road.

Seegmuller Mountain (SmM) aka Seegmiller Mountain
Also referred to as North Seegmuller Mountain located on east side of road ("Main Street Valley Road") leading to Seegmuller Mountain from St. George, Utah. Section is 23.0 km from Utah-Arizona border on "Main Street Valley Road" (also listed as Arizona Strip Road on some maps). Section is due east of head of Mokiah Wash. Map location: northeast in T40N, R12W.

Hobble Canyon (HC)
7.0 km southwest of Mustang Knoll along northern end of Grand Wash Cliffs. Map Location: slightly west of center in T38N, R13W.

Hidden Canyon (HdC)
10.0 km east of Grand Wash Cliffs and due east of Last Chance Canyon and 1.5 to 3.0 km south-southeast of road divide in Hidden Canyon. Map location: center of T36N, R13W.

Pigeon Creek (PC)
18.0 km west of Grassy Mountain and 10.0 km (road distance) west of wire fence on top of Shivwits Plateau. Section is within a canyon on north side of road. Map location: lower-central portion of T34N, R13W.

Snap Point (SP)
8.0 km east of Lake Mead and along north end of Snap Point Cliffs. Map location: north-central portion of T32N, R14W.

Andrus Canyon (AC)
0.5 km west of Andrus Point in first ravine west of Andrus Point. Map location: southeast corner of section 28, T33N, R11W.

Parashant Canyon (PsC)
Also referred to as Mule Canyon, located on east side of road leading into Parashant Canyon (Mule Canyon Road) and 2.7 km north-south from abandoned miners' shack at top of Uinkaret Plateau. Map location: northeast portion of section 2, T33N, R10W.

Whitmore Point (WP)
5.0 km due west of southern end of Uinkaret Plateau in Whitmore Wash and 5.0 km due west of southern extremity of Hurricane Cliffs. 3.0 km north along cliffs from Whitmore Point. Section begins in the first major ravine on east side of Whitmore Point at north center of section 4, T32N, R9W.

Uinkaret Plateau

Short Creek (SC)
Section is located 0.8 km (road distance) south of Arizona-Utah border on road (north part of road is paved and south part is dirt) leading south from Hurricane, Utah. Section is 16.0 km south of Hurricane, Utah and is along Hurricane Cliffs on east side of road. Section is directly east of a major valley exposure of the Hermit Shale and 1.0 km south of a black basalt flow in center of valley. Map location: T4IN., and on the border of R10W and R9W.

Navajo Trail (NT)
2.5 km south of where Navajo Trail crosses the Hurricane Cliffs. Section is along Hurricane Cliffs in center of T38N, R9W.

Atkins Ranch (AR)
20.0 km south of where Navajo Trail crosses the Hurricane Cliffs and 4.0 km northeast of Twin Buttes. Section is along Hurricane Cliffs 4.5 km northeast of Atkins Ranch and is east of dirt road due east of stock tank. Map location: T37N, R9W.

Iverson Ranch (IR)
Along Hurricane Cliffs 1.75 km northeast of abandoned ranch (Iverson) in major ravine north of ranch house. Map location is southeast corner of section 1, T35N, R10W.

Whitmore Canyon (WC)
Along the Central Hurricane Cliffs within Whitmore Wash 1.0 km east of dirt airstrip (north end) and 0.75 km east of northern-most stock tank in Whitmore Wash. Section was measure in second major
ravine south of prominent fault-block hills just south of Wood’s Ranch. Map location: south center of section 12, T33N, R9W.

Cove (C)
0.75 km west of Grand Canyon National Monument boundary fence in second major ravine west of primitive campground designated as the Cove. Map location: southeast portion of section 33, T33N, R8W.

Kanab Plateau

Paradise Valley (PV)
9.7 km north of Ranger Station (John Riffie) in Toroweap Valley (Grand Canyon National Monument). Section is on east side of northern end of Toroweap Valley in first major ravine east of a promontory formed by the Toroweap Cliffs. Map location: northwest portion of section 3, T34N, R7W.

Brady Canyon (BC)
6.4 km north of Ranger Station in Toroweap Valley. Type section of the Toroweap Formation and the Brady Canyon Member of the Toroweap Formation. Map location: boundary between sections 15 and 16, T34N, R7W.

Tuckup Canyon (TC)
3.7 km north of Tuckup Point on west side of Tuckup Canyon and between Cottonwood Spring and Schmutz Spring. Map location: unnumbered section, T34N, R6W.

Hack Canyon (HkC)
1.9 km southeast of Hack Reservoir at northern end of Hack Canyon. Immediately east of unimproved dirt road and 3.5 km north of Hack Canyon Mine. Map location: unnumbered section, T37N, R5W.

SB Point (SbP)
Son-of-a-Bitch Point abbreviated on U.S.G.S. maps as SB Canyon and SB Point. 7.0 km northeast of SB Point and 0.35 km south-southwest of Buckhorn Spring. Section was measured due north of horse corral in large amphitheater-like exposure. Map location: unnumbered section, T34N, R5W.

Jumpup Canyon (JC)
Section begins in stream gully and 50 m northeast of abandoned ranch house at dead end of Grand Canyon National Park Service Road #423 and at the head of Jumpup Canyon. Map location: west-central portion of T37N, R2W.

Kaibab Plateau

Ryan Canyon (RC)
11.3 km (road distance) west of Jacob Lake along Grand Canyon National Park Service Road #461. Section is on north side of dirt road and along cliffs forming Buck Ridge Point. Map location: center of section 18, T38N, R1E.

Nail Canyon (NC)
Section is located along west Kaibab monocline and 1.0 km southeast of head of Snake Gulch, along cliffs on east side of logging-trail road (Park Service Road #422) and 2.5 km due south of Ryan water tank. Map location: west side of section 30, T38N, R1E.

Parisawampitts Point (PP)
1 km due east of Parissawampitts Point on south-facing ravine cliffs and 0.5 km west of where road ends which leads into Parissawampitts Point. Map location: northeastern part of section 23, T35N, R1W.

Point Sublime (PS)
17.5 km due west of Grand Canyon Lodge on north rim of Grand Canyon National Park. Map location: southwest-facing cliffs at tip of tourist viewpoint designated "Point Sublime".

Saddle Mountain (SdM)
4.0 km southwest of Saddle Mountain bench mark 8424* and due east of "Boundary Ridge Fence-Grand Canyon National Park" located on east Kaibab monocline in a major amphitheater. Map location: 112°01'00W, 36°17'30"N.
Appendix B - Detailed Descriptions of Measured Sections

Note - Thin sections are listed in parenthesis, e.g., (KT 1-1). Thickness of the measured strata are listed in centimeters (cm). Sections are numbered according to the order of field descriptions e.g.; Section 1 was first to be described and Section 27 was last.

Section 1: Andrus Canyon

Kaibab Formation has been removed during the current cycle of erosion.

Section 2: Central Hurricane Cliffs - Whitmore Wash

Kaibab Formation
Harrisburg Member

Note: Above this unit lies red, sandy conglomerate, massive to thick bedded, cut-and-fill structures - c., forms massive cliff (Moenkopi Formation).

Covered: 590 cm.

Ss. yellow to tan dolomitic ss., medium bedded, moderately weathered (dull orange), quartz conglomerate and breccia - c., many cut-and-fill structures, mudcracks and ripple marks – c: 235 cm.

Covered: 68 cm.

Ss. lt. gray medium-grained calcareous ss., thick bedded, f. chert nodules (pink) at top, weathers round, highly weathered and crumbly, forms four steps: 235 cm.

Ch. pink to lt. gray chert w/ thin dolomite interbeds, medium bedded, weathers massive, slightly sandy, moderately fractured, weathers dark brown and forms resistant ledge: 182 cm.

Ls. lt. gray to tan ms. w/ f. chert nodules, medium bedded, chert nodules are pink and average 6-12 cm, slightly sandy, weathers dull yellow to red, forms series of steps: 135 cm.

Ls. pale green silty ms., thin to medium bedded, very wavy, convoluted beds, replaced (pink silica) evaporite crystals - ab., chert nodules - c., weathers medium green, vuggy, moderately weathered and slightly fractured: 85 cm.

Ls. medium gray to tan ws. w/ ab. chert nodules and lenses, thick bedded, beds are very wavy, highly fossiliferous, crinoids, molluscs, ramose and fenestrate bryozoa - c., most fossils are disarticulated and broken, chert weathers w/ iron stain to form a densely mottled surface, has subconchoidal fracture: 105 cm.

Dolo. dull yellow ws. w/ f. breccia clasts, medium to thick bedded, high-spired gastropods and molluscan debris - c., many replaced (pink chert) evaporite halite(?) crystals, forms indent: 173 cm.

Dolo. gray to lt. tan ws. w/ f. chert nodules and lenses, massive, crinoids and bivalves - c., contains one distinct layer of chert nodules and lenses, calcite and iron nodules - c., sandy texture, minor amounts of fossil-moldic porosity, replaced (silica) evaporite crystals, weathers round, forms wall w/ laminated ms. at base (KT 2-29?): 400 cm.

Covered: 405 cm.

Dolo. medium tan brecciated ms., massive to thin bedded, weathers as one massive unit, vuggy and pitted, slightly fractured, iron nodules - c., cut-and-fill structures - c., slightly sandy: 505 cm.
Dolo. dull yellow silty ms.: 35 cm

Covered: 170 cm.

Ls. lt. gray ms., massive, most fossils are silicified, gastropods and bivalves - c., slightly sandy, f. calcite and chert nodules, moderately weathered, contains one distinctive layer of iron nodules in center of unit, cut-and-fill structures - c. at top, forms wall: 330 cm.

Chert. dull orange to tan chert w/ f. ms. interbeds, medium to thin bedded, weathers medium orange, much fracture porosity, weathers to form very resistant ledge: 165 cm.

Dolo. lt. gray ms. w/ many chert nodules, thick to massive, most fossils are silicified, crinoids and molluscs(?) – f., chert nodules separate bedding and occur in four distinct layers, weathers slightly vuggy, pitted and fractured, forms massive wall: 475 cm.

Dolo. lt. gray ms. w/ ab. chert nodules, massive to thick bedded, chert is found in six layers parallel to bedding, moderately weathered, slightly fractured, highly vuggy, chert is iron stained and weathers to stand in relief: 240 cm.

Dolo. lt. brown to tan ms. w/ chert nodules, lenses and f. "cannonball" cherts, thick to medium bedded, most fossils are silicified, ramose bryozoans and crinoids - c., gastropods - f., may be slightly mudcracked in upper part of unit, gypsum nodules (at top) - f., highly weathered, vuggy and pitted, chert is iron stained and weathers to stand in relief, forms a series of jagged steps: 445 cm.

Ls. medium gray ws. w/ chert nodules, lenses, and f. "cannonball" cherts, thick to medium bedded, highly fossiliferous, large crinoids (up to 2 cm in diameter), molluscs and ramose bryozoans - c., Rugatia - f., chert is pink and white but weathers w/ iron stain to form slightly mottled surface, highly fractured, chert separates bedding, surface weathers very rough and moderately pitted: 300 cm.

Fossil Mountain Member

Ls. lt. gray ws. to ps. w/ ab. chert tracery, thick bedded to massive, highly fossiliferous, productids, ramose and fenestrate bryozoans and crinoids – c., Rugatia – f., unit weathers to produce a very distinctive dark gray, iron-stained band across outcrop, “cannonball” chert - f., chert is lt. gray when fresh, moderately fractured, forms series of steps: 375 cm.

Ls. medium gray to tan ws. w/ many chert nodules, lenses, and f. "cannonball" cherts, massive, fossils are in both chert and matrix, productids, crinoids, ramose and fenestrate bryozoans - c., chert is white to pink when fresh, many "cannonballs" are up to 10 cm in diameter, chert weathers w/ an iron stain and stands in relief, moderately fractured and slightly pitted, unit weathers dull yellow to brown, chert separates bedding, forms cliff: 595 cm.

Dolo. medium gray ms. w/ many chert lenses and "cannonball" cherts, massive, very f. fossils, moderately fractured, calcite nodules - c., "cannonballs" are white and average 15 cm in diameter, forms cliff, (KT 2-28): 345 cm.

Dolo. medium gray crinoidal ws. w/ many "cannonballs," in distinct lenses, and chert nodules, massive, crinoids (disarticulated and broken) - ab., productids, ramose and fenestrate bryozoans - c., Derbyia(?) chert has iron stain and weathers to form densely mottled surface, weathers very rough and pitted: 234 cm.

Dolo. lt. gray crinoidal ms. to ps. w/ ab. chert tracery, massive, vaguely laminated, crinoids - ab., productids and fenestrate bryozoans - c., Derbyia - f., Rugatia(?) -f., chert weathers w/ iron stain and stands in relief, moderately weathered, moderately pitted, sandy texture, forms cliff, (KT 2-27): 348 cm.

Dolo. lt. tan to gray ms. w/ ab. chert tracery, thick bedded, most fossils are disarticulated and broken, crinoids – c., vuggy and highly pitted, chert weathers w/ iron stain and stands in relief: 108 cm.
Dolo. lt. tan crinoidal ws. to ms., thick bedded, crinoids - ab., ramose bryozoa, bivalves and *Peniculauris bassi* - f., f. chert nodules (white) at base and mottled chert tracery at top, "cannonball" chert - f., highly pitted and vuggy, (KT 2-26): 132 cm.

Dolo. medium gray crinoidal ws. w/ densely mottled chert tracery, massive, crinoids - ab., fenestrate bryozoa and brachiopods – c., ramose bryozoa and *Meekella* - f., few 12-cm "cannonball" cherts at base, most chert weathers w/ iron stain and stands in relief: 113 cm.

Dolo. medium to lt. gray crinoidal ws. w/ densely mottled chert tracery, massive, crinoids (disarticulated and broken) - ab., much disarticulated and broken fauna in chert, weathers dark gray, vuggy and pitted, chert weathers to stand in relief, highly fractured, unit weather very dark gray: 127 cm.

Dolo. medium gray crinoidal ws. w/ ab. crinoids and "cannonballs," thin bedded at base and becomes massive towards top, productids and crinoids – c., solitary corals - f., chert weathers w/ very dark iron stain and causes the outcrop to have a highly weathered surface, chert stands in relief, highly fractured, vuggy and highly pitted, forms cliff, (KT 2-24): 567 cm.

Ls. medium gray fossiliferous ps. w/ many chert nodules and "cannonball" cherts, massive, fossils are disarticulated and broken and occur in both chert and matrix, productids - ab., crinoids and ramose bryozoa - c., *Composita* - f., *Rugatia* - f., chert forms densely mottled surface, unit may be slightly laminated, chert is white to pink when fresh, moderately fractured, forms distinctive highly weathered (dark gray) unit which can be traced laterally across the outcrop, (KT 2-23): 354 cm.

Ls. medium gray fossiliferous ws. to ps. w/ densely mottled chert tracery, massive, crinoids - ab., molluscs – c., fenestrate bryozoa - f., *Derbyia (?)* - r., unit is distinctively mottled and highly weathered to form dark gray cliff, (KT 2-22): 654 cm.

Ls. lt. gray to tan fossiliferous ws. w/ ab. chert tracery, massive to thick bedded, fossils are ab. in both chert and matrix, very distinctive by its dark gray weathering characteristic, crinoids, *Peniculauris bassi* and other productids, and fenestrate bryozoa - c., *Composita* - f., chert weathers w/ iron stain and stands in relief, forms cliff: 178 cm.

Ls. medium tan crinoidal ws. w/ very densely mottled chert surface, massive, crinoids and molluscs - c., *Rugatia* - f., forms basal units of distinctively weathered (very dark gray) cliff, chert weathers w/ iron stain and stands in relief: 126 cm.

Ls. gray to medium yellow to brown fossiliferous ws. to ps. w/ ab. chert nodules and lenses, massive, molluscs and crinoids – c., much chert trachyte but does not weather as darkly as upper cliff units, chert separates bedding, chert nodules are pink when freshly broken and contain no fossils, forms cliff: 208 cm.

Ls. medium gray crinoidal ws. to ps. w/ very densely mottled chert tracery surface, massive, surface weathers w/ very distinctive dark gray iron stain, crinoids - ab., *Peniculauris bassi* and ramose bryozoa - c., *Composita* - f., slight amounts of fossil-moldic porosity in matrix, f. fossils in chert, highly fractured, forms cliff, (KT 2-21): 693 cm.

Ls. lt. gray crinoidal ws. to ps. w/ very densely mottled chert tracery surface, massive, highly fossiliferous, crinoids - ab., ramose bryozoa, productids and molluscs – c., *Derbyia (?)* - f., "cannonball" chert - c. at top, chert is pink to lt. gray and weathers dark gray w/ iron stain, unit weathers to form very
prominent, densely mottled “voodoo” cliffs or pillars (aka hoodoos) and a distinctive band across outcrop, moderately fractured. (KT 2-20 and 2-19): 610 cm.

Ls. lt. gray crinoidal ps. w/ very densely mottled chert tracery surface, massive, highly fossiliferous, crinoids and productids – c., molluscs and ramose bryozoa - f., becomes unfossiliferous at base, unit weathers almost black to produce a very distinctive band across outcrop, weathers to form densely mottled “voodoo” cliffs (pillars), chert weathers w/ iron stain and stands in relief, becomes sandy at top, slightly fractured, chert lenses separate bedding, forms base of massive cliff: 680 cm.

Covered: 192 cm.

Ls. medium to lt. gray fossiliferous ws. to ps., thin bedded, ramose bryozoa - ab., Squamaria ivest(?) - c., fenestrate bryozoa - f., highly fractured, slightly cherty, (KT 2-18): 78 cm

Covered: 342 cm.

Dolo. lt. gray ms. to pelletal ws. to ps. w/ ab. chert lenses, nodules and f. thin chert interbeds, thick to thin bedded, vaguely laminated, ramose bryozoa - c., productids - f., most fossils are disarticulated and broken, centimeter-size cut-and-fill structures - c., forms series of steps: 260 cm.

Total thickness, Fossil Mountain Member: 7615 cm.

Total thickness, Kaibab Formation: 12893 cm.

Section 3: Whitmore Point

Kaibab Formation

Harrisburg Member

Ss. dull orange to brown dolomitic ss. w/ ab. chert nodules (2 cm), medium bedded, upper beds contain cut-and-fill structures, crinoids - f., conical-shaped scaphopods - r., highly weathered and pitted, calcite veins - f., (K 2-14, 13a and 13): 177 cm.

Covered: 198 cm.

Cht. brown to tan chert, thin bedded, dark brown iron stain coats surface, mudcracks - c., weathers massive, forms upper rim of plateau, (K 2-12): 205 cm.

Dolo. lt. gray to tan ms. w/ many chert nodules, medium bedded, mudcracks filled w/ calcite(?), chert nodules are iron stained and weather to stand in relief, moderately weathered and pitted, forms prominent recess: 175 cm.

Dolo. tan to lt. gray ms. w/ ab. chert tracery, thick bedded, chert tracery weathers medium brown and forms highly irregular oblong nodules, highly resistant, highly weathered, slightly pitted, chert is iron stained and weathers to stand in relief: 115 cm.

Dolo. lt. tan ms. w/ wavy chert beds, thinly bedded but weathers as one massive unit, moderately weathered: 155 cm.

Dolo. lt. tan ms. w/ many chert lenses at base of unit, massive, fossils are c. in upper part of unit, gastropods and brachiopods - c., mudcracks – c., many calcite veins especially in mudcracks, weathers dark brown, highly pitted moderately porous, vuggy, chert nodules separate bedding and form three distinctive layers at base of unit, forms cliff: 795 cm.

Dolo. yellow to brown ms., thin bedded, forms recess below massive beds, may have few desiccation cracks: 55 cm.

Covered: 175 cm.
Dolo. lt. gray to tan ms. w/ f. chert nodules at base, laminated, intraclasts - c. (up to 13 cm), contorted (algal?) laminations, mudcracks - c., weathers to form three beds: 170 cm.

Covered: 95 cm.

Dolo. medium tan ms. w/ f. chert lenses and nodules, massive, mudcracks - c. (filled w/ calcite cement), small iron and calcite nodules - c., moderately weathered and pitted, highly brecciated (2 cm clasts) toward top, most chert nodules are iron stained and weather to stand in relief, vuggy porosity, middle part of unit contains ab. chert nodules and weathers to form indent: 725 cm.

Dolo. dull tan to yellow ms., laminated but weathers massive, weathers pink to red and forms prominent marker bed across cliffs, most laminations are wavy, highly weathered, forms indent: 115 cm.

Covered: 130 cm.

Dolo. medium gray to lt. tan ms., massive to thick bedded, f. iron and calcite nodules at top, weathers dull yellow and blocky, breccia - c., mudcracks - c., forms cliff: 300 cm.

Dolo. lt. tan to beige ms. w/ laminated chert bed at top, medium bedded, highly fractured, forms resistant ledge, chert nodules and lenses separate bedding: 150 cm.

Dolo. lt. tan to medium gray ms. w/ many chert nodules and lenses, thick bedded to massive, chert separates bedding and weathers w/ iron stain, weathers dull yellow to brown, slightly pitted and vuggy: 210 cm.

Dolo. lt. tan to dull yellow ms. w/ ab. chert nodules and lenses, medium bedded, highly pitted and moderately weathered, forms cliff, chert weathers w/ iron stain and stands in relief: 110 cm.

Dolo. lt. gray ms. w/ many chert nodules and lenses, massive, chert and calcite nodules – c., chert separates bedding, moderately weathered and pitted: 120 cm.

Dolo. medium tan to brown ms. w/ f. chert nodules, massive, base of unit has layer of iron-stained chert nodules, weathers to form cliff: 165 cm.

Dolo. lt. gray ms. w/ many chert lenses, massive, f. horizontal stylolites, moderately weathered and pitted, weathers to form two massive units: 205 cm.

Dolo. medium tan ms. w/ very densely mottled chert tracery, thick bedded, many horizontal stylolites, calcite nodules - c., highly pitted and rough: 85 cm.

Total thickness, Harrisburg Member: 4630 cm.

Fossil Mountain Member

Dolo. lt. gray ws. w/ ab. chert nodules and lenses, thick bedded, chert forms very distinct iron-stained bands, pitted, weathers rough: 50 cm.

Dolo. medium gray to tan ms. w/ ab. chert tracery, massive, chert weathers dark brown and forms very distinctive band across outcrop, highly resistant, vuggy, pitted, forms cliff: 500 cm.

Dolo. medium gray ws. to ms. w/ many "cannonball" cherts and chert nodules, massive, crinoids, ramose bryozoa and productids - c., fenestrate bryozoa - f., many "cannonballs" have concentric banding, forms large indent below densely mottled chert zone, (KT 3-33): 155 cm.

Dolo. medium gray ws. w/ mottled chert tracery, massive, most fossils are disarticulated and broken, crinoids, fenestrate and other bryozoa - c., much fauna in chert, highly weathered and pitted, forms cliff: 410 cm.
Dolo. medium gray ms. to ws. w/ densely mottled chert tracery, massive, ramose and fenestrate bryozoa, crinoids and molluscan debris - c., *Peniculauris bassi* - f., *Composita (?)* - r., the centers of some chert nodules contain spongelleike structures, (KT 3-32): 195 cm.

Dolo. medium gray ms. w/ chert tracery and f. "cannonball" cherts, massive, chert weathers white, highly vuggy, many chert nodules weather to stand in relief: 325 cm.

Dolo. dark brown ms. w/ ab. chert tracery, thick bedded, highly weathered and pitted, weathers to form lip: 75 cm.

Dolo. lt. gray ms. w/ ab. "cannonball" cherts and chert nodules, massive, fenestrate and ramose bryozoa (especially in "cannonball" cherts), productids and crinoids - f., the interiors of some "cannonballs" have sponge-like structures and others are concentrically banded, weathers orange to yellow, forms recess, (KT 3-31): 385 cm.

Dolo. lt. gray ws. to ms. w/ two thick chert bands, massive, *Peniculauris bassi*, *Composita* and crinoids - c., highly weathered and pitted, forms distinctive unit due to having two individual layers of chert, highly resistant and forms lip, (KT 3-30): 175 cm.

Dolo. lt. gray ps. to ms. w/ ab. "cannonball" chert and chert lenses, may be laminated but weathers as massive beds, molluscs, ramose and fenestrate bryozoa - c., some "cannonballs" have sponge-like centers, f. "cannonballs" reach 10 cm in diameter, chert clasts - f., weathers to form recess, (KT 3-29): 650 cm.

Dolo. lt. gray ws. w/ many chert lenses and chert nodules, massive, chert is pink, calcite nodules – c., forms recess: 290 cm.

Dolo. lt. gray ws. to ms. w/ ab. chert nodules and lenses, massive, most fossils are disarticulated and broken, *Peniculauris bassi*, other productids, and fenestrate bryozoa - c., highly weathered and pitted, chert weathers w/ iron stain and stands in relief, (KT 3-28): 265 cm.

Dolo. lt. to medium tan ws. w/ many chert nodules and densely mottled chert tracery, massive, *Peniculauris bassi*, molluscan debris, fenestrate bryozoa and crinoids - c., highly weathered and pitted cliff forming: 435 cm.

Dolo. lt. tan ms. w/ densely mottled chert tracery surface, massive to thick bedded, productids, ramose and fenestrate bryozoa - c., chert occurs in bands: 220 cm.

Dolo. medium gray ws. to brecciated ws. w/ many chert nodules and f. "cannonball" cherts, massive, *Derbyia* and other productids, fenestrate bryozoa and crinoids – c., ramose bryozoa - f., chert nodules reach 6 cm and are white and pink, matrix weathers yellow, may be moderately sandy, f. chert nodules are iron stained and weather to stand in relief, (KT 3-27): 465 cm.

Dolo. lt. tan ms. w/ f. "cannonball" cherts, massive to thick bedded, molluscan debris, productids, bivalves – c., ramose bryozoa – f., "cannonballs" av. 4 cm., calcite nodules – c., very slightly pitted, forms cliff: 390 cm.

Ss. dark red highly brecciated ss., massive, brown to yellow crumbly ss. at top, clasts average 3 cm and are bronze-colored chert, (KT 3-26): 98 cm.

Dolo. lt. gray to tan ms. w/ many chert lenses and very densely mottled chert tracery, massive, abundance of productids increases toward top, productids - c. crinoids, brachiopods and *Rugatia* - f., *Composita* and *Derbyia (?)*, may be slightly brecciated at top, highly weathered and pitted, chert weathers to stand in relief, forms cliff, (KT 3-25): 540 cm.

Dolo. medium gray ws. to ms. w/ much chert tracery and nodular chert, massive, weathers very rough and pitted, forms cliff (KT 3-24): 970 cm.

Dolo. lt. gray brecciated ms., massive, breccia clasts (chert) reach 6 cm in diameter, densely mottled chert surface, forms massive cliff, (KT 3-23): 780 cm.
Dolo. lt. to medium gray ms. to ws. w/ ab. chert nodules, massive, many productid spines and other fossil debris in chert nodules, brachiopods and ramose bryozoan - c., chert occurs mainly in parallel bands and separates bedding, chert is iron stained and stands in relief, matrix has much moldic porosity, calcite nodules - f., slightly pitted and weathered to produce very rough surface, forms massive vertical wall, (KT 3-22 and KT 3-21): 1145 cm.

Dolo. red to yellow and brown brecciated ss. to ms., thick bedded, becomes more quartz-rich toward top, forms indent below massive cliffs: 96 cm.

Total thickness, Fossil Mountain Member: 8614 cm.

Total thickness, Kaibab Formation: 13244 cm.

Section 4: Iverson Ranch

Kaibab Formation
Fossil Mountain Member

Ls. medium gray crinoidal ms., thick bedded, crinoids - ab., much fauna in chert nodules, moderately fractured, chert nodules are weathered w/ an iron stain and stand in relief, (KT 4-26): 190 cm.

Ls. medium gray crinoidal ws. to ps., massive, crinoids - ab., Rugatia - f., highly fractured, bronze-colored chert tracery mottled surface and forms two distinct bands which weather to stand in relief, (KT 4-25): 115 cm.

Ls. medium gray crinoidal ws., thick bedded, contains f. vaguely laminated interbeds, crinoids - ab., productids and ramose bryozoan - c., moderately fractured, chert nodules - c., (KT 4-24): 175 cm.

Ls. medium gray crinoidal ps., medium to thin bedded, wavy beds, crinoids - ab., Peniculauris bassi - c., many small unidentifiable brachiopods, chert nodules are very c. and separate bedding: 96 cm.

Ls. medium gray ps., massive, vaguely laminated, ramose bryozoan - ab., fenestrate bryozoan, bryozoan (general), crinoids, productids (general) and Peniculauris bassi - c., bivalves - f., most fossils are broken and unoriented, chert nodules separate bedding planes, some chert forms mottled lenses, chert is slightly weathered: 410 cm.

Covered: 50 cm.

Ls. medium gray crinoidal ps., thick bedded, crinoids - ab., ramose bryozoan and productids - c., Peniculauris bassi - f., fauna is both in chert and matrix, moderately weathered, chert weathers bronze: 145 cm.

Ls. medium to lt. gray crinoidal ws. to ps., massive, crinoids - ab., fenestrate bryozoan, and small brachiopods, Rugatia and Peniculauris bassi - f., forms cliff, (KT 4-23): 193 cm.

Ls. medium gray crinoidal ws. w/ "cannonball" chert up to 12 cm., massive, may be laminated in minor zones, crinoids - ab., productids, ramose and fenestrate bryozoan, brachiopods and Peniculauris bassi - c., Rugatia(!?) - r., some spongelike structures in centers of "cannonballs", both chert and matrix contain much fauna, chert weathers lt. bronze: 290 cm.

Ls. medium gray ps. to ws. w/ f. "cannonball" cherts, massive, productids and ramose bryozoan - c., most fauna is confined to chert nodules, moderately weathered and slightly fractured: 655 cm.

Ls. medium gray crinoidal ws., massive, crinoids - ab., productids, Peniculauris bassi and ramose bryozoan – c., horizontal stylolites - f., vaguely laminated, very cherty but not densely mottled, (KT 4-22): 273 cm.

Ls. lt. to medium gray ps. w/ ab. chert tracery, massive, ramose bryozoan - c., fenestrate bryozoan - f., chert forms very dense chert tracery, weathers bronze and stands in relief: 510 cm.
Ls. medium gray crinoidal ws. to ps., massive, crinoids and ramose bryozoa - c., slightly weathered, densely mottled bronze chert tracery weathers to stand in relief, (KT 4-21): 225 cm.

Ls. lt. gray crinoidal ws. to ps., massive, crinoids - ab., *Meekella, Peniculauris bassi* and other productids - c., fenestrate bryozoa - f., forms cliff, chert is ab. and weathers to stand in relief: 280 cm.

Ls. medium gray crinoidal ps. w/ ab. chert nodules, thin to medium bedded, beds are wavy, crinoids - ab., ramose bryozoa – c., *Composita, Peniculauris bassi, Meekella, Euphemites* – f., small, low-spired gastropods - r., highly fractured and moderately weathered, (KT 4-20): 158 cm.

Covered: 610 cm.

Ls. medium gray fossiliferous ps. w/ ab. chert nodules, thick to medium bedded, highly fossiliferous, crinoids, small brachiopods, *Composita* and *Peniculauris bassi* – ab., fossils are in both chert and matrix, moderately fractured and weathered, forms gentle slope, partially covered: 395 cm.

Ls. lt. to medium gray fossiliferous ws. w/ ab. chert nodules, massive, ramose and fenestrate bryozoa, crinoids, *Peniculauris bassi* and other productids - c., highly weathered (dark brown) and slightly pitted, chert weathers to stand in relief: 375 cm.

Ls. medium gray fossiliferous ws. to ps. w/ ab. chert nodules, massive, ramose bryozoa, small brachiopods and crinoids – c., *Peniculauris bassi* – f., *Composita(?)* -f., forms cliff, chert separates bedding planes, weathers lt. gray, (KT 4-19): 580 cm.

Ls. medium gray fossiliferous ps. to ws. w/ ab. chert nodules, massive, productids - ab., ramose bryozoa and crinoids - c., *Composita(?)* – f., chert weathers lt. gray and contains most of the fauna within the unit, very slightly pitted, forms cliff: 440 cm.

Ls. medium gray to tan ps. w/ ab. chert nodules, massive, brachiopods, productids - ab., ramose bryozoa - f., forms cliff at base of Fossil Mountain Member, horizontal stylolites - f., (KT 4-18): 375 cm.

Ls. medium gray fossiliferous ps. w/ densely mottled chert tracery, thick bedded, crinoids - ab., brachiopods and *Peniculauris bassi* - c., moderately weathered, chert weathers to stand in relief, (KT 4-17): 62 cm.

Ls. medium gray fossiliferous ps., thick to medium bedded, highly fossiliferous, ramose and fenestrate bryozoa, small brachiopods, crinoids, *Peniculauris bassi, Composita* and *Euphemos* - ~c., fossils are in both chert and matrix, highly fractured, chert separates bedding and weathers white, (KT 4-16): 375 cm.

Ls. medium gray fossiliferous ws. to ps., massive, ramose bryozoa, crinoids, brachiopods - c., productids and *Composita* - f., much fauna in chert, slightly weathered and forms blocky unit, many chert nodules up to 4 cm in diameter (weather lt. gray), horizontal stylolites - f., (KT 4-15): 105 cm.

Covered: 145.

Total thickness, Fossil Mountain Member: 7227 cm

Total thickness (partial section), Kaibab Formation: 7227 cm.

**Section 5: Paradise Valley (Toroweap)**

Kaibab Formation
Harrisburg Member

Dolo. medium tan to dull orange, silty ws. to ms., massive, unit contains much fossil debris, crinoids - c., highly pitted and vuggy, weathers round, copper-colored nodules - c., many nodules are iron stained, calcite nodules - f., (KT 5-22): 225 cm.

Gyp. white gypstone, massive, no visible laminations, partially covered, forms slope: 880 cm.
Dolo. dark gray to black fossiliferous ms. to ws., thick bedded, bivalves and ramose bryozoa - c., vertical burrows - f., slightly pitted, dense, hackly fractured, (KT 5-21): 105 cm.

Dolo. tan ms., massive to medium bedded, slight amounts of moldic porosity, slightly pitted: 162 cm.

Gyp. white gypstone, massive, well exposed, upper portion is iron stained, forms slope: 720 cm.

Gyp. white gypstone, thick bedded to massive, forms resistant beds, (KT 5-20): 80 cm.

Gyp. white and lt. gray gypstone, massive, well exposed, forms slope: 575 cm.

Dolo. medium gray pelletal ws., thin bedded, (KT 5-19): 20 cm.

Covered: 142 cm.

Dolo. medium tan ms., thick bedded (vaguely laminated), slightly pitted and vuggy, f. small chert nodules at base, one distinctive chert band at top (weathers bronze and is up to 25 cm in diameter): 98 cm.

Gyp. white to lt. gray gypstone, partially covered, forms slope: 720 cm.

Gyp. white to gray gypstone, massive, mostly covered in upper one half of unit and partially covered in lower one half, forms slope: 295 cm

Dolo. medium tan to dull orange ms., weathers to form thick beds but is laminated, crinoids and bivalves - c., slightly cherty in upper part, pitted and vuggy, mudcracks(?) - f., (KT 5-18): 187 cm.

Dolo. medium tan fossiliferous ws., thin to medium bedded, productids, ramose bryozoa, crinoids, and scaphopods - c., *Peniculauris bassi* - f., moderately fractured and pitted: 173 cm.

Ls. medium tan ws., massive, crinoids - c., weathers blocky and slightly pitted: 210 cm.

Ls. medium gray fossiliferous ws. w/ f. chert nodules, thin to medium bedded, moderately fractured and slightly pitted, forms cliff: 280 cm.

Ls. medium gray fossiliferous ps. to ws. w/ many chert lenses and f. nodules, thick bedded, crinoids, ramose bryozoa, and productids (general) - c., *Meekella* and *Composita* - f., moderately fractured, 4 cm horizontal stylolites in upper one third, (KT 5-17): 465 cm.

Total thickness, Harrisburg Member: 5337 cm.

Fossil Mountain Member

Ls. lt. gray fossiliferous ws. w/ dense chert tracery, massive, ramose bryozoa, crinoids and productids - c., fenestrate bryozoa and *Composita* - f., weathers to form very distinctive band across canyon, moderately weathered, chert weathers to stand in relief: 260 cm.

Ls. medium gray ps. to ws. w/ many "cannonballs," massive, crinoids - ab., fenestrate and ramose bryozoa, *Peniculauris bassi*, productids (general) and small bivalves - c., *Meekella* - f., most fauna is in "cannonballs" that are up to 20 cm in diameter, (KT 5-16): 340 cm.

Ls. medium gray crinoidal ws. w/ ab. "cannonballs," massive, crinoids, ramose and bryozoa (general) - c., fenestrate bryozoa - f., corals(?) - r., centers of "cannonballs" have sponge-like structures, "cannonballs" - up to 20 cm in diameter, slightly fractured, very slightly pitted: 430 cm.

Ls. medium gray to tan ps., massive, productids (general), *Peniculauris bassi*, ramose and fenestrate bryozoa, *Meekella* and crinoids – c., corals(?) and *Composita* - f., moderately fractured, forms cliff: 360 cm.

Ls. medium gray fossiliferous ps. w/ many "cannonballs," massive, crinoids, bivalves (general), productids (general), *Peniculauris bassi* and ramose bryozoa – c., *Meekella* - f., most fossils are in chert, some chert nodules up to 10 cm, moderately fractured, forms base of cliff, (KT 5-15): 560 cm.
Ls. medium gray ws. to ps., thick bedded to massive, *Peniculauris bassi*, productids (general) and *Derbyia* - c., slightly pitted, chert weathers to stand in relief (bronze to black), very densely mottled and highly weathered, forms large amphitheater: 425 cm.

Ls. medium gray ps. to ws., massive, highly fossiliferous, bryozoa (general), ramose bryozoa, *Derbyia*, productids (general), bivalves (general) and spines - c., *Peniculauris bassi* - f., most fossils are disarticulated and broken, weathers black - very distinctive, very densely mottled chert tracery surface, "cannonball"-type structures weather out to form large (6 cm) vugs, (KT 5-14): 415 cm.

Ls. medium gray ws., massive, crinoids, productids (disarticulated and broken) and bryozoa (general) - c., *Composita*, ramose bryozoa and *Peniculauris bassi* - f., dark gray to black mottled chert tracery, very distinctive horizontal stylolites (6 cm) at top and base: 205 cm.

Ls. medium gray fossiliferous ps. and gs.(?), massive, brachiopods - ab., crinoids - c., most fossils are broken, moderately weathered, horizontal stylolite (4 cm) at top, (KT 5-13): 310 cm.

Ls. medium gray crinoidal ps. to gs. w/ many chert lenses, massive, crinoids - ab., productids - c., *Peniculauris bassi*(?) and "cannonballs"(?) - f., chert nodules up to 6 cm., slightly fractured, horizontal stylolites - f., becomes gs. at top, (KT 5-12): 430 cm.

Ls. medium gray fossiliferous ps. w/ many chert nodules, massive, crinoids and productids – c., ramose bryozoa - f., moderately weathered: 110 cm.

Ls. very dark brown fossiliferous ps. w/ ab. chert tracery, massive, ramose bryozoa - c., medium gray when fresh (chert - white): 188 cm.

Ls. medium gray fossiliferous ps., massive to thick bedded, ramose bryozoa - c., crinoids, fenestrate bryozoa and brachiopods - f., spines(?) -r., most fossils are broken, f. sponge-like structures in center of chert, slightly vuggy and pitted, calcite nodules - c., f. chert nodules stand in relief: 645 cm.

Ls. medium gray ps. to ws., massive, crinoids ab., ramose bryozoa and *Peniculauris bassi* - f., most fossils are small, chert weathers medium brown and stands in relief, forms slope: 154 cm.

Ls. lt. gray cherty ps., massive, bivalves (general), brachiopods, and productids - c., crinoids and *Chonetes* - f., most fossils are in chert: 185 cm.

Ls. lt. gray fossiliferous ps., medium bedded, crinoids, *Peniculauris bassi*, brachiopods, productids and ramose bryozoa - c., most fossils are broken and abraded, many chert nodules, slightly fractured: 173 cm.

Ls. medium gray fossiliferous ps., massive, faint laminations, brachiopods - c., much fauna in chert and matrix: 145 cm.

Ls. medium gray ps. w/ ab. chert nodules, thick bedded: 58 cm.

Ls. lt. gray ws. w/ f. chert nodules, massive, vaguely laminated, ramose bryozoa, productids and brachiopods - c., *Peniculauris bassi*(?) - f., forms base of cliff: 160 cm.

Ls. medium brown to dull orange ps. to ws. w/ f. chert nodules, medium bedded, productids and ramose bryozoa - f., much shell debris in chert nodules, vuggy and moldic porosity -c., weathers to form smooth indent (KT 5-11): 255 cm.

Ls. lt. gray crinoidal ws., massive, ramose bryozoa - f., weathers blocky, moderately fractured: 104 cm.

Total thickness, Fossil Mountain Member: 5912 cm.

Total thickness, Kaibab Formation: 11249 cm.

**Section 6: Hack Canyon**

Kaibab Formation (partial section)
Fossil Mountain Member (partial section)

Ls. medium gray crinoidal ps. to ws. w/ f. chert nodules and "cannonball" cherts, thick bedded to massive, crinoids ab., ramose and fenestrate bryozoa, Composita, Meekella, and Peniculauris bassi - c., "cannonball" cherts average 15 x 10 cm and weather white (gray when fresh), chert is iron stained, (KT 6-20): 120 cm.

Ls. medium gray crinoidal ws. to ps. w/ many chert nodules, medium bedded, crinoids - ab., ramose and fenestrate bryozoa, productids, and Derbyia - c., Peniculauris bassi - f., chert weathers white and has high concentrations of fossil-moldic porosity, moderately fractured, slightly pitted, forms slope, (KT 6-19): 345 cm.

Ls. medium gray fossiliferous ws. w/ f. chert nodules, thin bedded, fenestrate and ramose bryozoa, productids, and crinoids - c., Peniculauris bassi, Derbyia, and Composita - f., moderately fractured, moderate amounts of fossil-moldic porosity in chert: 125 cm.

Ls. medium gray crinoidal ps. w/ f. chert nodules, mostly covered slope: 120 cm.

Ls. medium to lt. gray crinoidal ps. w/ many chert nodules, medium bedded, crinoids - ab., fenestrate bryozoa - c., most fossils are broken, chert weathers lt. gray to white, moderately fractured and slightly pitted, forms partially covered gentle slope: 510 cm.

Ls. medium to lt. gray crinoidal ps. w/ many chert nodules, massive, highly fossiliferous, crinoids, ramose bryozoa, brachiopods, and Composita - c., Squamaria ivest(?)- f., moderately fractured, wavy bedding, vaguely laminated, slightly pitted, f. large "cannonball" cherts at top, moderate amounts of fossil(?)- moldic porosity in chert, (KT 6-18): 225 cm.

Ls. Is. medium gray fossiliferous, cherty ps. to ws., massive, contains much broken fossil debris, Meekella, bivalves, crinoids, and ramose bryozoa - c., fenestrate bryozoa - f., Composita - r., "cannonball" chert is distinctively ab. and occurs in five discrete bands, unit weathers lt. gray, "cannonball" cherts weather to stand in relief and are iron stained, many contain sponge-like structures and small bivalves, forms gently sloping cliff, (KT 6-17): 234 cm.

Ls. medium gray fossiliferous ws. w/ ab. chert nodules, massive, contains much broken fossil debris, Derbyia, and ramose bryozoa - c., slightly pitted, chert is iron stained and weathers to stand in relief, surface is densely mottled w/ chert: 295 cm.

Ls. medium gray fossiliferous ws. w/ ab. chert nodules and lenses, massive crinoids, ramose bryozoa, productids, and Peniculauris bassi - c., weathers dark gray, moderately pitted, chert tracery mottles the surface, forms cliff, has two (5 cm) marker beds at top and base which are green silty ms. (both form indent and appear to be continuous across outcrop): 142 cm.

Ls. medium gray fossiliferous ws. w/ ab. chert nodules and lenses, massive small bivalves, crinoids, ramose bryozoa, productids, Peniculauris bassi - c., slightly fractured and pitted, forms cliff, slight amounts of moldic porosity: 265 cm.

Ls. medium gray fossiliferous ps. w/ ab. chert nodules, massive, much fossil debris, Peniculauris bassi, small productids and ramose bryozoa - c., most fauna is in chert, weathers medium to dark gray, moderately weathered and fractured, some beds are wavy and highly fractured, forms gentle cliff w/ distinctive indent at base: 780 cm.

Ls. medium gray fossiliferous ps. w/ many chert nodules, massive, crinoids - ab., fenestrate and ramose bryozoa, Peniculauris bassi and other productids - c., Derbyia and Composita - f., most fossils are disarticulated and broken, much fauna in chert, moderately fractured, weathers medium gray, f. chert nodules have sponge-like centers, horizontal stylolites at base, forms cliff, (KT 6-16): 520 cm.
Ls. medium gray ws. w/ ab. chert nodules, massive, fenestrate and ramose bryozoans, crinoids, productids and brachiopods - c., *Derbyia* (?)- f., weathers dark gray, moderately fractured, chert weathers lt. gray to white and contains many fossil fragments, forms cliff: 470 cm.

Ls. medium gray ws. w/ ab. chert nodules, massive, crinoids, *Composita* and ramose bryozoans - c., chert weathers to stand in relief: 157 cm.

Ls. medium gray to tan fossiliferous ws. w/ ab. chert nodules, massive to thick bedded, brachiopods - ab., crinoids, *Composita* and ramose bryozoans - c., much fauna in both chert and matrix, weathers dark gray and rough, (KT 6-15): 250 cm.

Ls. medium gray fossiliferous ps. w/ ab. chert nodules, massive, crinoids - ab., ramose bryozoans and productids - c., *Derbyia* (?)- f., forms cliff: 270 cm.

Ls. medium- to lt.-gray fossiliferous ws. w/ ab. chert nodules, thick bedded, ramose bryozoans - ab., bivalves, crinoids, productids and *Peniculauris bassi* - c., *Meekella* - f., chert nodules weather white to lt. gray, weathers to form partially covered talus slope: 522 cm.

Ls. medium gray crinoidal and productid ws. w/ ab. chert nodules, thick bedded, crinoids - ab., productids and *Peniculauris bassi* - c., most crinoids are disarticulated, slightly fractured, (KT 6-14): 323 cm.

Ls. lt. gray cherty ms. w/ ab. chert nodules, thin to medium bedded, fossil debris - c., weathers to form a slope, moderately fractured: 108 cm.

Ls. medium gray ws., thick bedded, much broken and abraded fossil debris, ramose bryozoan – f: 40 cm.

Covered: 230 cm.

Total thickness (partial section), Fossil Mountain Member: 6051 cm.

Total thickness (partial section), Kaibab Formation: 6051 cm.

**Section 7: Nail Canyon**

Kaibab Formation (partial section)

Harrisburg Member (partial section)

Dolo. lt. gray crinoidal ws. to ps., thick bedded, contains much fossil debris, crinoids - ab., brachiopods - c., f. calcite nodules, weathers dark gray and blocky, moderately fractured at base, f. chert nodules at base, (KT 7-14): 150 cm.

Covered: 150 cm.

Total thickness (partial section), Harrisburg Member: 300 cm.

Fossil Mountain Member

Dolo. medium gray crinoidal ws., thick bedded, much broken fossil debris, crinoids - ab., *Composita* - f., weathers blocky, chert - c. and weathers to stand in relief: 90 cm.

Dolo. medium gray crinoidal ws., thick bedded, much broken fossil debris, crinoids - ab., *Composita* - f., weathers blocky, chert is dispersed throughout unit and weathers to stand in relief: 84 cm.

Dolo. medium gray cherty ws., thick bedded, crinoids and *Composita* - c., much fossil debris in chert nodules, (KT 7-13): 105 cm.

Covered: 245 cm.

Dolo. medium gray ws. w/ f. 'cannonball" and chert nodules, thick bedded, *Derbyia*, ramose and fenestrate bryozoa - c., weathers dark gray and vuggy: 70 cm.
Dolo. medium gray ws. w/ ab. chert nodules, thick bedded, highly fossiliferous, ramose and fenestrate bryozoa and productids - c., *Acanthopecton* - f., chert is white when fresh and contains much faunal debris, moderate amounts of moldic porosity, forms slope: 172 cm.

Dolo. medium gray ws., thick bedded, fenestrate bryozoa - c., crinoids - f., moderately pitted, weathers dark gray, chert nodules - f.: 68 cm.

Dolo. medium gray ws., thick bedded, *Peniculauris bassi*, *Meekella* and crinoids - c., weathers medium tan, chert is white when fresh: 35 cm.

Dolo. medium gray ws., massive, crinoids, fenestrate and ramose bryozoa, *Peniculauris bassi* and *Meekella* - c., "cannonball" chert - f., weathers medium tan, chert is white when fresh: 104 cm.

Dolo. medium gray ws. w/ ab. chert nodules and lenses, massive to thick bedded, crinoids and ramose and fenestrate bryozoa - c., *Peniculauris bassi* - f., "cannonballs" up to 12 cm in diameter, weathers dark gray, slightly pitted: 125 cm.

Dolo. medium gray fossiliferous ws. w/ ab. chert nodules, lenses and "cannonballs," massive, productids (general), ramose bryozoa and crinoids - c., chert is white when fresh and weathers dark gray: 170 cm.

Dolo. medium to lt. gray crinoidal ws. and ps. w/ ab. "cannonballs" and chert lenses, massive, crinoids - ab., ramose and fenestrate bryozoa, bivalves and productids (general) - c., *Meekella* - f., solitary corals - r., many "cannonballs" contain sponge-like structures, "cannonballs" up to 20 cm in diameter, weathers dark gray, much fossil-moldic porosity in "cannonballs," has few wispy laminations, slightly fractured, forms cliff: 540 cm.

Covered: 2030 cm.

Dolo. medium gray fossiliferous ws., thin to medium bedded, *Peniculauris bassi*, productids (general), ramose bryozoa, *Composita*, bivalves and crinoids - c., highly fractured, forms gentle slope, (KT 7-12): 120 cm.

Cherty, Ls.- covered slope: 1690 cm.

Dolo. lt. tan sandy ms., thick bedded, productids (general)(?) - f., weathers medium gray, round and smooth, forms top of major cliff: 155 cm.

Dolo. medium to lt. gray sandy ws., massive, weathers dark gray and smooth, forms massive cliff: 210 cm.

Ls. medium gray to tan fossiliferous silty ms. to ps., thin bedded, crinoids and ramose bryozoa - c., most fossils are broken, bedding planes are wavy, center of unit is composed of two thick beds, moderately fractured, (KT 7-11): 167 cm.

Ls. dull yellow ms. to ws., massive at top and thin bedded at base, much fossil (bivalve) moldic porosity, lower beds form indent: 178 cm.

Ls. medium tan silty ws. to ms. w/ ab. chert nodules, weathers massive but may be laminated, intraclasts - c., slightly sandy, chert weathers lt. gray, moderately fractured, (KT 7-10): 240 cm.

Dolo. medium gray silty ws. to ms., massive, f. fossil fragments, calcite nodules - c., chert nodules - f. and weather to stand in relief (nodules up to 7 cm), most chert nodules contain iron-stained fragments (0.1 cm), forms blocky ledge, (KT 7-9): 106 cm.

Total thickness, Fossil Mountain Member: 6704 cm.

Total thickness, Kaibab Formation: 7004 cm.

**Section 8: Navajo Trail**
Kaibab Formation (partial section)
Fossil Mountain Member

Ls. lt. tan crinoidal ws. w/ ab. chert tracery, massive, crinoids - ab., productids, *Peniculauris bassi* and ramose bryozoa - c., chert is white when fresh and becomes iron-stained on weathered surfaces, dark densely mottled tracery when weathered, unit is distinctive by forming an iron-stained band across cliffs, weathers rough, low amounts of fossil-moldic porosity in chert, forms top of cliff, (KT 8-15): 410 cm.

Ls. lt. gray fossiliferous cherty ps. to ws. w/ many chert nodules, massive, large ramose bryozoa - ab., crinoids, fenestrate bryozoa, bivalves, productids and *Peniculauris bassi* - c., weathers medium gray, moderately fractured, stylolites separate bedding, moderately weathered and pitted, chert is iron stained, much fossil-moldic porosity in chert nodules, forms cliff, (KT 8-14): 340 cm.

Ls. lt. gray crinoidal ps. to ws. w/ many chert nodules, massive, highly fossiliferous, large ramose bryozoa - ab., crinoids (average 2 cm), bryozoa (general), productids, *Peniculauris bassi*, fenestrate bryozoa and bivalves - c., *Derbyia* - f., and large *Meekella* - r., bedding planes are vaguely defined, chert weathers medium tan and is highly weathered and pitted, many horizontal stylolites separate bedding, forms massive cliff: 560 cm.

Ls. lt. gray fossiliferous ps. to ws., massive, crinoids, productids, ramose and fenestrate bryozoa and *Peniculauris bassi* - c., solitary corals - f., moderately weathered, high amounts of moldic porosity in chert, vertical calcite veins - f., f. chert nodules are iron-stained, surface weathers slightly pitted, horizontal stylolites separate bedding, forms cliff: 240 cm.

Ls. medium gray fossiliferous ws. to ps., massive to thick bedded, much broken fossil debris, *Composita*, *Derbyia* and *Meekella* - c., forms very distinctive unit by having a very densely mottled chert tracery surface which is observable across the cliffs, unit is highly weathered and iron-stained, forms cliff: 470 cm.

Ls. medium gray fossiliferous ps. w/ many chert nodules, massive, *Derbyia*, fenestrate and ramose bryozoa, and bivalves - c., *Meekella* - f., *Squamaria ivest* (?) - r., slightly weathered and pitted, forms cliff: 520 cm.

Ls. medium gray fossiliferous ws. w/ ab. chert nodules, massive, *Derbyia* - c., fossils are aligned parallel to bedding in distinctive zones, moderate amounts of fossil-moldic porosity in both chert and matrix, chert weathers white to lt. gray and brown, moderately fractured, forms base of massive cliff: 315 cm.

Ls. medium gray fossiliferous ws., mostly covered, forms slope: 720 cm.

Ls. medium gray fossiliferous ws. w/ ab. chert nodules, medium to thick bedded, ramose bryozoa and crinoids - c., *Derbyia* (?) - r., highly weathered (dark brown) w/ mottled chert tracery surface, bedding is vaguely defined, forms upper beds of cliff: 245 cm.

Ls. medium gray fossiliferous ws. w/ ab. chert nodules, thick bedded to massive, ramose bryozoa and crinoids - c., slightly fractured, forms cliff: 175 cm.

Ls. medium gray ws., massive, ramose bryozoa - c., chert weathers to stand in relief and is iron stained, moderately weathered and pitted, cliff forming, (KT 8-12): 245 cm.
Ls. medium gray fossiliferous ws. w/ ab. chert nodules and dark gray tracery surface, massive, skeletal debris is disarticulated and broken, ramose bryozoa - c., productids - f., partially dissolved calcite nodules - c., weathers to form dark band across outcrop: 135 cm.

Ls. medium gray fossiliferous ws. to ps., massive, crinoids - ab., ramose bryozoa and productids - c., most fossils are disarticulated and broken, moderately 255 fractured, chert nodules - ab., weathers medium tan, large horizontal stylolites at base of unit, forms cliff: 310 cm.

Ls. medium gray fossiliferous ps. w/ many chert nodules, massive, many broken molluscan fossils, slightly fractured, horizontal stylolites - c: 575 cm.

Ls. medium gray fossiliferous ws., massive, molluscan debris - c., fossils are in chert and matrix, horizontal stylolites - c., moderate amounts of moldic porosity, forms base of cliff: 125 cm.

Total thickness, Fossil Mountain Member: 5995 cm.

Total thickness (partial section), Kaibab Formation: 5995 cm.

Section 9: Parissawampitts Point

Kaibab Formation

Harrisburg Member

Dolo. medium tan to yellow cherty and sandy ms., massive to thick bedded, moderately fractured and weathered, weathers dark gray, sand grains are well rounded and medium grained, chert is white (fresh) and ab., (KT 9-14): 255 cm.

Dolo. medium tan sandy ms. w/ ab. chert lenses, thin bedded, very small disarticulated crinoids – f., chert is white (fresh) and contains many moldic vugs, chert nodules average 4 – 10 cm, vuggy, moderately fractured, forms major indent: 135 cm.

Dolo. dull yellow to medium tan sand ms. w/ many chert nodules, medium bedded (average 10 cm), crinoids – f., moderately pitted: 115 cm.

Dolo. medium tan sandy ms. w/ many chert nodules, thick bedded, large crinoids – c., productids (general) and Meekella – r., moderately fractured, weathers very dark gray in upper two beds: 220 cm.

Dolo. lt. tan ms. to ws., thick to thin bedded (may be laminated), solitary corals – c., crinoids and productids – f., sponge-like structures form centers of chert nodules, calcite vugs – c., slightly weathered, many fine-grained quartz crystals dot the surface: 110 cm.

Dolo. lt. tan cherty ms. w/ ab. chert nodules, laminated to thin bedded, chert nodules average 5 cm, moderately fractured, chert weathers lt. tan, slightly mudcracked, (KT 9-13): 105 cm.

Dolo. medium tan sandy ms. w/ f. chert nodules, thick bedded, crinoids – c., bivalves -r, many calcite nodules, chert nodules average 6 cm, chert nodules form one distinctive band, many silt grains, slightly weathered: 90 cm.

Dolo. medium tan sandy ms. w/ one distinctive chert lens in center and scattered nodules at base, massive to thick bedded, weathers medium to dull yellow, moderately pitted, many small sand grains on surface: 105 cm.

Dolo. lt. tan sandy ms. w/ many chert nodules, medium to thick bedded, ramose and fenestrate bryozoa – c., crinoids and Meekella – f., Euphemites – r., much fossil debris (especially ramose bryozoa) in chert, high amounts of moldic porosity, many fine sand grains, slightly pitted and vuggy, highly weathered, weathers to form very dark surface across outcrop, chert weathers white: 185 cm.
Ls. dull yellow to tan sandy ms. to ws., massive to thick bedded, productids, crinoids, fenestrate bryozoa and *Meekella* – c., *Peniculauris bassi* – f., f. chert nodules, highly pitted and vuggy, much moldic porosity, surface is very rough, forms wall: 180 cm.

Ls. dull yellow sandy ms. To ws. w/ f. chert lenses, massive to thick bedded, f. fossils in chert and matrix, ramose and fenestrate bryozoa – c., *Meekella* - f., vuggy, much moldic porosity, highly pitted, medium-size sand grains, weathers dark brown, forms lip: 175 cm.

Total thickness, Harrisburg Member: 1675 cm.

Fossil Mountain Member

Ls. medium gray to tan sandy ms. to ws. w/ ab. chert beds, lenses and nodules, medium bedded, productids, ramose and fenestrate bryozoa – c., *Composita* and *Meekella* -f., very characteristic by its dense chert which weathers to form iron-stained band across outcrop, moderately fractured, forms indent, (KT 9-12): 215 cm.

Ls. medium gray crinoidal ws t pas. w/ ab. “cannonball” chert and nodules, thick bedded t massive, ramose bryozoa -ab., crinoids, *Derbyia*, solitary corals and fenestrate bryozoa – c., “cannonball” chert is ab. and contains much fossil debris, the centers of some “cannonball” chert are up to 20 cm in diameter, moderately weathered and fractured, forms upper beds of major cliff (KT 9-11): 720 cm.

Ls. medium gray fossiliferous ws. w/ ab. “cannonball” chert and nodules, massive to medium bedded, ramose bryozoa, *Chonetes*, crinoids, productids (general) and *Peniculauris bassi* – c., *Meekella* and *Composita* – f., solitary corals(?) – r., some chert nodules contain much moldic porosity, slightly pitted, weathers dark gray, moderately fractured, (KT 9-10): 580 cm.

Ls. medium to lt. gray fossiliferous ws. to ps. w/ ab. chert nodules and f. “cannonball” cherts, medium bedded, crinoids, productids (general) and *Peniculauris bassi* – c., fenestrate bryozoa and *Derbyia* – f., chert is white to cream when freshly broken and often contains sponge-like structures, moderately fracture, weathers medium gray, (KT 9-9): 310 cm.

Ls. medium gray fossiliferous silty ws. To ms. w/ ab. chert nodules, laminated to thin bedded but weathers massive, highly fossiliferous, crinoids – ab., productids, bryozoa and *Composita* -c., *Meekella* and solitary corals - f., ramose bryozoa increase in abundance toward top of unit, weathers dark gray, many beds are separated by yellow intervals, forms massive cliff (KT 9-8): 710 cm.

Ls. medium gray fossiliferous ws. to ps., thin bedded, crinoids ab., productids, ramose bryozoa, *Composita*, *Chonetes* and *Peniculauris bassi* -c., solitary corals -f., units is distinctive in that lower-most bed is literally crowded w/ well-preserved, very large *Peniculauris bassi* (KT 9-7), moderately fractured, many chert nodules, weathers dark gray, forms gentle slope: 460 cm.

Ls. lt. gray silty fossiliferous ws. to ps. w/ f. chert nodules, medium bedded, highly fossiliferous, crinoids -ab., ramose and fenestrate bryozoa, solitary corals and *Peniculauris bassi* – c., weathers medium gray, forms gentle slope (KT 9-6): 245 cm.

Ls. dull yellow to tan sandy ms. w/ f. silty chert nodules, thick bedded, many large calcite nodules, weathers smooth, silty, f. chert nodules weather to stand in relief: 90 cm.

Ls. lt. tan ms. w/ many chert nodules, laminated to very thin bedded, moderately fractured, silty, slightly sandy, weathers dull yellow, forms lip: 185 cm.

Ls. medium tan cherty ms., laminated to very thin bedded, ramose bryozoa and productids – c., most fossils are in matrix, contains one distinctive 10 cm chert bed at top, contains ab. chert nodules and lenses (lt. and dark gray), weathers dull orange, highly fracture, forms major indent: 120 cm.

Ls. medium gray cherty ms. w/ many chert nodules, massive by becomes laminated at base, many brecciated chert clasts at top, sandy to silty texture, f. white chert veins, most chert nodules are laminated
w/ laminations extending from matrix through chert, chert becomes dark gray at base, f. chert nodules are iron stained and weather to stand in relief: 155 cm.

Ls. medium tan fossiliferous ws. to ms., w/ ab. chert nodules, massive, *Squamaria ivest* (?), crinoids and ramose and fenestrate bryozoa - c., *Composita* - f., most fossils are well preserved, unbroken and articulated, many moldic vugs in chert, chert is white to cream and contains a high silt content, weathers dull tan, slightly pitted and highly fractured, much fossil-moldic porosity in chert, (KT 9-5): 245 cm.

Ls. lt. tan sandy ms. w/ ab. chert nodules, laminated to thin bedded, chert nodules are oblong (5 x 20 cm) and weather medium to dark gray, forms base of gentle cliff: 95 cm.

Ls. dull orange t tan ms. w/ ab. chert nodules, thin bedded, crinoids and ramose bryozoa – c., productids - f., moderately fractured, chert is medium brown and rarely contains white calcite veins, forms major indent: 100 cm.

Ls. lt. tan ms. w/ many chert nodules, massive, may be ripple marked, slightly weathered, sandy texture, chert weathers out to form vugs, forms top of cliff: 190 cm.

Ls. lt. tan cherty ms. w/ many chert nodules, laminated but weathers massive, laminations drape over chert nodules, becomes a crinoidal ps. at top, crinoids -ab., large ramose bryozoa (up to 4 cm in diameter) - c., chert nodules are as large as 20 x 10 cm., forms indent: 120 cm.

Ls. dull orange to brown cherty ms., laminated but weathers as one massive unit, becomes a crinoidal ws. at top, crinoids -c., ramose bryozoa, *Derbyia* and productids -f., may be mudcracked, laminations drape over chert nodules, chert is very dark gray, partially dissolved calcite nodules f., f. calcite veins in chert nodules, highly fractured: 165 cm.

Ls. medium gray fossiliferous ps. to ws. w/ ab. chert nodules, thick to medium bedded, may be laminated, much fauna in chert and matrix, large ramose and fenestrate bryozoa -c., productids, *Squamaria ivest* (?) and brachiopods -c., *Meekella* -f., moderately fractured, chert is white when fresh but weathers w/ iron stain, (KT 9-4): 80 cm.

Ls. lt. gray fossiliferous ws. to ps. w/ ab. chert nodules, thin to medium bedded, large ramose bryozoa (up to 6 x 1 cm) -c., fenestrate bryozoa, productids and crinoids -c., *Meekella* -f., moderately fractured, chert is white and contains similar amounts of fossils as matrix, chert nodules average 6 cm: 60 cm.

Total thickness, Fossil Mountain Member: 4845 cm.

Total thickness, Kaibab Formation: 6520 cm.

**Section 10: Saddle Mountain**

Kaibab Formation
Fossil Mountain Member

Sltst. dull yellow well-sorted quartz sltst., weathers massive but may be laminated, well-sorted silt, calcite and chert nodules – f., chert weathers to stand in relief, moderately weathered w/ vugs up to 10 cm, highly porous, pitted and blocky, (KT 10-11): 170 cm.

Sltst. dull yellow quartz sltst., weathers massive but may be laminated, horizontal burrows – f., well sorted and round grains, calcite nodules (average 2 cm) – c., moderately pitted and weathered, f. chert nodules weather to stand in relief, may be slightly cross-bedded w/ low-angle (10 - 20°) foresets, forms cliff: 490 cm.

Sltst. dull yellow quartz sltst., massive, highly weathered dark gray and pitted, 1-2 cm calcite nodules weather to stand in relief, chert nodules -f., many calcite nodules appear to have been replaced fossils, silt moderately well sorted and rounded: 150 cm.

Covered: 235 cm.
Sltst. dull yellow to tan quartz siltstone, massive but becomes medium to thin bedded at top, silt is well sorted and subrounded, highly weathered (dark gray), pitted and vuggy, moderately fractured, many vertical joints, calcite and chert nodules -f., iron nodules up to 10 cm -c. weather to stand in relief, forms gentle cliff, (KT 10-10): 355 cm.

Sltst. medium yellow quartz siltstone, massive, silt- well sorted and rounded, slightly pitted, vuggy porosity, chert nodules -f., (KT 10-9): 245 cm.

Sltst. dull tan to yellow quartz siltstone, thin to massive, center of unit contains 1 cm calcite nodules that weather to stand in relief, f. chert nodules (10 cm) at base, many large vugs on smoothly weather surface: 475 cm.

Covered: 60 cm.

Sltst. dull tan to yellow quartz siltstone, massive, weathers lt. tan, slightly pitted, many 1 cm partially dissolved calcite nodules dot the surface in lower half of unit, iron nodules are c. in center of unit (one very large nodule measures 140 x 20 cm), silt- well sorted, subrounded, many massive vugs, one distinctive band of 10 cm chert nodules at base and top of unit, chert and iron nodules weather to stand in relief, iron nodules are stained and vuggy, forms minor cliff, (KT 10-8): 455 cm.

Covered: 85 cm.

Sltst. dull yellow to tan well-sorted quartz siltstone, massive, much fossil debris in lower half of unit, bivalves -c., fossil (bivalve)-moldic porosity -ab., large horizontal stylolites (5 cm) found in center of unit, many iron nodules (average 10 x 8 cm) in middle of unit, moderately pitted w/ vugs up to 50 cm, f. large “cannonball” cherts (20 x 10 cm), forms wall, (KT 10-7): 375 cm.

Dolo. medium tan silty cherty ms., laminated to thin bedded, chert lenses (average 20 x 5 cm) -c., weathers dark tan, forms major indent across outcrop: 50 cm.

Covered: 65 cm.

Ss. dull yellow fine-grained quartz sandstone w/ many chert nodules, vaguely laminated but weathers as one massive unit, vertical burrows – c., sand – well rounded and sorted, weathers very dark gray and blocky: 105 cm.

Ss. dull tan to yellow fine-grained quartz sandstone, massive, calcite nodules -f., very distinctive with many 20 x 15 cm smoothly weathered vugs which may have been former “cannonball” cherts, weathers dark gray and smooth, sand- well sorted and subrounded, forms minor cliff: 390 cm.

Ss. tan fine-grained calcareous sandstone. w/ ab. chert nodules, thin to medium bedded, calcite nodules -c., chert nodules are cream to white, forms manor indent: 175 cm.

Total thickness, Fossil Mountain Member: 3880 cm.

Total thickness, Kaibab Formation: 3880 cm.

**Section 11: Point Sublime**

Kaibab Formation
Harrisburg Member

Ss. medium tan calcareous sandstone to sandy ms., thick bedded, mudcracks -ab., highly brecciated, vuggy, highly weathered (forms dull red surface coating), slightly silty: 80 cm.

Ss. medium tan calcareous sandstone weathers to form one massive unit but may be laminated, ab. intraclasts and mudcracks (especially at top), intraclasts average 2 cm in diameter, slump structures – c., slightly vuggy, weathers dull tan, moldic porosity -c., calcite nodules -c., sand is fine to medium grained, moderately to poorly sorted and subrounded: 235 cm.
Dolo. lt. gray and green silty ms., laminated, forms indent: 25 cm.

Ss. medium tan calcareous ss. to sltst., well-defined laminations (0.2 cm), mudcracks -ab., most grains are fine sand, subrounded and well sorted, weathers dull tan and blocky, forms cliff: 150 cm.

Ss. medium tan, fine-grained, calcareous ss. w/ ab. chert lenses, thin bedded to laminated, bedding is highly contorted and moderately weathered, mudcracks -c., slightly pitted, chert lenses average 20 x 5 cm, sand grains- well sorted and subrounded, forms wall: 95 cm.

Slstst. medium tan sltst., thin bedded, forms indent, partially covered: 65 cm.

Slstst. medium tan sltst. w/ ab. chert nodules, thin bedded, chert is iron stain, moderately fractured and weathered: 75 cm.

Dolo. medium tan silty ms. w/ ab. chert nodules, thin to very thin bedded, chert weathers w/ iron stain at top of unit, forms major cliff, moderately fracture and weathered, mudcracks -c., weathers to produce a very densely mottled chert surface, bedding planes are contorted and wavy, chert is white to gray or pink when broken, (KT 11-10): 445 cm.

Ss. medium tan, fine-grained, calcareous ss. massive (may be laminated), small crinoids -c., contains much fossil-moldic (crinoid) porosity in chert, moderately weathered and pitted, chert nodules are iron stained, f. calcite vugs, mudcracks -r., slightly vuggy, forms cliff, sand grains- well sorted and moderately well rounded: 300 cm.

Dolo. medium tans ws. w/ f. chert nodules, massive (slightly laminated at base), very f. fossils, crinoids -c., calcite nodules –c., highly porous, pitted and slightly vuggy, moderately weathered, many be slightly sandy, chert separates bedding, forms cliff: 270 cm.

Dolo. lt. tan sandy ms. w/ many vuggy chert nodules, massive to thick bedded (may be slightly laminated), crinoids, ramose and fenestrate bryozoa, *Peniculauris bassi*, and other productids -c., fossil abundance decreases in upper half of unit, moderate amounts of fossil-moldic porosity in chert and matrix, very vuggy and highly pitted, moderately weathered, forms cliff: 570 cm.

**Total thickness, Harrisburg Member:** 2195 cm.

**Fossil Mountain Member**

Dolo. medium tan ms. to ws. w/ many chert nodules, thick bedded to massive, crinoids and productids -c., calcite nodules –c., highly porous, pitted and slightly vuggy, moderately weathered, many be slightly sandy, chert separates bedding, forms cliff: 270 cm.

Dolo. medium tan fossiliferous ws. w/ many chert nodules, thick bedded to massive w/ thin bedded units in central portion, solitary corals, productids, crinoids and ramose bryozoa -c., much fauna in both chert and matrix, slightly pitted and weathered, forms cliff: 180 cm.

Dolo. medium tan fossiliferous ps. w/ ab. chert nodules and “cannonball”(?!) cherts, massive, vaguely laminated, highly fossiliferous, *Composita*, solitary corals, ramose bryozoa, productids and *Peniculauris bassi* -c., *Meekella* -f., many fossils in both chert and matrix, weathers dark gray, slightly pitted, chert weathers to stand in relief, forms cliff: 305 cm.

Dolo. tan fossiliferous ps. w/ ab. chert nodules, massive, much fossil debris in both chert and matrix, *Peniculauris bassi*, solitary corals, *Meekella*, *Composita*, bivalves (general) and crinoids -c., ramose bryozoa – f., chert is highly fractured and weathers to stand in relief, moderately fractured, forms cliff: 219 cm.

Dolo. medium tan fossiliferous ws. w/ ab. chert nodules, massive, productids, *Derbyia*, ramose bryozoa and *Peniculauris bassi* -c., chert nodules average 10 x 5 cm, moderately fractured, major horizontal stylolite at base: 120 cm.
Dolo. medium tan cherty fossiliferous ws. to ps. w/ many chert nodules, weathers massive but contains many wavy laminations, most fossils are broken and disarticulated, *Peniculauris bassi*, *Derbyia*, crinoids and ramose bryozoa -c., fauna in both chert and matrix, chert weathers white and stands in relief, moderately weathered and fractured, forms massive cliff, (KT 11-8): 495 cm.

Ss. medium tan calcareous ss. to sltst. w/ ab. chert nodules, thin bedded, bedding planes are wavy, some fossil debris, highly weathered and fractured, chert weathers medium gray, forms major indent at base of cliff: 135 cm.

Ss. medium tan fine-grained calcareous ss. to sltst. w/ many chert nodules, massive but contains laminations in lowermost 20 cm, much fauna in both chert and matrix, fossils are broken and disarticulated, productids – ab., small crinoids, *Composita*, *Derbyia* and *Peniculauris bassi* – c., chert weathers to stand in relief, moderately weathered and pitted, forms cliff: 470 cm.

Sltst. light gray cherty sltst., thin to very thin bedded, highly weathered and fractured, forms well-defined indent: 160 cm.

Ss. medium tan fine-grained ss., massive, much fossil debris, productids -c., very dense iron stain on surface, chert nodules weathers to stand in relief, highly weathered, moderately pitted, weathers to two distinct units, forms cliff: 275 cm.

Ss. medium tan fine-grained ss, thick bedded, chert nodules ab., sand grains- well sorted and moderately well rounded, forms indent: 145 cm.

Sltst. medium tan sltst. massive, much fossil debris, *Composita* and productids (general) – C., highly weathered, moderately pitted: 140 cm.

Ss. medium tan fine-grained ss. w/ many chert nodules, massive, much fossil debris, dense iron stain on surface, highly weathered, forms cliff: 135 cm.

Ss. medium tan ss. w/ ab. chert nodules, thin bedded, sand grains- poorly sorted and well rounded, beds become solid chert in places, forms major indent, weathers dull orange, highly fractured: 220 cm.

Ss. medium tan fine-grained ss. w/ many chert nodules, massive, chert nodules up to 10 x 20 cm and most are iron stained and weather to stand in relief, very vuggy, moderately weathered and pitted, forms cliff: 350 cm.

Ss. medium tan calcareous ss. w/ ab. chert nodules, wavy laminations, slight amounts of fossil debris, highly fractured, sand grains- well sorted and subrounded: 90 cm.


Sltst. medium tan fine-grained sltst., weathers as one massive unit but is laminated, moderately fractured, dense iron stain on surface, slightly pitted, moderate amounts of vuggy porosity, sand grain – well sorted, moderately well rounded, forms cliff, (KT 11-6): 330 cm.

Ss. medium gray fine-grained ss. w/ ab. chert nodules, chert – highly fractured, weathers white to light gray, average 4 x 10 cm, forms indent: 150 cm.

Ss. white to light tan calcareous fine-grained ss., weathers as one massive cliff but may be laminated, iron stain coats the surface, many vertical joints, very slightly pitted and highly weathered, weathers smooth and round, one layer of chert nodules at top: 365 cm.

Ss. medium tan fine-grained ss. weathers massive but is slightly laminated, iron stain coats the surface, many vertical joints, highly weathered and slightly pitted, moderately fractured, sand grains – well sorted and moderately rounded, layer of chert nodules at top: 185 cm.
Sltst. medium tan calcareous sltst., medium to thick bedded, moderately fractured, very cherty at base, forms recess: 145 cm.

Ss. medium tan fine-grained ss. w/ ab. chert nodules, thin bedded, wavy bedding planes, few calcite nodules, moderately fractured and weathered, chert weathers light gray and is highly fractured, calcareous cement, sand grains – well sorted and moderately well rounded, forms indent: 305 cm.

Ss. medium tan medium-grained ss., massive, moderately vuggy and pitted, vertical burrows – c., contains two distinct bands of chert nodules which weather to stand in relief, weathers dull tan, slight amounts of moldic porosity, many calcite nodules: 355 cm.

Ss. medium tan ss. to ms. w/ many chert nodules, massive, vertical burrows – c. and weather to stand in relief, one well-defined chert lens at base: 120 cm.

Sltst. medium tan sltst. w/ ab. chert nodules, thin bedded, bedding is contorted and wavy, bivalves and crinoid – f., chert averages 4 cm and weathers white to gray, highly fractured: 255 cm.

Total thickness, Fossil Mountain Member: 6069 cm.

Total thickness, Kaibab Formation: 8264 cm.

Section 12: S.B. Point

Kaibab Formation
Harrisburg Member

Ss. white to lt. gray ss., medium to thin bedded, mudcracks – ab., f. rounded calcite grains, vuggy, very well sorted grains and moderately well rounded, (KT 12-19): 40 cm.

Dolo. medium tan ms., massive, f. calcite nodules, moderately pitted and fractured, mudcracks(?)-f. medium tan chert nodules (2 x 5 cm), weathers to form round wall (KT 12-18): 195 cm.

Ss. medium tan ss. to sltst., laminated, very friable, forms indent: 95 cm.

Sltst. red, fine-grained sltst. to ss. medium bedded, weathers blocky, (KT 12-17): 35 cm.

Cht. dark gray chert w/ interbedded dolomicitic ms., weathers as one very distinctive massive chert bed but individual beds average 10 cm and are interbedded w/ ms., wavy bedding planes, much chert is pink when fresh, forms major lip, very resistant beds: 160 cm.

Dolo. lt. tan cherty ms. w/ ab. chert nodules, very thin bedded, inter-bedded w/ green, medium-grained ss. calcite nodules -c., forms major indent below very resistant chert beds: 110 cm.

Dolo. medium tan ms., w/ many chert nodules, thick bedded, crinoids and bivalves -f., mudcracks -f., slightly pitted, minor amounts of vuggy porosity, chert is highly fractured, largest chert nodules are 8 cm, chert weathers orange, unit weathers blocky, (KT 12-16): 125 cm.

Dolo. medium tan sandy ms., thin to medium bedded, silica-replaced evaporite (halite(?)) crystals in chert -c., chert nodules (average 10 cm) form band at top, moderately fractured at base, partially dissolved calcite nodules within the carbonate matrix: 160 cm.

Dolo. medium tan sandy ms., massive, brecciated, iron nodules -f., most quartz grains (medium grained) weather to stand in relief, minor amounts of vug porosity, calcite nodules -f., weathers dark tan, forms cliff, (KT 12-15): 330 cm.

Dolo. dull yellow laminated ms., laminated to thin bedded (most laminations are contorted and wavy), moderately brecciated, very crumbly, forms partially covered cliff: 465 cm.

Dolo. medium to lt. gray ms., massive, breccia -c., one 5 cm copper-bearing (green) bed at top, highly vuggy and moderately pitted, weathers medium tan and blocky, forms minor cliff: 135 cm.
Dolo. lt. to medium gray ms., massive, mudcracks -f., red chert nodules (2 – 3 cm) -c., partially dissolved calcite nodules -c., weathers blocky and forms cliff, (KT 12-14): 380 cm.

Gyp. red to gray gypstone, massive w/ f. medium gray ms. interbeds, partially covered, vuggy, forms slope: 970 cm.

Cht. lt. to medium gray chert, thin bedded but weathers as two thick beds, highly fracture, weathers dark gray and forms lip: 110 cm.

Dolo. medium gray ws., to ms., w/ 5 cm chert lenses separating bedding, vaguely laminated but weathers thin to medium bedded and blocky, slightly fracture, slightly sandy, chert layers weather to form indents, calcite nodules -f., (KT 12-13): 190 cm.

Total thickness, Harrisburg Member: 3535 cm.

Fossil Mountain Member

Ls. medium gray ms. to ws. w/ many chert nodules separating bedding, massive to thin bedded, crinoids and productids -c., fenestrate bryozoa f., chert weathers to stand in relief, blocky, moderately fractured, forms gentle cliff: 290 cm.

Ls. medium gray ws. w/ many chert nodules, thin bedded, crinoids -c.: 110 cm.

Ls. medium gray ws. w/ many chert nodules, medium bedded (may be vaguely laminated), *Peniculauris bassi* and other productids -c., ramose bryozoa -f., weathers dark gray, chert separates bedding: 210 cm.

Ls. medium gray fossiliferous ws. w/ f. chert nodules, medium to thick bedded, ramose bryozoa and crinoids -c., productids -f., fewer fossils than in lower unit, moderately fractured, (KT 12-12): 330 cm.

Ls. medium gray fossiliferous ws. w/ many “cannonball” cherts, medium to thick bedded, crinoids, ramose bryozoa and productids -f., “cannonballs” are highly fossiliferous on the surface, white and up to 20 cm, moderately fractured and forms cliff: 430 cm.

Ls. medium gray fossiliferous ws. w/ ab. chert nodules and “cannonball” cherts, thick to medium bedded, crinoids, ramose bryozoa, productids and *Meekella* -c., fenestrate bryozoa -f., chert contains moderate amount of fossil-moldic porosity, weathers dark gray, very rough and highly fractured, chert weathers to sand in relief, forms cliff: 360 cm.

Ls. medium gray fossiliferous ws., ps. and gs., w/ ab. “cannonball” cherts (becomes crinoidal gs. at top), medium to thick bedded, much fossil debris, crinoids and productids -c., *Meekella* and *Peniculauris bassi* -f., solitary corals -r., most “cannonballs” are slightly flattened (average 10 – 20 cm), moderately fractured, forms cliff, (KT 12-11): 420 cm.

Ls. medium gray fossiliferous ws. w/ many chert nodules (5 cm) thick to medium bedded, productids, crinoids, ramose bryozoa and bivalves -c., solitary corals -f. and occur only in chert, *Meekella* -r., moderately fractured, weathers dark to medium gray, forms jagged surface: 510 cm.

Ls. medium gray fossiliferous ws. thin to medium bedded, contains much fossil debris, crinoids, productids and ramose bryozoa -c., *Composita, Meekella, Peniculauris bassi, Derbyia*, bivalves, solitary corals and fenestrate bryozoa -f., chert is white and contains much fossil-moldic porosity, chert lenses (6 cm) -c., moderately fractured, horizontal stylolites -f., forms cliff: 220 cm.

Ls. lt. gray fossiliferous ws. to ps. w/ one 6 cm bed of green sltst. at top, thin to medium bedded, productids, crinoids and ramose bryozoa -c., *Peniculauris bassi* -f., fenestrate bryozoa -r, moderately to highly fractured, many horizontal stylolites (3 cm) separate bedding, very rough and abrasive surface, slight amounts of moldic porosity, forms cliff: 450 cm.

Ls. medium gray productid ps. to ws. w/ many chert nodules, thick bedded to vaguely laminated, contains much fossil debris, small brachiopods and productids, *Peniculauris bassi, Composita* and ramose bryozoa
-c., moderately fractured and pitted, weathers dark gray, many horizontal stylolites separate bedding, forms cliff, (KT 12-10): 410 cm.

Ls. medium gray fossiliferous ws. w/ f. chert nodules, medium to thick bedded and may be laminated, crinoids, ramose bryozoa, small brachiopods and productids, *Peniculauris bassi* and *Composita* -c., chert shows slight amounts of fossil-moldic porosity, most fossils are disarticulated and broken, moderately fractured and pitted, weathers to form very jagged and abrasive surface, horizontal stylolites – c., forms cliff: 300 cm.

Ls. medium gray fossiliferous ps. w/ many chert nodules, massive to thick bedded, crinoids, *Peniculauris bassi*, productids and ramose bryozoa -c., much fauna in both chert and carbonate matrix, many bedding planes are separated by horizontal stylolites w/ amplitude up to 8 cm, moderately fractured, weathers dark gray, f. chert nodules weather to stand in relief, forms cliff: 225 cm.

Ls. medium gray fossiliferous ps. w/ ab. chert nodules, most beds have wispy laminations but weather thick to massive, very highly fossiliferous, much fauna in chert and matrix, crinoids, ramose bryozoa and *Peniculauris bassi* -c., horizontal stylolites -c., moderately fractured, weathers dull yellow to brown, f. chert nodules weather to stand in relief, forms cliff, (KT 12-9), 290 cm.

Covered: 680 cm.

Ls. medium gray fossiliferous ps. to ws. w/ ab. chert nodules, thin to medium bedded, fauna is in both chert and carbonate matrix, crinoids, productids and ramose bryozoa -c., f. sponge-like structures in chert nodules, highly weathered (dark gray), moderately fractured: 140 cm.

Covered: 980 cm.

Total thickness, Fossil Mountain Member: 6355 cm.

Total thickness, Kaibab Formation: 9890 cm.

**Section 13: Hidden Canyon**

Kaibab Formation
Fossil Mountain Member

Ls. lt. tan cherty fossiliferous ws., medium bedded, crinoids, fenestrate and ramose bryozoa, and *Peniculauris bassi* - c., chert is iron stained and weathers to stand in relief, (KT 13-12): 665 cm.

Covered: 105 cm.

Ls. medium gray cherty ws. w/ ab. chert nodules, medium bedded, crinoids and ramose bryozoa -c., *Meekella, Peniculauris bassi* and other productids - f., mudcracks(?)- f.: 60 cm.

Covered: 80 cm.

Ls. lt. gray cherty ws., thick bedded, fenestrate and ramose bryozoa and *Peniculauris bassi* - c., *Composita* - f, chert contains much fossil-moldic porosity, chert is white and weathers medium tan: 75 cm.

Covered: 190 cm.

Ls. lt. tan fossiliferous ws. w/ ab. chert nodules, thick bedded, *Peniculauris bassi* and *Derbyia* - c., *Meekella* and solitary corals - f., most fossils are disarticulated and broken, chert is iron stained and weathers to stand in relief, bedding planes are poorly defined, chert is very dense, unweathered and forms mottled surface, (KT 13-11): 195 cm.
Ls. lt. gray fossiliferous ws. to ms. w/ ab. chert nodules, massive to thick bedded, *Peniculauris bassi*, *Composita* and ramose bryozoa - c., highly weathered (very dark gray), vuggy and pitted, chert is iron stained: 330 cm.

Ls. medium gray fossiliferous ws. w/ very dense chert tracery surface, thick bedded but weathers massive, *Peniculauris bassi*, *Composita* and ramose bryozoa - c., fossil-moldic porosity in chert, chert is very rough, iron stained (black) and weathers to stand in relief, forms gentle cliff: 335 cm.

Ls. medium tan to lt. gray fossiliferous ws. w/ many chert nodules, medium bedded but weathers massive, *Derbyia*, *Composita*, *Peniculauris bassi* and ramose bryozoa – c., solitary corals - f., fossil-moldic porosity in chert, moderately fractured and slightly pitted, chert forms dense mottling and is iron stained, forms massive cliff, horizontal stylolites at base: 435 cm.

Ls. medium gray fossiliferous ps. w/ many chert nodules, medium bedded but weathers massive, *Composita*, *Peniculauris bassi*, ramose and fenestrate bryozoa, crinoids and bivalves – c., moderately fractured, chert is white when fresh and weathers w/ iron stain: 275 cm.

Ls. medium gray fossiliferous ps. w/ ab. chert nodules, medium to thick bedded, crinoids, *Peniculauris bassi*, other productids, and fenestrate and ramose bryozoa – c., *Composita* - f., chert is highly porous (fossil-moldic), chert is white to lt. gray when fresh and weathers to stand in relief, moderately weathered and fractured, forms cliff: 280 cm.

Ls. lt. tan fossiliferous ws. w/ many chert nodules, thick bedded, highly fossiliferous w/ fauna in both chert and matrix, bivalves, crinoids, and *Peniculauris bassi* – c., *Derbyia*, *Meekella* and fenestrate bryozoa - f., solitary corals - r., many sponge-like structures in centers of chert nodules, bedding planes are separated by chert, moderately weathered and fractured, forms cliff: 290 cm.

Ls. medium tan fossiliferous ws. w/ ab. chert mottling the surface, vaguely laminated but weathers medium to thick bedded, productids, ramose and fenestrate bryozoa, *Peniculauris bassi*, *Derbyia* and other productids - c., moderately fractured, chert locally forms black iron-stained bands and weathers to stand in relief, unit is vuggy, highly pitted and rough, (KT 13-10): 540 cm.

Ls. medium gray cherty ws., medium bedded, highly fossiliferous, crinoids, *Peniculauris bassi*, other productids and ramose bryozoa - c., chert nodules and lenses separate bedding, chert is iron stained and weathers to stand in relief, moderately weathered and fractured: 610 cm.

Ls. gray cherty ms. to ws., mostly covered slope: 520 cm.

Ls. medium gray fossiliferous ps. w/ ab. chert nodules, medium bedded, crinoids - ab., bivalves, productids and ramose bryozoa - c., chert (average 6 cm) is white when fresh, highly fractured: 340 cm.

Ls. medium to lt. gray sandy ms., thick bedded, bivalves and ramose bryozoa – c., crinoids and *Composita* - f., many calcite nodules and veins, moderately fractured, forms wall, (KT 13-9): 150 cm.

Covered: 360 cm.

Total thickness, Fossil Mountain Member: 5835 cm.

Total thickness, Kaibab Formation: 5835 cm.

**Section 14: Snap Point**

Kaibab Formation
Fossil Mountain Member

Ls. lt. gray fossiliferous ws. w/ f. chert nodules, massive to thick bedded, ramose bryozoa, *Meekella* and other productids - c., fenestrate bryozoa - f., much fossil-moldic porosity in chert, chert weathers yellow to brown and stands in relief, forms cliff, (KT 14-10): 430 cm.
Ls. lt. gray fossiliferous ps. w/ f. chert nodules, medium to thick bedded, solitary corals, crinoids, fenestrate and ramose bryozoa - c., much disarticulated and broken fossil debris, vaguely laminated, highly fractured, chert weathers w/ iron stain, "cannonball" cherts - f., (KT 14-9): 380 cm.

Ls. lt. gray fossiliferous ws. w/ ab. chert nodules, medium bedded, ramose and fenestrate bryozoa, *Peniculauris bassi* and *Meekella* - c., solitary corals and bivalves - f., chert has slight amounts of fossil-moldic porosity, chert is white when fresh and weathers w/ iron stain to stand in relief, most chert separates bedding, moderately weathered and pitted, highly fractured, many veins of gypsum (selenite) are dispersed throughout unit, forms cliff: 840 cm.

Ls. medium gray fossiliferous ws. w/ ab. chert nodules, thin to thick bedded, crinoids, ramose bryozoa and productids - c., fenestrate bryozoa and *Peniculauris bassi* - f., weathers medium to dark gray, highly fractured, chert separates bedding, and is iron stained and weathers to stand in relief, many gypsum (selenite) veins up to 7 cm occur throughout unit, forms cliff: 610 cm.

Covered: 140 cm.

Ls. medium gray ws. w/ many chert nodules, medium to thick bedded, contains fewer fossils than lower unit, *Peniculauris bassi* and crinoids – c., bivalves and ramose bryozoa - f., most fossils occur in carbonate matrix w/ lesser amounts in chert, highly fractured, moderately pitted and weathers dark gray, forms cliff: 370 cm.

Ls. medium gray fossiliferous ws. w/ many chert nodules, thin to thick bedded, highly fossiliferous, crinoids, *Peniculauris bassi*, *Derbyia* and ramose bryozoa – c., fenestrate bryozoa and solitary corals – f., highly fractured, forms vertical cliff, (KT 14-8): 440 cm.

Ls. medium tan fossiliferous ws. w/ many chert nodules, medium to thick bedded but weathers massive, bedding planes are non-distinct, crinoids, ramose bryozoa, *Peniculauris bassi* and *Derbyia* - c., much fossil-moldic porosity in chert, weathers dark gray, highly weathered and fractured, chert (white) weathers w/ iron stain and stands in relief, forms vertical wall: 1180 cm.

Ls. medium gray fossiliferous ws. w/ many chert nodules, thick bedded to massive, fossil abundance increases toward top of unit, *Peniculauris bassi* (?), crinoids and ramose bryozoa - c., chert nodules separate bedding, moderately fractured and highly weathered (dark gray), chert weathers to stand in relief, gypsum (selenite) nodules are c., and few are 15 cm thick, forms wall, (KT 14-7): 760 cm.

Ls. medium gray fossiliferous ws. w/ many chert nodules, medium bedded, productids and crinoids - c., weathers dark gray, highly fractured, chert is highly vuggy, partially covered, f. partially dissolved selenite nodules, forms gentle slope: 630 cm.

  Total thickness, Fossil Mountain Member: 5780 cm.
  Total thickness, Kaibab Formation: 5780 cm.

**Section 15: Seegmuller Mountain**

Kaibab Formation
Harrisburg Member

Cht./dolo. medium gray chert w/ interbedded tan ms., medium bedded, w/ few defined laminations, forms very resistant ledge, weathers w/ slight iron stain, mudcracks - f., slightly fractured and pitted, forms two steps, (KT 15-10): 115 cm.

Dolo. white to lt. gray silty ms., well-defined cross-laminations in upper half of unit, f. chert nodules and mudcracks at top, (KT 15-9): 120 cm.

Dolo. lt. gray silty ms., laminated, highly weathered and crumbly, forms step: 75 cm.

Covered: 520 cm.
Dolo. lt. tan silty ms. to crystalline carbonate, massive at base, medium bedded in upper half, may be laminated, f. chert nodules weather to stand in relief, partially dissolved gypsum nodules – r., cavernous to vuggy porosity, crumbly, forms massive lip, (KT 15-8): 315 cm.

Dolo. lt. tan silty ms., weathers massive to thick bedded but may be laminated, partially dissolved gypsum nodules – f., cavernous porosity, slightly pitted, crumbly, forms small amphitheater, f. lt. gray chert nodules at base: 190 cm.

Gyp. lt. tan gypsum, massive, partially covered, forms slope: 940 cm.

Gyp. red and white gypstone, massive, wall exposed, forms slope, (KT 15-7): 485 cm.

Gyp. white gypstone w/ f. thin pelleted ms. interbeds, massive, ms. units are not continuous but pinch out over an area of a few tens of feet: 2950 cm.

Dolo. medium tan cherty ms., medium bedded, weathers rough and slightly pitted, chert nodules - c., mudcracks(?)- f., chert nodules weather to stand in relief, forms slope: 270 cm.

Dolo. medium tan cherty ms., medium bedded, weathers rough and slightly pitted, chert is iron stained and stands in relief, slightly silty: 140 cm.

Dolo. medium tan cherty ms., thick, bedded to massive, weathers rough, slightly pitted, f. vugs, chert is iron stained and stands in relief, highly fractured, forms minor wall, (KT 15-6): 265 cm.

Total thickness, Harrisburg Member: 6385 cm.

Fossil Mountain Member

Ls. lt. tan cherty ms. w/ many chert lenses, thick bedded to massive(?) may contain very f. productids, moderately weathered (dull yellow), slightly pitted, carbonate clasts (may be fossils) - f., chert is iron stained and stands in relief, slightly silty, (KT 15-5): 235 cm.

Ls. medium gray crinoidal ps. w/ many chert nodules, medium to thick bedded, crinoids - ab. in lower half, bivalves - f., unfossiliferous in upper half of unit, slightly sandy, much of the chert is iron stained and stands in relief, slightly pitted, weathers to form a series of steps: 370 cm.

Ls. medium gray cherty ws. w/ many chert nodules, medium bedded, ramose bryozoa and crinoids - c., productids and bivalves - f., chert nodules contain many ramose bryozoa (fossil-moldic porosity), chert is iron stained and stands in relief, slightly pitted, forms a series of steps: 285 cm.

Ls. lt. gray fossiliferous ws. w/ many chert nodules, vaguely laminated but weathers medium to thick bedded, crinoids, ramose and fenestrate bryozoa, *Peniculauris bassi* and other productids – c., solitary corals - r., horizontal stylolites - c., weathers dark gray and rough, slightly fractured, forms a series of steps: 205 cm.

Ls. lt. gray fossiliferous ps. w/ many chert nodules, medium bedded, large crinoids (2.5 cm) and ramose bryozoa - c., productids - f., horizontal stylolites (2 cm amplitude) - c., "cannonball" chert - f., freshly fractured surface: 155 cm.

Ls. lt. gray fossiliferous ps. w/ many chert nodules, medium bedded, *Composita*, ramose and fenestrate bryozoa, *Peniculauris bassi* and other corals - c., many sponge-like structures in chert nodules, moderately fractured, slight amounts of moldic porosity, surface is freshly fractured, "cannonball" chert - f.: 125 cm.

Ls. medium tan fossiliferous ps. to ws. w/ many chert nodules, medium bedded, ramose bryozoa (5 cm in diameter) and fenestrate bryozoa, productids, and crinoids – c., *Peniculauris bassi* - f., *Deltopecten*, solitary corals and low-spired gastropods - r., much fauna in chert and matrix, some chert is iron stained...
and stands in relief, slight amounts of moldic porosity in chert nodules, "cannonball" chert - f., horizontal burrows - f., weathers dark gray, slightly fractured and pitted, forms amphitheater, (KT 15-4): 435 cm.

Ls. medium tan fossiliferous ps. w/ f. chert nodules, medium bedded, ramose and fenestrate bryozoa, productids and crinoids – c., Composita - f., fauna in both chert and matrix, chert has rare fossil(?)-moldic porosity, weathers medium gray, slightly pitted and fractured, forms wall: 210 cm.

Ls. medium tan fossiliferous ws. to ps. w/ many chert nodules and f. "cannonball" cherts, medium bedded, ramose bryozoa and crinoids - c., many broken productids, fenestrate bryozoa and Derbyia - f., chert seldom contains sponge-like centers, slight amounts of fossil-moldic porosity in chert, has large horizontal stylolite at base, chert is moderately fractured, forms two steps: 215 cm.

Ls. medium gray fossiliferous ws. w/ many chert nodules, medium bedded, crinoids, ramose and fenestrate bryozoa, Derbyia and productids (general) - c., Composita and solitary corals - f., most fossils are broken and disarticulated, chert is white to cream and separates the bedding, chert contains slight amounts of moldic porosity, weathers dull gray, moderately fractured, forms wall, (KT 15-3): 345 cm.

Ls. medium tan fossiliferous ws. w/ many chert nodules, weathers medium bedded but may be laminated, crinoids, bivalves, Composita and Meekella - c., fossils occur in both chert and matrix, most fossils are disarticulated, most chert forms lenses which separate bedding, moderately weathered and fractured, large horizontal stylolite at base, forms wall, (KT 15-2): 180 cm.

Ls. lt. tan ms. to ws. w/ pink chert lenses, medium to thick bedded, crinoids, bivalves and Meekella - f., contains many horizontal stylolites (4 cm amplitude) which are iron stained, may contain f. partially dissolved selenite nodules, weathers to form smooth wall: 215 cm.

Total thickness, Fossil Mountain Member: 2975 cm.

Total thickness, Kaibab Formation: 9360 cm.

Section 16: Parashant Canyon

Kaibab Formation

Harrisburg Member

(Note: Above the following unit lies white and pink quartz-pebble conglomerate, massive, forms cliff, Moenkopi Formation)

Ls. dull yellow and tan sandy crystalline carbonate, medium bedded, becomes dark red, coarse-grained ss. at top, f. chert nodules (10 cm round) at base, many breccia clasts at base, sand - well sorted and subangular, wavy bedding, (KT 16-21): 265 cm.

Covered: 140 cm.

Dolo. medium gray cherty ms. w/ very dense chert tracery, massive to thick bedded, forms very resistant rim of plateau, chert is pink and highly fractured, slightly contorted bedding, forms top of massive wall, (KT 16-20): 100 cm.

Cht. pink and gray chert, massive, forms very dense iron-stained surface, laminated mudstone unit forms indent at base: 200 cm.

Covered: 235 cm.

Dolo. lt. tan cherty ms. w/ many chert nodules, thick bedded, Composita - f., highly pitted, chert weathers to stand in relief: 75 cm.

Dolo. lt. tan ms. w/ many chert nodules, thin bedded w/ one bed of dense chert at top, bivalves - f., mud clasts - f., moderate amounts of moldic porosity, forms indent: 120 cm.
Dolo. medium tan cherty ms. w/ f. chert nodules, weathers massive but is vaguely laminated, slight amounts of unidentifiable fossil debris, pink chert nodules - f., chert nodules weather to stand in relief, carbonate mud clasts - f., weathers slightly round, very few iron nodules, calcite nodules - c., highly pitted, sandy texture, forms massive wall: 325 cm.

Covered: 310 cm.

Dolo. medium tan brecciated ms., massive, f. broken shell fragments, mudcracks(?) slightly fractured, vuggy, weathers to form highly pitted surface, calcite nodules - c., forms wall: 350 cm.

Covered: 170 cm.

Dolo. medium gray ms. w/ ab. chert tracery, medium bedded, Composita - c., chert nodules weather to stand in relief, very rough surface, chert nodules are iron stained and rough: 40 cm.

Dolo. medium gray ms., medium to thick bedded, calcite nodules and breccia clasts - c., highly pitted and very rough, (KT 16-19): 115 cm.

Dolo. medium gray ms., may be laminated but weathers as one massive unit, most fossils are broken and disarticulated, bivalves and crinoids - c., f. calcite nodules at top, moderately pitted w/ very rough surface, iron nodules (2 cm) - f., horizontal stylolites (4 cm amplitude) - f., carbonate mud clasts - f., forms cliff: 255 cm.

Covered: 75 cm.

Dolo. medium tan ms. w/ f. chert nodules, laminated but weathers to form one thick bed, mudcracks – f., slightly pitted and blocky: 80 cm.

Ls. tan cherty ms., medium bedded, chert nodules weather to stand in relief, forms steps separated by partially covered intervals: 470 cm.

Total thickness, Harrisburg Member: 3325 cm.

Fossil Mountain Member

Ls. medium tan cherty ms., medium bedded, calcite nodules - c., slightly silty, chert is highly fractured, unit is slightly pitted and forms wall: 156 cm.

Ls. medium tan cherty ms., medium bedded, crinoids - c., bivalves - f., calcite nodules - c., slightly silty, chert is highly fractured, slightly pitted, "cannonball" cherts – c., partially covered to form a series of steps: 510 cm.

Ls. medium tan ms. w/ many chert nodules, medium bedded (may be slightly laminated), highly fossiliferous, most fossils are broken and disarticulated, crinoids - c., bivalves - f., moderate amounts of fossil-moldic porosity, weathers medium gray, "cannonball" cherts - c. at top, slightly fractured: 155 cm.

Ls. medium tan silty ms. w/ many "cannonball" cherts, medium and thin bedded, crinoids and ramose bryozoa – c., fossil debris in chert nodules and "cannonballs – c.," "cannonball" chert - c., calcite nodules – c., many "cannonballs" contain concentric bands, weathers slightly pitted and forms slope: 250 cm.

Ls. medium tan fossiliferous ws. w/ many chert nodules, lenses, and "cannonballs," medium to thick bedded, crinoids and ramose bryozoa - c., productids - f., most fossils are disarticulated, much fossil debris in chert and matrix, moderate amounts of fossil-moldic porosity in chert, slightly fractured and pitted, "cannonballs" average 15 cm and are up to 20 cm, chert is white and pink but weathers w/ iron stain, slightly vuggy, forms cliff w/ distinct horizontal stylolite at base: 265 cm.

Ls. medium tan cherty ms., medium to thick bedded, ramose bryozoa and crinoids - c., fenestrate bryozoa and productids - f., most fossils are broken and disarticulated, chert is iron stained and stands in relief, moderately fractured and pitted, weathers w/ very rough surface, chert is highly fractured, forms cliff,
horizontal stylolites - f., "cannonball" cherts - c., slight amounts of moldic porosity in chert, chert nodules up to 20 cm: 390 cm.

Ls. medium tan fossiliferous ws. to ps. w/ many chert nodules, medium bedded, crinoids, productids (general), *Peniculauris bassi*, ramose and fenestrate bryozoa - c., most fossils are broken and disarticulated and are aligned parallel to bedding, highly fractured and slightly pitted, chert is white and pink (fresh) w/ moderate amounts of fossil-moldic porosity, contains distinctive band of iron-stained chert tracery at top, weathers to form steep slope, (KT 16-18): 375 cm.

Ls. medium tan fossiliferous ps. w/ many chert nodules, medium and thin bedded, crinoids, and *Peniculauris bassi* - c., *Meekella* - f., partially covered slope: 120 cm.

Ls. medium tan fossiliferous ps. to gs. w/ many chert nodules, thick bedded, crinoids and *Peniculauris bassi* - c., *Meekella* - f., many productid spines in chert nodules, forms step, (KT 16-17): 60 cm.

Covered: 410 cm.

Ls. medium tan ms. w/ ab. chert tracery, medium to thick bedded, productids and crinoids - f., slight amounts of fossil-moldic porosity, chert forms very densely mottled surface, much of the chert is iron stained and moderately fractured, weathers very dark gray, slightly pitted w/ very rough surface, slightly vuggy, becomes gentle slope at top: 210 cm.

Ls. medium gray ws. w/ very densely mottled chert surface, thick bedded to massive, *Derbyia, Composita, Meekella* and crinoids - c., equal amounts of fossils are found in chert and matrix, bedding is non-distinct, slightly fractured, weathers to form black band across outcrop, very rough surface, vuggy and slightly pitted, chert is moderately fractured, weathers to form wall: 350 cm.

Ls. medium tan fossiliferous ws. to ps. w/ ab. chert nodules and f. lenses, medium bedded, crinoids, ramose bryozoa, productids and *Composita* - c., bivalves, fenestrate bryozoa and *Meekella* - f., weathers dark gray, slightly pitted w/ very rough surface, chert separates bedding, chert is white but weathers w/ iron stain (almost black), moderate amounts of moldic porosity in chert, moderately fractured: 125 cm.

Ls. medium tan fossiliferous ws. w/ ab. chert nodules and f. lenses, medium to thick bedded, crinoids, productids, ramose bryozoa and *Composita* - c., bivalves, fenestrate bryozoa and *Meekella* f., weathers dark gray, slightly pitted w/ very rough surface, chert separates bedding, chert is white but weathers w/ iron stain, slight amounts of moldic porosity in chert, moderately fractured: 275 cm.

Ls. medium tan fossiliferous ws. w/ ab. chert nodules, medium bedded, crinoids, small brachiopods, productids, solitary corals, *Composita* and ramose bryozoa - c., most fossils are broken and disarticulated, surface weathering (black) is distinctive, chert forms very densely mottled surface and separates bedding, chert is white when fresh and contains moderate amounts of fossil-moldic porosity, moderately fractured and slightly pitted, many calcite nodules, forms wall: 290 cm.

Ls. medium tan fossiliferous and cherty ws., medium to thick bedded, *Derbyia, Composita* and ramose bryozoa - c., productids - f., solitary corals(?) -f., most fossils are oriented parallel to bedding, f. iron nodules at base, chert is white and separates bedding, slight amounts of moldic porosity in chert, chert weathers black and forms band across outcrop, highly fractured.: 240 cm.

Ls. medium tan ws. to ps. w/ many chert nodules, medium bedded, crinoids, productids, fenestrate and ramose bryozoa - c., *Meekella* - f., *Chonetes* - r., most chert nodules weather w/ iron stain and stand in relief, highly fractured, slightly covered: 255 cm.

Ls. medium tan cherty ws. to ps., thin to medium bedded, crinoids, productids, fenestrate and ramose bryozoa - c., *Meekella* and *Chonetes* - r., fossil abundance and diversity increase toward top, chert is white and contains many fossils, chert weathers w/ iron stain and stands in relief, bedding is non-distinct, very f. yellow sltst. and ms. clasts, chert nodules are up to 10 cm, moderately fractured and slightly pitted, matrix weathers pink, forms series of steps, (KT 16-16): 580 cm.
Covered: (talus is tan ms. w/ many chert nodules): 600 cm.

Ls. medium tan siltys., massive, crinoids, ramose bryozoa and \textit{Peniculauris bassi} - c., \textit{Composita} - f., highly fractured, becomes cherty at top, weathers medium gray, slightly pitted, f. horizontal stylolites, forms cliff: 840 cm.

Ls. medium tan siltys., massive, crinoids, ramose bryozoa and \textit{Peniculauris bassi} - c., \textit{Composita} and small productids - f., moderately fractured, many horizontal stylolites separate bedding, forms cliff: 180 cm.

Ls. lt. tan sandy ms., massive, ramose bryozoa and \textit{Peniculauris bassi} - c., crinoids, small productids and \textit{Composita} f., many fossils are disarticulated and broken, f. chert nodules, moderately fractured, many horizontal stylolites: 275 cm.

Ss. medium tan calcareous ss. massive, much disarticulated and broken fossil debris, crinoids and bivalves - c., minor amounts of fossil(?)- moldic porosity, f. of the chert nodules may be "cannonballs," sand - well sorted and rounded, moderately fractured: 235 cm.

Dolo. red to yellow and brown sandy brecciated ms., massive, many slump features, bedding planes are non-distinct, weathers w/ red iron stain, bedding is highly contorted, most of the clasts are ms., breccia clasts - ab. (up to 50 cm), forms base of cliff: 185 cm.

\begin{itemize}
\item \textbf{Total thickness, Fossil Mountain Member:} 7331 cm.
\item \textbf{Total thickness, Kaibab Formation:} 10656 cm.
\end{itemize}

\textbf{Section 17: Cove}

\textbf{Kaibab Formation}
\textbf{Harrisburg Member}

(Note: Above the following unit lies red quartz conglomerate, cut-and-fill structures w/ large mudcracks in mudstone interbeds, (KT 17-23), Moenkopi Formation)

Covered, partially covered slope w/ red soil cover at top and white to yellow to lt. red soil cover at base: 180 cm.

Covered: 180 cm.

Sltst. yellow to brown calcareous sltst. to ss., thin bedded, (KT 17-22): 60 cm.

Covered, partially covered slope w/ red soil: 190 cm

Sltst. white to lt. gray calcareous medium-grained sltst. to ss., massive, surface is slightly coated w/ iron stain, slightly weathered, (KT 17-21): 220 cm

Ls. dull red sandy ps., thin bedded: 30 cm

Covered: 275 cm.

Cht. medium brown to beige interbedded chert and calcite, beds average 5 cm and are slightly contorted, weathers massive and blocky, very dense, highly fractured, very resistant forming the major rim of the plateau, (KT 17-20): 170 cm.

Dolo. lt. tan to yellow ws. w/ large chert concretions (20 cm) and lenses, massive, partially dissolved calcite nodules - f., forms top of a major cliff: 295 cm.

Dolo. dull yellow to lt. brown cherty ms., thin bedded: 70 cm.
Dolo. yellow to brown to dull red sandy ms. to crystalline carbonate, massive, weathers as one round unit, small (millimeter-size) evaporite crystals, (KT 17-19): 440 cm.

Dolo. dull yellow to medium brown quartz ws. w/ slight traces of red iron stain on surface, small vugs w/ evaporite crystals – c: 210 cm.

Covered: 220 cm.

Dolo. lt. gray ms. to ws., thin bedded, slightly brecciated w/ small solution pits: 70 cm.

Dolo. lt. gray ws. to ms. w/ breccia and mudcracks, thick bedded, small vugs partially filled w/ anhydrite form c. surface features: 170 cm.

Dolo. lt. gray ms. to ps. w/ intraclasts, breccia, mudcracks and horizontal burrows, thick bedded, veins of anhydrite - c., moderately weathered, solution pitted, (KT 17-18): 120 cm.

Dolo. lt. to medium gray ms. w/ solution vugs (5-15 cm), thick bedded, highly weathered: 80 cm.

Dolo. lt. gray ms. w/ breccia clasts enclosed in pinkish matrix, thin bedded, clasts range in size from 1-15 cm: 100 cm.

Dolo. lt. gray dolomitic brecciated ws. to ps. w/ pink matrix, thick bedded, mudcracks - c., unit forms a prominent cliff: 140 cm.

Covered: 120 cm.

Dolo. dull yellow to brown ms., medium bedded (30 cm), forms slight indentation, fauna consist of broken shell fragments and crinoid debris, (KT 17-17): 120 cm.

Dolo. lt. gray ms., medium bedded, silicified crinoids and gastropods – c: 120 cm.

Dolo. lt. tan to gray ms. to ws., thinly laminated w/ brownish-yellow chert lenses, small iron concretions - c., (KT 17-16): 330 cm.

Dolo. lt. tan to gray ps., medium bedded: 170 cm.

Dolo. lt. gray ws. to ps. w/ lt. gray chert nodules which occur in distinct lenses parallel to bedding, massive to medium bedded, nodules weather yellow and brown and contain many productids, productids (general) and crinoids - c., crinoids are partially silicified, upper part of unit contains no lenses of chert but a few scattered chert nodules: 500 cm.

Dolo. tan to buff gray ws., thin bedded and blocky, ramose bryozoa, productids and spirifers - c., crinoids – f: 60 cm.

Dolo. lt. gray ps., thick bedded, unit is highly fossiliferous, ramose bryozoa and productids - ab., crinoids - c., gastropods(?)- f.: 170 cm.

Dolo. medium tan ps., medium to thick bedded, much of the fauna is broken, productids, ramose and fenestrate bryozoa - ab., minor veins of calcite: 260 cm.

Dolo. medium tan ps., medium bedded, crinoids - ab., ramose bryozoa and productids - c., distinct absence of chert tracery: 230 cm.

Total thickness, Harrisburg Member: 5300 cm.

Fossil Mountain Member

Ls. medium gray to tan ws. w/ ab. chert tracery (tan to medium brown) covering the surface, thick bedded, much fauna found in the chert tracery as well as in matrix, crinoids, ramose bryozoa and molluscan shell fragments - f. chert nodules are subrounded, slightly weathered, very dense: 470 cm.
Ls. medium gray fossiliferous ps. to ws. w/ ab. chert tracery, massive, fenestrate bryozoa, crinoids and productids - c., "cannonball" chert (average 10 cm) - f., densely mottled surface, (KT 17-15): 330 cm.

Ls. medium gray fossiliferous ps. w/ ab. chert tracery and many "cannonball" cherts, thick bedded, crinoids, productids, ramose and fenestrate bryozoa - c., chert weathers black and forms very densely mottled surface, forms cliff, "cannonballs" reach 15 cm in diameter: 225 cm.

Ls. medium gray crinoidal ps. w/ ab. "cannonball" chert and mottled chert tracery, thick bedded to massive, highly fossiliferous, crinoids, ramose and fenestrate bryozoa, productids and productid spines, and Composita - c., chert weathers very dark gray and stands in relief, moderately fractured, forms cliff: 610 cm.

Ls. medium gray crinoidal ps. w/ ab. "cannonball" chert and chert lenses, medium bedded to massive, crinoids, Composita, productids and productid spines, and ramose and fenestrate bryozoa - c., fossils are contained in both chert and matrix, weathers to form very dark gray unit, forms cliff 405 cm.

Ls. medium tan fossiliferous ps. w/ ab. chert tracery and chert nodules, thin to thick bedded, highly fossiliferous, Derbyia, Composita, crinoids and ramose bryozoa - c., highly weathered moderately pitted, forms cliff: 1205 cm.

Ls. medium tan fossiliferous ps. w/ ab. chert tracery, medium bedded, Composita, Derbyia, productids (general) and ramose bryozoa - c., crinoids - f., highly weathered and pitted, forms cliff: 1410 cm.

Ls. medium tan fossiliferous ps. to ws. w/ ab. chert tracery (especially at top) and chert nodules at base, thin to thick bedded, large bivalves, Composita, crinoids and productids - c., highly fossiliferous, most fossils are broken and disarticulated, much fauna in both chert and matrix, chert- lt. gray to beige, slightly pitted, bedding planes are very distinct, moderately to slightly fractured, highly weathered, forms series of walls, (KT 17-14): 295 cm.

Covered: 115 cm.

Ls. medium tan fossiliferous ps. w/ many chert nodules, medium to thick bedded, highly fossiliferous, fossils are vaguely oriented parallel to bedding, crinoids, Peniculauris bassi and other productids, productid spines, fenestrate and ramose bryozoa - c., bivalves - f., most crinoids are disarticulated but productids are usually well preserved and articulated, moderately fractured, weathers dull tan, slightly pitted, chert is white and contains slight amounts of moldic porosity, chert weathers w/ iron stain, forms top of major cliff: 280 cm.

Ls. medium tan fossiliferous ws. w/ ab. chert nodules, massive at base and thin bedded at top, bedding is very distinct and well defined, highly fossiliferous (especially at top), fossils are disarticulated and broken, Derbyia, ramose and fenestrate bryozoa, and productids - c., slight amounts of fossil-moldic porosity, chert w/ dark iron stain and stands in relief, chert separates bedding, moderately fractured and slightly pitted, (KT 17-13): 395 cm.

Ls. medium tan ms. w/ ab. chert nodules, thick bedded to massive, productids - f., chert is white when fresh and weathers w/ iron stain to stand in relief, sandy texture, weathers dull tan, slightly fractured, forms cliff: 275 cm.

Ls. medium tan fossiliferous ms. w/ ab. chert nodules, thick to thin bedded, very f. fossils, ramose bryozoa - f., moderately fractured, chert is highly fractured and weathers to stand in relief, weathers w/ very rough surface, chert separates bedding, moderately pitted, (KT 17-12): 190 cm.

Ls. medium tan-ws. w/ ab.-chert nodules, medium to thick bedded, may be vaguely laminated, f. fossils, crinoids and ramose bryozoa - f., weathers dark gray, may contain slight amounts of quartz sand, chert weathers to stand in relief, forms slope in center of ravine: 360 cm.
Ls. lt. tan silty ms. w/ ab. chert nodules, medium to thick bedded, may be laminated, ramose and other bryozoa, and crinoids - f., weathers medium gray, moderately fractured, chert weathers medium gray and stands in relief, chert forms a mottled surface, slightly pitted: 295 cm.

Ls. medium gray fossiliferous ps., medium bedded, vaguely laminated, highly fossiliferous, crinoids, productids, and ramose and fenestrate bryozoa - c., bivalves - f., moderately weathered, highly fractured, chert nodules - c., slightly pitted, horizontal stylolites - c., forms cliff: 390 cm.

Ls. medium gray fossiliferous ps. to ws., medium bedded, crinoids, Peniculauris bassi and other productids, ramose bryozoa and bivalves - c., highly fossiliferous, highly fractured, chert separates bedding, forms cliff, (KT 17-11): 370 cm.

Dolo. dull yellow highly brecciated ms., thin bedded but weathers massive, yellow laminated sltst. at base, crinoids - f., horizontal stylolites - f., weathers medium yellow, chert breccia clasts, forms base of massive cliff, (KT 17-11a): 200 cm.

Total thickness, Fossil Mountain Member: 7820 cm.
Total thickness, Kaibab Formation: 13120 cm.

Section 18: Brady Canyon

Kaibab Formation
Harrisburg Member

Dolo. orange to dull red silty ms., thin bedded, wavy bedding planes, (KT 18-26): 135 cm.

Covered: 171 cm.

Cht. pink to dull red iron-stained chert, thick to medium bedded, very dense and resistant, forms upper rim of plateau, highly fractured, wavy bedding, very distinctive due to its resistivity, (KT 18-25a): 110 cm.

Dolo. lt. tan cherty fossiliferous ws., thin bedded, crinoids and fenestrate bryozoa - c., productids and small brachiopods - f., moderately- fractured w/ subconchoidal fracture, very dense carbonate beds are separated by chert, bedding surfaces are wavy, (KT 18-25): 275 cm.

Covered: 149 cm.

Dolo. dark orange ms. w/ many carbonate clasts, medium bedded, sandy texture, weathers round, forms top of cliff: 33 cm.

Dolo. dark orange ms. w/ many carbonate clasts, massive, sandy texture, weathers round, forms cliff, chert nodules - c. and weather to stand in relief: 248 cm.

Dolo. dull orange ms., massive, distinctive by its round weathering character, sandy texture, 0.5-m vugs - c., slightly pitted, many calcite nodules: 212 cm.

Dolo. lt. tan cherty ms. w/ many chert nodules, thin bedded, forms distinctive indent below round-weathering bed: 66 cm.

Dolo. tan ms., laminated, partially covered: 70 cm.

Gyp. tan gypstone, massive(?), partially covered, forms slope: 1337 cm.

Dolo./Ls. lt. tan fossiliferous ms. to ws., laminated, productid spines and small brachiopod debris - c., brecciated and burrowed in upper part, interbedded w/ gypstone, very dense and partially cherty in upper part, (KT 18-24): 460 cm.

Gyp. massive, partially covered, forms slope: 800 cm.
Dolo. tan pelleted ms. w/ f. gypsum and chert nodules, laminated, crinoids - c. (only in upper 10 cm of unit), most gypsum nodules are partially weathered out, weathers as one massive unit, breccia - f., (KT 18-23): 172 cm.

Dolo. lt. tan ms. w/ many gypsum nodules (3-4 cm), massive, weathers blocky and smooth, distinctly laminated at base w/ f. chert nodules: 108 cm.

Dolo. lt to gray ms., laminated, forms major indent, high clay content: 60 cm.

Gyp. gypstone w/ f. interbedded ms. units, massive, partially covered, forms slope: 1600 cm.

Ls. lt. tan fossiliferous ps., medium to thin bedded, Peniculauris bassi, ramose bryozoa, crinoids and productid spines - c., Acanthopecten(?) - r., moldic porosity - c., moderately fractured: 125 cm.

Covered: 190 cm.

Ls. lt. tan fossiliferous ws., thick bedded crinoids and productid spines - c., productids - f., much broken brachiopod debris, sandy texture: 106 cm.

Ls. lt. tan bryozoan ps., medium bedded, crinoids, productid spines and brachiopods - c., most fossils are broken, f. chert nodules at base, moderately pitted, slightly vuggy, highly fractured, (KT 18-22): 306 cm.

Ls. lt. tan fossiliferous ps. w/ many chert nodules and lenses, massive, crinoids, ramose and fenestrate bryozoa, and small brachiopods - c., Meekella, Peniculauris bassi, Derbyia and Composita - f., "cannonball" chert - f., (KT 18-21): 458 cm.

Ls. lt. gray fossiliferous ps. w/ much chert tracery, massive to thick bedded, crinoids, ramose and fenestrate bryozoa, and small brachiopods - c., Meekella, Peniculauris bassi, Derbyia and Composita - f., "cannonball" chert - f., forms steep slope, chert weathers to stand in relief: 202 cm.

Total thickness, Harrisburg Member: 7393 cm.

Fossil Mountain Member

Ls. tan cherty ps., massive, crinoids, Composita, Peniculauris bassi and small brachiopods - c., very distinctive by its densely mottled chert tracery surface which weathers very dark brown, highly pitted chert is iron stained, forms upper part of massive cliff, separated from lower unit by stylolite: 220 cm.

Ls. lt. tan fossiliferous ps., massive to thick bedded, crinoids, fenestrate and ramose bryozoa, brachiopods, Composita and solitary corals - c., bivalves and trilobites - f., productid spines - ab. in "cannonball" chert, cliff forming unit, moderately fractured, chert nodules- very c. and weather w/ iron stain and stand in relief, separated from upper unit by a stylolite, (KT 18-20): 378 cm.

Ls. lt. gray ps. w/ many chert nodules and "cannonball" cherts, thick bedded to massive, crinoids, ramose and fenestrate bryozoa, solitary corals and small brachiopods - c., trilobites and bivalves - f., contains fewer "cannonball" cherts than underlying unit, cliff former, highly fractured: 400 cm.

Ls. lt. gray ps. w/ ab. "cannonball" chert, massive, solitary corals, crinoids, ramose bryozoa, brachiopods and Composita - c., trilobites and bivalves - f., productid spines - ab. in "cannonball" chert, many "cannonballs" are pink, forms cliff: 369 cm.

Ls. lt. gray fossiliferous ps. to ws. w/ ab. chert nodules, lenses and "cannonballs," thick to medium bedded, ramose and fenestrate bryozoa, brachiopods, Composita and solitary corals - c., trilobites and bivalves - f., productid spines - ab. in "cannonball" chert, much fossil-moldic porosity in chert, many chert nodules and "cannonballs" show concentric banding, forms base of cliff, (KT 18-19): 269 cm.

Covered: 200 cm.

Ls. dark gray ws. w/ densely mottled chert tracery surface, massive to thick bedded, Derbyia, Peniculauris bassi, brachiopods and crinoids - c., much fossil-moldic porosity in chert, forms very dark
stained, rust-colored (iron) bands across canyon, chert weathers to stand in relief, forms upper beds of massive cliffs: 325 cm.

Ls. lt. tan fossiliferous ws. to ps., massive, crinoids, ramose bryozoa and brachiopods - c., Squamaria ivest(?) - f., fossils are well distributed between chert and matrix, chert weathers to form very dense iron-stained surface which stands in relief: 418 cm.

Ls. tan fossiliferous gs., thick bedded to massive, trilobites, ramose and fenestrate bryozoa - c., fenestrate bryozoa - ab. in chert, chert is densely mottled on weathered surface, forms cliff: 301 cm.

Ls. tan fossiliferous gs. to ws., massive, small productids and brachiopods - c., Composita - f., slight amounts of fossil-moldic porosity, may be a ps. in lower part, forms cliff, (KT 18-18): 394 cm.

Ls. lt. tan fossiliferous ws. to ps., massive, crinoids, productids, large brachiopods and fenestrate bryozoa - c., trilobites(?) - f., upper half of unit is a fossiliferous gs., weathers to form sheet-like masses, very cherty at base, calcite veins - f., many horizontal stylolites separate bedding and are iron stained: 300 cm.

Ls. medium tan fossiliferous ws. to ms., massive to thick bedded, productids and crinoids c., chert weathers to stand in relief, chert is iron stained, very rough and pitted, (KT 18-17): 276 cm.

Ls. tan fossiliferous ms. w/ ab. chert nodules, thick bedded, fewer fossils than in upper units, small productids - f., some chert shows sponge-like centers, chert mottles surface, very rough and pitted, carbonate mud clasts – f.: 242 cm.

Ls. tan ms. to ws. w/ chert tracery, weathers massive but may be laminated, chert nodules contain sponge-like centers, f. small (centimeter size) iron-stained horizontal stylolites, forms major cliff at base of “voodoo” structures, highly weathered and pitted, very rough surface, chert weathers to stand in relief: 288 cm.

Ls. lt. tan ms. w/ chert tracery, massive, highly pitted, weathers medium gray, chert nodules weather to stand in relief, very rough surface, chert occurs in 10 - 30 cm bands: 295 cm.

Ls. lt. tan ms. w/ f. chert nodules and lenses, massive at top and thin bedded at base, chert lenses separate bedding, highly pitted, moderately fractured, may be slightly brecciated, forms indent at base of Fossil Mountain Member: 347 cm.

Total thickness, Fossil Mountain Member:  5022 cm.
Total thickness, Kaibab Formation: 12415 cm.

**Section 19: Tuckup Canyon**

Kaibab Formation
Harrisburg Member

Dolo. dull orange dolomitic ms. w/ ab. chert nodules, thick bedded, silicified brachiopods - c., chert is iron stained and weathers to stand in relief, moderately pitted, forms two distinct beds, (KT 19-14):  155 cm.

Covered: 100 cm.

Dolo. dull orange sandy ws. w/ many chert nodules, thick bedded, chert is iron stained and weathers to stand in relief, rough surface, forms top of massive cliff: 82 cm.

Dolo. dull orange dolomitic ws., massive, crinoids - f., moderate amounts of millimeter-size fossil-moldic porosity, forms very distinctive round-weathering bed, forms predominant ledge across outcrop, weathers vuggy, moderately pitted, many iron nodules (average 10 cm) stand in relief, scattered quartz grains (1-2 mm) increase in abundance toward top and weather to stand in relief, calcite nodules (partially
dissolved) - c., has 20 cm iron-stained, desiccation cracked caliche zone (disrupted lamination) at base, (KT 19-13): 281 cm.

Covered: 635 cm.

Dolo. lt. tan sandy ms. w/ many iron nodules, medium to thick bedded, iron nodules (average 2 cm) are stained w/ deep rust coating, mudcracks - c. in upper beds, slightly pitted, moderately vuggy, most vugs contain iron-stained molds, molds may have been pre-existing molluscans, weathers medium gray, (KT 19-12): 184 cm.

Ls. medium tan pelleted ms., thick bedded, mudcracks at top, forms lip, (KT 19-11): 100 cm.

Dolo. tan slightly brecciated ms., thin to medium bedded, may be mudcracked, moderately fractured, forms series of steps: 126 cm.

Covered: 348 cm.

Dolo. lt. tan brecciated ms., weathers as three massive beds, breccia average 1 - 3 cm, matrix is calcite and clasts are dolomite, calcite nodules - f., highly pitted and vuggy, contains 30 cm interval of highly contorted beds in center of unit, forms steps: 343 cm.

Dolo. medium tan ms. w/ many chert stringers (1 - 5 cm), laminated to thin bedded, f. chert nodules are iron stained, chert occurs in distinctive layers, many well-rounded quartz grains dispersed throughout unit: 73 cm.

Cht./Dolo. medium tan iron-stained chert and pelletal ms., weathers as one massive bed but contains highly contorted thin beds (individual beds are 3 - 5 cm thick), very unusual and distinctive by its bedding, chert lenses are iron stained, moderately fractured, and stand in relief, forms resistant wall, (KT 19-9): 165 cm.

Cht. iron-stained chert w/ occasional interbeds of ms., thick bedded, forms very resistant chert rim across outcrop, forms step: 92 cm.

Dolo. medium tan ms. w/ f. chert nodules, laminated but weathers massive to thick bedded, slightly brecciated, calcite clasts - f., many vertical burrows, bedding planes., are separated by chert nodules (average 4 cm) forms slope, (KT 19-8): 170 cm.

Dolo. medium tan ms., medium to thick bedded, productids - f., chert nodules - f., has thin bedded cherty layer at base which forms indent: 162 cm.

Dolo. tan dolomitic ms. w/ f. chert nodules, thick bedded, has thin bedded cherty layer at base: 70 cm.

Dolo. tan ms. w/ f. chert nodules, massive, productids - f., chert separates bedding, is iron stained and stands in relief, forms cliff: 110 cm.

Dolo. tan ms. w/ two chert lenses, massive, crinoids and productids - f., (KT 19-7): 142 cm.

Dolo. tan ms. w/ f. chert nodules, medium to thick bedded, productids - f., fossils occur only in chert, slight amounts of fossil-moldic porosity, chert weathers w/ iron stain to stand in relief: 270 cm.

Ls. tan ms., vague, wispy laminations but weathers massive, *Peniculauris bassi* - c. at base of unit, *Composita* - f., calcite nodules - f., sandy, chert nodules - f., are iron stained and stand in relief, forms cliff: 169 cm.

Ls. lt. tan fossiliferous ws. w/ f. chert nodules, thin bedded to laminated, crinoids and *Peniculauris bassi* - f., forms indent: 53 cm.

Ls. medium brown fossiliferous ws. to ms. w/ many chert lenses and f. "cannonball" cherts, thin to medium bedded, bedding planes are wavy, crinoids, *Peniculauris bassi*, productid spines and ramose
bryozoa - c., fossils are oriented parallel to bedding, chert occurs as lenses at top and nodules separating bedding at base, weathers lt. gray, forms series of steep steps, (KT 19-6): 284 cm.

Covered: 126 cm.

Ls. lt. gray fossiliferous ws. w/ ab. chert tracery, medium bedded but weathers as one massive unit, crinoids, brachiopods and *Peniculauris bassi* - c., fenestrate bryozoa - f., "cannonball" chert (over 15 cm in diameter) - f., chert nodules and "cannonballs" weather to stand in relief, forms wall: 191 cm.

Ls. lt. gray fossiliferous ps. w/ many chert lenses and "cannonball" cherts, massive, crinoids, brachiopods and *Peniculauris bassi* - c., moderately fractured: 149 cm.

Total thickness, Harrisburg Member: 4580 cm.

Fossil Mountain Member

Ls. lt. gray fossiliferous ps. w/ many chert lenses and "cannonball" cherts, massive, productids and productid spines, ramose bryozoa and crinoids - c., fenestrate bryozoa and bivalves - f., *Derbyia*(?) – r., weathers w/ very dense iron stain to form highly weathered chert band across outcrop, chert is highly weathered, pitted, vuggy, and stands in relief: 219 cm.

Ls. lt. gray fossiliferous ps. w/ many chert lenses and "cannonball" cherts, medium bedded, crinoids, productids, productid spines and ramose bryozoa - c., fenestrate bryozoa and bivalves - f., *Derbyia* - r., chert weathers white, cannonballs" average 8 cm, forms a series of steps: 192 cm.

Ls. lt. tan cherty ms. w/ f. chert lenses, thin bedded: 62 cm.

Ls. lt. gray fossiliferous ws. to ps. w/ many "cannonball" cherts, thin to thick bedded, crinoids, productids and ramose bryozoa - c., bivalves - f., some "cannonballs" are pink, weather dull orange, moderately fractured, calcite veins - f., chert weathers w/ iron stain to stand in relief, forms wall, (KT 19-5): 241 cm.

Ls. lt. gray fossiliferous ps. w/ ab. "cannonball" cherts, thick bedded, crinoids, ramose bryozoa, brachiopods and *Peniculauris bassi* - c., solitary corals - f., much fauna in both chert and matrix, "cannonballs" up to 25 cm in diameter, many contain interior concretionary banding, others have sponge-like centers, some "cannonballs" weather to stand in relief, others weather out to form circular vugs, moderately fractured, forms slope: 380 cm.

Ls. gray fossiliferous ws. w/ many "cannonball" cherts and chert nodules, medium bedded, crinoids, ramose bryozoa and *Peniculauris bassi* - c., corals - f., chert separates bedding and weathers w/ iron stain, forms wall: 152 cm.

Ls. gray fossiliferous ws. w/ many chert nodules and "cannonball" cherts, thick bedded, highly fossiliferous, crinoids, *Peniculauris bassi*, productid spines, ramose bryozoa and *Composita* - c., solitary corals - f., some of the chert shows concentric banding, chert separates bedding, "cannonballs" average 8 cm, moderately fractured and pitted: 218 cm.

Ls. gray fossiliferous ws. w/ many chert nodules and f. "cannonball" cherts, thick bedded, highly fossiliferous, crinoids, bivalves, productid spines, *Derbyia* and *Peniculauris bassi* – c., solitary corals - f., ab. chert tracery, surface weathers very rough and slightly pitted: 160 cm.

Ls. lt. gray fossiliferous ws. to ws. w/ many "cannonball" cherts and f. chert nodules, medium to thin bedded, crinoids, productid spines, *Peniculauris bassi* and *Composita* - c., bivalves - f., "cannonballs" reach 10 cm in diameter, chert weathers white, moderately fractured, partially covered, forms slope, (KT 19-4): 637 cm.

Ls. lt. gray fossiliferous ws. to ps. w/ f. chert nodules, thin bedded, crinoids and productids - c., chert nodules - c. in upper part and form densely mottled surface, slightly pitted, forms series of steps: 243 cm.
Ls. lt. gray fossiliferous ps. w/ f. chert nodules, uniformly thin beds (10 cm), highly fossiliferous, crinoids, ramose and fenestrate bryozoa, productid spines and *Peniculauris bassi* - c., solitary corals and *Meekella*? - f., chert weathers w/ iron stain to stand in relief, forms series of steps: 179 cm.

Ls. lt. tan cherty ms. w/ many chert nodules, laminated, forms indent: 39 cm.

Ls. gray fossiliferous ps. w/ f. chert nodules, thin bedded (15 - 20 cm), crinoids (broken and disarticulated) - ab., ramose and fenestrate bryozoa, *Composita, Peniculauris bassi* and productids (general) - c., solitary corals and *Rugatia* - f., chert lenses - f., partially covered, forms slope: 352 cm.

Covered: 144 cm.

Dolo. tan fossiliferous ws. w/ many chert nodules, thick bedded to massive, crinoids, *Composita* and *Peniculauris bassi* - c., *Rugatia* and *Derbyia* - f., chert contains much brachiopod debris, contains laminated chert lens at top, chert tracery is highly weathered and stands in relief, forms step w/ indent at base: 109 cm.

Covered: 71 cm.

Dolo. tan ms. to crystalline carbonate, thin bedded, solitary corals - f., becomes cherty at top, chert separates bedding and forms two distinct layers, sandy texture, calcite veins are parallel to bedding, (KT 19-3): 80 cm.

Covered: 131 cm.

Dolo. lt. tan cherty ms., massive, weathers very rough and pitted, contains slight amounts of quartz sand, forms gently sloping cliff: 254 cm.

Dolo. lt. tan cherty ms. w/ very densely mottled chert tracery surface, thick bedded, vuggy, highly weathered, chert weathers w/ iron stain to stand in relief: 149 cm.

Dolo. lt. tan cherty ms. to ws. w/ ab. small chert nodules, weathers massive but has few wispy laminations, f. sponge-like structures in chert nodules, chert tracery is very dense, highly weathered (rust) and stands in relief, becomes vuggy at top, 1 cm carbonate clasts - c., weathers as two massive units, highly pitted, many iron-stained moldic vugs, sandy texture, (KT 19-2): 269.

Dolo. lt. tan fossiliferous ws. w/ very dense chert mottling, massive and medium bedded, most fossils are found in chert and are broken and disarticulated, productids and productid spines - c., weathers very rough and highly pitted, forms black unit across outcrop, chert is iron stained and stands in relief, forms two steps: 137 cm.

Dolo. lt. gray ws. to ms. w/ very densely mottled chert tracery, may be laminated but weathers massive, chert is very rough, pitted, iron stained, and stands in relief, chert nodules are found in distinct bands and appear to separate bedding, forms wall, (KT 19-1): 358 cm.

Dolo. lt. tan fossiliferous ws. w/ ab. chert tracery, massive, crinoids, productids and brachiopods - c., all fossils are disarticulated and broken, most fossils are contained in chert nodules, chert is iron stained and stands in relief, unit weathers very rough and highly pitted: 198 cm.

Dolo. lt. tan fossiliferous ws. w/ f. chert nodules, thick bedded, crinoids and productids - f., chert nodules have sponge structures in centers, chert nodules- iron stained and stand in relief, weathers smooth: 60 cm.

Total thickness (partial section), Fossil Mountain Member: 5034 cm.

Total thickness (partial section), Kaibab Formation: 9614 cm.

**Section 20: Virgin River Gorge**

Kaibab Formation Fossil Mountain Member (partial section)
Is. lt. gray crinoidal ps. to ws. w/ many chert lenses, massive, most fossils are disarticulated and broken, crinoids, productids, productid spines and ramose bryozoal - c., gastropods(?) slight amounts of fossil-moldic porosity in chert, chert is iron stained, very densely mottled, and weathers to stand in relief, slightly pitted and fractured, (KT 20-20): 320 cm.

Ls. lt. gray crinoidal ws., medium bedded, crinoids and ramose bryozoal - c., productids (disarticulated and broken) - c., chert forms very densely mottled tracery surface, weathers w/ iron stain and stands in relief: 132 cm.

Ls. lt. gray crinoidal ws. w/ f. chert lenses, thick bedded, crinoids, ramose and fenestrate bryozoal - c., chert separates bedding, forms wall: 235 cm.

Ls. lt. gray crinoidal ws. to ps. w/ densely mottled chert tracery, massive, crinoids and fenestrate bryozoal (disarticulated and broken) - c., unit is distinctive by containing three iron-stained chert layers which can be traced laterally across the outcrop, (KT 20-19): 297 cm.

Ls. lt. gray crinoidal ps. w/ very dense chert tracery at top, medium bedded, crinoids, ramose and fenestrate bryozoal and Peniculauris bassi - c., weathers very dark gray at top, forms three steps: 258 cm.

Ls. gray crinoidal ps. to ws. w/ many chert lenses and f. chert nodules, massive, crinoids, ramose and fenestrate bryozoal - c., some chert nodules have sponge-like centers, surface is highly weathered w/ densely mottled (iron-stained) chert, moderately fractured, forms cliff, (KT 20-18): 441 cm.

Ls. lt. gray crinoidal ps. w/ much chert tracery, thick bedded to massive, fossils are contained in both chert and carbonate matrix, most fossils are disarticulated and broken, crinoids, productids and ramose bryozoal - c., moderately fractured and weathered, chert weathers to stand in relief and separates bedding, forms small cliff: 386 cm.

Ls. gray fossiliferous ws. w/ very densely mottled chert tracery, massive, crinoids - c., productids - f. but increase in abundance toward top, slightly pitted, forms cliff: 447 cm.

Ls. lt. gray cherty, fossiliferous ps., thick bedded to massive, crinoids, Peniculauris bassi and Composita - c., solitary corals and bellerophon gastropods - f., chert is iron stained, stands in relief, and forms very densely mottled surface, (KT 20-17): 171 cm.

Ls. lt. gray fossiliferous ws. to ps. w/ very densely mottled chert tracery surface, massive, fossils are in both chert and carbonate matrix, unit is distinctive by weathering to form massive black unit across outcrop, forms massive protruding cliff: 524 cm.

Ls. lt. tan fossiliferous ws. w/ densely mottled chert surface, massive, fossils are broken and disarticulated, crinoids and Peniculauris bassi - c., weathers to form two massive cliff units, (KT 20-16): 277 cm.

Ls. lt. gray fossiliferous ws. w/ many chert nodules, massive to thick bedded, many broken and disarticulated fossils, crinoids and Peniculauris bassi - c., iron nodules f., chert is densely mottled and stands in relief, forms gently sloping cliff: 389 cm.

Ls. gray fossiliferous ps. to gs. w/ many chert nodules and lenses, medium bedded to massive, highly fossiliferous, fauna in both chert and matrix, crinoids, brachiopods, bivalves, ramose and fenestrate bryozoal - c., bryozoal (general) Peniculauris bassi, Composita and Rugatia f., slight amounts of fossil-moldic porosity in chert, chert is iron stained and stands in relief, moderately fractured, very rough and slightly pitted, forms cliff: 529 cm.

Ls. lt. gray fossiliferous ps. w/ ab. chert tracery, thick bedded to massive, crinoids, fenestrate bryozoal, Peniculauris bassi, Composita, Rugatia and disarticulated and broken brachiopods - c., weathers very dark gray, slightly pitted, chert weathers to stand in relief, forms cliff: 349 cm.
Ls. lt. gray crinoidal ws. w/ many chert nodules, weathers massive but may be thin bedded, crinoids, productids, productid spines, fenestrate and ramose bryozoa, and brachiopods (general) - c., chert weathers w/ iron stain to form densely mottled surface, forms cliff: 298 cm.

Ls. gray cherty crinoidal ws., medium bedded but weathers massive, crinoids and brachiopods - c., Derbyia - f., weathers dark gray w/ iron stain, slightly pitted, chert is densely mottled w/ iron stain and stands in relief, base of unit has large horizontal stylolite: 381 cm.

Ls. lt. gray fossiliferous ws. w/ f. chert nodules, thick bedded, crinoids and productids - c., spirifers, ramose bryozoa and small brachiopods (2 mm) - f., slight amounts of fossil-moldic porosity in chert and matrix, moderately fractured, forms cliff, (KT 20-15): 313 cm.

Ls. lt. gray fossiliferous ws. w/ many chert nodules, unit contains f. fossils, crinoids and productid spines - f., moderately weathered and fractured, many vertical joints, forms cliff: 332 cm.

Ls. tan to gray fossiliferous cherty ws. w/ many chert nodules, thick bedded but weathers as one massive cliff, crinoids and productids - c., moderately fractured, (KT 20-14): 400 cm.

Ls. lt. gray fossiliferous ws. w/ many chert nodules, massive, crinoids, productids and brachiopods (general) - c., ramose bryozoa, Rugatia and Composita (?) - f., slight amounts of moldic porosity, slightly fractured, weathers dark gray, chert weathers w/ iron stain to stand in relief, forms sheer cliff: 598 cm.

Ls. gray fossiliferous ws., massive, crinoids and productids - c., freshly fractured, may be slumped and brecciated, f. chert nodules separate bedding, becomes covered on opposite side of wash, forms base of major cliff: 757 cm.

Total thickness (partial section), Fossil Mountain Member: 7834 cm.

Total thickness (partial section), Kaibab Formation: 7834 cm.

Section 21: Ryan

Kaibab Formation (partial section)
Fossil Mountain Member (partial section)

Ls. lt. tan sandy, calcareous ms. w/ many chert nodules and lenses, wispy laminations but weathers thin bedded, crinoids, ramose bryozoa, productids, Peniculauris bassi and bivalves - c., fenestrate bryozoa - f., wavy bedding, (KT 21-15): 280 cm.

Ls. lt. tan sandy, calcareous ms. w/ f. chert nodules and lenses, wispy laminations but weathers thin bedded, laminations bend around chert nodules, large Peniculauris bassi, ramose bryozoa, crinoids, productids, productid spines and bivalves - c., fenestrate bryozoa - f., not as fossiliferous as lower unit, chert nodules are iron stained and weather to stand in relief, forms wall: 183 cm.

Ls. medium gray silty, fossiliferous ps. to ws. w/ ab. chert nodules and lenses, thin bedded, wispy laminations - c., highly fossiliferous w/ most fossils being well preserved, ramose bryozoa, crinoids, productids, productid spines, bivalves and Peniculauris bassi - c., fenestrate bryozoa - f., most chert nodules have sponge-like centers, forms wall, (KT 21-14): 270 cm.

Dolo. lt. tan cherty, silty ms., medium bedded, wispy laminations are very c. and beds around chert, highly fossiliferous, productids, ramose bryozoa, crinoids, productid spines, and Composita - c., Peniculauris bassi - f., moderately burrowed, forms wall, (KT 21-13): 215 cm.

Ss. lt. tan fine-grained ss. to sltst., thick bedded, brachiopods - f., coarse (2 mm) sand grains at top, sand - poorly sorted and rounded, forms wall: 311 cm.

Ss. tan medium-grained ss. massive to thick bedded, but may be laminated, slightly calcareous, very clean sand: 177 cm.
Covered: 200.

Slst. tan dolomitic slst. w/ f. chert nodules, massive, may be slightly laminated, forms massive wall, (KT 21-12): 448 cm.

Dolo. tan silty ms. w/ many chert nodules, laminated but weathers massive, sand - well sorted, moderately well rounded, forms cliff: 159 cm.

Dolo. lt. tan sandy ms. w/ many chert nodules, has many drape-like laminations but weathers massive, algal stromatolites(? - f., forms base of cliff, (KT 21-11): 159 cm.

Ls. lt. gray silty, fossiliferous ws. to ms., massive, crinoids - ab., ramose bryozoa - c., most fossils are well preserved and articulated, chert nodules - f., moderately fractured, (KT 21-10): 168 cm.

Total thickness (partial section), Fossil Mountain Member: 2570 cm.

Total thickness (partial section), Kaibab Formation: 2570 cm.

Section 22: Jumpup Canyon

Kaibab Formation
Harrisburg Member

Dolo. gray chert interbedded w/ fine-grained ss. and fossiliferous ws., thin bedded but weathers as three massive units, bedding is contorted and reminiscent of algal laminations, very resistant and forms distinctive ledge across outcrop, iron nodules - f., sand grains are aligned parallel to bedding, (KT 22-21 and KT 22-20): 345 cm.

Covered: 161 cm.

Dolo. medium tan sandy ms., massive, weathers as distinctive round unit, chert nodules f., many medium-size sand grains weather to stand in relief: 95 cm.

Covered: 454 cm.

Dolo. medium tan calcareous, fine-grained ss. to slst. to crystalline carbonate, thick bedded, very pure (highly resistant) iron nodules weather to stand in relief, highly pitted and moderately fractured, forms three steps, (KT 22-19): 152 cm.

Covered: 285 cm.

Dolo. tan silty and sandy ms. to ws. interbedded w/ laminated chert, laminated but weathers thick bedded to massive, chert is highly contorted and very resistant, sand - very well sorted and well rounded, unit is moderately weathered and highly fractured, forms four continuous beds: 251 cm.

Covered: 75 cm.

Ss. dull yellow to tan medium-grained, well rounded, calcareous ss. w/ f. chert nodules, medium bedded, chert weathers to stand in relief, partially covered: 277 cm.

Covered: 27 cm.

Dolo. lt. tan silty ws. to ms. w/ f. chert nodules, medium to thick bedded, crinoids and brachiopods - c., most fossils are disarticulated and broken, slightly pitted, forms wall: 190 cm.

Dolo. lt. tan silty ms. to ws., medium bedded to massive, disarticulated crinoids - c., solitary corals – r., chert nodules occur in distinct bands parallel to bedding, chert nodules are iron stained and weather to stand in relief, forms rim or plateau of massive cliff: 169 cm.

Total thickness, Harrisburg Member: 2481 cm.
Fossil Mountain Member

Dolo. lt. tan silty ws., medium bedded but appears to contain few algal(?) laminations, most fossils are disarticulated and broken, crinoids and brachiopods - c., solitary corals - f., chert occurs in bands parallel to bedding, sand - very clean and well sorted, forms wall: 226 cm.

Dolo. tan, highly weathered ms. w/ ab. chert nodules and lenses, massive, crinoids - c., productids (disarticulated and broken) - c., moderate amounts of fossil-moldic porosity, forms major cliff above slope-forming units, slight amounts of moldic porosity in chert, weathers dark gray, chert is iron stained and stands in relief, (KT 22-18): 200 cm.

Ls. lt. gray bryozoan ps. to ws. w/ f. "cannonball" cherts and chert lenses, thin to medium bedded, bedding planes are very wavy, large crinoids, productids and ramose bryozoa - c., moderately fractured, (KT 22-17): 200 cm.

Covered: 84 cm.

Ls. lt. gray, highly fossiliferous ws. to ps. w/ many "cannonball" cherts, medium to thin bedded, crinoids (up to 2 cm in diameter), ramose and fenestrate bryozoa, *Peniculauris bassi* and other productids - c., moldic porosity in chert -f., moderately fractured, forms series of steps, (KT 22-16): 172 cm.

Ls. gray, highly fossiliferous ps. to gs. w/ ab. "cannonball" cherts, thin bedded, large crinoids, productid spines, *Peniculauris bassi*, other productids, and ramose and fenestrate bryozoa - c., chert weathers white, moderately fractured, forms slope, partially covered, well exposed at base: 1085 cm.

Ls. lt. tan fossiliferous ps. w/ many "cannonball" cherts, medium bedded, crinoids, productid spines, *Peniculauris bassi* and other productids - c., *Meekella* and *Composita* - f., weathers dark gray to form wall: 135 cm.

It. tan fossiliferous ps. to ws. w/ ab. "cannonball" cherts, medium to thick bedded, crinoids, productids and productid spines, and *Peniculauris bassi* - c., *Meekella* and *Composita* - f., much fauna in both chert and matrix, "cannonballs" average 8 - 10 cm and weather white, moderately fractured, chert weathers to stand in relief, partially covered, forms slope, (KT 22-15): 1175 cm.

Ls. tan, highly fossiliferous ps., medium to thin bedded, crinoids - ab., disarticulated and broken productids, and ramose bryozoa - c., moderately fractured: 90 cm.

Ls. lt. tan fossiliferous ps. to ws. w/ ab. chert nodules, thin to thick bedded, highly fossiliferous, most fossils are disarticulated and broken, most fossils are very large, ramose and fenestrate bryozoa, crinoids, *Peniculauris bassi* (some reach 6 cm in length), *Derbyia, Composita*, solitary corals, brachiopods and productids (general) - c., moderately fractured, forms steep slope, (KT 22-14): 1114 cm.

Ls. tan, highly fossiliferous, silty ps. to ws. w/ ab. chert nodules, thin to thick bedded, *Peniculauris bassi*, crinoids, and ramose and fenestrate bryozoa - c., chert separates bedding and weathers white, bedding planes are very wavy, forms gentle slope, (KT 22-13): 565 cm.

Ls. tan, highly fossiliferous, cherty ps., thin to very thin bedded, many fossils weather w/ purple or red stain, *Peniculauris bassi*, crinoids, ramose and fenestrate bryozoa - c., chert separates bedding, forms steep slope w/in stream channel: 474 cm.

Total thickness, Fossil Mountain Member: 5520 cm.

Total thickness, Kaibab Formation: 8001 cm.

**Section 23: North Seegmuller Mountain (Mokiah Wash)**

Kaibab Formation

Harrisburg Member
Ls. lt. tan fossiliferous ws. w/ many chert nodules, medium to thin bedded, crinoids, bivalves and Derbyia - c., *Peniculauris bassi* and fenestrate bryozoa - f., chert nodules weather bronze and stand in relief, highly fractured, (KT 23-14): 390 cm.

Ls. lt. tan fossiliferous ws. w/ many chert nodules, thick bedded but weathers massive, crinoids, *Peniculauris bassi, Composita* and disarticulated and broken brachiopod debris - c., *Rugatia* - f., highly cherty and forms densely mottled, iron-stained surface, slight amounts of moldic porosity in chert, forms cliff, (KT 23-13): 338 cm.

Total thickness, Harrisburg Member: 728 cm.

Fossil Mountain Member

Ls. lt. tan fossiliferous ws. w/ many chert nodules and lenses, massive but may be laminated, *Composita* (small), crinoids, ramose and fenestrate bryozoa, and productids - c., *Meekella(?)* - f., moldic porosity in chert -f., unit is distinctive by weathering w/ very densely mottled chert tracery surface which forms continuous band across outcrop, horizontal stylolites c., forms vertical wall, (KT 23-12): 274 cm.

Ls. medium gray fossiliferous ps. to ws. w/ many chert nodules, massive to thick bedded, crinoids, fenestrate and ramose bryozoa, productids, and bryozoa (general) - c., very resistant chert bed (20 cm) at top, weathers lt. to medium tan, fossil-moldic(?) porosity in chert -f., chert is iron stained and stands in relief, (KT 23-11): 426 cm.

Ls. medium gray fossiliferous ws. w/ many chert nodules and lenses, massive to thick bedded, crinoids, *Derbyia*, productids, bryozoa (general) - c., very resistant chert bed (20 cm) at top, weathers lt. to medium tan, fossil-moldic(?) porosity in chert -f., chert is iron stained and stands in relief, moderately fractured, slightly pitted, slightly vuggy at top, forms cliff: 735 cm.

Ls. lt. tan fossiliferous ws. w/ many chert nodules and lenses and "cannonballs"(?), may be laminated but weathers thick bedded to massive, ramose bryozoa and crinoids - c., fenestrate bryozoa, solitary corals, *Composita, Derbyia* and small productids - f., "cannonball" chert - f., chert is iron stained and stands in relief, moderately weathered and fractured, forms two cliffs: 539 cm.

Ls. lt. gray fossiliferous ws. w/ many chert nodules and f. "cannonball" cherts, thin to thick bedded, crinoids, *Peniculauris bassi* and ramose bryozoa - c., fenestrate bryozoa, *Derbyia* and *Composita* - f., (KT 23-10): 169 cm.

Ls. gray fossiliferous ws. w/ many chert nodules and f. "cannonball" cherts, massive, fauna is contained in both chert and matrix, *Meekella, Peniculauris bassi* and crinoids - c., trilobites and *Composita*- f., f. iron-stained "cannonball" cherts at top: 154 cm.

Ls. medium gray fossiliferous ps., medium to thick bedded, *Meekella, Peniculauris bassi* and crinoids - c., trilobites and *Composita* - f., few 6 cm "cannonball" cherts, freshly weathered, moderately fractured, few chert nodules and lenses, forms cliff: 514 cm.

Ls. gray fossiliferous and cherty ws. to ps., medium bedded, spirifers and *Peniculauris bassi* - c., *Composita* - f., chert is iron stained and weathers to stand in relief forming a densely mottled surface, forms cliff: 221 cm.

Ls. lt. tan fossiliferous ws. w/ many chert nodules, thick bedded to massive, fenestrate bryozoa, *Derbyia, Peniculauris bassi* and *Composita* - c., solitary corals - f., slight amounts of moldic porosity in chert, forms cliff, (KT 23-9): 517 cm.


Covered: 98 cm.
Ls. lt. tan fossiliferous ws. w/ very dense chert tracery, thick bedded to massive, crinoids and ramose bryozoa - c., fenestrate bryozoa, Derbyia and Composita - f., slight amounts of moldic porosity in chert, weathers very rough and pitted, chert is iron stained and weathers to stand in relief, forms four predominant steps: 384 cm.

Ls. medium gray ws. w/ very densely mottled chert tracery, massive, crinoids and productids - c., fenestrate bryozoa - f., weathers very dark gray to form band across outcrop: 293 cm.

Ls. medium gray ws. w/ very densely mottled chert tracery, massive to thick bedded, crinoids and productids - c., fenestrate bryozoa - f., chert is densely iron stained (dark gray), stands in relief and forms distinctive band across outcrop: 275 cm.

Ls. medium gray ws. w/ very densely mottled chert tracery, massive, crinoids and brachiopods (disarticulated and broken) - f., chert is iron stained, stands in relief and forms very distinctive dark weathered band across outcrop, weathers as one massive cliff: 341 cm.

Ls. lt. gray fossiliferous ws. w/ many chert nodules and lenses, medium bedded, fossils are in both chert and matrix, productid spines - ab., productids, ramose bryozoa, crinoids and small brachiopods - c., fenestrate bryozoa - f., moderately fractured and freshly weathered, forms cliff: 563 cm.

Ls. lt. tan highly fossiliferous ps. w/ many chert nodules, medium to thin bedded, wavy bedding surfaces, Composita, ramose bryozoa, crinoids and brachiopods (disarticulated and broken) - c., has slight amounts of fossil(?)- moldic porosity, freshly fractured and very slightly weathered, forms cliff: 359 cm.

Ls. medium gray productid ws. w/ many chert nodules, thin to medium bedded, productid spines, Composita, small brachiopods (disarticulated and broken) - c., trilobites - f., highly fossiliferous, fossils in both chert and matrix, moderately fractured (fresh), forms base of massive cliffs, (KT 23-8): 546 cm.

Total thickness, Fossil Mountain Member: 6705 cm.

Total thickness, Kaibab Formation: 7433 cm.

**Section 24: Pigeon Creek Canyon**

Kaibab Formation has been removed during the current cycle of erosion

**Section 25: Atkin's Ranch**

Kaibab Formation

Harrisburg Member

Dolo. dull orange tan ms., thick bedded but laminated at base, mudcracks - c., many small (1 cm) carbonate clasts, sandy texture, calcite nodules - f., slightly pitted, chert nodules - c. and stand in relief, (KT 25-16): 217 cm.

Covered: 167 cm.

Dolo. dull orange and yellow dolomitic ms. w/ f. chert nodules, medium to thick bedded, weathers slightly pink, mudcracks(?) - f., chert weathers to stand in relief, forms ledge: 100 cm.

Covered: 177 cm.

Dolo. dull orange to yellow ms. w/ f. chert nodules, massive, weathers blocky, chert nodules weather to stand in relief, weathers as one massive unit: 358 cm.

Gyp. white and red gypstone, laminated, weathers red in lower half of unit and white in upper part, forms slope: 4437 cm.

Dolo. medium gray cherty ms., thin bedded, many wavy beds, mudcracks - c., has many interbeds and lenses of chert, highly fractured, most of the ms. units are laminated, forms two distinct walls: 310 cm.

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Covered: 264 cm.

Ls. lt. tan crinoidal ws., many chert nodules, thin to thick bedded, crinoids and *Peniculauris bassi* (at top) - c., small brachiopods (broken and disarticulated) - f., calcite nodules - f., forms slope w/ step: 512 cm.

Ls. medium gray crinoidal ws. to gs. w/ f. chert nodules and interbeds, thin to thick bedded, very large ramose bryozoa (up to 3 cm in diameter) - ab., crinoids, *Peniculauris bassi* and other productids (disarticulated and broken) - c., many ramose bryozoa have been replaced w/ pink rhodochrosite(?), weathers round at top, chert has slight amounts of fossil- (crinoids) moldic porosity, forms wall, (KT 25-15): 320 cm.

Total thickness, Harrisburg Member: 7060 cm.

**Fossil Mountain Member**

Ls. lt. tan fossiliferous ps. w/ many chert nodules, medium to thick bedded, highly fossiliferous, ramose and fenestrate bryozoa, crinoids, and productid spines - c., has very densely mottled chert surface which forms dark band across outcrop, forms cliff: 227 cm.

Ls. lt. tan fossiliferous ps. w/ many chert nodules, medium bedded, ramose and fenestrate bryozoa, crinoids and productid spines - c., *Meekella* - f., highly fossiliferous, weathers medium gray, f. chert nodules are iron stained and stand in relief, forms cliff: 258 cm.

Ls. lt. tan fossiliferous ws. w/ f. chert nodules, thick to medium bedded, ramose bryozoa and crinoids - c., weathers round, forms two massive steps: 235 cm.

Ls. lt. tan fossiliferous gs. to ps. w/ many chert nodules and "cannonball" cherts, massive, bedding planes are wavy, fenestrate and ramose bryozoa, and crinoids - c., *Composita* - f., many "cannonballs" have sponge-like centers, "cannonballs" reach 15 cm in diameter, f. "cannonballs" weather to stand in relief, forms cliff, (KT 25-14): 610 cm.

Ls. lt. tan fossiliferous gs. w/ many chert nodules, lenses and f. "cannonballs- massive to thick bedded, crinoids, ramose and fenestrate bryozoa, and *Peniculauris bassi* - c., most fossils are disarticulated and broken, many ramose bryozoa are replaced w/ pink rhodochrosite(?), many large calcite veins at top, forms two large cliffs: 460 cm

Covered: 90 cm.

Ls. lt. gray fossiliferous ws. and ps. w/ f. chert nodules, medium to thick bedded, very large ramose bryozoa (3 cm in diameter), *Peniculauris bassi*, other productids and crinoids, most fossils are disarticulated and broken, minor amounts of fossil(?)-moldic porosity in chert, slightly pitted and moderately fractured, contains many horizontal stylolites, weathers blocky and forms cliff: 610 cm.

Ls. lt. gray fossiliferous ps., thick bedded to massive, ramose bryozoa, *Peniculauris bassi* and crinoids - c., fenestrate bryozoa - f., highly fossiliferous, bedding planes -wavy, and often separated by horizontal stylolites, chert nodules - f., chert nodules weather to stand in relief, forms massive cliff, (KT 25-13): 522 cm.

Ls. lt. gray fossiliferous ws. w/ f. chert nodules, thick bedded, crinoids, *Peniculauris bassi* and other productids - c., moderately and freshly fractured, many horizontal stylolites, f. chert nodules weather to stand in relief, forms cliff: 265 cm.

Covered: 277 cm.
Ls. lt. tan fossiliferous ws. w/ many chert nodules and lenses, massive, ramose bryozoa, crinoids, *Peniculauris bassi* and *Composita* - c., bryozoa (general) - f., forms top of cliff: 218 cm.

Ls. lt. tan fossiliferous ws. w/ many chert nodules and lenses, massive, ramose bryozoa, crinoids, *Peniculauris bassi, Composita* and solitary corals - c., bryozoa (general) - f., many chert nodules have sponge-like centers, chert weathers white, highly fractured, f. wavy beds, slight amounts of porosity in chert, forms cliff, (KT 25-12): 424 cm.

Covered: 300 cm.

Ls. lt. tan fossiliferous ws. to ps. w/ many chert nodules and lenses, massive, to thick bedded, ramose bryozoa, *Composita, Peniculauris bassi* and crinoids - c., solitary corals and *Meekella* - f., chert weathers white and has slight amounts of moldic porosity, chert weathers to stand in relief, f. horizontal stylolites, forms cliff: 531 cm.

Ls. medium gray fossiliferous ps., massive to thick bedded, crinoids and *Peniculauris bassi* - c., solitary corals, *Derbyia* and *Rugatia* - f., many spicule-like features in chert nodules, many chert nodules reach 12 cm in diameter and contain sponge-like centers, slight amounts of porosity in chert, chert is highly fractured, forms massive cliff: 354 cm.

Covered, 357 cm.

Ls. lt. tan cherty, fossiliferous ws. to ps. w/ many chert nodules and lenses, massive to thick bedded, ramose bryozoa, *Composita, Peniculauris bassi* and crinoids - c., solitary corals and *Meekella* - f., chert weathers white and has slight amounts of moldic porosity, chert weathers to stand in relief, f. horizontal stylolites, forms cliff, (KT 25-11): 398 cm.

Ls. medium gray fossiliferous ps., massive to thick bedded, crinoids and *Peniculauris bassi* - c., solitary corals, *Composita* - f., chert weathers white, highly fractured but becomes highly fractured at top, slightly iron stained, forms wall: 535 cm.

Ls. medium gray cherty ws., medium to thick bedded, wispy laminations f., carbonate clasts (breccia(?)), much moldic porosity at top, weathers smooth and forms base of cliff, (KT 25-10): 151 cm.

**Total thickness, Fossil Mountain Member:** 7671 cm.

**Total thickness, Kaibab Formation:** 14731 cm.

**Section 26: Hobble Canyon**

Kaibab Formation

Harrisburg Member

Dolo. lt. tan, well-laminated, silty crystalline carbonate w/ dense chert tracery, massive, well sorted quartz silt, minor amounts of calcareous cement, chert weathers w/ iron stain and stands in relief, laminations continue from sltst. through chert layers, forms wall, (KT 26-10): 198 cm.

Covered: 283 cm.

Dolo. lt. tan to dull yellow, sandy and cherty ms., massive, fenestrate bryozoa, crinoids, *Composita* and brachiopods - c., may be burrowed, calcite nodules - c., many large (up to 8 cm) chert nodules, weathers round, (KT 26-9): 286 cm.
Covered: 636 cm.

Dolo. dull orange dolomitic and sandy ms. w/ many chert nodules, broken productids and crinoids - c., calcite nodules and iron nodules (up to 2 cm) - c. and weather to stand in relief, (KT 26- 8): 290 cm.

Gyp. gypsum, partially covered slope: 1375 cm.

Ls. very dark gray fossiliferous ms., thick bedded, moderately burrowed, one cephalopod (5 cm), iron nodules - f., weathers blocky, distinctive due to its subconchoidal fracture, slightly pitted, (KT 26-7): 165 cm.

Covered: 2165 cm.

Total thickness, Harrisburg Member: 5398 cm.

Fossil Mountain Member

Ls. lt. gray fossiliferous ws. to ps. w/ many chert nodules and lenses, thick bedded, highly fossiliferous, large crinoids, productids and Peniculauris bassi - c., most fossils are broken and disarticulated, partially covered, forms a series of steps separated by covered intervals, (KT 26-6): 1347 cm.

Ls. lt. tan fossiliferous ws. to ps. w/ f. chert nodules, medium to thick bedded, crinoids, ramose bryozoa and Peniculauris bassi - c., Meekella - f., partially covered, (KT 26-5): 306 cm.

Ls. lt. tan fossiliferous ws. w/ f. chert nodules, medium bedded, Peniculauris bassi, ramose bryozoa and crinoids - c., Meekella - f., most fossils are broken, forms" gently sloping wall: 237 cm.

Ls. mostly covered cherty ws.: 1869 cm.

Ls. lt. gray ws. to ps. w/ very densely mottled chert tracery, massive, Composita, Peniculauris bassi, crinoids and ramose bryozoa - c., most fossils are disarticulated and broken, chert is highly weathered and stands in relief, very rough surface, individual units may be separated by stylolites, sets back from underlying cliff, forms steep wall: 348 cm.

Ls. lt. gray fossiliferous ps. w/ ab. chert tracery, massive to thick bedded, crinoids, ramose bryozoa, Composita, Peniculauris bassi and other productids- c., fenestrate bryozoa and solitary corals - f., much fauna in both chert and matrix, very densely mottled iron-stained chert and weathers to stand in relief, highly pitted and vuggy, highly weathered (dark brown) forming dark band across outcrop, fossil(?)-moldic porosity in chert -f., forms top of major cliff: 247 cm.

Ls. lt. gray fossiliferous ps., thick to medium bedded, very highly fossiliferous, crinoids, solitary corals, ramose and fenestrate bryozoa, Peniculauris bassi, Derbyia and Composita - c., very dense chert tracery which is iron stained and weathers to stand in relief, cliff forming, rough surface: 141 cm.

Ls. lt. tan cherty, fossiliferous ps. w/ many chert nodules, massive, Derbyia, productids, ramose bryozoa and Peniculauris bassi - c., bivalves, Composita and Rugatia - f., fossil-moldic porosity in chert, weathers to form massive cliff, (KT 26-4): 327 cm.

Ls. lt. tan ws. w/ very densely mottled chert, massive, crinoids and productids - c., Derbyia, solitary corals and bivalves - f., productid spines - c., much broken brachiopod debris, slight amounts of fossil-moldic porosity in chert, iron nodules - f., lowermost beds are very thin bedded and form indent, forms base of cliff: 140 cm.

Total thickness, Fossil Mountain Member: 4962 cm.

Total thickness, Kaibab Formation: 10360 cm.

Section 27: Short Creek

Kaibab Formation has been removed during the current cycle of erosion
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