Geologic Map of Eastern Grand Canyon, Arizona*

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*After: Geologic Map of the Butte Fault/East Kaibab Monocline Area, Eastern Grand Canyon, Arizona, which was published by the Grand Canyon Association in 2007. The Geological Society of America made the printing of this 2012 map possible.

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©Karl Karlstrom Geology Department, CHUAR VALLEY MAP UNITS

- QUATERNARY UNITS Colluvium—Hillslope deposits of significant thickness that generally grade to fill-terrace gravels of tributary canyons and the mainstem Colorado River, particularly Qg3, but also include undifferentiated colluvium and talus. Colluvium ranges in texture, structure, and depositional process from proximal to distal hillslopes dominated by mass wasting and Hortonian overland flow, respectively.
- Landslide deposits—Translational slides, slumps, or areas of downslope creep of relatively competent material over fine-grained sedimentary rock. In many cases this involves blocks of the Tapeats Sandstone overlying shale-rich formations of the Grand Canyon Supergroup, especially the Chuar Group. Landslides are still active in a few places but appear to physically correlate, like colluvium, with fill-terrace gravels Qg_2 , Qg_3 , and Qg_4 , suggesting a broad range of ages for landsliding.
- Qes Eolian sand (Recent-Holocene)—Sand of significant local eolian deposits along Colorado River corridor. Coppice or compound dunes of reworked beach sand and flood deposits of mainstem Colorado River. Qal Alluvium (Holocene)—Poorly to moderately sorted sandy gravel to sand of side-canyon stream channels and the channel and flood deposits of certain reaches of the Colorado River. Active alluvium along side-canyon streams is incised as much as 2 m, and channels locally contain eolian deposits. For readability, this map unit in certain places includes gravel of the lowest, most
- recently formed (Holocene) terrace. Indications are that the same sedimentary deposit (Qal) may underlie both this terrace Gravel and sand of mainstem and tributary fill terrace 1 (Holocene)—Matrix and clast-supported, sandy pebble-to-cobble gravel to silty sand associated with fill terrace and inset cut-and-fill terraces. Clasts are subangular to subrounded and locally imbricated. Contains varying amounts of deposits interpreted as debris flow and stream flow depending upon location within catchments, and
- the size and relief of catchments, with steeper, smaller, lower-order drainages having more debris flow deposits. Qg2 Gravel of tributary fill terrace 2 (upper Pleistocene)—Matrix and clast-supported, sandy pebble-to-boulder gravel and gravelly sand associated with fill terrace and inset degradational terraces. Clasts are subangular to subrounded and locally imbricated. Contains varying amounts of deposits interpreted as debris flow and stream flow depending upon location within catchments, and the size and relief of catchments, with steeper, smaller, lower-order drainages having more debris flow deposits. Terrace height varies along the length of side drainages from 32 to 65 ft (10 to 20 m) above grade, and gravel thickness is <65 ft (<20 m).
- Gravel of mainstem and tributary fill terrace 3 (upper Pleistocene)—Matrix and clast-supported, sandy pebble-to-boulder gravel and gravelly sand associated with fill terrace and inset degradational terraces. Clasts are subangular to subrounded and locally imbricated. Contains varying amounts of deposits interpreted as debris flow and stream flow depending upon location within catchments, and the size and relief of catchments, with steeper, smaller, lower-order drainages having more debris flow deposits. Mainstem gravels have lenticular beds, crossbedding, are clast-supported, rounded, imbricated, and entirely stream flow deposited. Terrace height varies along the length of side drainages from 100 to 200 ft (30 to 60 m) above grade, and aravel thickness is <130 ft (<40 m). Gravel of mainstem and tributary fill terrace 4 (middle Pleistocene)—Matrix and clast-supported, sandy pebble-to-boulder gravel
- imbricated. Contains varying amounts of deposits interpreted as debris flow and stream flow depending upon location within catchments, and the size and relief of catchments, with steeper, smaller, lower-order drainages having more debris flow deposits. Mainstem gravels have lenticular beds, crossbedding, are clast-supported, rounded, imbricated, and entirely stream flow deposited. Terrace height varies along the length of side drainages from 230 to 278 ft (70 to 85 m) above grade, and gravel thickness is Gravel of mainstem fill terrace 5 (middle Pleistocene)—Clast-supported, sandy cobble gravel associated with fill terrace. Lenticular

and gravelly sand associated with fill terrace and inset degradational terraces. Clasts are subangular to subrounded and locally

- bedding and crossbedding. Clasts are rounded and imbricated. Terrace tread is not well preserved, and gravel is interbedded with and cemented with travertines locally. Gravel of high, uncorrelated mainstem and tributary deposits (middle-lower Pleistocene?)—Matrix and clast-supported, sandy pebble-to-boulder gravel and gravelly sand. Clasts are subangular to subrounded and locally imbricated. Found in two main locations stratigraphically high in the Nankoweap and Kwagunt drainages and along the Colorado River corridor in Furnace
- Flats. Deposits generally lie >492 ft (>150 m) above grade and may represent several different episodes of deposition. Qtr Travertine (Recent to middle Pleistocene)—Fresh-water carbonate deposits of active and inactive springs. Commonly cements colluvium and may be interbedded with mainstem gravels Qg_3 , Qg_4 , and Qg_5 along the Colorado River corridor between the Kwagunt and Little Colorado side canyons. Texture ranges from dense, banded flowstone to coarse, punky carbonate; deposits tend to be located near structures and at impervious horizons such as the top of the Bright Angel Shale. BEDROCK UNITS
- **Kaibab Formation** (Permian)—The Kaibab Formation is composed of two members, the upper Harrisburg Member and the lower Fossil Mountain Member. The Harrisburg Member is a cliff-forming unit dominated by dolomitized siliciclastic facies in eastern Grand Canyon. The Fossil Mountain Member is dominated by interbedded cherty and sandy limestone, with subordinate siltstone, sandstone, and gypsum beds. The Kaibab Formation thickens westward; in eastern Grand Canyon it is approximately 300-400 ft
- thick (92–122 m). Further descriptions can be found in Sorauf and Billingsley (1991). Toroweap Formation (Permian)—The Toroweap Formation is divided into three members. The uppermost Woods Ranch Member is a slope-forming interval composed of interbedded gypsiferous siltstone, thin-bedded limestone, and sandstone. The middle Brady Canyon Member is predominantly a thin- to medium-bedded cliff-forming fossiliferous limestone. The lower Seligman Member is composed of interbedded dolomite, sandstone, and gypsum. The lower member is locally interfingered with uppermost Coconino Sandstone. Thicknesses of the formation vary across northern Arizona, with great lateral and vertical changes reflecting the series of transgressions and regressions that occurred during its deposition. In eastern Grand Canyon, the Toroweap Formation is
- Coconino Sandstone (Permian)—The Coconino Sandstone is a cliff-forming, well-sorted, fine-grained quartzitic sandstone. The unit contains broad, sweeping crossbeds and invertebrate and vertebrate fossils that indicate the unit was deposited in a relatively dry dune environment. The thickness of the Coconino Sandstone is approximately 57 ft (17 m) in eastern Grand Canyon. Ph Hermit Formation (Permian)—The siliciclastic sequence of the Hermit Formation is composed of red-brown siltstone, mudstone, and very fine grained sandstone. The unit is generally as interlegable of the Hermit Formation is composed of red-brown siltstone, mudstone, and very fine grained sandstone. The unit is generally an interbedded silty sandstone and sandy mudstone that is increasingly muddy toward the upper beds. The formation was deposited in environments that may include shallow marine, estuarine, fluvial, and
- eolian environments. The upper boundary of the Hermit Formation forms a distinct disconformity with the Coconino Sandstone. The slope-forming unit ranges in thickness from approximately 100 ft (30 m) in eastern Grand Canyon to as much as 900 ft **Esplanade Sandstone** (Permian)—Cliff-forming, medium- to thick-bedded, fine-grained, well-sorted quartz sandstone. Subordinate thin-bedded siltstone is interbedded within the formation. The formation is approximately 300 ft (92 m) thick.
- MIPu Wescogame, Manakacha, and Watahomigi Formations (Pennsylvanian-Mississippian)—Mixed siliciclastic section of siltstone, mudstone, and medium- to thin-bedded sandstone with minor carbonate beds. The formations can be distinguished in the field by low relief unconformities between them. The combined thickness of the lower three formations is approximately 450 ft (135 m). Mr/Msc Surprise Canyon Formation and Redwall Limestone (Mississippian)—The Surprise Canyon Formation, in eastern Grand Canyon, is dominantly a red-brown, slope-forming, fossiliferous, conglomeratic sandstone and siltstone. There is no limestone in the Surprise Canyon in eastern Grand Canyon, unlike in more western reaches of the canyon. The Surprise Canyon Formation formed as a channel and cave fill in a dendritic fluvial system that formed on the surface of the Redwall Limestone. It ranges in
- phases of transgression and regression. It ranges in thickness from 500 to 800 ft (150 to 250 m). Temple Butte Formation (Devonian)—In eastern Grand Canyon the Temple Butte Formation forms a discontinuous channel-fill sequence representing deposition in intertidal to supratidal environments. The lens-shaped deposits are composed of reddish-purple

thickness from 0 to 75 ft (0 to 23 m). The Redwall Limestone is a massive, cliff-forming, karstic limestone stained by overlying red beds of the Hermit Formation and Supai Group. It is made up of four members: the uppermost Horseshoe Mesa, Mooney Falls, Thunder Springs, and lowermost Whitmore Wash. The Redwall Limestone formed in a shallow epeiric sea during two

- dolomite or sandy dolomite and are as much as 100 ft (30 m) thick and 400 ft (120 m) across. The unit thickens to more than Muav Limestone (Cambrian)—The subtidally and peritidally deposited Muav Limestone is dominantly siliciclastic, with decreasing amounts of carbonate in eastern Grand Canyon. It is divided into seven members, but in eastern Grand Canyon, only the upper
- three members are distinguished. The thickness of the unit also decreases toward the east, thinning to as much as 136 ft (42 m). The Muav Limestone can be difficult to distinguish from the underlying Bright Angel Shale because of interlayered beds. Bright Angel Shale (Cambrian)—The Muav Limestone intertongues with the Bright Angel Shale, which forms the broad Tonto Platform in eastern Grand Canyon. The Bright Angel Shale is composed of interbedded, fine-grained sandstone, siltstone, and shale, as well as conglomerates and coarse sandstone. The unit is known for the dominantly greenish color due to glauconite within the siltstone and sandstone. The Bright Angel was deposited in a shallow, open-shelf environment, below wave base depths. The thickness of the Bright Angel Shale is approximately 340 ft (104 m) in eastern Grand Canyon.
- Tapeats Sandstone (Cambrian)—The Tapeats Sandstone is a medium to coarse-grained feldspar-rich and quartz-rich sandstone, with basal conglomerate. The depositional setting of the Tapeats is primarily a braided stream and intertidal to shallow subtidal environments. The thickness of the unit is locally controlled by the relief of the underlying Precambrian units. In eastern Grand Canyon the thickness ranges from 0 to 200 ft (0 to 61 m). NEOPROTEROZOIC ROCKS (Z)
- Sixtymile Formation—The Sixtymile Formation is preserved only in four small areas in the axis of the Chuar syncline east of and parallel to the Butte fault. The original thickness of the formation is unknown due to an erosional unconformity at the top of the formation. It has a maximum preserved thickness of approximately 196 ft (60 m). There are three informal members within the Sixtymile Formation. The upper member (channel-fill member) contains channels filled with intraformational breccia derived from the middle member, and red fluvial sandstones. The channels are \sim 49 ft (\sim 15 m) deep and trend north-northwest. The middle member of the Sixtymile Formation (siltstone member) is a thick sequence of white to red, laminated and thinly bedded siltstone, with laminations of several millimeters to several centimeters. The beds are irregularly disrupted by intraformational brecciation and disharmonic folding that probably developed soon after deposition, yet after lithification of coarser grained siliciclastics. The lower member, exposed only in Sixtymile Canyon is composed of slumped blocks of dolomite surrounded by black shale.

Walcott Member—The Walcott Member is approximately 838 ft (255 m) thick and is dominated by black to gray mudstone facies

- with carbonate marker beds. The base of the member is marked by the "flaky dolomite," which ranges from 12 to 31 ft thick (3.75 to 9.6 m). Above this unit are black shale with interbedded oolite and pisolite beds (>15-30 cm thick) and three carbonate marker beds including a lower dolomite "couplet" and upper "karsted" dolomite. The lower dolomite in the "couplet" ranges from 11.5 to 22.9 ft (3.5 to 7 m) thick, and the upper dolomite couplet is 29.5-39.2 ft (9-12 m) thick. The "karsted" dolomite is approximately 39.2 ft (12 m) thick and preserves complex mingling of dissolution features, brecciated dolomite, and sandstone. A thin (1 cm) tephra deposit was collected for dating and yielded an U-Pb zircon age of 742 ± 6 Ma, providing an upper age limit for the Chuar Group (Karlstrom et al., 2000). Matubi Member—The Awatubi Member is marked at its base by a stromatolitic carbonate unit that is overlain by very fine grained
- variegated siliciclastic rocks. The member has a reported measured thickness ranging from 1,128 ft (344 m; Ford and Breed, 1973b) to 823 ft (251 m; Ford and Dehler, 2003). The variation in thicknesses may reflect actual thickness changes across the Chuar growth syncline (Timmons et al., 2001). The basal stromatolite carbonate features biohermal domes that are similar to the form Boxonia. Overlying mudstones contain thin-bedded sandstone and siltstone beds that preserve ripple foresets and mud-crack casts. Near the top of the member, organic shale preserve the fossil Chuaria circularis first described by Ford and Breed (1973a). Zkcb Carbon Butte Member—The Carbon Butte Member is a siliciclastic unit that has at its base a thick sandstone unit that marks the base of the Kwagunt Formation. This unit is readily identifiable in the field as a distinctive marker bed in the area. The member is approximately 252 ft (76 m) thick at its type locality (Ford and Breed, 1973b) but has been documented to show dramatic thickness variation across the Chuar syncline from 112 to 223 ft (34 to 68 m; Timmons et al., 2001; Ford and Dehler, 2003). The basal
- sandstone is medium- to fine-grained and preserves many bedforms and sedimentary structures, including low-angle crossbeds, symmetric and interference ripple patterns, and mud-crack casts. Soft sediment deformation features are also abundant in the lower sandstone unit. Above the basal sandstone unit are variegated shale and interbedded siltstone and sandstone beds, one of which is the "white" sandstone unit that expresses well-preserved symmetric ripples that parallel main structural trends (Timmons et al., 2001). Duppa Member—The Duppa Member is a fine-grained siliciclastic unit dominated by shale with interbedded thin-bedded siltstone units. The member has been measured in a number of locations in the area yielding different thicknesses depending on where one marks the base of the member. Measured thickness for the member ranges from 571 ft (174 m; Ford and Breed, 1973b) to approximately 2,050 ft (625 m; Ford and Dehler, 2003). Interbedded siltstone units tend to be calcareous and approach 3 ft Carbon Canyon Member—The Carbon Canyon Member is a heterolithic member dominated by fine-grained siliciclastic units
- 2001). Interbedded fine-grained siliciclastic rocks include variegated shale and thin-bedded <2 ft (<61 cm) sandstone. Sandstone beds preserve mud-crack casts, symmetric and interference ripple marks, low-angle crossbeds, and trough crossbeds. Stromatolites become more common toward the top of the member, and stromatolite forms appear to resemble the genus Baicalia (Dehler et al., Jupiter Member—The Jupiter Member is also a fine-grained siliciclastic-dominated package with abundant dolomite and sandstone marker beds interbedded with variegated shale. The base of the member is marked by a thick (40 ft or 12 m) stromatolitic dolomite unit and has poorly defined stromatolitic columns that are similar to *Inzeria* (Ford and Dehler, 2003). The member has measured thicknesses that range from 1,516 ft (462 m; Ford and Breed, 1973b) to 868 ft (264 m; Ford and Dehler, 2003),

with important marker beds of carbonate and sandstone. The total thickness of the member is 1,546 ft (471 m; Ford and Breed, 1973b). Carbonate marker beds are 3-6 ft (1-2 m) thick. One dolomite marker bed exhibits unusual large-scale (0.5 m) deep mud cracks infilled with micritic material, and has been interpreted to record prolonged exposure and desiccation (Dehler et al.,

perhaps suggesting that the thickness variations seen in upper members, due to the development of the Chuar syncline, are also observed in lower members. Interbedded sandstone units tend to be very thin but do preserve symmetric ripple marks, mud-crack

Tanner Member—The Tanner Member has a thick (20-80 ft or 6-24 m) dark-brown dolomite at its base. The dolomite unconformably overlies sandstone of the Nankoweap Formation. The entire member is approximately 640 ft (195 m) thick and is dominated by very fine grained siliciclastic rocks (Ford and Breed, 1973a). Interbedded with the shale of the upper Tanner Member are thin-bedded siltstone and sandstone beds and a few thin dolomite beds. The microfossil Chuaria circularis has been found in the uppermost shale beds of the member (Ford and Dehler, 2003). Nankoweap Formation—The unconformity-bounded Nankoweap Formation separates rocks of the Neoproterozoic-age Chuar Group above and Late Mesoproterozoic Unkar Group rocks below. The Nankoweap type section in Basalt Canyon measures approximately 330 ft (100 m) thick (Gebel, 1978). The upper member is composed of siltstone and thin-bedded fine-grained

casts, and raindrop impressions (Ford and Dehler, 2003).

- red bed sandstones toward the base and more massive meter-thick sandstone beds toward the top of the section. The capping white sandstone is composed of a fine-grained quartz-cemented quartz arenite. Abundant sedimentary features are identified in the section and include planar tabular and trough crossbedding, ripple marks, mud cracks, soft-sediment deformation, and rare salt casts. The lower member is dominated by hematite-cemented quartzitic sandstone and siltstone with important lenses of lithic sandstone derived from the underlying Cardenas Basalt. MESOPROTEROZOIC ROCKS (Y) Cardenas Basalt—The Cardenas Basalt is approximately 981 ft (300 m) thick and consists of >30-ft (>9-m) flow units (Hendricks, 1972). Three marker units have been identified and are described as informal members: the bottle-green member, fan-jointed member, and lapillite member (Lucchitta and Hendricks, 1983). Rocks of the bottle-green member are approximately 294 ft (90 m)
- thick, are highly altered, and contain secondary chlorite, epidote, talc, and zeolites. The fan-jointed member is dominated by basaltic andesite (~163.5 ft or ~50 m thick) and has a range of textures from porphyritic to aphanitic and vesicular (Hendricks and Lucchitta, 1974). The lapillite member ranges in thickness from a few meters to several tens of meters thick and is composed of scoriaceous fragments (~10 cm) and volcanic bombs (<1 m) in ash matrix, suggesting a proximal vent to volcanic material (Lucchitta and Hendricks, 1983). The lapillite member is interbedded in massive flows of basalt that comprise the remaining thickness of the Cardenas Basalt. Diabase intrusions: Intrusive rocks that intrude both the Unkar Group and crystalline basement are similar in texture, mineralogy, and chemistry to the Cardenas Basalt suggesting that intrusive and extrusive rocks were coeval and shared a common source. Intrusive rocks occur as dikes and sills within the Unkar Group with sills ranging in thickness from a few tens of meters to 981 ft (300 m); dikes typically are much thinner and locally utilize fault planes. Unkar Group igneous rocks have been correlated to similar mafic intrusions of similar age in the southwest U.S. (Howard, 1991).
- Ydo Ochoa Point Member—The Ochoa Point Member is dominantly a fine-grained siliciclastic unit and is approximately 250-300 ft (76-91 m) thick (Stevenson and Beus, 1982). The member is dominated by micaceous mudstones and grades into silty sandstone toward the conformable contact with the Cardenas Basalt. Sedimentary features include thin-bedded sandstone with abundant symmetric ripple marks that is intimately interbedded with extensively mud cracked shale. Comanche Point Member—The Comanche Point Member is approximately 508 ft (155 m) thick and is composed of interbedded sandstone, siltstone, and mudstone (Stevenson and Beus, 1982). Marker beds within this member are rare; however, a thin (20-30 cm) stromatolitic dolomite occurs approximately 100 ft (30 m) from the base of the member. This unit can be traced over the entire mapped area; however, the lithology can vary from argillaceous dolomite to calcareous siltstone. Another marker bed

has been identified approximately 33 ft (10 m) below the stromatolitic bed and is a thin (20-30 cm thick) contorted sandstone

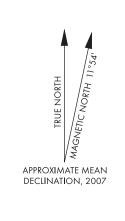
- exhibiting soft-sediment deformation (Timmons, 2004). Sedimentary features are common in sandstone beds including symmetric and asymmetric ripple marks and occasional mud-crack casts. Solomon Temple Member—This member is composed of dominately fine grained sandstone with subordinate siltstone and mudstone. It is approximately 920 ft (280 m) thick with the lower two-thirds of the member consisting of thin (< 1 m) sandstone beds interbedded with siltstone and subordinate mudstone rock (Stevenson, 1973). Abundant load features and mud cracks are found over this interval, although ripple marks are uncommon. The upper one-third of the member is sandstone dominated, and siltstone and mudstone units are less abundant. This part of the member is more resistant to weathering and forms prominent cliffs near Unkar Rapids. Sandstone exhibits broad channel forms that are commonly less than 10 ft (3 m) thick. Low-angle tabular
- crossbeds are common, and parting lineations in the tops of sandstone beds are abundant. Paleocurrent analyses suggest a northerly transport direction for detritus (Timmons, 2004). Escalante Creek Member—The Escalante Creek Member is the lowest member of the Dox Formation, and it is in conformable contact with the underlying Shinumo Sandstone. The member is approximately 1,278 ft (390 m) thick and is a sandstone-dominated siliciclastic package (Beus et al., 1974). The upper part of the member contains very few channel forms, sandstone beds tend to be more laterally continuous and thinner (<1 m), and siltstone and massive very fine grained sandstone dominate. The middle 654 ft (200 m) of the member exhibit more widely spaced and smaller channel sandstone interbedded with siltstone and mudstone interfluvial deposits. The lower 130 ft (40 m) is composed of large-scale (3 m) channel arkosic sandstone with subordinate interfluvial mudstone and siltstone. Channel forms are impressive, commonly exceeding 100 ft (30 m) in width and 2 m deep. Tool marks, channel axes, and other paleocurrent indicators suggest a southern source for detritus.
- Shinumo Sandstone—The Shinumo Sandstone is informally subdivided into five members: the upper Seventyfive Mile Rapid Member, Cottonwood Camp Member, Papago Creek Member, Ribbon Falls Member, and basal Surprise Valley Member. The predominant lithology in the Shinumo Sandstone is quartz arenite; however, subarkose sandstone is more common in the Surprise Valley Member. Sedimentary structures in sandstone beds are dominated by cm-scale to m-scale planar-tabular cross stratification and trough crossbeds that record bi-directional paleocurrent directions commonly as herringbone crossbed sets (Timmons, 2004). Trough crossbeds suggest a more northerly transport direction and are more common near the top of the section and its contact with the Dox Formation. Upper massive sandstone beds of the Shinumo show dramatic convolute bedding and hence do not preserve abundant sedimentary structure. The presence, abundance, and repetition of very thick (meters to 10's of meters) contorted beds in upper beds have been cited as evidence for earthquake activity and fluid evulsion during Shinumo deposition (Sears, 1973; Daneker, 1975; Middleton and Blakey, 1998; Timmons et al., 2001). The depositional environment proposed for the Shinumo is near-shore, marginal marine, fluvial/deltaic (Daneker, 1975).
- into three members. The uppermost Stone Creek Member is dominated by arkosic coarse sandstone. The middle member (Cheops Pyramid) is mudstone dominated. The Hance Rapids Member is dominated by thin-bedded subarkose to quartz arenite sandstone. The Hakatai Shale is more heterolithic than the name implies as it contains many sandstone beds. Marker beds are generally absent in the section; however, two prominent sandstone markers (~ 0.5 m thick) are present approximately 98 ft (30 m) above the base. Sedimentary features, including mud cracks, ripple marks, tabular-planar crossbedding, salt casts, and tool marks, indicate shallow-water deposition probably in a marginal marine/tidal flat environment (Reed, 1976). Bass Formation—The Hotauta Conglomerate and Bass Limestone were described by Dalton (1972). He recognized the heterolithic composition of the Bass Limestone, and suggested that it should have formation status including the Hotauta Conglomerate as a member. The Bass Formation (196-327 ft or 60-100 m) is dominated by dolomite facies, with subordinate conglomerate, breccia,

Hakatai Shale—The Hakatai Shale (448–981 ft or 137–300 m) is a mudstone- to coarse sandstone-dominated package that appears to be in gradational contact with the Bass Formation (Reed, 1976). The Hakatai Shale has been informally subdivided

- sandstone, and mudstone. These intercalations and primary structures such as wave-rippled sandstone and mud-cracked surfaces indicate that the Bass Formation underwent repeated subaerial exposure and flooding, and is interpreted to record relatively low energy intertidal to supratidal depositional environments in a general transgressive sequence (Dalton, 1972; Beus et al., 1974; Hendricks and Stevenson, 2003). Also interbedded with dolomite and mudstone rocks, toward the base of the section, are beds of white, very fine grained tephra deposits. One of these ash-fall beds had zircons for U-Pb geochronology that yielded an age of PALEOPROTEROZOIC ROCKS (X)
- and small plutons. U-Pb zircon ages range from 1685 ± 1 to 1680 ± 1 Ma (Hawkins et al., 1996).
- Granodiorite-gabbro-diorite-granodiorite complexes—Weakly to well-foliated medium- to coarse-grained quartz-plagioclase and diorite-hornblende bearing granitoids of probable volcanic arc origin (1.74-1.71 Ga). Vishnu Schist of Granite Gorge Metamorphic Suite—Quartz-mica schist, pelitic schist, and meta-arenites of probable volcanic arc basin origin. Locally contains graded bedding and turbidite layering. Strongly foliated with multiple generations of folds and
- Rama Schist and Gneiss of Granite Gorge Metamorphic Suite—Quartzofeldspathic schist and gneiss of probable felsic to intermediate metavolcanic origin; strongly foliate deviated by the Physical Schief Schief and Gneiss of probable felsic to intermediate metavolcanic origin; strongly foliated; yields a U-Pb zircon age of 1741 ± 1 Ma (Hawkins et al., 1996). Xbr Brahma Schist of Granite Gorge Metamorphic Suite—Amphibolites, biotite-hornblende schist, and biotite schist of probable mafic volcanic origin. Local metafelsite interbeds contain phenocrysts of quartz and feldspar; these beds yield a U-Pb zircon age of

1750 ± 2 Ma (Hawkins et al., 1996).

- MAP SYMBOLS - Lithologic contact—Dashed where approximately located Phanerozoic fault—Relative movement shown by U/D (up/down); dashed where approximately located, dotted where concealed $\frac{u}{d}$ --··· Proterozoic fault-Relative movement shown by u/d (up/down); dashed where approximately located, dotted where concealed Fault, unknown age—Ball on downthrown side; arrow shows direction and angle of dip; dashed where approximately located, dotted where concealed
- Detachment fault—Related to massive landslide deposits ----- Monoclinal hinge—Dashed where approximately located, dotted Precambrian monoclinal hinge approximately located, dotted where concealed
- Precambrian synclinal hinge—Showing plunge direction; dashed where approximately located, dotted where concealed ^{⊥⊥⊥⊥⊥} Landslide detachment Phanerozoic and Proterozoic age; dashed where approximately located, dotted where concealed
- 17> Strike and dip of beds K65 Strike and dip of overturned beds 33 Strike and dip of igneous dike
- 35 Strike and dip of minor fault planes and trend and plunge of slickenlines ⁷⁹ Strike and dip of first generation foliation (S1)
- Strike and dip of second generation foliation (S2) Strike and dip of third generation foliation (S3)



1 .5 CONTOUR INTERVAL: 40 FT

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Ilg, B. R., 1996, Tectonic evolution of Paleoproterozoic rocks in the Grand Canyon: Insights into middle crustal processes: [Dissertation], *University of New Mexico*, 101 p. Field assistance: Laurie Crossey, Carol Dehler, Adam Read, Stacy Timmons, John Bloch, Tony Prave, Paul Bauer, Steve Cather, Mary Simmons, Colin Shaw, Brad Ilg, Mike Doe, Jake Armour, Casey Cook, Sarah Tindall, Arlo Weil, Annie McCoy, Micah Jessup, Mark Quigley, Matt Heizler, Andy Stone, Lisa Peters, Andy Knoll, Susannah Porter, Tim Lite, and Jason Rauci

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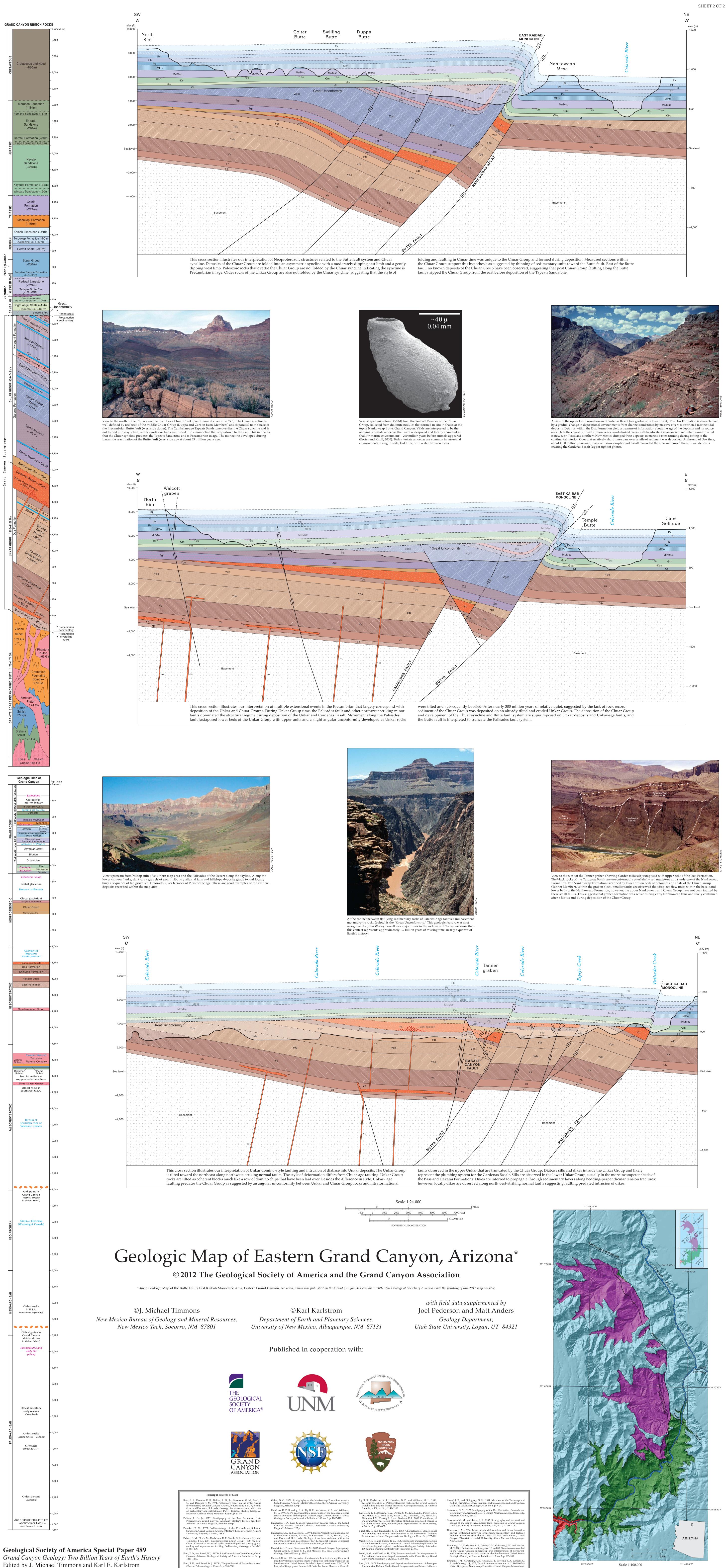
This map represents the culmination of new mapping efforts in the Grand Canyon Supergroup and surficial deposits in Grand Canyon with major contributions from Masters' studies (Timmons, 1999; Anders, 2003) and Ph.D. dissertation studies (Ilg, 1996; Timmons, 2004), and with additional mapping from many collaborating scientists and students, including those listed above. We would like to express our gratitude for research permits from Grand Canyon National Park to Karl Karlstrom of UNM for research within Grand Canyon. Scientific research was funded by the National Science Foundation under grants EAR-9706541 (to Karl Karlstrom of UNM) and EAR-9902955 (to Karl Karlstrom of UNM and Matt Heizler of NMT). The first printing of an earlier version of this map was done by the Grand Canyon Association with financial assistance from Arizona Geological Survey, Schlumberger, and Ben Donagan. This printing was made possible by The Geological Society of America. We thank George Billingsley and Richard Chamberlin for reviews of the mapping.



CANYON







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111°55'30"W

Scale 1:100,000

metamorphic and igneous rocks of Granite Gorge are about 1.7 billion years old and are shown in red. Rocks of the

Unkar Group (1.25 – 1.1 billion years old) are shown in green. The Chuar Group is shown in purple and is dated at

Physiographic map of the eastern Grand Canyon area showing distribution of major rock groups. Basement

about 800–742 million years in age. Paleozoic rocks are shown in blue and unconformably overlie older rocks.