The Rusty Brown Dolostones, Bright Angel Formation, Tonto Group Grand Canyon (Cambrian); Exploring the sequence stratigraphic and diagenetic history of

enigmatic marker beds recording the Sauk Transgression

**Abstract.** Several early workers have noted what are now called the “Rusty Brown Dolostones” (RBDs) within the Bright Angel Formation of the Cambrian Tonto Group in Grand Canyon National Park, Arizona (Marvine, 1875; Schenk and Wheeler, 1942; Edwin McKee, 1945). These conspicuous dolomite beds appear as prominent reddish-brown cliffs within the walls of the Grand Canyon corridor. It is hypothesized that the RBDs are diagenetic tongues of the Muav Limestone (Edwin McKee, 1945), yet these RBDs can be traced laterally for 10s to 100s of kilometers (Fig. 1).

Through detailed stratigraphic, sedimentologic, and petrographic analysis of RBD tongues, we hope to test the following research questions: 1) What defines an RBD? Can one create a single lithological definition for an RBD that allows for their identification in all sections of the Grand Canyon?; 2) What paleoenvironment do RBDs represent?; 3) Are the RBDs useful as tools for time and/or lithostratigraphic correlation?; 4) We will also test McKee’s hypothesis that RBDs are a function of diagenetic alteration of Muav Limestone tongues.

**Problem and Scope of Study.** Within the Bright Angel Formation (BAF) of the Grand Canyon’s Cambrian Tonto Group, idiosyncratic dolostone intervals have been identified which weather to a characteristic rusty brown color; the Rusty Brown Dolostones or RBD’s (Marvine, 1875; Noble, 1922; Longwell, 1936; Edwin McKee, 1945). The lowest and most accessible, couplet of these RBD’s occurs in the *Glossopleura* (trilobite) Biozone of western Grand Canyon as two parallel cliff-forming bands of variable thickness (meter scale) separated by an interval of glauconitic sandstone. This RBD pair is located above the Tapeats Formation (including the “transition beds”) and immediately below the Flour Sack member of the Bright Angel Formation, which lies immediately below the base of the Muav Limestone (Edwin McKee, 1945). The lower RBD is here called the Tincanebits while the overlying RBD is called the Meriwitica (Edwin McKee, 1945). These and all RBDs are interpreted to be diagenetically altered fingers of the Muav limestone existing as “tongues” within the Bright Angel Formation, that extend eastward (shoreward) from beyond the Grand Wash Cliffs and western edge of the Grand Canyon. These intervals have been classically interpreted as indicating transgression, deposited as coastal flooding increased accommodation space and pushed clastic sedimentation shoreward along the shallow shelf slope permitting carbonate precipitation (Edwin McKee, 1945).

Preliminary petrographic microfacies and mineralogical analysis elucidates the sedimentological origin of these intervals as well as their place within a comprehensive sequence stratigraphic framework. Initial thin section analysis indicates the occurrence of multiple dolomite recrystallization events, at minimum three, potentially blurring or entirely eliminating traces of the original mode of dolomitization. Additionally, the presence of saddle dolomite was noted, an indicator of high temperature (60-1500C) recrystallization events resultant from deep burial depths (Radke and Mathis, 1980). Through these generations of dolomite, primary features such as aeolian quartz silt lenses, oncoids, ooids, and glauconite can be identified, which together indicate shallow conditions in an upper shelf environment. Grain size across both the Tincanebits and Meriwitica tongues fines upwards, with far more clastic, poorly sorted quartz grains and fossil material seen in the basal portions of the two dolomite intervals (i.e., transgressive lags).

The two tongues are separated at Diamond Bar (Road Section) by 10’s of meters of hummocky cross-stratified sandstone, indicative of storm deposition (below fairweather wave base). We hypothesize that the fining-upward trends seen within the RBD’s as well as the occurrence of hummocky cross stratification together indicate that the dolostone intervals represent two separate periods of transgression punctuated by transgressive flooding surfaces above and below the sandstone which separates them (potentially ravinement surfaces). The intervening hummocky cross-stratified sandstone interval coarsens upwards, indicating increased storm activity during a period of regression, wherein clastic sedimentation results in a cessation of local carbonate precipitation. This hypothesis is supported by the presence of ooids, mud rip- up clasts, phosphatic shell fragments, coarse quartz sand grains, and various other fossil fragments including trilobite shell pieces occurring immediately above transgressive flooding surfaces; these clasts were likely dragged down slope during the storm event and trapped within the RBD’s as carbonate precipitation resumed.

Further, at the Diamond Bar Road Section, these regressive deposits, consisting of plane bedded to wave rippled arenites interbedded with cm scale beds of green to red shales and massive glauconitic siltstones to sandstones, increase in grain size and frequency as well as thickness of sandstone beds up section towards the base of the Meriwitica. The Meriwitica itself can be seen forming two distinct morpho-types: 1) interbedded clastic dolomite and dolomite cemented sandstones that are gradational with the underlying regressive package and onlap onto

2) massive, cryptic, and globular dolomite mounds that erosively/sharply contact the underlying regressive package and protrude 1m+ above the bedded morpho-type. We hypothesize that these mounds represent bioherms, likely thrombolitic or dendrolitic, formed in a warm shallow upper shelf environment.

Within the RBD’s themselves, we can see evidence of sedimentation lags in the form of glauconite; the mineral occurring as two or more textural variations (pelletal, vermicular, and fragmented) often in bands or clusters along bedding planes. Preliminary C-isotope data from Diamond Bar RBDs show homogeneous values of -1.5 per mil throughout both RBDs (sub meter scale sampling). More sampling at other sections is needed to interpret these values, but we hypothesis that the homogenous -1.5 per mil values are the result of diagenetic alteration of the carbon.

**Significance.** One of the core questions of this project asks what paleoenvironment these dolostone intervals represent, whether that be a foreshore beach, backreef lagoon, or basin slope. Recent fieldwork in the Diamond Bar region of Northern Arizona has led to our hypothesis that these deposits, in part, represent bioherms; reef structures composed of calcium carbonate built partially or wholly by sedentary organisms such as thrombolites or dendrolites (Cumings, 1932). Should our research demonstrate that these rusty brown dolostone intervals are indeed in part bioherm deposits, we will have discovered the first recorded Cambrian reefs in the Grand Canyon. These reefs would provide a critical historical marker for the study of evolution and early life, chronologically occurring soon after the early Cambrian decline of the archeocyathids (James and Debrenne, 1980; Lee et al., 2015, 2016). Lying within the greater Sauk transgression, these beds record, in detail, a geologically brief period in the history of the ice-free Cambrian coastal margin that is comparable to other notable hot house periods such as the Paleocene- Eocene Thermal Maximum (PETM) (Babcock et al., 2015; Hearing et al., 2018; Karlstrom et al., 2020).

The sections proposed for study herein (Fig. 1) constitute some of the most historic strata in the Grand Canyon, having been examined by such notable figures as G.K. Gilbert and Edwin

Dinwiddie McKee ((Schenk and Wheeler, 1942; Edwin McKee, 1945)). The results of this project may be used in the future to educate the more than 6 million visitors who annually view this national geoheritage site (Park Statistics, National Park Service). We will collaborate with researchers and undergraduate interns of the Denver Museum of Nature and Science and Dr.

Fred Sundberg a consulting paleontologist and current Grand Canyon National Park research permit holder.

**Study Area.** Field locations for this project will include measured sections in Diamond Bar, Arizona (12N 230225m E 3975771 m N, 12N 232870m E 3975510m N), Blacktail Canyon, Arizona (12N 370682m E 4011560m N), near Rampart Cave, Arizona (12N 236541m E 3999049m N), and Frenchman Mountain, Nevada (11N 680657m E 4007488m N).

**Methods**. Further analysis of the RBDs using Raman spectroscopy, thin section petrography, scanning electron microscopy (SEM) and C-isotope stratigraphy coupled with detailed field descriptions of stratigraphic relationships, is necessary to answer questions regarding the depositional and diagenetic history of the RBD’s and how they relate to their hypothesized lateral facies equivalents to the west (unaltered Muav Limestone) and the greater Sauk Transgression. With Raman spectroscopy and SEM analysis we will gather textural and chemical data that will allow us to describe in detail the complex paragenetic relationships between mineral constituents and thus illustrate the chemical and physical evolution of the rocks through time. Carbon isotope analysis will assist in this effort, elucidating the potential sources (e.g. methanogenesis etc) of carbon as well as the changes in carbon composition that have occurred.

From the sandstone samples collected within these 70m sections, zircons will be separated and analyzed using various geochronological methods in order to further constrain the age at which these intervals formed. To define an RBD, an additional younger couplet in Blacktail Canyon, the Elves Chasm and Garnet Canyon tongues, will be described and compared to the more westerly Tincanebits and Meriwitica tongues. Detailed field descriptions coupled with thin section petrography of collected samples is the most critical analytical technique of this project, providing macro and micro scale data on fabric and mineral relationships.

This project began in June of 2022, sampling and analysis will be completed by the spring of 2024 and all publications and written products will be finished by June 2024. Three field excursions are currently planned: 1) Grand Canyon, Colorado river uprun trip to Rampart Cave locality 2023 2) river trip to Blacktail Canyon locality in September 2024 3) final work in Diamond Bar, January 2024.

**Budget.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **#** | **Budget Item** | **Total Amount Budgeted** | **Amount Requested From GSA** | **Amount Requested From Other**  **Sources** |
| **1** | Field Work at  Diamond Bar Locality | **2375** | **2000** | **0** |

**Budget Justification**

1) Work in the Diamond bar locality, including spatial mapping of bioherm deposits and field description of relevant outcrops, is critical to this project. We have budgeted a total of

$2375.00. Lodging at $100 per person for two people over six nights to total $1200. Travel/mileage at $0.55 per mile for 1226miles (roundtrip distance between Grand Canyon Western Ranch, AZ and Logan, UT) to total $674.00. Food and field supplies totaling $500.

Tonto Group

Ma Biozones

Toroweap

Frenchman Mountain

Rampart Cave

East-West Stratigraphic Correlation Panel Grand Canyon, Arizona

496

# Cr

Guzhangian

497

Diamond Bar

Meriwitica

Granite Park

Havasu Canyon

Blacktail Canyon

Bass Trail

Bright Angel Trail

Little Colorado

498 Ce

## Franchman Mtn Dolomite

499

500

Miaolingian

Drumian

501

502

503

504

505

506

Bo

# Eh G

Scale

M

Lyndon limestone

Pd

Meriwitica “tongue”

Reduced

Tincanebits “tongue”

?

?

?

?

? ? ?

W

proposed

507

508.2

Series 2

Stage 4

uluian

508

509

510

507.7

Frenchman mtn Dolostone

Ol

Bright Angel

Ol *Olenellus* Pd

*Bolaspidella*

Muav Limestone

Tapeats Sandstone

*Poliela denticu-* M

Flour Sack Member

red brown sandstone

*mexicella* G

*Cedaria*

Rusty Brown Dolomite

Bioherms

*Glossopleura*

Lake Mead

Diamond

TP

Rampart

Cave

GP

HC

Blacktail Canyon BT

LC

15

BAT

0

Arizona

48280.8m (30mi)

520

*lata*

*mexicana*

*walcotti*

Bar

#### MR A. Section Locations

detrital zircon

locations

Eh *Ehmaniella*

# Bo Ce Cr

*Crepicephalus*

0 20

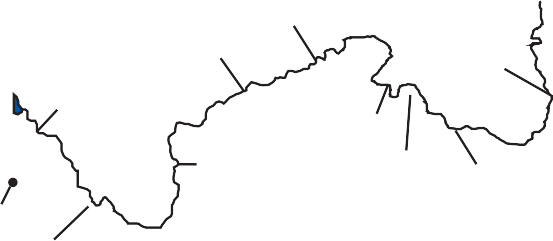
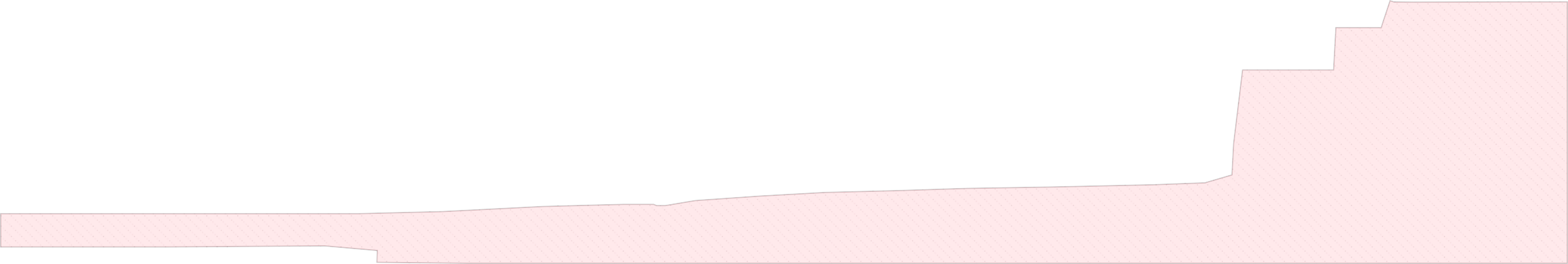
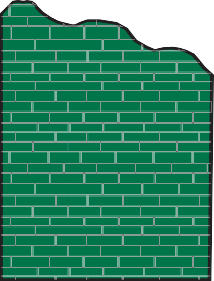
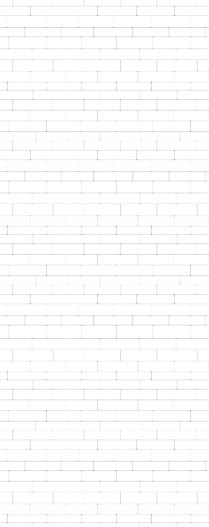
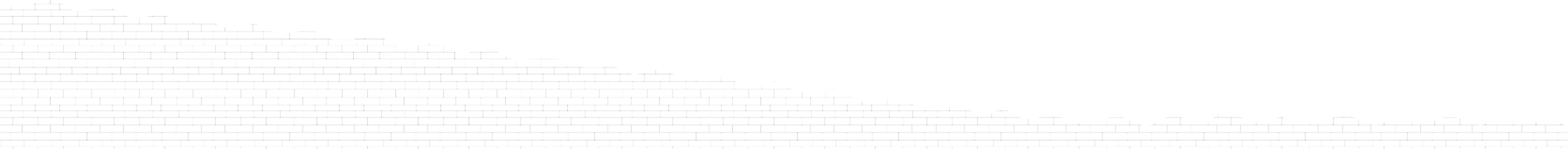
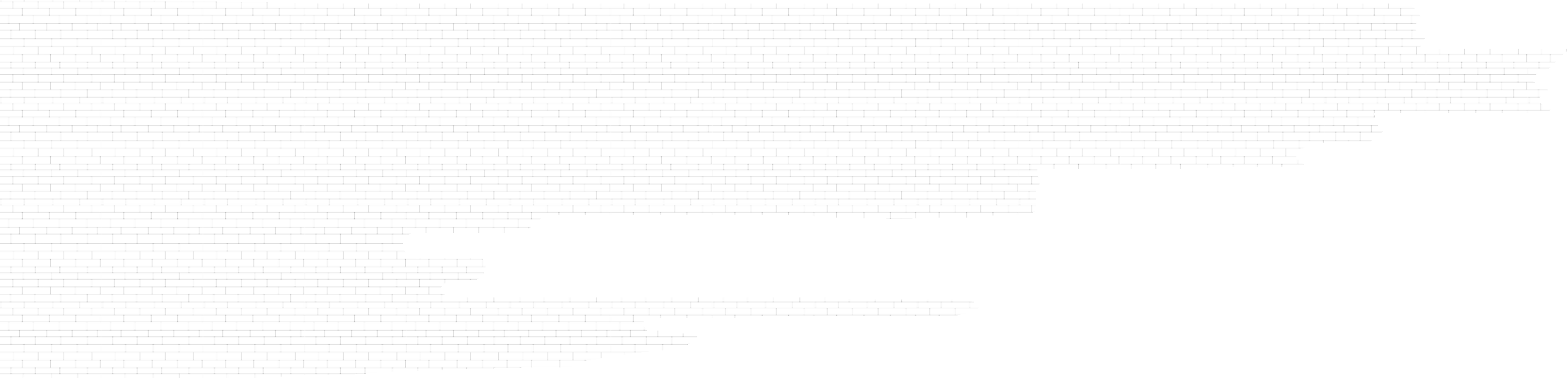
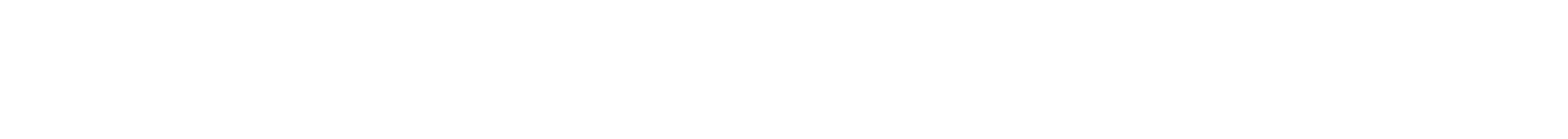
***Along***

0 30

Modified from Mckee and Resser 1945

Zircon age from Karlstrom et al 2020

Figure 1: Figure modified from Mckee and Resser 1945, showing cross Grand Canyon correlation of measured sections in an imagined transgressive sequence wherein east (right) is shoreward, and west (left) is basinward. Here we have differentiated between the Lyndon Limestone, a unit recognized at Frenchman Mountain which is implied to be the unaltered equivalent of the Tincanebits anf Meriwitica tongues, and the remainder of the Muav limestone, which are separated stratigraphically by the Flour Sack Member of the Bright Angel Formation. In Mckee and Resser 1945 Fig 1, the Flour Sack member of the Bright Angel Formation was depicted as limestone west of Grand Wash Cliffs (here Diamond Bar); in light of uncertainty regarding this designation we have chosen to merely highlight its relationship to the Bright Angel Formation and not differentiate it’s lithology. This units undefined contact in eastern Grand Canyon is dashed and queried in pink. Notice the strange facies position of the rusty brown dolostones (RBDs), the units of primary interest in this study, which lie between undolomitized Lyndon Limestone basinward/west and Bright Angel Formation shale shoreward/east. Recent field work (this study) reveals that the RBDs are in part bioherms and record the first Cambrian reefs in Grand Canyon. The white shadow between Diamond Bar and Bright Angel Trail represents concealed portions of the stratigraphy. Titles of sections studied in this work are highlighted in red (top). Most recent detrital zircon ages published by Kalrstrom et al 2020 are labeled with a blue zircon at the approximate location of their collection as are newly proposed sampling locations.



**Works Cited**

Babcock, L.E., Peng, S.C., Brett, C.E., Zhu, M.Y., Ahlberg, P., Bevis, M., and Robison, R.A., 2015, Global climate, sea level cycles, and biotic events in the Cambrian Period: Palaeoworld, v. 24, p. 5–15, doi:10.1016/J.PALWOR.2015.03.005.

Cumings, E.R., 1932, REEFS OR BIOHERMS ? PRESIDENTIAL ADDRESS: GSA Bulletin,

<http://pubs.geoscienceworld.org/gsa/gsabulletin/article-pdf/43/1/331/3430353/BUL43_1-> 0331.pdf (accessed February 2023).

Edwin McKee, C.E.R., 1945, McKee and ressor 1945 Cambrian\_history\_of\_the\_Grand\_Canyon\_reg: Hearing, T.W., Harvey, T.H.P., Williams, M., Leng, M.J., Lamb, A.L., Wilby, P.R., Gabbott, S.E., Pohl, A.,

and Donnadieu, Y., 2018, Climatology. An early Cambrian greenhouse climate:, https://[www.science.org.](http://www.science.org/)

James, N.P., and Debrenne, F., 1980, Lower Cambrian bioherms: pioneer reefs of the Phanerozoic: Acta Palaeontologica Polonica, v. 25.

Karlstrom, K.E., Mohr, M.T., Schmitz, M.D., Sundberg, F.A., Rowland, S.M., Blakey, R., Foster, J.R., Crossey, L.J., Dehler, C.M., and Hagadorn, J.W., 2020, Redefining the Tonto Group of Grand Canyon and recalibrating the Cambrian time scale: Geology, v. 48, p. 425–430, doi:10.1130/G46755.1.

Lee, J.H., Chen, J., and Chough, S.K., 2015, The middle-late Cambrian reef transition and related geological events: A review and new view: Earth-Science Reviews, v. 145, p. 66–84, doi:10.1016/j.earscirev.2015.03.002.

Lee, J.H., Hong, J., Choh, S.J., Lee, D.J., Woo, J., and Riding, R., 2016, Early recovery of sponge framework reefs after Cambrian archaeocyath extinction: Zhangxia Formation (early Cambrian Series 3), Shandong, North China: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 457, p. 269–276, doi:10.1016/j.palaeo.2016.06.018.

Longwell, C.R., 1936, Geology of the Boulder reservoir floor, Arizona-Nevada: Bulletin of the Geological Society of America, v. 47, p. 1393–1476.

Marvine, A.R., 1875, Report on the geology of route from St: George, Utah, to Gila River, Arizona: US Geological and Geographical Surveys West of the 100th Meridian (Wheeler), v. 3, p. 189–225.

Noble, L.F., 1922, A section of the Paleozoic formations of the Grand Canyon at the Bass Trail: USGS Professional Paper 131:

Radke, B.M., and Mathis, R.L., 1980, ON THE FORMATION AND OCCURRENCE OF SADDLE DOLOMITE t:

Journal of Sedimentary Research, v. 50, p. 1149–1168, <http://pubs.geoscienceworld.org/sepm/jsedres/article-> pdf/50/4/1149/2808207/1149.pdf?casa\_token=ZDeofan\_Q3kAAAAA:IgH78CnoSJsA5NYPP4Kqbf\_9 qpknoADOqgXT\_yGk0LQnLiwv79Q7NPeG832YUhY38OI (accessed February 2023).

Schenk, E.T., and Wheeler, H.E., 1942, Cambrian Sequence in Western Grand Canyon, Arizona:, https://about.jstor.org/terms.