Depositional and Deformational History of the Jurassic through Oligocene Strata exposed in the Parowan Gap area of the Red Hills, near Parowan City, Southwestern Utah

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Contents

Report

Figures

Abstract

Within the Parowan gap various Jurassic to Oligocene strata are prominently exposed. These strata were described and mapped over the course of 10 days, after which a depositional and tectonic history was determined for the area. The Jurassic Navajo sandstone was the earliest Unit deposited, determined to have been deposited in a vast erg, due to the numerous High angle cross bedding within the sandstone. Following the Navajo was the Carmel, a grey micrite determined to have been deposited in a fairly shallow marine, possibly lagoonal environment on the edge of the Sundance Sea, based upon the generally fossil poor nature of the micrite as well as the facies. The straight cliffs likely represent progradational nearshore, shoreface, and back beach deposition on or near the western edge of the Cretaceous Western interior seaway. This is based upon a distinctive succession of sandstone facies; additionally, the presence of Trough cross bedding and gritty layers are consistent with flowing currents. Oysters and other shell fragments within the straight cliffs indicate a marine depositional environment. The apparently Aeolian wedge within the straight cliffs is indicative of a back beach environment due to separation from water action.

The Iron springs formation was likely deposited in a braided fluvial depositional environment. Evidence for this includes the multiple stacked fining upwards sequences seen in the iron springs formation, as well as the various tuff filled channel cuts. Higher up, the Iron springs becomes notably finer grained. Indicating a possible transition to a meandering fluvial system. The Conglomerate of Parowan Gap was determined to be deposited by debris flows on the overturned and eroded beds of the straight cliffs and Carmel formations. Due to poor sorting, Clast support, and Clast derivation from thrust sheets. The depositional environment of

the Claron was determined to be Lacustrine. This is indicated by the large amounts of oncolites throughout the formation, as well as the various burrows and faint, broken bivalve and gastropod shells are all consistent with a lacustrine depositional system. The ignimbrite volcanics (Bryan Head, Wah Wah Springs, and Isom Tuff) were determined to have been derived from, at least in the case of the Wah Wah springs and Isom, a large scale pyroclastic event. The primarily Tuff matrixes and random sorting crystal content within all these units are extremely typical of pyroclastic flow. The fiamme bedding within the Isom tuff in particular are fairly common in ignimbrite and welded pyroclastic flow volcanics. Furthermore, the generally "flat" distribution of the outcrops is consistent with ash fall.

In addition to the lithologies and depositional environments of the exposed strata, numerous faults, both normal and thrust in the area of the gap where observed and dated based upon characteristics and cross-cutting relationships. The two "main" thrust faults in the area were determined to have occurred as a result of the Sevier orogeny, with the coal canyon thrust being the younger of the two(though roughly speaking, they are of similar time frames geologically.). This conclusion is due to both their somewhat similar orientations, as well as being constrained to post deposition of the straight cliffs and Iron springs, having been the cause for deformation in the former, while predating the Conglomerates of the grand castle, them having been deposited upon the already over turned Straight cliffs.

The Normal faults in the Parowan Gap area were determined to be a result of Basin and Range extension with normal faulting occurring in roughly similar time frames. This conclusion was determined based upon their generally parallel Northerly orientations. An additional factor in the timing and character normal faulting being constrained to post Claron deposition, but pre-quaternary deposition, due to offsetting the Claron in various places, but generally disappearing underneath Quaternary sediments.

Introduction

The Jurassic to Oligocene strata exposed in the Parowan gap, in the Red Hills west of Parowan, Utah provide a valuable record of depositional history as well as deformation due to the Late-stage Sevier Orogeny and Basin and Range Normal faulting. In order to interpret this some of this history, 10 days were spent in the area of Parowan gap are of Southwestern Utah in which depositional contacts between the various depositional units and faults were described, measured, and mapped. The units of interest included the Lower Jurassic Navajo sandstone, Middle Jurassic Carmel, Late Cretaceous Iron springs and Straight cliffs, Late Cretaceous to Paleocene Conglomerate of Parowan gap and Grand castle, Eocene Claron, and Oligocene Ignimbrite volcanics, as well as many quaternary strata such as landslides and alluvium from active and inactive alluvial fans. These depositional contacts, as well as the Strikes and dips of each unit of interest were measured with a Brunton and drafted onto a 1:12,000 scale 7.5 minute map of the Parowan Gap quadrangle with a 20 foot contour interval. (Figure 15) Using this map and information a cross section of the A-B-C transect in the Northern mapping area was constructed in an attempt to interpret the some of the geologic information of the area.(Figure 16) In addition to this, physical characteristics of each sedimentary strata was observed, and stratigraphic columns of the Late Cretaceous aged Iron springs and straight cliffs formation were constructed(Figure 13)(Figure 14), as well as a generalized stratigraphic column of the strata exposed in the gap(Figure 17). Using these, depositional environments were determined based upon physical and lithological characteristics, and a complete geologic history constructed from all the available data.

Geologic setting

The Jurassic period (201-145 Ma) was characterized by large scale tectonic plate activity and substantial changes in global paleogeography. During this period, sea floor spreading caused the supercontinent Pangaea to begin to rift apart, causing a rise in global sea levels and large-scale subduction along plate boundaries, beginning the creation of various North-south Trending mountain ranges along the western coast of modern North America Such as the Rocky Mountains. (Tang 2013)

During the early Jurassic period (201-174 Ma), the area of the modern Colorado Plateau was located at a fairly low altitude, approximately 5-20 degrees north of the equator. Due to the atmospheric circulation the easterly trade winds delivered very little rain and water to the western interior of North America, creating an extremely arid paleoclimate. This arid climate led to the accumulation of a vast amount of Aeolian wind-blown sand which formed the largest known erg (Aeolian sand sea) in Earth's history, covering most of modern day Utah, as well as parts of modern day New Mexico, Arizona, Colorado, and Wyoming. (Kocurek & Dott 1983)(Figure 1)

By the Middle to Early- Late Jurassic(~174-163 Ma), the western edge of the United States was covered by a series of shallow seaways, with up to 5 cycles of transgression and regression known collectively as the "Sundance Seaway". The seaway throughout Middle Jurassic time deposited a series of marine shales, sandstones, and limestones. (Tang, 2007). (Figure 2).

The late Jurassic period (~163-145 Ma) westward movement of the North American plate caused oceanic crust to be subducted underneath what is now the North American continent. Spurring the onset of the Nevadan orogeny, the first major cordilleran mountain building event. This orogenic episode caused substantial changes in deposition on the western edge North America. Due to the Orogeny, sea levels began to drop, and the Sea began its final stage of regression from the western interior the North American continent. This orogenic episode caused a non-depositional or erosional Hiatus from the late Jurassic to the Early cretaceous period in the area of the red hills region, possibly as a result of its location on the flexural bulge or Nevadan Thrust sheets. (Schweikart Et Al 1984) (Dinter 2017) (Figure 3)

By the time the Cretaceous period (~145-79 Ma) began, Pangaea had been fully rifted apart, and the landmass of the earth was divided into two continents. Laurasia in the North, and Gondwana in the south. Divided by the Tethys seaway which lied on the equator. Throughout the Cretacous, Laurasia and Gondwana would continue to rift apart into the continents we see in the present day. Compared to the generally arid paleoclimate of the Jurassic period, the climate of the Cretaceous was much more humid and warmer, likely due to extremely high rates of volcanism due to large occurrences of seafloor spreading. This seafloor spreading also caused a rise in sea levels, with the ocean being about 330 to 660 feet higher than the present in the Early Cretaceous, and 660 to 820 feet higher than present day by the Late Cretaceous. This rising sea level created various shallow epicontinental seas such as the Western Interior Seaway which covered North America (Hanson & Koch 2017.)

The Early Cretaceous (~145-100 Ma) was marked in large part by the onset of the Sevier orogenic episode (Occurring from roughly 140-50 Ma). A mountain building event produced by the subduction of the oceanic Farallon plate underneath the continental North American plate. Causing conductive heating and compression which caused folding and thrusting which formed many of the mountain ranges in Western Utah, and Eastern Nevada, as well as a series of thrust faults and folds in response to these compressional forces. (Livacarri 1991)(Figure 3)(Figure 4)

By the Middle Cretaceous (~100 Ma) rising sea levels and lowering of landmass due to traction from the subducting Farallon plate ushered in the arrival of the Western Interior seaway. A large inland sea which split the North American continent into two landmasses, Appalachia to the east, and Laramidia to the West. The Western interior seaway persisted throughout the Cretaceous and early Paleocene, with various cycles of Transgression and Regression. At its largest in the late Cretaceous, during the Turonian highstand, the Western interior seaway stretched ~620 miles from Eastern Utah all the way to the Appalachian Mountains on the Eastern Coast of North America. (Mitrovica 1989)(Steven 1999)(Figure 5)(Figure 6)

By the End of the Cretaceous (~79 Ma) Lowering sea levels and further uplifting from the Laramide Orogeny, which occurred simultaneously with the Sevier Orogeny but further to the East began to uplift the landmass which the Western interior seaway had covered. Such as the Rocky Mountains, and caused a division and retreat of the Larger Western interior seaway. Though small portions of it continued to exist throughout the early Paleocene epoch. (Steven 1999)(Figure 7)

The Paleogene period (~66-23 Ma) departed from the hot and humid climate of the Cretaceous and began a trend of drying and cooling. During the Paleogene, the continental drifting that had started in the Cretaceous continued. With most continents drifting closer to their current positions, and seaways that dominated many of the landmasses including North America finally retreated. (Hooker 2005)

The Paleocene Epoch (~66-56 Ma), the first geological Epoch of the Paleogene came on the heels of the Cretaceous-Tertiary extinction which marked the demise of non-avian Dinosaurs, giant marine reptiles, and numerous other flora and Fauna. The climate of the Early Paleocene was cooler and drier than the extremely humid Cretaceous period that preceded it. With North America having a warm and temperate paleoclimate with a general warming trend. The Paleocene was largely similar to the Late Cretaceous in terms of Paleogeography. Earths landmasses were continuing to move to their present day locations. The Laramide and Sevier orogenies continued to uplift various areas of the Western North American continent. Both eventually ending in the Succeeding Eocene epoch (~50 Ma), and the last vestiges of the Sundance Sea finally retreated from North America. (Britannica 2013)(Hooker 2005)(Figure 8)

The Oligocene (~33.9-23 Ma) is the final Geological Epoch of the Paleogene. Continents in the Oligocene continued their movement to the modern day positions, and global paleoclimate began a transition to one not unlike that which exists in the present day. Notably, many large scale super volcano eruptions occurred during the Oligocene. Perhaps the most notable of these eruptions was the eruption of the indian peak Caldera complex, which released a total volume of approximately 10,000 cubic kilometers(~5X larger than the Largest Yellowstone eruption), most of which was the Wah Wah springs tuff. (Woolf 2008) (Figure 9)(Figure 10).

The Miocene (~23-5 Ma) is the first geological Epoch of the Neogene Period (~23-3 Ma). During the Early Micocene, around 17 Ma tectonic expansion began, which ushered in the beginning of the Basin and Range province, which covers much (~500 miles) of the Western United States from the Westernmost edge of the Colorado plateau, where the Wasatch Mountains and Wasatch Fault define its Easternmost Border, to the Fault Scarp in the Sierra Nevada Mountain Range, Which Defines its easternmost edge. Basin and Range extension is likely the result of lithospheric thinning and extension with extension characterized by listric normal faulting (Faults which level with depth). Total lateral displacement of the Basin and Range varies from about 60-300 Km since the early Miocene, with the southern portion having a larger degree of extension than the North (about 60 km in Utah). Basin and Range extension continues to play an important role in the deformational history of the Western United states. Extending at a rate of approximately 0.2-0.6 centimeters per year, and continuing to deform the rocks within the greater Basin and Range province, creating a variety of High Angle Normal faults within Utah and to the West. (Salyards and Shoemaker, 1987) (Dinter 2017) (Figure 11)(Figure 12)

In the Quaternary period Basin and Range extension continues, and numerous Quaternary deposits are created due primarily to erosion from wind, water, and mass wasting. Current Quaternary processes continue unabated in this area and serve only as a minor blip in the overall geologic picture of the area.

Rock Descriptions

Early Jurassic Navajo Sandstone

The early Jurassic Navajo sandstone regionally measure about 2000 feet in total thickness, with about ~300-400 feet of exposure forming the "gap" in the area of study. The Navajo is a white to red Fine-medium grained sandstone. The grains in the Navajo are well sorted and well rounded, with the overall rock characterized by numerous 2-3 meter thick high angled cross beds. Small scale features such as grain flow and grain fall laminae are hard to discern due to the heavily deformed and weathered nature of the outcrops exposed in the Parowan gap area. North of the large Navajo cliffs that form the gap are several instances of hydrothermally metamorphosed Navajo Sandstone. Characterized primarily by their stark white color, and the presence of sulfur and oxidized iron. Bedding and other features in the hydrothermally altered Navajo are nearly impossible to distinguish.

<u>Middle Jurassic Carmel</u>

The Middle Jurassic Carmel formation is 500 feet in total thickness, but only 200-250 feet are exposed in the Parowan gap area of study. The Carmel is primarily characterized by tan-grey very fine-fine grained platey micrite. Bedding in the micrite measures approximately 15-20 cm in thickness. While in general the Carmel exposed in the Parowan gap area is extremely homogeneous micrite, in certain areas of the gap, ooids, crinoids, and brachiopods, measuring about 5 mm to 2 cm in diameter can be seen with various abundance. The uppermost member of the Carmel is a pinkish/peach colored, medium grained sand in stark contrast to the lower portions of the formation. Calcite veins measuring about 2 cm in diameter, as well as what appears to be a halite “crust” is abundant across it.

<u>The late cretaceous straight cliffs</u>

The straight cliffs formation bounds the area between the major eastern and western thrust faults. The straight cliffs are a tan to grey, cliff forming sandstone forming distinctive “fin” shapes. Outside of the outcrops of the straight cliffs, large patches of dark grey to black sediment and gypsum fragments can be seen, indicating the presence of low grade coal and gypsum throughout the unit.

The bottom 0.25-0.30 meters of Unit 1 consist of medium grained, well sorted sub-rounded sandstone with parallel bedding. Atop this is about 0.75 meters characterized by 2 gravel lags, one at the top and one at the bottom. With trough cross-bedded sandstone between them. Above the gravel lag unit is a meter of grey, coarse grained well sorted, and sub-rounded sandstone. Filled with 4-6 cm thick pebble lenses spaced about 10 centimeters apart. Abundant calcite veins measuring about 2 centimeters run throughout. Atop this is a 10 cm gradational contact consisting of medium grained sandstone. The one meter above this contact is characterized by well sorted medium grained sandstone with tangential cross bedding capped by a layer of grit. The next 1.5 meters is medium grained sandstone with grain fall and grain flow laminae, as well as dune bedding. Possibly representing an Aeolian dune wedge. Following this is about 1 meter of unexposed material, followed by a 2-2.5 meter outcrop of medium grained sandstone with faint crossbedding. As well as an abundance of parallel beds.

The middle of the straight cliffs (designated unit 2 for ease) outcrops after approximately 10 meters of unexposed area, assumed to be mudstone. The bottom meter of the unit consists of a fine grained, sub-rounded yellow quartz sandstone, with trough cross beds measuring approximately 30-40 cm in thickness. This is topped by a 20-25 cm bed of well sorted, notably much more coarse sand with planar bedding. The next 1.5 meters consists of grey fine-grained sandstone, with abundant parallel laminations capped with a 10-15 centimeter gradational contact with wavy ripple bedding. The next 2 meters consists of tan-yellow fine grained sandstone with cross beds sets measuring approximately 10-15 centimeters, some soft sediment deformation can be seen within the troughs. The next 0.5 meters is characterized by weathered yellow fine-grained sandstone full of iron concretions, capped by about 10 centimeters of well sorted, coarse grained grey gritty sandstone. The top 2-3 meters of unit 2 consists of medium to coarse grained light grey sandstone with the bottom being characterized by soft sediment deformation. Following this is about 1.5 meters of trough cross bedding, followed by about 1.0 meters of planar bedding.

The bottom 0.25-0.30 meters of the top of the fins (designated unit 3) consists of medium-coarse grained coquina full of oysters, both full shells as well as hash, and bivalves serving as geopetal indicators indicated bedding is overturned. Above the Coquina is a small ~0.20 meter bed of faintly rippled bedded sub-rounded to rounded well sorted medium grained quartz sandstone. On top of the coquina and medium grained sandstone is about 2 meters of finer grained, tan colored sandstone full of trough cross beds, as well as various concretions. The topmost 1.5 meters consists of medium grained, sub-rounded and well sorted sandstone with mottled beds. Likely created due to diagenetic processes, as well as an abundance of parallel laminations. The bottommost unit is capped by 1-2 meters of poorly exposed fine grained sediment. (Figure 13)

Late cretaceous iron springs

The Iron springs formation is a fine-grained tan-grey to orange-red cliff forming sandstone measuring about 2000 feet in total thickness. With only about 300 feet of exposure in the easternmost area of the gap ornithopod tracks measuring about 30-50 cm in diameter are abundant throughout the lower areas of the exposed unit, and serve as something as a tourist draw. One primary exposure totaling about 25 meters was studied and divided into two units based upon general characteristics and lithology.

For the first unit, the bottom 2 meters is characterized by medium grained trough cross bedded (2-4 cm thick) sandstone. Atop the sandstone is a channel cut filled with about 60 centimeters of water-laid grey tuff, bounded by jointing and heavily weathered in spherical shapes. Lying atop this is about a meter of gritty sandstone with gravel lag, and medium grained, trough cross bedded sandstone about 2 meters in thickness. Overlain by .25 meters of similarly grey tuff, but without the spherical weathering seen in the older tuff-filled channel. Above this, at about four meters from the base, is 1.0-1.5 meters of fine-medium grained parallel laminated sandstone beds overlain by another 0.25 meters of tuff. Above this tuff is about 0.5-1 meter of matrix supported intraformational conglomerate with pebble sized clasts of primarily chert and limestone, measuring 1-4 cm in diameter with smaller amounts of quartzite. Above the conglomerate is about 2 meters of medium grained, trough cross bedded sandstone with what appears to be various wood fragments. Overlaying this is more tuff, followed by a fairly homogeneous massive sandstone, with poorly defined wavy bedding and faint cross beds. Overall, the bottommost 10 or so meters can be summarized by 6-7 stacked fining upwards sequences ranging from 65 centimeters up to approximately 3 meters in thickness. In between these fining upwards sequences are 4-5 beds of grey tuff of varying thickness ranging from approximately 25-60 centimeters thick.

Unit 2 is begins by approximately 5 meters of unexposed mudstone, and is fairly distinctive from unit one. As opposed to the fairly consistent exposure and lithology of unit 1, unit two is primarily defined by single channels of fine-medium grained sandstone with trough cross bedding, half a meter to a meter thick, followed by unexposed sections, assumed to be mudstone measuring approximately 2 meters thick each. The top of the exposure is characterized by a grey, gritty sandstone and purple, paleosol, approximately 20 centimeters thick that represents the contact between the iron springs, and the overlying grand castle conglomerate. The general transition from coarse to finer grained exposures indicates a change in flow characteristics (Figure 14)

Late cretaceous conglomerate of Parowan gap

The conglomerate of Parowan gap is approximately 4 meters thick and overlies the straight cliff and carmel formations on an angular unconformity. The conglomerate of Parowan gap is also overlain by the grand castle, and constrained to the area between the eastern and western thrust faults, appearing in neither the eastern area of the gap where the iron springs lies, nor the westernmost area where the claron and volcanics dominate. The conglomerate of Parowan gap at first glance appears extremely similar to the grand castle formation, however, upon further observation, the conglomerate of Parowan gap differs from the grand castle in color, clast size and lithology. The conglomerate of Parowan gap is dark brown to black in color, and is a poorly sorted, matrix supported conglomerate, with rounded clasts of primarily quartzite and chert measuring from about 4 mm-10 centimeters in diameters. Chert clasts are pervasive within the grand castle, and limestone, while appearing from time to time, is extremely rare. These characteristics serve as a great source of differentiation between the conglomerate of Parowan gap and the overlying grand castle formation, which has an abundance of limestone clasts and little to no chert.

Late Cretaceous/Early Paleocene Grand castle

Unconformably overlying the irons springs formation is the late cretaceous aged grand castle formation. The grand castle is primarily characterized by brown to reddish-pink to grey clast supported conglomerate(~80% clasts), with sub-rounded to rounded clasts measuring from as small as 1 centimeter, to as large as 31 centimeters in total diameter. Clasts are very poorly sorted, and tend to fine upwards from the base of the grand castle to the top.

The dominant lithology within the grand castle are larger quartzite clasts, with a large amount of smaller clasts of limestone typically in the range of about 5-10 centimeters in diameter. The bedding of the grand castle in some areas consists of primarily medium to coarse grained sub rounded sandstone in 7 meter thick lenses. The matrix appears to consist primarily of sand and calcite grains. The grand castle was previously believed to have been Paleocene in age, but the discovery of dinosaur tracks within it indicate that at the minimum, the basal beds may be late cretaceous in age.

Late Paleocene to Oligocene claron

The Oligocene Claron is approximately 900 feet thick, but only 300 feet or so can be seen in the area of study. The Claron conformably overlies the grand castle formation, with the contact between the Grand Castle and Claron consisting of a marl with mottled purple-yellow coloration as well as signs of pervasive vertical burrowing. Also within the various marl beds are abundant oncolites, spherical structures formed by algae, varying from about 2mm to 15 cm in diameter, and vaguely defined ripple bedding.

In addition to the purplish yellow mottled marl, the Claron also contains conglomerate, as well as sandstone beds, all appearing to follow a general fining upwards trend. The conglomerate of the claron is clast supported, and consists primarily of limestone and quartzite clasts measuring from about 1 to 18 centimeters in total diameter and intercolated with paleosols. Conglomerate clasts appear to be more limestone rich near the bottom, while quartzite clasts become more abundant going upwards. Within the conglomerate are sandstone lenses, averaging about 30 cm thick/

In addition to the conglomerate, the claron also consists of sandstone beds with coarse to medium sub-rounded grains, and contain trough cross bedding, planar laminations, and what appear to be burrows. Also within the Claron are various beds of carbonate limestone with peloids, about 2 mm in diameter, burrows, and calcite veins.

<u>Oligocene ignimbrites</u>

The Oligocene volcanics are divided into 3 separate formations based upon age and general lithology. Of these 3 are the Brian head, about 30-36 Ma in age, the Wah Wah springs Tuff, about 30 Ma in age, and the Isom formation, about 26-27 Ma in age.

The Brian head tuffaceous sandstone is in general, poorly exposed and not abundant in the area of Parowan gap, with only around 3 or so highly weathered and poorly exposed outcrops in the entire area of study, as well as minimal amounts of float. The Brian head consists of tufffaceous sandstone and tuff breccia that is grey to stark white in color. There are few crystals within the Brian head, and the lithology appears to consist primarily of only an ash matrix within the exposures in the Parowan gap.

The Wah Wah springs tuff overlies the Brian head and consists of pinkish/orange tuff matrix. The Wah Wah springs tuff is extremely crystal rich, with crystals ranging from about 2-4 mm. The general composition of the wah wah springs is about 60% crystal content, being made up of approximately 30% quartz, 20% spar, and about 8-9% euhedral mafics, most of which are biotite and hornblende. Trace amounts of white mica, likely muscovite are also present throughout the rock in about 1-2% abundance. About 40% of the rock is composed of an ashy matrix.

The Isom is the youngest of the ignimbrite volcanics in the area and is a dense, reddish brown welded tuff with few obvious crystals. What crystals there are in the isom are similar to those within the Wah Wah springs, but in abundance of less than ~10%. Fiamme bedding is abundant in the Isom tuff in various orientations.

Quaternary deposits

Quaternary deposits, while generally of less import, also play a role in the geologic story of the Parowan gap area. Of these are landslides, talus slopes, and alluvium from both active and inactive fans. Talus are slope forming deposits of crushed and broken rocks that form at the base of cliff faces, and mark many of the more cliffy areas of the gap, particularly at the base of the massive cliffs of the iron springs and grand castle formations. Landslides, a form of mass wasting, cover many exposures and are indicated by both poorly exposed rocks, as well as a wide variety of seemingly random rock types from every area of the landslide area. The alluvium is indicated by rounded pebbles in quaternary sediments, with active fans forming distinctive fans shapes, while inactive ones are cut by additional drainages.

Depositional environments

Navajo Sandstone

The Navajo sandstone is roughly equivalent to the Nugget formation exposed in the Wasatch Mountains around Salt Lake City, UT and studied in previous work. The high angle, large-scale cross bedding seen in the Navajo sandstone "gap" is extremely characteristic of aeolian deposits, and while smaller scale characteristics such as grain fall and grain flow laminae can't be seen in the area of the gap due to the extreme weathering, they can be seen elsewhere from the area of study. Similarly, the generally well sorted and well-rounded nature of the predominantly quartz sandstone is typical of aeloian wind-blown deposition. These interpretations lead to the conclusion that the Navajo is Aeolian in nature and was deposited within the massive Erg on the Northwestern Coast of the US. (Kocurek, 1991)

Carmel

The carmel based on the primarily fine grained micrite that make up the majority of the bedding in the Parowan gap area was likely deposited in a fairly shallow marine environment, possibly a lagoonal environment on the edge of the Sundance Sea. The relatively few fossils contained within the Parowan gap exposures would be consistent with the closed off nature of a lagoon, while the presence of small amounts of fossils elsewhere would indicate times where the water level rose and the lagoon was no longer "cut off", allowing more movement of particles and life to the depositional area. Furthermore, the sandstone layers alternating with layers of Micrite are indicative of possible transgressive and regressive phases. This cyclical lowering and raising of water levels is consistent with this interpretation.

Straight cliffs

The straight cliffs likely represent progradational nearshore, shoreface, and back beach deposition on or near the western edge of the Cretaceous Western interior seaway. This is based upon a distinctive succession of sandstone facies. The presence of Trough cross bedding and gritty layers are consistent with flowing currents. Trough cross bedding is typical of an upper shore face, while parallel bedding and laminations which are characteristic of a foreshore environment. Oysters and other shell fragments within the straight cliffs indicate a marine depositional environment. The apparently Aeolian wedge within the straight cliffs is indicative of a back beach environment due to separation from water action, while the coal and gypsum are indicative of an area with “swamp” cycles, as well as cycles of drying, indicative of rising/falling tides.

Iron springs

The Iron springs formation was likely deposited in a braided fluvial depositional environment which became a meandering environment. Evidence for this include the multiple stacked fining upwards sequences seen in the iron springs formation, as well as the various tuff filled channel cuts. These channel cuts and fining upwards sequences have abundant cross bedding, as well as gravel lags and rip up clasts. The general grain size, various conglomerate bed, gravel lags, and general fining upwards sequences along with wood fragments indicate a high energy depositional environment of a braided river. The upper portions of the formation where large areas are unexposed in between outcrops of trough cross bedded sandstone representing channels are consisting with a slower stream, and likely represent a transition from the braided fluvial system that deposited the lower portions of the Iron springs, to a meandering fluvial system. The topmost layer of the iron springs is a paelosol which likely formed on the banks of this river, where vegetation grew.

Conglomerate of Parowan gap

The Conglomerate of Parowan Gap was likely deposited by debris flows on the overturned and eroded beds of the straight cliffs and Carmel formations. Evidence of being deposited by debris flow are its relatively small thickness, extremely small area of deposition, as well as the major clast support and lack of any discernible sedimentary structures or features, all of which are to be expected in debris flow deposition. Further evidence Is that composition of the clasts appear to be derived from the Sevier thrust sheet.

Grand castle

The generally poor sorting and poor sub-angular/sub-rounded nature of the clasts of the conglomerate within the grand castle formation is consistent with that of an alluvial fan. Furthermore, the lack of any easily defined better is also consistent with an alluvial fan depositional environment. This is due to the current slowing at the end of the “fan” dropping an assortment of sediments. Subsequent flash floods or other activity can “disturb” these sediments even more, causing the poor sorting typically seen in such depositional environments. This can be further scene in quaternary alluvium deposits, in which float is seemingly randomly distributed.

Claron

The Claron has two main lithologies, the carbonate/limestone and marl and the conglomerates within the unit. The likely depositional environment overall is likely that of a lacustrine environment. This is indicated by the large amounts of oncolites throughout the formation, as well as the various burrows and faint, broken bivalve and gastropod shells are all consistent with a low-energy lacustrine depositional system. The conglomerate within the claron, based upon the general clast support, as well as poorly defined bedding indicate that they might be from an alluvial fan or debris flow into the lake. The large clasts and faint cross bedding and pebble lags are further evidence of some sort of debris flow/alluvial fan deposition.

Ignimbrite volcanics

The ignimbrite volcanics (Bryan Head, Wah Wah Springs, and Isom Tuff) were likely derived from a pyroclastic event which occurred outside the gap and fell within the area of deposition. The primarily Tuff matrixes and random sorting crystal content within all these units are extremely typical of pyroclastic flow. The fiamme bedding within the Isom tuff in particular are fairly common in ignimbrite and welded pyroclastic flow volcanics. Furthermore, the generally “flat” distribution of the outcrops is consistent with ashfall. Additionally, the somewhat “random” nature of the orientations of the volcanics is indicative of this deposition and possible landslides which caused them to rest at their present orientations.

Structural descriptions and timing relationships

The most notable structures throughout the mapping area of the Parowan gaps are the numerous faults generally oriented to the Northeast/Southwest. In the Easternmost area of the Gap, near the border of the mapping area is a Fault which brings the Tertiary aged Claron formation in direct contact with the Cretaceous aged Iron springs formation. The fault is easily recognizable in the field due to the direct contact between the generally sandy, yellowish Tan sandstone prevalent within the iron springs formation, and the Reddish Conglomerate prevalent throughout the Claron formation, giving an offset of several hundred feet(Up to ~500 Ft, based on Regional thicknesses between them.) Due to the Fault offsetting the Claron, a Paleocene-Miocene aged formation, the actual age of the fault has to be at the maximum post deposition of the Claron formation, making it younger than the late Paelocene/Early Eocene**.**

Further westward is another roughly parallel normal fault in the area colloquially known as “confusion Canyon” This normal fault is easily recognized due to the abrupt “disappearance” of the Marl contact between the Claron formation and grand castle formation, as well as a repeating section of Iron springs with Grand Castle beneath, followed by another appearance of the Iron springs underneath that. A clear sign of faulting. The fault has an offset of roughly 100-150 feet, based on where the contacts can be found lower in the canyon. The timing of the “Confusion Canyon” fault is roughly equivalent in age to the Fault further to the east, as it cuts through the Iron springs, the Grand Castle, and the Claron, meaning it occurred post deposition of all 3. However, it is lost underneath Quaternary alluvium, making it pre-modern.

Going further west is a prominent thrust fault. It is notable from the road at the beds of the Iron springs begin dipping around ~36 degrees from their previous ~6 degree dip due to drag folding from the thrust. Another sharp evidence for the Thrust fault is the abrupt transition to the overturned beds (indicated by Oysters and other shells) of the Straight cliffs formation to the iron springs. The Contact of the fault can be roughly determined by the exact change between these two formations, indicating the Thrusting events is post cretaceous. In the north, the thrust is covered by Quaternary landslides, while in the south, the thrust is cut off by a normal fault that offsets Cretaceous deposited sediments. Constraining it to between deposition of the straight cliffs and Iron springs, and the landslides and normal fault activity.

On the very end of the straight cliffs is another thrust fault, with the contact of this thrust fault being indicated by an abrupt transition between the straight cliffs, which lies between the two major thrust faults, and the carmel limestone, which lies on the western side of the westernmost thrust. This thrust is likely similar to the other one in age, and was likely partially responsible for overturning the beds of the straights cliffs. Putting it in the same post cretaceous time period. Due to the thrust ending at the conglomerate of Parowan gap, it can be determined that these thrusting events had to have occurred sometime roughly in the late Cretaceous/early Paleocene.

Between the two thrust faults is two larger scale normal faults, with about ~20 feet of offset each. They are easily recognizable due to the sudden 20 foot jumps of the conglomerate of Parowan gap (which itself is only about 4 meters in thickness.)Due to both being of similar orientation, as well as cutting through the same formations, these parallel faults can be determined to be of the same age. As each of these faults cuts through the grand castle formation, straight cliffs, and conglomerate of Parowan gap, they have to be at least Paleocene in age at the minimum, and due to not being seen in the road, have to be some age older than the quaternary. These thrust faults are younger in age than the thrust faults on either side, due to cutting the conglomerate of Parowan gap which was deposited on the straight cliffs, which themselves were overturned as a result of these thrusts.

The furthest most large scale normal fault is a massive normal fault roughly parallel to the other normal faults. It is recognizable immediately due to the emplacement of the much younger red Claron sandstone directly next to the older grey Carmel micrite. This emplacement gives this fault an at minimum, massive ~3000 feet of offset at the very least and due to its nature has to have occurred after the deposition of the Claron, placing it post Eocene in time, while it somewhere disappears underneath the quaternary alluvium and sediments further down the canyon.

In addition to the 5 major normal Faults and 2 major thrust faults, numerous smaller faults (typically normal faults) are evident all throughout these are recognized easily by the evident offset in between contacts in the areas of this fault. Most of these "minor faults" typically fall within the same constraints as the major ones, as they tend to largely cut through and offset the same formations. These minor normal faults are likely from the same, or close to the same general time period as the larger more major faults.

Geologic history and Discussion

The earliest geologic event in the area of the Parowan gap was the deposition of the Navajo Sandstone in the by vast aeloian winds in the Erg east of the Sierran magmatic arc during the Early Jurassic. Following this, in the Middle Jurassic was the deposition of the Carmel micrite in the shallow Sundance Seaway, which covered large parts of Utah. After the deposition of the Carmel, there is a large hiatus o deposition spanning from the Late Jurassic to the Early cretaceous, a time span of approximately 65 Million years. This large span of nondeposition may be due in Part to the Red Hills being positioned on the Flexural bulge of the Nevadan thrust sheets.

After this long nondepostional hiatus, the Western Interior seaway transgressed upon the North American continent, depositing the marine sourced Straight cliffs atop the Carmel formation. Following the deposition of the straight cliffs, Sevier thrusting began overturning the straight cliffs to their current orientation, isoclinally folding them. Sevier thrusting continued unabated, and eventually led to the Navajo Sandstone being folded and thrust over the younger Carmel limestone, forming the massive cliffs known as the “gap”. Not content to end there, further thrust the Carmel atop the younger Straight cliffs formation, and both formations were folded.

The erosion of the Carmel and Straight cliff thrust sheets served as a source of clasts for the conglomerate of Parowan gap, which was deposited atop the faulted and overturned Straight Cliffs and Carmel formations. Concurrently to this activity, the Late Cretaceous Iron springs formation was deposited in a braded fluvial system within the Sevier foreland basin to the East of these other formations. Following the deposition of the Iron Springs formation, a third major thrusting episode began, which pushed the folded and deformed straight cliffs, as well as other beds eastward onto the Iron Springs. This event formed the somewhat younger Coal Canyon thrust which then emplaced the folded straight cliffs over the iron springs, which was then followed by the deposition of the Cretaceous Grand Castle (originally believed to be Paleocene until the discovery of dinosaur tracks) over both eastern thrusts, and atop the Iron Springs and Straight Cliffs formation. The next major event was the deposition of the Claron Formation on top of the grand castle conglomerate in the east, and atop the Carmel and Navajo sandstone to the west Indicated by the presence of Claron atop hydrothermally altered Navajo Sandstone. A late-stage reactivation of the coal canyon thrust then proceeded to cut the grand castle conglomerate, and at minimum the basal beds of the claron formation.

In the Oligocene period, large scale volcanic activity and pyroclastic flows occurred. The earliest deposition was the Brian head, then the Wah-Wah, followed by the Isom, indicated by them lying vertically atop each other in that order. The Brian Head came from an unknown source roughly 33 million years ago, while the Wah Wah springs and Isom formation were sourced from the Indian Peak Caldera super volcanic eruption, a massive eruption roughly 5X the size of the largest Yellowstone eruption ever recorded. Accumulation of the Wah Wah and Isom atop the weaker Brian head caused an emplacement upon the Claron Formation from a massive mass wasting (landslide) event.

Basin and Range extensional faults began about 20 million years ago (Dinter 2017) after deposition of the Ignimbrite volcanics and offset various beds deposited throughout the gap, as well as Juxtaposing the high western gap exposures to the west directly to the lower deposited eastern-side exposures. Further Basin and Range activity eventually uplifted areas, which in turn formed a meandering stream at the western margin of the Colorado plateau. This stream began erosion of the various deposited strata in the area, and eventually formed what became known as the "Gap. In the Late Tertiary to early Quaternary, normal faulting, particularly from the eastern normal fault formed the Parowan Valley Graben. This Graben dropped the area of the Parowan Gap, and eventually Isolated the Red Hills from the Markagunt Plateau. This isolation cut off the source of the meandering steam, and caused the Parowan gap to become an antecedent, or inactive stream. In the Quaternary, mass wasting has caused mass wasting to varying degrees, causing landslides to form on steep erosional slopes. Coevally with this, basalt flows in the North, as well as deposition in Quaternary alluvial fans occurred, with Alluvium and Land slide deposition continuing still to this day.

Conclusions

The Parowan Gap provides a good picture of depositional and deformational history from the Jurassic throughout the Quaternary. The Strata themselves tell a story of various depositional environments and locales which can be used to piece together a coherent story of Earths past.The Navajo Sandstone Was determined to be deposited in an aeolian Erg based on Cross bedding and other features. The Carmel a shallow marine carbonate shelf or lagoonal environment based upon sandstone and micrite facies. The straight cliffs, a progradational shoreface/back beach, based upon variations in sandstone facies, as well as oysters, cross bedding, and parallel lamination. The Iron springs as a braided fluvial, based upon many fining upwards sequences and channel lags with the conglomerates being generally alluvial fan in nature, and the Claron being Lacustrine.

In addition to the story the strata tells, the various thrust and Normal faults serve as excellent clues for the deformational processes. The thrust faults were determined to occur from Sevier orogenic episode based upon ages of the formations and cross cutting relationships, while normal faulting was concluded to be from Basin and Range extension, due similarly to cross cutting relationships and being post Claron deposition. Using all these pieces the geologic picture in the puzzle becomes clearer, and the lessons and processes can be used to determine processes and events elsewhere. However, this is in only something of a preliminary study, and further research would be needed to get the full geologic story.

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References

Dinter, David (2017) University of Utah, Geo 4510: Lectures and Handouts

Hansen, Thor Arthur, and Carl Fred Koch. "Cretaceous Period." Encyclopædia Britannica. Encyclopædia Britannica, Inc., 08 May 2017. Web. 25 May 2017. https://www.britannica.com/science/Cretaceous-Period

Kocurek, Gary, and Robert H. Dott. "Jurassic Paleogeography and Paleoclimate of the Central and Southern Rocky Mountains Region." (1983)

Livacarri, R.F., 1991, Role of crustal thickening and extensional collapse in the tectonic evolution of the Sevier-Laramide Orogeny, Western United States, Geology [Boulder], Vol. 19, Issue 11, pp. 1104-1107.

Mitrovica, J. X.; Beaumont, C.; Jarvis, G. T. (1989). "Tilting of continental interiors by the dynamical effects of subduction". Tectonics. 8: 1079

Salyards and Shoemaker. “Landslide and Debris Flow Deposits in Miocene Horse Spring Formation, Nevada: A Measure of Basin and Range Extension”. GSA Centennial Field Guide, 1987.

Schweikert, Richard; Bogan, Nicholas L.; Girty, Gary H.; Hanson, Richard E.; Merguerian, Charles (1984). "Timing and Structural Expression of the Nevadan Orogeny, Sierra Nevada, California". Geological Society of America Bulletin. 95: 967–979.

Tertiary to Present: Paleocene", pp. 459-465, Vol. 5. Of Selley, Richard C., L. Robin McCocks, and Ian R. Plimer, Encyclopedia of Geology, Oxford: Elsevier Limited, 2005

Stanley, Steven M. (1999). Earth System History. New York: W.H. Freeman and Company. pp. 487–489

Tang, Carol Marie. "Jurassic Period." Encyclopædia Britannica. Encyclopædia Britannica, Inc., 17 May 2013. Web. 20 Apr. 2017.
https://www.britannica.com/science/Jurassic-Period

Woolf, Kurtus S. (2008). "Pre-Eruptive Conditions of the Oligocene Wah Wah Springs Tuff, Southeastern Great Basin Ignimbrite Province"

"Basin and Range Province." Wikipedia. Wikimedia Foundation, 05 Apr. 2017. Web. 24 Apr. 2017.
https://en.wikipedia.org/wiki/Basin_and_Range_Province