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GEOLOGIC MAP OF THE GOLDEN THRONE QUADRANGLE,
WAYNE AND GARFIELD COUNTIES, UTAH

by

Daniel Holt Martin

A thesis submitted to the faculty of

Brigham Young University

in partial fulfillment of the requirements for the degree of

Master of Science

Department of Geology

Brigham Young University

December 2005

BRIGHAM YOUNG UNIVERSITY

GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

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ABSTRACT

GEOLOGIC MAP OF THE GOLDEN THRONE QUADRANGLE, WAYNE AND GARFIELD COUNTIES, UTAH

Daniel Holt Martin

Department of Geology

Master of Science

The Golden Throne Quadrangle is located within Capitol Reef National Park, south-central Utah. Geologic mapping of this 1:24,000 scale 7.5 minute quadrangle began in 2003 as the National Parks Service desired to have geologic maps at this scale produced within the park.

Stratigraphically, ten bedrock formations and ten Quaternary deposits are exposed within the Golden Throne Quadrangle. Geologic formations range in age from Permian to Jurassic. This map contains details not included on previous geologic maps including; the members of the Carmel, Chinle, and Moenkopi Formations. Additionally, the Page Sandstone is herein mapped as an independent unit.

Structurally the Golden Throne Quadrangle encompasses most of the southern quarter of the Miners Mountain uplift. The crest of this southwest verging uplift is cut by

the left-lateral strike-slip Teasdale Fault zone. Preparation of a cross-section through the axis of the uplift within the quadrangle has not permitted the use of usual faulting and folding mechanisms (i.e. fault-bend folds and fault-propagation folds) for the creation of the uplift. Two structural models can account for the geometries observed in the field. The first model is a high angle reverse basement fault; the second model is a fold over an inverted basin.

The Jurassic Page Sandstone, in the Golden Throne Quadrangle, is composed of the Harris Wash and Thousand Pockets Members, which are divided by the Judd Hollow Tongue, a member of the overlying Carmel Formation. It represents an eolian deposit and is primarily composed of eolian sandstone. Study of the formation within the Golden Throne Quadrangle helped in the understanding of its local characteristics. Previous research has helped to develop a regional stratigraphic framework for the Page Sandstone. This study cannot be easily incorporated into the regional framework of previous studies. In order to fully understand the sedimentology of the Page Sandstone additional research will need to be accomplished.

PREFACE

The thesis is divided into two chapters and four appendices. Both chapters are complete with their own illustrations and references. Appendix A, the geological map and legend, will be published by the Utah Geological Survey.

Chapter 1 contains a detailed overview of the preparation of the geologic map of the Golden Throne Quadrangle. It contains a summary of previous research conducted in the area. It also contains a description of methods used to create the map, and lists and discusses the important conclusions observed within this process. It includes a list of mappable geologic units which can be found within the quadrangle, and a discussion on the structure of the quadrangle.

Chapter 2 is a review of all findings pertaining to the research on the Page Sandstone. It includes an explanation of previous work, description of this study's meaningful findings, discussion about problems encountered with respect to previous research, and recommendations of future work to be accomplished.

Appendix A is a paper copy of the geologic map and legend. Appendix B is a diagram displaying the five digitized measured sections of the Page Sandstone.

Appendix C is a data CD containing digital files of the geologic map, map legend, Page Sandstone correlation diagram, and copy of this thesis. Appendix D is a collection of important and interesting photos taken within the Golden Throne Quadrangle.

ACKNOWLEDGMENTS

First of all I would like to thank my thesis advisor Tom Morris for his support and friendship throughout all my time at Brigham Young University; especially for his patience, understanding, and encouragement through the trials I have experienced during the last year of this thesis work. I would also like to thank my parents Kerry and Virginia Martin for the love and support that they have shown to me throughout my life. Dad, thanks for teaching me to love nature and to wonder how the world works, Mom thank you for the wonderful example of how to live a beautiful life. Thanks are also extended to James Eddleman for his insight, enthusiasm, and humor; Ron Harris for his assistance on the subsurface portion of the study; Sam Sorber for his valuable insights and hard work; Grant Willis of the Utah Geological Survey for his assistance in the map preparation and support for publishing this map; Helmut Doelling also of the Utah Geological Survey for his valuable suggestions which have greatly increased the quality of this map; Tom Clark of Capitol Reef National Park for his logistical assistance and mentoring; and the people of the Department of Geology at Brigham Young University for their assistance and instruction. I would also like to thank all the institutions who helped fund this research which include; the United States National Park Service, the United States Geologic Survey, and the College of Physical and mathematical Sciences at Brigham Young University. Lastly, I want to thank my wife Becca Martin for her love,

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CHAPTER 1

GEOLOGIC MAP OF THE GOLDEN THRONE QUADRANGLE, WAYNE AND
GARFIELD COUNTIES, UTAH

INTRODUCTION

Capitol Reef National Park, located in south-central Utah, was created in 1971 in order to protect and promote the geology and natural history of the Waterpocket Fold region. The Golden Throne Quadrangle is located mostly within the boundary of the national park (Figure 1). The landscape of the Golden Throne Quadrangle is dominated by the steep Western Escarpment of the Waterpocket Fold, at the crest of which sits a giant monolith called the Golden Throne. It is a spectacular specimen of golden Navajo and Page Sandstone, windswept and stained with desert varnish. It is this feature for which the quadrangle was named.

The Golden Throne Quadrangle contains the Scenic Drive road. It is the only paved road, other than Utah Highway 24, in the park. This road provides the only easy access into the center of the park and is therefore heavily traveled by park visitors. The Golden Throne Quadrangle was designated as a high priority for geologic mapping because of its relatively high visitation along Scenic Drive. Along with high visitation, park officials desired to have a geologic map for park service and public education, for facility expansion planning, for identification of geologic hazards, and to provide a more accurate geologic map for biological studies.

Support for mapping in the Golden Throne area has been provided by the U.S. National Park Service, the U.S. Geological Survey's EDMAP program (Award No. 03HQAG0035), the Utah Geological Survey, Brigham Young University College of Physical and Mathematical Sciences, and the Brigham Young University Department of Geology. This map has been accepted for publication and will be published by the Utah Geological Survey.

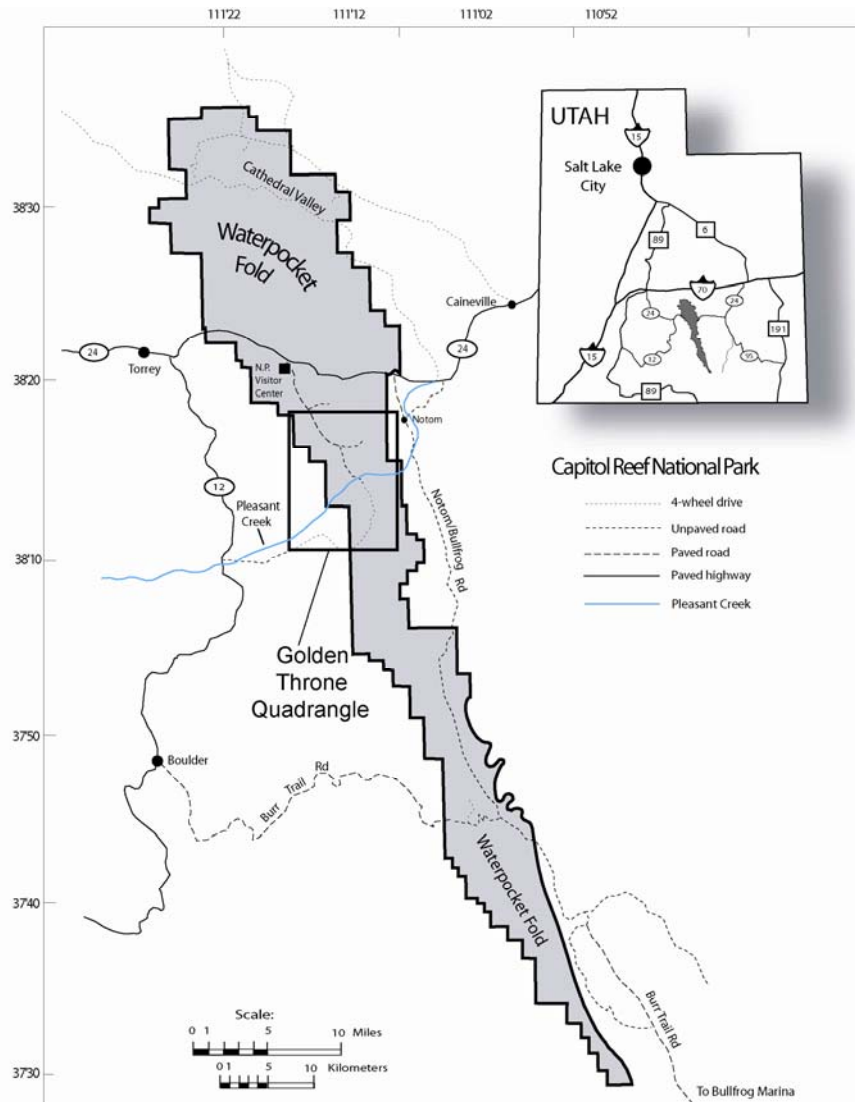


Figure 1. Reference map of Capitol Reef National Park and the Golden Throne Quadrangle (Modified from Morris et al., 2000).

BACKGROUND AND PREVIOUS WORK

Study of the geology in and around Capitol Reef National Park began with the first explorers/geologists who visited the area. Howell (1875), Gilbert (1877), and Dutton's (1880) studies during the late 1800's were among the first to describe and decipher the complex and stunning geology of this area. Gregory and Anderson's (1939)

paper contained the first detailed unit descriptions, stratigraphic analysis, measured sections, and geomorphic information of the Capitol Reef area.

The first detailed geologic maps (1:24,000) of the area were produced by Smith et al. (1957) in association with a study of uranium-bearing rocks found in the region. These maps were funded by the U.S. Atomic Energy Commission. These maps were used as the base map for a 1:62,500 scale regional geologic map included with a U.S. Geological Survey Professional Paper (Smith et al., 1963). Billingsley et al. (1987) published a 1:62,500 scale map of the entire national park, which added greater understanding to the geology of the park.

Renewed interest in mapping in the park began in 2001 with the Fruita Quadrangle (McLelland et al. 2002). Additional mapping was requested by the National Park Service as they desired to have published and updated 1:24,000 scale 7.5 minute geologic maps of the park. The Golden Throne Quadrangle is the second in a series of three 1:24,000 scale 7.5 minute quadrangles completed by Graduate Students from Brigham Young University. Also included are the Fruita Quadrangle and the Twin Rocks Quadrangle.

This map includes some important details not included in previous maps:

- Mapping separately the members of the Carmel Formation; the Paria River Member, the Lower Windsor Member (gypsum member), and the Upper Windsor Member (banded member).
- Mapping separately the members of the Chinle Formation; the Shinarump Conglomerate, the Monitor Butte Member, the Petrified Forest Member, and the Owl Rock Member.

- Mapping separately the Members of the Moenkopi Formation; the Black Dragon Member, the Sinbad Limestone, the Torrey Member, and the Moody Canyon Member.
- The Page Sandstone mapped as an independent unit. The Page Sandstone was mentioned in the unit descriptions in the map by Billingsley et al. (1987) but was not officially mapped as a separate unit until (McLelland et al., 2002).
- Greater detail of Quaternary deposits such as; two levels of alluvial deposits (Qal1, Qal2), designation of two basalt boulder alluvial terrace levels within the Glen Canyon section of Pleasant Creek (Qatb1, Qatb2), and mapping of landslide deposits (Qms).
- More detailed hypotheses of subsurface folding mechanism and geometry of the Miners Mountain uplift (included with the map legend, Appendix A, Plate 2).

MAPPING METHODOLOGY

Data collection for the map was conducted on two fronts; mapping in the field and the study of 1:12,000 scale true-color aerial photos. Field maps and photo interpretations were then digitized using GIS software.

Field mapping of the quadrangle was accomplished during 2003, 2004, and 2005. Field mapping methods included: creating paper field maps showing bedrock and Quaternary geology contacts on the 7.5 minute topographic map of the Golden Throne Quadrangle; rock formation study to determine lithology, color, grain size, and formational contacts for the creating of unit descriptions; and the gathering of structural information such as strike and dip measurements and fault information for creating a geologic cross-section. Strike and dip measurements were made in as many areas as

possible, however the formations of the Glen Canyon Group posed a challenge due to their inaccessibility and lack of good bedding planes. Special attention in obtaining abundant strike and dip data was paid to the Teasdale Fault/Pleasant Creek area in order to aid in accurate cross-section construction.

1:12,000 scale true-color aerial photos of Capitol Reef National Park were taken in 2002 specifically for the National Park Service use. These aerial photos were very useful in mapping because large portions of the quadrangle are very remote, rugged, and accessible only by hiking great distances. Bedrock formation contacts, Quaternary deposits, and fault traces were mapped in part with the aid of these photos.

Further modifications and edits to the map were made using VR1 mapping software at a workstation located at the Utah Geologic Survey (UGS) with input from UGS Geologist Helmut Doelling in order to prepare the map for final acceptance and publication.

STRATIGRAPHY

Bedrock Geology

The Golden Throne Quadrangle contains bedrock formations and members mappable on a 1:24,000 scale, ranging in age from the Middle Permian to Upper Jurassic (Figure 2). These formations and members include:

- Cutler Group (Permian) (Pc)
- Kaibab Limestone (Permian) (Pk)
- Moenkopi Formation (Triassic) and its members:
 - Black Dragon Member (Trmb)
 - Sinbad Limestone Member (Trms)

- Torrey Member (Trmt)
- Moody Canyon Member (Trmm)
- Chinle Formation (Triassic) and its members:
 - Shinarump Conglomerate Member (Trcs)
 - Monitor Butte Member (Trcm)
 - Petrified Forest Member (Trcp)
 - Owl Creek Member (Trco)
- Wingate Sandstone (Jurassic-Triassic) (JTrw)
- Kayenta Formation (Jurassic) (Jk)
- Navajo Sandstone (Jurassic) (Jn)
- Page Sandstone (Jurassic) (Jpc)
- The Carmel Formation (Jurassic) and its members:
 - Paria River Member (Jcpr)
 - Lower Windsor (gypsum) Member (Jcwg)
 - Upper Windsor (banded) Member (Jcwb)
- Entrada Sandstone (Jurassic) (Je)

(Morris et al., 2000; Jones and Blakey, 1997; Blakey et al., 1996; Hintze, 1993; Kamola and Chan, 1988; Peterson, 1988; and Mitchell, 1985). Descriptions of formations, members, and age data can be found on the legend of the geologic map (Appendix A, Plate 2).

SYSTEM	FORMATION	Member	THICKNESS feet (meters)	MAP SYMBOL	LITHOLOGY	ENVIRONMENT	
JURASSIC	San Rafael Group	Entrada Sandstone		450-480 (137-146)	Je		tidal flat
		Carmel Fm.	Upper Windsor	180-200 (55-61)	Jcb		marine
			Lower Windsor	180-200 (55-61)	Jcg		
			Paria River Member	150-200 (46-61)	Jcpr		
	Page Sandstone		133-153 (41-47)	Jp		sabkha	
	Glen Canyon Group	Navajo Sandstone		1000-1300 (305-396)	Jn		eolian
Kayenta Fm.		300-400 (91-122)	Jk		fluvial		
Wingate Sandstone		350-400 (107-122)	Jw		eolian		
TRIASSIC	Chinle Fm.	Owl Creek Mbr.	180-220 (55-67)	Trco		lacustrine/ fluvial	
		Petrified Forest Mbr.	180-200 (55-61)	Trcp			
		Monitor Butte Mbr.	150-200 (46-61)	Trcm			
		Shinarump Cgl. Mbr.	0-30 (0-9)	Trcs			
	Moenkopi Fm.	Moody Canyon Mbr.	250-300 (76-91)	Trmm		coastal plain & tidal flat	
		Torrey Mbr.	200-220 (61-67)	Trmt			
		Sinbad Ls. Mbr.	40-70 (12-21)	Trms		marine	
	Black Dragon Mbr.	50-70 (15-21)	Trmb				
PERMIAN	Kaibab Limestone		500-550 (152-168)	Pk		marine	
	Cutler Group Undivided		1500 (457)	Pc		eolian	

Figure 2. Stratigraphy of the Golden Throne Quadrangle (Modified from Morris et al., 2000).

Quaternary Geology

Quaternary deposits in this quadrangle have been broken into ten units. They are; alluvial and floodplain deposits (Qal), alluvial and floodplain deposits of an older river level (Qal2), talus deposits (Qmt), basalt boulder terraces (Qatb1, Qatb2 Qatbu), basalt

boulder terrace colluvial deposits (Qmtb), terrace deposits composed of locally derived material (no basalt) (Qatl), eolian deposits (Qe), and landslide deposits (Qms). Relative age information of these units and lithologic descriptions can be found in the legend of the included geologic map (Appendix A, Plate 2).

Basalt boulder terraces found in the Pleasant Creek drainage are a deposit of special interest. Work by Eddleman (2005) has determined that basalt boulder terraces within the Waterpocket Fold section (Moenkopi Formation, Chinle Formation, Wingate Sandstone, Kayenta Formation, Navajo Sandstone, and Carmel Formation) of the river can be divided into two distinct groupings (Qatb1, Qatb2) that represent two major episodes of down-cutting of the Pleasant Creek streams. These groupings may correlate to terraces in the nearby Fremont river drainage. An explanatory summary of the work done by Eddleman (2005) on the basalt boulder terraces, and their correlation to the landscape evolution of the Pleasant Creek drainage will be included with the map legend of the Golden Throne Quadrangle (Appendix A, Plate 2).

STRUCTURE

Capitol Reef National Park encompasses a geographic feature historically called the Waterpocket Fold. This fold is composed of two distinct structures, the Miners Mountain uplift to the north and the Circle Cliffs uplift to the south. The Miners Mountain uplift has only been recently recognized as a separate uplift from the larger Waterpocket Fold (Bump et al., 1997). This quadrangle lies just north of the transition zone between the two uplifts. The Miners Mountain uplift was formed during the Laramide Orogeny which occurred during the Late Cretaceous to Early Tertiary. It is a doubly-plunging anticline whose axis trends N60°W (Bump and Davis, 2003). This large

fold (27 miles northwest-southeast by 12 miles northeast-southwest) has been described as having three structural components; the gently dipping (10° - 15°) backlimb known as the Waterpocket Monocline, the anticlinal crest known as the Miners Mountain Anticline, and the steeply dipping (30° - 60°) forelimb of the fold called the Teasdale Monocline (Billingsley et al., 1987; Anderson and Barnhard, 1986). Studies of faults, fractures, and deformation bands found within the uplift have shown that this fold was formed by left hand oblique slip, likely associated with a basement-initiated reverse fault (Bump and Davis, 2003; Anderson and Barnhard, 1986). Direction of maximum compression (σ_1) was determined to be $N60^{\circ}E$ - $N70^{\circ}E$ (Bump and Davis, 2003; Anderson and Barnhard, 1986). The Golden Throne Quadrangle encompasses a portion of the lower quarter of the Miners Mountain uplift.

Teasdale Fault

The Teasdale Fault is a prominent fault which cuts the rim of the Teasdale Monocline along much of its trace. It runs, for most of its length, parallel to the forelimb of the fold (roughly northwest southeast). Within the Golden Throne Quadrangle, this fault curves eastward and crosses the anticlinal crest of the Miners Mountain uplift just south of Pleasant Creek. Previous maps have shown this fault to be a normal fault (Billingsley, 1987; Smith et al., 1963). Although the fault does have mostly normal offset, it also has a component of left lateral strike-slip motion. This is recorded by slickensides in the fault zone (Figure 3) and a change of apparent offset from down to the south, to down to the north, as the fault crosses the anticlinal crest of Miners Mountain. The strike-slip component is thought to be a consequence of left lateral basement



Figure 3. Slickensides demonstrating left-lateral movement along the hanging wall of the Teasdale Fault with a rake of 22° . Photo taken at the point where Pleasant Creek intersects the Fault Trace.

movement. The change of direction in the fault zone from southeast to east is thought to be a result of the wrench zone created by the eastward verging Circle Cliffs uplift.

The interpretation of the normal component of offset encountered in the Pleasant Creek area depends on the subsurface folding mechanism model used. The offset may be related to fold accommodation faulting which terminates into the neutral surface of the fold in the inverted basin model, or is directly connected to the underlying large scale fault structure in the basement reverse fault model.

Subsurface Geometry

Only a few models have been proposed to describe the formation of the Miners Mountain uplift. In their cross-section Smith et al. (1963) only project far enough into the subsurface to show exposed bedding and do not show the fold-causing fault.

Billingsley et al. (1987), show a simple high-angle reverse fault as the mechanism of the fold. The simple high angle basement fault is probably correct, however, it was hoped that this present study would be able to shed some additional light on the question.

Several factors increase the difficulty of construction and interpretation of a cross-section in the Golden Throne Quadrangle area, and perhaps make the area less representative of the larger Miners Mountain uplift. First, the uplift morphology within the Golden Throne Quadrangle is unique. It has a relatively shallow dipping (60°) forelimb, very short toplimb, and extremely long backlimb. Second, the Teasdale Fault for most of its length is parallel to the forelimb of the fold (roughly northwest southeast). Near Pleasant Creek it suddenly turns to the east bisecting the southern portion of the structure. Third, the northwest-southeast trending forelimb sharply turns south near Sheets Draw. This is best observed where the Shinarump Conglomerate bends sharply south. Lastly, in this area the forelimb and backlimb are not parallel; therefore any straight cross-section would intersect at least one of the limbs of the uplift at an angle other than perpendicular. This creates, in cross-sectional view, limbs which are inaccurately long or short.

A cross-section has been constructed that bisects the fold near the Pleasant Creek area. Hypotheses of the subsurface structure have been developed using the exposed fold morphology to model a likely subsurface geometry. Careful study of the exposed

structural information was done in order to construct a cross-section which most accurately interprets the subsurface relationships. Models such as fault-bend folds and fault-propagation folds (van der Pluijm and Marshak, 1997; Bump, 2003; Tindall and Davis, 1999) must be ruled out because of the geometric constraints (Figure 4) encountered in this portion of the Miners Mountain uplift. Two folding models have been identified which fit the narrow geometric requirements. These models are (1) - high angle reverse faults initiated in the basement proposed by Billingsley et al. (1987), and (2) - a fold occurring over an inverted basin (Figure 5).

1. Davis (1978) used a clay and pine board experiment to model the effect of a high angle reverse fault on an overlying succession of strata. This model showed that immediately over the tip of the fault the strata were folded and faulted at a high angle. However, further up section the degree of folding dissipated and was taken up in reverse faults and flexural flow in the fold area. The reverse faults and the flexural flow caused the dip of the forelimb of the surface geometry to not be as severe as the underlying structure.

The Miners Mountain uplift may be similar to this model because of the good fit of the fold geometry. The Teasdale Fault and other smaller faults can be explained as

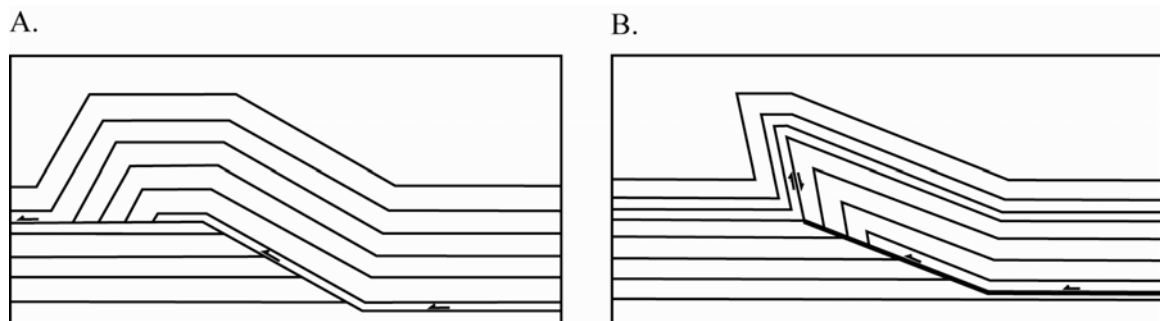


Figure 4. Schematic diagrams of a fault-bend fold (A) and fault-propagation fold (B), after van der Pluijm and Marshak (1997). A. Fault-bend fold morphology displays a shallow forelimb, long toplimb, and backlimb that mirrors the fault ramp. B. Fault-propagation fold morphology displays an overturned forelimb, short toplimb, and a backlimb that mirrors the fault ramp. Neither of these models fit the geometric constraints of the Miners Mountain Uplift within the Golden Throne Quadrangle.

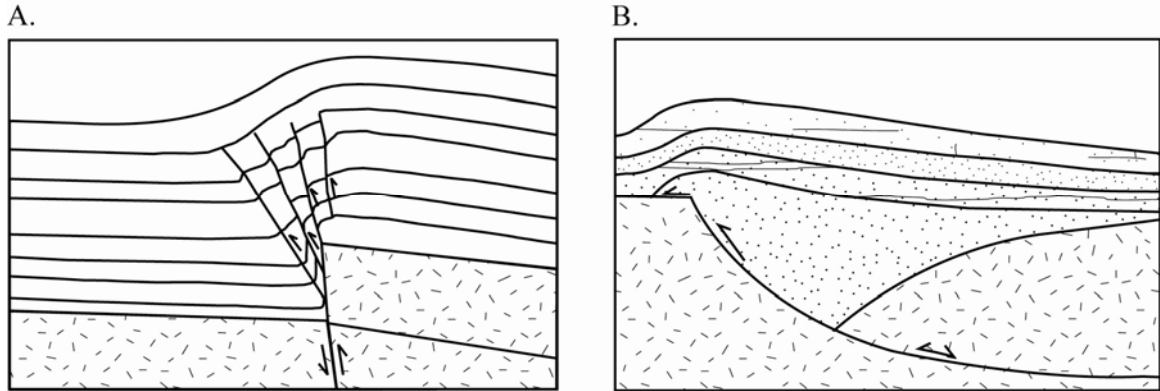


Figure 5. A. Schematic diagram showing a high angle reverse thrust into overlying strata, after Davis (1978). Fold morphology shows that directly over the tip of the fold the forelimb is dipping at a high angle and faulted. Higher in the section the degree of folding is taken up by reverse faults which lessen the steepness of the forelimb. This model has a short toplimb and a potentially long backlimb. This morphology is a better fit with the Miners Mountain Uplift within the Golden Throne Quadrangle. B. Schematic figure demonstrating folding which occurs as a reactivated normal fault injects synrift sediments into the overlying sediment package, after McClay and Buchanan (1992). Fold morphology displays a shallow dipping forelimb, short toplimb, and a long backlimb that mirrors basin morphology. This morphology also fits well with the Miners Mountain Uplift in the Golden Throne Quadrangle.

reverse faults by this model. Having been successfully modeled in experiments, examples of these types of fault geometries can readily be found in nature. For example, Laramide aged structures such as Rattlesnake Mountain and the Bighorn Uplift (Wyoming) both display this fold geometry at depth.

2. Folds over inverted basins offer an alternative model. These types of uplifts have geometries that are similar to the Miners Mountain Fold (McClay and Buchanan, 1992). An inverted-basin fold forms when a listric normal fault is reactivated with reverse fault motion and displaces syn-rift sediments into the overlying rock column. It has been proposed that faults causing Laramide uplifts are reactivated ancient normal faults (Marshak et al., 2000). Rift zones adjacent to normal faults likely contain syn-rift sediments.

In surrounding areas, deposition of syn-rift sediments have occurred during the Pennsylvanian (Paradox and Oquirrh basins) (Hintze, 1993) and during the Precambrian (Grand Canyon area) (Huntoon et al., 1996). Well data precludes thick successions of Pennsylvanian age rock in the Capitol Reef region (Hintze, 1993). The Grand Canyon area does contain significant accumulations of Precambrian aged syn-rift sediments (Grand Canyon Series) and may be a similar situation. Precambrian-age rock is not exposed and little well data exists in the area between the Uncompahgre Uplift in Colorado and the Grand Canyon in Arizona (Hintze, 1993). The lack of information about the Precambrian section of the Colorado Plateau does not rule out the possibility that syn-rift sediments may exist in some locations. It is possible that a Precambrian rift zone with syn-rift sediments exists in the Capitol Reef area, and that reactivation during later compressional events (Laramide Orogeny) of these earlier rift zones has caused the Miners Mountain uplift. In this model the Teasdale Fault would initiate a fold accommodation fault and terminate into the neutral surface of the fold.

CONCLUSIONS

The geologic map and map legend presented in this thesis summarize the stratigraphic and structural geology of the Golden Throne Quadrangle. The following conclusions can be determined from this map:

- This edition of the map contains the members of the Moenkopi, Chinle, and Carmel Formations.
- Eighteen mappable bedrock formations and members ranging from Permian to Jurassic in age are found within the map area.
- Ten Quaternary geologic units are found in the map area.

- Basalt boulder terraces within the Waterpocket Fold portion of the drainage can be divided into two terrace levels (Qatb1, Qatb2) representing two down-cutting episodes possibly linked to climate fluctuations.
- The quadrangle contains a northwest-southeast trending Laramide aged monoclinial structure.
- Morphologic constraints preclude simpler models such as fault-bend folds and fault-propagation folds from being the mechanism of folding of the quadrangle.
- The fold mechanism of the uplift may either be caused by a basement thrust fault or a fold over an inverted basement fault.
- The Teasdale Fault has some component of strike-slip motion and bisects the crest of the fold. It is either connected to the deeper structure, or terminates into the neutral surface of the fold.

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CHAPTER 2
STRATIGRAPHIC ANALYSIS OF THE PAGE SANDSTONE WITHIN THE
GOLDEN THRONE QUADRANGLE

ABSTRACT

The Jurassic Page Sandstone in the Golden Throne Quadrangle crops out in many places as the capstone of the huge monoliths which tower above the Waterpocket Fold. In the Capitol Reef area the Page Sandstone is composed of the Harris Wash and the Thousand Pockets Members which is divided by the Judd Hollow Tongue, a member of the overlying Carmel Formation. It represents an erg deposit, and is primarily composed of eolian sandstone; however it does contain some amounts of siltstone, shale, and limestone. The Page Sandstone lies stratigraphically above the Navajo Sandstone. This contact has been called the J2 unconformity and displays pervasive polygonal fractures.

Study of the formation within the Golden Throne Quadrangle helped in the understanding of its local characteristics. Previous research has helped to develop a regional stratigraphic framework for the Page Sandstone. This study cannot be easily incorporated into the regional framework of previous studies. In order to fully understand the sedimentology of the Page Sandstone additional research will need to be accomplished.

INTRODUCTION

The Page Sandstone is the capstone for the Golden Throne and other surrounding monoliths that are at the crest of the Waterpocket Fold. The scene of the Golden Throne rising out of the Utah desert is one of the most awe inspiring in all the Colorado Plateau. The Page Sandstone was recently mapped as an independent unit in the Capitol Reef area (McLelland et al., 2002). The Page Sandstone was deposited by eolian processes during the Bajocian and Bathonian Stages of the Middle Jurassic Series (Jones and Blakey, 1997). The Page Sandstone is separated from the Navajo Sandstone by an unconformity

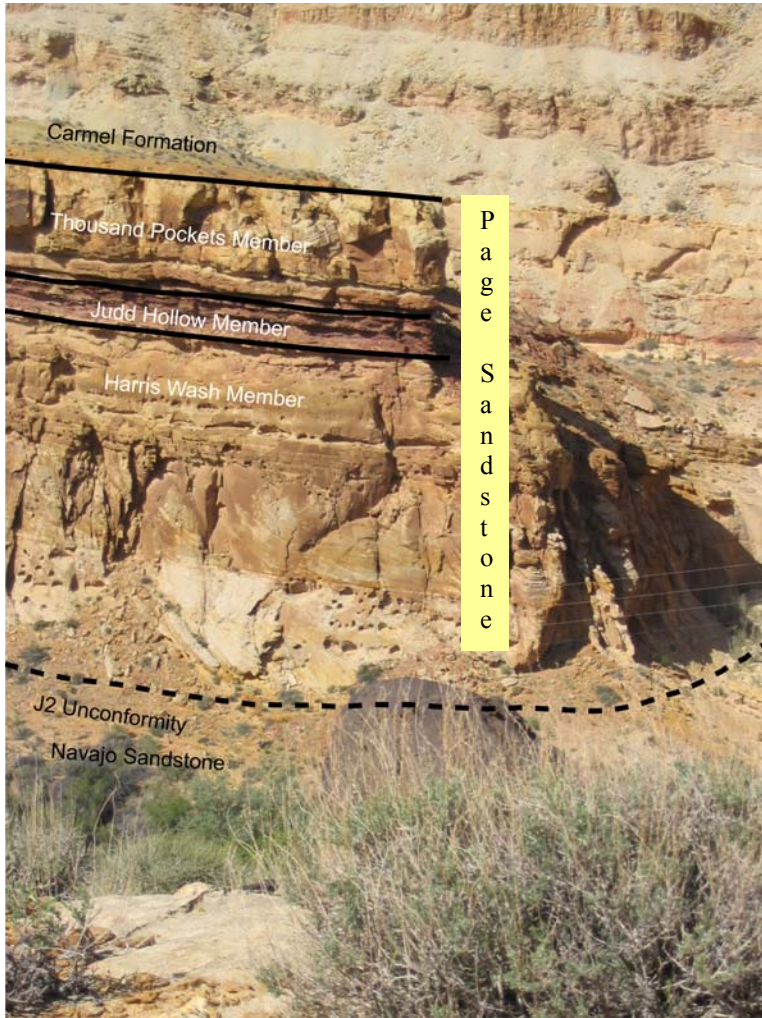


Figure 6. Annotated photo displaying the members of the Page Sandstone. Taken at the Fremont River section.

which displays pervasive polygonal fracture sets. This contact has been called the J2 unconformity (Pipiringos and O’Sullivan 1978).

In order to better describe and more accurately map the Page Sandstone in the Golden Throne Quadrangle five sections of the formation were measured in and around the quadrangle. It was also hoped that the information gleaned from the measured sections could be used to correlate the stratigraphy and

sedimentology of the Page Sandstone to work by previous researchers of the Page Sandstone.

BACKGROUND/PREVIOUS REASEARCH

The Page Sandstone has been rigorously studied in various localities in Utah and Arizona concentrating around the Page, Arizona and Lake Powell regions, and the Boulder, Utah and Escalante, Utah regions (Jones and Blakey, 1997; Blakey et al., 1996;

Havholm and Kocurek, 1994; Capps, 1990). These papers addressed rock type, sequence-stratigraphy, sedimentology, and age of the formation, but focused on areas south and west of the Golden Throne Quadrangle.

Meaningful surfaces called super bounding surfaces or super surfaces have been observed within the Page Sandstone. Super surfaces are defined as regionally extensive (up to 100 miles in Page Sandstone examples) bounding surfaces which represent a hiatus in erg development (i.e. unconformities) (Kocurek, 1988). These unconformities are thought to represent the on-land expression of the maximum flood of sea level rise.

Super surfaces can be identified by any of the following characteristics: 1- truncation of 1st order bounding surfaces; 2- a pebbly lag surface; 3- a surface with evaporates, preferential cementation, and /or polygonal fractures; 4- paleosols, rhizoliths, and / or bioturbation; and 5- irregular surfaces, eroded surfaces, and / or eolian, lacustrine, fluvial, or sabkha infill (Kocurek, 1988; Capps, 1990).

A sequence stratigraphic framework has been developed for the Page Sandstone in areas ranging from Page, Arizona to Boulder, Utah (Blakey et al., 1996, Havholm and Kocurek, 1994), using super surfaces as sequence boundary markers. These studies included little information from the Capitol Reef area.

Mark Capps' Master's Thesis (1990) studied the Page Sandstone in and around Boulder and Escalante, Utah, with a small portion of work in the Capitol Reef area. His paper contained research close to the Golden Throne Quadrangle and was therefore the most relevant and most useful. The bulk of Capps' work was accomplished at least 20 and up to 100 miles southeast of the Golden Throne Quadrangle, separated by the Circle Cliffs uplift and Boulder Mountain, where he measured forty five sections. He, however

only measured three sections in the Capitol Reef area, the nearest one at the waterfall of the Fremont River on Highway 24. Included in his thesis are several cross-sections through his study areas including one along strike with the Waterpocket Fold. In the Capitol Reef area Capps (1990) identified seven super surfaces which were displayed on the cross-section. Sections of rock between these super surfaces can be broken into six packages of rock.

STRATIGRAPHY AND SEDIMENTOLOGY

The Jurassic Page Sandstone in the Golden Throne Quadrangle has been broken into two members, the Harris Wash Member and the Thousand Pockets Member (Jones and Blakey, 1997; Blakey, personal communication)(Figure 6). The Judd Hollow Tongue, which divides the two members, has been identified as a tongue of the overlying Carmel Formation (Jones and Blakey, 1997). Additionally, work by Doug Sprinkel and Helmut Doelling (UGS, personal communication) has determined that the Judd Hollow Tongue can further be subdivided into the Judd Hollow and the Crystal Creek Members of the Carmel Formation. This division has been made based on pollen collected at the waterfall section on Utah Highway 24. For discussion purposes within this thesis the portions of Carmel Formation within the Page Sandstone will be called the Judd Hollow Tongue.

Member Descriptions

The Harris Wash Member ranges in thickness from twenty seven to thirty five meters. The member is almost entirely composed of sandstone of fine-to medium-grained sand size and is composed dominantly of quartz. This sandstone was mostly deposited as trough-crossed and high angle trough-crossed stratified sand, with minor

sections of planar laminated sand and massive sand. Some finer grained sediment is also in the section. This is manifested as shale and very fine crinkly bedded silt layers between the sand bodies.

The Judd Hollow Tongue ranges in thickness from two to five meters. The member is composed of red silt and shale beds with a few fine grained sandstone beds. Two measured sections include thin carbonate beds, ranging from one centimeter to fifty centimeters in thickness. Bedforms include crinkly beds, planar laminated beds, and massive beds.

The Thousand Pockets Member ranges in thickness from five to ten meters in thickness. It is mainly composed of medium- to fine-grained quartz sandstone, but does contain some siltstone and shale. Bedforms in the sandstones include: planar laminated beds, trough-cross stratified beds, and contorted bedding. The contorted bedding is of special interest as it occurs directly above the Judd Hollow Tongue and is possibly related to soft sediment deformation events caused by sea level fluctuations?

STUDY METHODOLOGY

For this study five sections within and near the Golden Throne Quadrangle were measured using a Jacob's Staff (Appendix B, Plate 3). Member characteristics such as: lithology, changes in lithology, thickness, bedforms, color, and grain size were noted. Nine facies types were identified to facilitate section interpretation. These were based on facies identified by Capps (1990) in his study. These facies types include the following:

- Cross-bedded Sandstone. This facies is composed of trough cross-stratified to high angle trough cross-stratified, medium- to fine-grained, quartz-rich sandstone.

It makes up a large percent of the Harris Wash Member and is encountered in small amounts in the Thousand Pockets Member.

- Massive Sandstone. This facies is composed of medium- to fine-grained sandstone that displays no bedding.
- Planar Laminated Sandstone. This facies is composed of medium- to fine-grained sandstone that displays planar lamination.
- Shale. Shale beds are composed of planar laminated clay-sized particles. They are often red in color and occasionally gray-green in color. Shale beds are most often encountered in the Judd Hollow Tongue and are also encountered in other members associated with super surfaces.
- Siltstone. Siltstone beds are composed of planar laminated silt-sized particles. They are usually red in color and are most often encountered in the Judd Hollow Tongue. Siltstone beds are also encountered in other members associated with super surfaces.
- Wavy Laminated Sandstone. Wavy laminated sandstone beds are composed of sand, silt, and clay-sized particles which are irregularly bedded. They are found in the Judd Hollow Tongue, and in the other members associated with super surfaces.
- Carbonate Deposits. This facies is found in thin beds and is associated with the Judd Hollow Tongue.
- Bioturbated Horizons. These beds exhibit some type of bioturbation.

- Contorted Bedding. This facies is composed of medium to fine sand grains. It is almost always encountered in the Thousand Pockets Member above the Judd Hollow Tongue transition.

Measured sections were digitized using Adobe Illustrator CS. Information concerning facies types, interpreted super-surface locations, member boundaries, and other surfaces was included. The sections were scaled to represent their correct spatial locations (Appendix B, Plate 3).

COMPARISONS TO PREVIOUS RESEARCH

Surfaces were observed within the Page Sandstone like those described by Kocurek (1988) and Capps (1990). During the process of measuring sections it became clear that a major challenge in comparing this project to other studies was the presence of multiple surfaces within the section that could possibly qualify as super surfaces. This problem manifests itself due to the somewhat broad definition of the super surface. The written descriptions of super surfaces in previous literature imply that the supersurfaces are easily recognized in the field. Clear correlations are, in reality, hard to recognize. It also became apparent that more measured sections were needed in this area in order to be able to follow all surfaces laterally to determine which surfaces were super surfaces. Unfortunately this further study was beyond the scope of the project and was not accomplished at this time.

The best surfaces (with features most like the super surface definition) were chosen as likely super surfaces. This study identified seven of these likely super surfaces in the Golden Throne region. These may be the same surfaces as those recognized by Capps (1990). However, there are other possible super surfaces within the sections; these

have also been plotted on the Page Sandstone measured sections diagram but have not been highlighted (Appendix B, Plate 3).

After analyzing the digitized measured sections we found that our work differed substantially from work done by Capps (1990). These differences include the following observations:

- Thickness of members in the Page and lithology in his measured section (waterfall on Highway 24) do not match our measured sections.
- Super surfaces in some cases do not line up.
- Packages of rock between super surfaces do not maintain thickness laterally. Packages change thickness and lithology drastically over short distances.
- The Judd Hollow Tongue's thickness in our sections is much thinner than Capps' sections.
- A limestone bed within the Judd Hollow Tongue is not continuous south of Highway 24.
- Capps' total thickness is around 26 meters thick, actual thickness is around 41 meters.

These differences call into question the validity of Capps (1990) work in the Capitol Reef area. It suggests the following possibilities: his work in the Capitol Reef area is in error, measured section thickness have been underestimated, rock packages between super surfaces do in fact vary substantially in thickness, and the stratigraphy in the Capitol Reef area does not correlate to other studied areas.

After reviewing these observations we conclude that we can describe in detail the lithology and sedimentology of the Page Sandstone in the Golden Throne area. However,

attempting to tie the findings of this study to Capps' regional stratigraphic framework is not possible because of problems found in Capps' data which do not match to our observations. What is needed in order to realistically correlate these surfaces to the Escalante/Boulder area, and the Page, Arizona/Lake Powell area is a study within the Capitol Reef area that contains the same density of measured sections as was conducted in other areas (Blakey et al., 1996, Capps 1990). Having measured sections at a higher density would permit identification of the number of super surfaces in the area, lateral extent of super surfaces, and test the validity of using super surfaces as stratigraphic markers in the Capitol Reef area. This study should be accomplished down the spine of the Waterpocket Fold in the area in between Capitol Reef and the Colorado River. With this information, detailed analysis of lateral changes in super surface morphology and facies changes could be tracked and meaningful comparisons could be made.

CONCLUSIONS

Study of the Jurassic Page Sandstone in the Golden Throne Quadrangle has led to the following conclusions:

- The Page Sandstone is composed of two members; the Harris Wash Member and the Thousand Pockets Member, which is divided by the Judd Hollow Tongue, a member of the overlying Carmel Formation.
- It is primarily composed of eolian sandstone with smaller amounts of siltstone, shale, and limestone.
- The Page Sandstone lies directly above the Navajo Sandstone. This contact has been called the J2 unconformity and displays pervasive polygonal fractures.

- Study of the formation within the Golden Throne Quadrangle was beneficial in understanding the local characteristics that have aided in the map-making process.
- In other places where it has been studied a stratigraphic framework has been developed. Our findings show discrepancies between our work and the work of Capps' (1990) which do not permit our research to be tied into his stratigraphic framework.
- In order to better understand the regional sedimentology of the Page Sandstone more sections need to be measured at higher density so that the number and lateral extent of super surfaces can be determined. This in turn will determine the validity of using super surfaces as stratigraphic markers as they are presently defined (Kocurek, 1988) in the Capitol Reef area.

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APPENDICIES

APPENDIX A

APPENDIX A—Plate 1. Geologic Map of the Golden Throne Quadrangle

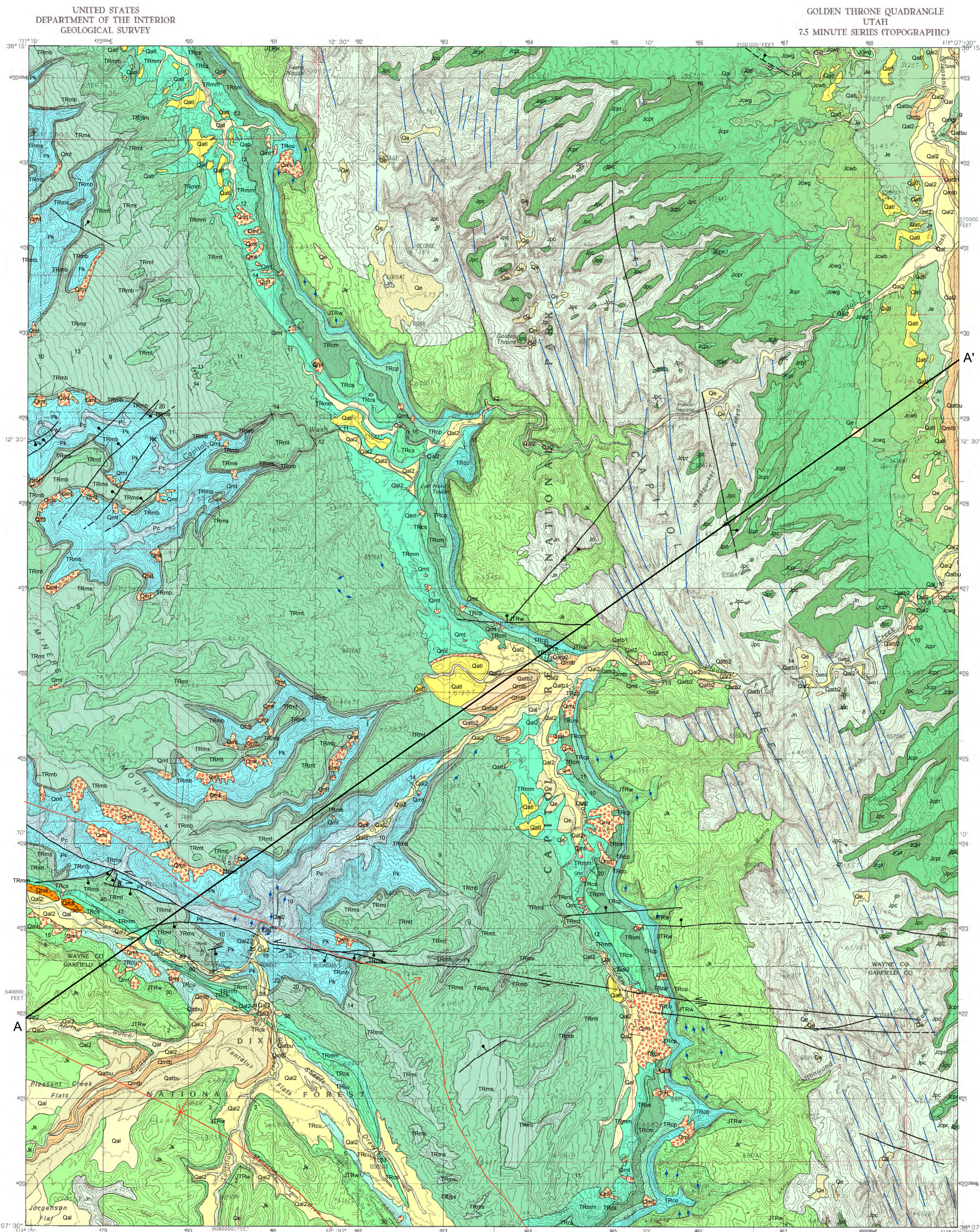
APPENDIX A—Plate 2. Legend for the map of the Golden Throne Quadrangle

including the following:

- A description of map units
- A geologic cross-section
- A lithologic column depiction of mapped units
- A diagram showing correlation of map units age
- A key explaining map symbols

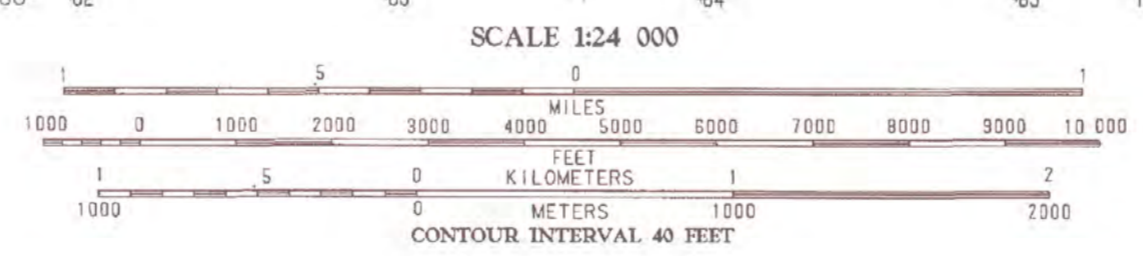
BRIGHAM YOUNG UNIVERSITY DEPARTMENT OF GEOLOGY
 in cooperation with
 THE UNITED STATES NATIONAL PARK SERVICE
 and
 THE UNITED STATES GEOLOGICAL SURVEY
 EdMap Award No. 03HQAG003
 and
 THE UTAH GEOLOGICAL SURVEY

Plate 1
 Brigham Young University
 Geologic Map of the Golden Throne Quadrangle



PRODUCED BY THE UNITED STATES GEOLOGICAL SURVEY
 COMPILED FROM AERIAL PHOTOGRAPHS TAKEN IN 1964
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PROVISIONAL MAP
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THE MAP COMPLES WITH NATIONAL MAP ACCURACY STANDARDS
 FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO 80215
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1	2	3	4	5	6	7	8
ADJOINING 7.5 QUADRANGLE NAMES							

ROAD LEGEND
 Improved Road
 Unimproved Road
 Trail
 Interstate Route
 U.S. Route
 State Route

GOLDEN THRONE, UTAH
 PROVISIONAL EDITION 1987
 3011-ED-TP-014

Geologic Map of the Golden Throne Quadrangle,
 Wayne and Garfield Counties, Utah

By

Daniel H. Martin, Thomas H. Morris, Samuel C. Sorber, and James L. Eddleman

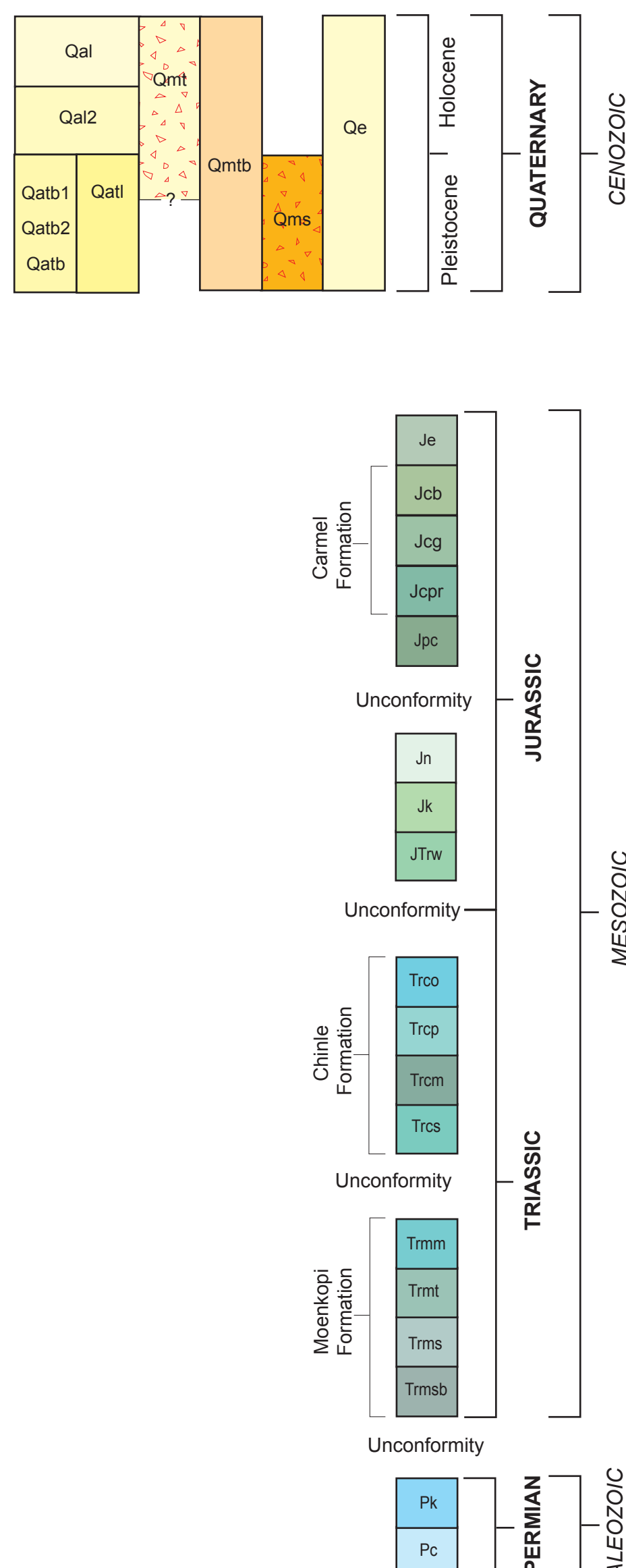
SYSTEM	FORMATION	Member	THICKNESS feet (meters)	MAP SYMBOL	LITHOLOGY	ENVIRONMENT	
JURASSIC	Entrada Sandstone		450-480 (137-146)	Je		tidal flat	
		Upper Windsor	180-200 (55-61)	Jcb		marine	
		Lower Windsor	180-200 (55-61)	Jcg		marine	
		Paria River Member	150-200 (46-61)	Jcpr		marine	
		Page Sandstone	133-153 (41-47)	Jpc		eolian	
	Glen Canyon Group	Navajo Sandstone		1000-1300 (305-396)	Jn		eolian
			Kayenta Fm.	300-400 (91-122)	Jk		fluvial
		Wingate Sandstone		350-400 (107-122)	Jw		eolian
			Owl Creek Mbr.	190-220 (58-67)	Trco		lacustrine/ fluvial
			Monitor Butte Mbr.	150-200 (46-61)	Trcm		lacustrine/ fluvial
TRIASSIC	Chinle Fm.	Petrified Forest Mbr.	180-200 (55-61)	Trcp		lacustrine/ fluvial	
		Shinarump Cgl. Mbr.	0-30 (0-9)	Trcs		lacustrine/ fluvial	
	Moenkopi Fm.	Moody Canyon Mbr.	250-300 (76-91)	Trmm		coastal plain & tidal flat	
		Torrey Mbr.	200-220 (61-67)	Trmt		coastal plain & tidal flat	
		Sinbad Ls. Mbr.	40-70 (12-21)	Trms		coastal plain & tidal flat	
	PERMIAN	Kaibab Limestone		500-550 (152-168)	Pk		marine
			Cutter Group Undivided	1500 (457)	Pc		eolian

- DESCRIPTION OF MAP UNITS**
- Qal** Alluvial and floodplain deposits - Fluviolacustrine deposits in modern streams and rivers. Includes clay to boulder size sediments composed of mudstone, sandstone, and limestone particles. Basaltic rocks found locally in the Pleasant Creek drainage. Thickness ranges from 0 to 10 feet (0-3 m).
 - Qal2** Alluvial and floodplain deposits of a former river level - Located 10 to 20 feet (3-6 m) above current floodplain. Clay to boulder size sediments composed of claystone, sandstone, and limestone particles. Basaltic rocks found locally in the Pleasant Creek drainage. Thickness is up to 20 feet (6 m).
 - Qml** Talus deposits - Talus deposits from mass movement by rock falls, rock slides, and slumps. Sediments composed of clay to boulder size locally-derived material consisting of mudstone, sandstone, and limestone. Terraces in the Glen Canyon section of Pleasant Creek have been divided into two groupings based on work by Dickerson (2003) (Qml1, Qml2). All other terraces with these characteristics have been labeled Qml (undivided). Terraces have generally irregular surfaces. Thickness 0 to 20 feet (0-6 m).
 - Qml1** Basalt boulder terraces - Sediments overlying river-cut strath terraces sourced from basalt covered highlands to the west. Composed of pebbles to boulder size extrusive (basaltic and andesitic) igneous rocks as well as clay to boulder size locally-derived material consisting of mudstone, sandstone, and limestone. Terraces in the Glen Canyon section of Pleasant Creek have been divided into two groupings based on work by Dickerson (2003) (Qml1, Qml2). All other terraces with these characteristics have been labeled Qml (undivided). Terraces have generally irregular surfaces. Thickness 0 to 20 feet (0-6 m).
 - Qml2** Basalt boulder terrace colluvial deposits - Predominantly composed of material weathering from basalt boulder terraces. Usually includes large extrusive (basaltic and andesitic) igneous boulders as well as locally-derived material. Thickness 0 to 5 feet (0-1.5 m).
 - Qml3** Terrace deposits locally derived - Terraces derived from local sources, composed of clay to boulder size particles of claystone, sandstone, and limestone. Usually very well cemented. Often located at the mouths of canyons which cut into mesa plateaus. Thickness 0 to 40 feet (1.5-18 m).
 - Qe** Eolian deposits - Deposits composed of wind-blown sand and silt particles. Often occur between domes of the Navajo Sandstone, as well as in other areas. Thickness 0 to 10 feet (0-3 m).
 - Qms** Landslide deposits - Slump block composed of the Moenkopi Formation which has slid over the Chinle Formation in an area of steeply dipping beds. Source location as well as slump scar are not mappable due to subsequent erosion. Moenkopi block has retained some bedding and topography. Thickness 50 to 60 feet (15-24 m).
 - Je** Entrada Sandstone (Middle Jurassic) - Grayish-red to moderate-red mudstones interbedded with moderate-red-orange fine-grained sandstones, grayish-orange crossbedded eolian sandstones also found at horizons within the formation. The middle of the Entrada Sandstone in this quadrangle is referred to as the "warty" facies as opposed to the "slick rock" facies found in active National Park (Peterson, 1988). Forms a slope. Thickness ranges from 450-480 feet (137-146 m).
 - Jcb** Upper Windsor (Banded Member of the Carmel Formation (Middle Jurassic)) - Pale-red, brown siltstone and mudstone with gypsum stringers interbedded with pale olive mudstone. Forms a slope. Beds are often deformed due to gypsum movement. Local gypsum diapirs cut out. Thickness ranges from 180 to 200 feet (55-61 m).
 - Jcg** Lower Windsor (Gypsum Member of the Carmel Formation (Middle Jurassic)) - Light-gray to white gypsum, pale-red-brown siltstone and mudstone beds with gypsum stringers and white to greenish-gray mudstone. Forms slopes and ledges. Ledges are composed of 40 foot (12 m) thick layers of gypsum. The beds are often deformed due to movement of gypsum beds. Thickness 180 to 200 feet (55-61 m).
 - Jcpr** Paria River Member of the Carmel Formation (Middle Jurassic) - Moderate-red-brown mudstone and siltstone, yellowish-gray siltstone, and light gray to white gypsum. Forms ledges. The gypsum bed is locally discontinuous due to gypsum flow. Thickness 150 to 200 feet (46-61 m).
 - Jpc** Page Sandstone (Middle Jurassic) - The Page Sandstone in this area is composed of two members: Hans (Member below) and Thousand Pockets (Member upper) and is divided by the Judah Hollow Tongue, a member of the overlying Carmel Formation. The Hans Member is 92 to 113 feet (28-35 m) thick. It is composed of very-pale-orange to pale-yellowish-orange, fine to medium-grained, cross-stratified sandstone. The Judah Hollow Tongue has been identified as a member of the overlying Carmel Formation. It is composed of ripple-laminated, moderate-red-brown to dark-red-brown mudstone and sandstone with local interbeds of limestone. The Judah Hollow Tongue forms a slope and ranges from 10 to 17 feet (3-5 m) thick. The Thousand Pockets Member is composed of very-pale-orange to pale-yellowish-orange, fine to medium-grained, cross-stratified sandstone with planar and contorted beds. It is 17 to 32 feet (5-9 m) thick. The Page Sandstone forms ledges and cliffs and forms a caprock of many of the prominent geographical features within the quadrangle including the Golden Throne monolith. The Page Sandstone can be distinguished from the underlying Navajo Sandstone by the abrupt change in weathering styles. The lower portion of the Page Sandstone forms a sheer cliff above the rounded expression of the Navajo Sandstone. Formation thickness ranges from 133 to 153 feet (41-47 m) and tapers slightly to the south.
 - Jn** Navajo Sandstone (Lower Jurassic) - Very-pale-orange to white, large scale crossbedded fine to very fine sandstone. Localized soft sediment deformation observable in the top 200 feet. Forms cliffs and rounded domes. The map contact in the transition between the Navajo and Kayenta Formations has been chosen as the last prominent red shale bed before uniform sandstones. Thicknesses ranges from 1000 to 1300 feet (305-396 m).
 - Jk** Kayenta Formation (Lower Jurassic) - Moderate-red-brown to moderate-red-orange irregularly bedded sandstone and siltstone. Forms stepped topography composed of ledges (occasional cliffs) and slopes. Thickness ranges from 300 to 400 feet (91-122 m).
 - Jw** Wingate Sandstone (Lower Jurassic to Triassic?) - Light brown to moderate-red-brown crossbedded to massive, very fine to fine-grained sandstone. Forms the sheer cliffs of the western escarpment of the Waterpocket Fold. Walls highly fractured and often covered with black to brown desert varnish. Thickness ranges from 350-400 feet (107-122 m).
 - Trco** Owl Rock Member of the Chinle Formation (Upper Triassic) - Orange and purple mudstone, siltstone, and sandstone with 1 to 3 feet thick interbeds of mottled dusky-red to pale-yellowish-green limestone representing galeses with abundant fossils and bivalved horizons. Forms a slope. Member often covered by talus deposits of the overlying Wingate and Kayenta Sandstones. Thickness ranges from 180 to 220 feet (55-67 m).
 - Trcp** Petrified Forest Member of the Chinle Formation (Upper Triassic) - Moderate-red-brown mudstone and siltstone interbedded with carbonate nodules 2 feet (0.6 m) thick interpreted to be paleosols. Petrified wood found within the member. The Petrified Forest Member is capped by a regionally extensive dark-red-brown, ledge-forming, medium to coarse-grained, crossbedded sandstone called the "Capitol Reef Bed". Most of the member forms a slope. Thickness ranges from 180 to 200 feet (55-61 m).
 - Trcm** Monitor Butte Member of the Chinle Formation (Upper Triassic) - Light-olive-gray to greenish-gray bentonitic clay with thin dusky-brown to dark-yellowish-orange, medium to coarse-grained, crossbedded sandstone beds. Forms a slope. Thickness ranges from 150 to 200 feet (46-61 m).
 - Trcs** Chinle Upper Undifferentiated (Upper Triassic) - Comprising members including Owl Rock, Petrified Forest, and Monitor Butte. Undivided due to difficulty in identifying members because of Quaternary cover and high dip of beds on the west flank of the Miners Mountain uplift.
 - Trmm** Shinarump Conglomerate Member of the Chinle Formation (Upper Triassic) - Grayish-orange to very-pale-orange medium to coarse-grained sandstone and conglomerate. Contains petrified wood. Shinarump beds are discontinuous due to its braided fluvial depositional history. The member contains uranium which has been actively mined within the quadrangle. Forms ledges and cliffs. Thickness ranges from 0 to 30 feet (0-9 m).
 - Trmt** Moody Canyon Member of the Moenkopi Formation (Lower Triassic) - Moderate-red-brown to moderate-red-orange laminated mudstone and siltstone with sparse fine-grained ripple-laminated sandstones with gypsum veins and stringers. Usually forms a slope but can be cliff-forming if overlain by the Shinarump Conglomerate. Thickness ranges from 250-300 feet (76-91 m).
 - Trms** Torrey Member of the Moenkopi Formation (Lower Triassic) - Moderate-red-brown to moderate-red-orange mudstone, siltstone and sandstone. Forms ledges and slopes. Thickness ranges from 200-220 feet (61-67 m).
 - Trms** Sinbad Limestone Member of the Moenkopi Formation (Lower Triassic) - Very-pale-orange to grayish-orange limestone and dolomite with interbeds of siltstone and sandstone. Upper bed commonly contains oolitic grains. Forms a cliff above Black Dragon Member. Thickness ranges from 40-70 feet (12-21 m).
 - Trmb** Black Dragon Member of the Moenkopi Formation (Lower Triassic) - Moderate-red-brown to moderate-red-orange interbedded mudstone, siltstone, and sandstone with gypsum stringers. Forms a slope. In many areas underlies overlying Sinbad Limestone Member and is often covered by talus composed of the overlying Sinbad Limestone. Thickness ranges from 0 to 70 feet (0-21 m).
 - Pk** Kaibab Limestone (Upper Permian) - Upper 100 feet is composed of white to yellowish gray shale and carbonate beds with calcine nodules. Lower portion is composed of white interbedded carbonate and sandstone beds. Locally sandstone beds contain glauconite grains. Forms slopes and ledges. Thickness ranges from 500 to 550 feet (152-168 m).
 - Pc** Cutter Group Undivided (Permian) - Undivided in this locality due to the absence of the Organ Rock Shale between White Rim Sandstone and Capitol Mesa Sandstone. Consists of white to yellowish-gray, medium to fine-grained, trough cross-stratified sandstone. Distinguished from the overlying Kaibab Limestone by the absence of any carbonate beds. Base not exposed within the quadrangle. Forms a sheer cliff. Thickness is at least 1500 feet (457 m).
 - Pu** Paleozoic Undivided - Subsurface rocks.
 - Pu** Precambrian Undivided - Subsurface rocks.

MAP SYMBOLS

- Formation Contact**
- Fault** - bar and ball on the downthrown block; dashed where approximate, dotted where covered.
- Fault with a component of strike slip motion** - dashed where approximate, dotted where covered.
- Anticline** - showing trace of the axial plain of the Miners Mountain Anticline.
- Syncline** - showing trace of the axial plain.
- Line of Cross Section**
- Strike and Dip of Bedding**
- Joints** - showing areas with prominent joint sets
- Joints within the Navajo Sandstone**

CORRELATION OF MAP UNITS



Basalt Boulder Terrace Information

Basalt Boulder Terraces within the Glen Canyon Group Section of the Pleasant Creek Canyon

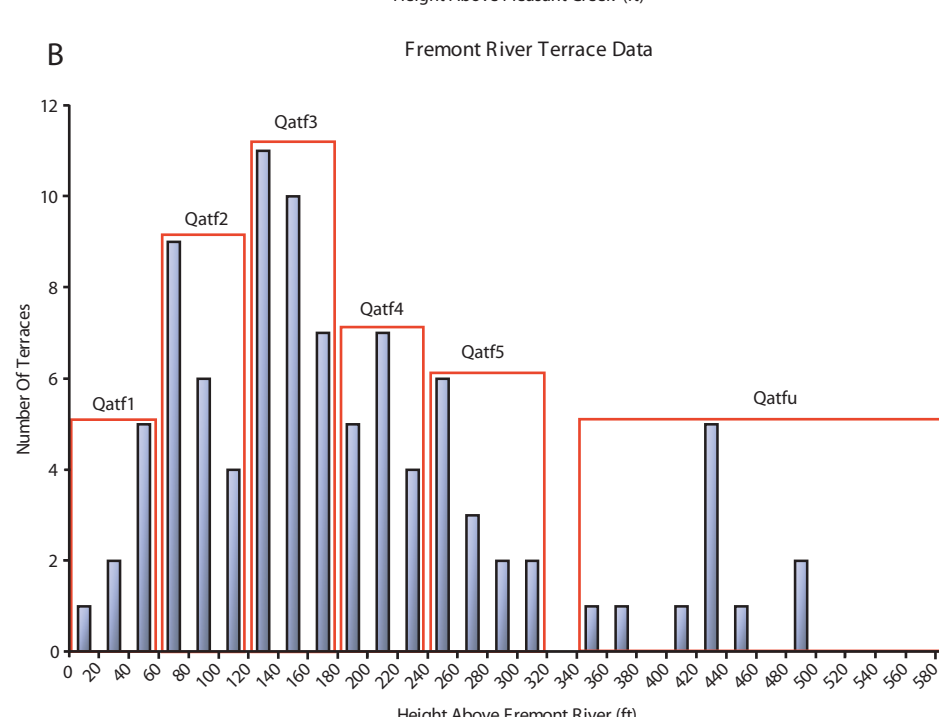
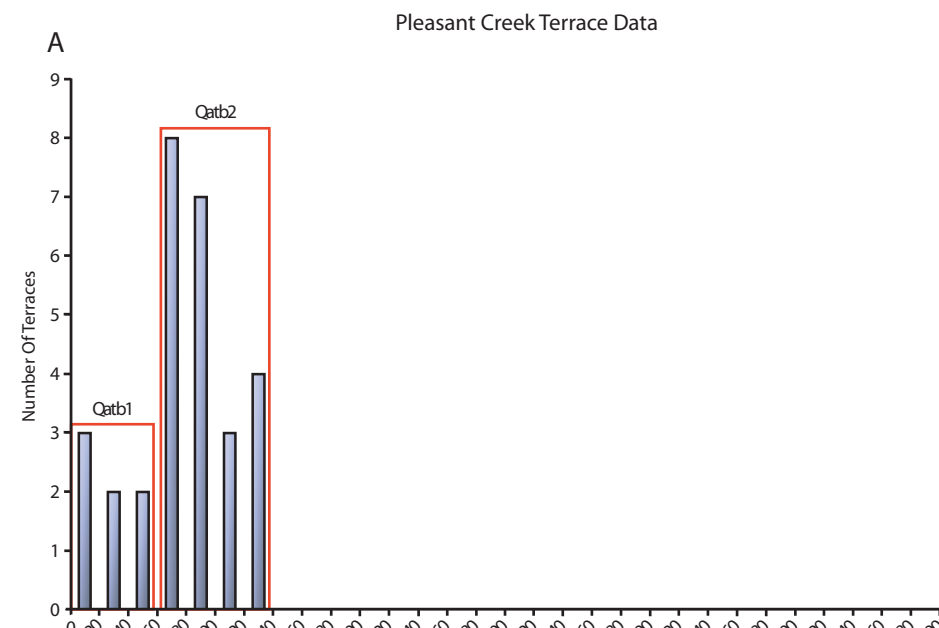
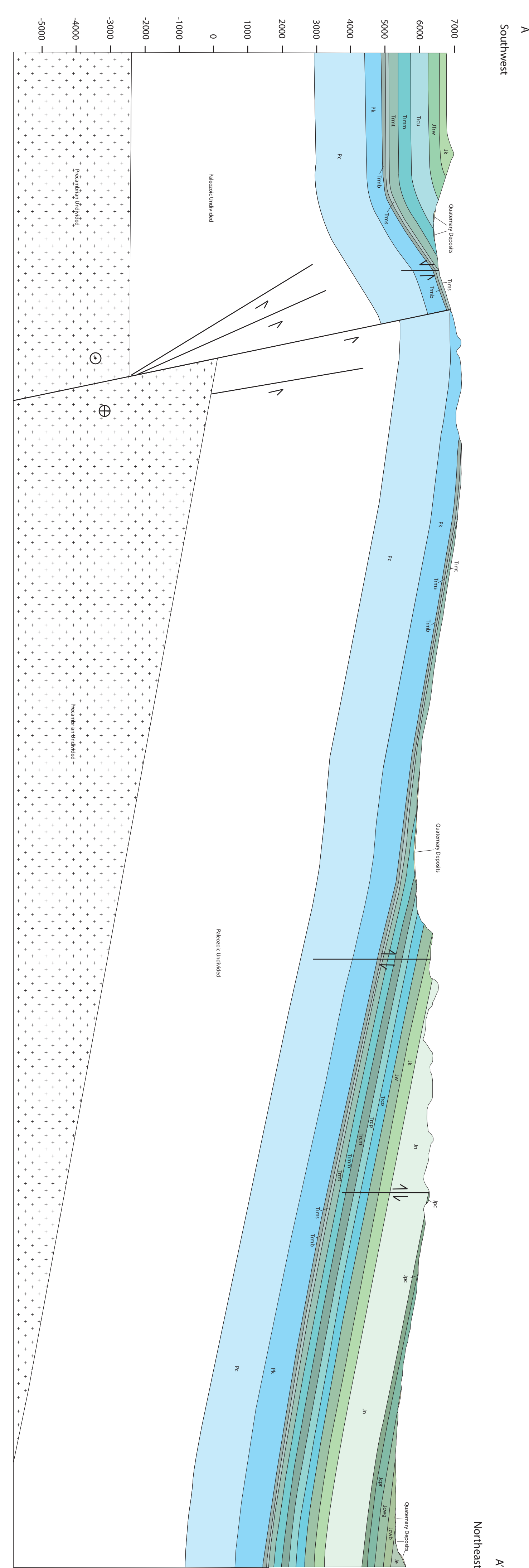


TABLE 1. Summary of strath terrace elevation and Schmidt Hammer data for both the Pleasant Creek and Fremont River drainages.

Fremont Terrace Profile	Elevation Above Current Stream Bed	Mean Schmidt Hammer R-Value	Pleasant Creek Profile	Elevation Above Current Stream Bed	Mean Schmidt Hammer R-Value
Qml9	> 381 ft.	33.59			
Qml8	340 - 380 ft.	37.66			
Qml7	241 - 320 ft.	39.22			
Qml6	181 - 240 ft.	39.30			
Qml5	121 - 180 ft.	44.87			
Qml4	61 - 120 ft.	46.55	Qml2	61 - 140 ft.	45.01
Qml3	< 60 ft.	52.46	Qml1	< 60 ft.	50.02
Present			Present		

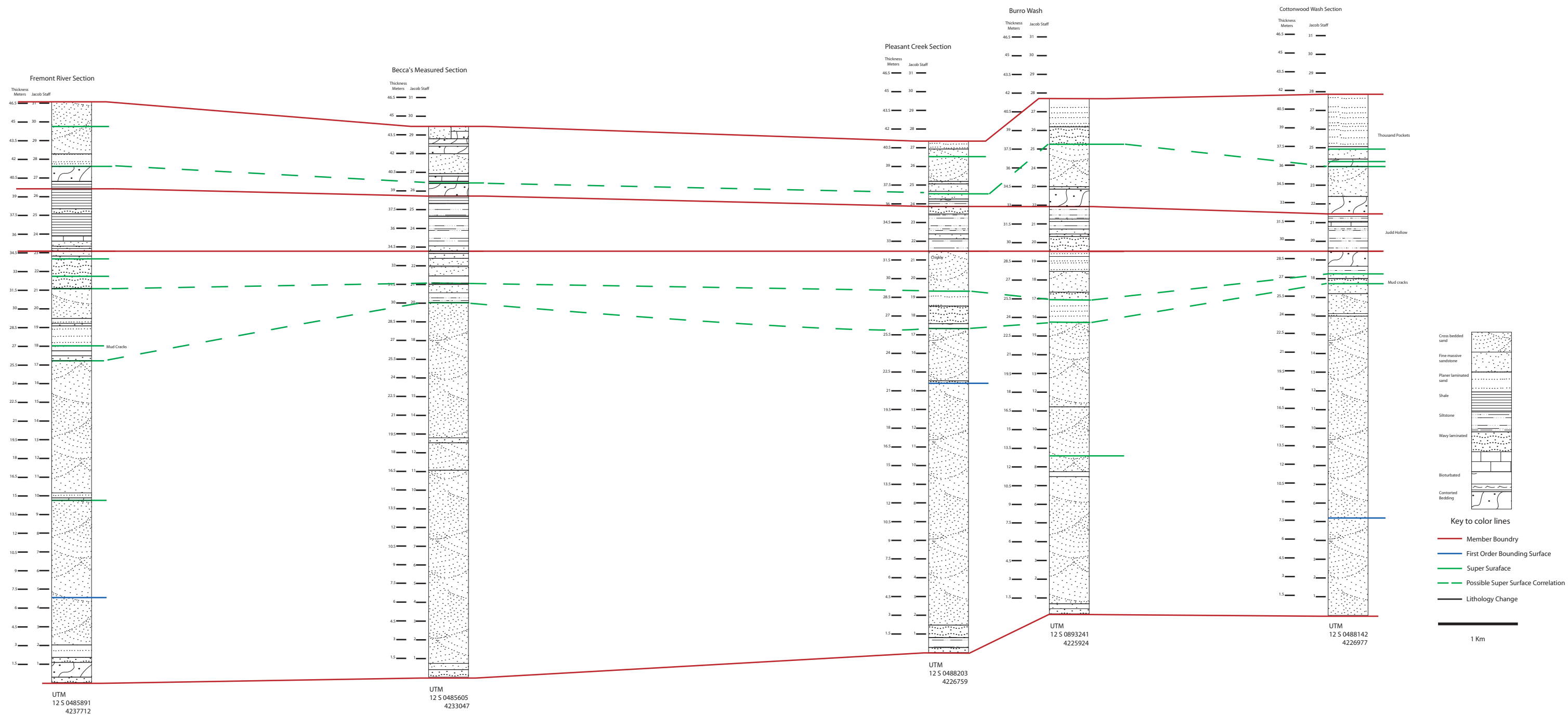


Basalt strath terraces are dominant landforms carved into the relatively resistant bedrock of the Pleasant Creek drainage. These fluvial terraces and their associated boulder deposits at one time represented the active river floor, but have since been abandoned. These terraces help to preserve stream bed histories and create an ideal surface with which to characterize overall drainage development. Glacial influence on landscape and drainage morphology has been significant within Pleasant Creek and surrounding drainages. Research suggests that strath terrace development (widening of the floodplain) and deposition occurred as Pleasant Creek responded to dramatic increases in discharge and sediment flux during glacial maxima/deglacial climate phases. Incision and subsequent abandonment of strath terraces began as drainages responded to continued elevated discharge (due to glacial retreat) and an overall decrease in sediment during deglacial/interglacial climate phases. Strath terrace populations were analyzed in an attempt to bring meaning to observed trends. Terraces were placed into 20 ft. bins and then grouped into larger terrace levels based on natural breaks in population data (occurring in intervals of ~60-80 ft.) and multiple modes. Results for Pleasant Creek were plotted (Figure A) and two terrace levels, labeled Qml2 and Qml1, respectively, were interpreted. An identical analysis for the Fremont River drainage (approximately 10 miles to the north in the Fruita 7.5 Quadrangle) yields similar results and was used in a comparative analysis between drainages (Figure B). A Schmidt hammer is a piston impact device designed to measure the hardness of a surface. Surface hardness can provide a valuable measure of rock surface weathering and therefore relative terrain age. A Schmidt hammer was used to obtain quantitative data (Schmidt hammer rebound or R-values) on the hardness of basalt boulder deposits on strath terraces. Schmidt hammer results indicate that elevation change between strath terraces is accompanied by a coincident change in mean R-values wherein the higher the elevation of the terrace above the present stream bed, the lower the mean R-values become. Mean Schmidt hammer data (Table 1) confirms terrace level designations (Figures A & B) for both the Pleasant Creek and Fremont River drainages. Schmidt hammer data also highlight very similar mean R-values for the most recent terrace levels of both the Pleasant Creek and Fremont River drainages (Table 1). Results, based on terrace populations and Schmidt hammer analysis, indicate that the Pleasant Creek drainage is likely much younger than the larger Fremont River drainage. Data, however, also support the conclusion that correlation exists between the Pleasant Creek terrace levels (Qml1 & Qml2) and the two lowest (most recent) terrace levels within the Fremont River (Qml1 & Qml2). This correlation is significant and illustrates that the root cause of drainage development and incision may be a forcing mechanism that is extrabasinal in nature. We suggest that the most probable forcing mechanism is regional Pleistocene glacial-interglacial climate cycles.

APENDIX B

APPENDIX B—Plate 3. Page Sandstone Correlation Chart

Page Sandstone Drafted Sections



APPENDIX C

APPENDIX C—A data CD containing the following information:

- The Golden Throne Quadrangle, Wayne and Garfield Counties, Utah (ESRI ArcView 9.3)
- Map Legend and Key of the Geologic map of the Golden Throne Quadrangle(Adobe Illustrator CS 1.3)
- Page Sandstone Correlation Chart (Adobe Illustrator CS 1.3)
- Digital version of this thesis (Adobe PDF)

APPENDIX D

Selected Photos from the Golden Throne Quadrangle



Photo 1. Photo taken looking north into the interior of the Miners Mountain Uplift. Photo montage taken near the south boarder of the quadrangle near Cottonwood Canyon.



Photo 2. Photo montage taken looking north from the south side of Pleasant Creek. Annotation shows the trace and relative movement along the Teasdale Fault. Also showing the juxtaposition of the Kaibab Limestone against the Cutler Group Sandstones.



Photo 3. Photo taken looking east toward the western escarpment of the Waterpocket Fold from Miners Mountain. White knobs are composed of Navajo Sandstone.



Photo 4. Photo taken at the J2 unconformity at the Fremont River near the waterfall. This photo displays the large scale polygonal cracks which are characteristic of the contact between the Navajo Sandstone and the Page Sandstone.



Photo 5. Photo taken at the contact of the Navajo Sandstone and the Page Sandstone near Pleasant Creek. This contact is known as the J2 unconformity. Large scale polygonal fractures characteristic of the contact. Black rocks appearing in this photo are mineralized sandstone which has eroded out of joints in the Page Sandstone.



Photo 6. Photo taken looking east toward the Western Escarpment of the Waterpocket Fold at locality where strike-slip faults cross the escarpment. Note appearance of normal offset. This phenomenon is caused by an erosional illusion.



Photo 7. Photo taken looking south. Fault graben located within the Carmel Formation. Caused by gypsum withdraw.



Photo 8. Photo taken looking north within the Carmel Formation. Same fault zone associated with previous photo. Caused by gypsum withdraw.



Photo 9. Photo taken looking north. Angular unconformity juxtaposing a fluvial terrace composed of locally derived material (Qatl) deposits, and the Moody Canyon Member of the Moenkopi Formation.



Photo 10. Photo taken looking east toward the western escarpment of the Waterpocket Fold near Pleasant Creek. Displaying basalt boulders and Basalt Boulder Terraces (Qatb) deposits.