GEOLOGIC MAP AND COLORATION FACIES OF THE JURASSIC NAVAJO SANDSTONE, SNOW CANYON STATE PARK AND AREAS OF THE RED CLIFFS DESERT RESERVE, WASHINGTON COUNTY, UTAH

BY GREGORY B. NIELSEN AND MARJORIE A. CHAN





Open-File Report 561 Utah Geological Survey *a division of* Utah Department of Natural Resources **2010**

GEOLOGIC MAP AND COLORATION FACIES OF THE JURASSIC NAVAJO SANDSTONE, SNOW CANYON STATE PARK AND AREAS OF THE RED CLIFFS DESERT RESERVE, WASHINGTON COUNTY, UTAH

by Gregory B. Nielsen and Marjorie A. Chan Department of Geology and Geophysics, University of Utah

Cover photos: Variations in the appearance of the Navajo Sandstone produced by diagenetic alteration. Top: bright yellow to orange cementation northwest of Three Ponds at Snow Canyon State Park (note person for scale). Lower left: small iron oxide concretions (diameter of largest is ~2 cm) that have eroded from the Navajo Sandstone in the Sand Hollow Reservoir area to the southwest of Snow Canyon State Park. Lower right: detail of patchy red and yellow cementation in the White Rocks area of Snow Canyon State Park (length of ruler is 15 cm).



OPEN-FILE REPORT 561 UTAH GEOLOGICAL SURVEY a division of UTAH DEPARTMENT OF NATURAL RESOURCES 2010

STATE OF UTAH

Gary R. Herbert, Governor

DEPARTMENT OF NATURAL RESOURCES

Michael Styler, Executive Director

UTAH GEOLOGICAL SURVEY

Richard G. Allis, Director

PUBLICATIONS

contact Natural Resources Map & Bookstore 1594 W. North Temple Salt Lake City, UT 84114 telephone: 801-537-3320 toll-free: 1-888-UTAH MAP Web site: mapstore.utah.gov email: geostore@utah.gov

UTAH GEOLOGICAL SURVEY

contact 1594 W. North Temple, Suite 3110 Salt Lake City, UT 84114 telephone: 801-537-3300 Web site: geology.utah.gov

This open-file release makes information available to the public that may not conform to Utah Department of Natural Resources, Utah Geological Survey policy, editorial, or technical standards; this should be considered by an individual or group planning to take action based on the contents of this report. The Utah Department of Natural Resources, Utah Geological Survey, makes no warranty, expressed or implied, regarding its suitability for a particular use. The Utah Department of Natural Resources, Utah Geological Survey, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product.

CONTENTS

ABSTRACT	1
INTRODUCTION AND MAPPING METHODS	1
MAP SUMMARY AND DESCRIPTION OF DIAGENETIC COLORATION FACIES	1
ACKNOWLEDGMENTS	2
REFERENCES	2
APPENDIX A: VISIBLE TO INFARED RELECTANCE SPECTROSCOPY	3
APPENDIX B: INDUCTIVELY COUPLED PLASMA MASS SPECTROMETRY RESULTS	4
APPENDIX C: SOXHLET EXTRACTION YIELDS FOR BLEACHED AND UNBLEACHED SAMPLES	.10
APPENDIX D: GAS CHROMATOGRAMS FOR EXTRACTED ORGANIC COMPOUNDS	.11

TABLE

PLATES

Plate 1.	Geologic map and coloration facies of the Jurassic Navajo Sandstone, Snow Canyon State Park and areas of the	
	Red Cliffs Desert Reserve, Washington County, Utah (1:10,000 scale)	on CD
Plate 2.	Spatial distribution of the mapped diagenetic facies/subfacies in the Snow Canyon area	on CD

GEOLOGIC MAP AND COLORATION FACIES OF THE JURASSIC NAVAJO SANDSTONE, SNOW CANYON STATE PARK AND AREAS OF THE RED CLIFFS DESERT RESERVE, WASHINGTON COUNTY, UTAH

by Gregory B. Nielsen and Marjorie A. Chan

ABSTRACT

Diagenetic coloration patterns and related structural features in the Jurassic Navajo Sandstone of Snow Canyon State Park and vicinity are mapped at a 1:10,000 scale. Mapped units include four major coloration facies and three subfacies, each having distinctive visual and compositional characteristics. Spectral and geochemical analyses indicate that variations in sandstone color result largely from changes in the concentration and distribution of iron oxides. Uniform reddish sandstone dominates the southern part of the park (red primary facies), whereas rock in the northern part of the park has been depleted in iron oxide (or "bleached") to produce shades of yellow, tan, and white (white bleached facies). Separating these zones is a broad transitional area where localized bands of bleached rock cut southward into red-colored sandstone (red/white intermixed facies).

Dark colored rock that is enriched in iron oxide (brown ferruginous facies) is common in the lower part of the Navajo Sandstone where it overprints other coloration facies. The upper boundary of this concentrated iron oxide zone is a sub-horizontal boundary that can be visually visually traced through many areas of the park. Brightly colored Liesegang-type bands and coloration patches are commonly associated with joints in the upper formation (multicolored local facies), but were not mapped due to their limited spatial extent. The excellent sandstone exposures, relatively undeformed strata, and broad variety of diagenetic features at Snow Canyon State Park make it an important locality for investigating diagenetic processes in the subsurface.

INTRODUCTION AND MAPPING METHODS

Map boundaries were selected to encompass a full section of the Jurassic Navajo Sandstone of Snow Canyon State Park and vicinity, including minor portions of underlying and overlying formations (plate 1). Mapping builds on the general geologic map of the Santa Clara quadrangle by Willis and Higgins (1996), with detailed focus on diagenetic coloration facies in the Navajo. Diagenetic coloration facies and other geologic features were mapped at a 1:10,000 scale using orthorectified, 1-meter-(3 ft) resolution color aerial photography

from the National Agricultural Imagery Program (NAIP). A digital base map was generated using 10-m- (33 ft) resolution values from the National Elevation Dataset (NED) and key points were georeferenced using a survey-grade global positioning satellite (GPS) receiver. Minor irregularities in topographic contours were smoothed slightly using neighborhood averaging (three cell circular radius). Outcrops were mapped in the field as well as from aerial photos. The map was then refined using 2000+ digital photographs taken at locations throughout the study area and extensively field checked.

MAP SUMMARY AND DESCRIPTION OF DIAGENETIC COLORATION FACIES

The Jurassic Navajo Sandstone of Snow Canyon State Park and vicinity is characterized by a broad diversity of colors related to iron oxide cementation and fluid diagenesis. Coloration units in this study correspond to diagenetic facies and subfacies defined and described by Nielsen and Chan (2009). The accompanying map and oblique-view image (plates 1 and 2) illustrate the spatial distribution of these coloration facies and their relationships to local structural features. Visual characteristics of mapped facies are summarized in table 1, with more detailed descriptions of these facies given in Nielsen and Chan (2009) and Nielsen and others (in preparation). Detailed descriptions of other geologic features at Snow Canyon State Park are given in Willis and Higgins (1996) and Higgins (2003).

The symbols used to reference coloration facies in this report (table 1; plate 1) include an abbreviation for the formation age and name (for example "Jn" for "Jurassic Navajo Sandstone"), and an abbreviation for the coloration facies name (for example "Jn-w" for the "white bleached facies"). Subfacies are designated with subscripts (for example "Jn-wt" for the "tan subfacies" of the white bleached facies). Chemical and mineralogical characteristics of each facies are summarized in appendices A through D. Analyses were performed by the Energy and Geosciences Institute at the University of Utah. These data are discussed in Nielsen and Chan (2009).

Table 1. Visual characteristics of major diagenetic facies and subfacies of the Navajo Sandstone at Snow Canyon State Park and the surrounding area. The multicolored local facies is present at Snow Canyon but was not mapped due to its limited spatial extent. Detailed descriptions of these facies (including associated Munsell color designations) are given in Nielsen and Chan (2009). From Nielsen and Chan (2009).

Facies	Subfacies	Symbol	Stratigraphic Position	Characteristic Features
Multicolore	ed Local	Jn-m	Middle/Upper	 Brightly colored Liesegang-type bands and coloration patches (not mapped).
White	Tan	Jn-w _t	Uppermost	 Blocky, weathered appearance. Silica-cemented deformation band shear zones.
White Bleached	White	Jn-w _w	Middle to Upper	Uniform white coloration.Shallow polygonal fracturing.
	Yellow	Jn-w _y	Middle	 Irregular areas of intermixed yellow and white coloration.
Red/White Intermixed		Jn-rw Middle		 Banded and interfingered zones of red and white sandstone. Mottled appearance (uneven coloration).
Red Prima	ry	Jn-r	Lower to Middle	 Even and pervasive reddish coloration.
Brown Fer	ruginous	Jn-b	Lower	 Dark-colored iron oxide cementation that overprints other facies (concentrated along upper boundary of facies). Concretions, ironstone slabs, etc. Liesegang-type bands in area immediately below boundary.

ACKNOWLEDGMENTS

This project was funded by the Utah Geological Survey (UGS) under the "Characterization of Utah's Natural Gas Reservoirs and Potential New Reserves" program, contract no. 53000453. We thank Tom Chidsey, Craig Morgan, Bryce Tripp, Robert Biek, Rick Allis, and others at the UGS who provided support and ideas for the project. We also thank Kristin Comella and the other staff at Snow Canyon State Park who provided research access and assistance. This project is part of the Ph.D. dissertation research of the senior author, conducted at the University of Utah.

REFERENCES

Higgins, J.M., 2003, Geology of Snow Canyon State Park, Utah, in Sprinkel, D.A., Chidsey, T.C., Jr., and Anderson, P.B., editors, Geology of Utah's parks and monuments: Utah Geological Association Publication 28, second edition, p. 479-494.

- Nielsen, G.B., and Chan, M.A., 2009, Mapping and correlation of diagenetic coloration facies, Jurassic Navajo Sandstone, Snow Canyon State Park, southwestern Utah, *in* Tripp, B.T., Krahulec, K., and Jordan, J.L., editors, Geology and geologic resources and issues of western Utah: Utah Geological Association Publication 38, p. 97-123.
- Nielsen, G.B., Chan, M.A., and Petersen, E.U., 2009, Diagenetic coloration facies and alteration history of the Jurassic Navajo Sandstone, Zion National Park and vicinity, southwestern Utah, *in* Tripp, B.T., Krahulec, K., and Jordan, J.L., editors, Geology and geologic resources and issues of western Utah: Utah Geological Association Publication 38, p. 67-96.
- Nielsen, G.B., Chan, M.A., and Bowen, B.B., in preparation, Concentrated iron-oxide horizons in the Jurassic Navajo Sandstone, southwestern Utah: Precipitation mechanisms and impact on reservoir quality.
- Willis, G.C., and Higgins, J.M., 1996, Interim geologic map of the Santa Clara quadrangle, Washington Co., Utah: Utah Geological Survey Open-File Report 339, 87 p., scale 1:24,000.

APPENDIX A



VISIBLE TO INFRARED REFLECTANCE SPECTROSCOPY

Figure A-1. Composite visible and infrared reflectance spectroscopy for each diagenetic coloration facies at Snow Canyon State Park, Utah (n = 53 variably colored samples). Samples were evaluated in the field using a portable reflectance spectrometer. Artificial illumination was used to provide consistency and eliminate atmospheric effects. Strong absorption near 0.9 µm is indicative of iron oxide. The absorption band at 2.2 µm is typical of clay minerals with the doublet indicating the mineral kaolinite. Prominent bands near 1.4 µm and 1.9 µm are also characteristic of clays. The overall similarity in reflectance patterns indicates similar mineralogy, whereas differences in band depth reflect variations in the abundance and spatial distribution of these minerals.

APPENDIX B

INDUCTIVELY COUPLED PLASMA MASS SPECTROMETERY RESULTS

Table B-1. Relative abundance of selected oxides and trace elements (inductively coupled mass spectrometry) for representative samples from various diagenetic coloration facies in the southwest Utah area. These data are discussed in Nielsen and others (2009) and Nielsen and Chan (2009).

#	Unit	Diagenetic Facies	Diagenetic Subfacies	Locality	Site	Coordinates	Map Location
1	Navajo Sandstone	Brown Ferruginous	Brown Spotty	Zion National Park	Canyon Overlook Area	N37° 12' 58, W112° 56' 22"	
2	Navajo Sandstone	Brown Ferruginous	Green Overprinted	Zion National Park	Canyon Overlook Area	N37° 12' 58, W112° 56' 22"	
3	Navajo Sandstone	Brown Ferruginous	Ironstone	Sand Hollow Reservoir Area	Knoll near Turf Sod Road	N37° 7' 44", W113° 23' 7"	
4	Navajo Sandstone	Brown Ferruginous	Overprinted Red	Snow Canyon State Park	Hidden Pinyon Area	N37° 12' 32", W113° 38' 51"	А
5	Navajo Sandstone	Brown Ferruginous	Overprinted Red	Zion National Park	East Rim Trail	N37° 16' 8", W112° 56' 23"	
6	Navajo Sandstone	Brown Ferruginous	Overprinted Red	Zion National Park	Taylor Creek Canyon	N37° 27' 30", W113° 9' 41"	
7	Navajo Sandstone	Brown Ferruginous	Overprinted Red	Zion National Park	Angel's Landing Area	N37° 16' 33", W112° 57' 4"	
8	Navajo Sandstone	Brown Ferruginous	Overprinted White	Snow Canyon State Park	SR 18 Trailhead	N37° 9' 42", W113° 36' 42"	
9	Navajo Sandstone	Multicolored Local	Liesegang-Banded	Zion National Park	East Rim Trail	N37° 16' 28", W112° 55' 39"	
10	Navajo Sandstone	Multicolored Local	Patchy	Zion National Park	Canyon Overlook Area	N37° 12' 57", W112° 56' 23"	
11	Navajo Sandstone	Multicolored Local	Yellow/Orange Patchy	Snow Canyon State Park	White Rocks	N37° 14' 19", W113° 38' 37"	В
12	Navajo Sandstone	Multicolored Local	Yellow/Orange Patchy	Snow Canyon State Park	Three Ponds Area	N37° 13' 20", W113° 39' 40"	С
13	Navajo Sandstone	Pink Altered	Ironstone Lens	Zion National Park	Angel's Landing Area	N37° 16' 28", W112° 57' 2"	
14	Navajo Sandstone	Pink Altered	Uneven Red/Orange	Zion National Park	East Rim Trail	N37° 16' 23", W112° 55' 56"	
15	Navajo Sandstone	Pink Altered	Uneven Red/Orange	Zion National Park	Canyon Overlook Area	N37° 12' 57", W112° 56' 23"	
16	Navajo Sandstone	Red Primary	-	Snow Canyon State Park	Lava Tubes Area	N37° 13' 21", W113° 39' 4"	D
17	Navajo Sandstone	Red Primary	-	Zion National Park	Taylor Creek Canyon	N37° 27' 26", W113° 9' 43"	
18	Navajo Sandstone	Red/White Intermixed	-	Snow Canyon State Park	Three Ponds Area	N37° 12' 44", W113° 39' 49"	E
19	Navajo Sandstone	Red/White Intermixed	-	Snow Canyon State Park	Three Ponds Area	N37° 12' 44", W113° 39' 49"	E
20	Navajo Sandstone	Red/White Intermixed	-	Zion National Park	Hop Valley	N37° 22' 52", W113° 7' 44"	
21	Navajo Sandstone	Red/White Intermixed	-	Zion National Park	Hop Valley	N37° 22' 52", W113° 7' 44"	
22	Navajo Sandstone	White Bleached	White	Snow Canyon State Park	White Rocks Area	N37° 14' 22", W113° 38' 32"	F
23	Navajo Sandstone	White Bleached	White Speckled	Zion National Park	East Rim Trail	N37° 16' 32", W112° 55' 48"	
24	Navajo Sandstone	White Bleached	Yellow	Snow Canyon State Park	White Rocks Area	N37° 13' 55", W113° 38' 23"	G
25	Navajo Sandstone	White Bleached	Yellow	Zion National Park	East Rim Trail	N37° 16' 34", W112° 55' 50"	
26	Navajo Sandstone	White Bleached	Tan	Snow Canyon State Park	North Rim Trail	N37° 15' 23", W113° 39' 34"	Н
27	Kayenta Formation	-	-	Snow Canyon State Park	Padre Canyon	N37° 11' 501", W113° 39' 42"	I
28	Kayenta Formation	-	-	Snow Canyon State Park	Padre Canyon	N37° 11' 51", W113° 39' 42"	I
29	Temple Cap Fm. (Sinawava Mbr.)	-	-	Zion National Park	East Rim Trail	N37° 16' 38", W112° 55' 54"	
30	Temple Cap Fm. (White Throne Mbr.)	-	-	Zion National Park	East Rim Trail	N37° 16' 38", W112° 55' 54"	

#	Specimen ID	Brief Description	SiO ₂ (wt. %)	Al ₂ O ₃ (wt. %)	Fe ₂ O ₃ (T) (wt. %)	MnO (wt. %)	MgO (wt. %)	CaO (wt. %)
1	Gr20070318-1320	Spotty brown sandstone from just below brown subunit boundary.	72.91	2.81	1.13	0.096	0.14	11.31
2	Gr20070318-1319	Secondary green sandstone with brown spots.	73.12	0.57	1.54	0.09	0.69	12.38
3	Gr20050801-0	Very dense and hard concretionary ironstone.	73.28	1.21	19.32	0.10	0.09	0.79
4	Gr20051208-3	Dark-colored, ferruginous sandstone with contorted banding.	92.84	2.49	1.58	0.19	0.13	0.09
5	Gr20061214-1147	Uniform reddish sandstone with numerous small brown oxidation spots.	89.39	4.93	0.8	0.036	0.08	0.07
6	Gr20061216-1454	Uniform reddish sandstone with some secondary iron oxide cementation.	92.3	3.57	1.33	0.006	0.12	0.09
7	Gr20061220-1318	Brown sandstone with darker brown spots (at Fe enrichment boundary).	93.74	2.35	1.77	0.01	0.02	0.03
8	Gr20061219-1314A	White sandstone with brownish patches and smaller black spots.	88.45	1.59	4.39	2.6	0.1	0.72
9	Gr20061214-1517	Bright pink and yellow Liesegang-banded sandstone.	95.55	1.77	1.4	0.01	0.06	0.12
10	Gr20070318-1202	Grayish sandstone with bright orangish patches.	90.59	2.04	2.57	0.018	0.03	0.04
11	Gr20051210-6b	Sandstone with patchy areas of bright yellowish and orangish coloration.	93.41	3.09	0.72	0.00	0.07	0.03
12	Gr20060401-2	Sandstone with patchy areas of bright yellowish and orangish coloration.	94.06	2.18	0.71	0.00	0.06	0.02
13	Gr20061220-1438	Concretionary ironstone with orangish oxidation spots.	82.57	1.27	13.22	0.041	0.09	0.04
14	Gr20061214-1355	Pinkish sandstone with darker brown cementation.	93.75	2.6	1.18	0.011	0.04	0.03
15	Gr20070318-1235	White sandstone with small orange specks.	92.24	2.53	0.72	0.004	0.03	0.04
16	Gr20060402-5	Uniform reddish sandstone.	94.85	1.87	0.58	0.01	0.05	0.02
17	Gr20061216-1552	Uniform reddish sandstone.	95.06	2.19	0.77	0.004	0.08	0.06
18	Gr20061218-1455A	Reddish sandstone from intermixed red/white zone.	94.3	2.82	0.97	0.008	0.09	0.02
19	Gr20061218-1455B	Bleached sandstone from intermixed red/white zone.	98.1	1.14	0.6	0.004	0.03	0.02
20	Gr20070317-1413A	Reddish sandstone from intermixed red/white zone.	97.86	0.88	0.7	0.006	0.04	0.02
21	Gr20070317-1413B	Bleached sandstone from intermixed red/white zone (bleached band).	89.88	1.93	1.87	0.009	0.06	0.21
22	Gr20051210-5c	Completely bleached sandstone from area of zonal bleaching.	94.13	3.10	0.20	0.00	0.06	0.02
23	Gr20061214-1603	Bleached sandstone with small brown oxidation specks.	94.36	2.27	1.24	0.008	0.07	0.04
24	Gr20060331-1	Uniform yellowish sandstone.	95.08	2.19	0.45	0.00	0.05	0.02
25	Gr20061214-1621	Uniform yellowish to gold colored sandstone.	93.78	1.7	0.69	0.004	0.04	0.02
26	Gr20061214-1500	Tannish sandstone that weathers to a reddish brown color.	93.88	2.78	0.88	0.006	0.08	0.04
27	Gr20051209-1b	Unbleached red siltstone.	74.18	6.68	1.72	0.03	2.99	3.52
28	Gr20051209-1a	Bleached pale green siltstone.	75.45	5.89	0.43	0.06	3.19	4.13
29	Gr20061214-1625	Deep brownish-red sandstone.	75.12	3.7	1.13	0.049	2.46	5.97
30	Gr20061214-1626	Light yellowish-tan sandstone with some surficial yellow and red alteration.	70.26	1.95	0.69	0.037	2.12	11.72

#	Na ₂ O	K ₂ O	TiO ₂	P_2O_5	Loss on Ignition	Oxide Total	Ag	As (nnm)	Ba (nnm)	Be (nnm)	Bi (nnm)	Ce (nnm)	Co
	(WU. 70)	(WL. 70)	(WL. 70)	(WVL. 70)	(WL. 76)	(WC. 76)	(ppiii)	(ppiii)	(ppiii)	(ppiii)		(ppiii) 7.00	(ppiii)
2	0.09	2.05	0.045	0.1	9.39	100.1	< 0.5	< 5	272	< 1	< 0.1	7.30	2
3	0.05	0.62	0.015	0.02	10.82	99.91	< 0.5	< 5 209.00	100.00	4.00	< 0.1	3.69	2
4	0.05	0.47	0.02	0.10	1.26	98.52	< 0.5	200.00	292.00	4.00	4.70	11 70	10.00
5	0.04	0.39	0.05	0.07	1.30	99.22	< 0.5	10	202.00	< 1	1.00	10	10.00
6	0.22	1.12	0.101	0.00	0.88	99.40	< 0.5	- 5	215	< 1	< 0.1	0.6	1
7	0.00	1.42	0.061	0.03	0.38	99.90	< 0.5	< 5	199	< 1	< 0.1	5.17	2
8	0.07	0.42	0.001	0.00	2 32	100.8	< 0.5	1/13	002	2	< 0.1	4.53	69
9	0.04	1 1	0.02	0.03	0.25	100.8	< 0.5	< 5	164	< 1	< 0.1	5.76	1
10	0.00	1.39	0.038	0.02	-0.24	96.72	< 0.5	< 5	171	< 1	< 0.1	4 94	3
11	0.05	0.80	0.000	0.04	1 09	99.51	< 0.5	8.00	146.00	< 1	1 00	12.30	< 1
12	0.07	0.70	0.03	0.05	0.79	98.66	< 0.5	7.00	472.00	< 1	0.30	6.71	< 1
13	0.04	0.42	0.038	0.06	2.35	100.2	< 0.5	266	64	2	< 0.1	13.3	10
14	0.18	1.84	0.032	0.03	0.29	99.99	< 0.5	< 5	236	< 1	< 0.1	7.14	2
15	0.44	1.8	0.108	0.04	0.25	98.19	< 0.5	< 5	204	< 1	< 0.1	9.51	< 1
16	0.05	0.53	0.05	0.04	0.63	98.67	< 0.5	< 5	108.00	< 1	0.20	6.71	< 1
17	0.06	1.2	0.037	0.03	0.65	100.1	< 0.5	< 5	163	< 1	< 0.1	6.66	< 1
18	0.04	0.88	0.162	0.04	0.99	100.3	< 0.5	< 5	145	< 1	< 0.1	9.59	1
19	0.09	0.22	0.023	0.03	0.45	100.7	< 0.5	< 5	66	< 1	< 0.1	4.96	< 1
20	0.04	0.5	0.025	0.02	0.21	100.3	< 0.5	< 5	52	< 1	< 0.1	4.61	< 1
21	0.3	1.42	0.084	0.15	-0.15	95.77	< 0.5	< 5	129	< 1	< 0.1	6.22	2
22	0.07	1.04	0.11	0.04	0.89	99.65	< 0.5	< 5	175.00	< 1	0.60	9.71	< 1
23	0.09	1.54	0.061	0.03	0.16	99.88	< 0.5	< 5	257	< 1	< 0.1	8.47	2
24	0.07	0.74	0.04	0.04	0.61	99.29	< 0.5	22.00	168.00	< 1	0.40	7.53	< 1
25	0.15	1.12	0.032	0.01	0.52	98.07	< 0.5	6	23150	< 1	< 0.1	6.07	< 1
26	0.1	0.92	0.066	0.04	1.25	100	< 0.5	10	194	< 1	< 0.1	9.28	1
27	0.15	2.52	0.47	0.11	7.48	99.87	< 0.5	5.00	300.00	< 1	1.10	34.30	3.00
28	0.14	2.37	0.35	0.09	7.86	99.95	< 0.5	5.00	308.00	< 1	0.60	26.50	12.00
29	0.08	2.41	0.095	0.07	8.05	99.15	< 0.5	< 5	283	< 1	< 0.1	12.4	3
30	0.08	1.23	0.046	0.04	12.15	100.3	< 0.5	< 5	195	< 1	< 0.1	7.84	1

#	Cr (ppm)	Cs (ppm)	Cu (ppm)	Dy (ppm)	Er (ppm)	Eu (ppm)	Ga (ppm)	Gd (ppm)	Ge (ppm)	Hf (ppm)	Ho (ppm)	In (ppm)	La (ppm)	Lu (ppm)
1	60	0.8	< 10	0.6	0.39	0 228	3	0.65	0.8	2	0.13	< 0.1	3 11	0.064
2	< 20	0.3	< 10	0.0	0.00	0.095	2	0.39	0.8	0.5	0.10	< 0.1	1.76	0.004
3	< 20	0.50	20.00	1.65	0.77	0.46	2 00	1 74	9 70	0.70	0.30	< 0.1	3.41	0.10
4	20.00	1.00	40.00	0.86	0.48	0.28	3.00	1 03	1 30	0.90	0.16	< 0.1	6.83	0.07
5	70	1	10	0.91	0.62	0.315	5	0.89	1.3	5.3	0.19	< 0.1	4.93	0.123
6	< 20	1.2	< 10	0.87	0.53	0.337	4	0.94	1.1	3.2	0.17	< 0.1	5	0.092
7	30	0.6	10	0.35	0.29	0.101	4	0.28	1.3	2.1	0.08	< 0.1	1.87	0.056
8	70	0.6	< 10	0.98	0.5	0.389	5	1.01	1.4	0.7	0.19	< 0.1	2.21	0.062
9	< 20	0.6	< 10	0.54	0.3	0.203	2	0.63	1	0.8	0.11	< 0.1	3.11	0.045
10	< 20	0.6	20	0.45	0.26	0.146	2	0.44	1.1	0.9	0.09	< 0.1	2.52	0.043
11	< 20	0.80	< 10	1.05	0.77	0.30	3.00	1.07	1.00	8.90	0.23	< 0.1	6.65	0.16
12	< 20	0.80	< 10	0.55	0.31	0.21	2.00	0.63	1.50	0.70	0.10	< 0.1	3.44	0.05
13	170	0.5	10	0.88	0.52	0.222	3	0.77	2.5	0.9	0.18	< 0.1	5.9	0.071
14	< 20	0.9	< 10	0.57	0.32	0.24	4	0.63	1.1	0.7	0.11	< 0.1	3.52	0.048
15	120	0.8	< 10	0.76	0.49	0.231	3	0.74	1.1	4.5	0.16	< 0.1	4.32	0.103
16	< 20	0.70	< 10	0.54	0.31	0.17	2.00	0.58	1.00	1.00	0.11	< 0.1	3.46	0.05
17	140	0.8	< 10	0.45	0.27	0.174	3	0.49	1.1	1	0.09	< 0.1	3.2	0.043
18	< 20	1.4	< 10	0.92	0.69	0.312	4	0.89	1.2	6.9	0.21	< 0.1	4.64	0.144
19	110	0.5	< 10	0.4	0.24	0.109	2	0.4	1.1	0.6	0.08	< 0.1	2.49	0.037
20	120	0.3	< 10	0.3	0.2	0.054	2	0.26	0.9	0.8	0.06	< 0.1	1.96	0.035
21	< 20	0.5	10	0.47	0.33	0.124	3	0.45	1.1	3.4	0.1	< 0.1	2.6	0.07
22	< 20	0.80	< 10	0.73	0.48	0.29	3.00	0.82	1.00	3.70	0.15	< 0.1	4.93	0.09
23	< 20	0.9	10	0.65	0.38	0.247	4	0.69	1.2	1.6	0.13	< 0.1	4.11	0.063
24	< 20	0.70	< 10	0.55	0.30	0.22	2.00	0.65	1.00	0.80	0.10	< 0.1	3.42	0.05
25	100	0.8	< 10	0.44	0.27	0.274	3	0.44	1.1	1.2	0.09	< 0.1	3.05	0.044
26	90	0.8	< 10	0.59	0.37	0.217	5	0.62	1.3	1.4	0.12	< 0.1	4.94	0.058
27	30.00	4.10	< 10	3.08	1.96	0.68	7.00	3.04	1.00	11.80	0.63	< 0.1	17.50	0.33
28	< 20	3.30	< 10	2.24	1.38	0.60	6.00	2.48	1.00	9.20	0.45	< 0.1	13.40	0.25
29	< 20	1.4	< 10	1.11	0.7	0.367	5	1.17	1.1	2.2	0.23	< 0.1	6.76	0.115
30	100	0.8	10	0.6	0.39	0.211	3	0.64	0.8	1.8	0.13	< 0.1	4.12	0.068

#	Mo (maga)	Nb (ppm)	Nd (ppm)	Ni (ppm)	Pb (ppm)	Pr (ppm)	Rb (ppm)	Sb (ppm)	Sc (ppm)	Sm (ppm)	Sn (ppm)	Sr (ppm)	Ta (ppm)	Tb (ppm)
1	< 2	1.4	3.26	< 20	7	0.79	44	< 0.2	<1	0.68	2	40	0.14	0.1
2	< 2	0.4	1.74	< 20	< 5	0.43	23	< 0.2	< 1	0.34	1	21	0.03	0.07
3	11.00	0.50	4.48	90.00	21.00	0.89	12.00	4.30	22.00	1.37	< 1	20.00	0.04	0.31
4	< 2	0.90	5.43	< 20	9.00	1.49	14.00	0.80	2.00	1.13	7.00	52.00	0.10	0.15
5	< 2	2.1	4.57	< 20	< 5	1.19	57	< 0.2	2	0.95	2	48	0.24	0.15
6	< 2	1.8	4.66	< 20	8	1.18	41	< 0.2	1	1.04	2	35	0.17	0.15
7	< 2	1.1	1.38	< 20	6	0.37	33	< 0.2	< 1	0.27	2	21	0.11	0.05
8	< 2	0.4	3.16	60	5	0.61	13	< 0.2	4	1.01	3	125	0.07	0.17
9	< 2	0.7	3.12	< 20	< 5	0.74	25	< 0.2	< 1	0.61	1	18	0.07	0.1
10	< 2	1	2.39	< 20	< 5	0.57	29	< 0.2	< 1	0.48	2	19	0.07	0.07
11	2.00	2.80	5.28	< 20	20.00	1.47	24.00	1.20	2.00	1.11	< 1	76.00	0.28	0.17
12	< 2	0.60	3.20	< 20	11.00	0.84	20.00	1.30	< 1	0.71	< 1	105.00	0.08	0.10
13	5	0.8	4.46	30	8	1.23	10	0.7	3	0.84	2	31	0.07	0.14
14	< 2	0.8	3.33	< 20	7	0.86	41	< 0.2	1	0.67	2	25	0.08	0.1
15	< 2	1.7	3.93	< 20	< 5	1	40	< 0.2	4	0.79	2	23	0.18	0.12
16	< 2	0.70	3.12	< 20	7.00	0.83	17.00	1.10	< 1	0.67	< 1	82.00	0.08	0.09
17	< 2	0.7	2.75	< 20	< 5	0.71	29	< 0.2	< 1	0.53	2	24	0.08	0.08
18	< 2	2.3	4.38	< 20	9	1.08	26	< 0.2	1	0.96	2	123	0.23	0.15
19	< 2	0.5	2.11	< 20	< 5	0.55	9	0.2	< 1	0.43	3	62	0.05	0.07
20	< 2	0.6	1.46	< 20	< 5	0.39	11	< 0.2	< 1	0.27	3	7	0.06	0.05
21	< 2	1.3	2.33	< 20	< 5	0.61	27	< 0.2	< 1	0.48	2	19	0.13	0.08
22	< 2	1.60	4.37	< 20	14.00	1.13	30.00	0.70	< 1	0.95	< 1	108.00	0.15	0.13
23	< 2	1.2	3.72	< 20	8	0.93	42	< 0.2	< 1	0.78	2	33	0.12	0.11
24	< 2	0.70	3.27	< 20	12.00	0.83	22.00	1.30	1.00	0.76	< 1	80.00	0.07	0.10
25	< 2	0.7	2.43	< 20	6	0.63	30	< 0.2	1	0.47	2	100	0.55	0.07
26	< 2	1.1	4.07	< 20	8	1.06	26	< 0.2	< 1	0.75	< 1	73	0.12	0.1
27	< 2	7.00	15.10	< 20	12.00	4.11	63.00	< 0.2	5.00	3.11	< 1	87.00	0.63	0.52
28	< 2	5.30	12.40	< 20	12.00	3.33	61.00	1.00	4.00	2.68	< 1	76.00	0.49	0.39
29	< 2	1.8	6.03	< 20	7	1.53	51	< 0.2	2	1.21	2	43	0.18	0.2
30	< 2	0.9	3.53	< 20	< 5	0.89	28	< 0.2	< 1	0.71	2	40	0.09	0.1

	Th	TI	Tm	U	V	W	Y	Yb	Zn	Zr
#	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
1	1.11	0.19	0.061	0.7	6	< 0.5	4.5	0.41	< 30	84
2	0.58	< 0.05	0.039	0.28	< 5	< 0.5	3.1	0.26	< 30	21
3	1.17	0.28	0.11	0.98	43.00	< 0.5	7.40	0.64	230.00	34.00
4	1.63	1.84	0.07	0.82	16.00	11.50	4.90	0.44	30.00	33.00
5	1.25	0.3	0.1	0.63	11	< 0.5	6.8	0.73	< 30	224
6	1.2	0.23	0.082	0.46	6	< 0.5	5.5	0.57	< 30	138
7	1.12	0.18	0.047	0.41	7	0.6	2.7	0.34	< 30	86
8	0.65	16.1	0.067	2.93	38	18.2	4.7	0.4	170	22
9	0.86	0.16	0.043	0.41	< 5	< 0.5	3.3	0.28	< 30	34
10	0.87	0.14	0.039	0.47	< 5	< 0.5	2.5	0.26	< 30	43
11	1.79	0.37	0.13	1.12	35.00	4.20	7.10	0.97	< 30	383.00
12	0.84	0.17	0.05	0.20	< 5	1.50	3.00	0.31	< 30	23.00
13	2.5	0.09	0.074	11.4	38	1.1	4.9	0.45	60	34
14	0.93	0.21	0.049	0.92	8	< 0.5	3.1	0.32	< 30	34
15	1.34	0.19	0.08	0.64	24	< 0.5	4.6	0.58	< 30	195
16	0.89	0.13	0.05	0.23	< 5	2.40	3.20	0.33	< 30	40.00
17	0.82	0.17	0.042	0.28	< 5	1.2	2.6	0.28	< 30	41
18	1.39	0.18	0.115	0.49	8	0.7	6.2	0.84	< 30	288
19	0.84	0.07	0.039	0.18	< 5	< 0.5	2.4	0.26	< 30	21
20	0.82	0.06	0.032	0.28	< 5	< 0.5	2	0.22	< 30	26
21	1.05	0.13	0.053	0.42	12	< 0.5	3.2	0.38	< 30	152
22	1.16	0.25	0.08	0.42	< 5	1.30	4.60	0.55	< 30	152.00
23	1.04	0.24	0.059	0.57	7	< 0.5	3.8	0.4	< 30	66
24	0.87	0.24	0.05	0.22	8.00	1.20	3.00	0.30	< 30	33.00
25	0.88	0.18	0.043	0.37	7	0.6	2.7	0.29	30	35
26	1.36	0.47	0.057	0.27	12	< 0.5	3.4	0.38	< 30	58
27	4.87	0.36	0.32	1.99	35.00	0.80	18.20	2.16	< 30	472.00
28	3.79	0.46	0.22	1.94	17.00	0.50	13.50	1.50	40.00	371.00
29	1.91	0.26	0.109	0.36	8	2.3	7.3	0.74	< 30	91
30	0.91	0.15	0.061	0.31	7	1.1	4.4	0.42	< 30	72

APPENDIX C

SOXHLET EXTRACTION YIELDS FOR BLEACHED AND UNBLEACHED SAMPLES

Table C-1. Soxhlet extraction yields (methylene chloride solvent) for bleached and unbleached samples from the Navajo Sandstone and Kayenta Formation at Snow Canyon State Park, Utah. Small amounts of unidentified organic material were extracted from all samples (both bleached and unbleached), but yields are very low.

Sample #	Formation	Sample ID	Coordinates	Map Location	Sample Description	Rock (g)	Extract (g)	Yield (mg/g)	Yield (wt%)
1		Gr20060402-4	N 37° 11' 24" W113° 39' 4"	J	Uniform reddish sandstone	137.8802	0.0006	0.004	0.0004
2		Gr20051001-6	N 37° 13' 25" W113° 39' 36"	к	White bleached sandstone	221.3850	0.0016	0.007	0.0007
3	Navajo	Gr20051208-12	N 37° 12' 23" W113° 40' 13"	L	White bleached sandstone (surfacial alteration to gray)	65.4970	0.0006	0.009	0.0009
4	Ss.	Gr20051209-9	N 37° 14' 18" W113° 40' 1"	М	White bleached sandstone	158.4657	0.0039	0.025	0.0025
5		Gr20051210-5b	N37° 14' 22", W113° 38' 32"	F	White bleached sandstone (surfacial alteration to gray)	218.0183	0.0033	0.015	0.0015
6		Gr20051210-4	N37° 13' 26", W113° 39' 1"	N	Yellow/white bleached sandstone	193.7021	0.0018	0.009	0.0009
7	Kaventa	Gr20060402-1	N 37° 11' 41" W 113° 39' 29"	о	Uniform reddish sandstone	170.1763	0.0018	0.011	0.0011
8	Fm.	Gr20051209-1	N 37° 11' 50" W 113° 39' 42"	I	Partially bleached red and white siltstone	171.7691	0.0032	0.019	0.0019
9	_	-			Laboratory blank	-	0.0002	-	-
10		-			Edos atory blank	-	0.0000	-	-

APPENDIX D

GAS CHROMATOGRAMS FOR EXTRACTED ORGANIC COMPOUNDS

Figures D1 to D10. Gas chromatographs for organic compounds extracted from samples from the Navajo Sandstone and Kayenta Formation at Snow Canyon State Park, Utah. The y axis (pA) is an electrical response measured in picoamps. The x axis (min) is time measured in minutes. Signatures have n-alkane peaks that may be associated with thermogenic hydrocarbon, but these are largely masked by other signatures likely representing recent environmental and/or human organic contaminants. If degraded hydrocarbon is present, it likely occurs across facies and only in trace amounts.



Figure D-1. Uniform reddish Navajo Sandstone with surficial alteration to gray (table C-1, sample 1).



Figure D-2. White bleached Navajo Sandstone (table C-1, sample 2).



Figure D-3. White bleached Navajo Sandstone with surficial alteration to gray (table C-1, sample 3).



Figure D-4. White bleached Navajo Sandstone (table C-1, sample 4).



Figure D-5. White bleached Navajo Sandstone with surficial alteration to gray (table C-1, sample 5).



Figure D-6. Yellow and white bleached Navajo Sandstone (table C-1, sample 6).



Figure D-7. Reddish Kayenta Formation (table C-1, sample 7).



Figure D-8. Partially bleached red and white siltstone from the Kayenta Formation (table C-1, sample 8).



Figure D-9. Laboratory blank (table C-1, sample 9).



Figure D-10. Laboratory blank (table C-1, sample 10).





Plate 1.

Geologic Map and Coloration Facies of the Jurassic Navajo Sandstone, **Snow Canyon State Park and** Areas of Red Cliffs Desert Reserve, Washington County, Utah

by **Gregory B. Nielsen** and Marjorie A. Chan

Scale: 1:10,000 1 inch equals approximately 0.15 mile Contour intervals 50 feet and 200 feet 0 0.125 0.25 Kilometei



Strike and Dip of Bedding — Strike of Vertical or Subvertical Joint

> Lineament (used for large, widely spaced joints or faults)

Eolian Paleocurrent (arrow points in direction of flow, not corrected for regional dip)

Small Road/Subdivision Sample locations referenced in this report

²⁰¹⁰



PLATE 2. SPATIAL DISTRIBUTION OF MAPPED DIAGENETIC COLORATION FACIES/SUBFACIES IN THE SNOW CANYON STATE PARK AREA, UTAH

Red Mountain

Red/White Intermixed Jn-rw

Brown Ferruginous Jn-b

Red Primary Jn-r

Padre Canyon

Image created by draping mapped unit boundaries onto a computer-generated, oblique view of the area. Grayish unit on top of Red Mountain represents soil cover where bleaching patterns are not visible. Refer to Plate 1 for geologic units.

From Nielsen and Chan (2009)

Plate 2 Utah Geological Survey Open-File Report 561 Geologic Map and Coloration Facies of the Jurassic Navajo Sandstone, Snow Canyon State Park and Areas of Red Cliffs Desert Reserve, Washington County, Utah

