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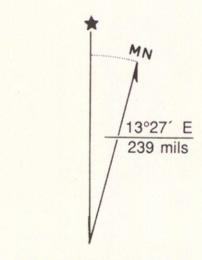
Plate 1
Utah Geological Survey Map 147
Geologic Map of the Barracks Quadrangle

Base map from U.S. Geological Survey, Barracks 7.5' quadrangle, 1980.

Field mapping by Doelling 1985-86 and by Sable 1987.
Cartography by Patricia H Speranza.



1993 DECLINATION AT CENTER OF MAP

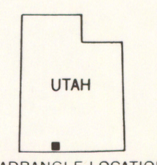
SCALE 1:24 000

1 MILE

7000 FEET

1 KILOMETER

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929



QUADRANGLE LOCATION

GEOLOGIC MAP OF THE BARRACKS QUADRANGLE, KANE COUNTY, UTAH

by

Edward G. Sable, U.S. Geological Survey, Denver
and Hellmut H. Doelling, Utah Geological Survey

1993

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Plate 2
Utah Geological Survey Map 147
Geologic Map of the Barracks Quadrangle

MAP SYMBOLS

Depositional contact--Includes precisely located, approximate, and inferred contacts.

Contact of informal units in Navajo Sandstone.

Fault--Dotted where concealed; queried where sense of movement is uncertain; bar and ball on downthrown block.

Joint or fault trace (with minimal or unknown offset) in bedrock, mostly plotted from aerial photographs.

Lineament in surficial deposits, observed on aerial photographs. Possibly caused by fault or joint trace in underlying bedrock.

Strike and dip of beds.

Structure contour--Datum, top of Navajo Sandstone; dashed where land surface is below datum; contour interval 100 feet (30 m).

PERIOD	EPOCH	FORMATION		SYMBOL	THICKNESS feet (meters)	LITHOLOGY
QUATERNARY	Holocene and Pleistocene	Quaternary		Q	0-50 ? (0-15)	
JURASSIC	Middle Jurassic	Carmel Formation	Winsor Member	Jcw	190-210 (58-64)	
			Paria River Member	Jcp	60-80 (18-24)	
			Crystal Creek Member	Jcx	150-180 (46-55)	
			Co-op Creek Limestone Member	Jcc	250 (76)	
		Temple Cap Sandstone		Jt	160-200 (49-60)	J-2 / J-1
	Lower Jurassic	Navajo Sandstone	White unit	Jnw	400-600± (122-183±)	
			Pink unit	Jnp	900± (274±)	
			Brown unit	Jnb	350 (107)	
		Kayenta Formation (part)		Jk	150+ (46+)	

CORRELATION OF MAP UNITS

QUATERNARY — Holocene and Pleistocene: Qa, Qc, Qac, Qms, Qaf, Qes, Qed, Qmt

Unconformity

JURASSIC — Middle Jurassic: Jcw, Jcp, Jcx, Jccu, Jccl, Jcc

*J-2 Unconformity

Jt

*J-1 Unconformity

Lower Jurassic: Jnw, Jnp, Jnb, Jk, Jn

*Unconformity of Pipiringos and O'Sullivan (1978)

DESCRIPTION OF MAP UNITS

Qa — Alluvium (Quaternary) -- *Dominantly fine- to medium-grained sand, mostly pale orange to yellowish brown, locally contains beds of poorly sorted, interstratified, pebble- to cobble-size gravel composed of locally derived limestone and sandstone. Includes modern stream deposits and older floodplain deposits adjacent to modern streams. In part includes poorly defined alluvial fans and aprons, and colluvium along valley walls.*

Qac — Mixed alluvium and colluvium (Quaternary) -- *Sand, silt, and clay on smooth, gentle, in part pediment-like surfaces, deposited mostly as sheetwash derived from reworking of eolian sand and colluvium. Unit probably less than 10 feet (3 m) thick.*

Qaf — Mixed stream alluvium and fan deposits (Quaternary) -- *Sand, silt, and poorly sorted, subangular to angular sandstone and limestone pebble and cobble gravel. Occurs in fan and fan-apron deposits mostly along stream valleys.*

Qmt — Talus (Quaternary) -- *Sand and sandstone talus blocks along base and sides of mesas and buttes. Thickness variable; probably less than 50 feet (15 m) thick.*

Qms — Landslide deposits (Quaternary) -- *Angular sandstone blocks of Cretaceous age in sand- to clay-sized matrix.*

Qes — Eolian sheet sand (Quaternary) -- *Sand, reddish orange, pale orange, and yellowish gray, fine to medium grained, derived mainly from Navajo Sandstone; widespread as sheets and as fillings in topographically low areas. Locally includes small bedrock outcrops. Estimated to be less than 10 feet (3 m), but locally as much as 30 feet (9 m) thick.*

Qed — Eolian sand in dunes and ramps (Quaternary) -- *Sand as above, mostly reddish orange, in mostly vegetation-stabilized sand ramps (climbing and falling dunes) flanking buttes and mesas and as small dune fields. May be as much as 50 feet (15 m) thick.*

Qc — Colluvium (Quaternary) -- *Homogeneous red and orange clay and silt matrix containing limestone platelets; on buttes and mesas where underlain by Co-op Creek Limestone Member of Carmel Formation, and silty to sandy material on other units of the Carmel Formation. Estimated to be less than 5 feet (1.5 m) thick.*

Carmel Formation (Middle Jurassic) -- *about 700 feet (213 m) thick; uppermost beds eroded.*

Jcw — Winsor Member -- *Upper 165 feet (50 m) is sandstone, yellowish gray, light gray and pale orange, medium grained, and cross-bedded. Lower 45 feet (14 m) is sandstone and mudstone, reddish brown to light brown, fine grained; unit thickness is 210 feet (64 m).*

Jcp — Paria River Member -- *Interbedded reddish-brown and gray siltstone, mudstone, gypsum, and minor fossiliferous limestone; basal unit is gypsum, white, gray, and moderate pink, massive, cliff forming, with minor shale, about 15 to 45 feet (6-14 m) thick; unit thickness is 60 to 80 feet (18-24 m).*

Jcx — Crystal Creek Member -- *Gypsiferous sandstone, siltstone, and mudstone, reddish brown, light brown, and light gray, interbedded with minor clay-ball conglomerate and gypsum, 150 to 180 feet (46-55 m) thick.*

Jcc (Jccu, Jccl) — Co-op Creek Limestone Member -- *Mostly limestone and calcareous shale. Limestone, very pale orange to gray, mostly micritic but also oolitic, sandy, and coquinoid; minor dolomite and sandstone. Fossils include pelecypods, gastropods, and crinoid columnals. Upper unit of ledge-forming limestone and dolomite (Jccu), about 100 feet (30 m) thick, weathers to very pale shades of gray; lower unit (Jccl) is slope-forming, platy limestone and shale overlying ledge-forming limestone containing thin beds of reddish-orange and gray siltstone, sandstone, mudstone, and local conglomerate at base, about 150 feet (46 m) thick. Basal contact is sharp and planar. Member thickness is about 250 feet (76 m).*

Jt — Temple Cap Sandstone (Middle Jurassic) -- *White Throne Member is gray to pink sandstone, with high-angle, thick crossbedding sets; massive and cliff-forming, 100 to 140 feet (30-43 m) thick. Underlying Sinawava Member is slope-forming, reddish-orange to reddish-brown sandstone, siltstone, and mudstone, 40 to 60 feet (12-18 m) thick. Two named members are visible in outcrops, but not mapped separately due to scale. Basal sandstone bed tabular and locally conglomeratic, 2 to 4 feet (1 m) thick, basal contact is abrupt and planar. Total formation thickness is 160 to 200 feet (49-60 m).*

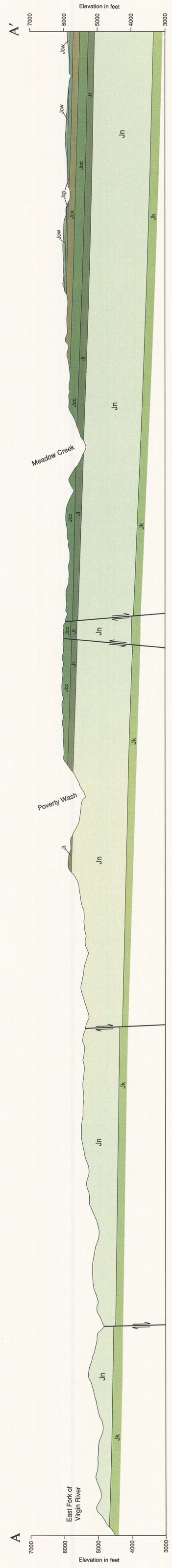
Navajo Sandstone (Lower Jurassic) -- *divided into three informal units, shown undivided only on cross section, 1,650 to 1,850 feet (503-564 m) thick.*

Jnw — White unit -- *Sandstone, pale orange to gray, quartzose, fine to medium grained, well sorted; large-scale tabular- and wedge-planar cross-beds and thick cross-bed sets; weathers to light-gray hues; moderately well indurated, in part with calcareous cement; forms steep-sided hillsides and cliffs. Unit is 400 to 600 feet (122-183 m) thick.*

Jnp — Pink unit -- *Sandstone similar to white unit, but weathers reddish orange, reddish brown, and pale to moderate red; is weakly to moderately cemented with iron oxides; forms rolling topography of low to moderate relief. About 900 feet (274 m) thick.*

Jnb — Brown unit -- *Sandstone and minor siltstone and mudstone; reddish brown to gray, contains large-scale tabular- and wedge-planar cross-beds to small-scale trough crossbeds; iron oxide and siliceous cement; resistant and cliff to ledge forming, lower beds appear to intertongue with the underlying Kayenta Formation. About 350 feet (107 m) thick.*

Jk — Kayenta Formation (Lower Jurassic) -- *Siltstone, mudstone, and sandstone, reddish orange to reddish brown, mostly medium-planar bedded, in part with small- to moderate-scale trough cross-beds. Only upper 150 feet (46 m) exposed.*



GEOLOGIC MAP OF THE BARRACKS QUADRANGLE KANE COUNTY, UTAH

by

Edward G. Sable, U.S. Geological Survey

Hellmut H. Doelling, Utah Geological Survey

Map 147 **1993**

UTAH GEOLOGICAL SURVEY

a division of

UTAH DEPARTMENT OF NATURAL RESOURCES

UTAH GEOLOGICAL SURVEY

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GEOLOGIC MAP OF THE BARRACKS QUADRANGLE, KANE COUNTY, UTAH

by

Edward G. Sable[1] *and Hellmut H. Doelling*[2]

ABSTRACT

Four bedrock formations of Early to Middle Jurassic age and eight unconsolidated units of Quaternary age are exposed in The Barracks quadrangle. The map area generally lies east of Zion National Park, Utah, but the park's eastern margin extends into the northwest corner of the quadrangle.

The exposed pre-Quaternary stratigraphy consists of, in ascending order, the uppermost part of the Lower Jurassic Kayenta Formation and Navajo Sandstone, and the Middle Jurassic Temple Cap Sandstone and Carmel Formation. The Kayenta Formation consists of alluvial siltstone and sandstone. The Navajo Sandstone, about 1,650 to 1,850 feet (503-564 m) thick, is subdivided into three informal units; a lower brown unit, about 350 feet (107 m) thick, a middle pink unit, about 900 feet (274 m) thick, and an upper white unit, about 400 to 600 feet (122-183 m) thick. The upper and lower contacts of the Temple Cap Sandstone are defined by sharp, nearly planar surfaces, interpreted to represent unconformities. The Temple Cap Sandstone is 160 to 200 feet (49-60 m) thick and may be divided into the Sinawava and White Throne Members. Both members are present in The Barracks quadrangle but were not mapped separately. The overlying Carmel Formation is more than 700 feet (213 m) thick and consists of the Co-op Creek Limestone Member, about 250 feet (76 m) thick, the Crystal Creek Member, about 150 to 180 feet (46-55 m) thick, the Paria River Member, 60 to 80 ft (18-24 m) thick, and the Winsor Member, of which an incomplete thickness of about 200 feet (60 m) is exposed.

Mapped Quaternary units include stream alluvium, fan deposits, landslide deposits, colluvium, and eolian sand in sheets, dunes, and ramps. Structures consist of a northeast-dipping, low-angle homocline cut by a few high-angle extensional faults with displacements of less than 100 feet (30 m), and fracture sets trending north-northwest and northeast.

There has been no commercial exploitation of mineral or energy resources or subsurface exploration in the quadrangle. The rock and mineral resource potential is considered to be subeconomic, the oil and gas potential to be moderate, and other energy resource potential to be low. Potential for surface geologic hazards is generally low. Thirty-three earthquakes of Richter magnitude 2.0 or greater have been recorded in the vicinity of the quadrangle between 1850 and 1986; those with monitored epicenters were located 8 to 15 miles (13-24 km) southeast of the quadrangle. The maximum Richter magnitude of these events was 5.5.

INTRODUCTION

The Barracks quadrangle, named after a temporary bivouac area used by militia in the 19th century, is located in southwestern Kane County, southwestern Utah. The quadrangle is bounded on the west, north, east, and south by the Springdale East, Clear Creek Mountain, Mount Carmel, and Elephant Butte 7 1/2-minute quadrangles, respectively (figure 1). The northwest quarter of the Kanab 15-minute quadrangle, which has been mapped geologically (Sargent and Philpott, 1987), adjoins The Barracks quadrangle on the east. Geologic maps have also been published for areas to the north of the quadrangle (Cashion 1961, 1967a, b), and for the Elephant Butte quadrangle to the south (Sable and Doelling, 1989).

The Barracks quadrangle is located within the Colorado Plateau physiographic province. Landforms include buttes and mesas that rise above a gently rolling, mostly sand-covered surface which has been deeply incised by the East Fork of the Virgin River and its tributaries. The cliffs along the river cul-

[1]*U. S. Geological Survey, Denver, Colorado.*
[2]*Utah Geological Survey.*

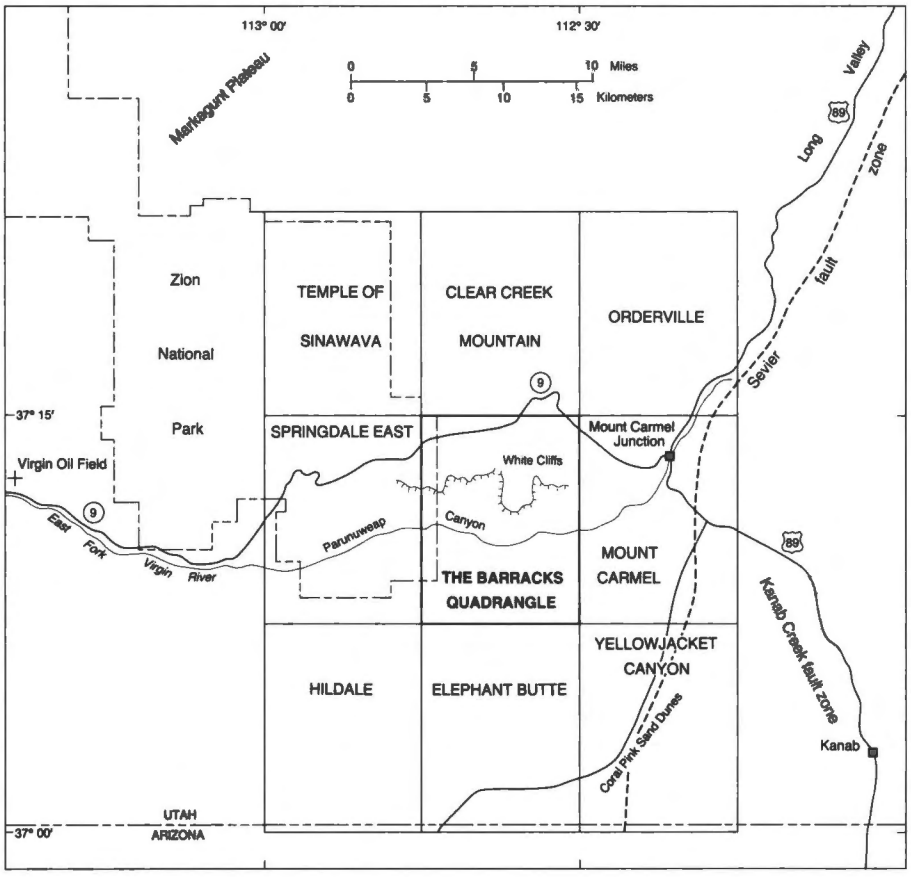

Figure 1. *Location of The Barracks and adjoining quadrangles and features discussed in text.*

minate in the spectacular 2,000-foot (610 m) deep Parunuweap Canyon just west of the quadrangle. North of the East Fork, the scenic White Cliffs form a south-facing rampart 400 to 500 feet (120-150 m) high that represents a main step in the regional topographic "Grand Staircase," which culminates to the north in the high Markagunt Plateau. Altitudes in the quadrangle range from 4,300 to 6,628 feet (1,310-2,020 m) above mean sea level.

The principal paved access road in the north part of the quadrangle is Utah State Highway 9, from which a few generally unimproved roads lead south to the tops of the White Cliffs, and one improved (partly paved and gravel) road that leads north to connect with Utah State Highway 14, about 20 miles (32 km) north of the quadrangle. On the south side of the East Fork of the Virgin River, roads and trails lead into the quadrangle from the northeast-trending partly paved "Sand Dunes Road" 7 to 8 miles (11.3-12.9 km) south of the quadrangle. Coral Pink Sand Dunes State Park lies 6 miles (9.6 km) southeast and Mount Carmel Junction 4.5 miles (7.2 km) east-southeast of the southeast and northeast corners of the quadrangle, respectively.

Except for the East Fork of the Virgin River and its major tributaries, Meadow Creek and Mineral Gulch, all streams in the quadrangle are ephemeral. The area is used principally for winter grazing of cattle. A few fresh water springs and seeps issue from bedding planes of the Navajo Sandstone. A few habitations, the east entrance to Zion National Park, and a private landing strip are located along and north of Utah State Highway 9.

There has been relatively little previous geologic work done in the area. Published geologic maps have been of small scale (Gregory, 1950; Hintze, 1963, 1980) or from photogeologic interpretation (Pillmore, 1956). The quadrangle was mapped in part by E. G. Sable in 1986 as part of the U. S. Bureau of Land Management Parunuweap Canyon Wilderness study area (Van Loenen and others, 1988b). The present map stems from this field mapping, from that by Doelling in 1985 and 1986, and by Sable in 1987, supplemented by interpretation of vertical aerial photographs. This included black-and-white photography at 1:33,200 scale flown for the U. S. Geological Survey in 1973, and 1984 natural-color photography at 1:24,000 scale obtained from *Intrasearch*, a private organization.

STRATIGRAPHY

Jurassic Rocks

About 2,900 feet (885 m) of sedimentary rocks are exposed in The Barracks quadrangle. They are divided into four formations consisting of nine mapped units (plate 1). In addition, Paleozoic and Mesozoic rocks underlying the quadrangle total about 9,500 feet (2,900 m) (Van Loenen and others, 1988a); however, no subsurface information from within the quadrangle is available.

The age of the Kayenta Formation and Navajo Sandstone has been considered by many investigators to be Late Triassic(?) to Early Jurassic. Equivocal age-diagnostic fossils of both Late Triassic and Early Jurassic ages have been reported from the Kayenta and overlying Navajo. Peterson and Pipiringos (1979, p. B31-B34) reported that Bruce Cornet, (Gulf Research and Development Company, Houston, Texas) identified palynomorphs of Early Jurassic age in the Moenave Formation, which underlies the Kayenta in the subsurface. Padian (1989) reinterpreted external bony plate fossil remains (scutes) from the Kayenta, previously assigned to the Late Triassic, as those from *Scelidosaurus,* a dinosaur of Early Jurassic age. The Kayenta and Navajo strata in The Barracks quadrangle are therefore considered Early Jurassic on the basis of their correlation with the fossil-bearing strata elsewhere.

Kayenta Formation (Jk)

The uppermost 150 feet (46 m) of the Kayenta Formation (Lower Jurassic) is exposed on the lower walls of Parunuweap Canyon along the western boundary of The Barracks quadrangle. The Kayenta strata are largely covered by colluvium derived from the overlying Navajo Sandstone. Scattered exposures of Kayenta are mostly reddish-orange, well-indurated, thin- to medium-bedded siltstone, silty shale and mudstone, with a few beds of pale-red, fine-grained sandstone. A resistant, cross-bedded sandstone about 10 feet (3 m) thick occurs near the base of the exposures. In the subsurface the Lamb Point Tongue of the Navajo Sandstone intertongues westerly into the Kayenta Formation and probably lies below the floor of the canyon. It is exposed above stream level less than 1/2 mile (1 km) downstream, west of the quadrangle. The Kayenta Formation is about 600 feet (180 m) thick 5 1/2 miles (9 km) west of The Barracks quadrangle. Based upon the low angle, fluvial-type cross-bedding, lack of organic plant debris, and the oxidized nature of the strata, the Kayenta was probably deposited in a low- to moderate-energy flood-plain environment under arid to semi-arid conditions.

The uppermost, exposed part of the Kayenta is known as the Tenney Canyon Tongue to the east. The upper contact of the Kayenta Formation (Tenney Canyon Tongue) is placed at the base of the sandstone above which the typical high-angle cross-beds of the overlying Navajo Sandstone are dominant.

Navajo Sandstone (Jn)

The Navajo Sandstone (Lower Jurassic) and correlative units form a vast body of cross-stratified sandstone that extends from north-central Wyoming to Nevada and Arizona (McKee, 1979, p. 209-217). It is the dominant bedrock unit exposed in the southern and southwestern parts of The Barracks quadrangle. The Navajo is predominantly fine- to medium-grained, well-sorted, quartzose sandstone of probable eolian (windblown) origin; it is characterized by thick sets of high-angle, tabular-planar and wedge-planar tangential cross-beds (figure 2). Cross-bed sets are commonly 10 to 25 feet (3-8 m) thick, some are more than 30 feet (9 m) thick; most dip 20° to 30° southwest to south in the quadrangle. Sand grains, predominantly quartz and sparse feldspar, magnetite, tourmaline, staurolite, zircon, garnet, and mica (Gregory, 1950) are mostly equant and subrounded to subangular. The morphology and scale of cross-beds, excellent sorting, paucity of heavy minerals, and grain shapes strongly suggest an eolian dune origin. Thin partings and lenses of reddish-brown silty sandstone and mudstone probably represent fluvial interbeds. Contorted beds as much as a few feet thick between sets of undisturbed strata are locally present and are probably the result of slumping prior to cementation. Most of the Navajo is loosely cemented by iron and manganese oxides, calcite, and silica, but moderately to firmly cemented sandstone is locally present. The upper 400 feet (120 m) is firmly cemented, massive, and cliff forming.

The Navajo, about 1,650 to 1,850 feet (503-564 m) thick, is divided into three informal units in The Barracks quadrangle. The brown, pink, and white units (in ascending order) are named after their dominant weathering colors and are differentiated to some extent by their geomorphic expression. These divisions are similar to those that C. D. Walcott observed in 1879 along Kanab Valley about 12 miles (19 km) east of The Barracks quadrangle (Cross, 1908). The color boundaries are not strictly delimited by bedding contacts and locally cross the bedding in a seemingly erratic manner. The brown unit of the Navajo, about 350 feet (107 m) thick, is generally firmly cemented by iron oxides, and thus is a resistant cliff- and ledge-forming unit that weathers reddish brown to gray. Cross-bed sets of the brown unit are generally thinner than those of overlying units. The brown unit contains interbedded, planar siltstone and sandstone

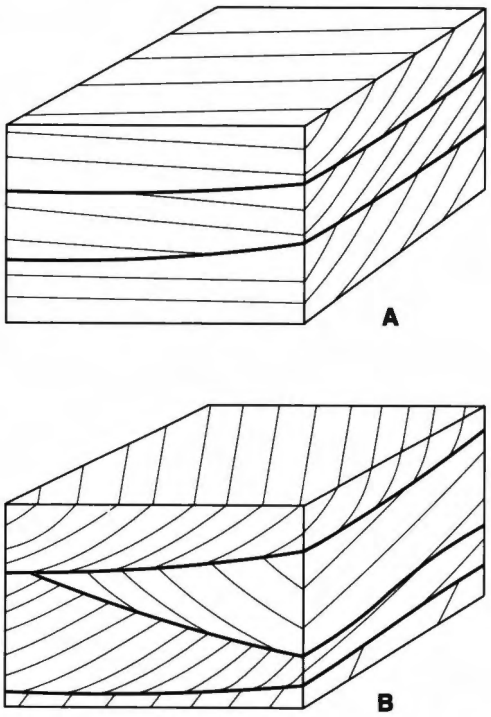

Figure 2. *Two basic forms of cross-strata recognized in eolian sandstones; A) Tabular-planar; B) Wedge-planar (McKee, 1979, p 192). 192).*

beds, some with small-scale trough cross-bedding and fining upwards grain size, probably indicative of fluvial sedimentation. The pink unit, about 900 feet (274 m) thick, is not as well cemented and thus forms rolling topography consisting of smooth, rounded rock hills and knolls, sloping rock surfaces, ledges, and hollows. The sandstone beds are weakly to moderately cemented by iron oxides; colors range from reddish orange to reddish brown to pale and moderate red. The white unit is commonly pale orange and weathers very light gray, pinkish gray, and yellowish gray. Bedding features and petrographic characteristics resemble those of the pink unit, except that the white unit locally possesses calcareous cement (Doelling and Davis, 1989, p. 48). The white unit forms steep-sloped cliffs and bare rock hillsides such as in the White Cliffs. In most of the quadrangle the white unit is about 400 feet (122 m) thick, but is more than 450 feet (137 m) thick in the southeastern part, and in one area in the northwest-central part of the quadrangle it is 600 feet (183 m) thick. The upper 400 feet (122 m) of the white unit in all of these areas weathers to very steep hillsides and cliffs, whereas the lower 50 to 200 ft (15-61 m) weathers to gentler topography like that of the pink unit. Differences in thicknesses of the white unit are probably due to intergrading of the pink and white colors, rather than to beveling by the unconformity at the top of the Navajo.

Concentrations of dark iron and manganese(?) oxides have locally formed concretionary bodies and ironstone sheets, mostly in the sandstone layers of the pink unit of the Navajo (Doelling and Davis, 1989, p. 50). These rocks are dark grayish brown to black, mostly less than an inch thick, but as much as a few feet thick and are present in part in contorted layers. Doelling and Davis (1989) suggest that the sheets formed during diagenesis. Limestone beds and associated chert, reported from the Navajo in other areas, were not seen during field studies in The Barracks quadrangle.

The upper contact of the Navajo Sandstone with the overlying Temple Cap Sandstone is sharp and nearly planar (figure 3). The basal bed of the Temple Cap is commonly a tabular, ragged-weathering bed of sandstone 1 to 2 feet (30-61 cm) thick, but it may consist of red mudstone and siltstone. The Temple Cap Sandstone sharply truncates the cross-bedded sandstone of the Navajo, and the contact is interpreted to correspond to the J-1 unconformity of Pipiringos and O'Sullivan (1978).

Temple Cap Sandstone (Jt)

The Temple Cap Sandstone (Middle Jurassic), formerly a member of the Navajo Sandstone, was raised to formation rank and subdivided into two members by Peterson and Pipiringos (1979). Type and reference section localities of the Sinawava and overlying White Throne Members are located about 5 miles (8 km) northwest of The Barracks quadrangle in Zion National Park. Both members are present in The Barracks quadrangle but were not mapped separately (figure 3). The total thickness of the Temple Cap Sandstone in the quadrangle ranges from 160 to 200 feet (49-60 m); differences in thickness largely are reflections of thickness variations in the White Throne Member of the Temple Cap Sandstone.

The Sinawava Member, 40 to 60 feet (12-18 m) thick, is a slope-forming unit of reddish-orange to reddish-brown mudstone, silty shale, and sandstone. Very coarse sand grains and small pebbles of chert characterize the basal beds. The contact with the overlying White Throne Member appears to be conformable and probably is intertonguing. The White Throne Member, as much as 140 feet (43 m) thick, is cliff-forming, gray to pale-red, cross-bedded sandstone like that in the pink and white units of the Navajo Sandstone. The Sinawava Member is interpreted to have been deposited in an arid flood-plain environment, and the White Throne Member to be a product of desert dune deposition. The contact of the Temple Cap with the overlying Co-op Creek Limestone Member of the Carmel Formation is abrupt, and is considered to correspond to the J-2 unconformity of Pipiringos and O'Sullivan (1978).

Carmel Formation (Jcc)

The Carmel Formation (Middle Jurassic), as defined by Gilluly and Reeside (1926), was a relatively restricted unit, but the term more recently has been expanded to include a larger stratigraphic succession composed of four or five members. In western Kane County these are the Co-op Creek Limestone, Crystal Creek, Paria River, and Winsor Members (Doelling and Davis, 1989; figure 4 of this report). Elsewhere in Kane County, the Wiggler Wash Member (Thompson and Stokes, 1970) is locally the uppermost unit of the Carmel. Excellent exposures of the Carmel Formation occur along the canyon walls of Meadow Creek, in the northeastern part of The Barracks quadrangle. These include the type section of the Co-op Creek Limestone Member of Doelling and Davis (1989, p. 57). No major unequivocal stratigraphic breaks between the members are known, although a sharp contact between the Crystal Creek and Paria is common, and Thompson and Stokes (1970, p. 6 and 9) interpreted this as a regional unconformity. The Carmel Formation is as much as 700 feet (213 m) thick in The Barracks quadrangle.

The Co-op Creek Limestone Member consists of about 250 feet (76 m) of gray- to white-weathering, pale-orange to gray micritic limestone and calcareous shale, and lesser amounts of dolomite, sandy limestone, oolitic limestone, coquinoid limestone, sandstone, and siltstone. In The Barracks quadrangle the member is divided into lower and upper informal map units. The lower unit, 130 to 170 feet (40-52 m) thick, has a basal 10 foot (3 m) section of reddish-orange and gray, thin-bedded, calcareous siltstone, sandstone, and mudstone. The pale-brown sandstone, part conglomeratic, is present in thin planar beds that weather to ragged surfaces. These basal beds, which locally contain white to light-gray chert clasts less than 2 inches (5 cm) in diameter, truncate the cross-bedded sandstone of the Temple Cap (figure 3). The basal beds are overlain by about 25 to 35 feet (8-11 m) of resistant, ledge-forming, medium-bedded limestone which grades upward to about 100 feet (30 m) of thin-bedded, slope-forming, shaly limestone and limy shale, containing a few interbeds of ledge-forming limestone. The upper unit, less than 100 feet (30 m) thick, is a medium- to thin-bedded, ledge-forming limestone that weathers to very light

Figure 3. *View in The Barracks quadrangle of the upper (white unit) Navajo Sandstone (Jnw) overlain by the Temple Cap Sandstone (Jt) and the lower unit of the Co-op Creek Limestone Member of the Carmel Formation (Jccl). The Navajo Sandstone is sharply truncated by the J-1 unconformity of Pipiringos and O'Sullivan (1978) (top of the cliff). The Temple Cap Sandstone consists of the reddish-brown, slope-forming Sinawava Member and the Navajo-like White Throne Member. The J-2 unconformity (top of middle cliff) separates the Temple Cap Sandstone from the Carmel Formation. The narrow slope between the Temple Cap and the lowermost prominent ledge of the Co-op Creek Limestone Member is mostly reddish-brown siltstone similar to that in the Sinawava Member.*

Gregory, 1950		*Cashion, 1967b*	*Thompson & Stokes, 1970*	*This Report*
WINSOR FORMATION	CARMEL FORMATION	WINSOR MEMBER	Wiggler Wash Mbr. WINSOR MEMBER	WINSOR MEMBER
CURTIS FORMATION		GYPSIF-EROUS MEMBER	PARIA RIVER MEMBER	PARIA RIVER MEMBER
ENTRADA SANDSTONE		BANDED MEMBER	CRYSTAL CREEK MEMBER	CRYSTAL CREEK MEMBER
CARMEL FORMATION		LIMESTONE MEMBER	KOLOB LIMESTONE MEMBER	CO-OP CREEK LIMESTONE MEMBER

Figure 4. *Diagram showing nomenclature history and relationships of Carmel Formation and related units in southwestern Utah (modified from Doelling and Davis, 1989).*

gray hues in contrast to the darker weathered colors below, and grades up into 10 to 12 feet (3-4 m) of gray limy shale and limestone (figures 5 and 6). The ledge-forming limestone unit contains algal laminae, rip-up clasts of limestone, cauliflower-shaped quartz concretions, and exhibits bird's-eye texture. Marine pelecypods, gastropods, and crinoids, including the star-shaped columnal segments of *Pentacrinus asteriscus*, are locally common. The age of the fossil assemblage, according to Imlay (1964, p. C5), is Middle Jurassic (Bajocian and possibly early Callovian).

The dominant micritic character of the limestones, the general scarcity of argillaceous constituents, and the presence of algal limestone suggest a low-energy intertidal depositional environment with little terrigenous influx, such as that in a protected bay or lagoon. Bird's-eye texture may indicate a supratidal, vadose exposure-zone.

The Crystal Creek Member, 150 to 180 feet (46-55 m) thick, is mostly weakly cemented: very fine- to fine-grained; poorly to moderately sorted; reddish-brown, light-brown, and light-gray; gypsum-cemented; quartzose sandstone. The weathered appearance is brown and reddish brown and banded. Lesser amounts of siltstone, mudstone, gypsum, and clay-ball conglomerate are interbedded with the sandstone. Secondary gypsum occurs as cross-cutting veins, segregations, and bedding-plane coatings.

The Paria River Member, 60 to 80 feet (18-24 m) thick, consists of a basal cliff- and ledge-forming gypsum unit 15 to 45 feet (6-14 m) thick overlain by reddish-brown and gray siltstone and mudstone, gray calcareous shale, and minor limestone. The gypsum is white to pink, massive to thin bedded, and contains crumpled gypsiferous shale partings. Limestone occurs as thin beds and limy concretions and nodules containing a sparse fauna of pelecypods, gastropods, and crinoid columnals. The faunal assemblage was reported by Reeside (Gregory, 1950, p. 96) to be older than middle Late Jurassic (mainly Argovian), but Imlay (1964, p. C5) assigned it only a Jurassic age.

The Winsor Member, about 210 feet (64 m) thick at Meadow Creek, consists of 45 feet (14 m) of reddish-brown to light-brown, fine-grained sandstone and lesser reddish-brown, thin-bedded mudstone overlain by 165 feet (50 m) of light-hued, very-pale-orange, yellowish-gray, and very-light-gray, medium-grained, weakly indurated sandstone. The sandstone consists mostly of quartz in a clay matrix, is poorly to moderately sorted, friable, and thin to thick bedded. It contains low- to high-angle, tabular-planar and wedge-planar cross-beds. The lighter colors of the upper part of the Winsor may be secondary colors (Peterson and Pipiringos, 1979, p. B16).

The clastic rocks of the Crystal Creek and Winsor Members and the gypsiferous, calcareous, and clastic strata of the Paria River Member probably were deposited in an arid floodplain sabhka-shelf environment.

QUATERNARY UNITS

Eight units of Quaternary unconsolidated surficial deposits were mapped in The Barracks quadrangle. Alluvial, eolian, and colluvial deposits, mostly sand derived from the Navajo Sandstone, cover bedrock in about 30 percent of the quadrangle.

Figure 5. *Upper part of the Co-op Creek Limestone Member of the Carmel Formation capped by a thin slope-forming remnant of the Crystal Creek Member in the northern part of The Barracks quadrangle. The uppermost Co-op Creek is a prominent ledge-forming limestone (see figure 6). The Crystal Creek Member consists of reddish-brown, light-brown, and light-gray-banded, fine-grained, slope-forming sandstone.*

Figure 6. *The upper ledge of the Co-op Creek Limestone Member consists of platy and blocky limestone beds, some of which are fossiliferous. The Crystal Creek Member has been stripped off the top of the ledge here, as in most areas of the quadrangle, forming a prominent bench (figures 3 and 5).*

Deposits of different origins interfinger and intergrade, so that mapped contacts of the Quaternary units are approximate.

Areas mapped as alluvium (Qa) include both modern stream deposits that occupy and adjoin modern drainage channels, and older stream deposits that underlie low-lying, vegetated flood plains. Alluvial deposits consist mostly of sand and silt, but along the larger streams such as the East Fork of the Virgin River and Meadow Creek, the deposits consist of gravelly sand. The alluvium probably is less than 30 feet (9 m) thick.

Talus (Qmt) includes talus, rockfall, and slump deposits which are of limited areal extent and consist mostly of a mixture of sand and sandstone blocks derived from cliffs of the Navajo and Temple Cap Sandstones. Mixed stream alluvium and fan-deposit material (Qaf) includes scattered fan deposits and fan-apron deposits intermixed with fluvial material along streams such as Co-op Creek. The mixed alluvium and colluvium unit (Qac) occurs largely in smooth-surfaced areas underlain by sheetwash sand, silt, and clay which mostly overlie pediment-like surfaces and represent reworked eolian and weathering residuum. The unit also includes indistinct alluvial fans and fan aprons which have been subject to sheet erosion and slow downslope movement. The Qac unit occurs notably on gently sloping surfaces of sand-ramp (Qed) and sheet-sand (Qes) deposits, and as reworked weathering residuum between Meadow Creek and Co-op Creek.

Eolian deposits cover large areas of low relief in the southern part of the quadrangle and fill valley bottoms or abut bedrock hillsides in the eastern and north-central parts. They are mapped on the basis of surface morphology. Climbing and falling sand dunes (sand ramps and sand aprons) and small sand dune fields (Qed), which fill some valleys and flank steep-walled buttes, are differentiated from more widespread sheet sand (Qes) which fills irregularities on the underlying bedrock surfaces and covers large areas. The sand-ramp deposits may locally exceed 50 feet (15 m) in thickness; the sheet sand ranges from a few feet (1 m) to perhaps 30 feet (9 m) in thickness.

Residual colluvium (Qc) occurs mostly on flat or gently sloping areas underlain by the Co-op Creek Limestone Member of the Carmel Formation in the northern and northeastern parts of the quadrangle and consists of red clay intermixed with limestone fragments or silty to sandy material. It is partly covered by thin eolian sand and is estimated to be less than 5 feet (1.5 m) thick. No soil horizons or profiles were observed.

The southernmost distal parts of fairly extensive landslide deposits (Qms) occur along the northern border of the quadrangle. They consist of pebble- to boulder-size, angular blocks of Cretaceous sandstone in an unconsolidated clay- to sand-sized matrix. They are probably the products of translational sliding (movement generally parallel to the ground surface), and in the quadrangle are perhaps not more than 20 feet (6 m) thick.

Isolated pebbles to small boulders (not mapped) occur in sandy surficial material south of Utah State Highway 9, at approximate latitude 37° 14′ 30" N, longitude 112° 48′ 00" W. The clasts consist of sandstone of Cretaceous age and rare

igneous rock, which on the basis of hand-specimen examination resemble latite porphyry of Tertiary-age intrusions that lie west and north of The Barracks quadrangle. Occurrences of gravels with similar igneous rock have been reported elsewhere on the Markagunt Plateau; they are discussed by Anderson and Mehnert (1979) who interpreted them to be from a western source.

All surficial deposits are probably Pleistocene and (or) Holocene age. Residual colluvium may be as old as late Tertiary, but since it lacks a strongly developed weathering profile, it is more likely to be of Quaternary age.

STRUCTURE

Structure in The Barracks quadrangle consists of a gently northeast-dipping homocline in which dips rarely exceed 2°. The homocline is interrupted by a few steeply dipping faults. Datum for the structure contours shown on plate 1 is the top of the Navajo Sandstone. The contours are extrapolated in the southwestern part of the quadrangle on the basis of estimated thickness of the Navajo and on structure in adjoining areas. The faults trend N 30° E and N 10° W, generally parallel to the dominant joint sets in the quadrangle. All faults are steeply dipping, with less than 100 feet (30 m) offset. All but one block is downthrown to the east, toward the north-northeast-trending Sevier fault zone located 5 miles (8 km) east of the quadrangle. The N 30° E fault trend may be related to Sevier fault zone movement, but the N 10° W trend may reflect a different, perhaps earlier, stress field or it may be related to the Kanab Creek fault zone deformation (figure 1). The steep dips of the fault planes and their parallelism to the dominant joint sets may indicate that they follow older joints formed by extensional stresses along which offset was the result of later shear stress, rather then being the result of primary extensional failure.

ECONOMIC GEOLOGY

No known mines or quarries have been opened for extraction of minerals or construction materials in The Barracks quadrangle. Two small prospects in ironstone concretions in the Navajo Sandstone are present near the southern border of the quadrangle. Gypsum and limestone occur within the quadrangle, but neither has been exploited commercially. Much of the Bureau of Land Management Parunuweap Canyon Wilderness Study Area (Van Loenen and others 1988b) lies in the quadrangle. Results of a reconnaissance geochemical survey by the U. S. Geological Survey, appraisal of identified resources by the U. S. Bureau of Mines, and assessment of undiscovered resources by the U. S. Geological Survey are reported in publications related to this and other near-wilderness study areas (Kreidler, 1986; Zelten, 1987; Bullock and others, 1988; Van Loenen and others, 1988a, 1988b, 1989). Gypsum, sandstone, sand and gravel, ornamental "colored" sand, ornamental sandstone (such as "picture rock" limestone), oil and gas, metals, coal, uranium, and geothermal energy potential are discussed in these reports. Rock and unconsolidated sedimentary materials are considered inferred subeconomic resources (the part of identified resources that does not meet the economic criteria of reserves and marginal reserves), oil and gas are considered to have moderate resource potential, and other energy resources are considered to have low resource potential. Doelling and Davis (1989) also discuss rock and mineral resources in their report on the geology of Kane County.

Much of the following information is extracted from the above-cited reports, to which the reader is referred for specifics. Limestone from the Co-op Creek Limestone Member of the Carmel Formation has been used as road metal or borrow from sources in the region around The Barracks quadrangle, and was used in construction of a few buildings during pioneer settlement. The more resistant blocky beds could be used for rip-rap and crushed stone products. Doelling and Davis (1989, p. 140, table 23) report analyses of limestone from the member elsewhere in the region as related to potential cement rock resource. The analyses indicate ranges from 18 to 70 percent CaO, as much as 9 percent MgO, 10 to 30 percent SiO_2, and as much as 3 percent FeO.

Colored sand derived from the Navajo Sandstone north of Kanab, 11 miles (17 km) east-southeast of The Barracks quadrangle, has been collected for filling decorative bottles or making sand paintings. The variety of sand in The Barracks quadrangle, derived from the color and mineralogy of the sandstone cement, offers a lesser choice of colors than in adjoining areas where abundant resources exist. Sand in the region has been tested for use as foundry sand, for sand-blasting purposes, and for glass making, but the sand grains are generally too fine and the iron content too high for these applications (Doelling and Davis, 1989, p. 137, table 22). The sandstones are mostly too weakly cemented to be used for building stone or for other rock construction purposes. Concretion-like masses cemented by as much as 15 percent iron oxide are locally found in the pink unit of the Navajo; some of these are of unusual shape and have potential as "rock shop" sale items.

The Virgin oil field, located about 15 miles (24 km) west of The Barracks quadrangle, has produced from the Triassic Timpoweap Member of the Moenkopi Formation and probably from the Permian Kaibab Formation. These units should be present in the subsurface of The Barracks quadrangle. As summarized by Brandt (1989), about 210,000 barrels of oil and 3.76 million cubic feet of gas were produced from the Virgin field between 1907 and 1986. Drilling depths of pay zones are shallow, averaging about 550 feet (170 m). Oil produced is good refining quality and consists of both paraffin- and asphalt-based oil, possibly from different horizons. Several oil tests have been drilled in the quadrangles to the east (Tapp, 1963), and 19 wells in northernmost Arizona were reported by Ryder (1983). Although no commercial oil or gas was found, many subsurface units contain gas shows and oil-stained rocks, and the Mississippian Redwall Limestone commonly exhibits "live" oil staining. Structural and stratigraphic traps have not been identified in The Barracks quadrangle, but deep exploration, particularly of Cambrian and Precambrian units, has not been attempted. The Parunuweap Canyon and Canaan Mountain Wilderness Study Areas, in and west of The Barracks quadrangle, respectively, were appraised as having moderate energy resource potential for

oil and gas with a C level of certainty (certainty level C indicates that available information gives a good indication of the level of mineral resource potential)(Van Loenen and others, 1988a, 1988b).

GEOLOGIC HAZARDS

The potential for most geologic hazards (such as mudflows, landslides, swelling soils, high ground-water table, and subsidence) in The Barracks quadrangle is generally low. Rockfalls occur from time to time along cliffs. The distal edge of a Quaternary landslide, which shows no evidence of historical movement, is mapped along the northern border of the quadrangle, north and northwest of Meadow Creek. The region receives occasional torrential rainfall from summer thunderstorms, which fill the intermittent stream channels beyond their capacity. The resultant flooding damages roads and causes local gullying. Dirt roads that lack drainage control tend to channel the floodwaters and erode so deeply as to render them impassable.

Windstorms commonly deposit considerable amounts of sand on and across roads and trails, especially in the southern two-thirds of the quadrangle. The resulting drifts commonly require 4-wheel drive or specialized vehicles for travel on them. During extended dry periods surface materials are subject to desiccation, which tends to reduce traction on the sand-based roads.

Earthquakes with epicenters in The Barracks quadrangle have not been recorded. From 1850 through 1988, however, 36 seismic events with Richter magnitudes of 2.0 and greater have been reported in the general vicinity of the quadrangle (Kane County) (Doelling and Davis, 1989). The greatest instrument-monitored earthquake magnitude during that period was 5.5 in 1959; the epicenter was south of Kanab along the Arizona state line (Arabasz and others, 1979; Richins and others, 1981 and 1984; Brown and others, 1986; and Nava and others, 1990). The earthquakes are apparently associated with the Sevier and Kanab Creek fault zones.

WATER POTENTIAL

Data on the general supply and chemical quality of surface and ground water of the Alton-Kolob coal fields area (from 37°00′ to 38°00′ north latitude and from 112°00′ to about 113°24′ west longitude) within which The Barracks quadrangle lies is available (Price, 1980, 1981, 1982, 1983). Ground-water conditions in the upper Virgin River drainage were discussed by Cordova (1981). The following discussion incorporates data from these reports.

All streams in The Barracks quadrangle are ephemeral, with the exception of the East Fork of the Virgin River and its major tributaries. Surface water is fresh to moderately saline. Chemical analyses indicate that runoff contains dominantly calcium carbonate and calcium-magnesium bicarbonate types of soluble compounds in the upper parts of the drainage area; chloride content increases downstream.

The ground-water potential in The Barracks quadrangle is considered good. A few wells have been drilled to obtain water in the northernmost part of the quadrangle. The Navajo Sandstone is considered by Cordova (1981) to be the best aquifer in Kane County. The towns of Kanab, Utah, and Fredonia, Arizona, obtain their water supplies from wells drilled into the Lamb Point Tongue of the Navajo. In general, the total dissolved solids in ground water from the Navajo Sandstone in wells less than 1,000 feet (300 m) deep are 100 to 900 milligrams per liter (mg/L). Ground water in rocks of the Carmel Formation, above the Navajo, contains total dissolved solids of 900 to 3,100 mg/L; total dissolved solids in the Jurassic and Triassic rocks below the Navajo are 260 to 9,500 mg/L. Porosities of sandstone samples from the Navajo range from about 15 to 40 percent and permeabilities from about 2 to 6 feet (0.6-2 m) per day. Potential well yields from the Navajo in the Virgin River basin range from 50 to 500 gallons per minute. The average specific capacity of selected wells in the Navajo Sandstone in the region is 6 gal/min/foot (Cordova, 1981, p. 27).

Limited amounts of perched water (unconfined ground water separated from an underlying main body of saturated rock by an unsaturated zone) can be developed in the quadrangle. Along some intermittent drainages, hollows have developed which are filled with sand saturated with water. In other places, water seeps into cross-beds of the Navajo and is prevented from further downward movement by relatively impermeable mudstone partings that separate cross-bed sets.

SCENIC AND RECREATIONAL POTENTIAL

The picturesque White Cliffs, an expression of the upper white unit of the Navajo Sandstone, are exposed across the northern part of the quadrangle. Although not as spectacularly displayed as in Zion National Park, the cross-bedding and vivid coloration of the Navajo give the area scenic appeal. Views from the tops of the mesas provide magnificent vistas of the sandy and barren-rock lands below and of the spectacular scenery of Zion National Park to the west. Except for the well-traveled corridor along Utah State Highway 9, most of the quadrangle is rarely visited; it affords recreational opportunities and solitude in a relatively accessible area.

ACKNOWLEDGMENTS

We are grateful to the many investigators who laid the foundation for deciphering the geology of southern Utah. The following either helped by reviewing the map and manuscript or by providing helpful comments and assistance in various ways: H.N. Barton, H.R. Blank, Jr., P.H. Briggs, K.L. Cook, T.J. Kreidler, Mike Lowe, Craig Morgan, R. L. Turner, R.E. Van Loenen, and G.C. Willis.

REFERENCES CITED

Arabasz, W.J., Smith, R.B., and Richins, W.D., editors, 1979, Earthquake studies in Utah 1850 to 1978: Salt Lake City, Utah, University of Utah Seismograph Stations, Department of Geology and Geophysics, Salt Lake City, Utah, 548 p.

Anderson, R.E., and Mehnert, H.H., 1979, Reinterpretation of the history of the Hurricane fault in Utah: Rocky Mountain Association of Geologists - Utah Geological Association 1979 Basin and Range Symposium, p. 145-173.

Brandt, C.J., 1989, Petroleum, *in* Doelling, H.H., and Davis, F.D., 1989, The geology of Kane County, Utah--geology, mineral resources, geologic hazards: Utah Geological and Mineral Survey Bulletin 124, p. 115-123.

Brown, E.D., Arabasz, W.J., Pechmann, J.C., McPherson, Erwin, Hall, L.L., Oehmich, P.J., and Hathaway, G.H., 1986, Earthquake data for the Utah region, January 1, 1984 to December 31, 1985: Salt Lake City, Utah, University of Utah Seismograph Stations, Department of Geology and Geophysics, 83 p.

Bullock, J.H., Jr., Barton, H.N., Fey, David, and Kennedy, Kay, 1988, Analytical results and sample locality map of stream-sediment samples, heavy-mineral-concentrate samples, and rock samples from the Deep Creek, La Verkin Creek, North Fork Virgin River, Orderville Canyon, and Parunuweap Canyon Wilderness Study Areas, Kane and Washington Counties, Utah: U.S. Geological Survey Open-File Report 88-581, 26 p.

Cashion, W.B., Jr., 1961, Geology and fuel resources of the Orderville Glendale area, Kane County, Utah: U.S. Geological Survey Coal Investigations Map C-49, scale 1:62,500.

Cashion, W.B., Jr., 1967a, Geologic map of the south flank of the Markagunt Plateau, northwest Kane County, Utah: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-494, scale 1:62,500.

Cashion, W.B., Jr., 1967b, Carmel Formation of the Zion Park region, southwestern Utah--A review, *in* contributions to stratigraphy, 1966: U.S. Geological Survey Bulletin 1244-J, 9 p.

Cordova, R.M., 1981, Ground-water conditions in the Upper Virgin River and Kanab Creek basins area, Utah: Utah Department of Natural Resources, Division of Water Rights Technical Publication 70, 87 p.

Cross, Whitman, 1908, The Triassic portion of the Shinarump Group, Powell: Journal of Geology, v. 16, p. 97-123.

Doelling, H.H., and Davis, F.D., 1989, The geology of Kane County, Utah- geology, mineral resources, geologic hazards: Utah Geological and Mineral Survey Bulletin 124, 192 p.

Gilluly, James, and Reeside, J.B., Jr., 1926, Jurassic formations of eastern Utah: Geological Society of America Bulletin, v. 37, no. 1, p. 158-159.

Gregory, H.E., 1950, Geology and geography of the Zion National Park region of Utah and Arizona: U.S. Geological Survey Professional Paper 220, 200 p., 1 plate, scale 1:125,000.

Hintze, L.F., compiler, 1963, Geologic map of southwestern Utah: Utah State Land Board, scale 1:250,000.

Hintze, L.F., compiler, 1980, Geologic map of Utah: Utah Geological and Mineral Survey, scale 1:500,000.

Imlay, R. W., 1964, Marine Jurassic pelecypods from central and southern Utah, *in* contributions to paleontology, 1963: U. S. Geological Survey Professional Paper 483, p. C1-C42.

Kreidler, T.J., 1986, Mineral investigations of a part of the Canaan Mountain Wilderness Study Area, Kane and Washington Counties, Utah, and Mohave County, Arizona: U.S. Bureau of Mines Mineral Land Assessment Open-File Report MLA 43-86, 13 p.

McKee, E.D., editor, 1979, A study of global sand seas: U.S. Geological Survey Professional Paper 1052, 429 p.

Nava, S.J., Pechmann, J.C., Arabasz, W.J., Brown, E.D., Hall, L.L., Oehmich, P.J., McPherson, Erwin, and Whipp, J.K., 1990, Earthquake catalog for the Utah region, January 1, 1986 to December 31, 1988: Salt Lake City, Utah, University of Utah Seismograph Stations, Department of Geology and Geophysics, Salt Lake City, Utah, 96 p.

Padian, Kevin, 1989, Presence of the dinosaur *Scelidosaurus* indicates Jurassic age for the Kayenta Formation (Glen Canyon Group, northern Arizona): Geology, v. 17, p. 438-441.

Peterson, Fred, and Pipiringos, G.N., 1979, Stratigraphic relations of the Navajo Sandstone to Middle Jurassic formations, southern Utah and northern Arizona: U.S. Geological Survey Professional Paper 1035-B, 43 p.

Pillmore, C.L., 1956, Photogeologic map of the Springdale NE quadrangle, Kane County, Utah: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-148, scale 1:24,000.

Pipiringos, G.N., and O'Sullivan, R.B., 1978, Principal unconformities in Triassic and Jurassic rocks, western interior United States--a preliminary survey: U.S. Geological Survey Professional Paper 1035-A, p. A1-A29.

Price, Don, 1980, Map showing general chemical quality of surface water in the Alton-Kolob coal-fields area, Utah: U.S. Geological Survey Miscellaneous Investigations Map I-1235-A, scale 1:125,000.

Price, Don, 1981, Map showing general chemical quality of ground water in the Alton-Kolob coal-fields area, Utah: U.S. Geological Survey Miscellaneous Investigations Map I-1235-B, scale 1:125,000.

Price, Don, 1982, Map showing general availability of ground water in the Alton-Kolob coal-fields area, Utah: U.S. Geological Survey Miscellaneous Investigations Map I-1235-C, scale 1:125,000.

Price, Don, 1983, Map showing selected surface-water data for the Alton-Kolob coal-fields area, Utah: U.S. Geological Survey Miscellaneous Investigations Map I-1235-D, scale 1:125,000.

Richins, W.D., Arabasz, W. J., Hathoway, G.M., Oehmich, P.J., Sells, L.L., and Zandt, George, 1981, Earthquake data for the Utah region, July 1, 1978 to December 31, 1980: Salt Lake City, Utah, University of Utah Seismograph Stations, Department of Geology and Geophysics, 127 p.

Richins, W.D., Arabasz, W.J., Hathaway, G.M., McPherson, Erwin, Oehmich, P.J., and Sells, L.L., 1984, Earthquake data for the Utah region, January 1, 1981 to December 31, 1983: Salt Lake City, Utah, University of Utah Seismograph Stations, Department of Geology and Geophysics, 111 p.

Ryder, R.T., 1983, Petroleum potential of wilderness lands in Arizona, *in* Miller, B.W., editor, Petroleum potential of wilderness lands in the United States: U.S. Geological Survey Circular 902-A, p. C1-C22.

Sable, E.G., and Doelling, H.H., 1989, Geologic map of the Elephant Butte quadrangle, Kane County, Utah, and Mohave County,

Arizona: Utah Geological and Mineral Survey Geologic Map 126, scale 1:24,000, 10 p.

Sargent, K.A., and Philpott, B.C., 1987, Geologic map of the Kanab quadrangle, Kane County, Utah, and Mohave and Coconino Counties, Arizona: U.S. Geological Survey Geologic Quadrangle Map GQ-1603, scale 1:62,500.

Tapp, S.C., 1963, Kanab Creek unit area, Kane County, Utah *in* Heylmun, E.B., editor, Guidebook to the geology of southwestern Utah: Intermountain Association Petroleum Geologists, 12th Annual Field Conference Guidebook, p. 193-198.

Thompson, A.E., and Stokes, W.L., 1970, Stratigraphy of the San Rafael Group, southwest and south-central Utah: Utah Geological and Mineral Survey Bulletin 87, 54 p.

Van Loenen, R.E., Sable, E.G., Blank, H.R., Jr., Barton, H.N., Briggs, P.H., Zelten, J.E., and Cook, K.L., 1989, Mineral resources of eight wilderness study areas bordering Zion National Park, Washington and Kane Counties, Utah: U.S. Geological Survey Bulletin 1746-E, p. E1-E23.

Van Loenen, R.E., Sable, E.G., Blank, H.R., Jr., Barton, H.N., Cook, K.L., and Zelten, J.E., 1988b, Mineral resources of the Parunuweap Canyon Wilderness Study Area, Kane County, Utah: U.S. Geological Survey Bulletin 1746-B, p. B1-B18.

Van Loenen, R.E., Sable, E.G., Blank, H.R., Jr., Turner, R.L., Kreidler, T.J., Zelten, J.E., and Cook, K.L., 1988a, Mineral resources of the Canaan Mountain and the Watchman Wilderness Study Areas, Washington and Kane Counties, Utah: U.S. Geological Survey Bulletin 1746-A, p. A1-A21.

Zelten, J.E., 1987, Mineral investigation of eleven wilderness study areas adjacent to Zion National Park, southwestern Utah: U.S. Bureau of Mines Mineral Land Assessment Open-File Report MLA 77-87, 55 p.