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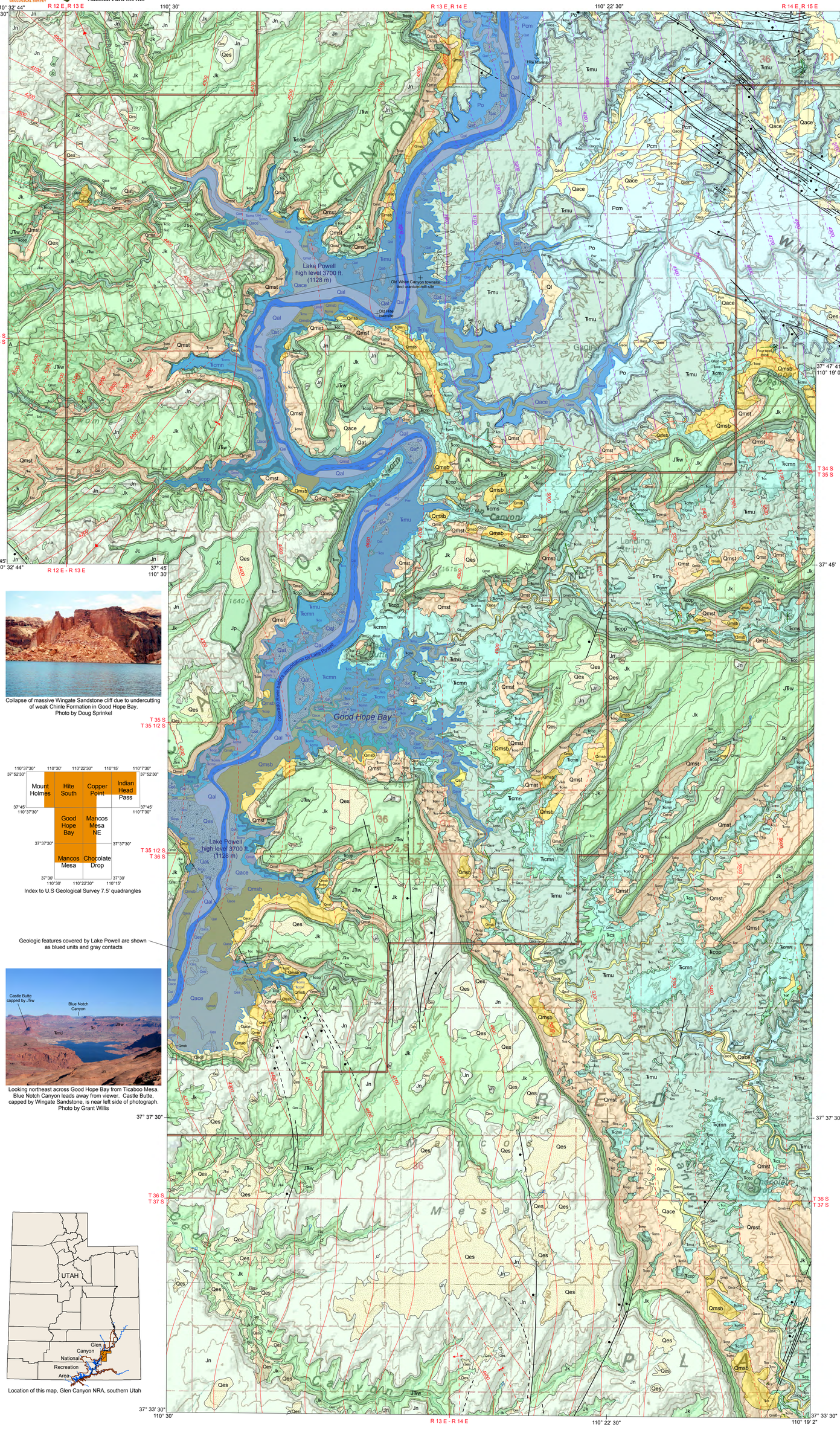


Geologic Map of the White Canyon-Good Hope Bay Area, Glen Canyon National Recreation Area, San Juan and Garfield Counties, Utah

by
Robert E. Thaden[1], Albert F. Trites, Jr.[1], Tommy L. Finnell[1], and Grant C. Willis[2]
[1]U.S. Geological Survey (in 1964) [2]Utah Geological Survey

2008

Digitized and modified from plate 1 in: Thaden, R.E., Trites, A.F., Jr., and Finnell, T.L., 1964, Geology and ore deposits of the White Canyon area, San Juan and G arfield Counties, Utah: U.S. Geological Survey Bulletin 1125, scale 1:48,000, 166 p.
Revised and added to by Grant C. Willis in 2005 -07.

Collapse of massive Wingate Sandstone cliff due to undercutting of weak Chinle Formation in Good Hope Bay.
Photo by Doug Sprinkel

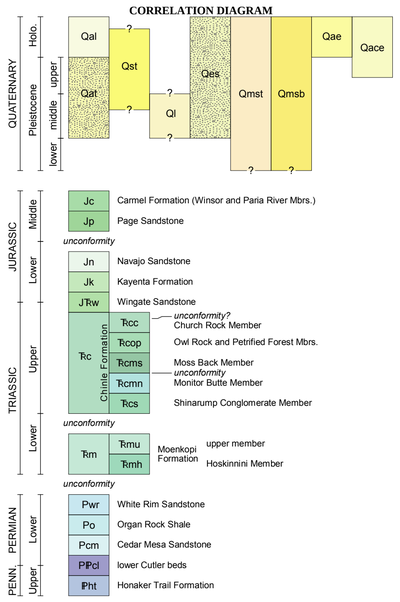
Index to U.S Geological Survey 7.5' quadrangles

Geologic features covered by Lake Powell are shown as blued units and gray contacts

Looking northeast across Good Hope Bay from Ticaboo Mesa. Blue Notch Canyon leads away from viewer. Castle Butte, capped by Wingate Sandstone, is near left side of photograph.
Photo by Grant Willis

Location of this map, Glen Canyon NRA, southern Utah

CORRELATION DIAGRAM



MAP EXPLANATION

Contact

Contact, covered by Lake Powell

High-angle normal fault – Bar and ball on downthrown side; dashed where approximately located; dotted where concealed

Paleo-channel fill in Chinle Formation – dashed where inferred

Anticline – Showing trace of the axial plane; approximately located

Syncline – Showing trace of the axial plane; dashed where approximately located; arrows show direction of plunge

Structural contours – Red contours drawn on top of Wingate Sandstone; purple contours drawn on top of Permian strata (mostly White Rim Sandstone, northern part of map) and on top of Triassic Hoskinnini Sandstone Member where present (northeastern part of map); dashed where projected; units are in feet above sea level. Contour interval 100 feet.

Boundary between structural contour datums

Line of cross section

Adit

Abandoned uranium mine

Prospect

Abandoned bore hole

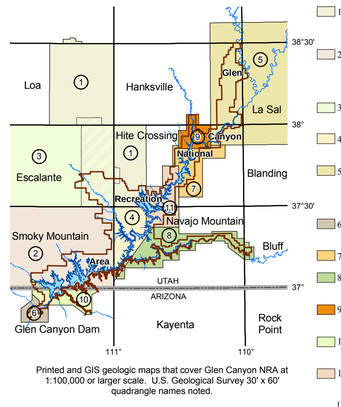
Spring

Glen Canyon National Recreation Area boundary

LITHOLOGIC COLUMN

SYSTEM	SERIES	GEOLOGIC UNIT		SYMBOL	THICKNESS Meters (Feet)		LITHOLOGY
JURASSIC	Middle	Carmel Formation (Paria River and Winsor Members)		Jc	30+ (100+)		Shallow marine - tidal flat; Eolian sandstone
		Page Sandstone		Jp	18-30 (60-100)		Judd Hollow Tongue?
	Lower	Glen Canyon Group	Navajo Sandstone	Jn	180-200 (590-660)		Massive eolian sandstone; Scattered interdunal carbonate lake deposits ("oasis")
			Kayenta Formation	Jk	56-90 (185-300)		Fluvial - lacustrine
			Wingate Sandstone	JTRw	85-95 (280-310)		Massive eolian sandstone
TRIASSIC	Upper	Chinle Formation	Church Rock Member	TRcc	25-60 (83-200)	180-240 (600-800)	Possible unconformity
			Owl Rock and Petrified Forest Members	TRcop	85-160 (280-520)		Stacked paleosols; Abundant landslides; Fluvial - lacustrine; Abundant smectite (swelling) clays from volcanic terrain in Arizona and California
			Moss Back Member	TRcms	0-60 (0-200)		Fluvial
			Monitor Butte Member	TRcmn	36-75 (120-250)		Greenish-gray fluvial - lacustrine
			Shinarump Congl. Mbr.	TRcs	0-24 (0-80)		Discontinuous fluvial
	M_ Lower	Moenkopi Formation	upper member	TRmu	53-67 (175-220)	53-114 (175-375)	Dark-red-brown tidal flat
			Hoskinnini Member	TRmh	0-30 (0-100)		Hoskinnini only on east side of map area-- scattered coarse grains and weak wavy bedding
PERMIAN	Lower		White Rim Sandstone	Pwr	0-6 (0-20)		Prominent white sandstone cliff
		Cutler Group	Organ Rock Shale	Po	67-107 (220-350)		Prominent pink sandstone marker bed; Fluvial - lacustrine; Broad bench with roads
			Cedar Mesa Sandstone	Pcm	290-300 (980-1000)		Massive eolian sandstone with few red-bed partings
?	?		lower Cutler beds (Halgaito Formation)	IPPcl	115-140 (375-460)		Red beds; Thin limestone beds
PENNSYLVANIAN	Upper	Hermosa Group	Honaker Trail Formation	IPht	120+ (400+) exposed; 355 (1165) (nearby drill hole)		Sandstone and fossiliferous limestone; Approximate high lake level at east side of Mille Craig Bend

See text for unit descriptions



Printed and GIS geologic maps that cover Glen Canyon NRA at 1:100,000 or larger scale. U.S. Geological Survey 30' x 60' quadrangle names noted.

1 Billingsley, G.H., Huntoon, P.W., and Breed, W.J., 1987, Geologic map of Capitol Reef National Park and vicinity, Emery, Garfield, Kane, and Wayne Counties, Utah: Utah Geological and Mineral Survey Map 87, scale 1:62,500. Geographic Information System (GIS) data - http://science.nature.nps.gov/nrdata/datastore.cfm?ID=39074; digital map image - http://geology.utah.gov/maps/geomap/parkmaps/pdf/M-87.pdf.

2 Doelling, H.H. and Willis, G.C., 2006, Geologic map of the Smoky Mountain 30'x 60' quadrangle, Kane and San Juan Counties, Utah, and Coconino County, Arizona: Utah Geological Survey Map 213, 2 plates, scale 1:100,000. GIS data - UGS Map 213DM published in 2008.
Also see: 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 (also published separately as UGMS Map 121), 192 p., 10 plates, scale 1:100,000.

3 Doelling, H.H., and Willis, G.C., 1999, Interim geologic map of the Escalante and parts of the Loa and Hite Crossing 30' x 60' quadrangles, Garfield and Kane Counties, Utah: Utah Geological Survey Open-File Report 368, 19 p., 2 plates, scale 1:100,000.

4 Doelling H.H. and Willis G.C., 2008, Geologic map of the lower Escalante River area, Glen Canyon National Recreation Area, eastern Kane County, Utah: Utah Geological Survey Miscellaneous Publication 06-3DM (GIS data), 8 p., 1 plate, scale 1:100,000.

5 Huntoon, P.W., Billingsley, G.H., Jr., and Breed, W.J., 1982, Geologic map of Canyonlands National Park and vicinity, Utah: Moab, Utah, Canyonlands Natural History Association, scale 1:62,500. GIS data - http://science.nature.nps.gov/nrdata/datastore.cfm?ID=38974.
Also see: Doelling, H.H., 2004, Geologic map of the La Sal 30' x 60' quadrangle, San Juan County, Utah: Utah Geological Survey Map 205, 2 plates, scale 1:100,000. GIS data - UGS Map 205DM published in 2006.

6 Phoenix, D.A., in press, Geologic map of part of the Lees Ferry area, Glen Canyon National Recreation Area, Coconino County, Arizona (digitized and modified from plate 1 of U.S. Geological Survey Bulletin 1137, 86 p., scale 1:24,000, published in 1963): Utah Geological Survey Miscellaneous Publication (GIS data), scale 1:24,000.

7 This map.

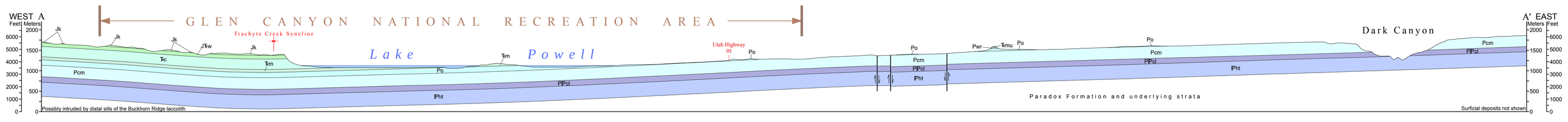
8 Willis, G.C., 2004, Interim geologic map of the lower San Juan River area, eastern Glen Canyon National Recreation Area and vicinity, San Juan County, Utah: Utah Geological Survey Open-File Report 443DM (GIS data), scale 1:50,000.

9 Willis, G.C., in press, Geologic map of the Hite Crossing – Lower Dirty Devil River area, Glen Canyon National Recreation Area, Garfield and San Juan Counties, Utah: Utah Geological Survey Miscellaneous Publication (GIS data), scale 1:50,000.

10 Willis, G.C., in press, Geologic map of the Glen Canyon Dam area, Glen Canyon National Recreation Area, Arizona and Utah: Utah Geological Survey Miscellaneous Publication (GIS data), scale 1:24,000.

11 Willis, G.C., in preparation, Interim geologic maps of the Bullfrog, Halls Crossing, Halls Crossing NE, Ticaboo Mesa, and Knowles Canyon quadrangles, Glen Canyon National Recreation Area, Garfield and San Juan Counties, Utah: Utah Geological Survey Open-File Reports, scale 1:24,000.

[Printed and GIS database files for UGS maps available at: Utah Department of Natural Resources Map and Bookstore: email: bookstore@utah.gov; phone: (801) 537-3320; and at Utah Geological Survey website at geology.utah.gov]



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11½°
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 2008

SCALE 1:100,000
Plot scale 1:48,000
This plot was enlarged from the 1:100,000-scale GIS data to show the detail of the original source map, which was published at 1:48,000 scale; during conversion to a digital GIS database, the geology was revised to fit the USGS 1:100,000-scale map series because a 1:48,000-scale base map is not available in a digital form; spatial accuracy is commensurate with 1:100,000 scale

0 0.5 1 2 3 4 5 6 7 8 MILE
0 5000 10000 15000 20000 25000 30000 35000 40000 FEET
0 0.5 1 2 3 4 5 6 7 8 9 10 KILOMETER

CONTOUR INTERVAL 50 METERS
STRUCTURAL CONTOUR INTERVAL 100 FEET

Geology of original source map by R. E. Thaden, A. F. Trites Jr., T. L. Finnell, W. E. Benson, E. P. Beroni, H. A. Hubbard, C. F. Lough, J. C. Feagar, R. B. Morrison, L. C. Huff, J. D. Sears, and T. G. Fails, assisted by E. J. Ostling, G.A. Hadd, J. C. Stimson, and G. E. Wales, 1951-54

Base from U.S.G.S. Hite Crossing (1980) 30'x60' quadrangle
Projection: UTM Zone 12 Units: Meters
Datum: Nad 1927 Spheroid: Clarke 1866

Project Manager: Bob Biek
GIS Analysts: J. Buck Ehler, Daryl Greer, and Pat Speranza
Cartographer: J. Buck Ehler

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2008

Scale 1:100,000

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Utah Geological Survey Miscellaneous Publication 08-3DM

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For use at 1:100,000 and smaller scales. Though the source map is 1:48,000-scale, these files were modified to fit the U.S. Geological Survey 1:100,000-scale 30'x60' quadrangle topographic map and may not be spatially accurate at larger scales. The Utah Geological Survey does not guarantee accuracy or completeness of data.

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The projection of the geospatial data included on this compact disc is UTM Zone 12, North American Datum 1927, and spheroid Clarke 1866. The units are in meters.

Citation

Please use this citation in bibliographies:

Thaden, R.E., Trites, A.F.,Jr., Finnell, T.L., and Willis, G.C., 2008, Geologic map of the White Canyon-Good Hope Bay area, San Juan and Garfield Counties, Utah (digitized and modified from U.S. Geological Survey Bulletin 1125, published in 1964): Utah Geological Survey Miscellaneous Publication 08-3DM, GIS data, CD-ROM, scale 1:100,000.

Description of Map Units

[map units are partially modified from the original source to match current Utah Geological Survey units and formats; however, some differences with normal UGS units still exist]

Quaternary

Qal **Alluvium** (Holocene) — Stream-deposited silt, sand, and pebble- to boulder-gravel; poorly to moderately sorted and rounded in ephemeral stream channels and moderately to well sorted and rounded along the Colorado River; deposits in ephemeral stream channels locally include alluvial fan, colluvial, and eolian deposits; 0 to 10 meters (0-30 ft) thick.

Qat **Alluvial terrace gravel deposits** (Holocene to middle Pleistocene) — Pebble- to cobble-gravel with less common boulders, sand, and silt deposited by rivers and streams and preserved as terraces; moderately to well sorted and rounded; clasts are mostly quartzite, chert, and igneous rocks, and less common sandstone, limestone, and gneiss (along Colorado River); clasts are better rounded and sorted than local alluvial deposits, and were derived primarily from outside the map area, but include small amounts of poorly sorted, locally derived sediment from side channels and adjacent slopes; mapped along Colorado River and larger streams; locally partially mantled by thin eolian sand; forms terraces at several levels up to about 90 meters (300 ft) above the modern channel; 0 to 10 meters (0-30 ft) thick.

Age of terrace gravel and correlative deposits – Rare volcanic ash beds, basalt flows, strath terrace and pediment deposits, and other dateable materials in surficial deposits in the Colorado River basin provide a means to calculate average regional incision rates of the major rivers, and by inference, to estimate ages of river terrace and correlative deposits. Published rates vary significantly from about 0.16 meters (0.5 ft) to about 0.5 meters (1.6 ft) per thousand years (table 1). Inferred ages of the deposits are only rough estimates because of the published rates vary significantly, dateable materials are rare, some data come from sites over 160 kilometers (100 miles) away, interpretation of data is commonly debatable, and incision rates probably varied over time. However, the data still yield useful estimates. Using these rates, river terrace gravels about 90 m (300 ft) above the modern riverbed (now under the lake) were deposited between about 500,000 and 190,000 years ago. These rates cannot be applied to low-level deposits near the modern river because short-term cut-and-fill cyclicity of the river probably significantly skews relative elevations, and thus calculated ages of these young deposits (for example, some low-level terrace gravels may be as young as Holocene though their elevation would place them in the Pleistocene).

Qae **Alluvial and eolian deposits** (Holocene) — Mostly small boulder- to pebble-gravel, sand, silt, and clay deposited in small drainages and mixed with or covered by minor to moderate amounts of windblown sand and silt; poorly to moderately sorted and poorly rounded to subangular; locally include minor colluvium and angular rubble from rock falls, landslides, and debris flows; clast composition reflects local lithologies; mapped in small washes where it includes deposits in active part of wash bottom to about 12 meters (40 ft) above wash floor; 0 to 6 meters (0-20 ft) thick.

Table 1. Selected published calculated incision rates of the Colorado River and major tributaries (eastern Grand Canyon rates are probably most applicable to Glen Canyon NRA)

Average calculated incision rate (per 1000 years)	Time interval forming basis for calculation	Location	References
0.79 feet (0.24 m)	3 million years	Glenwood Springs, Colorado	Kirkham and others, 2001; and references cited therein
0.59 feet (0.18 m)	620,000 years	Westwater Canyon northeast of Moab, Utah	Willis, 1992, 1994; Willis and Biek, 2001
1.25 to 1.57 feet (0.38-0.48 m)	189,000 years	Fremont River about 80 miles (130 km) upstream of Lake Powell	Marchetti and Cerling, 2001
0.36 feet (0.11 m)	1.4 million years	Bluff, about 30 miles (50 km) east of the eastern part of the map area	Wolkowinsky and Granger, 2004
1.6 feet (0.5 m)	500,000 years	Navajo Mountain pediments near Glen Canyon	Hanks and others, 2001
0.46 feet (0.14 m) 0.24-0.30 feet (0.07-0.09 m)	500,000 years 600,000 years	Eastern Grand Canyon Western Grand Canyon	Pederson and others, 2002
1.31 feet (0.4 m)	500,000 years	Eastern Grand Canyon	Davis and others, 2001
1.02 to 1.6 feet (0.31-0.5 m)	600,000 years	Eastern Grand Canyon	Lucchitta and others, 2001
0.49-0.5 feet (0.15-0.18 m) 0.16-0.25 feet (0.05-0.075 m)	500,000 years 720,000 years	Eastern Grand Canyon Western Grand Canyon	Karlstrom and others, 2007
0.54-1.35 feet (0.166-0.411 m) 0.18-0.4 feet (0.055-0.123 m)	3.7 million years 17 million years	Eastern Grand Canyon Western Grand Canyon	Polyak and others, 2008

Qace **Mixed alluvial fan, colluvial, and eolian deposits** (Holocene to upper Pleistocene) — Poorly to moderately sorted large boulders with interstitial sand to clay deposited as alluvial fan, ephemeral stream, and colluvial deposits on low-relief slopes and benches, in areas where gullies, washes, and small stream channels reduce gradient as they cross from more-resistant to less-resistant bedrock units, and in poorly developed terraces along ephemeral streams; sparsely to moderately mantled by eolian sand in some areas; includes mixed alluvial-fan, debris-flow, slope-creep, slope-wash, eolian, and ephemeral-stream deposits; common on slopes below cliff- and ledge-forming units; distal parts commonly have more eolian cover and are gradational with eolian sand deposits (Qes); 0 to 10 meters (0-30 ft) thick.

Qst **Tufa** (Holocene(?) to middle Pleistocene(?) — Pale-gray, yellowish-gray, and reddish-gray, vuggy, calcareous tufa deposited by springs; cements bedrock and talus rubble, colluvium, and other surficial deposits; mapped in small area in lower Red Canyon where adheres to canyon walls and caps small knolls; 0 to 5 meters (0-15 ft) thick.

Ql **Lacustrine deposits** (middle(?) Pleistocene) — Thinly laminated, poorly consolidated silt and very fine sand; deposited in abandoned meander channel of the Colorado River in lake probably formed by landslide deposits; partly blanketed by loose eolian silt and sand; 0 to 10 meters (0-30 ft) thick.

Qes **Eolian sand** (Holocene to middle Pleistocene) — Very well-sorted, well-rounded, mostly fine- to medium-grained, frosted quartz sand derived from the weathering of sandy bedrock; deposited by wind in sheets, mounds, and small dunes in protected areas on benches and slopes; locally includes minor alluvial and colluvial deposits; locally reworked by water; 0 to 15 meters (0-45 ft) thick.

Qmst **Mass-movement landslide and talus deposits** (Holocene to lower(?) Pleistocene) — Sand- to large boulder-size rock fragments that have slid down slopes, and rock-fall debris that forms talus veneer on and at the base of steep slopes; similar to and gradational with slump block deposits (Qmsb) except that individual blocks are generally smaller and deposits are more chaotic; poorly to moderately cemented; most common on the Chinle Formation, but also on other slope-forming units; thickness highly variable but generally less than 30 meters (90 ft).

Qmsb **Mass-movement slump blocks** (Holocene to lower(?) Pleistocene) — Intact to partially intact blocks of rock as much as 2.7 kilometers (1.5 mi) long that have slumped down-slope; most common are Wingate Sandstone blocks that have slid on the Chinle Formation, but other formations locally involved; blocks are commonly rotated backwards and dip toward the nearby cliff; thickness highly variable.

Unconformity

Jurassic

Jc **Carmel Formation, undivided** (combined Paria River and Winsor Members) (Middle Jurassic) —Upper part (Winsor Member) is mostly medium- to dark-reddish-brown to brown, slope-forming, earthy-weathering, silty sandstone and siltstone intercalated with sporadic irregular beds of very pale yellowish-gray, calcareous, fine-grained sandstone that is locally gypsiferous; lower part (Paria River Member) is mostly dark-reddish-brown siltstone and silty sandstone with a few tan to brown, fine-grained sandstone beds capped by silty to sandy, pale-gray to pink, chippy-weathering limestone; lower contact is gradational and laterally variable and is picked at top of eolian sandstone-dominated interval; deposited in shallow-marine, sabkha, and tidal-flat environment near southeast side of an inland sea (Peterson, 1994); bedding is commonly slightly warped to locally strongly contorted (probably due to loading and foundering of the overlying Entrada Sandstone before lithification, and to dissolution and movement of gypsum); top not preserved in map area but small remnants of foundered Entrada Sandstone may be present in uppermost part of map unit; in Glen Canyon area upper part (Winsor) is typically 18 to 45 meters (60-150 ft) thick, and lower part (Paria River) is 15 to 20 meters (50-70 ft) thick; in this map area only erosional remnants up to about 30 meters (100 ft) preserved.

Jp **Page Sandstone** (Middle Jurassic) — Pale-yellow to pale-reddish-brown, thick- to massive-bedded, large-scale cross-bedded, fine-to medium-grained sandstone interbedded with reddish-brown, planar- to lenticular-bedded siltstone and reddish-brown to grayish-orange, thin-bedded, fine-grained sandstone; sand grains are mostly well-rounded and frosted; in most areas consists of a massive, cliff-forming sandstone bed overlain by slope-forming thin siltstone beds (possibly Judd Hollow Tongue) and then overlain by a laterally variable interval of less-resistant, cross-bedded eolian sandstone; lower unconformable contact is sharp to obscure, planar to slightly undulating, beveled unconformable surface commonly marked by evidence of bioturbation, mudcracks, and rare lag of slightly coarser sand grains with scattered angular chert clasts up to about 1 centimeter (0.4 in) in diameter; the Page was deposited in an eolian erg environment, but the interbedded finer-grained intervals show sabkha, ephemeral stream, and tidal flat influence (Blakey, 1994; Jones and Blakey, 1997); typically 18 to 30 meters (60-100 ft) thick.

Unconformity

Jn **Navajo Sandstone** (Lower Jurassic) — Pale-yellowish-gray to reddish-orange, massive, cross-bedded eolian sandstone with fine- to medium-grained, well-rounded, frosted quartz grains; interlayered horizontal and cross-bedding near base; has local limestone, dolomite, and siltstone interdunal lenses up to 6 meters (20 ft) thick and up to 5 kilometers (3 mi) long; forms massive rounded cliffs and domes; gradational with underlying Kayenta Formation; main part deposited in large sand desert (erg) with local interdunal playas (oasis-like setting), basal part deposited in sabkha with abundant wind-blown sand; 180 to 200 meters (590-660 ft) thick.

Jk **Kayenta Formation** (Lower Jurassic) — Pale-reddish-brown to purplish-red, lenticular, planar- to cross-bedded, fine- to medium-grained sandstone and silty sandstone with a few thin lenses of intraformational conglomerate, claystone, limestone, and siltstone; weathers to alternating cliffs and steep slopes; deposited in fluvial-lacustrine environment with abundant eolian input (Peterson, 1994); lower contact is sharp to interfingering; 56 to 90 meters (185-300 ft) thick.

Jurassic-Triassic

JTRw **Wingate Sandstone** (Lower Jurassic to Upper Triassic) — Reddish-brown, massive, fine-grained, cross-bedded, eolian sandstone with well-rounded, frosted quartz grains, and with rare lenses of silty sandstone; forms massive vertical cliff; 85 to 95 meters (280-310 ft) thick.

Triassic

Chinle Formation (Upper Triassic) — Divided into five map units in original source (Thaden and others, 1964) – commonly accepted names (Stewart and others, 1972a) are herein applied to these units; deposited in fluvial-lacustrine and floodplain environments (Lucas, 1993; Lucas and others, 1997); generally 180 to 240 meters (600-800 ft) thick, but locally thicker; Lucas (1993) proposed elevating the Chinle to group status, but that change has not been formally completed.

TRcc **Church Rock Member of Chinle Formation** (Upper Triassic) ("siltstone-sandstone unit" in original text, Thaden and others, 1964) — Pale- to moderate-reddish-brown, irregularly

laminated to cross-bedded, interbedded, fine- to coarse-grained sandstone and siltstone; weathers to alternating steep slopes and cliffs; in the southwestern part of the map area the unit is capped by a 9- to 12-meter (30-40 ft) thick bed of coarse conglomeratic and arkosic purplish-red sandstone called the Hite bed of Stewart and others (1959) and Stewart and others (1972a); the base of the Hite bed may be an unconformity with the upper part of the Church Rock Member gradational with the overlying Wingate Sandstone; 25 to 60 meters (83-200 ft) thick.

TRcop **Owl Rock and Petrified Forest Members of Chinle Formation** (Upper Triassic) ("limy unit" in original text, Thaden and others, 1964) — Upper part (Owl Rock Member) is dominantly very pale-red, gray, and pale-green claystone and limestone that contains some limestone breccia and is primarily stacked alluvial-plain paleosols (fossil soil); lower part (Petrified Forest Member) is dominantly variegated purple, red, gray, green, and yellow, smectitic and silicic claystone interbedded with resistant siltstone and medium-grained to locally pebbly sandstone beds, and was deposited in a fluvial-floodplain-lacustrine environment sourced by volcanic terrains to the southwest; weathers to a steep slope; commonly develops massive landslides that involve overlying units; 85 to 160 meters (280-520 ft) thick.

TRcms **Moss Back Member of Chinle Formation** (Upper Triassic) — Gray to pale-orange, lenticular, cross-bedded, fine- to coarse-grained sandstone and thin lenses and beds of siltstone and pebble conglomerate; deposited in a broad fluvial channel system; forms cliff to steeply ledgy slope; 0 to 60 meters (0-200 ft) thick; averages about 15 meters (50 ft) thick.

Unconformity

TRcmn **Monitor Butte Member of Chinle Formation** (Upper Triassic) ("mudstone-sandstone unit" in original text, Thaden and others, 1964) — Pale-greenish-gray to reddish-gray, variegated mudstone with many lenticular, cross-stratified, gray, red, and yellowish-gray sandstone and conglomeratic sandstone beds; locally includes beds below Moss Back that are similar in lithology and color to Petrified Forest strata; forms steep slope with small cliffs; deposited in fluvial-lacustrine environment (higher energy than Petrified Forest Member); map unit may locally include thin unmapped lenses of Shinarump Conglomerate Member; unconformably overlies Meonkopi Formation where Shinarump not present; 36 to 75 meters (120-250 ft) thick.

TRcs **Shinarump Conglomerate Member of Chinle Formation** (Upper Triassic) — Gray- to yellowish-gray, lenticular, cross-bedded, fine-grained to pebbly conglomeratic sandstone with lenses and beds of mudstone; only present in a few areas where basal fluvial channels of Chinle unconformably overlie and are cut into Moenkopi Formation; locally contains uranium and copper deposits; forms prominent ledge; 0 to 24 meters (0-80 ft) thick; averages about 5 meters (15 ft) thick.

Unconformity

TRm **Moenkopi Formation** (Lower Triassic) — Deposited in tidal-flat, sabkha, and low coastal-plain environments (Dubiel, 1994); 53 to 114 meters (175-375 ft) thick, averaging about 90 meters (300 ft).

TRmu **Upper member of Moenkopi Formation** (Lower Triassic) — Consists of three to four distinct intervals (Stewart and others, 1972b); basal interval is gray, yellowish-brown, and reddish-brown, poorly to moderately sorted, angular to subrounded limestone- and chert-pebble conglomerate 0 to about 3 meters (10 ft) thick; second and fourth intervals are dominantly medium- to dark-reddish-brown, slope-forming siltstone and sandstone with a few thin resistant ledges of fine-grained sandstone; third interval is series of lenticular, medium-reddish-brown to pale-orange, ledge- to ledgy cliff-forming, very fine grained sandstone beds interstratified with reddish-brown siltstone and calcareous sandstone; contains few thin limestone beds; deposited in tidal flat 53 to 67 meters (175-220 ft) thick.

TRmh **Hoskinnini Sandstone Member of Moenkopi Formation** (Lower Triassic) — Pale- to moderate-reddish-brown to grayish-orange, very fine to coarse-grained sandstone; only present near east side of map area where it forms knobby cliff; characterized by medium to coarse quartz grains scattered through the fine-grained sandstone and siltstone beds and by unusually poorly developed stratification with thin indistinct wavy lamination (Stewart and others, 1972b); interfingers with upper member (TRmu) between thin conglomerate interval and lower slope-forming interval where both members are present; deposited in a sabkha environment with abundant siliciclastic input (Dubiel, 1994); filled paleo-lows carved into the unconformably underlying Organ Rock Shale; 0 to about 30 meters (0-100 ft) thick.

Unconformity

Permian

Pwr **White Rim Sandstone** (part of Cutler Group) (Lower Permian) — Yellowish-orange, cross-bedded, very fine grained, silty sandstone; deposited in eolian environment; forms a cliff and broad bench and is a prominent marker bed throughout the region; 0 to about 6 meters (0-20 ft) thick; thickens to north; pinches out to south and southeast.

Po **Organ Rock Shale** (part of Cutler Group) (Lower Permian) — Reddish-brown and grayish-red, horizontally bedded, micaceous siltstone alternating with fine- to medium-grained sandstone; in northwestern part of map area, middle part of unit consists of a series of reddish-brown siltstone beds interbedded with and grading laterally into one or more very prominent light-brownish-pink, trough cross-bedded, medium-grained sandstone beds; much less resistant than Cedar Mesa Sandstone – forms broad slope or bench that gradually steepens up-section to form steep ledgy slopes and small cliffs where protected by overlying unit; deposited in floodplain environment with abundant paleosols and local eolian dunes (Huntoon and others, 2003); local 67 to 107 meters (220-350 ft) thick.

Pcm **Cedar Mesa Sandstone** (part of Cutler Group) (Lower Permian) — Light-grayish-orange, cross-bedded, fine-grained sandstone interbedded with lenses of reddish-brown to grayish-green sandy siltstone that increase in upper part; convoluted bedding common; weathers to massive cliffs with scattered ledges at siltstone beds and topped by a very broad bench due to erosion of Organ Rock Shale; deposited in eolian environment occasionally overrun by small rivers or streams,

floodplains, and playas (Huntoon and others, 2003); about 290 to 300 meters (980-1000 ft) thick.

Permian-Pennsylvanian

Permian-Pennsylvanian boundary. *The position of the Permian-Pennsylvanian boundary is debatable in southeastern Utah. Condon (1997) indicated that the time boundary is within the lower part of his "lower Cutler beds," the former Rico Formation of this area. Stevenson (2003) discussed the Permian-Pennsylvanian question and indicated that recent data place the time boundary within the lower part of the Cedar Mesa Sandstone. This map follows Condon (1997), though more work is required to resolve this question.*

PIPcl **Lower Cutler beds** (part of Cutler Group) (Lower Permian, but may include Upper Pennsylvanian strata near base) (Rico Formation in original text [Thaden and others, 1964]; Halgaito Shale in Huntoon and others [1982] map of Canyonlands National Park area to northeast; Condon [1997] recommended using "lower Cutler beds" for this interval; Doelling [2004, 2006] also used "lower Cutler beds" northeast of this map area) — Pale-pinkish-orange to pale-yellowish-gray, thin- to thick-bedded, lenticular, fine- to coarse-grained sandstone; alternating light and dark sandstone beds give unit a banded appearance; has increasingly abundant limestone beds to northeast (Huntoon and others, 1982); Thaden and others (1964) reported that no limestone beds were seen within the map area; however, Condon (1997) noted that the unit at Dark Canyon (northeast corner of map) is similar to the type locality near the confluence of the Green and Colorado Rivers where limestone is common, and that limestone is seen in many well logs near the map area; forms a ledgy slope; deposited in tidal flat, delaic, eolian, and shallow marine environments (Condon, 1997; Anderson and others, 2003; Huntoon and others, 2003); about 115 to 140 meters (375-460 ft) thick.

Pennsylvanian

IPht **Honaker Trail Formation** (part of Hermosa Group) (Upper Pennsylvanian) (Hermosa Formation in original text, Thaden and others, 1964) — Only upper part of formation is exposed, which is dark-gray to grayish-brown, thick-bedded limestone interstratified with thin beds of sandstone and limy sandstone; weathers to cliffs separated by short slopes; upper bed is a prominent dark-grayish-brown limestone 4 to 6 meters (12-20 ft) thick that forms a bench beneath slope-forming lower Cutler beds; deposited in a cyclic marine environment (Wengerd, 1963, Ritter and others, 2002; Stevenson, 2003); maximum of about 120 meters (400 ft) exposed, but a drill hole in a fork of Dark Canyon just east of the map area penetrated 355 meters (1165 ft) of probable Honaker Trail strata (Thaden and others, 1964).

Hite, Hite Crossing, and White Canyon

The northwestern part of this map, the area where Trachyte Wash and White Canyon join the Colorado River, has a long history. Until 1966, a site near the mouth of Trachyte Wash was the only "good" natural crossing of the Colorado River (due to the weak nature of the Organ Rock

Shale and Moenkopi Formation, and to North Wash and the White River canyons that created well-graded routes cut through cliffs common in other areas) for 300 miles (480 km) between Moab, Utah and Lees Ferry, Arizona (McCourt, 2003) (there were also three "difficult" crossing sites, all within Glen Canyon National Recreation Area: Halls Crossing, Hole-in-the-Rock, and Crossing of the Fathers). Native Americans, probable early Spanish traders, trappers, early settlers, ranchers, miners, and other travelers followed North Wash to the river (just north of the map border), and then traveled downstream a short distance to a wide calm spot near the old Hite town site where they swam horses and floated goods across the river; the route continued east near the White River on the White Rim Sandstone. This site became known as Hite Crossing, named for Cass Hite, a gold miner who settled at the site in 1883 and who worked flour gold from the river gravel bars. Arth Chaffin built a ferry at Hite Crossing in 1946 that he operated until 1966 (last two years at a temporary location near North Wash as Lake Powell waters flooded the landings at the original site) when the Utah Highway 95 bridges over the Colorado and Dirty Devil Rivers were completed. Hite and White Canyon, on opposite sides of the river near the old crossing, became temporary "boomtowns" during the uranium boom in the early 1950s. A uranium mill operated at White Canyon for a few years (most tailings were hauled to other sites and the remnants were buried before the lake flooded the area). Hite and Hite Marina, shown on this map, borrow their names from the old crossing and town, which are now under Lake Powell. The name "Hite Crossing" was "moved" to the Highway 95 bridge over the Colorado River just north of this map (shown on Willis, in press [a]).

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References Cited

Anderson, P.B., Chidsey, J.C., Jr., Sprinkel, D.A., and Willis, G.C., 2003, Geology of Glen Canyon National Recreation Area, Utah-Arizona, *in* Sprinkel, D.A., Chidsey, T.C., Jr., and Anderson, P.B., editors, Geology of Utah's parks and monuments, 2nd edition: Bryce Canyon Natural History Association and Utah Geological Association Millennial Guidebook Publication 28, p. 301-336.

Billingsley, G.H., Huntoon, P.W., and Breed, W.J., 1987, Geologic map of Capitol Reef National Park and vicinity, Emery, Garfield, Kane, and Wayne Counties, Utah: Utah Geological and Mineral Survey Map 87, scale 1:62,500.

Blakey, R.C., 1994, Paleogeographic and tectonic controls on some Lower and Middle Jurassic erg deposits, Colorado Plateau, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region, U.S.A.: Denver, Colorado, Rocky Mountain Section SEPM (Society for Sedimentary Geology), p. 273-298.

Condon, S.M., 1997, Geology of the Pennsylvanian and Permian Cutler Group and Permian Kaibab Limestone in the Paradox Basin, southeastern Utah and southwestern Colorado: U.S. Geological Survey Bulletin 2000-P, 46 p.

Davis, S.W., Davis, M.E., Luchitta, I., Hanks, T.C., Finkel, R.C., and Caffee, M., 2001, Erosional history of the Colorado River through Glen and Grand Canyons, *in* Young, R.A., and Spamer, E.E., editors, Colorado River origin and evolution: Grand Canyon, Arizona, Grand Canyon Natural History Association, symposium volume, p. 135-140.

Doelling, H.H., 2004, Geologic map of the La Sal 30'x60' quadrangle, San Juan, Wayne, and Garfield Counties, Utah, and Montrose and San Miguel Counties, Colorado: Utah Geological Survey Map 205, 2 plates, scale 1:100,000.

Doelling, H.H., 2006 (digital release), Geologic map of the La Sal 30'x60' quadrangle, San Juan, Wayne, and Garfield Counties, Utah, and Montrose and San Miguel Counties, Colorado: Utah Geological Survey Map 205DM, 2 plates, GIS data, CD-ROM, scale 1:100,000.

Doelling, H.H., and Willis, G.C., 1999, Interim geologic map of the Escalante and parts of the Loa and Hite Crossing 30'x 60' quadrangles, Garfield and Kane Counties, Utah: Utah Geological Survey Open-File Report 368, 19 p., 2 plates, scale 1:100,000.

Doelling, H.H. and Willis, G.C., 2006, Geologic map of the Smoky Mountain 30' x 60' quadrangle, Kane and San Juan Counties, Utah, and Coconino County, Arizona: Utah Geological Survey Map 213, 2 plates, scale 1:100,000; GIS data - UGS Map 213DM published in 2008.

Doelling, H.H., and Willis, G.C., 2008, Geologic map of the lower Escalante River area, Glen Canyon National Recreation Area, Eastern Kane County, Utah: Utah Geological Survey Miscellaneous Publication 06-3DM, 8 p., 1 plate, scale 1:100,000.

Dubiel, R.F., 1994, Triassic deposystems, paleogeography, and paleoclimate of the western interior, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region, U.S.A.: Denver, Colorado, Rocky Mountain Section SEPM (Society for Sedimentary Geology), p. 133-168.

Hanks, T.C., Luchitta, I., Davis, S.W., Davis, M.E., Finkel, R.C., Lefton, S.A., and Garvin, C.D., 2001, The Colorado River and the age of Glen Canyon, *in* Young, R.A., and Spamer, E.E., editors, Colorado River origin and evolution: Grand Canyon, Arizona, Grand Canyon Natural History Association, symposium volume, p. 129-134.

Huntoon, P.W., Billingsley, G.H., Jr., and Breed, W.J., 1982, Geologic map of Canyonlands National Park and vicinity, Utah: Moab, Utah, Canyonlands Natural History Association, scale 1:62,500.

Huntoon, J.E., Stanesco, J.D., Dubiel, R.F., and Dougan, J., 2003, Geology of Natural Bridges National Monument, Utah, *in* Sprinkel, D.A., Chidsey, T.C., Jr., and Anderson, P.B., editors, Geology of Utah's parks and monuments, 2nd edition: Bryce Canyon Natural History Association and Utah Geological Association Millennial Guidebook Publication 28, p. 233-249.

Karlstrom, K.E., Crow, R.S., Peters, L., McIntosh, W., Raucci, J., Crossey, L.J., Umhoefer, P., and Dunbar, N., 2007, $^{40}Ar/^{39}Ar$ and field studies of Quaternary basalts in Grand Canyon and model for carving Grand Canyon – quantifying the interaction of river incision and normal faulting across the western edge of the Colorado Plateau: Geological Society of America Bulletin, v. 119, no. 11/12, p. 1283-1312.

Kirkham, R.M., Kunk, M.J., Bryant, B., and Streufert, R.K., 2001, Constraints on timing and rates of late Cenozoic incision by the Colorado River in Glenwood Canyon, Colorado — a preliminary synopsis, *in* Young, R.A., and Spamer, E.E., editors, Colorado River origin and evolution: Grand Canyon, Arizona, Grand Canyon Natural History Association, p. 113-118.

Jones, L.S., and Blakey, R.C., 1997, Eolian-fluvial interaction in the Page Sandstone (Middle Jurassic) in south-central Utah, USA – a case study of erg-margin processes: Sedimentary Geology, v. 109, p. 181-198.

Lucas, S.G., 1993, The Chinle Group – revised stratigraphy and chronology of Upper Triassic nonmarine strata in western United States: Museum of Northern Arizona Bulletin 59, p. 27-50.

Lucas, S.G., Heckert, A.B., Estep, J.W., and Anderson, O.J., 1997, Stratigraphy of the Upper Triassic Chinle Group, Four Corners region, *in* Anderson, O.J., Kues, B.S., and Lucas, S.G., editors, Mesozoic geology and paleontology of the Four Corners region: New Mexico Geological Society Guidebook, 48th Field Conference, p. 81-107.

Lucchitta, I., Curtis, G.H., Davis, M.E., Davis, S.W., Hanks, T.C., Finkel, R.C., and Turrin, B., 2001, Rates of downcutting of the Colorado River in Grand Canyon region, *in* Young, R.A., and Spamer, E.E., editors, Colorado River origin and evolution: Grand Canyon, Arizona, Grand Canyon Natural History Association, symposium volume, p. 155-158.

Marchetti, D.W., and Cerling, T.E., 2001, Bedrock incision rates for the Fremont River, tributary of the Colorado River, *in* Young, R.A., and Spamer, E.E., editors, Colorado River origin and evolution: Grand Canyon, Arizona, Grand Canyon Natural History Association, p. 125-128.

McCourt, T., 2003, White Canyon – remembering the little town at the bottom of Lake Powell: Southpaw Publications, Price, Utah, 225 p.

Pederson, J., Karlstrom, K., Sharp, W., and McIntosh, W., 2002, Differential incision of the Grand

Canyon related to Quaternary faulting — constraints from U-series and Ar/Ar dating: Geology, v. 30, p. 739-742.

Peterson, F., 1994, Sand dunes, sabkhas, streams, and shallow seas – Jurassic paleogeography in the southern part of the Western Interior basin, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region, U.S.A.: Denver, Colorado, Rocky Mountain Section SEPM (Society for Sedimentary Geology), p. 233-272.

Phoenix, D.A., in press, Geologic map of part of the Lees Ferry area, Glen Canyon National Recreation Area, Coconino County, Arizona (digitized and modified from plate 1 of U.S. Geological Survey Bulletin 1137, 86 p., scale 1:24,000, published in 1963): Utah Geological Survey Miscellaneous Publication (GIS data), scale 1:24,000.

Polyak, V., Hill, C., and Asmerom, Y., 2008, Age and evolution of the Grand Canyon revealed by U-Pb dating of water table-type speleothems: Science, v. 319, p. 1377-1380.

Ritter, S.M., Barrick, J.E., and Skinner, M.R., 2002, Conodont sequence stratigraphy of the Hermosa Group (Pennsylvanian) at Honaker Trail, Paradox Basin, Utah: Journal of Paleontology, v. 76, no. 3, p. 495-517.

Stevenson, G.M., 2003, Geology of Goosenecks State Park, San Juan County, Utah, *in* Sprinkel, D.A., Chidsey, T.C., Jr., and Anderson, P.B., editors, Geology of Utah's parks and monuments, 2nd edition: Bryce Canyon Natural History Association and Utah Geological Association Millennial Guidebook Publication 28, p. 433-448.

Stewart, J.H., Poole, F.G., and Wilson, R.F., 1972a, Stratigraphy and origin of the Chinle Formation and related Upper Triassic strata in the Colorado Plateau region: U.S. Geological Survey Professional Paper 690, 336 p.

Stewart, J.H., Poole, F.G., and Wilson, R.F.,1972b, Stratigraphy and origin of the Triassic Moenkopi Formation and related strata in the Colorado Plateau region: U.S. Geological Survey Professional Paper 691, 195 p.

Stewart, J.H., Williams, G.A., Albee, H.F., and Raup, O.B., 1959, Stratigraphy of Triassic and associated formations in part of the Colorado Plateau region, with a section on sedimentary petrology by R.A. Cadigan: U.S. Geological Survey Bulletin 1046Q, p. 487-576.

Thaden, R.E., Trites, A.F., Jr., and Finnell, T.L., 1964, Geology and ore deposits of the White Canyon area, San Juan and Garfield Counties, Utah: U.S. Geological Survey Bulletin 1125, 166 p., scale 1:48,000.

Wengerd, S.A., 1963, Stratigraphic section at Honaker Trail, San Juan Canyon, San Juan County, Utah, *in* Bass, R.O., editor, Shelf carbonates of the Paradox Basin, a symposium: Four Corners Geological Society 4th Annual Field Conference, p. 235-243.

Willis, G.C., 1992, Lava Creek B volcanic ash in pediment mantle deposits, Colorado Plateau, east-central Utah — implications for Colorado River downcutting and pedogenic carbonate accumulation rates: Rocky Mountain Section Geological Society of America Abstracts with Programs, v. 24, no. 6, p. 68.

Willis, G.C., 1994, Geologic map of the Harley Dome quadrangle, Grand County, Utah: Utah Geological Survey Map 157, 18 p., scale 1:24,000.

Willis, G.C., 2004, Interim geologic map of the lower San Juan River area, eastern Glen Canyon National Recreation Area and vicinity, San Juan County, Utah: Utah Geological Survey Open-File Report 443DM (GIS data), scale 1:50,000.

Willis, G.C., in press (a), Geologic map of the Hite Crossing – lower Dirty Devil River area, Glen Canyon National Recreation Area, Garfield and San Juan Counties, Utah: Utah Geological Survey Miscellaneous Publication (GIS data), scale 1:50,000.

Willis, G.C., in press (b), Geologic map of the Glen Canyon Dam area, Glen Canyon National Recreation Area, Arizona and Utah: Utah Geological Survey Miscellaneous Publication (GIS data), scale 1:24,000.

Willis, G.C., in preparation, Interim geologic maps of the Bullfrog, Halls Crossing, Halls Crossing NE, Ticaboo Mesa, and Knowles Canyon quadrangles, Glen Canyon National Recreation Area, Garfield and San Juan Counties, Utah: Utah Geological Survey Open-File Reports, scale 1:24,000.

Willis, G.C., and Biek, R.F., 2001, Quaternary incision rates of the Colorado River and major tributaries in the Colorado Plateau, Utah, *in* Young, R.A., and Spamer, E.E., editors, Colorado River origin and evolution: Grand Canyon, Arizona, Grand Canyon Natural History Association, symposium volume, p. 119-124.

Wolkowinsky, A.J., and Granger, D.E., 2004, Early Pleistocene incision of the San Juan River, Utah, dated with ^{26}Al and ^{10}Be: Geology, v. 32, no. 9, p. 749-752.

Explanation of Attributes and Attribute Categories used in Geologic Map Digital Database Files produced by

Utah Geological Survey
Geologic Mapping Program

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July 30, 2007

Introduction

Digital GIS data files of geologic maps produced by the Utah Geological Survey have three types of data: arcs, polygons, and point data. A special class of point data is annotations (text that actually appears on the map), which has two types: (1) names or information that are attributes of arcs, polygons, or points (such as the map unit label, name of a fault, or the dip angle of a strike and dip symbol), and (2) short strings of text placed on the map by the geologist to label, point out, or explain some feature, such as "breccia zone," "disturbed area," etc.

The following list provides a brief explanation of the primary attributes and attribute categories used on the arcs, polygons, and point data. This list applies to most geologic maps; no map has every type of attribute. A few maps have additional rarely used attributes not explained below, but which are explained on the explanation plate accompanying such maps. The actual list of all attribute possibilities is very large and combinations of these attributes may be used. Examples taken from various maps published are given for some explanations. See references at end for additional explanations of geologic features and common map symbology.

Discussion about Faults

Faults are a unique type of geologic feature that are one of the more difficult features to handle in GIS databases and thus commonly cause confusion. They can be created and attributed in two basic ways: (1) break faults into segments in the arc coverage and attribute each part of the fault separately (dotted, dashed, solid, solid doubling as a contact, queried, etc.), allowing each segment to form the boundary of a polygon as necessary; or (2) convert all faults on the arc coverage to "contacts" and treat them only as polygon boundaries on that coverage; then duplicate them on a separate coverage where they are attributed by type. The UGS requires that the <u>first</u> method be followed. The second method creates too many problems with shifted arcs and "sliver" polygons formed between duplicated fault segments as edits are made and arcs are shifted around slightly during production.

ARC - POLYGONS

Linear geologic features – some may also form boundaries of polygons.

Type – major categories of arcs and arc-polygons.

contact	boundary between mappable geologic units; usually selected at a prominent change in rock type.
fault	fracture in rock or sediment with discernable offset between opposite sides.
marker bed	prominent bed that map author has chosen to show on the map
marker bed/contact	marker bed that also serves as a contact.
moraine	mound or linear ridge of glacial debris, generally till, deposited by a glacier.
scarp	steep slope or cliff at the upper end of a landslide or other geomorphic feature (head, main, landslide, etc. is given in subtype).
joint	fracture in rock with no discernable offset between opposite sides.
lineament	linear feature of known or unknown origin visible on ground, map, or air photos.
scarp	steep slope or increase in slope of ground surface created by movement on a fault or landslide.
closed depression	naturally created small or large basin or low area in ground surface.
shoreline	linear feature created by still-stand of a lake; may be erosional or constructional.
water boundary	mapped edge of a lake, river, pond, or other water body.
snowfield boundary	mapped edge of a permanent or semi-permanent snowfield.
map boundary	defined edge or limit of the map.
dike	cross-cutting intruded body of rock, commonly igneous magma, but sedimentary dikes also occur in some areas.
vein	fracture containing mineralized material; may be discordant or concordant; quartz and calcite are common vein materials.

Subtype – primary characteristics or defining features of the types listed above; terms explained below may apply to one, many, or all of the types listed above. Feature may be shape, type of movement (faults), age, or some other characteristic deemed important by map author.

normal	type of fault that is typically moderate- to high-angle and the hanging wall (upper block) appears to display extensional offset.
reverse	type of fault that is typically moderate- to high-angle and the hanging wall (upper block) appears to display compressional offset.
thrust	type of reverse fault that is typically at a low-angle, and is commonly, but not always parallel or at low angle to bedding planes.
detachment	type of low-angle extensional fault; sometimes referred to as a “gravity fault”.
strike-slip	fault on which movement was parallel to the fault’s strike (opposite side moved left or right in reference to the observer).
attenuation	extensional fault or fault zone that thins strata.

dextral	strike-slip fault in which opposite side moved to right (right-lateral).
sinistral	strike-slip fault in which opposite side moved to left (left-lateral).
Bonneville	highest of four major named shorelines of Latest Pleistocene Lake Bonneville.
Provo	second highest of four major named shorelines of Latest Pleistocene Lake Bonneville; formed after Bonneville flood.
Stansbury	prominent intermediate named shoreline of Latest Pleistocene Lake Bonneville.
Gilbert	prominent low-level named shoreline of Latest Pleistocene Lake Bonneville.
Gunnison	a major Late Pleistocene lake.
regressive	formed during a lake regression (generally applied to shorelines).
transgressive	formed during a lake transgression (generally applied to shorelines).
intermediate	as applied to shorelines, any local prominent shoreline.
unknown	insufficient geologic data to determine.
Pinedale	major Late Pleistocene ice age that peaked about 16,000 to 23,000 years ago (C^{14} yrs b.p.) (Smiths Fork and other terms are used locally in Utah).
Bull Lake	major Late Pleistocene ice age peaking about 140,000 to 160,000 years ago (Blacks Fork and other terms are used locally in Utah).
Pine Valley	local prominent glacial episode in Late Pleistocene.
other	many other terms may be added by map author.

Modifier – additional information that further clarifies the types/features listed above; may be information such as how accurately the feature is located or understood by the map author, the type of data that was used to identify or interpret the feature, etc.

well located	position of contact, fault, or other feature is well constrained by geologic data.
approximately located	position of contact, fault, or other feature is not well constrained by geologic data.
concealed	contact, fault, or other feature is concealed by overlying deposits or water.
queried	existence of feature is questionable.
queried concealed	existence of concealed feature is questionable.
queried approximately located	position of questionable feature not well constrained.
gradational	generally a mapped contact that is placed in a broad transitional interval between different formations or lithologies.
scratch	contact or boundary between different map units based on some criteria selected by map author that is not typically used in formation and member contacts; may be a nomenclature change, a boundary across which definitions of map units changes, or a boundary separating units that are lumped together differently; commonly discordant to bedding; for example, may separate a map unit in which members of a formation are combined together from map units of the formation in which members are mapped separately.
inferred	contact, fault, or other feature inferred to be present based on circumstantial data.
geophysical	feature, usually a fault, recognized based on geophysical evidence.

other	many other terms may be added by map author.

Notes – any additional information added to attributes to help explain types/features listed above. Includes but not limited to text that appears on map. Brackets [ ] indicate that some defining information is to be entered, such as the geologic age of a feature.

low-angle	shallow dipping surface or lineament.
high-angle	steeply dipping surface or lineament.
steeply dipping	understood.
historic	understood.
prehistoric	understood.

[geol. age]
[strike and dip of plane (such as a fault) - not bedding strike and dip]
[trend and plunge]
[key comment]
[line name - such as name of fault]
[dike vein name]
[marker bed name]
other – many other terms may be added by map author.

Decorated lines, that is, lines with some sort of symbol on one side of the line, such as teeth on thrust faults, require that the lines be digitized in a fixed direction relative to the decorations so the decoration will plot on the side determined by the map author as shown on the source map. For example, teeth on faults are placed on the hanging wall (over-riding or upper plate or block).

Arcs bounding “overlayered” or “superimposed” polygons that overprint maps units are placed in separate coverages if the basic geologic unit is also recognized (examples of overlayered polygons are shear zones, alteration zones, and mineralized zones). For example, if part of the Isom Tuff is silicified, it can be shown on the map as Ti (Tertiary Isom Tuff) with a pattern over the silicified portion (si). The patterned area is placed in a separate polygon coverage and the bounding arcs are placed in a separate arc coverage. This differs from the way stacked units are handled. Stacked units are map units in which the map author shows a thin mantle of one map unit over another map unit. For example: Qal/Ts indicates a thin mantle of Quaternary alluvial deposits over a Tertiary unit. For GIS purposes, each stacked unit variation is treated as a unique unit with unique attributes in the map unit polygon coverage.

Polygon Names and Symbols – generally the formation, member or other map unit name, and a shorthand symbol for each.

Unit Symbol – a shorthand abbreviation of the full map unit age and name. Must be unique for every distinct map unit. The capital letter(s) always denote the geologic age (generally at period/system level) of the unit following international guidelines (see age discussion below). The small letters denote the name and/or relative age of the unit. The unit symbol is used as the label on the map, cross sections, and illustrations, and is defined in an explanation accompanying the map.

Examples:
Qa
Qap_3
QTms
Qaf/Qls
Qaf/Qls/Ct
Tgda
TRcp
PIPo
IPe
SOlf
Zmf
Xfhs

Unit Name – unique name for each map unit. Some are formally defined, indicated by upper-case letters. Some are informal terms assigned by the map author, indicated by lower-case letters.

Examples	(possible matching unit symbol)
alluvial deposits	Qa
level 3 alluvial pediment-mantle deposit	Qap_3
old mass-movement landslide deposit	QTms
alluvial fan deposits over lacustrine sand	Qaf/Qls
alluvial fan deposits over lacustrine sand over Tintic Quartzite	Qaf/Qls/Ct
Tongue A of Douglas Creek Member of Green River Formation	Tgda
Petrified Forest Member of Chinle Formation	TRcp
Oquirrh Formation	PIPo
Ely Limestone	IPe
Laketown and Fishhaven Dolomites, undivided	SOlf
Mineral Fork Formation	Zmf
hornblende-biotite schist unit of Farmington Canyon Complex	Xfhs

Age – age or age range of map unit as assigned by map author. Generally stated as accurately and precisely as evidence from geologic setting, fossils, or laboratory analyses allow (age designation in unit symbol [for example Q or IPM] is more generalized than age given here). Some examples are given below, with the letters that would be used in the unit symbol given in parentheses. See most geology textbooks or several web sites such as the U.S. Geological Survey web site at (http://geology.er.usgs.gov/paleo/geotime.shtml) or the Berkely University website at

(http://www.ucmp.berkeley.edu/help/timeform.html) for tables showing numeric ranges of geologic age terms.

Examples:
Quaternary (Q)
Quaternary-Tertiary (QT)
Pennsylvanian-Mississippian (IPM)
Lower Pennsylvanian-Upper Mississippian (IPM)
Devonian-Cambrian (DC)
Upper Proterozoic (Z)
Middle Proterozoic (Y)
Lower Proterozoic-Upper Archean (XW)
Holocene (Q)
Oligocene-Eocene (T) (for Tertiary)

Certain age characters have been long-used under international convention. Some are unique font symbols that do not have standard keyboard characters in most software. The following conventions are used for these special symbols: K – Cretaceous, TR or TR – Triassic, IP – Pennsylvanian, C – Cambrian. Precambrian subdivisions use Z,Y,X, and W. The following terms and symbols are rarely used, but may appear on a few geologic maps: IPM – Carboniferous (Pennsylvanian-Mississippian), CZ – Cenozoic, MZ – Mesozoic, PZ – Paleozoic, pC – Precambrian. Occasionally the map author may drop the Q or QT letters to save space – the age is given in the Map Explanation.

Notes – any additional information added to attributes to help explain types/features listed above. Includes, but not limited to, text that appears on map.

[geologic group to which unit belongs]
[modifications to age of unit made during GIS compilation]

ARCS

Structural Lines – lines used to depict structural features of the geology.

Type

structural contour	a contour (an imaginary horizontal line) drawn on a specified bedding surface to denote a structural surface; generally defined relative to sea level.
anticline	a fold, generally convex upward, whose core contains the stratigraphically oldest rock; in simple anticlines limbs dip away from plane of curvature.
syncline	a fold, generally concave upward, whose core contains the stratigraphically youngest strata; in simple synclines limbs dip toward plane of curvature.
monocline	a local steepening in an otherwise uniform planar dip; consists of two adjacent folds that form a step-like flexure.
monocline, anticlinal bend	generally the upper of the two folds forming a monocline; an inclined anticlinal fold in which the upper limb is low-angle and the lower limb is steep; may form a broad or tight anticline.
monocline, synclinal bend	generally the lower of the two folds forming a monocline; an inclined synclinal fold in which the upper limb is steep and the lower limb is low-angle; may form a broad or tight syncline.
antiform	any fold whose limbs close (converge) at the top; generally looks like a simple upright anticline except that bedding is overturned or relative age of involved rock is unknown.
synform	any fold whose limbs open (diverge) at the top; generally looks like a simple upright syncline except that bedding is overturned or relative age of involved rock is unknown.
dome	structural uplift or anticline-like fold in which beds dip away from culmination in all directions; may be circular or elliptical.
basin	structural downwarp or syncline-like fold in which beds dip toward depression from all directions; may be circular or elliptical.

Subtype

asymmetric	parts are unequal; in folds, tightness varies across hinge.
inverted	upside down, overturned, or opposite.
overturned	in folds, a fold in which one limb is overturned such that both limbs dip in the same direction.
antiformal	looks like a simple anticline; an antiformal syncline is a syncline (youngest strata in the core) that has been completely overturned such that it looks like an anticline.
synformal	looks like a simple syncline; a synformal anticline is an anticline (oldest strata in the core) that has been completely overturned such that it looks like a syncline.

Modifier

well located	see above.
projected	shown hypothetically how the feature would project or trend through space above the ground surface.
approximately located	see above.
concealed	see above.
queried	see above.
queried concealed	see above.
queried approximately located	see above.
elevation	elevation of feature above sea level.

Notes

plunging	fold axis is inclined or plunges into ground.
doubly plunging	fold axis is curved such that both ends are inclined.
isoclinal	in folds, a fold in which limbs are parallel.
recumbent	in folds, a fold in which axial plane is approximately horizontal.
open	in folds, a fold in which limbs form angle greater than 90 degrees.
closed	in folds, a fold in which limbs form angle less than 90 degrees.
[contour interval]	elevation or interval spacing of structural or other contours.
[bearing]	compass bearing.
[plunge]	amount, in degrees, of dip or inclination.
[name of 2nd, 3rd, etc contoured surface]	enter name of surface or feature.
[name of structure]	name of a fold or other structure [ex: Cane Creek anticline].

Isopleth Lines – any type of contoured data other than structural contour lines.

Type

thickness isopleth	thickness of a particular unit [ex: thickness of a coal bed].
chemical isopleth	chemical composition or content data [ex: copper oxide content of a particular unit].
depth isopleth	depth below ground surface of a plane.

Subtype

<u>Examples of data or features that might be shown with isopleth lines:</u>
coal
tar sand
gypsum
alteration zone
mineralization
chemical variations
[give name of mineral, product, or topic]

Modifier

well located	see above.
approximately located	see above.
queried	see above.
queried approximately located	see above.
scratch	see above.
projected	see above.

(can combine terms)

Notes – includes, but not limited to, text that appears on map.

[age]
[datum]
[source of data]
[method]
etc.

Indicator Lines – extra lines placed on map to clarify or identify features or locations of supporting explanatory data. For example: cross-section lines, label leader lines, locations of measured sections.

Type

cross-section line	line on map showing position of a cross section included elsewhere in supporting materials; field is commonly labeled xsection**.**
label leader line	line indicating a feature or polygon identified by a label.
measured section	shows location or line of traverse where a section of strata discussed or mentioned in supporting materials was measured.

Subtype

(use if needed)

Modifier

(use if needed)

Notes

Examples:
A-A'
B-B'-B"
section 3a
measured section through Moenkopi Formation

Symbol Arcs – in some geologic map databases, the point data, such as strike and dip and foliation measurements, are treated as arcs that actually depict the symbol rather than as attributed point data. The reason is that point data in geology is commonly rotated to a specific orientation reported as degrees from true north. Different software create these rotations differently, possibly resulting in symbols with erroneous rotations that could mislead users. As a result, some data producers prefer to create a file that shows the symbols as arcs and annotations so that they can assure that the orientation of the symbol is correct. Most point data described below may be depicted this way in some databases.

POLYGONS

Overprinted Features – special spatial features that overprint or overlay standard map unit polygons. These are always placed in separate coverages. For example: breccia zones, altered zones, shear zones.

Unit Symbol – shorthand abbreviation of polygon name that generally appears on map as label.

Examples:
br (breccia zone)
fe (hematitic alteration)
si (silicified zone)
sz (shear zone)

[at discretion of map author, unit symbols may or may not be placed on map - the overprinted zone may only be identified on map by a pattern fill]

Unit Name – full name of overprinted polygon.

Examples:
breccia zone
hematitic alteration
silicified zone
shear zone

etc.

Modifier – generally describes contact or border type.

well located	see above.
approximately located	see above.
concealed	see above.
queried	see above.
queried concealed	see above.
queried approximately located	see above.
gradational	see above.
etc.	

Notes

[intensity term]
[source of data]
[age or event]
[other comments]
See note regarding superimposed units and stacked units on arc-polygon coverage 1.

POINT DATA

Geologic data that occur at a point, such as strike and dip and foliation measurements, are not attributed as point data in all UGS geologic map GIS databases. In some databases, point data symbols are depicted as vector files treated as arcs. See Symbol Arcs above.

Point-Source Features and Data – most map data collected at point locations and do not form polygons.

Type – primary explanation of point data.

strike and dip	strike is the direction of a line made by the intersection of a surface such as strata with the horizontal; dip is the inclination of planar strata or surfaces in the rock; generally depicted as a strike and dip symbol but may be shown using structural contours.
foliation	planar textural or structural fabric or features repeated through the rock; generally depicted as a strike and dip.
joint	planar fracture, crack, or parting in a rock; commonly repeated to form joint sets; generally depicted as a strike and dip; large joints are commonly mapped.
cleavage	in structural terms, a local planar fabric in a generally fine-grained rock that promotes a tendency to split along planes or parallel surfaces; produced by structural deformation; generally depicted as a strike and dip.
lineation	any linear geologic feature mapped at author's discretion; may be small or large.
adit	horizontal passage from surface into a mine; a tunnel; commonly includes gently inclined passages.
shaft	near vertical mine excavation or opening.
quarry	open excavation for stone or minerals.
prospect	small exploratory pit or excavation.
bore hole	hole drilled for exploration or extraction.
sample locality	location where a rock or sediment sample is collected for analysis; sample identifier and type generally given in attributes; results of analyses generally explained in accompanying materials, but may be placed on map; coverage may be given a name such as palynosample or fossilsample.
spring	location where naturally flowing water emerges from ground.
other	many other types may be used by map author.

Subtype – defines, explains, or augments point data (meaning of most of following terms is evident).

inclined	understood.
vertical	understood.
horizontal	understood.
overturned	understood.

fossil	understood.
geochemical	understood.
isotopic	sample collected for analysis of isotopes, usually to determine age of rock.
petroleum exploration	bore hole drilled to explore for petroleum resources.
water	bore hole drilled to extract water.
injection	bore hole drilled to inject water or other liquids.
mineral exploration	bore hole drilled to explore for mineral resources.
etc.	

Modifier

steep	understood.
moderate	understood.
shallow	understood.
field	data collected in field.
calculated	data calculated following established procedures.
from photogrammetry	data determined from aerial photographs visually or using computer algorithms.
dry	no oil or gas encountered in bore hole.
show oil	small amount of oil encountered.
show gas	small amount of gas encountered.
plugged and abandoned	bore hole has been plugged and capped and no longer in use.
oil	significant oil encountered in bore hole.
gas	significant gas encountered in bore hole.
oil and gas	significant oil and gas encountered in bore hole.
water	significant water encountered in bore hole.
saline brine	significant saline water encountered in bore hole.
approximately located	see above.
uncertain	insufficient data to determine how a mapped bore hole, prospect, or other feature was used or what resources were encountered.
from unpublished data	information came from unpublished sources available to author.

Examples of other information that might be provided:
hot
cold
reclaimed
modified
[type of marker or stand pipe found during mapping]
conodont
palynomorph
vertebrate
etc.

Rotation – some point data have specific orientations that author should record; symbol should be rotated on map accordingly.

<u>Examples:</u>

023
145.3
360
Note: map author should verify that symbols are rotated properly.

Dip – inclination in degrees from horizontal of a shaft, adit, bore hole, or other feature (angle is generally placed on map).

Examples:
0
12
45
68

Descriptor – includes but not limited to, text that appears on map.

Examples:
49±0.3 Ma
sample WA23
WA23
A
B
1989 [date]
50 bbl/day
0.03% Au
12% Cu
12 ft
43°
183°
[name]
[linked text comment]
etc.

Annotations – text that is not an attribute of a line, polygon, or point, and that is placed in a specific location on the map by the map author to locate and identify a specific feature. It generally does not include labels that are attributes of mapped polygon, arc, or point features. Most text that appears on the printed map is an attribute of an arc, polygon, or point, and can be placed anywhere along the line, within the polygon, or near the point symbol at the convenience of the cartographer, in which case it is not placed in this separate annotation category.

Type

Examples of text that could be included in this category:
[dune field; such as Antelope Valley Dune Field]
[breccia zone]
[disturbed area]
[fault zone]
[silicified in this area]
[name of a broadly defined geomorphic feature]

Examples of text that should **NOT** be included in this category:
Qal
TRm
marker bed
Wasatch fault
Virgin anticline
Texaco State #1-12
Chesterfield Mine
2,000 feet
5,280
TD -12,460
8 (dip or plunge angle)
WA23 (sample number)
U
D

Subtext

(use if needed)

Modifier

(use if needed)

Rotation

[enter rotation or orientation of text]

Point Symbols – symbols to show trend, plunge direction, sense of offset on faults, and other features selected by map author. Map author may create as needed. Examples are: arrows, balls and bars on faults, line decorations.

Type

plunge arrow	inclination of linear feature such as fold axis.
rake arrow	inclination of striations on a fault plane.
ball and bar	placed on down-dropped side of a high-angle normal or reverse fault.
up indicator	in certain cases a U may be used to indicate up-thrown side of a fault.
down indicator	in certain cases a D may be used to indicate down-thrown side of a fault.
left strike slip	arrow indicating left-lateral or sinistral movement on a strike-slip fault.
right strike slip	arrow indicating right-lateral or dextral movement on a strike-slip fault.
long arrow	used at discretion of mapper; defined in explanation of map.
short arrow	used at discretion of mapper; defined in explanation of map.
bold arrow	used at discretion of mapper; defined in explanation of map.
thin arrow	used at discretion of mapper; defined in explanation of map.

Following features may be shown symbolically by map author if too small or congested to map individually; see definitions above:

anticline
syncline
monocline
asymmetric anticline
asymmetric syncline
overturned anticline
overturned syncline
inverted anticline
inverted syncline
etc.

Subtype

(use if needed)

Modifier

(use if needed)

Rotation

[enter rotation of arrow, ball and bar, etc.]

Dip (or plunge) – place label near symbol

Examples:

5
8
23
74

Notes

[name of feature]
etc.

Additional Descriptions and Explanations of Geologic Features and Map Symbols

Geologic Data Subcommittee of Federal Geographic Data Committee, 2000, Public review draft – digital cartographic standard for geologic map symbolization: U.S. Geological Survey Open-File Report 95-525, variously paginated.

Neuendorf, K.K.E., Mehl, J.P.Jr., and Jackson, J.A., editors, 2005, Glossary of Geology, (fifth edition): Alexandria, Virginia, American Geological Institute, 779 p.