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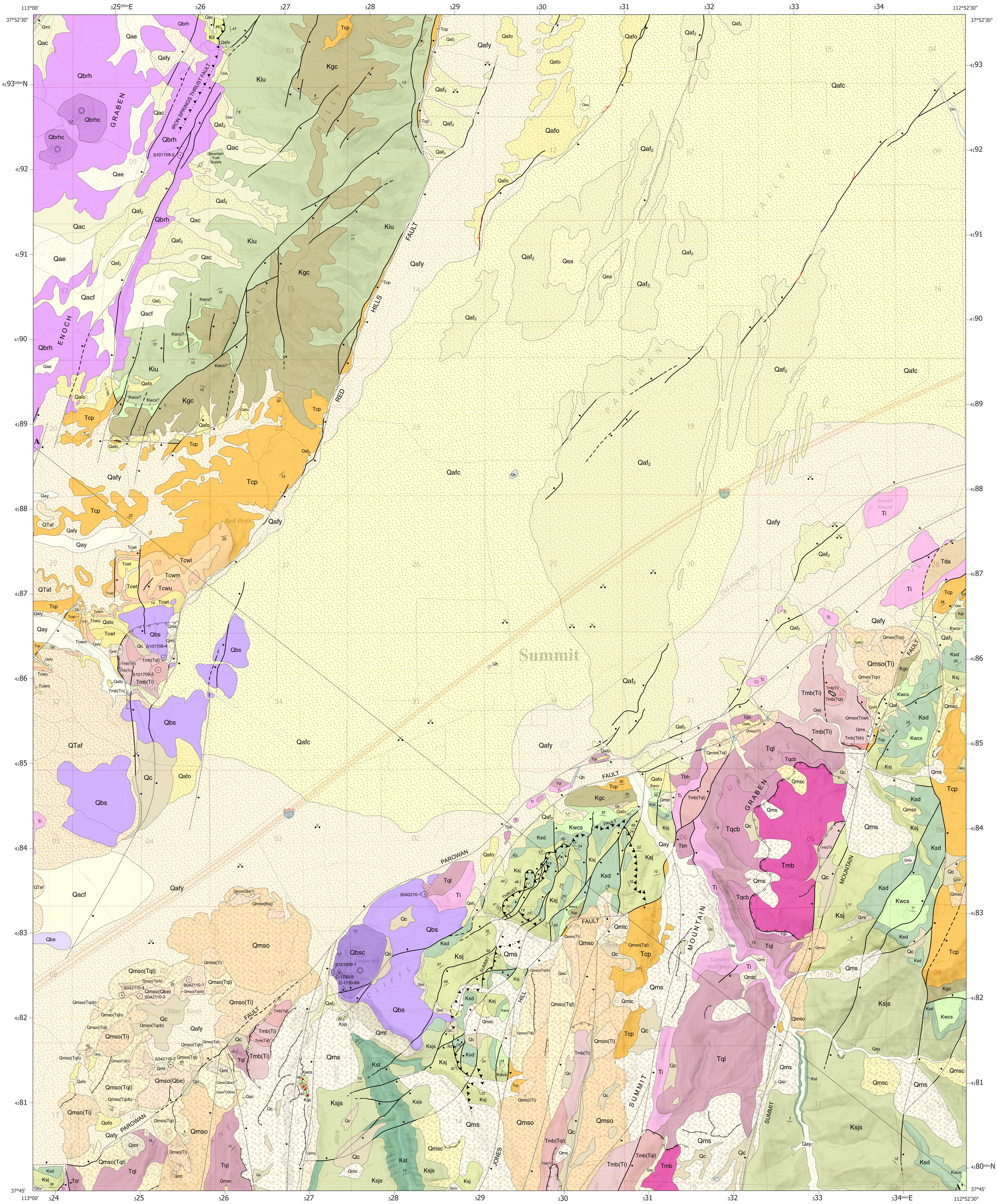

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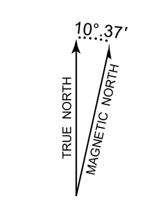
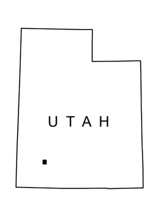


APPROXIMATE MEAN DECLINATION, 2026

SCALE 1:24,000

1 0.5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0.5 0 1 KILOMETER

CONTOUR INTERVAL 40 FEET



MAP LOCATION

Base from USGS US Topo Summit 7.5′ Quadrangle (2023)
Shaded relief derived from USGS 10-meter NED
Projection: UTM Zone 12
Datum: NAD 1983

Project Manager: Stefan Kirby
GIS and Cartography: Joshua A. Dustin and Tyler R. Knudsen

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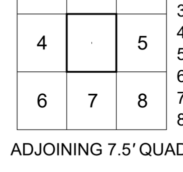
INTERIM GEOLOGIC MAP OF THE SUMMIT QUADRANGLE, IRON COUNTY, UTAH

by

Tyler R. Knudsen

2026



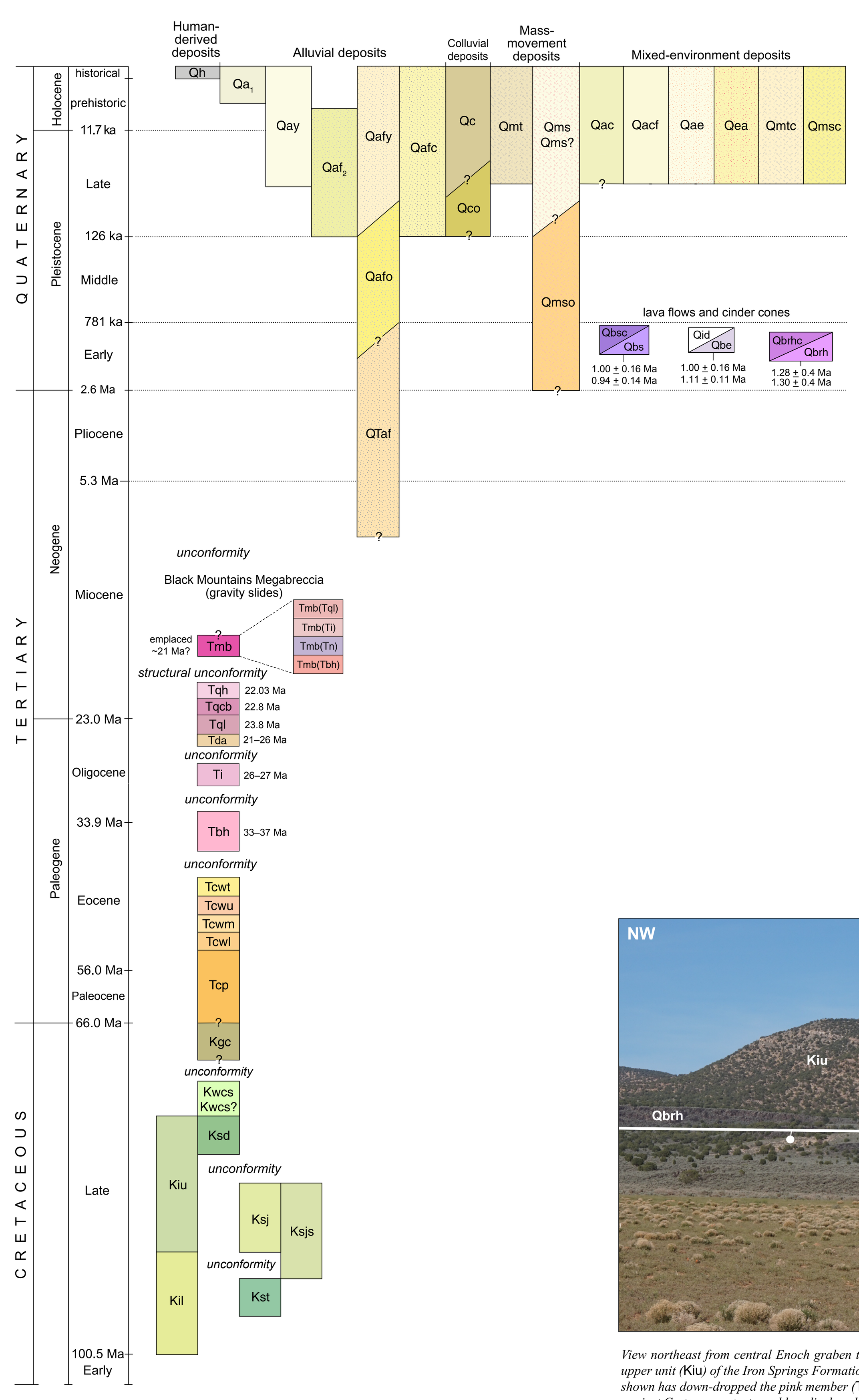
1. Enoch NE
2. Parowan Gap
3. Paragonah
4. Enoch
5. Parowan
6. Cedar City
7. Flanigan Arch
8. Brian Head

ADJOINING 7.5′ QUADRANGLE NAMES

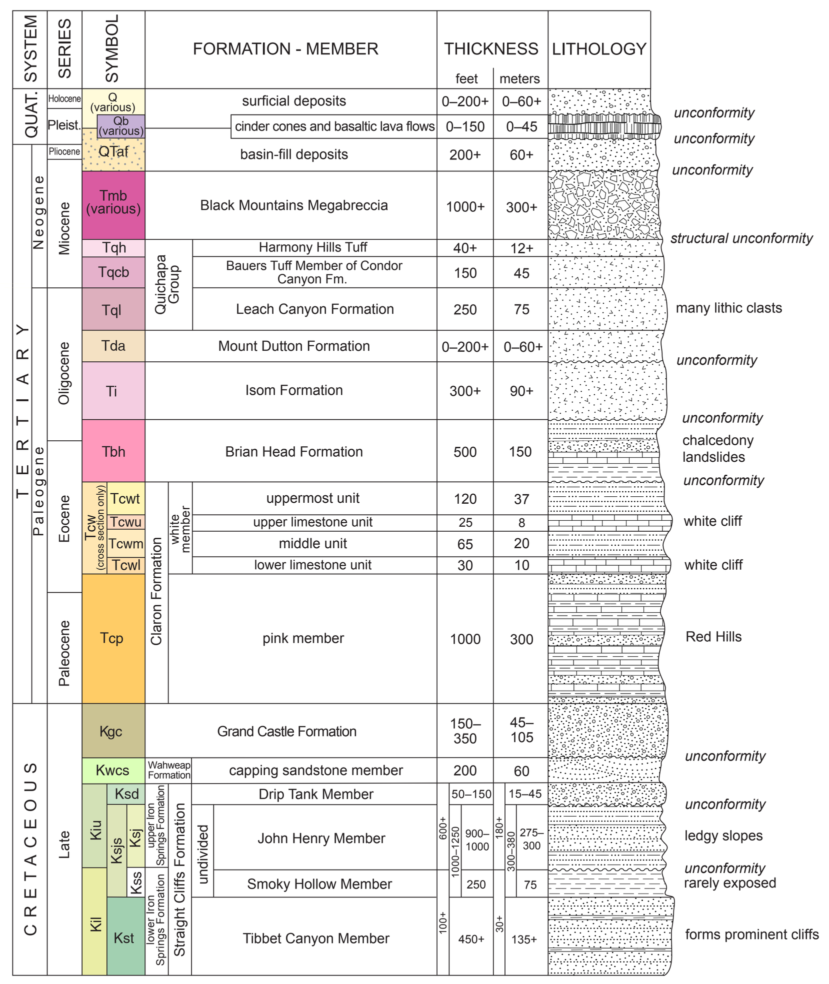
GEOLOGIC UNITS

Symbol	Unit
Qh	Artificial fill
Qa_1	Stream alluvium
Qay	Young alluvium
Qaf_2	Level-2 fan alluvium
Qafy	Younger fan alluvium
Qafc	Coalesced fan alluvium
Qafo	Older alluvium
Qc	Colluvium
Qco	Older colluvium
Qms	Landslide deposits
Qms(Qbe) Qms?(Qbe)	Landslide deposits of the Elliker Basin lava flow
Qmso	Older landslide deposits
Qmso(Qbe) Qmso(Qbe?)	Older landslide deposits of Elliker Basin lava flow
Qmso (Tqh)	Older landslide deposits of Harmony Hills Tuff
Qmso (Tqcb)	Older landslide deposits of Bauers Tuff Member of the Condor Formation
Qmso (Tql)	Older landslide deposits of Leach Canyon Formation
Qmso (Ti)	Older landslide deposits of Isom Formation
Qmso (Tcwl)	Older landslide deposits of lower white member of the Claron Formation
Qmso (Tcp)	Older landslide deposits of pink member of the Claron Formation
Qmso (Ksj)	Older landslide deposits of John Henry Member of the Straight Cliffs Formation
Qmt	Talus
Qac	Alluvium and colluvium
Qacf	Alluvium, colluvium, and fan alluvium
Qae	Alluvium and eolian sand
Qea	Eolian sand and alluvium
Qmtc	Talus and colluvium
Qmsc	Landslides and colluvium
Qbs	Summit lava flow
Qbsc	Summit cinder cone
Qbe	Elliker Basin lava flow
Qbrh	Red Hills lava flow
Qbrhc	Red Hills cinder cone
QTaf	Basin-fill deposits
Tmb	Black Mountains Megabreccia deposits, undivided
Tmb (Tql)	Black Mountains Megabreccia deposits of Leach Canyon Formation
Tmb(Ti)	Black Mountains Megabreccia deposits of Isom Formation
Tmb (Tn)	Black Mountains Megabreccia deposits of Needles Range Group, undivided
Tmb (Tbh)	Black Mountains Megabreccia deposits of Brian Head Formation
Tqh	Quichapa Group, Harmony Hills Tuff
Tqcb	Quichapa Group, Bauers Tuff Member of Condor Canyon Formation
Tql	Quichapa Group, Leach Canyon Formation, undivided
Tda	Mount Dutton Formation, alluvial facies
Ti	Isom Formation, undivided
Tbh	Brian Head Formation, middle volcaniclastic unit
Tcwt	Claron Formation, uppermost mudstone, siltstone, and sandstone unit of white member
Tcwu	Claron Formation, upper limestone unit of white member
Tcwm	Claron Formation, middle mudstone, siltstone, and sandstone unit of white member
Tcwl	Claron Formation, lower limestone unit of white member
Tcp	Claron Formation, pink member
Kgc	Grand Castle Formation
Kwcs Kwcs?	Capping sandstone member of the Wahweap Formation
Kiu	Iron Springs Formation, upper unit
Kil	Iron Springs Formation, lower unit
Ksd	Straight Cliffs Formation, Drip Tank Member
Ksjs	Straight Cliffs Formation, John Henry and Smoky Hollow Members, undivided
Ksj	Straight Cliffs Formation, John Henry Member
Kst	Straight Cliffs Formation, Tibbet Canyon Member

CORRELATION OF MAP UNITS

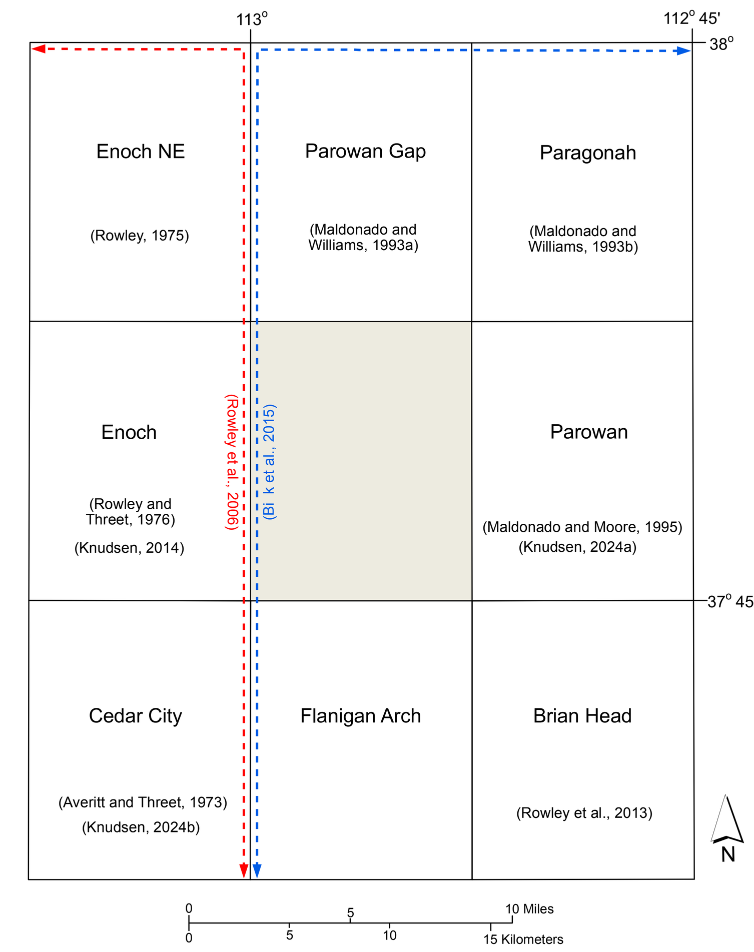


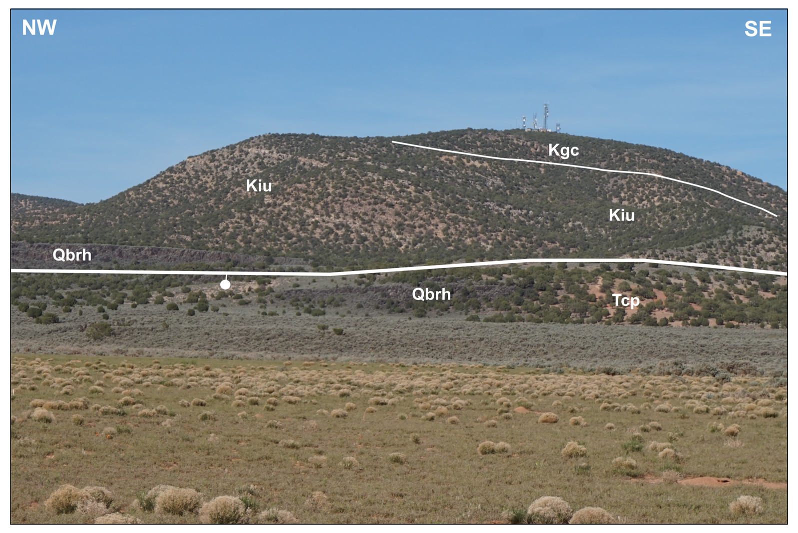
LITHOLOGIC COLUMN



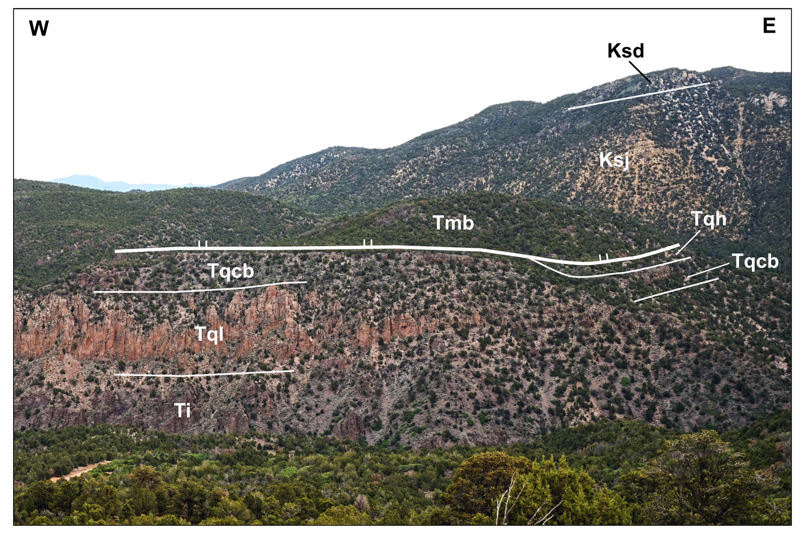
MAP SYMBOLS

- Contact, dashed where approximately located
- Normal fault, dashed where approximately located, dotted where concealed; bar and ball on downthrown side; arrows on cross section indicate direction of relative movement
- Thrust fault, dashed where approximately located, dotted where concealed; teeth on upper plate; arrows on cross section indicate direction of relative movement
- Gravity-slide detachment fault, dashed where approximately located, dotted where concealed; barbs on upper plate
- Earth fissure, dashed and queried where uncertain
- Qid — Basaltic dike
- Scarp, landslide
- A — A' Line of cross section
- 6 Strike and dip of inclined bedding
- 13 Approximate strike and dip of inclined bedding determined photogrammetrically
- 52 Strike and dip of overturned bedding
- Sand and gravel pit
- Mine or quarry
- Prospect
- Volcanic vent
- Spring
- Oil and gas exploration drill hole, plugged and abandoned (Table 3)
- C-1730-9 Radiometric age sample and number (Table 2)
- S101909 Geochemical sample and number (Table 1)



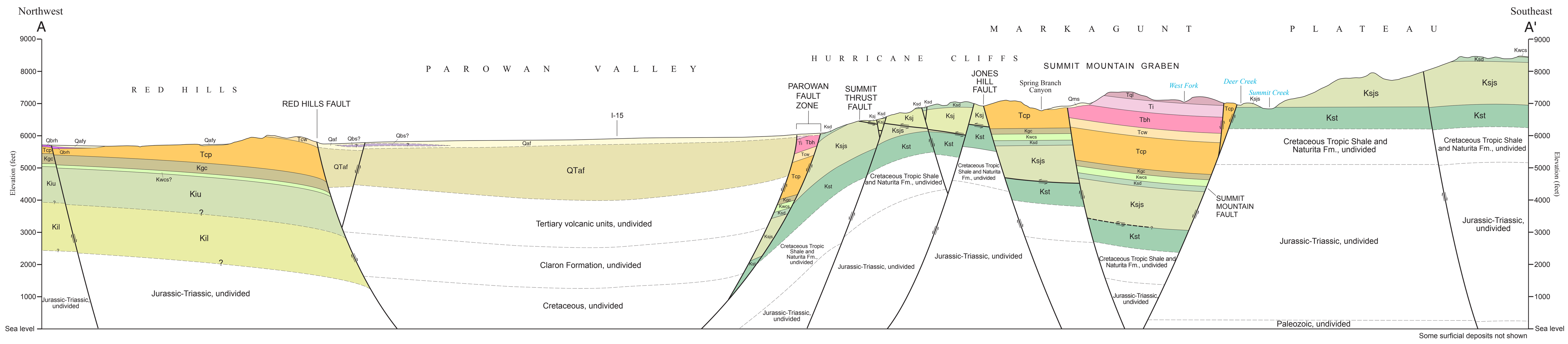


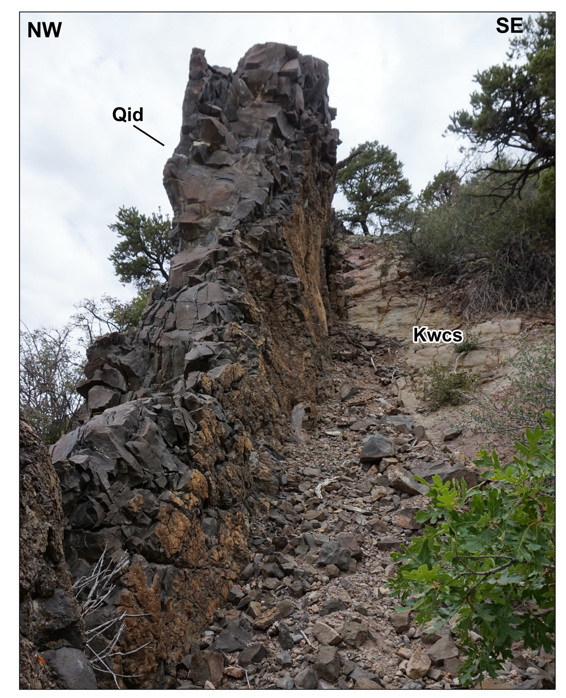
View northeast from central Enoch graben toward the Red Hills where the Grand Castle Formation (Kgc) and the upper unit (Kiu) of the Iron Springs Formation dip gently southeast. The west-dipping, eastern graben-bounding fault shown has down-dropped the pink member (Tcp) of the Paleogene Claron Formation approximately 350 feet (105 m) against Cretaceous strata and has displaced the ~1.3 Ma Red Hills lava flow (Qbrh) about 60 feet (18 m).



The Goat Ledges of Summit Canyon expose the quadrangle's most complete Oligocene–Miocene volcanic section, which is overlain by the chaotic volcanic debris of the Black Mountains Megabreccia (Tmb). In the distance, the Drip Tank Member (Ksd) caps the large hillside of John Henry Member (Ksj), both of the Straight Cliffs Formation. View is towards the north. Tqh, Harmony Hills Tuff; Tqcb, Bauers Tuff Member of Condor Canyon Formation; Tql, Leach Canyon Formation; Ti, Isom Formation.

The Sevier-age Summit thrust fault is well exposed in lower Cheney Spring Canyon just south of Summit. Here, the fault places gently dipping Straight Cliffs strata over a lower plate of steeply northwest-dipping Straight Cliffs strata. View is towards the northeast. Ksd, Drip Tank Member of the Straight Cliffs Formation, Ksj, John Henry Member of the Straight Cliffs Formation, dotted lines represent bedding form lines.





One of four basaltic dikes (Qid) exposed in West Fork Braffits Creek. This northeast-trending dike intruded the capping sandstone member (Kwcs) of the Wahweap Formation and is as much as 5 feet (1.5 m) thick. View is toward the northeast.

Table 1. *Whole-rock major- and trace-element geochemistry of volcanic rocks in the Summit 7.5' quadrangle (https://ugspub.nr.utah.gov/publications/open_file_reports/ofr-775/ofr-775.xlsx).*

Sample No.	Lava Flow or Formation Name	Easting (NAD27)	Northing (NAD27)	Map Symbol[1]	Rock Type[2]	J Code	K Code	L Code	Lab Used	Collected by	SiO2[3,4]	Al2O3[3,4]	Fe2O3[3,4]	CaO[3,4]	MgO[3,4]	Na2O[3,4]	K2O[3,4]	Cr2O3[3]	TiO2[3,4]	MnO[3,4]	P2O5[3,4]	SrO[3]	BaO[3]	LOI[5]	Total	Ag[3]
NE29	Red Hills[4]			Qbrh	basaltic andesite				USGS	Nealey et al. (1997)	53.60	15.70	9.09	7.51	7.18	3.46	1.47		1.32	0.14	0.41			0.02		
NE30	Red Hills[4]			Qbrh	basaltic andesite				USGS	Nealey et al. (1997)	53.50	15.80	9.10	7.43	7.24	3.45	1.49		1.31	0.14	0.39			nd		
NE4	Red Hills[4]			Qbrh	basalt				USGS	Nealey et al. (1997)	51.40	16.40	10.00	9.57	5.80	3.17	0.88		1.29	0.16	0.25			0.44		
NS5	Summit (near Braffits Creek)[4]			Qbs	basalt				USGS	Nealey et al. (1997)	50.00	16.40	9.43	9.21	7.11	3.56	1.22		1.39	0.16	0.64			nd		
NS7	Summit (Cinder Hill)[4]			Qbs	basalt				USGS	Nealey et al. (1997)	50.40	16.10	9.54	9.29	7.57	3.54	1.22		1.36	0.16	0.64			nd		
NS8	Summit (Cinder Hill)[4]			Qbs	basalt				USGS	Nealey et al. (1997)	50.40	16.70	9.29	9.34	6.74	3.65	1.21		1.37	0.16	0.64			nd		
S042110-1	Elliker Basin	325683	4182210	Qbe	shoshonite	2	2	1	ALS Chemex	Biek et al. (2015)	52.43	16.26	8.34	7.29	5.26	3.41	3.74	0.03	1.80	0.13	0.81	0.16	0.27	0.01	99.94	<1
S042110-2	Elliker Basin	325487	4181259	Qbe	shoshonite	2	2	1	ALS Chemex	Biek et al. (2015)	52.95	15.91	8.30	7.38	5.75	3.34	3.40	0.03	1.74	0.13	0.72	0.14	0.24	0.03	100.05	<1
S042110-3	Elliker Basin	325106	4182023	Qbe	shoshonite	2	2	1	ALS Chemex	Biek et al. (2015)	52.54	16.09	8.29	7.54	5.21	3.35	3.53	0.02	1.78	0.13	0.79	0.15	0.26	0.42	100.10	<1
S042110-4	Bauers Tuff	324839	4182246	Tqcb	rhyolite	1	7	9	ALS Chemex	Biek et al. (2015)	72.70	14.11	1.75	1.12	0.36	3.69	5.20	0.01	0.33	0.05	0.06	0.04	0.12	0.53	100.05	<1
S042210-1	Summit	328496	4183150	Qbs	basalt	2	2	1	ALS Chemex	Biek et al. (2015)	50.29	16.35	9.25	9.21	7.50	3.56	1.20	0.04	1.43	0.16	0.56	0.08	0.11	0.09	99.83	<1
S101709-2	Red Hills	325772	4191926	Qbrh	basaltic andesite	2	1	1	ALS Chemex	Biek et al. (2015)	52.00	15.49	9.85	8.26	7.56	3.16	1.11	0.03	1.20	0.15	0.25	0.05	0.07	0.76	99.94	<1
S101709-3	Leach Canyon Fm.	325380	4186049	Tql	rhyolite	1	2	9	ALS Chemex	Biek et al. (2015)	72.55	12.94	1.82	2.18	0.52	2.88	4.99	<0.01	0.26	0.05	0.07	0.02	0.06	1.45	99.80	<1
S101709-4	Summit	325409	4186218	Qbs	basalt	2	2	1	ALS Chemex	Biek et al. (2015)	49.90	16.20	9.51	9.70	7.39	3.50	1.18	0.03	1.39	0.16	0.58	0.09	0.11	0.22	99.96	<1
S101909-1	Summit	327385	4182262	Qbs	basalt	2	2	1	ALS Chemex	Biek et al. (2015)	50.22	16.28	9.62	9.41	7.28	3.63	1.27	0.03	1.46	0.16	0.59	0.09	0.11	-0.27	99.89	<1

Sample No.	Ba[3,4]	Ce[3,4]	Co[3,4]	Cr[3,4]	Cs[3,4]	Cu[3,4]	Dy[3]	Er[3]	Eu[3,4]	Ga[3]	Gd[3,4]	Hf[3,4]	Ho[3]	La[3,4]	Lu[3,4]	Mo[3]	Nb[3,4]	Nd[3,4]	Ni[3,4]	Pb[3]	Pr[3]	Rb[3,4]	Sc[3,4]	Sm[3,4]	Sn[3]	Sr[3,4]	Ta[3,4]	Tb[3,4]	Th[3,4]	Tl[3]	Tm[3,4]	U[3,4]	V[3]	W[3]	Y[3,4]	Yb[3,4]	Zn[3,4]	Zr[3,4]
NE29	669	62.6	36.0	288	0.30	52			1.72		5.66	4.59		29.7	0.38		18.0	27.8	143			24	24	5.73		548	1.0	0.79	2.9		0.42	0.65			27	2.75	79.7	198
NE30	659	60.4	37.0	261	0.29	46			1.69		5.56	4.50		29.2	0.38		16.0	27.7	155			22	23.7	5.61		573	0.9	0.76	2.6		0.42	0.63			26	2.62	77.6	211
NE4	453	40.8	34.0	150	0.17	59			1.45		4.80	3.53		19.2	0.39		11.0	20.6	63			17	29.6	4.62		466	0.4	0.76	2.3		0.43	0.62			33	2.7	77.4	178
NS5	942	95.3	35.0	227	0.04	51			2.08		5.89	4.47		49.7	0.37		40.0	40.2	94			18	26.3	7.10		846	1.9	0.83	6.7		0.42	1.24			26	2.58	78.1	194
NS7	921	96.4	37.0	258	0.17	50			2.08		5.79	4.62		49.0	0.38		38.0	40.6	101			19	27.9	7.39		876	1.9	0.82	6.5		0.41	1.58			29	2.57	76	214
NS8	957	98.9	33.0	204	0.16	57			2.09		6.10	4.50		50.8	0.38		39.0	39.9	94			19	24.6	7.21		867	1.9	0.85	6.8		0.41	1.60			27	2.5	77.5	210
S042110-1	2250	146.0	27.1	120	0.31	33	5.53	2.91	3.03	21.0	9.99	9.10	1.04	65.3	0.37	<2	19.7	72.6	63	16	18.85	36.7		11.80	2	1355	1.0	1.19	5.6	<0.5	0.39	0.96	161	<1	26.5	2.4	109	380
S042110-2	2030	128.0	29.0	160	0.31	31	5.40	3.03	2.77	20.2	9.06	8.60	1.03	57.9	0.37	<2	18.0	64.9	79	15	16.55	33.5		10.65	2	1230	1.0	1.14	5.1	<0.5	0.37	0.85	162	1	26	2.37	109	361
S042110-3	2270	140.5	27.2	120	0.29	32	5.45	2.94	2.89	20.7	9.39	8.80	1.01	64.3	0.36	<2	18.9	70.8	63	16	18.15	33.2		11.35	2	1340	1.0	1.19	5.3	<0.5	0.40	0.85	160	<1	26.3	2.34	111	378
S042110-4	1105	113.5	1.5	30	5.06	5	3.39	2.18	1.07	16.5	5.62	7.50	0.72	60.4	0.32	2	15.2	41.0	<5	24	12.60	177		6.29	1	252	1.1	0.70	33.2	<0.5	0.32	6.86	21	3	19	2.14	36	268
S042210-1	912	92.4	35.4	270	0.13	49	4.97	2.81	2.05	18.8	6.71	4.50	1.00	49.3	0.38	<2	33.9	39.9	102	9	10.90	17		7.15	1	709	1.7	0.95	6.7	<0.5	0.40	1.60	205	1	24.9	2.37	94	214
S101709-2	563	48.3	41.2	300	0.32	48	4.84	3.00	1.41	18.2	5.43	4.00	0.95	23.4	0.41	<2	10.2	24.4	166	12	6.10	23		5.03	1	425	0.5	0.85	3.1	<0.5	0.40	0.63	161	<1	25.1	2.73	93	165
S101709-3	522	72.4	3.6	10	3.71	6	2.23	1.43	0.65	16.0	3.61	4.30	0.40	44.2	0.24	2	14.8	24.0	10	25	7.45	180.5		3.67	1	178.5	1.2	0.45	28.9	<0.5	0.21	5.72	28	2	12.6	1.53	30	139
S101709-4	932	86.1	36.0	250	0.07	44	4.78	2.66	1.93	17.9	6.60	4.60	0.90	47.1	0.35	<2	35.0	38.6	112	11	10.20	13.3		6.86	1	775	1.7	0.92	6.3	<0.5	0.36	0.94	199	<1	23.7	2.38	91	204
S101909-1	966	97.0	36.7	250	0.20	59	5.06	2.99	2.06	19.1	7.15	4.90	0.97	50.3	0.36	<2	36.2	39.9	101	10	10.55	17.4		6.85	2	750	1.8	0.94	7.0	<0.5	0.39	1.59	206	1	25	2.45	96	232

NOTES:
[1]Map symbols are those used on this geologic map of the Summit 7.5' quadrangle
[2]Rock names based on the TAS classification diagram of LeBas et al. (1986)
[3]Major oxides reported in weight percent by X-ray fluorescence; minor and trace elements by inductively coupled plasma mass spectrometry in parts per million
[4]Samples from Nealey et al. (1997): only general locations provided; major elements determined by wavelength dispersive X-ray spectroscopy; trace elements by instrumental neutron activation analysis; Nb, Y, and Cu determined by energy dispersive X-ray spectroscopy
[5]LOI = Loss on ignition

Table 2. *K-Ar formation age.*

Lava Flow	Map Symbol	Sample number	K-Ar age (Ma)	Mineral	Longitude	Latitude	Lab used	Reference	Comments
Summit	Qbs	C-1730-8A	0.94 ± 0.14	whole rock	-112.9592	37.7700	USGS	Anderson and Mehnert (1979)	
Summit	Qbs	C-1730-9	1.00 ± 0.16	whole rock	-112.9597	37.7733	USGS	Anderson and Mehnert (1979)	incorrectly listed as 112º 58' 35' '

NOTES:
Age uncertainity = 2 standard deviations

Table 3. *Oil and gas exploration well information.*

Operator	Well Name	API Well Number	Year Abandoned	Qtr/Qtr	Section	Township-Range	Latitude	Longitude	Elevation	Total Depth (feet)	Formation Tops (feet)
Moutain Fuel Supply Co.	Little Salt Lake Gov't 1 (WSW)	43-021-10758	1963	NESE	9	34S-10W	37.8592	-112.97825	6113	4400	Jurassic, undivided: 2929 Monzonite: 3490

Source: Utah Division of Oil, Gas and Mining Data Explorer: https://dataexplorer.ogm.utah.gov/

INTERIM GEOLOGIC MAP OF THE SUMMIT QUADRANGLE, IRON COUNTY, UTAH

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Tyler R. Knudsen

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Disclaimer

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UTAH DNR GEOLOGICAL SURVEY

OPEN-FILE REPORT 775DM
UTAH GEOLOGICAL SURVEY
UTAH DEPARTMENT OF NATURAL RESOURCES
2026

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SUMMARY

The Summit 7.5' quadrangle is centered on the town of Summit, Iron County, in southwestern Utah. The quadrangle covers the precipitous Hurricane Cliffs along the northwestern margin of the Markagunt Plateau and part of southern Parowan Valley. The northwestern part of the map area covers the southern Red Hills. The quadrangle is bisected from northeast to southwest by Interstate 15. Bedrock in the Summit quadrangle consists of a vertical sequence of sedimentary and volcanic rocks ranging in age from Late Cretaceous to Early Pleistocene. Along much of the Hurricane Cliffs, Cretaceous through Eocene strata dip moderately to steeply northwest as part of the Cedar City-Parowan monocline. The newly described Summit thrust fault places gently north-dipping Cretaceous rocks over west-dipping Cretaceous rocks of the Cedar City-Parowan monocline. Structural relations show that the Summit thrust fault and Cedar City-Parowan monocline are genetically linked and represent the eastward progression of Sevier-age deformation in this area that was active into the Eocene. The modern landscape is dominated by northeast-southwest-trending Basin and Range normal faults that form a series of horsts and grabens. The largest graben, Parowan Valley, is bound by the Parowan fault on the east and the Red Hills fault on the west. The Parowan fault and nearby intrabasin faults in Parowan Valley have locally displaced Late Pleistocene to Holocene alluvial-fan deposits, indicating that the faults should be considered hazardous. This horst-graben system extends onto the Markagunt Plateau, where the Summit Mountain graben preserves Oligocene and Miocene volcanic rocks and Miocene regional-scale gravity-slide deposits derived from the Marysvale volcanic field about 45 miles (72 km) to the north. Extensive Quaternary landslide complexes conceal much of the bedrock near Elliker Basin, Braffits Creek, and Summit Creek.

MAP UNIT DESCRIPTIONS

QUATERNARY

Human-derived deposits

Qh **Artificial fill** (Historical) – Borrow material and engineered fill used to construct flood-control dams, retaining ponds, and other uses; minor fill associated with roadways and building pads generally not mapped; typically less than 20 feet (6 m) thick.

Alluvial Deposits

Qa_1 **Stream alluvium** (Late Holocene) – Stratified, moderately to well-sorted gravel, sand, silt, and clay-size sediment deposited in channels, floodplains, and minor river terraces of Parowan Creek, which no longer receives water/sediment flow in the Summit quadrangle due to diversions; maximum thickness about 20 feet (3 m) thick.

Qay **Young alluvium** (Holocene to Late Pleistocene) – Moderately sorted sand, silt, clay, and pebble to boulder gravel deposited in low-gradient stream channels, floodplains, and adjacent low river terraces; includes small alluvial-fan deposits from adjacent minor drainages and colluvium from adjacent slopes too small to map separately; locally incised by narrow, active stream channels; includes historical debris-flow and debris-flood deposits; probably less than 20 feet (6 m) thick, but deposits in Summit Canyon and Winn Hollow may locally exceed 30 feet (9 m) thick.

Qaf_2 **Level-2 fan alluvium** (Early Holocene to Late Pleistocene) – Poorly to moderately sorted, subangular to subrounded, clay- to boulder-size sediment deposited principally by debris flows and debris floods; forms mostly inactive, moderately incised surfaces cut by younger stream and fan deposits; fault scarps locally prominent on these deposits; equivalent to the older, lower part of younger fan alluvium (Qafy); less than 30 feet (9 m) thick.

Qafy **Younger fan alluvium** (Holocene to Late Pleistocene) – Poorly to moderately sorted, non-stratified, subangular to subrounded, boulder- to clay-size sediment deposited at the mouths of streams and washes; forms both active depositional surfaces and low-level mostly inactive surfaces incised by small streams (Qaf_2 equivalent) that are undivided here; deposited principally as debris flows and debris floods, but colluvium locally constitutes a significant part of the deposits; small isolated deposits are typically less than a few tens of feet thick, but large, coalesced deposits are probably as much as 200 feet (60 m) thick.

Qafc **Coalesced fan alluvium** (Holocene to Late Pleistocene) – Poorly to moderately sorted, non-stratified, subangular to subrounded, boulder- to clay-size sediment that forms coalesced alluvial fans in Parowan Valley; deposited principally by debris flows and debris floods; similar to younger fan alluvium (Qafy) but typically exhibits a lower overall slope and a larger percentage of fine-grained deposits; locally includes small eolian-sand deposits too small to map separately; unconsolidated to poorly consolidated Neogene basin-fill deposits are as much as 2000 feet (610 m) thick in southern Parowan Valley (Hurlow, 2002); only the uppermost part of this basin fill is included in map unit Qafc; likely less than 200 feet (60 m) thick.

Qafo **Older alluvium** (Early? to Late Pleistocene) – Poorly to moderately sorted, non-stratified, subangular to subrounded, clay- to boulder-size sediment with moderately developed pedogenic carbonate; forms broad, gently sloping, deeply dissected surfaces; deposited principally as debris flows and debris floods; exposed thickness is generally less than 40 feet (12 m), but Qafo deposits on the floor of Parowan Valley may be more than 100 feet (30 m) thick.

Colluvial Deposits

Qc **Colluvium** (Holocene to Late? Pleistocene) – Poorly to moderately sorted, angular to subrounded, clay- to boulder-size, locally derived sediment deposited principally by slope wash and soil creep on moderate slopes and in shallow depressions; locally includes talus and alluvial deposits too small to map separately; typically less than 20 feet (6 m) thick.

Qco **Older colluvium** (Late? Pleistocene) – Poorly to moderately sorted, angular, clay- to boulder-size, locally derived sediment deposited principally by slope wash and soil creep; forms gently sloped, moderately resistant caps on Claron Formation exposed in upper Red and Dalley Canyons; locally includes talus and alluvial deposits too small to map separately; typically less than 20 feet (6 m) thick.

Mass-movement deposits

The Summit quadrangle contains extensive mass-wasting deposits that span in age from older Miocene megabreccia deposits (mapped and described separately) of the Marysvale gravity slide complex (Biek et al., 2019, 2020, 2022) to younger, historically active landslides in West Fork Braffits Creek. The youngest landslide deposits (Qms) are locally derived from adjacent slopes and exhibit youthful landslide features such as hummocky topography, main and internal scarps, and lobate morphologies indicating a Late Pleistocene age or younger. Older Quaternary landslides (Qmso) are mapped where deposits are perched high above modern drainages, and/or where source areas have been removed by erosion, indicating a Middle Pleistocene or older age. Quaternary landslide deposits are generally unfaulted by underlying high-angle normal faults, although the Parowan fault appears to displace Qmso deposits near Elliker Basin.

Qms **Landslide deposits** (Historical to Late? Pleistocene) – Very poorly sorted, locally derived material deposited principally by rotational and translational movement; locally includes flow-style deposits with lobate morphology; composed of clay- to boulder-size debris as well as large, partly intact bedrock blocks; composition and color depends on local source; characterized by hummocky topography, internal scarps, chaotic bedding attitudes, small ponds, marshy depressions, and meadows; where possible, monolithologic and polylithologic landslide debris composed of recognized map units are mapped separately, with the bedrock units identified in parentheses within the label—for example, Qms(Qbe); parts of the landslide complex filling the West Fork Braffits Creek drainage are historically active; age and stability determinations require detailed geotechnical investigations; thickness highly variable, some larger landslide complexes are likely at least 200 to 300 feet (60–90 m) thick.

Qms(Qbe), Qms?(Qbe)

Landslide deposits of the Elliker Basin lava flow (Holocene to Late? Pleistocene) – Back-rotated slump blocks of Elliker Basin lava flow southeast of Elliker Basin; queried where a mostly coherent, moderately northwest-dipping sheet of Elliker Basin lava flow may be in place on the footwall of the Parowan fault; see Qms unit description for more information; several tens of feet thick.

Qmso **Older landslide deposits** (Late? to Early? Pleistocene) – Very poorly sorted, locally derived material deposited principally by rotational and translational movement; locally includes flow-style deposits; composed of clay- to boulder-size debris as well as large, partly intact bedrock blocks; deposits are deeply dissected by modern drainages and source areas have locally been removed by erosion, indicating a likely Pleistocene age; composition and color depends on local source; characterized by hummocky topography and chaotic bedding attitudes, generally lack youthful landslide features such as scarps and lobate morphology; even landslides that have subdued morphology (suggesting that they are older, weathered, and have not experienced recent, large-scale movement) may continue to exhibit slow creep or are capable of renewed movement if stability thresholds are exceeded (Ashland, 2003); age and stability determinations require detailed geotechnical investigations; where possible, monolithologic landslide debris composed of a recognized map unit is mapped separately, with the bedrock unit identified in parentheses within the label—for example, Qmso(Ti); many Qmso deposits mapped in the Summit quadrangle may be equivalent to older Quaternary-Tertiary landslide deposits (QTms) mapped in the adjacent Parowan quadrangle (Knudsen, 2024a), but are not differentiated here due to low confidence in that correlation; thickness highly variable, but locally exceeds several hundred feet.

The hummocky topography and the apparent complexly folded and faulted volcanic units that characterize the Elliker Basin area have previously been explained by the effects of Neogene monoclinal folding (e.g., Anderson and Bucknam, 1979; Anderson and Christenson, 1989, p. 10) or are the result of faulted and juxtaposed megabreccia and lower-plate autochthonous volcanic rocks (Maldonado et al., 1997, plate 1; Biek et al., 2015). Interpretation of lidar (Utah Geospatial Resource Center, 2020) shows hummocks, closed basins, scarps, and lobate topography that are typical of landslide complexes. The unusual topography and geological complexity at Elliker Basin are here interpreted as the result of the Early Pleistocene deposition of landslide blocks derived from the ancestral Hurricane Cliffs. The 0.9 Ma Elliker Basin lava flow (Qmso[Qbe]) is present within the landslide complex, although it is less deformed than underlying landslide blocks. Therefore, most of the landsliding at Elliker Basin occurred prior to the emplacement of the Elliker Basin lava flow, with only minor remobilization of the deposits and overlying lava flow since 0.9 Ma. The source area for landslide deposits was likely a now-eroded series of cliffs located about where lower West Fork Braffits Creek is today. North-northeast of Elliker Basin, distal blocks of Cretaceous strata (Qmso[Ksj]) have no plausible source in the modern landscape, indicating that the current Hurricane Cliffs at this latitude are significantly more subdued today than they were in the Early Pleistocene. The Elliker Basin landslide complex largely conceals the Parowan fault, although subtle scarps aligned with the inferred trace of the fault indicate that the landslide deposits are likely displaced by recurrent movement on the fault.

The large landslide complexes preserved in the Summit Mountain graben contain several recognizable blocks of the Isom and Leach Canyon Formations, and Bauers Tuff. Brian Head strata are dispersed throughout many of the deposits and likely hosted detachment surfaces in the landslides' source areas. Some monolithic landslide blocks in the Summit Mountain graben are likely remobilized gravity-slide deposits, although differentiating between slump blocks derived from gravity-slide deposits versus slump blocks derived from autochthonous Tertiary volcanic rocks was not always possible.

Qmso(Qbe), Qmso(Qbe?)

Older landslide deposits of Elliker Basin lava flow (Late? to Early? Pleistocene) – Mapped where the Elliker Basin lava flow has slumped and been transported as large blocks within the Elliker Basin landslide complex; queried north-northeast of Elliker Basin where large distal slump blocks of lava flow are tentatively correlated with the Elliker Basin lava flow but could also be correlative with the Summit lava flow; see Qmso unit description for more information; several tens of feet thick.

Qmso(Tqh)

Older landslide deposits of Harmony Hills Tuff (Late? to Early? Pleistocene) – Discontinuous, sheared blocks of Harmony Hills Tuff mapped as part of the Elliker Basin landslide complex; see Qmso unit description for more information; less than 50 feet (15 m) exposed.

Qmso(Tqcb)

Older landslide deposits of Bauers Tuff Member of the Condor Formation (Late? to Early? Pleistocene) – Small, structurally isolated slivers of Bauers Tuff Member mapped as part of the Elliker Basin landslide complex; includes some larger partly intact slump blocks mapped in the Summit Mountain graben; see Qmso unit description for more information; thickness highly variable, but deposits in the Summit Mountain graben likely exceed 150 feet (45 m).

Qmso(Tql)

Older landslide deposits of Leach Canyon Formation (Late? to Early? Pleistocene) – Structurally isolated slivers of Leach Canyon Formation mapped as part of the Elliker Basin landslide complex; includes larger, partly intact slump blocks mapped in the Summit Mountain graben; see Qmso unit description for more information; thickness highly variable, but deposits in the Summit Mountain graben likely exceed 200 feet (60 m).

Qmso(Ti)

Older landslide deposits of Isom Formation (Late? to Early? Pleistocene) – Structurally isolated slivers of Isom Formation mapped as part of the Elliker Basin landslide complex; includes larger, partly intact slump blocks mapped in the Summit Mountain graben; see Qmso unit description for more information; thickness highly variable, but deposits in the Summit Mountain graben likely exceed 200 feet (60 m).

Qmso(Tcwl)

Older landslide deposits of lower white member of the Claron Formation (Late? to Early? Pleistocene) – Single rotated block of white micritic limestone exposed within an unnamed drainage between Red and Dalley Canyons near the base of the Hurricane Cliffs; see Qmso unit description for more information; about 80 feet (25 m) exposed.

Qmso(Tcp)

Older landslide deposits of pink member of the Claron Formation (Late? to Early? Pleistocene) – Mapped where highly sheared slivers of pink member are interspersed within older landslide deposits of Isom Formation between Dalley and Red Canyons near the base of the Hurricane Cliffs; see Qmso unit description for more information; less than 150 feet (45 m) exposed.

Qmso(Ksj)

Older landslide deposits of John Henry Member of the Straight Cliffs Formation (Late? to Early? Pleistocene) – Back-rotated slump blocks of John Henry Member mapped at the distal northern edge of the Elliker Basin landslide complex; see Qmso unit description for more information; less than 100 feet (30 m) exposed.

Qmt **Talus** (Holocene to Late Pleistocene) – Poorly sorted, angular cobbles and boulders and finer-grained interstitial sediment deposited principally by rockfall on or at the base of steep slopes and cliffs; talus is common at the base of steep slopes across the map area, but is only mapped where it conceals contacts or forms broad aprons below cliffs of resistant bedrock units; typically grades downslope into colluvium and combined where impractical to differentiate the two; may also include alluvium in the bottom of washes where too small to map separately; typically less than 30 feet (9 m) thick.

Mixed-environment deposits

Qac **Alluvium and colluvium** (Holocene to Late Pleistocene?) – Poorly to moderately sorted, generally poorly stratified, clay- to boulder-size, locally derived sediment deposited in swales and small drainages by fluvial, slope-wash, and creep processes; gradational with alluvial and colluvial deposits; generally less than 20 feet (6 m) thick.

Qacf **Alluvium, colluvium, and fan alluvium** (Holocene to Late Pleistocene) – Poorly to moderately sorted, non-stratified, clay- to boulder-size sediment deposited principally by debris flows, debris floods, and slope wash at the mouths of active drainages and the base of steep slopes; locally reworked by small, ephemeral streams; forms coalesced apron of fan alluvium and colluvium impractical to map separately; typically 10 to 40 feet (3–12 m) thick.

Qae **Alluvium and eolian sand** (Holocene to Late Pleistocene) – Moderately to well-sorted, mostly light-reddish-brown silt and sand deposited by sheetwash and ephemeral streams and locally reworked by eolian processes on the Red Hills lava flow; probably less than 15 feet (5 m) thick.

Qea **Eolian sand and alluvium** (Holocene to Late Pleistocene) – Moderately to well-sorted, light-brown, fine- to medium-grained eolian sand locally reworked by alluvial processes in Parowan Valley; locally includes minor gravel, sand, and silt deposited in small stream channels; generally less than 20 feet (6 m) thick.

Qmtc **Talus and colluvium** (Holocene to Late Pleistocene) – Poorly sorted, angular to subangular, cobble- to boulder-size and finer-grained interstitial sediment deposited principally by rockfall and slope wash on steep slopes; includes minor alluvial sediment at the bottom of washes and locally contains small landslides; generally less than 30 feet (9 m) thick.

Qmsc **Landslides and colluvium** (Holocene to Late Pleistocene) – Unsorted, locally derived, clay- to boulder-size material deposited by slope wash and shallow landslides; mapped where landslide deposits are difficult to identify and intermixed with colluvium; most deposits are less than 40 feet (12 m) thick.

Basaltic lava flows

Qbs, Qbsc

Summit lava low and cinder cone (Early Pleistocene) – Medium- to dark-gray, fine-grained olivine basalt (Table 1) that Maldonado et al. (1997) referred to as the Cinder Hill cone and flow; lava flow (Qbs) erupted from a vent at a cinder cone (Qbsc) at the base of the Hurricane Cliffs, about 2 miles (3 km) southwest of Summit; the cinder cone has been displaced downward and folded by west-dipping normal faults associated with the Parowan fault so that the cone now sits at a lower elevation than much of the flow exposed higher in the Hurricane Cliffs; Qbs also crops out at the southeast margin of the Red Hills near Braffits Creek (Nealey et al., 1997) and is presumed to underlie the southern part of the Parowan Valley graben, where it is displaced by graben-bounding faults; yielded K-Ar ages of 1.00 ± 0.16 Ma and 0.94 ± 0.14 Ma (Anderson and Mehnert, 1979; Table 2); lava flow is as much as 60 feet (18 m) thick above East Fork Braffits Creek.

Qbe **Elliker Basin lava low** (Early Pleistocene) – Medium- to dark-gray, fine-grained olivine basaltic trachyandesite (shoshonite; Table 1) mapped near the southern end of the Red Hills and near Elliker Basin; lava flow remnants at Elliker Basin are not continuous and commonly rotated to disparate attitudes and are here interpreted to be part of the Elliker Basin landslide complex; vent area is uncertain, but outcrop patterns and discovery of basaltic dikes in West Fork Braffits Creek indicate the vent may have been centered there; yielded K-Ar ages of 1.00 ± 0.16 Ma and 1.11 ± 0.11 Ma (Anderson and Mehnert, 1979); lava flow is generally less than 20 feet (6 m) thick.

Qid **Basaltic dikes** (Early Pleistocene?) – Medium-gray, fine-grained olivine basalt dikes exposed in the north canyon wall of West Fork Braffits Creek; appears to be of similar composition to nearby Summit and Elliker Basin lava flows, but based on location, is here interpreted to be feeder dikes to the Elliker Basin vent area that has since been removed by erosion and landslides; dikes intruded into Grand Castle Formation and the capping sandstone member of the Wahweap Formation; most dikes trend northeast and are subvertical, although the northernmost exposed dike dips 48° to the west, concordant with Wahweap bedding; thickness ranges from 3 to 10 feet (1–3 m).

Qbrh, Qbrhc

Red Hills lava low and cinder cone (Early Pleistocene) – Medium- to dark-gray, fine-grained basaltic andesite (Table 1) with small olivine and plagioclase phenocrysts; lava flows (Qbrh) erupted from vents at three cinder cones (Qbrhc) along the central axis of the Enoch graben in the Red Hills—two in the Summit quadrangle and one in the Enoch quadrangle (Rowley and Threet, 1976; Knudsen, 2014; Biek et al., 2015); lava flow partially fills the Enoch graben and is cut by graben-bounding faults; yielded K-Ar ages of 1.28 ± 0.4 Ma (Anderson and Mehnert, 1979) and 1.30 ± 0.4 Ma (Best et al., 1980); lava flow is typically about 25 feet (8 m) thick.

unconformity

QUATERNARY-TERTIARY

QTaf **Basin-fill deposits** (Pleistocene? to Late Miocene?) – Poorly to moderately sorted, non-stratified, subangular to subrounded, clay- to boulder-size sediment with moderately to well-developed calcic soils (caliche); forms deeply dissected surfaces with no remaining fan morphology; deposited principally as debris flows; widely exposed in the southern Red Hills where these deposits are stranded on exhumed, fault-bounded horst blocks; presumed to underlie much of Parowan Valley; prominent clasts include Tertiary volcanic rocks, pale-reddish-orange and light-pinkish-gray limestone and calcareous mudstone of the Claron Formation, and yellowish-brown Cretaceous siltstone and sandstone; includes lesser amounts of chalcedony and recycled quartzite from the Grand Castle Formation, Drip Tank Member of the Straight Cliffs Formation, and Claron Formation; locally overlain by the ~1 Ma (Anderson and Mehnert, 1979) Summit lava flow; texture and clast lithology is similar to QTaf deposits mapped in the Cedar City quadrangle (Knudsen, 2024b), where the unit is interpreted as basin-fill deposits shed off of the ancestral Hurricane Cliffs (Averitt, 1962, 1964; Knudsen, 2024b); maximum exposed thickness in map area is about 200 feet (60 m).

unconformity

TERTIARY

Marysvale gravity slide complex (Early Miocene to Late Oligocene) – Gravitational collapse of the south flank of the Oligocene to Miocene Marysvale volcanic field produced three gigantic catastrophic gravity slides—the Sevier (SGS), Markagunt (MGS), and Black Mountains (BGS)—that form an overlapping contiguous complex covering an area >2800 mi^2 (>7200 km^2) (Biek et al., 2019, 2020, 2022). Each mega-slide travelled southward away from the volcanic edifice with runout over the former land surface of at least 20 miles (32 km). Features such as basal cataclastic breccias and shears, clastic dikes (injectites), jigsaw puzzle fracturing of clasts, and rare pseudotachylyte (frictionite) indicate high-velocity movement aided by over-pressured fluids (Biek et al., 2019, 2022; Braunagel et al., 2023). The principal zone of failure was in mechanically weak, clay-rich, Brian Head Formation sedimentary strata at the base of the volcanic section.

The gravity slide masses become younger westward, possibly following westward migration of volcanism in the field. SGS emplacement was at about 25 Ma, MGS emplacement was at about 23 Ma, and BGS emplacement was at about 21 Ma (Biek et al., 2019; Holliday et al., 2022; Mayback et al., 2022; Stevens et al., 2023; Rivera et al., 2025).

Biek et al. (2019, 2022) provided a history of discovery and current understanding of the gravity slides along with a guide to locations of particularly instructive exposures wherein they drew their conclusions about size, distinctive structural features, emplacement ages, and interpreted emplacement mechanisms.

The BGS is the most recently discovered part of the Marysvale gravity slide complex and is currently the most poorly understood (Rowley et al., in review). The Summit quadrangle lies within the southernmost extent of the BGS as currently understood (Biek et al., 2022), and I tentatively assign gravity-slide (megabreccia) deposits in the Summit quadrangle to the BGS. Components of the Black Mountains Megabreccia (Tmb) are listed below; for their descriptions, see the named pre-existing (undeformed) rock unit elsewhere in the text and in the correlation chart.

Tmb **Black Mountains Megabreccia deposits, undivided** (Early Miocene) – Chaotic mix of mostly Isom Formation blocks interspersed with sheared blocks of Leach Canyon Formation and calcedony-rich Brian Head Formation with lesser amounts of Bauers Tuff Member; deposits rest on a seemingly autochthonous Tertiary volcanic section well-exposed in the Summit Narrows that includes rocks as young as the ~22 Ma Harmony Hills Tuff; as much as 400 feet (120 m) thick.

Tmb(Tql)

Black Mountains Megabreccia deposits of Leach Canyon Formation (Early Miocene) – Mapped where monolithic piles of intensely brecciated Leach Canyon Formation are present in the Summit Mountain graben, along a ridge east of Elliker Basin, and north of Winn Hollow; typically rests on similarly brecciated Isom Formation, but appears to rest on autochthonous Leach Canyon Formation near Elliker Basin; as much as 400 feet (120 m) thick in the Summit Mountain graben.

Tmb(Ti)

Black Mountains Megabreccia deposits of Isom Formation (Early Miocene) – Mapped where monolithic piles of intensely brecciated Isom Formation are present in the Summit Mountain graben, along a ridge east of Elliker Basin, and at Winn Hollow; typically rests on highly sheared Brian Head Formation or highly brecciated Leach Canyon Formation, and is locally repeated with intervening Leach Canyon breccia; maximum exposed thickness is about 450 feet (135 m) in Dalley Canyon.

Tmb(Tn)

Black Mountains Megabreccia deposits of Needles Range Group, undivided (Early Miocene) – Pale-red to grayish-orange-pink, moderately welded, crystal-rich, poorly exposed, dacitic ash-flow tuff (Mackin, 1960) that crops out between underlying Brian Head Formation and overlying Isom Formation near Winn Gap, but is here interpreted to be part of the Black Mountains Megabreccia; phenocrysts of plagioclase, hornblende, and biotite (plus minor quartz, Fe-Ti oxides, and sanidine) constitute about 40% of the rock; derived from the 27 to 32 Ma Indian Peak caldera complex that straddles the Utah-Nevada border (Best et al., 1989a, 1989b, 2013); Lund Formation unconformably overlies the similar Wah Wah Springs Formation, but is undivided here due to structural complications; today, the Wah Wah Springs covers at least 8500 square miles (22,000 km^2) with an estimated volume of as much as about 720 cubic miles (3000 km^3), making it one of the world's most voluminous ash-flow tuffs (Best et al., 1989a); the Lund Formation is of similar volume; Lund Formation is about 27.9 Ma and the Wah Wah Springs Formation is about 29.5 Ma on the basis of many K-Ar and $^{40}Ar/^{39}Ar$ age determinations (Best and Grant, 1987; Best et al., 1989a, 1989b; Rowley et al., 1994a; Best et al., 2013); about 100 to 300 feet (30–90 m) thick in the southern Black Mountains (Rowley, 1976), but only about 25 feet (8 m) of structurally thinned Tn is preserved in the Summit quadrangle.

Tmb(Tbh)

Black Mountains Megabreccia deposits of Brian Head Formation (Early Miocene) – Slivers of sheared white to light-gray sandstone and mudstone and multi-hued chalcedony of the Brian Head Formation mapped in Dalley Canyon and Winn Hollow; underlies gravity-slide deposits of Isom Formation and Needles Range Group; maximum exposed thickness is about 100 feet (30 m) in Dalley Canyon.

structural unconformity

Quichapa Group (Early Miocene to Late Oligocene) – Consists of three regionally distinctive ash-flow tuffs: in ascending order, the Leach Canyon Formation, Condor Canyon Formation, and Harmony Hills Tuff (Mackin, 1960; Williams, 1967; Anderson and Rowley, 1975; Rowley et al., 1995).

Tqh **Harmony Hills Tuff** (Early Miocene) – Pale-pink to grayish-orange-pink, crystal-rich, moderately welded dacitic ash-flow tuff; contains about 50% phenocrysts that include plagioclase (~60%), biotite (~15%), hornblende (~10%), quartz (~10%), pyroxene (~5%), and sanidine (trace) (Williams, 1967); weathers to rounded outcrops and glittery, sandy soils; the only in-place exposure of Harmony Hills Tuff in the map area is in the northwest corner of section 8, T. 35 S., R. 9 W. in Summit Canyon where it overlies the Bauers Tuff Member and underlies deposits of the Black Mountains Megabreccia (Tmb); rotated blocks of Tqh elsewhere in the map area are interpreted to be Quaternary landslide blocks; source of the Harmony Hills Tuff is unknown, but isopach thickness is greatest near Bull Valley (Williams, 1967), suggesting that it was derived from the eastern Bull Valley Mountains, probably from an early, much more voluminous eruptive phase of the Bull Valley/Hardscrabble Hollow/Big Mountain intrusive arch, as suggested by Blank (1959), Williams (1967), and Rowley et al. (1995, 2006); a preliminary $^{40}Ar/^{39}Ar$ age of 22.023 ± 0.093Ma (hornblende) and 22.14 ± 0.03 Ma (biotite) for the unit in Parowan Canyon (written communication from Tiffany Rivera, University of Missouri, as reported by Rowley et al. [in review]) agrees well with an $^{40}Ar/^{39}Ar$ plateau age of 22.03 ± 0.15 Ma by Cornell et al. (2001); less than 40 feet (12 m) is exposed in Summit Canyon.

Tqcb **Bauers Tuff Member of Condor Canyon Formation** (Early Miocene) – Resistant, crystal-poor, light-brownish-gray to pinkish-gray, densely welded, rhyodacitic ash-flow tuff; contains about 10% to 20% phenocrysts of plagioclase (40%–70%), sanidine (25%–50%), biotite (2%–10%), Fe-Ti oxides (1%–8%), and pyroxene (<3%), but lacks quartz phenocrysts (Rowley et al., 1995); bronze-colored biotite present in the upper part of the unit, light-gray flattened lenticules are conspicuous throughout the unit, and a basal vitrophyre 10 to 20 feet (3–6 m) thick is normally present; overlies the Leach Canyon Formation between Summit and Dalley Canyons, and appears as rotated Quaternary landslide blocks elsewhere in the map area; derived from the northwest part (Clover Creek caldera) of the Caliente caldera complex; at the time of its eruption, covered an area of at least 8900 square miles (23,000 km^2) (Best et al., 1989b; Rowley et al., 1995) with an estimated volume of 740 mi^3 (3200 km^3) (Best et al., 2013); the preferred $^{40}Ar/^{39}Ar$ age of the Bauers Tuff Member is 22.7 Ma (Best et al., 1989a) or 22.8 Ma (Rowley et al., 1995), which is the $^{40}Ar/^{39}Ar$ age of its intracaldera intrusion exposed just north of Caliente, Nevada (Rowley et al., 1994b); about 150 feet (45 m) thick in Summit Canyon but thins to about 50 feet (15 m) to the north in Parowan Canyon (Maldonado and Moore, 1995; Biek et al., 2015; Knudsen, 2024a).

Tql **Leach Canyon Formation, undivided** (Late Oligocene) – Light-pinkish- to orangish-gray, poorly to moderately welded, crystal-rich rhyolite ash-flow tuff that contains abundant white to pale-yellow pumice fragments and lithic clasts, many of which are reddish-brown; contains as much as 25% to 35% total phenocrysts of plagioclase and subequal amounts of quartz and sanidine, with minor biotite, hornblende, Fe-Ti oxides, and a trace of pyroxene; disconformably overlies the Isom Formation and is locally overlain by Black Mountains Megabreccia; source is uncertain, but it is probably the Caliente caldera complex because isopach thickness increases toward the complex spanning the Utah-Nevada border (Williams, 1967; Rowley et al., 1995); total volume of the Leach Canyon is estimated to be 830 cubic miles (3600 km^3), representing the largest eruption of the Caliente caldera complex (Best et al., 2013); widely agreed to be about 23.8 Ma (Best et al., 1993; Rowley et al., 1995; Biek et al., 2015); as much as 250 feet (75 m) thick in Summit Canyon.

Tda **Mount Dutton Formation, alluvial facies** (Early Miocene to Early Oligocene) – Resistant to non-resistant, brown, tan, pink, and gray, volcanic mudflow breccia containing matrix-supported angular clasts; mudflow clasts are mostly aphanitic and andesitic rock with sparse small phenocrysts of mostly pyroxene and plagioclase; includes lesser interbedded volcaniclastic conglomerate and tuffaceous sandstone, lava flows, and flow breccia; well exposed in a single mapped outcrop southeast of Second Mound where it rests on Isom Formation; additional Tda rubble—too small to map separately—was found worked into Qms, Qmso, and Tmb deposits at scattered locations in the Summit Mountain graben; deposited from clustered stratovolcanoes that formed most of the southern Marysvale volcanic field (e.g., Callaghan, 1938; Anderson and Rowley, 1975; Rowley et al., 1979, 1998, 2002; Steven et al., 1979, 1990; Cunningham et al., 1983; Campbell et al., 1999); K-Ar dated at 21 to 26 Ma (Fleck et al., 1975), but some deposits predate the Wah Wah Springs Formation and therefore are 30 Ma or older; the most voluminous unit in the Marysvale volcanic field; thickness varies from 0 to at least 200 feet (60 m).

unconformity

Ti **Isom Formation, undivided** (Late Oligocene) – Resistant, medium-gray to reddish-brown, crystal-poor, densely welded, trachydacitic ash-flow tuff, typically having distinctive rheomorphic features including flow folds, elongated vesicles, and flow breccias and thus informally described as a “tufflava” (Mackin, 1960; Cook, 1965, 1966; Anderson and Rowley, 1975, 2002); small (1–3 mm) phenocrysts constitute 10% to 15% or less of the rock and are mostly plagioclase (90%) and minor pyroxene and Fe-Ti oxides in a devitrified-glass groundmass; exhibits pronounced subhorizontal lamination or platiness, which Mackin (1960) called “lenticules”; most outcrops have a glass-like fracture habit and weather to grussy, ledgy slopes; the Isom Formation is about 26 to 27 Ma on the basis of many $^{40}Ar/^{39}Ar$ and K-Ar ages (Best et al., 1989b; Rowley et al., 1994a), and because it is locally interbedded with the ~26 Ma Buckskin Breccia (Anderson et al., 1987); Rivera et al. (in review) reported a U-Pb age on zircon of 26.26 ± 0.24 Ma for the Isom Formation in Summit Canyon; likely derived from the Indian Peak caldera complex at the Utah-Nevada border (Best et al., 1989a, 1989b); base not exposed, but is as much as 300 feet (90 m) thick in Summit Canyon; Biek et al. (2015) reported a thickness of about 350 feet (110 m) at Black Ledge about 8 miles (13 km) east of the Summit quadrangle.

unconformity

Brian Head Formation (Early Oligocene to Late Eocene) – The Brian Head Formation is the oldest widespread Tertiary volcaniclastic unit in the southern part of the Marysvale volcanic field. See Sable and Maldonado (1997) and Biek et al. (2015) for a summary of the long and complicated nomenclatural history of the Brian Head Formation. The Brian Head Formation was deposited in low-relief fluvial, floodplain, and lacustrine environments in which large amounts of volcanic ash accumulated (Sable and Maldonado, 1997). Northern exposures include coarser deposits on the distal flanks of early stratovolcanoes of the Marysvale volcanic field. The Brian Head Formation is 30 to 37 Ma, based on numerous isotopic and fossil ages (e.g., Fleck et al., 1975; Sable and Maldonado, 1997; Eaton et al., 1999a; Korth and Eaton, 2004; Biek et al., 2015; Malone et al., 2025).

Tbh **Brian Head Formation, middle volcaniclastic unit** – White, light-gray, and pale-yellow sandstone and limestone, with lesser amounts of varicolored mudstone, conglomerate, and multi-hued chalcedony; conglomerate clasts are quartzite, limestone, and chert with minor clasts of intermediate-composition volcanic rocks; chalcedony is various shades of white, gray, yellow, red, black, and brown, typically has a white weathering rind, is commonly highly brecciated and re-silicified, typically occurs in beds 1 to 3 feet (0.3–1 m) thick, is locally stained by manganese oxides, and likely produced by silicification of limestone beds (Maldonado, 1995; Sable and Maldonado, 1997; Schinkel, 2012); abundant bentonitic clay derived from weathered volcanic ash, weathers to strongly swelling soils; unit forms large landslide complexes; typically nonresistant, poorly exposed, and extensively covered by colluvium derived from overlying volcanic units; deposited in low-relief fluvial, floodplain, and lacustrine environments in which large amounts of volcanic ash accumulated (Sable and Maldonado, 1997); about 500 feet (150 m) thick at its type section on Brian Head Peak in the adjoining Brian Head quadrangle (Sable and Maldonado, 1997; Rowley et al., 2013; Biek et al., 2015) and probably of similar thickness in the Summit quadrangle, although less than 150 feet (45 m) is exposed.

unconformity

Claron Formation (Middle Eocene to Paleocene?) – Claron Formation strata are among the most visually striking rocks in the western U.S. and are prominently displayed at Cedar Breaks National Monument and Bryce Canyon National Park, among other places. In the Red Hills and Markagunt Plateau, the Claron Formation is divided into two informal members—an upper white member (which is itself divided into an uppermost mudstone interval, an upper limestone interval, a middle mudstone and sandstone interval, and a lower limestone interval) and the lower pink member (Biek et al., 2015). Claron strata were deposited in fluvial, floodplain, and lacustrine environments of an intermontane basin bounded by Laramide and Sevier uplifts; the pink member is almost entirely fluvial, and the white member is both lacustrine and fluvial (Goldstrand, 1990, 1991, 1992, 1994; Bown et al., 1997). Much of the pink member, and clastic parts of the white member, were greatly modified by bioturbation and pedogenic processes, creating a stacked series of paleosols (Mullett et al., 1988a, 1988b; Mullett, 1989; Mullett and Wells, 1990).

The age of the white member is well constrained as late Middle Eocene (Duchesnean Land Mammal Age), based on limiting U-Pb zircon ages for overlying Brian Head Formation (Rowley et al., 2013; Malone et al., 2025) and conglomerate at Boat Mesa (Biek et al., 2015; Malone et al., 2025), and by Late Eocene mammals and ostracods from what we now know to be part of basal Brian Head strata on the Markagunt Plateau (where it was originally misidentified as uppermost Claron Formation [Eaton et al., 2011, 2018]). Along Sweetwater Creek north of Bryce Canyon National Park, Eaton et al. (2018) recovered the Early Eocene (Wasatchian North American Land Mammal Age) rodents *Knightomys reginensis* and *K. minor* from their unit 7, roughly 900 feet (275 m) above their base of the formation in what may be Tcwm equivalent strata. Charophytes recovered from near the base of the lower pink member at Griffin Top, about 3 miles (5 km) north of Sweetwater Creek, suggest an Early Eocene (Ypresian) age for basal Claron strata (Sanjuan and Eaton, 2016). This suggests that the entire Claron Formation in the Bryce Canyon region is Early Eocene in age. However, throughout the western part of its outcrop belt the maximum age of the mostly nonfossiliferous pink member is poorly constrained as Early Eocene to Paleocene(?) (Goldstrand, 1990, 1994; Sanjuan and Eaton, 2016; Eaton et al., 2018; Biek et al., 2015).

Tcwt **Uppermost mudstone, siltstone, and sandstone unit of white member** (Late and Middle Eocene) – Varicolored and commonly mottled, pale-reddish-orange, reddish-brown, moderate-orange-pink, dark-yellowish-orange, and grayish-pink, calcareous mudstone and siltstone mapped in the southern Red Hills; locally includes minor fine-grained silty sandstone and micritic limestone; indistinguishable in lithology and color from the middle unit of the White Member (Tcwm) of the Claron Formation; forms a brightly colored slope on top of the upper limestone ledge of the white member; about 120 feet (37 m) thick in Winn Hollow.

Tcwu **Upper limestone unit of white member** (Eocene) – White, pale-yellowish-gray, pinkish-gray, and pale-orange micritic limestone, locally containing intraformational rip-up clasts mapped in the southern Red Hills; typically poorly bedded and knobby weathering; locally vuggy with calcite spar and commonly cut by calcite veinlets; resistant and so forms prominent ledges and flat ridge tops; upper conformable contact with Tcwt corresponds to a pronounced color change from white to pale-orange micritic limestone below to brightly colored reddish-orange mudstone and siltstone above; about 25 feet (8 m) thick.

Tcwm **Middle mudstone, siltstone, and sandstone unit of white member** (Eocene) – Varicolored calcareous mudstone and siltstone, and minor fine-grained calcareous sandstone mapped in the southern Red Hills; weathers to a poorly exposed slope; upper conformable contact corresponds to a pronounced color change from brightly colored reddish-orange mudstone and siltstone below to white to very pale-orange micritic limestone above; about 65 feet (20 m) thick.

Tcwl **Lower limestone unit of white member** (Eocene) – White, pale-yellowish-gray, and pale-orange micritic limestone mapped in the southern Red Hills; typically forms a cliff above the pink member (Tcp); upper conformable contact corresponds to a pronounced color change from white to pale-orange micritic limestone below to brightly colored reddish-orange mudstone and siltstone above; about 30 feet (10 m) thick.

Tcp **Pink member** (Eocene to Paleocene?) – Orangish-red, reddish-brown, and light-blue-gray limestone, mudstone, siltstone, sandstone, and conglomerate; locally mottled; oncolitic beds are common; limestone is poorly bedded, microcrystalline, and sandy, with 2% to 20% fine-grained quartz sand; locally argillaceous beds formed as calcic paleosols; fluvial and floodplain deposits greatly modified by bioturbation and pedogenic processes (Mullett et al., 1988a, 1988b; Mullett, 1989; Mullett and Wells, 1990); sandstone is thick-bedded, fine- to coarse-grained, calcareous, locally cross-bedded quartz arenite; mudstone is generally reddish-orange, silty, calcareous, contains calcareous nodules, and weathers to earthy, steep slopes between ledges of sandstone and limestone; pebbly conglomerate forms lenticular beds typically 5 to 15 feet (2–5 m) thick, containing rounded quartzite, limestone, and chert pebbles and cobbles; upper conformable contact corresponds to a pronounced color change from reddish-orange mudstone and siltstone below to white to very pale orange, resistant, micritic limestone of the white member above; about 1000 feet (300 m) thick.

CRETACEOUS

Kgc **Grand Castle Formation** (Late Cretaceous?, Maastrichtian? to late Campanian?) – Light-gray and light-red massive conglomerate; clasts are well-rounded, pebble- to boulder-size quartzite, limestone, sandstone, and chert; typically cliff-forming; redefined and restricted by Biek et al. (2015) to only the upper of three informal members (resistant upper conglomerate, nonresistant middle sandstone, and resistant lower conglomerate) of the Grand Castle Formation of Goldstrand and Mullett (1997); deposited in a braided fluvial environment with paleoflow principally to the east and south-southeast, suggesting source areas in the Wah Wah, Blue Mountain, and Iron Springs thrust sheets of southwest Utah (Goldstrand and Mullett, 1997); Biek et al. (2015) recovered late Campanian to Maastrichtian pollen from Grand Castle strata south of Cedar Breaks National Monument; upper contact with reddish-orange Claron strata is poorly exposed on the Markagunt Plateau, but appears to be gradational and largely conformable in the Red Hills; thickness varies from about 150 feet (45 m) on the Markagunt Plateau to as much 350 feet (105 m) in the southern Red Hills.

unconformity

Kwcs, Kwcs?

Capping sandstone member of the Wahweap Formation (Late Cretaceous, middle Campanian) – White to very pale orange, locally iron stained, mostly medium-grained, trough cross-bedded quartz arenite; the sandstone “caps” the lower mudstone-rich members of the Wahweap Formation near its type section (Kaiparowits Basin) (Eaton, 1991) and much of the Markagunt Plateau; lower undivided mudstone members are generally missing in the Summit quadrangle and the capping sandstone member appears to sit conformably on the Drip Tank Member of the Straight Cliffs Formation; limited exposures in West Fork Braffits Creek include several feet of varicolored and mottled mudstone typical of lower undivided members of the Wahweap; named the Pardner Canyon Member by Beveridge et al. (2022) in the Kaiparowits Plateau; upper part of Kwcs contains abundant pebble stringers and conglomeratic beds with rounded quartzite, dolomite, chert, and limestone clasts; clasts are typically about 1 inch (2.5 cm) in diameter but as large as 2 to 3 inches (5–7.5 cm), and include common reddish-brown and purple quartzite clasts; quartz grains are typically well rounded and commonly frosted, recycled from Mesozoic eolianites (Pollock, 1999; Lawton et al., 2003; see also UGS and AtoZ, 2013); Goldstrand and Mullett (1997) and Lawton et al. (2003) showed that the member was deposited in a braided fluvial environment with a paleoflow direction principally to the east and south-southeast, suggesting source areas in Navajo Sandstone exposed in the upper plate of the Iron Springs thrust; contains carbonized or petrified plant debris, small mudstone rip-up clasts, iron concretions, and soft-sediment deformation features; typically poorly cemented, forming distinctive white, manzanita-covered slope-and-bench topography; queried in the southern Red Hills where yellow-weathering, easily erodible sandstone appears between underlying upper Iron Springs Formation and overlying Grand Castle strata; unusually iron-rich Kwcs concretionary zones in the southern Red Hills, and debris derived from them, appear to be the target of several shallow prospects in the area; Campanian to Santonian palynomorphs and a theropod dinosaur track discovered in Kwcs strata in the adjoining Parowan quadrangle confirm a Late Cretaceous age (Hunt et al., 2011; Biek et al., 2015); chronostratigraphic studies (based on new U-Pb zircon ages) by Beveridge et al. (2022) on the Kaiparowits Plateau placed the upper and lower boundaries of the Wahweap at about 77 and 82 Ma, respectively; typically about 200 feet (60 m) thick.

Iron Springs Formation (Late Cretaceous, Santonian or early Campanian to Cenomanian) – Mapped as upper and lower units in the Red Hills. Iron Springs strata were deposited principally in braided-stream and floodplain environments of a coastal plain (Johnson, 1984; Fillmore, 1991; Eaton et al., 2001; Milner et al., 2006) and is typically correlated to the Naturita Formation, Tropic Shale, and Straight Cliffs Formation (Eaton, 1999; Eaton et al., 2001). Late Cretaceous age is from Goldstrand (1994) and an ash that is 712 feet (217 m) below the top of the formation in Parowan Canyon, which yielded an $^{40}Ar/^{39}Ar$ age of 83.0 ± 1.1 Ma (Eaton et al., 1999b). Lower Iron Springs strata (Kil) in the upper plate of the Iron Springs thrust may be associated with the maximum transgression of the Greenhorn Sea of late Cenomanian or early Turonian age (Eaton et al., 1997; Eaton, 1999; Biek et al., 2015). The entire formation is about 3500 to 4000 feet (1070–1220 m) thick in the Pine Valley Mountains southwest of the quadrangle (Cook, 1960).

Kiu **Upper unit** – Interbedded, ledge-forming, calcareous, cross-bedded, fine- to medium-grained sandstone and less-resistant, poorly exposed sandstone, siltstone, and mudstone present in the footwall of the Iron Springs thrust; variously colored grayish orange, pale yellowish orange, dark yellowish orange, white, pale reddish brown, and greenish gray; locally stained by iron-manganese oxides; Liesegang banding is common in the sandstone beds; sandstone beds range from quartz arenite to litharenite in composition (Fillmore, 1991; Goldstrand, 1992); weathers to repetitive, thick, tabular sandstone beds and thinner interbedded mudstone; upper contact with the Grand Castle Formation (redefined by Biek et al. [2015]) is locally difficult to map because of abundant Grand Castle-derived colluvium covering downslope units; Milner et al. (2006) reported on dinosaur tracks in upper Iron Springs strata near Parowan Gap, and also noted a diverse assemblage of plant fossils, bivalves, gastropods, turtles, fish, and trace fossils suggestive of late Santonian to early Campanian age; an incomplete section exposed in the Red Hills is about 600 feet (180 m) thick.

Kil **Lower unit** – Interbedded sandstone, siltstone, and mudstone similar to that of the upper unit (Kiu) but restricted to the upper plate of the Iron Springs thrust fault; a single incomplete thrust-fault bounded section that is partially concealed by the Red Hills lava flow and is less than 100 feet (30 m) thick.

Straight Cliffs Formation (Late Cretaceous, early Campanian to Turonian) – Peterson (1969) divided the Straight Cliffs Formation into four members in the Kaiparowits Basin, in descending stratigraphic order: the Drip Tank, John Henry, Smoky Hollow, and Tibbet Canyon Members. Several geologists mapped these members (separately or as lumped upper and lower Straight Cliffs strata) on the Paunsaugunt Plateau, including Tilton (1991, 2001a, 2001b), Doelling and Willis (1999), Sable and Hereford (2004), and Doelling (2008). Biek et al. (2015) described the difficulty encountered in early attempts to carry this nomenclature westward into the Markagunt Plateau. The Straight Cliffs Formation is an overall regressive sequence that formed during the last marine incursion of the Western Interior Seaway (e.g., Eaton et al., 2001; Moore and Straub, 2001; Tibert et al., 2003).

Cretaceous strata exposed along the western margin of the Markagunt Plateau from Fiddlers Canyon, in the adjoining Cedar City quadrangle, to Parowan are warped down to the northwest along the Cedar City-Parowan monocline (Threet, 1963; Anderson and Bucknam, 1979; Anderson and Mehnert, 1979; Anderson and Christenson, 1989). Early workers interpreted the monocline to be related to Basin and Range extension. Mapping by Biek et al. (2015) showed that Late Oligocene to Early Miocene regional ash-flow tuffs are not affected by monoclinal folding, and that the fold is likely related to Sevier-age deformation, a conclusion supported by this map. A newly discovered west-verging thrust fault—here called the Summit thrust fault—that extends from Strawberry Canyon northward to Summit Canyon, duplicates the upper parts of the Straight Cliffs Formation. The fault places gently northeast-dipping strata over a lower plate of steeply northwest-dipping rocks of the Cedar City-Parowan monocline, indicating a genetic link between the thrust faulting and the monocline. The Summit Canyon thrust fault likely formed during the late stages of folding that produced the Cedar City-Parowan monocline. Grand Castle and Claron formations exposed near the mouths of Summit and Red Creek Canyons are involved in monoclinal folding indicating that the fold largely developed after Claron strata were deposited. In contrast, the Iron Springs thrust fault exposed in Parowan Gap 8 miles (13 km) north-northwest of Summit Canyon, largely formed prior to deposition of the Grand Castle and Claron Formations with relatively minor displacements continuing into Claron time (Anderson and Dinter, 2010; Biek et al., 2015). Thus, the Cedar City-Parowan monocline and Summit thrust fault represent the Early Eocene eastward progression of Sevier deformation in this area.

Maldonado and Moore (1995) mapped a single thrust fault along the Cedar City-Parowan monocline near the east-central edge of the Parowan quadrangle that they interpreted to place Cretaceous rocks over the pink member of the Claron Formation. Maldonado et al. (1997) described additional thrust faults associated with the monocline in the Summit quadrangle that involve rocks as young as Early Miocene and named the faults the Parowan thrust fault zone. However, I favor the interpretation of Biek et al. (2015; p. 64), who argue that these features are best explained by high-angle normal faulting and landsliding.

Ksd **Drip Tank Member** (Late Cretaceous, early Campanian) – Massive, typically cliff-forming, white to light-gray, medium-grained sandstone and pebbly conglomerate; larger clasts (pebble to cobble) are subrounded to rounded, white, gray, and purplish-red quartzite, with local minor blue-gray Paleozoic limestone and black chert; sandy matrix consists of white to light-gray, subangular sand and silt; locally iron stained; forms a low, narrow ridge; formerly called the lower conglomerate member of the Grand Castle Formation (Eaton, 1991), but Biek et al. (2015) established the Drip Tank correlation used for this map; unit was deposited by east- and northeast-flowing braided streams (Tilton, 1991, 2001a, 2001b; Lawton et al., 2003); upper contact with the Wahweap Formation appears conformable and corresponds to the top of a white pebbly sandstone, above which is yellowish-brown, fine-grained sandstone of the capping sandstone member of the Wahweap; recent chronostratigraphic studies (based on new U-Pb zircon ages) on the Wahweap

Formation in the Kaiparowits Plateau by Beveridge et al. (2022) placed the lower boundary of the Wahweap with the Drip Tank Member at about 82 Ma, providing a minimum age for Drip Tank strata; thickness ranges widely from 50 to 150 feet (15–45 m).

unconformity

Ksjs **John Henry and Smoky Hollow Members, undivided** (Late Cretaceous, Santonian to Turonian) – Undivided in the Summit quadrangle, where underlying Smoky Hollow is commonly concealed by colluvium or landslides, and the Calico bed (Peterson, 1969) is either poorly developed or absent (Biek et al., 2015); Smoky Hollow strata are described below and John Henry strata are described separately; combined unit is about 1250 feet (380 m) thick near the southeastern corner of the map area and appears to thin to about 1000 feet (300 m) thick in the structurally complicated Hurricane Cliffs.

Smoky Hollow strata are slope-forming, brown and gray mudstone, shale, and interbedded yellowish-brown fine-grained sandstone; lower part contains a few thin coal beds, common carbonaceous shale, and several thin oyster coquina beds; upper unconformable contact typically corresponds to the base of the Calico bed—a stacked series of fluvial channel deposits of white to light-gray, fine- to medium-grained sandstone and conglomeratic sandstone—that is not recognized in the Summit quadrangle; deposited in fluvial and floodplain environments of a coastal plain (Eaton et al., 2001; Primm et al., 2018); Smoky Hollow strata are middle to late Turonian on the basis of a diverse assemblage of mollusks, benthic foraminifera, and ostracods from exposures in Cedar Canyon (Eaton et al., 2001; Tibert et al., 2003); Szwarc et al. (2015) reported a maximum depositional age for the member of 89.1 ± 6.35 Ma; probably about 250 feet (75 m) thick in the Summit quadrangle.

Ksj **John Henry Member** (Late Cretaceous, Santonian to late Turonian) – Yellowish- to reddish-brown, fine- to medium-grained, subarkosic sandstone and siltstone, and interbedded, locally mottled, gray, brown, and reddish-brown mudstone; forms ledgy slopes; sandstone is commonly bioturbated and locally stained by iron-manganese oxides; stacked or amalgamated sandstone beds make up most of the upper part of the unit; upper unconformable contact corresponds to a break in slope at the base of the Drip Tank Member; woody material and leaf impressions are locally abundant; Chentnik et al. (2015) identified four regressive-transgressive cycles within the member on the Kaiparowits Plateau and Benhallam et al. (2016) noted that the member provides an ~6-million-year record of coastal-plain to marginal-marine deposition; biotite from an ash bed about 800 feet (245 m) above the base of the member in Cedar Canyon yielded an $^{40}Ar/^{39}Ar$ age of 86.72 ± 0.58 Ma (late Coniacian), and biotite from an ash bed 700 feet (213 m) below the top of the member in Parowan Canyon yielded an $^{40}Ar/^{39}Ar$ age of 83.0 ± 1.1 Ma (early Campanian to late Santonian) (Eaton et al., 1999b); Szwarc et al. (2015) reported a maximum depositional age for the member of 82.8 ± 4.1 Ma; Eaton (2006) reported on mammal fossils in Cedar Canyon that suggest the lower part of the member there is late Turonian; thickness about 900 to 1000 feet (275–300 m) in the Summit quadrangle.

Kst **Tibbet Canyon Member** (Late Cretaceous, Turonian) – Yellowish-brown, medium- to thick-bedded, generally planar bedded, fine- to medium-grained quartzose sandstone and interbedded gray mudstone, carbonaceous shale, and thin to thick beds of oyster coquina; forms prominent cliffs along East Fork Braffits Creek canyon; upper conformable contact corresponds to a pronounced break in slope and is placed at the top of a coquina oyster bed and base of overlying thin coal and carbonaceous shale interval that caps the member; deposited during initial progradation of the Greenhorn Cycle in shoreface, beach, lagoonal, and estuarine environments adjacent to a coastal plain (Laurin and Sageman, 2001, 2007; Tibert et al., 2003); Szwarc et al. (2015) reported a maximum depositional age (U-Pb zircon) for the member of 94.3 ± 1.4 Ma; incomplete section is at least 450 feet (135 m) thick in the map area, but is typically 650 to 800 feet (200–245 m) thick on the west flank of the Markagunt Plateau (Biek et al., 2015).

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