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DEPARTMENT OF NATURAL RESOURCES
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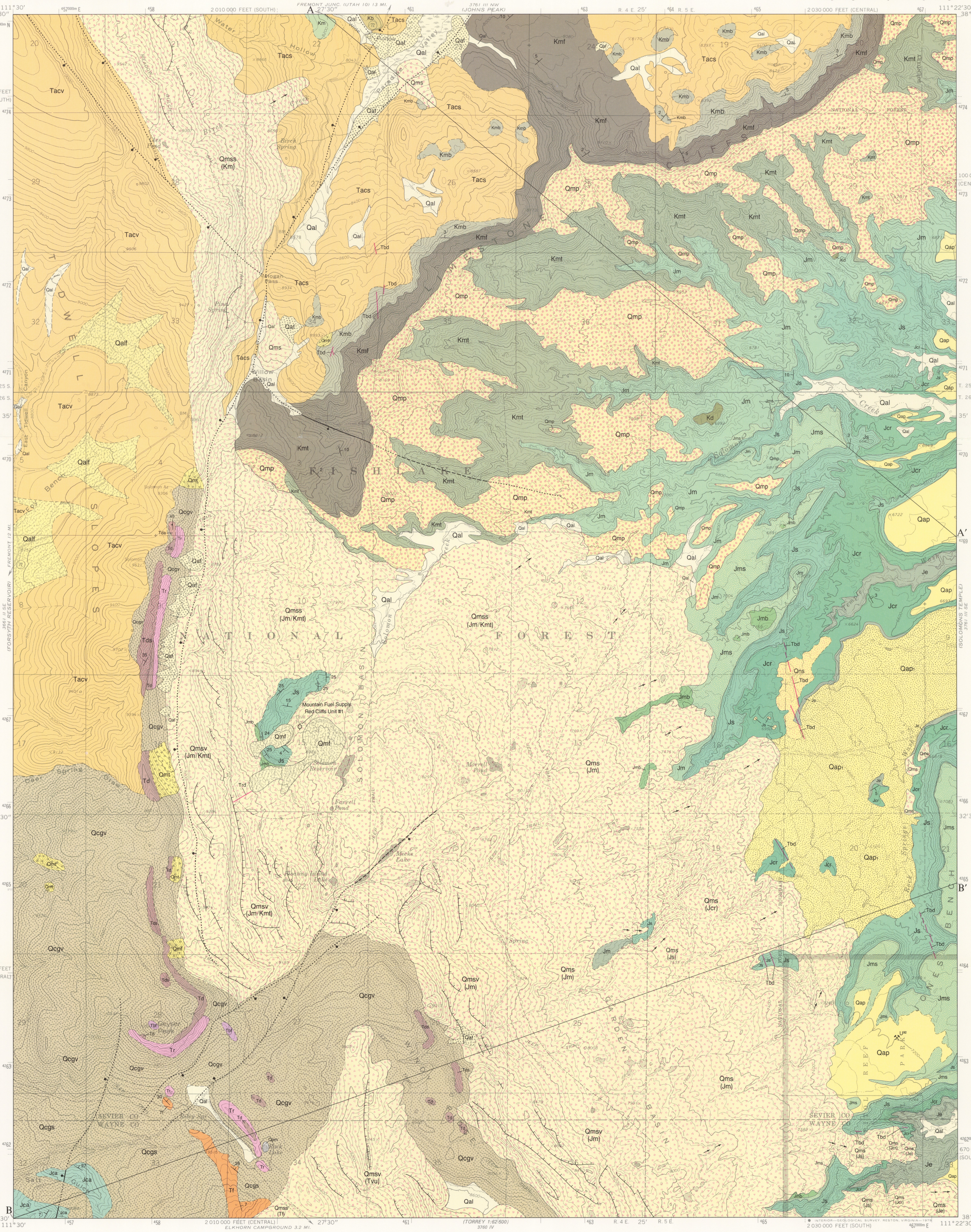


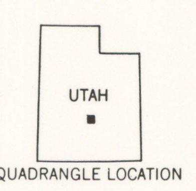
Base from U.S. Geological Survey, Geyser Peak Quadrangle, 1968

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Myron G. Best, Thesis Chairman
J.W. Parker, Cartographer

UTM GRID AND 1989 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET


QUADRANGLE LOCATION

GEOLOGIC MAP OF THE GEYSER PEAK QUADRANGLE, SEVIER AND WAYNE COUNTIES, UTAH

by
Stephen T. Nelson

1989

CORRELATION OF MAP UNITS

Qal, Qaf, Qalf, Qap, Qmf, Qmt, Qmp, Qpm, Qns, Qcgv, Qcgs, Qap₁, Qmsv, Qmss — HOLOCENE / PLEISTOCENE — QUATERNARY

Unconformity

Tac(v/s)

Unconformity

Tbf, Tbd, Tda, Tds, Td, Tr, Trd — TERTIARY

Tvu — TERTIARY VOLCANIC ROCKS *Shown in cross-section only.*

Unconformity

Tf

Unconformity

Kb

Unconformity

Kme — *Shown in stratigraphic column only.*

Kmb, Kmf, Kmt — UPPER CRETACEOUS

Km — MANCOS SHALE UNDIVIDED

Unconformity

Kd

Unconformity

Jmb, Jms, Jm

Unconformity

Js, Jcr — UPPER JURASSIC

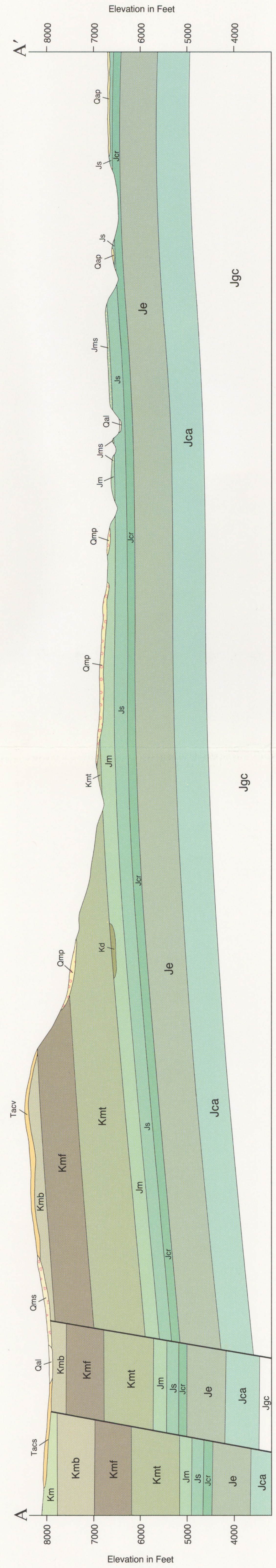
Unconformity

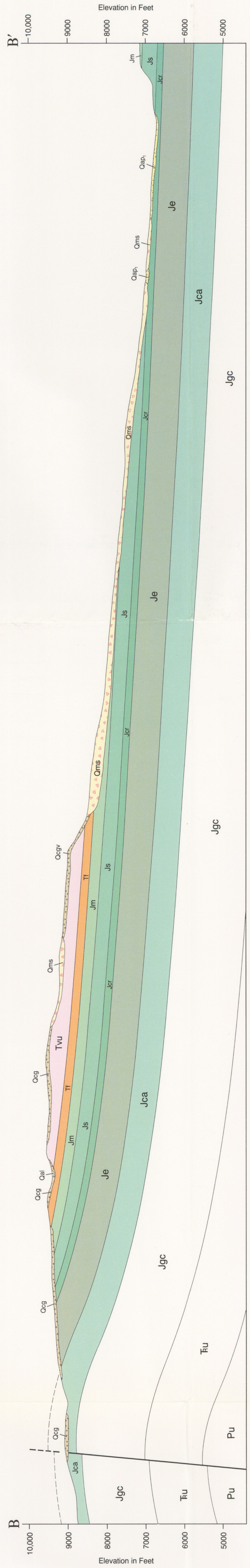
Je, Jca — MIDDLE AND UPPER JURASSIC

Other units on cross-section only:

Jgc, Ŧiu — UPPER TRIASSIC AND LOWER JURASSIC

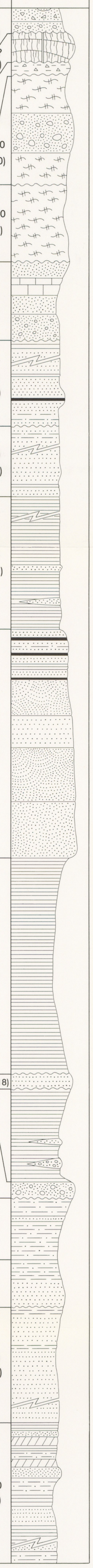
Pu — PERMIAN





SYSTEM	SERIES	FORMATION (MEMBER)	SYMBOL	THICKNESS FEET (METERS)
QUAT.	PLEIST. AND HOLOC.	Unconsolidated Tertiary and Quaternary deposits	All Q-units and Tac	0-75 (0-22.5)
TERTIARY	PLIOC.	Trachybasalt flow of Geyser Peak	Tbf	0-100? (0-30?)
	OLIGOCENE	Antimony Tuff Member of the Mount Dutton Formation	Tda	?
		Trachyte flows of Deer Spring Draw	Td	150-400 (45-120)
		Shoshonite flow of Riley Spring	Tr	200-300 (60-90)
	PALEOCENE?	Flagstaff Limestone?	Tf	200+ (60+)
CRETACEOUS		Black Hawk Formation	Kb	±750 (±225)
		Mancos Shale (Emery Sandstone Member)	Kme	±800 (±240)
		Mancos Shale (Blue Gate Shale Member)	Kmb	900+ (270+)
		Mancos Shale (Ferron Sandstone Member)	Kmf	730 (220)
		Mancos Shale (Tununk Shale Member)	Kmt	700 (210)
		Dakota Sandstone	Kd	0-60 (0-18)
JURASSIC		Morrison Formation (Brushy Basin Member)	Jmb	295 (90)
		Morrison Formation (Salt Wash Sandstone Member)	Jms	0-50 (0-15)
		Summerville Formation	Js	208 (62)
		Curtis Formation	Jcr	160 (48)
		Entrada Sandstone	Je	±780 (±237)
		Carmel Formation	Jca	±1000 (±300)

LITHOLOGY



DESCRIPTION OF MAP UNITS

Qal Low-level alluvium — *Poorly sorted, found along modern stream courses.*

Qaf Alluvial-fan deposits — *Coarse, poorly sorted.*

Qalf Reworked alluvial-fan deposits — *Poorly defined, partly reworked by ephemeral and intermittent streams.*

Qap Pediment alluvium — *Alluvial sand and gravel deposits at a high level.*

Qmf Mudflow deposits — *Re-mobilized shaly mudflows superimposed on older landslide deposits.*

Qms(v/s) Landslide deposits — *Complex landslide facies including toreva blocks, slump masses and debris flows with a composition of well-mixed volcanic and sedimentary clasts in a clay matrix, Qms, volcanic rocks, Qmsv, or sedimentary rocks, Qmss.*

Qmt Talus deposits — *accumulated rock-fall deposits of angular blocks found on steep slopes.*

Qmp Armored pediments — *Rock-fall debris which armor elevated pediment surfaces that overlie soft Mesozoic sedimentary rocks.*

Qpm Playa mud — *Sediments accumulated in a playa lake.*

Qns Sand deposits of uncertain or mixed origin.

Qcg(v/s) Colluvium — *Coarse, poorly sorted, of gravel size or larger, overlying volcanic bedrock, Qcgv, or sedimentary bedrock, Qcgs.*

Qap₁ Pediment alluvium — *Alluvial sand and gravel deposits at a low level.*

Tac(v/s) Tertiary alluvial deposits — *High-level alluvial and/or reworked volcanic mudflow deposits of pebbles, cobbles and boulders with a significant colluvial component overlying volcanic bedrock, Tacv, or sedimentary bedrock, Tacs.*

Tvu Tertiary volcanic rocks — *Shown in cross-section only.*

Tbf Trachybasalt lava flows of Geyser Peak

Tbd Trachybasalt dike of Geyser Peak

Tda Antimony Tuff Member of the Mount Dutton Formation — *Welded, crystal-poor ash flow tuff with phenocrysts of sanidine, plagioclase, and augite with large eutaxitic pumice lenticulates.*

Td Trachyte lava flows of Deer Spring Draw.

Tds Trachyte interbedded volcanic conglomerates of Deer Spring Draw.

Tr Shoshonite lava flows of Riley Spring.

Trd Shoshonite dike of Riley Spring.

Tf Flagstaff Limestone? — *Light-colored terrestrial deposits including lacustrine limestone, sandstone, and pebble conglomerate overlain by thin unconsolidated alluvial sand; the bottom contact is not exposed such that observed thickness is less than 200 feet.*

Kb Blackhawk Formation — *Tan to yellow lenticular sandstone and minor shale; top and bottom contacts not exposed such that observed thickness is less than 150 feet; contains a coal bed in excess of 10 feet thick.*

Km Mancos Shale, undivided.

Kme Emery Sandstone Member of Mancos Shale — *Shown in stratigraphic column only.*

Kmb Blue Gate Shale Member of Mancos Shale — *Gray shale and minor interbedded sandstone; top contact not exposed such that observed thickness is generally less than 600 feet.*

Kmf Ferron Sandstone Member of Mancos Shale — *Tan to yellow, thin to massive sandstone lenses containing beds of coal and shale; thickness about 730 feet.*

Kmt Tununk Shale Member of Mancos Shale — *Dark gray shale; thickness about 700 feet.*

Kd Dakota Sandstone — *Yellow lenticular sandstone and interbedded coal and carbonaceous shale; highly discontinuous; thickness 0 to 60 feet.*

Jm Morrison Formation, undivided.

Jmb Brushy Basin Member of Morrison Formation — *Variegated bentonitic shales and minor interbedded sandstone and pebble conglomerate; probably contains beds of the Cretaceous Cedar Mountain Formation; thickness 295 feet.*

Jms Salt Wash Sandstone Member of Morrison Formation — *Light yellow massive sandstone and conglomerate with minor claystone lenses; thickness 0 to 50 feet.*

Js Summerville Formation — *Reddish brown interbedded siltstone and mudstone; thickness about 200 feet.*

Jcr Curtis Formation — *Pale yellow to pale green medium-grained sandstone grading upward into siltstone and mudstone at the top; maximum thickness 162 feet.*

Je Entrada Sandstone — *Reddish brown very fine-grained sandstone with minor interbedded mudstone; only the upper 100 feet are exposed.*

Jca Carmel Formation — *Red and white interbedded sandstone, siltstone, mudstone and gypsum; bottom and top contacts are not exposed.*

Jgc Glen Canyon Group — *Includes from the base upwards: Wingate Sandstone, about 350 feet thick; Kayenta Formation, about 550 feet thick; Navajo Sandstone, about 1000 feet thick. (On cross-section only).*

Ŧiu Undivided Triassic rocks — *Includes from the base upwards: Moenkopi Formation, about 900 feet thick; Chinle Formation, about 540 feet thick. (On cross section only).*

Pu Undivided Permian rocks — *Includes from the base upwards: Coconino Sandstone, about 1200 feet thick; Kaibab Limestone, about 300 feet thick (on cross section only).*

MAP SYMBOLS

CONTACT
Dashed where approximately located; dotted where concealed.

GENERALIZED LANDSLIDE CONTACT
Location highly uncertain.

CONTACT BETWEEN LANDSLIDES

FAULT
Dashed where approximately located; dotted where concealed; ball and bar on downthrown side.

TOREVA BLOCK SCARP

DIRECTION OF LANDSLIDE FLOW

45
STRIKE AND DIP OF COMPACTION FOLIATION

25
STRIKE AND DIP OF BEDS

MINE OR PROSPECT

(Jm)
STRATIGRAPHIC UNIT BELOW LANDSLIDE COVER
Indicated by symbol in parentheses.

Suspended or shut-down hole.

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by

Stephen T. Nelson

UTAH GEOLOGICAL AND MINERAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
MAP 114 **1989**

UTAH GEOLOGICAL AND MINERAL SURVEY

606 Black Hawk Way
Salt Lake City, Utah 84108-1280

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GEOLOGIC MAP OF THE GEYSER PEAK QUADRANGLE, WAYNE AND SEVIER COUNTIES, UTAH

by

Stephen T. Nelson[1]

ABSTRACT

The Geyser Peak quadrangle is underlain by a thick sequence of Mesozoic sedimentary rocks locally intruded by dikes and partially covered by lava flows of Tertiary age. These igneous rocks reflect two episodes of alkaline magmatism at the eastern end of the Marysvale-Pioche volcanic belt. Late Oligocene, potassium-rich shoshonite and trachyte lava flows exhibit phenocrystic disequilibrium textures which indicate a complex magmatic history of magma mixing or polybaric crystallization. Miocene-Pliocene trachybasalt magmas were emplaced as lava flows and dikes.

Structurally, the quadrangle lies at the eastern margin of the Basin and Range-Colorado Plateau transition zone as defined by the eastern termination of significant normal faulting. Two major folds of post-Laramide age involve the entire stratigraphic section exposed within the quadrangle except Miocene-Pliocene trachybasalt flows and Quaternary units.

Four huge composite landslide masses, covering altogether 18.5 square miles (47.9 km^2), developed during the Pleistocene when elevated precipitation triggered movement along major tectonic or erosional escarpments with as much as 3000 feet (915 m) of relief. Failure of two landslides was localized in shales on the limb of a large anticline.

INTRODUCTION

The Geyser Peak 7.5-minute quadrangle encompasses the extreme eastern part of the Marysvale-Pioche volcanic belt in the Fish Lake Plateau of south-central Utah. The plateau is capped by Tertiary lava flows which have received little geologic investigation. These flows are underlain by a thick sequence of Mesozoic sedimentary rocks. Jurassic, Cretaceous and Tertiary sedimentary rocks, including beds of coal, are exposed in the eastern part of the quadrangle. They include, from the base upwards: 1) Carmel Formation, 2) Entrada Sandstone, 3) Curtis Formation, 4) Summerville Formation, 5) Morrison Formation, 6) Cedar Mountain Formation, 7) Dakota Sandstone, 8) Tununk Shale, Ferron Sandstone, and Blue Gate Shale Members of the Mancos Shale, 9) Black Hawk Formation, and 10) Flagstaff Limestone. Large Quaternary landslides have sloughed off the north-south-trending eastern escarpment of the plateau and have involved both the Mesozoic and Tertiary sections (figure 1).

Several investigations peripheral to the quadrangle have been done. Lupton (1916) mapped the coal-bearing units of the Emery coal field in the Wasatch Plateau, the southernmost part of which is exposed in the northern part of the quadrangle. Doelling (1972) documented the coal resources in the southwest quarter of the Emery 15-minute quadrangle, now known as the Geyser Peak quadrangle. Smith and others (1963) investigated the sedimentary and volcanic geology of the Capitol Reef National Park area and included some chemical analyses. Anderson and Barnhard (1986) studied Laramide and neotectonic paleostresses in essentially the same area as Smith and others (1963). Best and others (1980) reported the age and composition of one volcanic rock sample from south of Fish Lake. McGookey (1958) studied the area of the Fish Lake Plateau north of the Geyser Peak quadrangle. Williams and Hackman (1971) compiled the Salina sheet on a scale of 1:250,000. Two recent reports (Delaney and others, 1986; Gartner, 1986) partially document the age, chemistry, and emplacement of the swarm of trachybasalt dikes exposed in the San Rafael Swell to the east, some of which are exposed in the quadrangle. Billingsley and others (1987) mapped the Capitol Reef National Park area adjacent the quadrangle to the south.

Contacts were mapped from 1:16,000-scale aerial photographs. Stratigraphic sections were measured with a Jacob's staff. K-Ar determinations were made by H.H. Mehnert in the U.S. Geological Survey laboratory in Denver and by Geochron Laboratories. Chemical analyses were done by x-ray fluorescence spectrometry at Brigham Young University by the author using the method of Norrish and Hutton (1969).

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STRATIGRAPHY

JURASSIC

Carmel Formation

The Middle to Upper Jurassic Carmel Formation is the oldest unit that crops out in the quadrangle and is poorly exposed beneath extensive colluvial and vegetative cover. It crops out only in the southwestern part of the quadrangle, but neither top nor bottom contacts are exposed. Outcrops are chiefly red and light-gray interbedded sandstone, siltstone, and mudstone with some thick beds of gypsum. The Geyser Peak quadrangle lies farther east than the generally accepted limits of the Arapien Shale (D. Sprinkel, personal communication, 1986). For this reason this unit is correlated with the Carmel Formation, following Smith and others (1963).

Entrada Sandstone

Only the uppermost 100 feet (30 m) of the Upper Jurassic Entrada Sandstone are exposed, covering much of the eastern part of the quadrangle. It is chiefly pale reddish-brown (10 R 5/4), very fine-grained sandstone with minor interbedded mottled and variegated sandstones and mudstones. The Entrada Sandstone is considered to represent Late Jurassic epicontinental deposition in tidal to deltaic environments (Smith and others, 1963; Smith, 1976). The upper contact with the Curtis Formation is a disconformity.

Partial measured section of the Entrada Sandstone NW ¼, sec. 17, T 26 S, R 5 E.

Jurassic Entrada Sandstone

4. *Mudstone, lower half mottled dark reddish brown (10 R 3/4) and pale greenish yellow (10 Y 8/2), upper half uniform pale greenish yellow (10 Y 8/2) . . . . 3.0 feet*
3. *Sandstone, pale reddish brown (10 R 5/4), very fine-grained, horizontally bedded from 1″ to 6′ thick, minor interbedded mudstone that is very dusky red (10 R 2/2) . . . . 14.0 feet*
2. *Sandstone, variegated between grayish red purple (5 RP 4/2), grayish pink (5 R 8/2), and pale reddish brown (10 R 5/4), very fine-grained, well sorted, thinly bedded . . . . 8.0 feet*
1. *Sandstone, same as unit 3, whole sequence forms ledges where capped by the Curtis Formation . . . . 56.0 feet*

Total: 81.0 feet

Bottom not exposed

Curtis Formation

The Upper Jurassic Curtis Formation consists of horizontally and cross-bedded, medium-grained sandstones that grade upward into mudstones and siltstones. At the base of the measured section the sandstone is medium-grained; however, pebble conglomerate lenses and coarse-grained sandstone lenses have been observed laterally at the base. The unit is predominantly very pale orange (10 YR 8/2), but appears greenish when viewed from a distance. The lower part of the Curtis Formation is commonly expressed as a resistant cap rock over the Entrada Sandstone, whereas the upper part erodes to a slope below the Summerville Formation, into which it grades. The contact is placed at a distinct color change from the light-gray-green beds of the Curtis Formation to the predominantly reddish-brown beds of the overlying Summerville Formation, similar to the contact used by Smith and others (1963). The Curtis Formation has been interpreted to represent one complete cycle of transgression and regression of the Late Jurassic (Oxfordian) epeiric sea (Smith, 1976). More recent work (Kreisa and Moiola, 1986) has suggested that many of the facies seen in the Curtis are results of tidal deposition, as part of the cycle when examined on a smaller scale.

Measured section of the Curtis Formation NW ¼, sec. 17, and NE ¼, sec.18, T 26 S, R 5 E.

Jurassic Curtis Formation

5. *Mudstone, pale greenish yellow (10 Y 8/2) grading to pale red at the top (10 R 6/2), minor interbeds of very fine-grained sandstone up to 6″ thick, slope former . . . . 60.0 feet*
4. *Sandstone, very pale orange (10 YR 8/2), fine-grained, well sorted and rounded, thick horizontal beds up from 1-6′ thick with some cross-bedded lenses up to 2′ thick, forms slopes and ledges . . . . 28.0 feet*
3. *Sandstone, very pale orange (10 YR 8/2), very fine-grained, well cemented, thick horizontal bedding, massive ledge former . . . . 44.0 feet*
2. *covered slope . . . . 15.0 feet*
1. *Sandstone, very pale orange (10 YR 8/2) to pale greenish yellow (10 Y 8/2), cross-bedded, predominantly medium-grained but containing coarse-grained pebble conglomerate lenses and very fine-grained sandstone lenses, 10% lithic fragments, 90% quartz grains, ripple marks common, calcified "slickensides" common along bedding plane partings, ledge former . . . . 15.0 feet*

unconformity

Total: 162.0 feet

Summerville Formation

The Upper Jurassic Summerville Formation is comprised of evenly interbedded siltstone and mudstone of various reddish-brown hues. Local sandstone beds are very light gray on a fresh surface but are usually stained reddish-brown due to weathering of overlying beds. Thin veinlets of gypsum occur throughout the unit. The formation typically forms ledges where it is capped by the unconformably overlying Salt Wash Sandstone Member of the Morrison Formation. The Summerville Formation has been interpreted in the San Rafael Swell to be a tidal flat accumulation (Stanton, 1976).

Measured section of the Summerville Formation SW ¼ sec. 16, T 26 S, R 5 E.

Jurassic Summerville Formation

1. *Siltstone and mudstone, pale brown (5 YR 5/2) and light brown (5 YR 6/4), silt is predominantly quartz, thin veinlets of gypsum, conspicuous horizontal bedding, contains some lenses of reddish-brown-stained white sandstone that are laterally extensive, forms steep slopes when capped by the Salt Wash Sandstone Member of the Morrison Formation, gradational contact with the Curtis Formation below . . . . 208.0 feet*

Total: 208.0 feet

JURASSIC/CRETACEOUS
Morrison/Cedar Mountain Formations

Two members of the Upper Jurassic Morrison Formation are exposed in the quadrangle: the lower Salt Wash Sandstone Member and the upper Brushy Basin Shale Member. The entire formation accumulated in fluvial to fluvial-lacustrine depositional systems, which is a radical change in environment from the marginally marine units discussed above.

The Salt Wash Sandstone Member in the Geyser Peak quadrangle is composed predominantly of pale yellow orange (10 Y 8/2) sandstone, pebble, and cobble conglomerates, which seem to contain coarser clasts than have been described elsewhere in the literature (Craig and others, 1955). The unit exhibits great lateral variation in thickness and tends to thin northward, as noted by Smith and others (1963). In places, the Salt Wash Sandstone Member pinches out, becomes so thin, or is exposed on such steep ledges, that it was not mapped separately from the overlying Brushy Basin Shale Member.

The Brushy Basin Shale Member of the Morrison Formation is composed of variegated bentonitic shales with minor sandstones and conglomerate lenses. The upper half is a more uniform yellowish gray (5 Y 8/1) and probably contains beds of the younger Cretaceous Cedar Mountain Formation of Stokes (1952). The lower conglomerate member of the Cedar Mountain Formation is missing. Several workers have noted that it is impractical, if not impossible, to separately map the Morrison and Cedar Mountain Formations when the basal conglomerate of the Cedar Mountain Formation is missing (Stokes, 1952; Smith and others, 1963). The two formations are strikingly similar in the Geyser Peak area and have been mapped as a single unit.

Using fission track dating, Kowallis and others (1986) have demonstrated that an unconformity of about 35 Ma exists between the shales of the two formations southeast of the area (not recognizable in the present mapping). They report an age spectrum of 132 to 143 Ma for the Morrison Formation, and 101 Ma for the Cedar Mountain Formation, which are in general agreement with other published ages.

Partial measured section of the Salt Wash Sandstone Member of the Morrison Formation NW ¼, sec. 28, T 26 S, R 5 E.

Jurassic Morrison Formation: *Salt Wash Sandstone Member*
Top not exposed

3. *Sandstone, very pale orange (10 YR 8/2), fine-grained, immature, moderately rounded and sorted, horizontally bedded with cross-bedded lenses . . . . 25.0 feet*
2. *Sandstone and conglomerate, chiefly very pale orange (10 YR 8/2), complex interbedded, sandstone; medium to coarse-grained cross-bedded lenses, some graded bedding, conglomerate: pebbles and cobbles up to 8″, mostly white and dark gray chert with minor silicified siltstone clasts, clasts comprise up to 80% of the rock, ledge former . . . . 9.0 feet*
1. *Siltstone, pale olive (10 Y 6/2), contains a 1′ thick sandstone lens, very pale orange (10 YR 8/2), very fine-grained . . . . . 5.0 feet unconformity*

Total: 39.0 feet

Measured section of the Brushy Basin Shale Member of the Morrison Formation and undifferentiated Cedar Mountain Formation NE ¼, sec. 6, T 26 S, R 5 E.

Cretaceous-Jurassic Morrison Formation: *Brushy Basin Shale Member*

1. *Shale, variegated colors in reds, pinks, and grays becoming nearly a uniform yellowish gray (5 Y 8/1) in the upper part, bentonitic, minor thin sandstone and conglomerate lenses in the lower portion of the unit, the upper uniform shale probably represents the Cedar Mountain Formation, but its basal conglomerate is not present, slope former . . . . 295.0 feet*

Total: 295.0 feet

CRETACEOUS
Dakota Sandstone

The Upper Cretaceous Dakota Sandstone is generally absent and only locally occurs as thin lenses that hold up ledges or cap hills in the quadrangle. The Dakota Sandstone occurs unconformably above the Morrison/Cedar Mountain Formation and has a maximum thickness of about 50 feet (15 m). It is covered by slope wash in many places. The Dakota is mainly composed of grayish yellow sandstones that include minor beds or lenses of impure coal. Many sandstone lenses contain numerous pelecypod fossils. The unit is thought to represent the first littoral deposits of the transgressing Cretaceous seaway (Hunt, 1953).

Mancos Shale/ Blackhawk Formation

Three members of the Upper Cretaceous Mancos Shale are exposed in the map area: Tununk Shale, Ferron Sandstone, and Blue Gate Shale. The small exposure of bedrock at the beginning of cross-section AA' on the map might be the Emery Sandstone Member of the Mancos Shale. The Tununk Shale Member lies unconformably over the Morrison/Cedar Mountain Formation or the Dakota Sandstone, where that unit is present. The Tununk Shale is a remarkably homogenous, thick sequence of soft, gray shale exposed in the northern half of the quadrangle. The Ferron Sandstone Member overlies the Tununk Shale and crops out as the prominent ledges, misnamed the Limestone Cliffs, in the north-central part of the quadrangle. The member is predominantly tan and yellow, cross-bedded, massive sandstone lenses, but minor lenses of shale and coal are interbedded. The Blue Gate Shale Member is incompletely preserved above the Ferron Sandstone. Exposures include the upper 500 to 600 feet (150-180 m). This unit is mostly gray shale but also includes several local thin sandstone beds.

A limited exposure of coal-bearing lenticular sandstone occurs in the northernmost part of the quadrangle, west of Paradise Valley. This unit is best correlated with the Blackhawk Formation (Blanchard, 1980; H. H. Doelling, personal communication, 1986) on the basis of an interbedded coal seam in excess of 10 feet (3 m) thick.

The Cretaceous sedimentary units in the northern map area are not present in the southwestern portion of the quadrangle

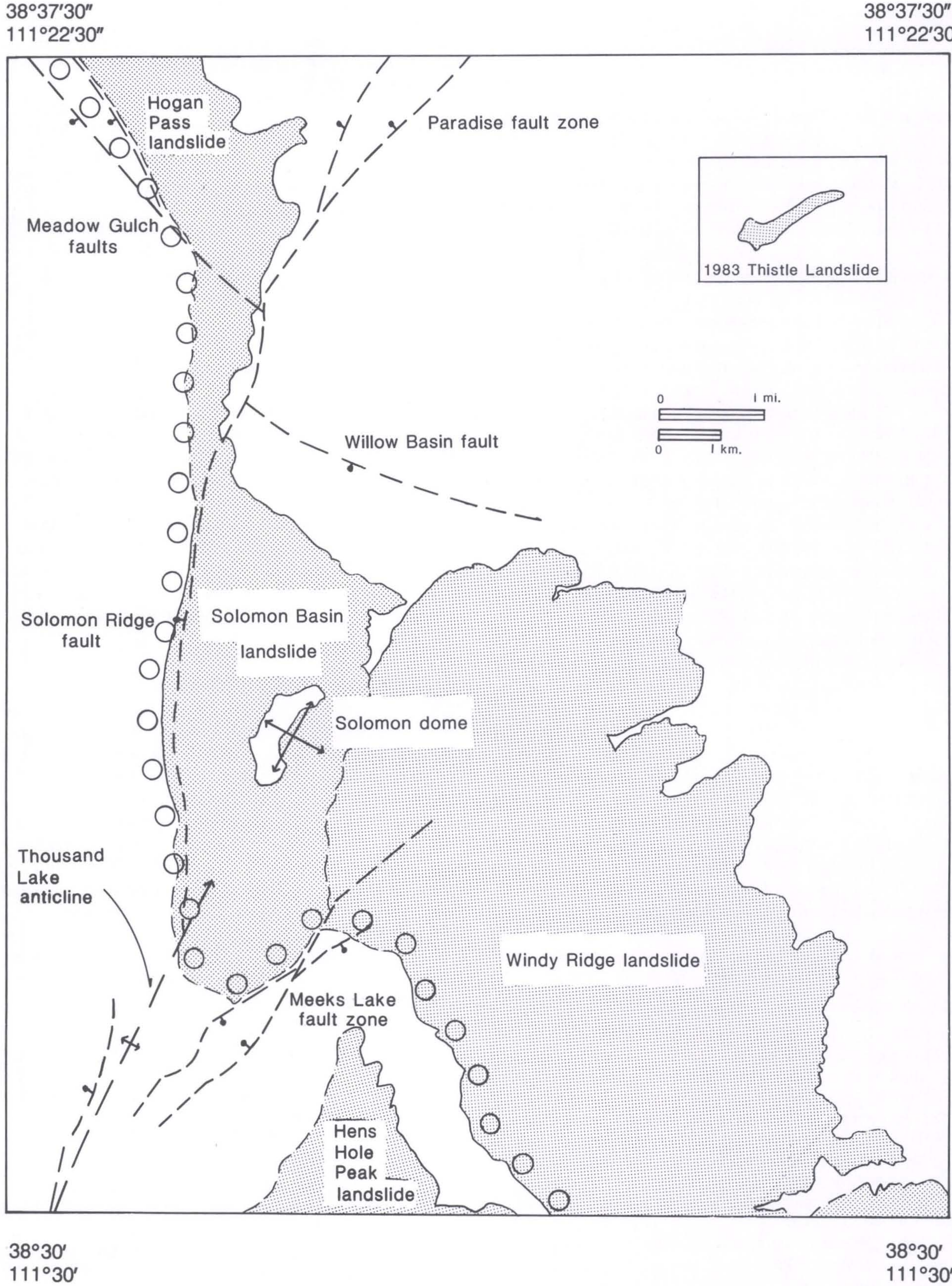

Figure 1. *Index map showing the location of topographic escarpment (circles), faults, major landslides, and the Thousand Lake anticline and Solomon Dome. The Thistle landslide is shown for scale.*

(see cross section BB'). It is lamentable that poor exposures in this area make it impossible to determine whether this absence is due to erosion or non-deposition. In either case, the Cretaceous coal-bearing units cannot be traced further south than the northern half of the Geyser Peak quadrangle.

TERTIARY/PALEOCENE-OLIGOCENE
Flagstaff Limestone (?)

A sequence of sedimentary rocks crops out in a small area in the south-central portion of the quadrangle. Microscopic algae and ostracodes were found in a limestone bed and demonstrate that these rocks were deposited in a fresh-water lacustrine environment (J.K. Rigby, personal communication, 1985). On this basis, and the work of previous geologists (Smith and others, 1963), this unit is tentatively correlated with the Paleocene Flagstaff Limestone, although other workers have suggested that it may actually be one of several Eocene or Oligocene units such as the Green River or Crazy Hollow Formations (H.H. Doelling, D. Sprinkle, G. Willis, personal communication, 1986). The Flagstaff(?) Formation is composed of a massive pebble conglomerate of multicolored chert clasts in a sandy matrix. The conglomerate is overlain by crystalline lacustrine limestone, but the limestone-conglomerate contact is not exposed in an intervening covered slope. Unconsolidated medium- to coarse-grained fluvial sand overlie the Flagstaff Limestone(?) beds and were mapped with it.

TERTIARY/OLIGOCENE
Volcanic Rocks

Late Oligocene lava flows (table 1), local volcanic conglomerates and one ash-flow tuff are poorly exposed in the western third of the quadrangle. The best outcrops occur on the steep slopes of Geyser Peak and on the line of peaks extending to the north which I will refer to as Solomon Ridge.

The lava flow of Riley Spring superficially appears to be a basalt or basaltic andesite based on its plagioclase, clinopyroxene, olivine, and orthopyroxene phenocrysts. However, the presence of abundant sanidine and/or potassic glass in the matrix as well as a potassic whole-rock composition indicate the rock is shoshonite. Similarly, the lava flow of Deer Spring Draw appears to be an andesite because of its plagioclase and sparse pyroxene phenocrysts, yet it has the whole-rock composition of a trachyte. These rocks constitute a significant potassic alkaline magmatic occurrence at the east end of the Marysvale-Pioche volcanic zone.

Lava Flows and Shoshonite Dike of Riley Spring

The late Oligocene shoshonite lava flows, herein informally referred to as the lava flows of Riley Spring (see table 1 for sample locations), are exposed just above the unconsolidated sand deposits included in the Flagstaff Limestone. The lava probably flowed into a valley in which the sand deposits were

Table 1. *K-Ar ages of selected rocks of South-central Utah.*

Sample	Location	Material Dated	$\%K_2O$	$^{40}Ar/^{40}K$	Apparent Age (Ma)	Reference
Basal lava flow of Riley Spring[2]	SW ¼, SE ¼, Sec. 28, T 26 S, R 4 E	Whole rock	—	—	23.85 ± 1.1	
Lava flow of Deer Spring Draw[1]	NE ¼, NW ¼, Sec. 16, T 26 S, R 5 E	Whole rock	5.147	0.001539	26.3 ± 1.1	
Antimony Tuff Member of the Mt. Dutton Fm.	—	—	—	—	25	H.H. Mehnert, written communication to P.D. Rowley, 1979
Tuff of Albinus Canyon	—	—	—	—	25	H.H. Mehnert, written communication to C.G. Cunningham, 1986
Isom Formation	(average corrected for	new decay constants)			26	Anderson & others, 1975
Trachybasalt flow near Hogan Pass	Long. 111° 28′ 06″W Lat. 38° 35′ 57″N	Whole rock	—	—	3.8 ± 0.2	Delaney and others, 1986
Trachybasalt flow of Forsyth Reservoir[1]	NE ¼, SE ¼, Sec. 18, T 26 S, R 4 E.	Whole rock	2.040	0.000313	5.4 ± 0.4	
Trachybasalt flow of Geyser Peak[2]	NE ¼, NE ¼ Sec. 28, T 26 S, R 4 E	Whole rock	—	—	3.95 ± 0.3	
Trachybasalt breccia body	Long. 111° 19′ 02″ W Lat. 38° 31′ 06″ N	Whole rock	—	—	3.8 ± 0.2	Delaney and others, 1986

[1]*Age determination by Geochron Laboratories, Cambridge, MA*
[2]*Age determination by H.H. Mehnert, U.S. Geological Survey, Denver, CO*

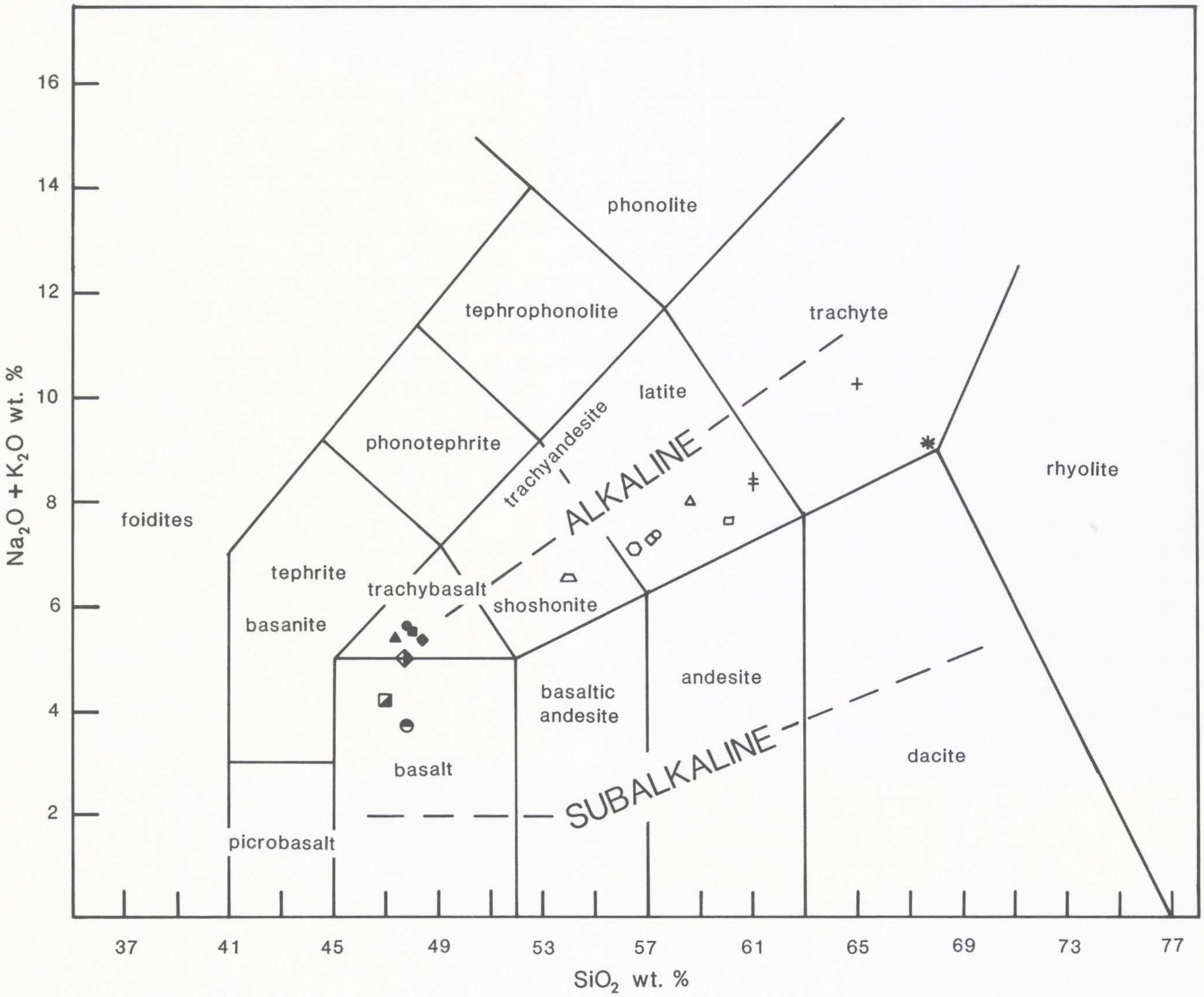

Figure 2. *IUGS classification of volcanic rocks (Le Bas and others, 1986) in the Geyser Peak quadrangle with comparisons.*

- lava flow of Deer Spring Draw
- average composition of Isom Formation (M.G. Best, unpublished data, 1986)
- tuff of Albinus Canyon (C.G. Cunningham, unpublished data, 1986)
- lava flow of Riley Spring
- basal lava flow of Riley Spring
- average of 6 analyses of Smith and others (1963)
- K-rich lava flow (M.G. Best, unpublished data, 1986) sample HPL-3
- vent facies lava flow of the Bullion Canyon Volcanics (C.G. Cunningham, unpublished data, 1986) sample 1606
- average shoshonite (Le Maitre, 1984)
- trachybasalt dike D-3a (low total alkalis due to deuteric alteration)
- trachybasalt dike D-3b (low total alkalis due to deuteric alteration)
- trachybasalt lava flow of Geyser Peak
- trachybasalt lava flow of Forsyth Reservoir
- trachybasalt dike (Gartner, 1986) sample SRS-84
- trachybasalt dike (Gartner, 1986) sample AVG. 18
- trachybasalt dike (Gartner, 1986) sample AVG. 16

deposited earlier. At least two separate flows are recognized on the southeast flank of Geyser Peak on the basis of vesicularity and flow breccia. These red to gray lava flows crop out at high elevations and are usually poorly exposed due to vegetation and colluvial cover. One sub-vertical shoshonite dike striking N 60° E occurs west of Solomon Reservoir (sec. 15, T 26 S, R 4 E).

Rocks of the unit are composed of 35% phenocrysts, represented by 24% plagioclase, 7% augite, 2% olivine, 2% cubic iron-titanium oxide, and trace amounts of orthopyroxene in a matrix of olivine, iron-titanium oxides, plagioclase, and glass or sanidine.

Phenocrystic plagioclases occur in two forms. The first are large, exhibit resorbed, sieve, or dusty disequilibrium textures, and commonly contain inclusions of clinopyroxene, iron-titanium oxides, and olivine. Many are conspicuously zoned and range in optically-determined composition, using the Michel-Levy method, from An27 to An47 with an average of An39. Included in this group are some large grains that are so resorbed that their compositions could not be determined. The second group of phenocrystic plagioclases are less conspicuous, smaller, better formed crystals that show much less resorption, and have a composition of about An60.

Augite phenocrysts, much like the first group of plagioclases, all show resorption. They occur singly, or clotted together with other minerals and contain inclusions of olivine, iron-titanium oxides, and plagioclase. Partially resorbed orthopyroxene occurs in small amounts. Olivines are partially to completely altered to iddingsite.

Lava Flows and Conglomerate Beds of Deer Spring Draw

The overlying poorly exposed trachyte lava flows, herein informally referred to as the lava flows of Deer Spring Draw, are red to gray, highly jointed, and form extensive talus and colluvium slopes. The unit includes volcanic conglomerates which appear to be locally interbedded between successive lava flows. The conglomerates contain pebbles and cobbles of the lava flows of Riley Spring and Deer Spring Draw in a finer grained matrix. The thickness of the unit is uncertain but appears to be about 200 feet (61 m).

The trachyte flow of Deer Spring Draw is weakly porphyritic; it contains 2% plagioclase phenocrysts, and only trace amounts of clinopyroxene, orthopyroxene, and cubic iron-titanium oxide in a groundmass of iron-titanium oxides interspersed among alkali feldspar laths and quartz. Although sparse, plagioclase phenocrysts are commonly large—up to 5 mm in diameter. Sieve, embayed, or dusty disequilibrium textures are ubiquitous, but some large euhedral crystals occur. Clinopyroxene phenocrysts show many of the same characteristics as those in the shoshonites. Iron-titanium oxide grains are commonly anhedral and rimmed by pyroxene.

Comparisons With Other Alkaline Rocks

The composition and geographic location of the shoshonite lava flows of Riley Spring and the trachyte lava flows of Deer Spring Draw have significant regional implications. Shoshonite was a term first used by Iddings (1895) for a rock type in the Absaroka volcanic field, Wyoming. Joplin (1968) noted that shoshonites tend to be found in association with potassic trachytes and/or leucite-bearing rocks, a kinship she called the shoshonite rock association.

Though shoshonite has been defined differently by various workers (MacKenzie and Chappell, 1972; Percillo and Taylor, 1975), there is general agreement that shoshonites have intermediate SiO_2 concentrations, the K_2O/Na_2O ratio is nearly one or greater, and the total $K_2O + Na_2O$ is 5 wt. % or more. They are poor in TiO_2, and rich in Al_2O_3 and lithophile trace elements (Morrison, 1980; Le Maitre, 1984). Nearly all shoshonites documented in the geologic literature exhibit resorbed phenocrysts and glomeroporphyritic textures (Hogg, 1972; MacKenzie and Chappell, 1972; Protska, 1972; and Leedom, 1974). Phenocryst assemblages of plagioclase, olivine, and pyroxene and a groundmass containing potassic glass or sanidine are characteristic.

Despite classic shoshonitic chemical and petrographic properties (figure 2; table 2) the more mafic Oligocene rocks of the Fish Lake Plateau plot as latites in the IUGS classification scheme of Le Bas and others (1986). In any case, the Geyser Peak volcanic rocks are alkaline.

Chemical analyses of Smith and others (1963), M. G. Best (unpublished data, 1986), and C.G. Cunningham (unpublished data, 1986) (table 2) show that shoshonites occur south and west of the Geyser Peak area; thus, a broad areal extent of the shoshonite rock association exists in the Fish Lake Plateau. Hogg (1972) and Leedom (1974) documented the presence in western Utah of chemically and petrographically similar, but older (37.3 Ma), rocks.

Comments on the Origin of the Magmas

The apparent worldwide similarities in texture and phenocryst assemblage of shoshonites suggests that similar petrogenetic processes were involved in their formation. Joplin (1968) described the tectonic setting of the shoshonite association as a *"...stabilizing mobile belt..."* but noted that shoshonites occur in a variety of tectonic settings we now relate to subduction margin and intraplate areas.

In subduction zones, many geologists (e.g., Lipman, 1980; Morrison, 1980) have suggested that potassium enrichment is due to increasing depth of the Benioff zone inland from the trench, and that the increasing depth of the descending plate preferentially enriches magmas in potassium. However, recent work indicates that the K_2O content in shoshonite depends on

Table 2. Chemical analyses recalculated (except for numbers 15 and 16) to 100%. Analytical totals are given in parentheses.

	1	2	3	4	5	6	7	8	9	10
SiO_2	57.40	56.51	57.15	56.78	58.70	57.15	56.90	56.55	58.61	60.43
TiO_2	0.89	0.95	0.99	0.98	1.01	1.01	0.96	1.01	1.02	0.93
Al_2O_3	16.22	17.11	16.79	17.09	17.07	16.73	17.43	17.77	16.68	17.27
Fe_2O_3	8.13	8.29	8.19	8.04	7.98	8.37	7.91	8.08	7.56	5.92
MnO	0.11	0.13	0.14	0.13	0.12	0.13	0.12	0.12	0.12	0.10
MgO	3.48	2.87	2.93	2.61	2.53	2.92	3.0	3.03	2.35	2.41
CaO	6.06	6.04	6.17	5.93	4.95	5.85	5.91	5.86	5.15	4.91
Na_2O	3.97	3.39	3.74	4.12	3.33	3.63	3.80	3.84	3.94	3.53
K_2O	3.40	3.33	3.44	3.92	3.74	3.63	3.40	3.43	4.09	4.13
P_2O_5	0.36	0.38	0.55	0.44	0.57	0.58	0.54	0.46	0.46	0.43
TOTAL	(96.90)	(99.16)	(98.86)	(99.55)	(98.98)	(99.21)	(99.86)	(99.03)	(97.10)	(96.14)
Rb	118	81	—	—	—	—	—	—	—	—
Sr	747	757	—	—	—	—	—	—	—	—
Y	11	7	—	—	—	—	—	—	—	—
Zr	143	150	—	—	—	—	—	—	—	—
Nb	10	n.d.	—	—	—	—	—	—	—	—
Ba	652	659	—	—	—	—	—	—	—	—

	11	12	13	14	15	16	17	18	19	20	21
	53.07	65.02	67.78	61.20	47.75	47.01	46.72	47.78	48.08	48.41	47.32
	1.45	0.81	0.75	0.83	1.15	1.51	1.14	1.23	1.40	1.33	1.38
	16.85	15.88	15.44	16.82	15.03	16.41	15.18	15.01	15.96	14.98	15.02
	9.17	4.54	3.46	6.05	8.71	9.11	10.20	10.22	9.42	8.99	9.20
	0.17	0.09	0.07	0.09	0.14	0.14	0.16	0.15	0.16	0.16	0.16
	4.65	1.05	1.1	1.39	8.73	8.36	10.71	10.01	7.29	8.14	8.47
	7.46	2.11	2.13	3.92	8.14	8.74	10.05	9.38	11.46	11.69	12.16
	3.43	4.35	3.5	3.81	0.4	2.10	3.01	3.32	2.20	2.74	2.72
	3.21	5.91	5.63	4.62	3.26	2.10	2.01	2.36	3.30	2.70	2.73
	0.55	0.27	0.12	0.37	0.42	0.52	0.84	0.55	0.76	0.79	0.83
	—	(100.39)	(99.92)	(98.74)	(93.74)	(95.99)	(99.24)	(100.40)	—	—	—
	—	200	219	—	76	52	55	62	—	—	—
	—	346	392	—	625	892	1429	971	—	—	—
	—	28	40	—	n.d.	n.d.	11	8	—	—	—
	—	386	454	—	171	81	69	74	—	—	—
	—	28	21	—	21	17	16	16	—	—	—
	—	961	1388	—	2275	1561	2339	1653	—	—	—

— not determined
n.d. not detected

1. basal lava flow of Riley Spring SE ¼, sec. 28, T 26 S, R 4 E.
2. lava flow of Riley Spring SW ¼, sec. 28, T 26 S, R 4 E.
3. lava flow of Smith and others (1963) sample Cr 61
4. lava flow of Smith and others (1963) sample Cr 98
5. lava flow of Smith and others (1963) sample Cr 126
6. lava flow of Smith and others (1963) sample Cr 131a
7. lava flow of Smith and others (1963) sample Cr 131b
8. lava flow of Smith and others (1963) sample Cr 235
9. K-rich lava flow (M.G. Best, unpublished data, 1986) sample HPL-3.
10. K-rich lava flow (C.G. Cunningham, unpublished data, 1986) sample 79-1606.
11. average shoshonite composition (Le Maitre, 1984).
12. lava flow of Deer Spring Draw SW ¼, sec. 9, T 26 S, R 4 E.
13. average composition of the Isom Formation.
14. tuff of Albinus Canyon (C.G. Cunningham, unpublished data, 1986) sample M 739.
15. trachybasalt dike, D-3a SE ¼, sec. 34, T 25 S, R 4 E.
16. trachybasalt dike,, D-3b NE ¼, sec. 34, T 25 S, R 4 E.
17. trachybasalt lava flow of Geyser Peak.
18. trachybasalt lava flow of Forsyth Reservoir.
19. trachybasalt dike, (Gartner, 1986) sample SRS 14-84.
20. trachybasalt dike, (Gartner, 1986) sample AVG. 18
21. trachybasalt dike, (Gartner, 1986) sample AVG. 16

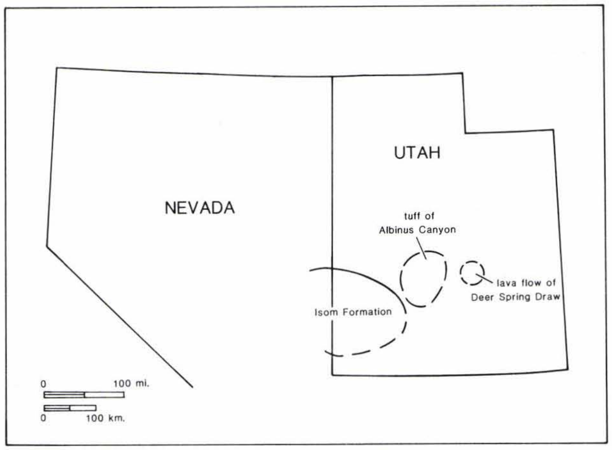

Figure 3. *Spatial distribution of trachytic magmatic centers at approximately 26 Ma. These units express similar age and composition in a prominent east-west trend.*

the fractional crystallization pressure rather than the depth of the Benioff zone (Meen, 1987). Modern shoshonites do indeed occur inland from contemporary calc-alkaline lavas, just as they do in areas such as the western U.S. (Morrison, 1980; Deruelle, 1981). Voluminous calc-alkaline volcanic rocks of the same age as the alkaline rocks of the Fish Lake Plateau are well known to the west.

Sullivan and Best (1986) found what appears to be an excellent correlation in time and space between the transition from calc-alkaline to alkaline Tertiary rocks and the foreland terminus of Mesozoic thrusting in the western U.S. Alkaline rocks occur almost exclusively in the foreland area of the thrust belt, and calc-alkaline rocks occur in thrusted areas. This correlation may reflect the stacking of radiogenic rock that raises isotherms and weakens underlying crust where voluminous calc-alkaline magmas are subsequently generated (Glazner and Bartley, 1985). Low-volume, contemporaneous alkaline rocks are emplaced in a different tectono-thermal setting, namely, one in which the isotherms are significantly lower and the crust is consequently much stronger.

Apart from the observations by Sullivan and Best (1986) and Joplin (1968) there exists a time-space-composition relationship between the trachyte flows in the Geyser Peak quadrangle and other Oligocene trachytic rocks in the Marysvale-Pioche zone, especially the Isom Formation and the tuff of Albinus Canyon. The trachytic rocks of the Geyser Peak quadrangle lie at the east end of what appears to be a clearly defined belt of rocks of similar age and composition (both bulk rock and mineralogic), extending westward into Nevada about 26 Ma (tables 1 and 2; figure 3). This east-west belt of trachytic rocks is a reflection of the east-west-oriented Marysvale-Pioche zone; therefore, understanding the origin of the trachytes may be related to the problem of east-west magmatic belts during north-south subduction under North America (Best, 1986). This occurrence of trachytic rocks might imply that the relationship of the Geyser Peak trachyte lavas to the shoshonites is coincidental rather than genetic. In any event, an intraplate model for the generation of these lavas seems to be needed since subduction does not adequately account for them; however, not enough data are present to favor any particular model(s).

Phenocrysts in the shoshonites and trachytes of the Geyser Peak quadrangle show resorbed, dusty, and sieve disequilibrium textures in sodic plagioclase but not in unresorbed calcic plagioclases. Two possible mechanisms can be envisaged to account for this. First, such textures, common in plagioclase phenocrysts of intermediate volcanic rocks, suggest magma mixing (Tsuchiyama, 1985). A higher temperature, more mafic melt with calcic plagioclases mixing with a less mafic, cooler melt containing sodic plagioclases would, upon contact, superheat the sodic plagioclases. They would become unstable and begin to resorb, causing their observed disequilibrium textures. The calcic plagioclases would be supercooled and quenched.

A second possible sequence of processes that would also account for the resorption textures involves the formation of relatively sodic (An40) plagioclase (more stable at higher pressure than calcic plagioclase; Green and Ringwood, 1968) in a relatively deep staging area, followed by ascent to a shallower level where resorption occurred prior to eruption. Smaller calcic crystals (An60) could form in the ascended magma. The resorbed glomeroporphyritic clots lend credence to this second model, as they indicate a history of crystallization and subsequent resorption. Experimental petrology on Geyser Peak shoshonites confirms that resorbed phenocrystic textures can develop in this manner (S.T. Nelson, work in progress, 1988).

Antimony Tuff Member of the Mount Dutton Formation

The Antimony Tuff Member of the Mount Dutton Formation (Rowley and others, 1979) is exposed in small ledges in the northern part of Solomon Ridge where the member overlies the lava flows of Riley Spring. The Antimony Tuff is reddish-brown, densely welded, and tends to break along large eutaxitic pumice lenticules.

TERTIARY/MIOCENE AND PLIOCENE

Trachybasalt Flow and Dikes of Geyser Peak

Small localized Miocene-Pliocene trachybasalt flows occur near Hogan Pass, Forsyth Reservoir, and Geyser Peak (table 1). In addition, dikes of the same composition and age occur elsewhere in the quadrangle. One trachybasalt flow, herein informally referred to as the trachybasalt flow of Geyser Peak, is about the same age as trachybasalt dikes exposed in the quadrangle and in the swarm to the east (Gartner, 1986; K.R. Sullivan, personal communication, 1986). A trachybasalt flow occurs west of Hogan Pass but was not differentiated on the map since it occurs within a landslide. Another trachybasalt flow, herein informally referred to as the trachybasalt flow of Forsyth Reservoir, underlies the western part of the quadrangle beneath colluvial cover. However, it crops out approximately one mile (1.6 km) west of the Geyser Peak quadrangle east of Forsyth Reservoir.

The dikes lie at the western edge of an extensive, more or less north-south-striking swarm of dikes in the San Rafael Swell whose field relations, petrography and composition have been documented by Gartner (1986). Dikes described in this report (D-3a and D-3b in table 2) were not included in Gartner's study.

Petrography of Dikes —D-3a is a black or dark green, altered diabasic dike containing phenocrysts of biotite, partially altered clinopyroxene, and pseudomorphs of serpentine after olivine in a groundmass of iron-titanium oxides, plagioclase, and hydrous alteration products. Vesicles are especially common near the wall of the dike and are lined with biotite and filled with secondary calcite. The presence of biotite as both phenocrysts and a vapor phase in vesicles indicates a significant volatile content in the magma. Subhorizontal flow of the intruding magma at the present level of dike exposure is reflected in elongate vesicles.

D-3b, though located near D-3a, is petrographically different. Unlike D-3a it contains phenocrysts of plagioclase, but biotite and elongate vesicles are absent. Partially altered clinopyroxenes and clay psuedomorphs after olivine are present. The groundmass contains plagioclase, iron-titanium oxides and hydrous alteration phases.

Petrography of Flows — The fresh, dark gray trachybasalt lava flow of Forsyth Reservoir is composed of 30% phenocrysts, including 12% olivine, 11% clinopyroxene, and 7% plagioclase in a groundmass of plagioclase, clinopyroxene and olivine. Olivine phenocrysts show only slight alteration to iddingsite around grain and fracture margins. Two conspicuous groups of fresh clinopyroxenes occur in equal proportions: sectoral zoned titanaugites and less titaniferous augites. Fresh euhedral plagioclase phenocrysts range in composition from An63 to An80. Significant cubic iron-titanium oxides are so small that they are counted as groundmass in the modal analysis.

The trachybasalt flow of Geyser Peak has less than 15% phenocrysts: almost entirely olivine (14%) and minor clinopyroxene (½%) in a groundmass of plagioclase, clinopyroxene and iron-titanium oxides with little or no olivine. It is dark gray and varies from fresh to somewhat altered. The olivine crystals are nearly unaltered to completely altered, subhedral to euhedral in thin section, and commonly prismatic.

Petrochemistry — Table 2 and figure 2 summarize the composition of the trachybasalt lava flows and dikes and some selected analyses by Gartner (1986). Despite the hydrous alteration of the dikes, which resulted in low weight percentages by x-ray fluorescence analysis, the data nonetheless provide useful information.

Most major element contents of the trachybasalt dikes and lavas in the Geyser Peak quadrangle are fairly uniform. The silica content ranges narrowly from 46.7 to 47.8 wt.%. Na_2O plus K_2O contents range from 3.67% to 5.68%. Alkali concentrations in the dikes may not represent the primary composition of the rocks because they have been altered and weathered. Na_2O values range over an order of magnitude, probably due to differential loss during deuteric alteration, which impacts the SiO_2 plot. By comparison, the trachybasalt lava flows of Forsyth Reservoir and Geyser Peak have total alkali contents of 5.0% or greater (figure 2; table 2).

Discussion

The trachybasalt flows of Forsyth Reservoir and Geyser Peak are considered to be extrusive equivalents of the San Rafael dike swarm on the basis of field considerations and petrographic, compositional, and age similarities. The dikes represent the *"...plumbing system..."* of a basaltic terrane (Gartner, 1986). The field evidence comes in two forms. First, a breccia body east of the Geyser Peak quadrangle but part of the San Rafael dike swarm is a maar remnant. Small ribbon bombs are found within the body and indicate that at emplacement, 3.8 ± 0.2 Ma (Delaney and others, 1986), this body was essentially at the surface. Therefore, the trachybasalt dikes, at present levels of exposure, were probably not far below the surface and many of them undoubtedly vented. Second, the trachybasalt lava flows in the Geyser Peak quadrangle are not far from exposed trachybasalt dikes; therefore, they are closely related in space.

The petrography of the trachybasalt flow of Geyser Peak and that of D-3a are quite similar, as are D-3b and the trachybasalt flow of Forsyth Reservoir. These similarities, together with observable variability in dike petrography accounts for limited dissimilarities in the dikes and flows. The chemical similarities have been discussed above and are summarized in table 2 and figure 2.

Three whole-rock K-Ar isotopic ages have been obtained on trachybasalt flows in or near the Geyser Peak quadrangle that correlate well with ages that have been obtained on the San Rafael dikes and breccia bodies (table 1). The ages of trachybasalt flows and dikes range from about 3.5 to 7.0 Ma (K.R. Sullivan, personal communication, 1986). Data of Delaney and others (1986), K.R. Sullivan (personal communication, 1986), and this report indicate the presence of a significant but little known Miocene-Pliocene magmatic terrane.

Regionally, there exists a northeast-southwest-oriented system of late Cenozoic (approximately 5 Ma or less) basaltic magmatic centers extending from the extreme southwest corner of Utah to the Geyser Peak area (Luedke and Smith, 1978). The map of Luedke and Smith (1978) shows the trachybasalt flow of Forsyth Reservoir, but mistakenly identifies a larger flow to the northeast on the Tidwell slopes that is actually high-level Tertiary alluvium. Their map is incomplete because it could not document the trachybasalts of the Geyser Peak area described in this study; thus, the trachybasalt lava flows and dikes in the quadrangle represent an extension of this northeast-southwest-trending system. The San Rafael dike swarm described by Gartner (1986) may be an even further extension.

It is noteworthy that alkaline Pliocene mafic rocks occur in the same area as the older Oligocene shoshonite rock association, but any genetic correlation between the two is only speculative.

Unconsolidated Deposits

Unconsolidated deposits (map unit Tac) of rounded, heterogeneous volcanic pebbles, cobbles, and boulders occur on Tidwell Slopes and areas north of the so-called Limestone Cliffs as well as broad areas to the north of the quadrangle. These high-level deposits that locally armor slopes of the Blue Gate Shale are considered to represent old uplifted and partially eroded alluvial fan deposits. Alternatively, they may represent Miocene volcanic mudflows that have been deeply eroded and possibly reworked. They are an enigma because of their poor exposure, uncertain age, and uncertain origin.

QUATERNARY
Landslide Deposits

Four major (figure 1) landslides (Qms) within the Geyser Peak quadrangle are components within the Fish Lake Plateau and Thousand Lake Mountain landslide zones of Schroder (1971). I will refer to these as the Solomon Basin, Hogan Pass, Hens Hole Peak, and Windy Ridge landslides.

As used in this report, the term landslide represents any large, composite mass-movement body, including toreva blocks, which are relatively coherent rock bodies that fail along a listric surface and rotate backward, and slump masses, which are coherent to jumbled. All of the landslides express an increasing downslope loss of coherence within the mass. They grade from a zone of brittle, failed toreva blocks at the headwall to plastic or viscous flow lobes at the distal margins of the landslides. This gradation has produced a readily observable corresponding gradual increase in the mobility of the landslide mass downslope (figure 4).

The Solomon Basin landslide, the only landslide exposed entirely within the quadrangle, covers bedrock over an area of approximately 4.5 square miles (11.6 km^2) in the west-central portion of the map area and is a complex system of mass-movement types. The escarpment from which the landslide failed is arcuate and contains significant talus accumulations which give the impression of cirques (for example see NE ¼ sec. 28, T 26 S, R 4 E). However, the recognition of the toreva blocks downslope determines that the deposit is indeed a landslide and not moraine of glacial origin.

The western half of the Solomon Basin landslide is characterized by a zone of toreva blocks capped by volcanic rocks that widens to the south. Downslope, the toreva blocks give way to a hummocky zone of slump masses of Jurassic and Cretaceous shales. Two recent mudflows (sec. 15, T 26 S, R 4 E) that lie on top of this landslide have open, generally north-south-striking vertical fissures in soft shale, indicating that much of their mass is still undergoing continued creep downslope. The smaller landslide appears very young, showing little vegetation or erosion, though its exact age is uncertain.

The Solomon Basin landslide grades into the Hogan Pass landslide in the northwest portion of the quadrangle and covers bedrock over an area of approximately 2.5 square miles (6.5 km^2) within the quadrangle. It involves Tertiary volcanic and Cretaceous sedimentary rocks in a series of slump masses that grade downslope into a lobate zone at the distal edges; this may represent a more fluid-dominated process.

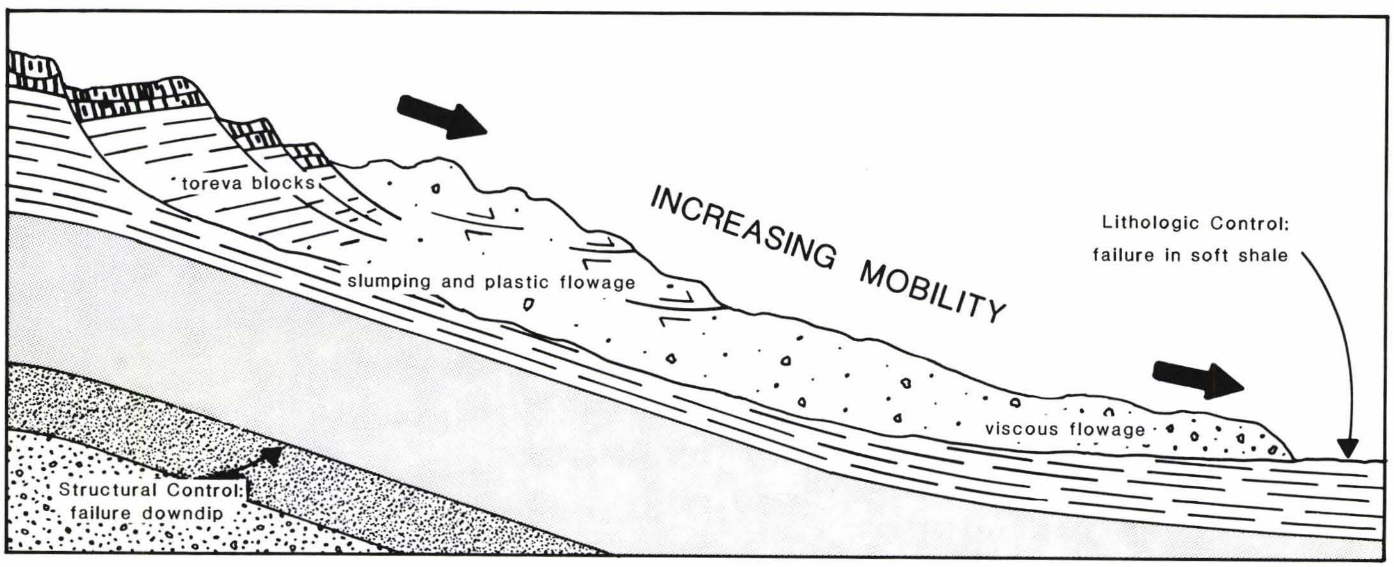

Figure 4. Idealized internal structure of the landslides. Note the increasing mobility of the landslide downslope.

Schroder (1971) noted that the morphology of Hens Hole Peak was formed by the failure of a block mass that moved downslope and away from what is now the peak. Only 1 square mile (2.6 km^2) of this landslide is exposed along the southernmost edge of the quadrangle. The Hens Hole Peak landslide consists primarily of hummocky slump masses of volcanic rock with a number of depressions occupied by lakes, springs, and playas. At the distal edges there are local lobes of shale and/or mudstone.

The largest mass-movement body in the quadrangle is the Windy Ridge landslide which overlies bedrock in approximately 10.5 square miles (27.2 km^2) and was mapped as boulder deposits by Smith and others (1963) where it occurs south of the Geyser Peak quadrangle. They were uncertain of the origin of these boulder deposits, but from additional study it is clear that they represent a landslide. The contact between the Windy Ridge and Solomon Basin landslides is drawn on the basis of topography produced by the differential timing and/or flow direction of both bodies.

The Windy Ridge landslide is a complex mass that detached and moved downslope away from Windy Ridge. It best reflects the increased downslope mobility of the landslides. The western quarter of the body consists of toreva blocks capped by volcanic rocks, some a mile or more in strike length, that have rotated as much as 20° back toward the headwall. East of, but concentric to this zone of toreva blocks, the landslide grades into a hummocky zone of slump masses. This crescent is marked by lakes and marshes, extending from Meeks Lake to Morrell Pond to Garden Basin. Outward from the slump zone the increasing mobility of the mass allowed fewer depressions to form into ponds and marshes. Springs are also common over the entire landslide. The landslide is a major watershed for farming at Baker Ranch (sec. 17, T 26 S, R 5 E) and for cattle grazing on the landslide and in the desert to the east.

The northern part of the Windy Ridge landslide consists of Tununk Shale and Brushy Basin/Cedar Mountain shales. The remainder of the landslide to the east of the toreva block zone consists of angular volcanic and sedimentary clasts well mixed in a shale matrix. The landslide is locally thin and in places has flowed around islands of bedrock where it covers a paleo-escarpment of the Summerville Formation (sections 18, 19 and unsurveyed sections 29, 30 of T 26 S, R 5 E). Canyons within the paleo-escarpment have thickened and channeled the landslide into two prominent lobes that spill out onto a low-level alluvial plain (secs. 18, 19, 20, and 29 T 26 S, R 5 E). The landslide also spills out over high pediments.

The Windy Ridge and Hens Hole Peak landslides occurred on the east-dipping limb of the Thousand Lake anticline (figure 1; cross section BB'; see also the map of Smith and others 1963) which provided structural control for the movements. Lithologic control was provided by shales of the Brushy Basin Shale Member of the Morrison Formation which are exposed in many places immediately downslope of the Windy Ridge landslide. Radbruch-Hall and others (1981) noted that landslides in the Colorado Plateau typically occur in these shales. These landslides probably failed downdip (which is also downslope) as water penetrated along bedding planes in the shales.

The Windy Ridge and Hens Hole Peak landslides are a huge system of mass-movements whose total aerial extent is much greater than the Solomon Basin and Hogan Pass landslides. It is clear that the combined structural and lithologic control of the type seen in the Windy Ridge and Hens Hole peak landslides greatly increases the potential size of landslide masses. With the exception of mudflows on the Solomon Basin landslide, none show current activity. The surfaces of all of the landslides have been significantly modified by erosion and deposition.

All landslides are considered to have been initiated during the Late Pleistocene. Landslides south of the map area have been interpreted to be Wisconsin in age because they cover pre-Wisconsin pediments (Smith and others, 1963). The development of unusually large-scale landslides such as occur in the Geyser Peak quadrangle must depend on an unusual set of factors. Well known, recently active Utah landslides (such as the 1983 Thistle landslide) caused by abnormally high precipitation, are considerably smaller than landslides in the quadrangle (figure 1). It may be that the steep escarpments from which the landslides in the quadrangle failed formed under more arid conditions. During the Pleistocene, when greatly elevated precipitation occurred, the slopes became unstable on a large scale by: 1) overloading due to the added mass of water, 2) effects of elevated pore pressure in the rock (McGookey, 1958; Smith and others, 1963), and in some cases 3) structural control. Regional landslides have been triggered in historic times by earthquake ground accelerations (McGookey, 1958).

Other Quaternary Deposits

A wide variety of unconsolidated Quaternary deposits are found in the map area other than the huge landslides just described. Armored pediments (Qmp) are composed of rockfall debris of Ferron Sandstone that protect broad pediment surfaces. These formed as a veneer of hard rock debris accumulated over soft sedimentary rocks with the westward retreat of the Ferron Sandstone in the Limestone Cliffs. These pediment surfaces are deeply incised, increasingly so away from the Limestone Cliffs.

Coarse alluvial fan deposits (Qaf) are found throughout the western part of the quadrangle. Other alluvial fans (Qalf) on the Tidwell Slopes contain poorly defined, partially reworked deposits that are presently being formed, but are also being reworked by intermittent streams — especially around their edges.

Along the eastern edge of the quadrangle lies pediment alluvium of sand and gravel at both high (Qap) and low (Qal) levels. High-level pediment surfaces have been deeply incised and dissected by stream erosion. Sand deposits (Qns) occur around the trachybasalt dike in sections 7, 8, 17, and 18 in T 26 S, R 5 E. They represent in-place weathering of the Curtis Formation, and locally, deposits reworked by wind or water.

Two mudflow deposit (Qmf) composed of clay occur superimposed on the Solomon Basin landslide in Sec. 15, T 26

S, R 4 E. Other small mass movement bodies (also Qms), including slumps and debris flows, are found along Jones Bench, south of Hogan Pass, and along the east side of Paradise Valley. Several talus deposits (Qmt) of large angular volcanic blocks occur chiefly on steep slopes in the western half of the quadrangle.

One deposit of playa mud was mapped in sec. 34, T 26 S, R 4 E, the extent of which is defined by the active shoreline of Rock Lake. Coarse, poorly sorted colluvium that includes clasts of gravel size and larger covers much of the southwestern corner of the quadrangle along with extensive soil and vegetation cover. Low-level alluvium is presently being deposited along intermittent stream courses and is composed of sand to boulder-size clasts.

STRUCTURE AND TECTONICS

STRUCTURAL SETTING

Physiographically, the Geyser Peak quadrangle lies at the transition between the Fish Lake Plateau and the western San Rafael Swell, both well within the Colorado Plateau. Structurally, the quadrangle lies at the east end of the broad transition zone between the Basin and Range province and the Colorado Plateau interior. This regional transition zone in Utah can be defined and characterized by the normally faulted high plateaus of the central part of the state, east of the Wasatch and Sevier fault zones, and west of the relatively unfaulted Colorado Plateau interior.

The Tertiary lava flows of the Fish Lake Plateau in the west of the quadrangle have been cut by Basin and Range-style normal faults which are not observed in the Mesozoic sedimentary rocks of the Colorado Plateau interior of the eastern half of the quadrangle. Therefore, the termination of normal faults in the map area can be considered to define the eastern edge of the Basin and Range—Colorado Plateau structural transition zone.

The area to the southeast and east of the Geyser Peak quadrangle exposes Mesozoic rocks that were folded during the Laramide orogeny (Davis, 1978). However, the folds in the Geyser Peak quadrangle appear to postdate this system of Laramide structures.

FOLDS

The largest fold in the quadrangle is the Thousand Lake anticline (Smith and others, 1963) (figure 1). It is a north-south-oriented structure with an axial trace that can be followed from the south in the vicinity of Salt Wash (sec. 33, T 26 S, R 4 E) into the quadrangle, but the fold abruptly dies out northward near the Solomon Dome. Based on structural contours on the fold (Smith and others, 1963) and bedding attitudes, the anticline is asymmetric with the eastern limb dipping more steeply. The Carmel Formation, exposed near Salt Gulch, lies in the core of the anticline. Further expression of the anticline is seen as the Summerville Formation increases its eastward dip going west from Jones Bench in the southeast corner of the quadrangle.

Outcrop patterns of the Summerville Formation give an excellent expression of the Solomon Dome (figure 1) whose limbs dip radially outward at a maximum of 25°. Small parasitic folds are exposed within the dome itself and are generally less than a few tens of feet in amplitude or wavelength. The dome does not seem to be more than 1 to 2 miles (1.5 - 3 km) across in any direction, but poor exposures make it difficult to ascertain its exact dimensions.

The Mesozoic rocks of the east and north-central parts of the quadrangle are only very gently and broadly folded, if at all. The beds are nearly horizontal, dipping 5° or less.

AGE AND CAUSE OF FOLDING

The Laramide orogeny occurred during the Late Cretaceous and early Tertiary Periods from 70-45 Ma (Dickinson and Snyder, 1978). Large structures near the quadrangle such as the San Rafael Swell and Waterpocket Fold are considered to be Laramide in style and age (Davis, 1978). However, in the Geyser Peak quadrangle, the Flagstaff Limestone (?) and Oligocene lavas are part of the Thousand Lake anticline; therefore, the fold was reactivated or formed after 26 Ma (table 1). Other major folds of similar age occur elsewhere in the Basin and Range-Colorado Plateau transition zone (Witkind and Page, 1984). The regional geology is so poorly understood that it is a matter of speculation at this time as to whether the structures are due to magmatic intrusion, salt tectonism, compression, or some other factor.

FAULTS

The Paradise fault zone (figure 1) is a system of normal faults between the Joes Valley and Thousand Lake Mountain fault zones (Smith and others, 1963; Blanchard, 1980). Foley and others (1986) give a detailed description of the Paradise-Joes Valley fault zones north of the quadrangle. Many of their data and conclusions may apply to faults in the quadrangle. The Paradise fault zone is found in the north-central part of the Geyser Peak quadrangle and strikes approximately N 30° E. At Paradise Valley, two major faults bound an erosional basin which Paradise Lake occupies. Both have their down-thrown blocks to the west. The fault traces continue south, join near Hogan Pass, and eventually become the Solomon Ridge fault.

The Solomon Ridge fault (figure 1) extends north-south in the west-central part of the quadrangle, immediately east of the north-south-trending Solomon Ridge, and it separates outcrops of Mesozoic sedimentary rocks on the east from Tertiary volcanic rocks on the west. A very large toreva block of the Solomon Basin landslide covers much of the fault trace.

The poorly exposed, approximately located, Meadow Gulch fault zone strikes approximately N 45° W in the northwest corner of the quadrangle (figure 1). The faults cut Tertiary lava flows on the northeast escarpment of the Tidwell Slopes. The faults join and strike southeast and terminate at the Paradise fault near Hogan Pass.

The Willow Basin fault (figure 1) strikes approximately N 75° W and cuts the Mancos Shale in surface exposures. East of Willow Basin the downthrown southern block is expressed in a duplication of the Ferron Sandstone. The fault ends in sedimentary units to the southeast and terminates westward at the Paradise fault. Possibly it is an extension of the Meadow Gulch fault zone. Both terminate about the same place on the Paradise fault, have similar strikes, and the same sense of displacement. If related, the Willow Basin-Meadow Gulch fault is older than, and cut by, the Paradise fault.

The Meeks Lake fault zone (figure 1) strikes approximately N 50° E and forms a graben southeast of Geyser Peak. This fault zone separates Geyser Peak from Windy Ridge which has been downthrown and displaced to the east. The faults are geomorphically expressed by canyons, springs, lakes, and a small stream that follow the strike of the faults.

AGE AND CAUSE OF FAULTING

Faults in the area cut Pliocene trachybasalts near Hogan Pass and Geyser Peak and, thus, are younger than about 5 Ma. Since these faults exhibit similar orientation and age to normal faults in the Basin and Range province, the faults in the Geyser Peak quadrangle are probably related to Basin and Range extension. The inception of Basin and Range faulting is considered to have been about 15 Ma (Stewart, 1978); therefore, faults in the Geyser Peak quadrangle are contemporary with younger Basin and Range uplift and extension. Foley and others (1986) give three specific models for the origin of the Paradise-Joes Valley fault zones which include: 1) high-angle normal faulting in response to extension, 2) graben collapse due to the dissolution of salt diapirs, and 3) listric faulting connected to a low-angle detachment.

Dikes and faults correlate in time, space, and orientation, and they reflect the paleostresses that produced them. The least principle stress, sigma-3, was apparently not significantly less than sigma-1 and sigma-2, or was variable, for the stresses produced faults and dikes with variable north-south strikes. Dikes may not always be a reliable indicator of paleostress directions (Delaney and others, 1986). However, it is generally recognized that stresses control dike orientations, at least in a general sense.

Humphrey and Wong (1983) documented recent seismicity in the region. Hamblin (1984) found that recent fault movement in the Basin and Range-Colorado Plateau transition has occurred by footwall uplift, although his study was far to the west. It is clear that the extensional stresses of the Basin and Range province extend well into the Colorado Plateaus and the processes producing Basin and Range faulting may be "eroding" the Colorado Plateau from the west (Best and Brimhall, 1974).

GEOMORPHOLOGY

The Geyser Peak quadrangle is an area of greatly contrasting landforms and geologic environments. The quadrangle encompasses alpine to desert terrain with more than 4000 feet (1200 m) of total relief. Physiographically, the quadrangle can be divided into three distinct zones.

The first, termed the plateau-montaine zone, includes all parts of the quadrangle west of the continuous escarpment of the Limestone Cliffs, Solomon Ridge, and Windy Ridge, and is considered to be structurally part of the Fish Lake and Wasatch Plateaus. Maximum relief within the area is in excess of 2500 feet (760 m), and local elevations exceed 10,500 feet (3200 m).

The ruggedness of the terrain is due largely to regional uplift and faulting, which has produced a prominent set of linear ridges punctuated by peaks. Especially prominent are Geyser Peak, Solomon Ridge, and the ridge immediately southwest of Meadow Gulch in the northwest quarter of the quadrangle. All are fault bounded. The Pliocene trachybasalt lava flow of Geyser Peak has been significantly offset by faulting and uplift and is exposed at the highest elevation in the quadrangle. The surface onto which the lava flowed has been relatively elevated by tectonism since about 4 Ma. The conclusion of regional uplift is strengthened by the presence of the high-level alluvial deposits.

Intermittent and ephemeral streams are at present modifying a heavily vegetated mantle of high-level Tertiary alluvium and colluvium which covers volcanic and sedimentary bedrock in nearly the entire zone. In the north-central part of the quadrangle, the Tertiary alluvium provides a resistant capping material for the Blue Gate Shale.

The second zone, termed the desert zone, consists of well-exposed sedimentary bedrock east of the plateau-montaine zone. Structurally, it is part of the Colorado Plateau interior. Maximum relief is about 2000 feet (610 m) and is due almost entirely to erosion. Landforms include buttes, mesas, and cliffs held up by resistant cap-rock, or elevated pediment surfaces. Deeply incised intermittent stream channels and alluvial plains intervene. The unique armored pediments, discussed above, occur as relatively broad, flat, dissected areas in the northern half of this zone southeast of the Limestone Cliffs. Although the relief is less than the plateau-montaine zone, the desert zone is very rugged.

The third zone, termed the Garden Basin zone, is comprised entirely of the Windy Ridge and Solomon Basin landslides (figure 1). The physiographic features of the landslides are discussed above. The Garden Basin zone is a transition between the plateau-montaine and desert zones.

The development of the present landforms in the quadrangle can be further defined. First, there has been a persistent north-south erosional and tectonic escarpment in the quadrangle since the landslides and trachybasalt magmatism. This escarpment presently consists of the Limestone Cliffs, Solomon Ridge, and Windy Ridge. The 3.8 Ma breccia body discussed above was emplaced relatively near the present surface; therefore, the escarpment must have been present to the west of the breccia body, as is the present case. The Windy Ridge landslide spilled out over paleo-topography that is essentially the same as modern topography such that there has been little significant change in the configuration of those landforms since the Wisconsin age. From these data we can conclude that the local erosional system has reached a relative steady state.

ECONOMIC GEOLOGY

An important economic resource of the Geyser Peak quadrangle is coal, and whether coal seams in the Ferron Sandstone are of sufficient quality and quantity to become economically recoverable in the future is an important question. The monograph on central Utah coal by Doelling (1972) provides the best documentation of the location, thickness, and quality of the coal in the Ferron Sandstone within the quadrangle. Approximately 50 measured coal sections were made including some coal quality analyses (Doelling, 1972).

Coal seams in the Ferron Sandstone crop out all along the Limestone Cliffs (figure 5). There are two major coal zones present (Doelling, 1972). The upper coal zone is exposed in the upper half of the unit and its seams are highly variable in thickness, ranging from 0-7.5 feet (0-2.3 m). The lower coal zone is exposed near the base of the unit. It is also variable in thickness, ranging from 0-6.5 feet (0-2 m). A small coal zone of limited extent is exposed in the upper 50 feet (15 m) of the unit in sections 19 and 30, T 25 S, R 5 E. This is called the M coal zone (Doelling, 1972) and ranges in thickness from 0-5 feet (0-1.5 m).

The average of four coal analyses is: moisture 14.6%, volatile matter 33.5%, fixed carbon 38.5%, ash 11.4%, sulfur 1.78%, and BTU/lb. 9453. The coal is considered to be subbituminous A to a high volatile C with an intermediate sulfur content (Doelling, 1972). Estimated coal reserves east of the Paradise fault zone in beds thicker than 4 feet (1.2 m) are 34,840,000 short tons (Doelling, 1972).

The coal seam in the Black Hawk Formation (NE ¼, sec. 22, T 25 S, R 4 E) (figure 5) is locally greater than 10 feet (3 m)

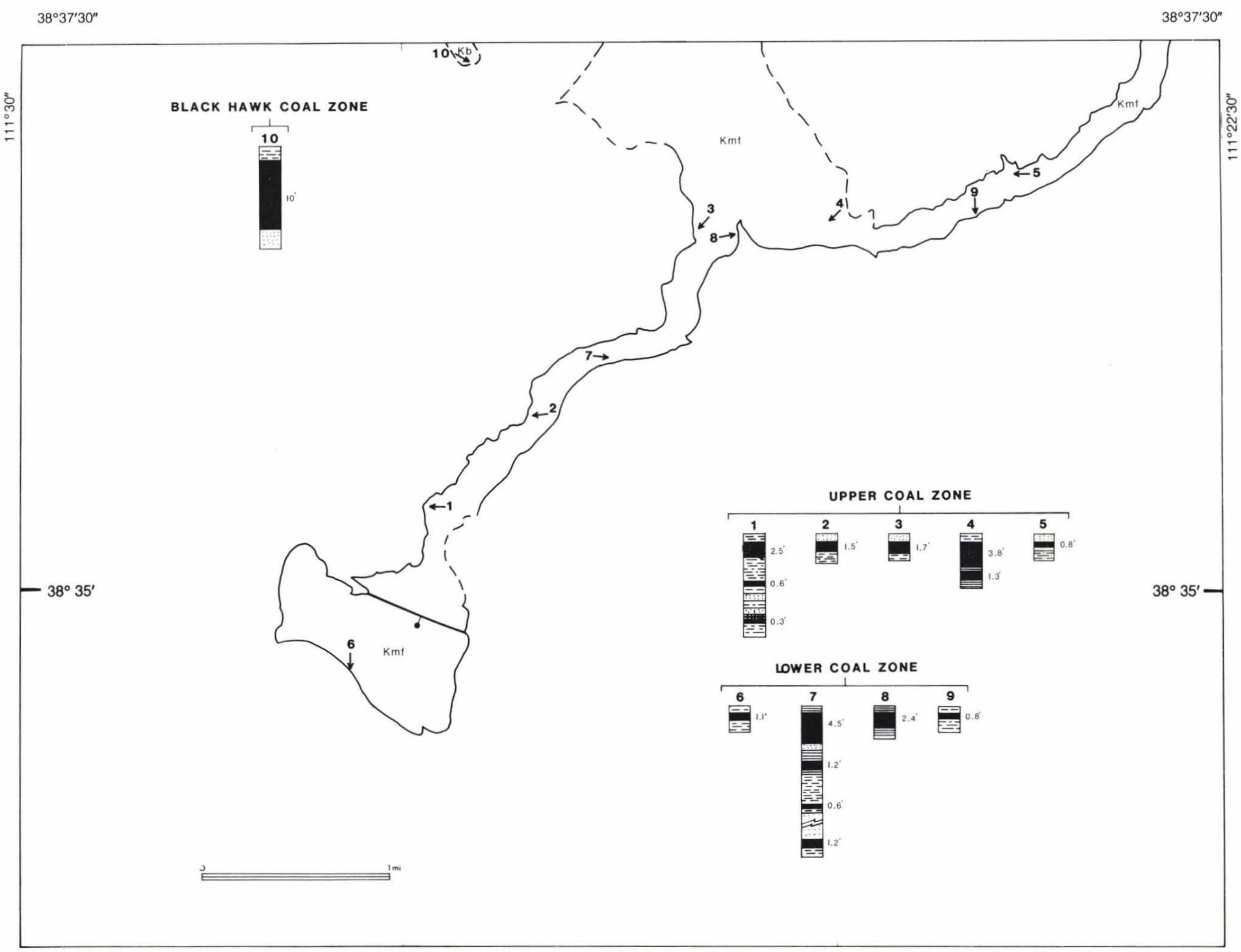

Figure 5. Map showing stratigraphic units containing coal beds thicker than 1 foot. The locations of corresponding coal sections are indicated. Note the variability in the thickness and number of coal seams in the upper and lower coal zones. Coal sections are from Doelling (1972).

thick and is exposed primarily to the north of the quadrangle. It crops out in a small graben and could prove to have future economic value.

There has been at least one attempt to recover uranium from the Salt Wash Sandstone Member of the Morrison Formation. An abandoned uranium prospect is found on Jones Bench (unsurveyed sec. 29, T 26 S, R 5 E), now in Capitol Reef National Park. Future prospecting there is unlikely. Sand deposits (Qns) are discussed above.

A now abandoned gas well was drilled in the center of the Solomon Dome (sec. 15, T 26 S, R 4 E). Wells drilled in adjacent quadrangles (Willow Springs and Forsyth Reservoir) failed to produce oil or gas. However, several wells were drilled on Oil Well Bench about 10 miles (16 km) east of the Geyser Peak quadrangle in the Salvation Creek quadrangle. These wells discovered natural gas, although none is presently being produced. This indicates a potential for future oil or gas discoveries.

The Fish Lake Plateau is relatively well watered compared to the desert to the east, and its watershed is a valuable resource. Numerous seeps and springs occur on the landslide masses and, in addition to snowmelt, form several small lakes and ponds. Leading to Baker Ranch (NE ¼, sec. 17, T 26 S, R 5 E) are more than 20 miles (32 km) of ditch that collect enough water to irrigate 200 acres (81 hm^2) of sandy farm land north of the ranch. The ditches were originally dug when the ranch was homesteaded near the turn of the century and must often be repaired after major runoff. After the growing season, the water is carried nearly 10 miles (16 km) to the east by underground plastic pipe to the Moroni Slopes in the San Rafael Swell to provide water for cattle (Dee Lyle Johnson, personal communication, 1985).

CONCLUSIONS

The Geyser Peak quadrangle contains the eastern termination of the Marysvale-Pioche volcanic zone, which is a terrane of recurring alkaline magmatism during late Oligocene and Miocene-Pliocene time. The Oligocene rocks in the quadrangle are members of the shoshonite rock association of Joplin (1968) and are part of the east-west trend of Cenozoic magmatism in the western U.S. (Best, 1986). The petrography suggests a complex magmatic evolution including magma mixing or a polybaric crystallization history.

Inception of magmatism was determined to have occurred about 26 Ma since rock samples from the base of the volcanic section were dated. Magmatism recurred about 5 Ma as lava flows and dikes were emplaced. Recent work on the San Rafael Swell dike swarm (Gartner, 1986) and this study have defined a significant terrane of trachybasalt magmatism in the earliest Pliocene.

Structurally, two large folds are found in the quadrangle. Their origin is uncertain, but their age is surprisingly young since they fold late Oligocene volcanic rocks. The folds are much younger than the accepted age of regional Laramide structures such as the nearby Water Pocket Fold and the San Rafael Swell. Further regional investigation of these youthful structures is needed.

The quadrangle lies at the eastern termination of the Basin and Range-Colorado Plateau structural transition zone, which coincides with the eastern edge of the Fish Lake Plateau. The western part of the quadrangle, which is part of the Fish Lake Plateau, is cut by normal faulting while the eastern half of the quadrangle is not. The age of normal faulting is less than approximately 5 Ma since the faults cut Miocene-Pliocene lava flows.

The geomorphology of the quadrangle reveals some interesting data on the relatively recent geologic history of the area. First, a north-south escarpment has persisted in the area during the last 4 Ma. Second, the topography of the desert area has not been altered appreciably since it was partly covered by the landslides. Third, the source area(s) for the volcanic clasts of the high-level Tertiary alluvium has subsequently been removed by erosion and/or tectonism.

The sedimentary stratigraphy indicates that the Emery coal field does not extend further south than the northern half of the quadrangle. However, there is a significant amount of coal in the area that is not now, but may become, economically recoverable in the future.

The large Quaternary landslides indicate a high potential for mass movement in the region, especially where the shales of the Brushy Basin Member of the Morrison Formation lie in structurally or topographically unstable conditions. The Windy Ridge landslide demonstrates that the development of large landslides can be enhanced by structural control where rock masses can fail downslope and downdip in an incompetent rock unit (see cross section BB'; figure 4). The magnitude and Pleistocene age of these landslides indicate that they developed under destablizing circumstances, namely prolonged and elevated precipitation on a rock mass perched on a high topographic escarpment that was relatively stable under more arid conditions.

Considering the size and origin of the large landslides, there seems to be little chance of their large-scale remobilization. However, the youthful mudflows on the Solomon Basin landslide indicate a potential for small-scale mass movements. The remoteness of the area minimizes damage potential, probably limiting it to watershed damage. However, several graded roads, including State Route 72, cross the landslides. The potential for damage to them warrants consideration. Graded roads also frequently wash out after heavy precipitation.

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