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Geologic Map of the Parran Quadrangle, Churchill County, Nevada

by

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OVERVIEW

This detailed geologic map of the Parran 7.5' quadrangle is located in the eastern Hot Springs Mountains of Churchill County, Nevada about 80 km northeast of Reno. This area contains the Desert Queen geothermal system, which is a hidden geothermal system (no surface expressions such as hot springs) with temperatures >140°C at depths as shallow as ~150 m (Benoit et al., 1982; Faulds et al., 2010; Dellerman et al., 2021). The map area includes the western part of a large composite basin, the Desert Queen basin, and adjacent parts of the Hot Springs Mountains. The detailed mapping has revealed the stratigraphic and structural framework of the area, which is critical to developing a conceptual model for the geothermal system as well as elucidating Neogene regional extension.

In the Desert Queen area, Tertiary volcanic and sedimentary strata rest nonconformably on Mesozoic metasedimentary-metavolcanic and plutonic basement. Quaternary deposits onlap the bedrock units. The Mesozoic basement is exposed directly west of the quadrangle in the footwall of the east-dipping Desert Queen fault zone (Faulds et al., 2012). An erosional surface of moderate relief (i.e., hundreds of meters) is developed on the Mesozoic rocks, above which rests the Tertiary section. The Tertiary section is a heterogeneous mix of volcanic and sedimentary rocks, with a total thickness of ~2–3 km. Only Miocene rocks are exposed in the quadrangle, but Oligocene units have been observed in deep wells in the area and altered sedimentary rocks of probable Eocene age crop out directly west of the map area. Although significant lateral variations exist, the Tertiary section exposed within the quadrangle can be grouped into several discrete packages. In ascending order, these include:

- A lower sequence of middle Miocene andesite, dacite, and rhyolite lavas and subordinate rhyolitic to dacitic ash-flow tuffs, ranging from ~16 to 13 Ma.
- A complex section of dominantly aphanitic basalt lavas, but with intercalated sequences of white siltstone, diatomite, and tuffaceous sedimentary rocks, ranging from ~13 to 10 Ma.
- A sequence of dominantly sedimentary rocks (mainly diatomite and tuffaceous siltstone) and lesser olivine basalt flows, ranging from ~12 to 10 Ma.
- An ~9–10 Ma limestone unit that pinches out eastward and interfingers with siltstone and diatomite units.
- Olivine basalt flows and porphyritic dacite domes and flows, which dominate the southern part of the map area.
- A capping 7.46±0.31 Ma aphyric dacitic ash-flow tuff.
- Late Miocene to Pleistocene basin-fill sediments primarily in the Desert Queen basin.

The age of the Miocene section is well constrained in the area by $^{40}Ar/^{39}Ar$ dating and tephrochronology. Tephras (i.e., ash-fall deposits) are common in the late Miocene section and facilitate dating and correlation of stratigraphic units through tephrochronology or geochemical fingerprinting (e.g., Perkins and Nash, 2002). The capping ~7.5 Ma ash-flow tuff is one of the youngest pyroclastic deposits in the region. It forms a resistant cap on the ridges and mesas to the south of the Desert Queen basin and appears to underlie the basin itself, as evidenced by several small exposures along the western margin of the basin. It provides an important marker from which to gauge the magnitude of late Miocene to recent extension.

The Quaternary sediments in the area are dominated by lacustrine deposits of Pleistocene Lake Lahontan (Morrison, 1964). Most of the closed basins in the Great Basin contained numerous pluvial lakes during the Pleistocene (Reheis, 1999; Reheis et al., 2002; Mifflin and Wheat, 1979). However, lacustrine deposits older than those of the late Pleistocene (Sehoo) cycle were not observed in the Desert Queen area. During the Sehoo highstand, Lake

Lahontan reached a maximum altitude of about 1328 m (Adams et al., 1999) submerging much of the map area. Due to isostatic rebound subsequent to desiccation of the lake, the highstand shoreline presently varies from around 1318–1340 m around the basin (Adams et al., 1999; Adams and Wesnousky, 1999). Lake Lahontan deposits include beach gravels and sands and lacustrine silt and mud. Quaternary alluvial deposits include alluvial fans of latest Pleistocene to Holocene age and active alluvial channels. In the central part of the map area, two small areas contain tufa mounds aligned ~NNE, parallel to the predominant structural grain in the area. These tufa mounds may mark the sites of late Pleistocene hot springs that issued along NNE-striking normal faults.

The structural framework of the Parran quadrangle is dominated by NNE-trending gently to moderately tilted (<10° to ~60°) fault blocks bounded by moderately to steeply dipping normal faults. Most of the faults accommodated relatively minor offset (i.e., hundreds of meters or less), but the east-dipping Desert Queen fault zone in the westernmost part of the quadrangle accommodated 2–3 km of normal displacement. West-tilted fault blocks dominate the area within and proximal to the Desert Queen basin. Bedding and layering show a distinct NNE-trending structural grain in accord with tilting along the NNE-striking normal faults. Stratigraphic and structural relations (e.g., tilt fanning in the Miocene section as shown in cross sections) suggest that the major pulse of extension occurred between ~13 and 9 Ma but has continued into the Quaternary (Faulds et al., 2010).

The geologic mapping and potential field geophysical data indicate that the Desert Queen geothermal system occupies a prominent step-over (or relay ramp) within the horse-tailing southern termination of the east-dipping Desert Queen normal fault system (Dellerman et al., 2021; Dellerman, 2021). Step-overs are the most common structural setting for known geothermal systems in Nevada (Faulds et al., 2021). Hybrid structural settings (i.e., more than one type of favorable structural setting), similar to that at Desert Queen, contain some of the more robust geothermal system in the Great Basin region (Faulds et al., 2013).

DESCRIPTION OF MAP UNITS

Quaternary Alluvial, Eolian, and Slope Deposits

Qa Alluvium (Historic, active) Moderately to well sorted, loose, sand, silt, and gravel deposits along floodplains and active washes. Generally flat surface morphology associated with fluvial terraces (particularly along Humboldt Slough). Generally less than 4 m thick.

Qa_1 Alluvium (Historic, active) Similar to Qa in composition and thickness, but only active in extreme flood events. Expressed as large meander belts incised into Qly deposits along Humboldt Slough.

Qe Eolian deposits (Historic to Holocene) Tan to light brown, loose, windblown medium to coarse-grained sand and silt derived from latest Pleistocene to middle Holocene lacustrine deposits. Contains sand sheets and small circular-shaped dunes along the western margin of Fortymile Desert. Thickness varies from up to 2 m for individual dune forms and generally less than 1 m for sand sheets.

Qd Eolian sand dune deposits (Historic to Holocene) Tan to light brown, loose, windblown medium to coarse-grained sand, silt, and trace gravel and pebbles derived from latest Pleistocene to middle Holocene lacustrine deposits. Prominent dune fields occur in the central part of the quadrangle in Fortymile Desert. Dune forms include linear, barchan, and star dunes. Thickness varies from ~2 m to greater than 5 m.

Qp Playa deposits (Historic to Holocene, ephemeral) White to tan fine sand, silt, and clay. Generally confined to isolated depressions between beach berms. Thickness less than 3 m.

Qc Colluvial deposits (Holocene to late Pleistocene) Poorly sorted sand and gravel with trace boulders mantling the basal part of moderately steep slopes in the Hot Springs Mountains; commonly greater than 2 m thick.

Qrf Rockfall deposits (Holocene to late Pleistocene) Isolated deposit in the southwestern part of the quadrangle consisting of poorly sorted subangular to angular boulders (up to ~2 m in diameter) and cobbles sourced from Tyt. Probably represents a relict rockfall or possibly a debris flow deposit. Thickness up to ~4 m.

Qay Alluvial-fan deposits (Holocene to latest Pleistocene, undivided) Poorly sorted gravel and sand deposits with subangular to subrounded cobbles and boulders within and adjacent to active washes. Surface morphology characterized by anastomosing distributary channels and bar and swale topography. Channel incision generally less than 2 m. Minimal or no soil development. Thickness ranges from several meters at fan heads to greater than 5 m downslope. Generally undivided, but in places separated into Qay_2 and Qay_1 based on relative topographic position.

> **Qay_2 Alluvial-fan deposits (late to middle Holocene)** Similar in composition and thickness to Qay. Generally preserved about 1 to 2 m above active Qa surfaces. Minimal or no soil development.
>
> **Qay_1 Alluvial-fan deposits (middle Holocene to latest Pleistocene)** Similar in composition and thickness to Qay and Qay_2. Bar and swale morphology slightly muted. Weak soil development.

Qai Alluvial-fan deposits (latest to middle Pleistocene) Remnant poorly sorted sand and pebble to cobble gravel deposits preserved above and incised by Qay deposits. Surfaces gently slope valleyward and typically have channel interfluves incised several meters. Surfaces contain remnant lag deposits associated with the Sehoo lacustrine cycle. Moderately developed soils. Range in thickness from 5 to 15 m.

QTa Older alluvium (early Pleistocene to late Miocene) Older pale-brown alluvium consisting of matrix-supported conglomerate and gravels with generally subangular pebbles to cobbles of locally derived volcanic and sedimentary rocks. Mantles older rock units. Exposed thickness outside the Desert Queen basin as much as ~30 m but probably much thicker (up to ~600 m) within the Desert Queen basin as shown in cross sections A–A' and B–B'.

QTbg Basalt gravels (early Pleistocene to late Miocene) Poorly exposed, essentially unconsolidated bouldery conglomerate containing angular to subrounded clasts of aphanitic and porphyritic basalt and Tyt. Only observed outcrop lies at an elevation of 1335 m (4380 feet) in southwestern part of the quadrangle just above the high stand of Lake Lahontan. Stratigraphic position is not clear. Thickness is as much as ~10 m.

Quaternary Lacustrine Deposits

Qhl Lacustrine deposits of Humboldt Lake (Historic) Moderately sorted sand, silt, and clay. Subject to seasonal wetting and drying cycles. Thickness unknown.

Qly Lacustrine deposits (Holocene) Gray, white, and tan moderately sorted sand, silt, and clay associated with Holocene lacustrine cycles. Occurs in the broad flat valley floor of Fortymile Desert. Active eolian (Qe), dune (Qd), and alluvial-fan (Qfl) deposits bury Qly deposits in the center and margins of the basin. Thickness greater than 10 m.

Ql Lacustrine deposits (latest Pleistocene) Tan to light brown moderately sorted sand, silt, and clay with trace cobbles associated with the Sehoo lacustrine cycle. Occurs along the margins of Fortymile Desert at elevations between 1190 and 1340 m. Locally overlain by beach and beach berm deposits. Thickness varies from several meters near bedrock knobs to greater than 15 m in embayments.

Qb Nearshore and onshore beach and shoreline deposits (latest Pleistocene) Moderately to poorly sorted sand and gravel associated with the Sehoo lacustrine cycle. Generally occur downslope of highstand deposits and characterized by curvilinear landforms related to beach and longshore processes during lake regression. Thickness generally less than 3 m.

Qbg Nearshore and onshore beach and shoreline deposits (latest Pleistocene) Similar to Qb deposits but consisting primarily of bouldery gravel. Associated with the Sehoo lacustrine cycle. Thickness generally less than 3 m.

Qbb Shoreline beach berm deposits (latest Pleistocene) Poorly sorted sand, pebbles, cobbles, and boulders associated with the Sehoo lacustrine cycle. Morphologically expressed by curvilinear bands that are broadly convex with a relief of less than 2 m above Ql deposits.

Qbbtu Shoreline beach berm deposits (latest Pleistocene) Similar in composition and thickness to Qbb with isolated massive lithoid tufa deposits. Associated with the Sehoo lacustrine cycle.

Qtu Lithoid tufa deposits (latest Pleistocene) Isolated, massive bands of lithoid tufa associated with the Sehoo lacustrine cycle. Possibly related to spring activity along concealed faults. Thickness ranges from 1 to 3 m.

Qtus Shoreline tufa deposits (latest Pleistocene) Tufa deposits mixed with moderately sorted sand and gravel associated with the Sehoo lacustrine cycle. Thickness less than 2 m.

Qfl Alluvial-fan and lacustrine deposits (Holocene to latest Pleistocene, undivided) Poorly sorted sand, gravel, and cobbles. Occurs along the margins of Fortymile Desert. Deposits are gently sloping and project upslope to channels incised into lacustrine and alluvial-fan deposits, representing the reworking and redeposition of these deposits. Thickness varies from several meters in midslope areas to less than 1 m on the valley floor.

Miocene Volcanic and Sedimentary Rocks

Tyls Limestone (Pliocene to late Miocene) Pale-gray sandy limestone and calcareous, medium-grained sandstone. Grains are generally subrounded to rounded. Limestone is commonly vuggy. Locally contains fossiliferous beds with abundant shell fragments and gastropods up to ~7 mm long. Caps ridge in northeastern part of the quadrangle with isolated exposures elsewhere. Smaller isolated exposures may correspond to buried Quaternary tufa associated with Lake Lahontan. Thickness as much as ~40 m.

Typu Pumice-rich sandstone (late Miocene) Pumice-rich massive, moderately to poorly indurated pale-brown sandstone. Contains abundant black and pale-brown, subrounded to angular black and pale-brown to yellowish-brown pumice up to ~20 cm long. Sandstone matrix consists of coarse-grained, rounded to subangular grains of pumice, lithics, and feldspar. Commonly weathers to unconsolidated sandy material with conspicuous pumice. Smaller mapped exposures may be reworked, pumice-rich beds in Lake Lahontan sediments. Thickness up to at least ~20 m.

Tyt Ash-flow tuff (late Miocene) Purplish-gray, generally moderately to strongly welded aphyric ash-flow tuff. Probably dacitic in composition. Sparse (<1%) phenocrysts of plagioclase, biotite, and rare sanidine. Lower part commonly contains abundant lithic fragments, black fiamme, and a basal vitrophyre up to 2 m thick. Plagioclase has yielded an $^{40}Ar/^{39}Ar$ age of 7.46±0.31 Ma on this unit from an exposure to the west of the quadrangle. Thickness is as much as ~125 m.

Tytu Upper ash-flow tuff (late Miocene) Upper poorly welded reddish-brown to locally pale-brown Tyt. Sparse lithic fragments in contrast to Tytl, Tytli, and lower part of Tyt. Thickness is as much as ~10 m.

Tytli Lithic-rich ash-flow tuff (late Miocene) Purplish-gray to reddish-brown, lithic-rich ash-flow tuff in the northeastern part of the Parran quadrangle. Aphyric with ~1% phenocrysts of feldspar and biotite

up to ~1 mm long. Commonly highly vesiculated. Lithic fragments are generally subangular, consist of mafic to felsic volcanic rock as well as metasedimentary rock, and range up to ~15 cm long. Lithics comprise up to 50% of Tytli. Probably correlates with Tyt in the southwestern part of the quadrangle. Thickness as much as ~40 m.

Tytl Lower ash-flow tuff (late Miocene) Lower pumice-rich, nonwelded to poorly welded Tyt, with pumice/fiamme up to ~12 cm long. Only mapped locally. Thickness up to ~20 m.

Tyss Sandstone (late Miocene) Pale grayish-brown to grayish-white, medium- to coarse-grained, moderately indurated, calcareous feldspathic arenite with subrounded to subangular grains of feldspar, quartz, calcite, and lithics. Thickness is as much as 50 m.

Tybt Tuffaceous sediment (late Miocene) White to pale-brown pumice-rich tuffaceous sediment containing angular clasts of basalt; pumice up to 2 cm long. Thickness as much as ~20 m.

Tb Basalt lavas (late Miocene) Dark to medium-gray, aphanitic, typically vesicular basalt lavas with lesser flow breccia. Flows contain ~1–10% phenocrysts of olivine, plagioclase, and clinopyroxene to ~3 mm long. Groundmass concentrate from a flow in the upper part of the section has yielded an $^{40}Ar/^{39}Ar$ age of 7.52±0.05 Ma directly south of the quadrangle. Upper part of section is distinct unit cropping out extensively across the southern part of the quadrangle and likely including the isolated exposure in the northeastern part of the map area. Lower part of section ranges from ~8 to 12 Ma and is complexly intercalated with Tds, as exposed to the west of the Parran quadrangle in the northern Hot Springs Mountains (Faulds et al., 2012, 2017). The lower part of Tb is probably extensive in the subsurface across the Parran quadrangle. Thickness of upper part of section is as much as ~150 m, whereas lower part of the section (together with Tds) may locally exceed 350 m in thickness.

Tpd Porphyritic dacite lavas (late to middle Miocene) Light-gray to purplish-gray porphyritic dacite containing ~35% phenocrysts of plagioclase (to ~6 mm long), lesser hornblende (to ~5 mm long), and biotite. Probably includes parts of domes. Appears to pinch out to the west. Plagioclase has yielded an $^{40}Ar/^{39}Ar$ age of 7.70±0.07 Ma. Thickness is as much as ~160 m.

Tst Siltstone (late Miocene) Pale-gray to white tuffaceous siltstone and lesser fine- to medium-grained sandstone. Locally includes diatomaceous shale, thin limestone beds, and light-gray tephras to ~1 m thick. Mainly exposed in the northeastern part of the quadrangle but probably extensive in the subsurface elsewhere. Isolated exposures and poorly exposed outcrops difficult to distinguish from Lake Lahontan silts in some areas. Thickness is as much as ~250 m in the subsurface.

Tds Diatomaceous shale (late Miocene) Thinly laminated, locally friable white diatomaceous shale that appears to thin eastward across the northern Hot Springs Mountains. This unit is complexly intercalated with Tb and crops out extensively to the west of the Parran quadrangle in the northern Hot Springs Mountains (Faulds et al., 2012, 2017). Numerous pale-gray tephras to ~1 m thick are intercalated within Tds. Geochemical correlations of the tephra beds constrain the age of Tds to between ~8 and 12 Ma. Tds is probably extensive in the subsurface across the Parran quadrangle. Thickness of the Tds/Tb section may locally exceed ~350 m in the subsurface.

Tls Limestone (late Miocene) Isolated exposure of pale-gray to grayish-white limestone that crops out in the northeastern part of the quadrangle and probably correlates with a much more extensive limestone deposit that extends across much of the northern Hot Springs Mountains to the west of the quadrangle. Limestone to the west of the Parran quadrangle contains tufa-rich intervals and is bracketed between ~9 to 10 Ma (Faulds et al., 2012, 2017). Thickness of exposure in the Parran quadrangle is ~10 m.

Tbo Basalt lavas (middle to early Miocene) Dark-gray weathering reddish-brown, generally aphanitic to locally porphyritic vesicular basalt lavas with lesser flow breccia. Flows are generally 1 to 3 m thick. Aphanitic lavas contain sparse (~1%) iddingsitized olivine and plagioclase phenocrysts to ~2 mm long. Less common porphyritic lavas are more abundant near the base of the section and contain olivine and plagioclase phenocrysts to ~9 mm long. Only exposed in northwestern part of the Parran quadrangle, but crops out extensively directly west of the quadrangle (Faulds et al., 2012). Lower part of section directly west of the quadrangle has normal magnetic polarity. Thickness is as much as ~300 m.

Tws Siltstone (middle to early Miocene) Thinly laminated, grayish-white siltstone and greenish-gray shale with lesser diatomite and fine- to medium-grained sandstone. Beds range from a few mm's to ~8 cm thick. Siltstone is commonly tuffaceous with abundant flecks of biotite and feldspar. Thickness as much as ~125 m.

Tda Dacite and andesite lavas (middle to early Miocene) Light-gray to purplish-gray, generally porphyritic andesite and dacite lavas containing up to ~20% phenocrysts. Dacite lavas contain plagioclase and biotite phenocrysts up to 1 cm and 1 mm long, respectively. Plagioclase up to 6 mm long in andesite lavas. Plagioclase is commonly altered to sericite and clays. Only exposed in northwestern part of the Parran quadrangle, but crops out extensively directly west of the quadrangle (Faulds et al., 2012). Thickness is as much as ~110 m.

Early Tertiary Rocks

Tas Altered sedimentary rocks (Oligocene to Eocene) Heterogeneous altered sedimentary rocks including layers of light brownish-gray to pale-brown and reddish-brown siltstone, fine- to medium-grained sandstone, and matrix-

supported conglomerate. Conglomerate contains subrounded to rounded clasts of hypabyssal igneous rocks of felsic to intermediate composition. Entire sequence is altered, commonly silicified, and locally cut by quartz veins. This unit does not crop out in the Parran quadrangle but is exposed directly west of the quadrangle on Cinnabar Hill, where it was inferred to be Jurassic-Triassic metasedimentary rocks (JŦms; Faulds et al., 2012). Zircons from Tas were dated using the U-Pb LA-ICPMS method following the detrital zircon method. The largest population of detrital grains are late Cretaceous, and the weighted mean of the youngest three concordant ages is ~104 Ma with the youngest concordant grain 97 Ma. These results constrain the maximum depositional age to late Cretaceous (Dellerman, 2021). Rough concordance of the attitude of this sedimentary unit with the lower part of the Miocene section indicates the possibility of a younger Paleocene–Eocene age. Tas appears to fill paleovalleys cut into Kd. Kd was probably a significant source of detritus to this sedimentary sequence. Exposed thickness is as much as at least 300 m directly west of the quadrangle (Faulds et al., 2012), but lower contact of unit is not exposed.

Mesozoic Basement Rocks

Kd Diorite (Late Cretaceous) Gray to greenish-gray, medium- to coarse-grained diorite cut by numerous quartz veins up to ~1 m wide. U/Pb zircon dating indicates that Kd is ~102 Ma (Dellerman, 2021). No exposures of Kd were observed in the Parran quadrangle. However, Kd is the only exposed Mesozoic basement unit in the northern Hot Springs Mountains and crops directly west of the quadrangle in the footwall of the Desert Queen fault (Faulds et al., 2012). Thickness is unknown but probably exceeds 1 km.

Mzu Plutonic and metamorphic rocks, undivided (Cretaceous to Triassic) Undivided plutonic and metamorphic rocks, including late Cretaceous diorite and granite and Jurassic to Triassic metasedimentary and metavolcanic rock. No exposures of Mzu were observed in the Parran quadrangle. Only the diorite is exposed in the northern Hot Springs Mountains directly west of the Parran quadrangle in the footwall of the Desert Queen fault; other Mesozoic basement units have been penetrated by drill holes. Thickness is unknown but probably exceeds several kilometers.

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