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Preliminary Geologic Map of the Tuscarora Geothermal Area, Elko County, Nevada

by

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DESCRIPTION OF MAP UNITS

Quaternary Deposits

Qa Active channels and recently active fan alluvium, undivided (Holocene to Pleistocene) Channel and overbank deposits of creeks, annually active washes, and recently to annually active alluvial fans. Generally consists of poorly sorted silt to pebble- cobble gravel up to 5 cm in diameter. Clasts are subrounded to well-rounded. In the southern reaches of the Hot Creek drainage, this unit consists of moderately well sorted pale gray silt and sand. Where incised by streams, Qa is exposed steep-sided gullies up to 5 m deep. Thicknesses are variable and poorly known, but greater than 5 m along Hot Creek.

Qfy Young alluvial-fan deposits (Holocene to Pleistocene) Poorly sorted silt to cobble gravel up to 15 cm in diameter; typically matrix supported; clasts are subangular to well-rounded; clasts are dominantly derived from unit Tdf, rocks of the Tuscarora volcanic field, and reworked older fan deposits. Surfaces are commonly vegetated with variable soil development. Includes recently reworked alluvium deposited in washes incised into older fan deposits of unit Qfo/Qfi. Qfy is less than 7 m thick.

Qfi Intermediate alluvial-fan deposits (Pleistocene) Poorly sorted silt to pebble gravel up to 6 cm in diameter; typically matrix supported; clasts are subrounded to well-rounded; clasts are dominantly derived from unit Tdf, rocks of the Tuscarora volcanic field, and reworked older fan deposits. Surfaces are commonly vegetated with variable soil development and erosionally rounded near fan edges. Qfi surfaces are distinguished based on their intermediate elevation, relative to units Qfy and Qfo. Thicknesses range from 2 to 10 m.

Qfo Old alluvial-fan deposits (Pleistocene) Poorly sorted sand to cobble gravel up to 15 cm in diameter; typically matrix supported; clasts are subangular to subrounded and consist of Miocene volcanic rocks; surfaces are commonly heavily vegetated with some soil development. Fan edges are erosionally rounded. Fan surfaces are typically dissected by Qfi, Qfy, and/or Qa. Unit Qfo is deposited on the flanks of the northeastern Tuscarora Mountains and the Independence Mountains. Qfo is less than 10 m thick.

Qfi/Qfo Old and intermediate alluvial-fan deposits, undivided (Pleistocene) Poorly to well- sorted sand to pebble-cobble gravel up to 15 cm in diameter. Typically clast-supported with very minor sand matrix; poorly indurated and nonstratified. Clasts are subangular to well-rounded and consist of rocks derived from unit Tdf and rocks of the Tuscarora volcanic field. Fan surfaces are smooth to undulating with little to no soil development. Unit Qfi/Qfo overlies lavas of the Tuscarora volcanic field and unit Tst. Thicknesses are poorly defined but range up to 12 m near fan heads.

Qfqy Young alluvial-fan deposits containing >10% quartzite clasts (Holocene to late Pleistocene) Poorly sorted silt to cobble gravel up to 20 cm in diameter; typically matrix supported; clasts are subangular to well-rounded and consist of quartzite and Miocene volcanic rocks. Qfqy is derived from older quartzite clast-bearing fan deposits, including Qfqi, Qfqo, Qfqi/Qfqo, and QTq and Miocene volcanic rocks, including units Tdf and Taf. Surfaces are sparsely to non-vegetated with weak to no soil development. Deposit thickness is poorly known, but does not exceed 5 m.

Qfqi Intermediate alluvial-fan containing >10% quartzite clasts (Pleistocene) Poorly sorted sand to cobble gravel up to 20 cm in diameter with isolated boulders up to 50 cm in diameter; matrix supported; clasts are subangular to well-rounded; surfaces are smooth to moderately dissected. Deposits are mostly derived from older quartzite clast- bearing fan deposits of northern Independence Valley, including Qfqo, Qfqi/Qfqo, and QTq. Locally contains subangular clasts of Miocene volcanic rocks, including units Tdf and Taf. Surfaces are sparsely to non-vegetated. Deposit is distinguished based on the intermediate elevation of the Qfqi surface, relative to units Qfqy and Qfqo. Deposit thickness is generally less than 8 m, but may be much greater along the Independence Mountains range front.

Qfqo Old alluvial-fan containing >10% quartzite clasts (Pleistocene) Poorly sorted sand to cobble gravel up to 20 cm in diameter with isolated boulders up to 50 cm in diameter. Typically matrix supported with subrounded to well-rounded clasts of quartzite and chert. Clasts are derived from unit QTq and possibly Pleistocene glacial till deposits of the northern Independence Mountains (Sibbett, 1982). Surfaces are broadly rounded to undulating. Soil development is weak and surfaces are sparsely vegetated. Deposits are at least 15 m thick.

Qfqi/Qfqo Old and intermediate alluvial-fan deposits containing >10% quartzite clasts, undivided (Pleistocene) Poorly sorted sand to cobble gravel with isolated boulders up to 50 cm in diameter; matrix- to clast-supported with subangular to well-rounded clasts. Typically dominated by quartzite pebbles and cobbles, and up to 10% pebbles derived from units Tdf and Taf. Locally contains subangular pebbles of chert, derived from unit QTf. Soil is locally up to 70 cm thick. Vegetation is sparse to dense. Thin deposits (≤1.5 m) of Qfqi/Qfqo mantle units Tst, Tdf, and Taf along the northern margin of Independence Valley. Thickness is 1–5 m.

Qgc Gravel and colluvium on low angle slopes, undivided (Holocene to Pleistocene) Moderate to well-sorted pebble-cobble gravel up to 10 cm in diameter deposited on gentle slopes. Clast-supported deposits contain angular to subround pebbles of porphyritic volcanic rocks. Soil is very weakly developed to absent. Deposits up to 1 m thick.

Qls Landslide deposits (Holocene to Pleistocene) Slope-failure-derived deposits of unconsolidated debris. Deposits are typically hummocky and lobate. Curvilinear headwall scarps are recognizable, though commonly rounded by erosion. Landslide deposits are moderately to densely vegetated. Estimated maximum thickness is ~10 m.

Qc Colluvium and talus, undivided (Holocene to Pleistocene) Deposits of colluvium and talus on, and at the base of steep slopes. Deposits are typically poorly sorted, clast-supported with angular to subangular pebbles to boulders up to 40 cm long. Deposits are generally less than 4 m thick.

Geothermal Deposits

Qss Siliceous sinter (modern to late Pleistocene) Undivided chalcedonic and opaline sinter terraces, mounds, and aprons precipitated at active and ancient hot springs; restricted to the northeast-trending zone of hydrothermal alteration and geothermal activity along the margins of Hot Creek. Locally, deposits of Qfy mantle unit Qss. Unit crops out in T41N R52E Sections 5 and 8. Estimated maximum thickness is ~10 m.

Qfs Silica-cemented alluvium (Holocene to late Pleistocene) Poorly to moderately- sorted coarse sand to cobble-gravel up to 15 cm in diameter cemented by silica; well-indurated deposits, locally forming erosionally resistant ledges; mainly mapped to the south and southeast of the large sinter terrace (unit Qss). Deposits from 0.5–1.5 m thick. Unit crops out in T41N R52E Sections 5, 8, and 17.

Qfsq Silica-cemented alluvium containing >10% quartzite clasts (Pleistocene?) Poorly sorted coarse sand to cobble-gravel up to 25 cm in diameter cemented by silica. Unaltered quartzite clasts are cemented by silicified sand matrix; well indurated; clast- supported, consisting of >10% rounded quartzite cobbles, as well as subangular to subrounded volcanic clasts. Silica induration is of the same style as unit Qfs. Less than 1 m thick. Unit crops out in T41N R52E Section 17 (NE ¼).Unit is up to 1.5 m thick.

Qbh Silicified breccia (Holocene to Pleistocene) Silica-cemented breccia. Qbh contains angular clasts of tuffaceous siltstone of unit Tst and porphyritic dacite of unit Tpd up to 15 cm long. Clasts are argillically altered, though phenocryst composition in dacite clasts remain discernible. Siltstone clasts are pitted and partially flooded with silica. The matrix consists of coarse cataclasite flooded with opalized silica. Locally, silica cement is finely banded. Dark orange to dark red exotic iron oxide coats the weathered outcrop surface. Qbh lies in the footwall of a west-dipping fault zone that bounds the large sinter terrace (Qss) to the east. Unit crops out in T41N R52E Section 8 (NE ¼).

Quaternary and Tertiary deposits

QTbf Silicified cataclasite Well-indurated silicified fault zone breccia. Composed of ~70% finely milled matrix, quartz stringers (1–5 mm wide), quartz vein fragments (≤15 cm long), and angular lithic clasts of tuff (≤5 mm long). Unit QTbf is exposed along the Cottonwood Peak fault in tabular, steeply dipping, fin-shaped outcrops with up to 5 m of vertical relief. The age of faulting and hydrothermal alteration along the fault zone is constrained to between ~16 Ma and Holocene. The age of the youngest clearly faulted unit (Tdf) is ~16 Ma. Locally, silicified cataclasite of the Cottonwood Peak fault forms a buttress unconformity with Quaternary fan deposits in the hanging wall. Quaternary units contacting the fault zone rocks are not offset by faulting. Rather, the fan deposits accumulated at the break in slope formed between the silicified fault zone rock and less resistant tuffaceous sedimentary rock (unit Tst) in the hanging wall. Unit crops out in T41N R52E Section 6 (NW ¼). Perpendicular to fault strike, QTbf ranges in thickness from ~1–8 m.

QTq Quartzite-bearing coarse gravel Moderate to well-sorted, well-rounded coarse pebble- to boulder-sized quartzite gravel mostly less than 40 cm in diameter with sparse boulders up to 1.2 meters in diameter. Clasts are possibly derived from Ordovician McAfee Quartzite of the Independence Mountains, described by Miller et al. (1981) and Muntean and Henry (2006). Quartzite boulders are up to 1.3 m in diameter. Deposits are non-stratified. Matrix was not exposed. Surfaces are typically smoothed and non-vegetated. Most QTq deposits are gently tilted (4° to 10^{o}) and not associated with the present drainage pattern. Margins of deposits commonly bleed out into younger fan surfaces. A QTq surface is gently deformed in part by drag in the hanging wall of the Independence Mountains fault zone (T41N R52E Sections 3 and 10). Erosional remnants of QTq are commonly only 1–2 m thick with a maximum observed thickness of ~6 m. This unit may be thicker along the Independence Mountains range front, where it is mostly concealed beneath younger fan deposits.

QTf Old fan alluvium (Pleistocene to late Tertiary) Poorly to moderately sorted sand to cobble gravel up to 20 cm in diameter; clast-supported; clasts are subrounded to well rounded. Dominated by chert with lesser quartzite and siltstone clasts. Deposit lies beneath unit QTq and is exposed in a single locality (T41N R52E Section 9). Thickness is approximately 3 m.

TERTIARY ROCKS

Miocene Lavas

Taf Porphyritic dacite (middle Miocene) Dacite flows, typically glassy, locally spheriulitic, with poorly developed columnar joints perpendicular to the base of flows. Flows contain 4–11% phenocrysts. Phenocrysts include 3–10% euhedral to subhedral plagioclase (0.5–4 mm long), 1% subhedral clinopyroxene (0.2–2 mm long), and <1% anhedral quartz (≤2 mm long). These flows are mainly preserved as erosional remnants atop more resistant Tdf flows. Thickness – 190 m.

Tvt Glassy dacite flow (middle Miocene) Dacite flow distinguished by very fine flow banding. Flow-parallel foliation is readily observed in outcrop where weathering accentuates finely banded groundmass. Tvt is relatively porous, and soft, though discrete vesicles are not evident in hand sample. This unit weathers easily and is preserved either atop, or as a distinctive flow within, the uppermost portion of unit Tdf. The lateral extent of Tvt is limited. Phenocrysts include 2–3% subhedral embayed sanidine (0.5–1 mm long), 1% plagioclase (2–3 mm long) with sharp normal zoning, and 1% anhedral quartz (≤0.5 mm long). Thickness – 40 m.

Tdf Porphyritic rhyolite—Jarbidge Rhyolite (middle Miocene) Laterally extensive package of grayish- pink porphyritic rhyolite flows. Distinctive flow-parallel platy partings spaced 1–3 cm apart characterize the middle of this unit. Dips of platy partings steepen near flow tops. Elliptical (flattened) vesicles are locally present at flow tops. Also contains sparse glass- dominant layers up to several meters thick and pods of flow breccia. Coarsely porphyritic unit with 12–20% phenocrysts, including 4–15% subhedral to euhedral plagioclase (0.5–3 mm long), 2–12% anhedral quartz (0.5–3 mm long), 2–3% euhedral sanidine (3–5 mm long with sparse cumulophyric aggregates up to 8 mm long), <1% magnetite (0.5 mm long). Groundmass ranges from entirely glass to 90% microcrystalline feldspar microlites with minor glass stringers. Sanidine yielded an $^{40}Ar/^{39}Ar$ age of 16.15±0.02 Ma (sample NV-0190, Henry et al., 2011). Thickness – 120 m.

Oligocene (?) Sedimentary Rocks

Tst Tuffaceous siltstone and sandstone of Chicken Creek (middle Eocene to middle Miocene) White to light-tan tuffaceous siltstone and sandstone with sparse conglomerate lenses up to 5 m thick. This unit encompasses the undivided package of sedimentary rocks that lie beneath unit Tdf and above the igneous rocks of the Tuscarora volcanic field. Tst is dominated by poorly-indurated massive siltstone composed of subrounded grains of devitrified tuff, angular grains of plagioclase (2–20%), quartz grains (<1%), and rare broken biotite grains (<1%). Sandstone is moderately indurated, thinly bedded, locally cross-bedded. The sandstone is a moderately sorted litharenite, consisting of coarse sand to coarse silt with subangular grains of feldspar, biotite, quartz, and well-rounded grains of pumice. Conglomerate lenses between 0.5 and 5 m thick occur throughout the section. These conglomerates are well indurated and consequently relatively resistant within the Tst section. Conglomerate lenses are clast-supported, moderately to poorly-sorted with subrounded to subangular clasts of porphyritic andesite, porphyritic dacite, argillite, quartzite, and siltstone of units Ms and Pu up to 10 cm long. Unit Tst is pervasively silicified adjacent to the Cottonwood Peak fault (T41N R52E Section 6) and within the geothermal area. Total thickness is ~300 m.

Eocene Rocks – Tuscarora Volcanic Field

Te Andesite and dacite undivided Poorly exposed porphyritic flows, domes, and intrusive rocks of andesitic to dacitic composition associated with the Tuscarora volcanic field. Unit Te encompasses units Tsa, Tsd, Tn, and Tao, where weathering and/or poor exposure prevents further distinction of these rocks. Phenocryst abundance ranges from 5–40% and consists of some combination of the following minerals: plagioclase (3–40% of rock volume), clinopyroxene (≤2%), orthopyroxene (≤2%), biotite (≤3%), and hornblende (≤1%). Unit Te includes all rocks of Tuscarora volcanic field that intrude and overlie intracaldera deposits of unit Tct. The estimated thickness of Te, constrained by drilling within the geothermal field, is ~250 m.

Tpd Porphyritic dacite Medium gray porphyritic (~17% phenocrysts) dacite domes and possibly flows. Weathers distinctly as platy talus (2–6 cm thick) which accumulates at the base of outcrops. Groundmass composed of pilotaxitic plagioclase microcrysts. Phenocrysts consist of 15% euhedral to subhedral plagioclase (0.3–4 mm long) are commonly embayed; 2–3% biotite (0.3–2 mm long), commonly partially replaced by magnetite. Weak hydrothermal alteration and secondary mineralization is present near the Cottonwood Peak fault and adjacent to the geothermal field. Secondary mineralization includes interstitial chalcedony in groundmass (≤3% of rock volume) and spotty replacement of biotite by chlorite. Unit Tpd is nonconformably overlain by unit Tst. Biotite yielded an $^{40}Ar/^{39}Ar$ age of 40.7±0.5 Ma (sample T11-128). Thickness probably varies and is estimated to be less than 250 m.

Tsa Densely porphyritic andesite Dark gray andesite flows locally exhibit flow- parallel planar partings spaced 5–20 cm apart. Tsa locally contains pods of flow breccia. Columnar jointing is well developed at the base of some flows within unit Tsa. Groundmass ranges from glass-dominant to felty, with plagioclase microlites. Phenocryst assemblage consists of 15–30% subhedral to euhedral plagioclase, commonly embayed (1–4 mm long) and 2% equant subhedral grains of clinopyroxene (0.2–1 mm long).

Ts Tuffaceous sandstone intercalations Moderately sorted, coarse-grained tuffaceous sandstone intercalated between lava flows of unit Tsa. Unit Ts is thin bedded and well indurated, consisting mainly of sand-sized particles of devitrified pumice with grains of rounded quartz, feldspar, and broken biotite. Thickness is less than 10 m.

Tsd Porphyritic andesite Pale gray hornblende-bearing andesite. The phenocryst assemblage consists of 15% euhedral plagioclase (0.8–3 mm long) commonly in cumulophyric aggregates up to 5 mm in diameter; 2% subhedral biotite (0.3–1 mm long); <1% euhedral to subhedral hornblende (0.4–0.8 mm), with partially resorbed rims. Groundmass is cryptocrystalline with microphenocrysts of plagioclase, lessor pyroxene, glass, and sparse magnetite. Plagioclase yielded an age of 40.4±0.3

Ma (sample T11-083). Thickness is poorly known but probably less than 300 m.

Tn Porphyritic andesite Medium-gray porphyritic andesite flow breccia poorly exposed beneath colluvium and alluvial fans along the north bank of the Owyhee River. Trachytic groundmass is composed of plagioclase laths and sparse pyroxene. Phenocryst assemblage consists of 7% subhedral to euhedral plagioclase (0.4–3 mm long); 2% subhedral to euhedral orthopyroxene (0.2–0.8 mm) occurs in cumulophyric aggregates up to 3 mm in diameter; <1% clinopyroxene (0.2–0.5 mm); and <1% subhedral biotite (0.5–0.8 mm long). Thickness is poorly known but probably less than 100 m.

Tao Porphyritic andesite Dark gray andesite with closely spaced (1–3 cm) planar partings, which are interpreted to be flow-parallel. Groundmass is commonly glassy and dark green. Phenocrysts (<9%) consist of ~5% euhedral plagioclase laths, 2% euhedral augite (≤5 mm long), and <1% biotite (≤1 mm long). Where present, this unit directly overlies Tct. Thickness is poorly known but probably less than 300 m.

Tct Tuff of Big Cottonwood Canyon Light gray to tan, moderately to densely welded, porphyritic (2–6% phenocrysts) intracaldera tuff, containing fine-grained phenocrysts of quartz, sanidine, plagioclase, and biotite. The tuff is abundantly lithic, containing up to ~15% subangular to angular clasts of bluish-gray argillite, quartzite, and siltstone derived from units Ms and Pu, as well as porphyritic dacite and andesite derived from the Tuscarora volcanic field. Lithic clasts are mostly less than 3 cm in length with the exception of a siltstone block ~1.5 m in diameter (T41N R51E Section 1 SW ¼). Unit Tct locally contains up to ~20% pale tan fiamme (1–5 cm long). Tuff is crystal poor and contains quartz (2–4%; 0.6–1.2 mm long), sanidine (1–3%; 0.6–1 mm long), plagioclase (<1–2%; ~1 mm long), and biotite (~1%; ≤1 mm long). Phenocryst assemblage, abundant lithics, and overall thickness distinguish tuff of the Big Cottonwood Canyon caldera from ash-flow tuffs elsewhere in the Tuscarora volcanic field (Henry et al., 1999). The tuff is non-stratified, though locally, fiamme define a prominent compaction foliation. Sanidine has yielded an $^{40}Ar/^{39}Ar$ age of 40.4 ± 0.2 Ma (sample T11-052). The tuff is at least 2.5 km thick, based on the 30°–60° northeast dips across a 4 km-wide area of continuous exposure west of the geothermal area. Tct thins eastward to ~700 m within the geothermal area.

Tr Dacite intrusion Porphyritic dacite intrusion with distinctive pale pink to light gray crystalline groundmass. Felty groundmass is mainly composed of plagioclase microlites. Phenocrysts consist of 15% euhedral to subhedral plagioclase (0.5–3 mm long) and 2–3% euhedral to subhedral biotite (≤1.5 mm long). Relatively abundant biotite phenocrysts against pale groundmass pink distinguish this unit from other andesite and dacite of the Tuscarora volcanic field.

Tbr Intracaldera megabreccia and mesobreccia deposits, undivided Volcanogenic breccia deposits near the inner walls and floor of the Big Cottonwood Canyon. Unit Tbr contains two main breccia subtypes: 1) Heterolithic mesobreccia that is variably matrix and clast-supported. The breccia matrix is quartz-rich and composed mainly of sand-sized dark gray clastic material. Clasts are angular to subrounded and range from 5 mm to ~1.2 m in diameter. Clasts of both Paleozoic metasedimentary rocks and Eocene volcanic rocks are present, with the ratio of Paleozoic to Eocene clasts ranging from 10:1 to 1:10. No gradation of rock type or clast size is apparent in the mesobreccia. These caldera- related mesobreccia deposits are further distinguished from tectonic breccias by their vertical thickness (up to 250 m). 2) Blocks of basement-derived megabreccia that range from 2 to 73 m in diameter, composed mainly of argillite and siltstone with lessor calcareous sandstone and sandy limestone. Unit Tbr does not crop out in the study but is encountered in drill holes within the geothermal field.

PALEOZOIC BASEMENT

Ms Siltstone, shale, and silty limestone—Schoonover Formation Poorly exposed siltstone, identified and described in detail by Fagan (1962) and Miller et al. (1984), belonging to the Mississippian–Devonian Schoonover Formation. Unit Ms weathers to reddish brown, tan, and blue-gray siltstone chips. Silty limestone turbidite sequences, interbedded with dark gray siltstone and metavolcanic rocks, of the Schoonover Formation are intercepted in geothermal drill holes but do not crop out in the study area.

Pu Paleozoic metasedimentary rocks, undivided Chert, argillite, shale, and quartzite of the Roberts Mountains allochthon, regionally correlated with the Ordovician Valmy Formation (Henry et al. 1999; Miller, 1984); described in detail by Coats (1987) and Muntean and Henry (2006).

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