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The Geology and Geochemistry of the Midas Geothermal System, north-central Nevada

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ABSTRACT

The Midas geothermal system is blind to the surface, and it was discovered in the course of drilling and deepening of the Ken Snyder mine in 2006. The mine is situated in an uplifted block, north of the Midas Trough, and gold-silver ore is produced from epithermal quartz veins, which are hosted by an alternating sequence of hydrothermally altered basalt and rhyolite. Hot water discharges (50-85°C) were encountered around 4550 ft asl, coinciding with the water table, which occurs 1000 ft below the surface. The modern thermal anomaly defined by a 50°C isotherm appears to extend for about 5 km^2, but its continuity and extent are poorly known. Anomalous heat flow is estimated to be ~1.5 MW.

Chemical and isotope analyses indicate thermal waters are dominated by aqueous bicarbonate and derive from old meteoric water. They also indicate that thermal waters have a common origin and that they have been affected by deep circulation and hydrothermal water rock interaction. Equilibration temperatures based on the Na/K, K/Mg and quartz-silica geothermometers range from 120 to 180°C. Hydrothermal alteration formed with the precious metal mineralization in the mid-Miocene, and a modern alteration overprint has yet to be detected.

The Midas thermal water compositions are similar to Beowawe and Tuscarora, which suggest that hydrothermal fluids derive from deep concealed Paleozoic carbonate aquifers. The basin bounding faults that localize near surface fluid flow in these systems possibly act as leakage points to regionally extensive reservoirs in hot sedimentary basins in northern Nevada.

1. INTRODUCTION

Midas, the site of the Ken Snyder mine, is located in the Great Basin in north central Nevada, approximately 100 km northeast of Winnemucca (Fig. 1). The underground mine has been in operation since the late 1990s, where gold-silver-rich ore is extracted from north-south and northwest-southeast trending epithermal quartz veins. In 2006, mining activities cut below the water table, intersecting localized zones of hot water (50-85°C) that discharged (>100 gal/min, >6 l/s) from sub-horizontal diamond drill holes and fractures in newly excavated tunnels. Evidently, the top of a blind geothermal system had been discovered.

This report summarizes results of a preliminary study of geothermal activity at Midas, centering on the geological setting and water chemistry. Fieldwork involved three site visits (2011-2013) to measure temperatures and collect thermal water samples from underground localities. Eight samples of core (MUC-02258) from a sub-horizontal hole (>750' long) were obtained for thin section and XRD analyses to assess occurrences of modern, versus ancient, hydrothermal alteration. Surface thermal features, such as warm-hot springs, are unknown, so all of the results derive from data on underground measurements and sampling.

2. GEOLOGIC SETTING

Midas is located in northern Nevada within a province of anomalously high regional heat flow of 80-125 mW/m^2 (Blackwell et al., 2011) where there are several producing geothermal fields, including Beowawe (18 MW), Dixie Valley (72 MW), and Tuscarora (18 MW). Evidence of modern magmatism is unknown. For the last 18 million years, however, this region has been the site of ongoing regional extension and sporadic pulses of volcanic activity (e.g., Dickinson, 2006), and it is likely that the high regional heat flow is the product of crustal thinning and deep intrusion of magmas (e.g., Kennedy and van Soest, 2007).

The mine is situated in an uplifted fault block in the southern Snowstorm Mountains north of the Midas Trough. Precious metal mineralization is hosted by a succession of lavas, tuffs and volcaniclastic sedimentary rocks (>1500 m thick) that dip gently eastward (Leavitt et al., 2004; Leavitt and Arehart, 2005; Fig. 2). These were emplaced during mid-Miocene (17-14 Ma) volcanic and hydrothermal activity related to the timing of the Northern Nevada Rift (Zoback and Thompson, 1978; Zoback et al., 1994; Leavitt et al., 2004; Dickinson, 2006; Ponce and Glen, 2008). Faults associated with the Midas Trough trend east-northeast and formed in the late Miocene (10-6 Ma) due to clockwise rotation of extensional regime that earlier produced the Northern Nevada Rift (Zoback and Thompson, 1978; Zoback et al, 1994).

The mine is accessed through a portal near the southern end of the Colorado Grande vein (Fig. 3), with underground development between 5700 and 4450 feet asl. The northern part of the mine is 1600 feet below the surface. The surface is incised by north-south trending drainages and varies in elevation from 5670 to 6160 feet asl. Judging from the occurrences of wetlands and springs in the Midas Trough to the south, the water table appears to be about 5100 feet asl. In the Ken Snyder mine, however, the water table appears roughly 600 feet deeper as most of the underground access is dry (Fig. 2).

3. HEAT FLOW

The Midas thermal anomaly is defined by the occurrences of hot water discharge in the mine and temperatures measured in hydrographs located in groundwater monitoring wells (Fig. 3). Hot water sample sites are described in Table 1. When first encountered by drilling, hot water flow rates were high, diminishing over time and eventually reaching steady state, suggesting that drill holes are draining compartments of rock filled with hot water near the water table.

Using shallow temperature gradients of 8 to 15°C/100 m measured in the hydrographs and assuming a thermal conductivity of 2.0 W/m°C, the natural conductive heat flow is estimated to be in the range of 175-300 mW/m^2 compared to the local background value of 90-100 mW/m^2 (Blackwell et al., 2011). The convective heat flow, estimated from a total discharge of 4.0-4.5 kg/s of hot water (50-85°C) and a base temperature of 15°C, is almost 1 MW.

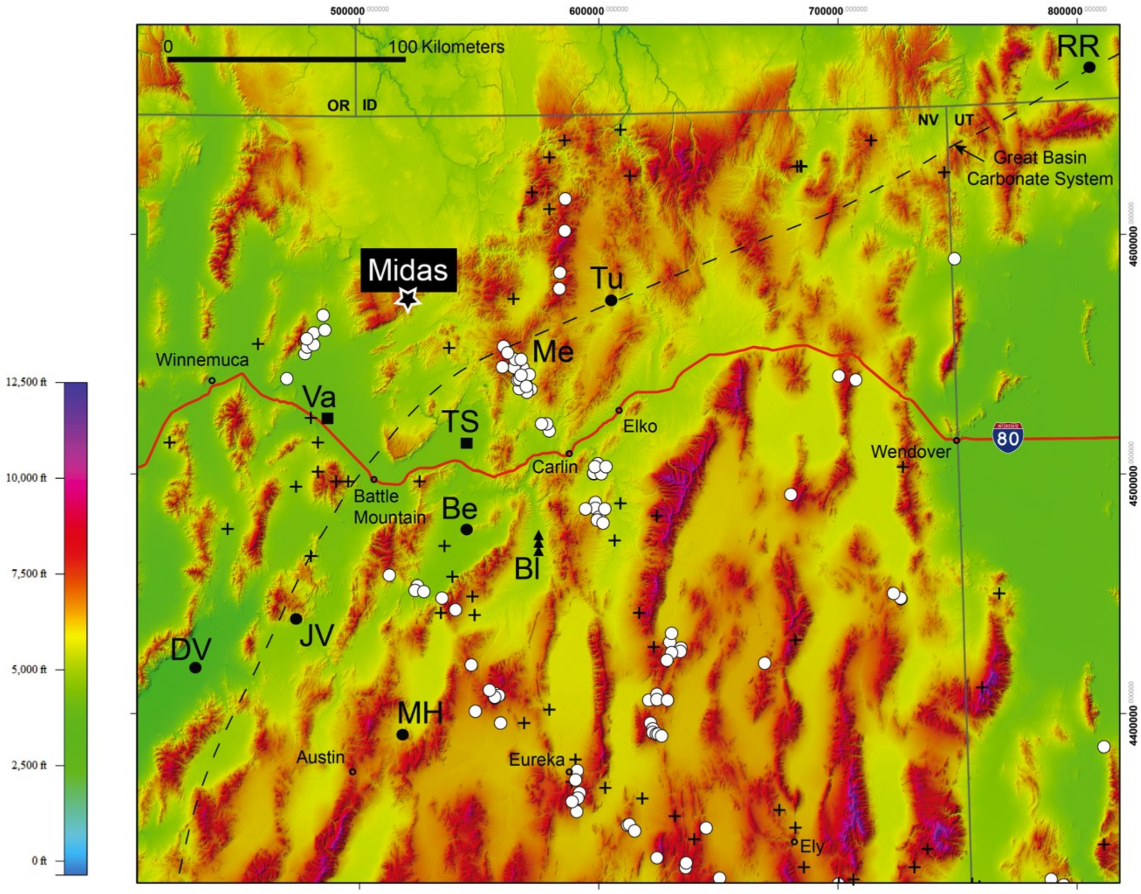

Figure 1: Map of northeast Nevada showing the locations of Midas, producing geothermal power stations (black filled circles), and thermal power stations (black filled squares), and other mineral deposits (Carlin-type gold=white filled circles; intrusion-related and epithermal deposits=black crosses). Abbreviations: Be=Beowawe; Bl=Blackburn oil field; DV=Dixie Valley; JV=Jersey Valley; Me=Meikle; Mi=Midas; MH=McGinness Hills; RR=Raft River; Tu=Tuscarora; Va=North Valmy). The dashed line represents the northern extent of the Great Basin Carbonate System (e.g., Heilweil et al., 2011). Modified from Simmons and Allis (2015).

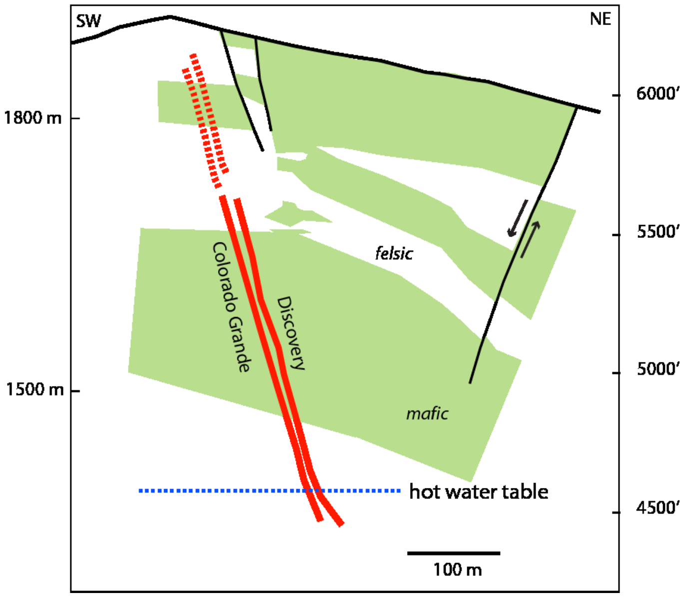

Figure 2: Schematic cross section of the Colorado Grande and Discovery veins, showing the host volcanic stratigraphy comprising interlayered felsic and mafic volcanic rocks, structure, and the location of the hot water table (modified from Leavitt and Arehart, 2005).

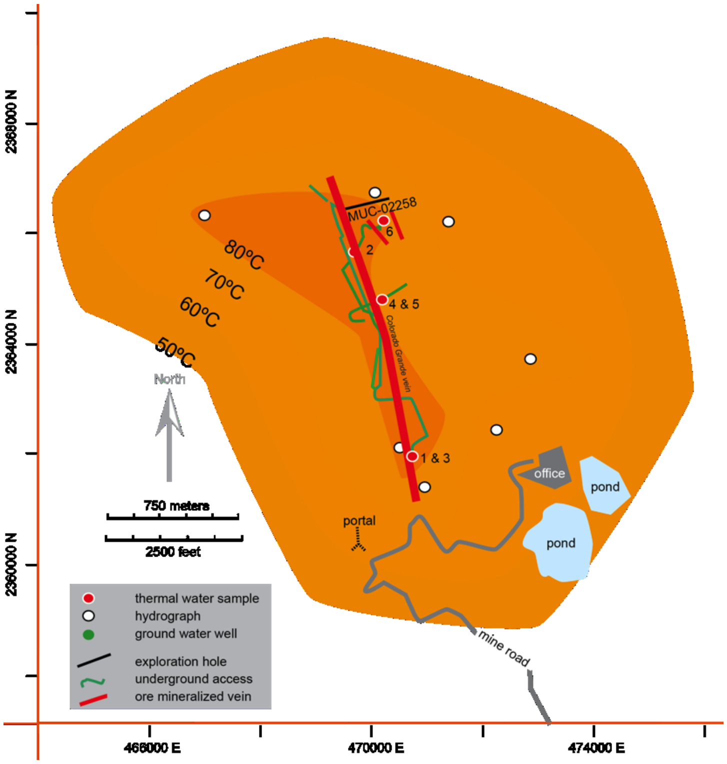

Figure 3: Plan view of the thermal anomaly at about 4350 to 4550’ asl as plotted from hydrographs and underground hot water discharges, along with underground access, sampling and hydrograph locations, surface features, and the mine portal.

4. FLUID CHEMISTRY AND HYDROTHERMAL MINERALS

Six water samples, obtained on three separate mine visits (2011, 2012, and 2013), were filtered, acidified and analyzed by Thermochem (2011 samples), and University of Minnesota in the Department of Earth Sciences (2012 and 2013 samples). Aliquots of thermal waters were collected for oxygen and hydrogen isotope analysis, which were performed by Prof. John Humphrey in the Department of Geology and Geological Engineering, Colorado School of Mines. All the data are reported in Table 2. Legacy data for thermal waters from Beowawe and Tuscarora are supplied for comparison (Table 3).

Midas thermal waters are characterized by relatively high concentrations of bicarbonate, subordinate sulfate, and minor chloride (Fig. 4), and near uniform Cl/B ratios of about 60 to 80 (Fig. 5). These results suggest that the thermal waters have a common origin as supported by the narrow range of stable isotope data (-14.8 to -15.8 ‰ $\delta^{18}O$; -129 to -132 ‰ δD; Fig. 6). The Midas water compositions plot to the right of the meteoric water line (Fig. 6), reflecting isotopic exchange associated with deep fluid circulation and hydrothermal water-rock interaction (e.g. Taylor, 1997). The isotope compositions also appear to be lighter with respect to the composition of regional ground water, suggesting they represent old meteoric recharge when the climate was much colder. Amongst the cations, sodium dominates with subordinate potassium and trace magnesium, which is typical a deeply circulated thermal waters (e.g., Giggenbach, 1988). Silica concentrations range from 59 to 87 ppm (Table 2), reflecting modest resource temperatures interpreted below.

Hydrothermal minerals, comprising quartz, adularia, albite, chlorite, illite, calcite, fluorite, prehnite, pyrite, and epidote, are common and widespread in the volcanic rocks that host epithermal vein mineralization, but they were emplaced during mid-Miocene hydrothermal activity (Leavitt et al., 2004; Leavitt and Arehart, 2005). No new information was gained from the examination of thin sections of diamond drill core samples in this investigation; i.e., alteration overprints associated with modern geothermal activity were not detected. Nonetheless, the formation of secondary minerals in volcanic rocks from an earlier hydrothermal event could be influencing the chemical effects of water-rock interaction and equilibration of modern thermal waters.

The concentration of aqueous silica (SiO_2) and the ratios of aqueous constituents (Na/K, K/Mg) were used to calculate equilibration temperatures (Giggenbach, 1988; 1991; Fournier, 1991). Quartz-SiO_2 equilibration temperatures range from 110 to 129°C, Na/K equilibration temperatures range from 152 to 187°C, and K/Mg equilibration temperatures range from 106 to 137°C (Table 4). This wide range of equilibration temperatures is not surprising, as Na/K values tend to reflect the deepest and hottest temperatures, whereas K/Mg and quartz-SiO_2 equilibration values reflect shallower and cooler temperatures (e.g., Simmons, 2013). The confidence of these values is improved by aforementioned occurrences of hydrothermal quartz, albite, adularia, illite, and chlorite in altered host rocks. Based on these calculations, the maximum temperature of a geothermal resource beneath the Ken Snyder Mine (<2 km depth) is probably in the range of 120-180°C.

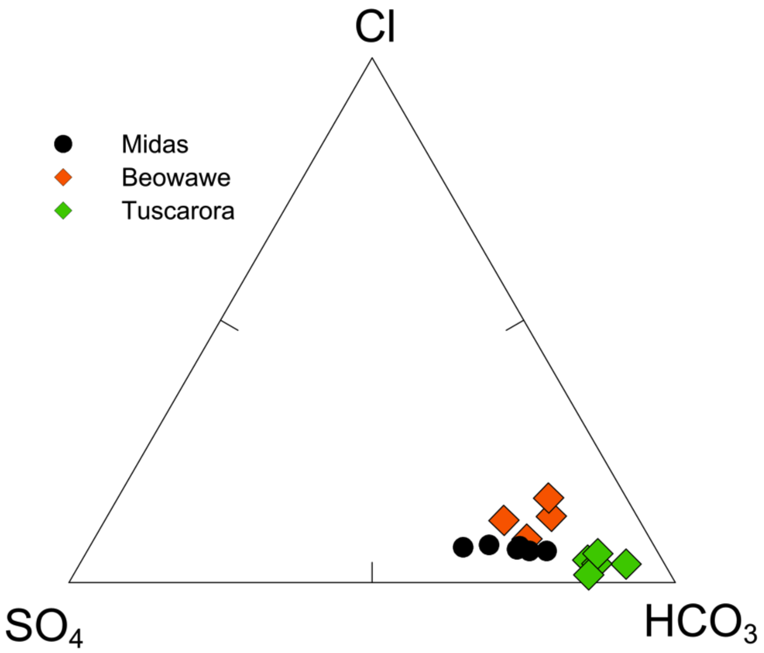

Figure 4: Relative concentrations of Cl-HCO_3-SO_4 in thermal waters.

Table 1. Midas sampling sites

1. Sept. 29, 2011, 1-4550 access, 50’ east of the Colorado Grande vein hanging wall contact. Fracture azimuth 12, dip 87. Host rock-June Belle rhyolite. 85°C, pH-7.5, 0.1-0.5 l/s. Clear water seeps from several cracks over a 2 m wide interval. Hottest seep lacks precipitate. Cooler low flow seeps have terracettes of travertine. E470725, N2361947, 4553’. Initial hot water discharge was 20 l/s, tapering with time to low steady state flow.
2. Sept. 29, 2011, 4-4500 south sill access on Colorado Grande hanging vein. 52°C, pH-7.5, 2 l/s. Clear water flowing out of tunnel (sill) and access to source is not possible, probably at least 500’ to the north. E469666, N2365648, 4495’.
3. Oct. 23, 2012, (nb same as 1, but a year later) 1-4550 access, 50’ east of the Colorado Grande hanging wall. Fracture azimuth 12, dip 87. Host rock-June Belle rhyolite. 82.8°C, pH-7.5, 0.1 l/s. Clear water seeps from several cracks over a 2 m wide interval. Hottest seep lacks precipitate. Cooler low flow seeps have terracettes of travertine. E470725, N2361947, 4553’.
4. Oct. 23, 2012, 8-4550 access, 90’ east of the Colorado Grande hanging wall. 75°C, pH-9, 0.1 l/s. Clear water flows from new drill rods (drilling was in progress at sampling), total flow ~1 l/s; no precipitates. E470180, N2364756, 4469’.
5. July 24, 2013, 8-4550 access, 40’ east of the Colorado Grande hanging wall. 68°C, pH-7, 0.5 l/s. Clear water flows from drill rods and bolts to secure mesh; no precipitates. E470156, N2364681, 4465’.
6. July 24, 2013, Spiral 7, just below 4540 level GP vein. 80°C, pH-7, 0.5 l/s. Clear water flows from floor of spiral ramp (SP7); no precipitates. E470236, N2366158, 4530’.

Table 2. Midas thermal water compositions.

Location	T° C	pH	Li	Na	K	Ca	Mg	Cl	HCO_3*	SO_4	B	SiO_2	δ D	δ ^{18}O
1	85	8.30	0.18	123	3.70	4.78	0.03	17	175	55	0.3	87	-129	-15.5
2	52	8.86	0.19	129	3.92	4.98	0.03	17	160	66	0.3	87	-131	-15.8
3	83	7.50	0.17	107	3.97	5.60	0.07	17	190	62	0.3	76	-131	-15.1
4	75	9.00	0.21	111	5.96	5.70	0.02	19	170	87	0.24	59	-130	-14.8
5	68	7.00	0.16	105	3.59	5.20	0.03	17	200	58	0.3	74	-132	-15.4
6	80	7.00	0.17	106	3.87	3.50	0.02	17	210	50	0.3	79	-131	-15.8

*For grey shaded cells, values of HCO_3 were determined by negative difference in the sums of cation milli-equivalents and anion milli-equivalents

Table 3. Beowawe and Tuscaroa thermal water compositions (Bowman and Cole, 1982; Cole and Ravinsky, 1984; White, 1992).

Location	T° C	pH	Li	Na	K	Ca	Mg	Cl	HCO_3	SO_4	B	SiO_2	δ D	δ ^{18}O
Beowawe														
Frying Pan geyser	98	8.98		230	16	1	0.10	69	383	130		320	-130	-14.8
Rossi 21-19	198	8.10	0.9	143	14	24.0	7.10	25	145	28	0.9	427		
Ginn-13	211	8.40	1.4	203	30	11.0	0.30	59	260	47	1.7	335		
85-18	160	9.10	1.9	277	35	2.5	0.30	31	267	76	8.0	436		
Tuscaroa														
7A	89	6.90	nd	151	15	10.0	0.50	18	352	52	0.8	129	-137	-16.1
7C	56	6.90	nd	169	11	19.0	3.00	19	484	34	0.9	122	-133	-16.6
8a	73	7.60	nd	145	19	17.0	2.00	16	382	50	0.9	103	-128	-16.1
8B	95	7.40	nd	148	20	1.0	0.50	6	345	55	0.9	104	-137	-14.0
DH 66-5	110	8.40	nd	163	25	14.0	2.00	26	397	47	0.8	109	nd	nd

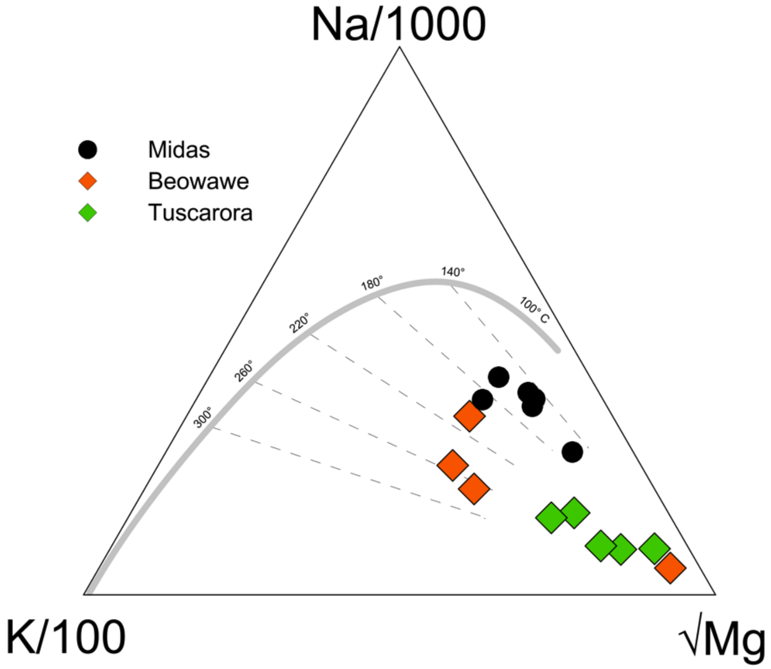

Figure 5: Relative concentrations of Cl-B-Mg in thermal waters.

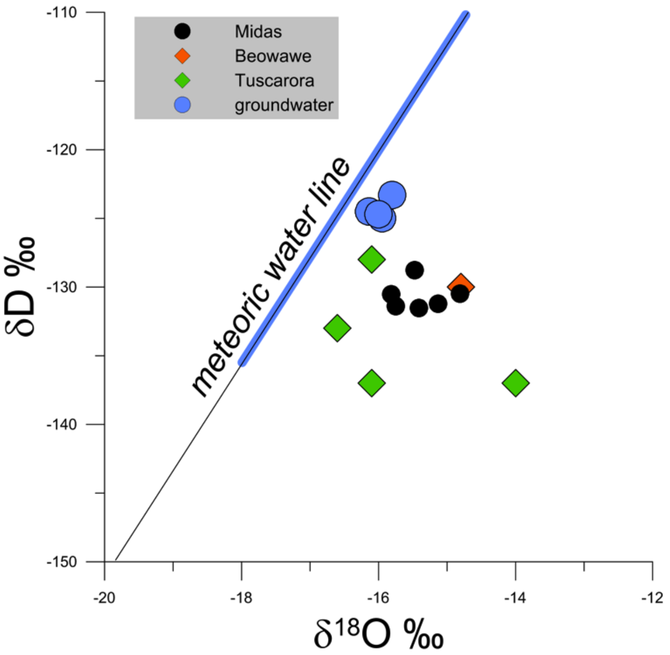

Figure 6. δD versus δ^{18}O isotope ratios for thermal waters compared to meteoric water (Tables 2-3). The blue highlighted line segment represents the range of meteoric water for northern Nevada (Friedman et al., 2002), and the blue filled circles represent ground water compositions near Battle Mountain about 100 km south of Midas (Prudic et al., 2007).

Table 4. Equilibration temperatures of thermal waters based on the quartz-silica, Na/K, and K/Mg chemical geothermometers (Fournier, 1992; Giggenbach, 1988, 1991).

Location	T°C Quartz-SiO_2	T°C Na-K	T°C K-Mg
Midas			
1	129	152	114
2	129	152	116
3	123	164	106
4	110	187	137
5	121	159	117
6	125	163	128
Beowawe			
Frying Pan geyser	196	205	143
Rossi 21-19	215	231	78
Ginn-13	199	266	146
85-18	216	252	116
Tuscarora			
7A	152	232	116
7C	149	200	83
8a	139	255	103
8B	140	258	124
DH 66-5	142	269	110

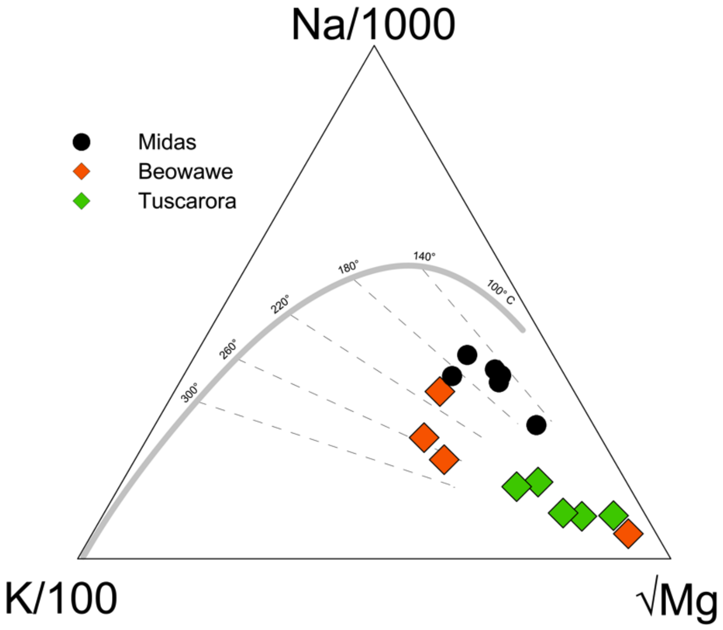

Figure 7. Relative concentrations of aqueous Na-K-Mg in thermal waters, with reference to Na/K equilibration temperatures and the full equilibrium curve (grey line; after Giggenbach, 1988).

5. DISCUSSION

The Midas thermal water compositions are similar to those at Beowawe, and Tuscarora (Figs. 4, 5, 6, and 7; Tables 2 and 3), and the dominance of aqueous bicarbonate implies interaction with deep concealed carbonate strata (e.g., Zoback, 1979; Simmons and Allis, 2015). The rocks intersected during drilling at Beowawe comprise a thick sequence (~1 km) of volcanic lavas from the Northern Nevada Rift and the underlying Ordovician Valmy formation made of siltstone, quartzite, chert and shale, which form the reservoir rocks >1 km thick (e.g, Hoang et al., 1987). The upper part of the stratigraphic sequence at Tuscarora is similar in that Tertiary volcanic deposits overlie Paleozoic siliciclastic rocks, however, carbonate units were intersected ~1300 m depth (Sibbet, 1982; Dering and Faulds, 2012; Chabora et al., 2015). These units correlate with limestones that make up the lower Paleozoic stratigraphy of northeast Nevada (e.g. Dickinson, 2006; Person et al., 2008; Heilwell et al. 2011). If thermal waters are being heated and stored in carbonate units, as suggested by their compositions, then the supply of hot water flow to near the surface is localized by vertical permeability associated with basin-bounding faults, which act as leakage points. This idea is consistent with the hypothesis that hot sedimentary aquifers extend regionally in the deep parts of basins in northeast Nevada (e.g., Allis et al., 2013; Allis and Moore, 2014; Simmons and Allis, 2015). For Midas, further geothermal exploration is required to evaluate the value of the geothermal resource below the mine. For the region, where mining and power demand are likely to be sustained for several decades, hot sedimentary aquifers could provide a new source of renewable energy and power production (Simmons and Allis, 2015).

6. CONCLUSIONS

The Midas geothermal system is a blind system that was discovered in the course of drilling and deepening of the Ken Snyder mine. Both the heat flow (~1.5 MW) and the estimated resource temperature (120-180° C) are modest, and the shallow part of the system covers about 5 km^2. The absence of surface thermal expression is due to the deep water table, and the localization of upflow beneath an uplifted fault block. The shallow stratigraphy is entirely comprised of hydrothermally altered and mineralized volcanic rocks which where emplaced during the mid-Miocene, and a modern alteration overprint has yet to be detected. The chemical and isotope compositions of thermal waters indicate deep circulation of ground water and hydrothermal water rock interaction, similar to Beowawe and Tuscarora. These data, the geological setting, and the high regional heat flow, suggest thermal waters could be supplied by deep hot geothermal aquifers hosted in Paleozoic carbonate rocks that are regionally extensive.

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