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Geology of the Tuscarora Geothermal Prospect
Elko County, Nevada

by

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FIGURE CAPTIONS

Figure 1. Location map of the Tuscarora geothermal area.

Figure 2. Geology of the Tuscarora geothermal area, Elko County, Nevada. The sample sites of age dated rocks are indicated by a square.

Figure 3. Geologic cross sections of the Tuscarora geothermal area, Elko County, Nevada. See Fig. 2 for explanation of units.

Figure 4. Lithologic log of Tuscarora 66-5 geothermal exploration hole. Unit intervals are given in feet.

Figure 5. Lithologic logs of three thermal gradient holes. Unit intervals are given in feet.

Figure 6. Detailed geologic map of Hot Sulphur Springs. See Fig. 2 for location.

Table 1. K-Ar age determinations for rocks in the Tuscarora geothermal area, Elko County, Nevada.

ABSTRACT

The Tuscarora geothermal prospect is located at the north end of Independence Valley in northern Nevada. Hot Sulphur Springs issues from Oligocene tuffaceous sediments near the center of an area of high thermal gradient. The springs are associated with a large siliceous sinter mound and are currently depositing silica and calcium carbonate. Measured fluid temperatures range up to 95°C and chemical geothermometers indicate a reservoir temperature of 216°C. The Independence Valley contains 35 to 39 m.y. old tuffs and tuffaceous sediments which overlie Paleozoic clastic rocks of the Western Facies, and are overlain by Miocene lava flows. The rocks have been deformed by normal faults trending north-south and northwest and by folds trending north-south which have been active in the Pleistocene. Alpine glaciers cut deep U-shaped valleys in the Independence Mountains during the Pleistocene. A terminal moraine is exposed near the Jack Creek Guest Ranch at an elevation of 1859 m.

INTRODUCTION

The Tuscarora geothermal prospect is located at the north end of Independence Valley, approximately 80 km north-northwest of Elko, Nevada. Independence Valley is a structural basin between the Independence Mountains on the east and the Tuscarora and Bull Run Mountains to the west and northwest (Fig. 1).

Surface expression of the geothermal resource consists of Hot Sulphur Springs and sinter deposits. The numerous hot springs extend for 1.4 km along Hot Creek. Deposits include an inactive opaline sinter mound 35 m high and about 1 km long, and a small area of calcareous sinter. The springs, some of which are boiling, are depositing both siliceous and calcareous sinter.

① The geothermal prospect was discovered by AMAX Exploration, Inc., Geothermal Branch in 1977 and their hydrogeochemical analyses indicated a reservoir temperature of 216°C (Pilkington and others, 1980). The exploration program has included drilling of 38 thermal gradient holes, gravity, aeromagnetic and electrical surveys (Berkman, 1981) and a deep (1663 m) test hole.

GEOLOGIC SETTING

Independence Valley is a north-south-trending graben in the northern Basin and Range Province. The northern Independence Mountains to the east of the valley consist of Ordovician quartzites, shales, cherts and volcanic rocks (Churkin and Kay, 1967) thrust over lower Paleozoic carbonate rocks (Kerr, 1962; Churkin and Kay, 1967). The allochthonous rocks are Valmy Group (Churkin and Kay, 1967) and part of the Roberts Mountains Allochthon (Miller and others, 1981) which was thrust east over eugeosynclinal rocks during the

Antler Orogeny (Roberts and others, 1958). These rocks were eroded and overlain by Mississippian to Permian shale, chert and quartzite tentatively correlated with the overlap assemblage by Miller and others (1981). The Schoonover Formation (Fagan, 1962) was thrust over or faulted against these rocks in the northern part of the Independence Mountains (Miller and others, 1981).

The Tuscarora Mountains to the southwest of the study area (Fig. 1) consist of Tertiary volcanic and sedimentary rocks overlying Ordovician rocks (Hope and Coats, 1976). To the north, lower Paleozoic limestone and quartzite and a Tertiary porphyritic andesite intrusive are exposed in the Bull Run Mountains (Decker, 1962). Mesozoic rocks are lacking in the area except for Cretaceous intrusive rocks in the Bull Run Mountains to the north (Decker, 1962).

Tertiary volcanism in northwestern Elko County started during late Eocene with eruption of silicic pyroclastics (Stewart and Carlson, 1976). Thick tuffaceous sediments derived from these rocks were deposited during early Oligocene. Extensional tectonism during the late Tertiary produced Basin and Range structures while volcanic activity continued in the form of lava flows and welded ash-flow tuffs.

STRATIGRAPHY

Paleozoic Rocks

Paleozoic sedimentary rocks crop out to the east and north of Jack Creek (Fig. 2), and underlie the Independence Mountains. The present geologic mapping was extended onto the Paleozoic rocks on a reconnaissance basis. The objective of the mapping in the Paleozoic rocks was to determine the

Fig. 2
Fig. 3

distribution of structures, especially high-angle faults, and lithologies which may play a role in controlling the movement of geothermal fluids beneath the Tertiary and Quaternary rocks west of the range-front fault. A detailed study of the stratigraphy and petrography of the Paleozoic section is beyond the scope of this study and the interested reader is referred to Churkin and Kay (1967), Fagan (1962), and Miller and others (1981) for a more detailed discussion.

Ordovician orthoquartzite is exposed on the east side of the study area on the west flank of the Independence Mountains (Fig. 2). The quartzite is generally white to hematite-stained and massive with discernible bedding rare. Dark-gray to black cherts and quartzites are interbedded with thin shale partings in the exposures along Schoonover Creek, Boyd Creek and Jack Creek. Based on fossils collected from chert and shale beds, the quartzite-chert sequence was determined to be Ordovician by Churkin and Kay (1967) and correlative with the Valmy Group. A conformable lower contact is not exposed in the area, and the Valmy Group is thought to be in thrust contact with the underlying carbonate rocks (Churkin and Kay, 1967).

The Valmy Group is unconformably overlain by argillites and quartzites of the Mississippian to Permian age overlap assemblages (Miller and others, 1981; Roberts and others, 1958). These rocks crop out in the foothills between Marsh Creek and Jack Creek on the east side of the study area (Fig. 2) and consist of poorly exposed argillite, quartzite, greenstone and chert with a conglomerate at the base.

Churkin and Kay (1967) mapped the lower contact of this unit as an unconformity but included the rocks with the Schoonover Formation. Miller and others (in press) agreed with the unconformity along Schoonover Creek but

mapped the contact as a thrust north of Marsh Creek and divided the unit between overlap assemblage and Schoonover Formation.

The present investigation did not resolve the nature of the contact on the north side of Marsh Creek, but the contact with the underlying Valmy Group is interpreted as depositional along both Boyd Creek and Schoonover Creek. All of the rocks overlying the Valmy Group between Marsh Creek and the Schoonover thrust along Jack Creek are here grouped with the overlap assemblage. These rocks are structurally complex, the lithologies occurring in discontinuous lenses with thick massive quartzite. The Schoonover Formation, however, as mapped by Fagan (1962) consists of relatively uniform and laterally continuous well-bedded units with a north to northeast dip. In outcrop and on aerial photographs the Schoonover Formation appears little deformed, whereas the overlap assemblage is highly deformed. The rocks south of Jack Creek have a different magnetic signature than the Schoonover Formation to the north (Fred Berkman, AMAX, 1981, oral commun.).

The Mississippian Schoonover Formation (Fagan, 1962) crops out north of Jack Creek (Fig. 2) and consists of deep-water eugeosynclinal deposits of shale, chert, greenstone, turbidites and well-bedded quartzite. The base of the Schoonover Formation is a fault exposed along Jack Creek which was mapped as a thrust by Miller and others (1981). Lithologic evidence, as mentioned above, indicates that the Schoonover Formation is not present to the south of the thrust in the lower plate.

Tertiary Rocks

Vent facies pyroclastic deposits consisting of rhyolitic ash, lapilli and blocks form a non-stratified, heterogeneous tuff-breccia two miles west of Hot Sulphur Springs (Fig. 2). The deposit includes ash-flow tuffs of limited

extent which grade into tuff-breccia. Quartz and biotite phenocrysts are present in the ash-flows. Lapilli to block size xenoliths of shale, chert and quartzite are abundant near the periphery and/or base of the deposit.

The tuff-breccia occurs in a fault-bounded horst, and depositional contacts with other units are rare. In a few exposures the tuff-breccia seems to overlie or intertongue with the tuffaceous sediment unit. Along Skull Creek, on the west side of the study area (Fig. 2), a small exposure of Paleozoic chert and quartzite is exposed under the tuff-breccia. If this outcrop is in place, and not a large xenolith brought up by the vent, it would indicate that the tuff-breccia lies directly on the Paleozoic basement at this locality.

A thickness of over 280 m of tuff-breccia is exposed along Skull Creek within the vent. The geothermal test well, Tuscarora 66-5, penetrated 183 m of a tuff-breccia which is interpreted as the same unit (Fig. 3 and 4). The tuff-breccia in Tuscarora 66-5 overlies Paleozoic rocks and is overlain by 323 m of tuffaceous sediments (Fig. 4). A similar stratigraphy was encountered 1.5 km to the southeast in Tuscarora 51-9 (Fig. 3; John Deymonaz, AMAX, 1980, oral commun.).

K-Ar dates of 38.6 ± 1.4 m.y. and 39.1 ± 1.3 m.y. on biotite were determined for two samples of dacitic ash-flow tuff within the tuff-breccia unit (S. H. Evans, Jr., 1981, written commun.; Table 1). This places the tuff-breccia in the age range of the ash-flow tuffs southwest of the study area in the Tuscarora Mountains (Stewart and Carlson, 1976).

A thick, well-bedded sequence of tuffaceous sediments, volcaniclastic conglomerate and non-welded tuffs is exposed from northern Independence Valley

to north of Deep Creek. A thickness of 323 m of tuffaceous sediments was penetrated in the geothermal test well Tuscarora 66-5 (Fig. 4). The sediments appear to be partially time equivalent to the tuff-breccia because of intertonguing exposed in outcrop. The pyroclastics were probably the local source of volcanic detritus when the vent was active.

The tuffaceous sediments correlate with the Ts1 and Ts2 units of Hope and Coats (1976). A K-Ar date of 35.2 ± 1 m.y. on biotite from a rhyolite ash within the unit was obtained on a sample collected in section 11, along Deep Creek, southwest of Lime Mountain (Schilling, 1965). The sample site appears to be outside the horst and may be part of the upper and younger part of the tuffaceous sediments unit.

Andesite and basaltic-andesite lava flows overlie the tuffaceous sediments and the tuff-breccia along the Owyhee River and are interbedded with the sediments on the west side of Hot Creek (Fig. 2). The flows are porphyritic and some are flow breccia (aa flows) or columnar jointed. Although the andesite flows clearly overlie tuff-breccia and tuffaceous sediments in some exposures, other contact relationships are unclear. The outcrop pattern on the west side of Hot Creek suggests that some andesite flows may be interbedded with the tuffaceous sediments (Fig. 2). Sample NVT-32, an andesite collected in section 14 along the South Fork Owyhee River, has a K-Ar date of 40.5 ± 1.3 m.y. (S. H. Evans, Jr., 1981, written commun.; Table 1). This flow overlies tuffaceous sediments to the north, and flows of the same unit but possibly a little younger overlie the tuff-breccia unit about 1 km to the northeast. The sample NVT-45 of a welded-ash flow within the tuff-breccia in the same area gave a K-Ar date of 39.1 ± 1.3 m.y. (Table 1). The andesite flows and the tuff-breccia are therefore contemporaneous

within the confidence interval of the K-Ar dates. Exposures indicate that the andesite flows are overlying the flanks of the tuff-breccia vent area. The andesite flows unit (Tal) of this report correlates with Ta₂ of Hope and Coats (1976).

Basaltic-andesite plugs and dikes have intruded the tuffaceous sediments along Hot Creek and the tuff-breccia along the vent margin. The age of these intrusions is uncertain but they are mineralogically very similar to some of the basaltic-andesite lava flows.

A sequence of intermediate-composition lava flows, quartz latite and dacite porphyries, overlie the tuffaceous sediments in most of the study area (Tvi, Fig. 2). Outcrops are reddish-brown and closely joined where the unit is devitrified. Dark green to black vitric zones are present and, where exposed, flow tops are vesicular. A porphyritic andesite flow containing 7 percent andesine phenocrysts and a trace of pyroxene is present at the top of the flows. A K-Ar date of 16.8 ± 1.1 m.y. on plagioclase was determined for sample NVT-42 from this flow (Table 1). There is a slight discordance between the bedding in the sediments and the base of the lava flows and it is therefore concluded that this contact is an angular unconformity. The thickness of the lava flow sequence varies from about 30 to over 120 m thick. Hope and Coats (1976) correlated these flows with the Jarbridge rhyolite.

Scattered erosional remnants of a poorly welded vitric-crystal ash-flow tuff (Tvt, Fig. 2) overlie the intermediate-composition lava flows. The tuff is 60 m or less thick and was extensively eroded before emplacement of the porphyritic andesite flow (Taf, Fig. 2) which overlies both tuff and intermediate-composition lava flows west of Harrington Creek. A K-Ar date of

15.3 \pm 0.6 m.y. on sanidine was determined for sample NVT-43 of the ash-flow tuff (Table 1). A similar K-Ar date of 15.3 \pm 0.5 m.y. on sanidine was determined for a welded tuff (McKee and others, 1976) a few miles to the west (Lat. 41° 33'N, Long. 116° 17' 30" W).

The porphyritic andesite flow along Harrington Creek (Taf, Fig. 2) may be the youngest lava flow in the study area and has been age dated at 13.6 \pm 0.7 m.y. by K-Ar methods (H. D. Pilkington, AMAX, 1980, written commun.). The andesite flow rests on the dacite-latitude lava flows along most of the exposure but the sanidine ash-flow tuff (Tvt) underlies the andesite where the tuff is preserved.

Quaternary Deposits

Extensive alluvial gravel deposits containing mostly Paleozoic quartzite boulders overlap the Tertiary and Paleozoic rocks around the north end of the Independence Valley. These gravel deposits have been subdivided into three units (QTg, Qg and Qoa, Fig. 2) based on their relationship to the present drainage system, general composition, outcrop characteristics, state of erosion and relationship to Pleistocene glacial moraines. The glacial outwash gravels which extend south from the terminal moraine on Harrington Creek (Fig. 2) are of particular significance because they provide time control for some of the younger faulting and deformation in the area.

Two large areas of pediment gravels east of Harrington Creek have been grouped with the glacial outwash gravels (Qg) even though they may not be directly related to glaciation. The gravels rest on an erosional surface which has been uplifted and deeply eroded and therefore predates the alluvial fans (Qoa) which are graded near the present drainage system. The pediment gravels contain abundant large boulders and are similar to the glacial outwash

deposits, whereas the Quaternary-Tertiary gravels have smaller cobbles and boulders and a larger sand and clay fraction.

STRUCTURE

Paleozoic Structures

The Paleozoic structures in the region are thrust faults and associated folds. During the Late Devonian Antler Orogeny the Roberts Mountains thrust developed (Roberts and others, 1958). The lower Paleozoic quartzites and shales in the Independence Mountains and the Bull Run Mountains are considered to be part of the Roberts Mountains allochthon. The Valmy Group has been thrust over autochthonous carbonates and quartzites of the eastern facies which are Cambrian to Carboniferous in age. Lower plate rocks are exposed in the northeastern Independence Mountains (Churkin and Kay, 1967), to the south in the Independence Mountains (Kerr, 1962), and to the north in the Bull Run Mountains (Decker, 1962).

Carbonate rocks of the lower plate are not exposed in the study area but 279 m of carbonates were penetrated in the bottom of the Tuscarora 66-5 hole, below 536 m of Valmy quartzite (Fig. 4). If the carbonates are part of the autochthonous eastern facies, then the base of the Valmy quartzite is the Roberts Mountains thrust.

During the Permian-Triassic Sonoma Orogeny the Golconda thrust formed in northern Nevada (Silberling, 1975). The thrusting generally placed deep water eugeosynclinal rocks over shallow shelf rocks to the east. The age of the Schoonover thrust which forms the base of the Schoonover Formation is not well defined because the oldest rocks overlying the formation are Tertiary. Miller and others (1981) suggest that the Schoonover thrust may be equivalent to the

Golconda thrust.

Mullion structures on the exposed Schoonover fault surfaces along Jack Creek indicate the last fault movement was strike-slip and east-west. Silberling (1975) reports the Golconda thrust movement was eastward. Measured dips on the exposed fault surface are 48 to 85 degrees to the north (Fig. 2) and may be vertical at its westernmost exposure. The Schoonover fault as exposed along Jack Creek could be interpreted as a right-lateral fault. It may be a tear fault offsetting the Schoonover thrust mapped to the northeast by Miller and others (1981). However the Schoonover Formation dips steeply to the north (Fig. 2), and post-thrusting deformation may have tilted both the formation and the thrust fault to the north. Dips to the south of the fault between Jack Creek and Marsh Creek are generally low and randomly oriented. The northern dip of the Valmy Group on the south side of Jack Creek steepens near the Schoonover fault (Fig. 2). It would appear therefore that the hinge line of an east-west-striking monocline is approximately coincident with the Schoonover fault or the thrusting has produced the northern dips.

Tertiary Structures

During Tertiary time east-west tensional forces have produced north-south-trending horst and grabens by normal faulting. The north-south faults are the dominant Tertiary structures in the Tuscarora geothermal area (Fig. 2). Perhaps the most significant of the faults is the range boundary fault on the west side of the Independence Mountains. This major structure trends north-south along most of the range front but trends N 30° W from Bull Creek to Marsh Creek then turns to N 10° E north of Marsh Creek (Fig. 2). Minimum offset across the fault can be estimated from the subsurface information. Thermal gradient hole 43 (Fig. 2) penetrated 317 m of Tertiary volcanic rocks

Fig. 5

without encountering Paleozoic rock (Fig. 5). Paleozoic rocks crop out just east of the hole, near the top of a 120 m high hill which is probably an eroded fault scarp now covered with glacial till. This indicates over 437 m of vertical displacement across the eastern branch of the fault. In Tuscarora 66-5 the top of the Paleozoic rocks was encountered at an elevation of 1280 m (Fig. 4) which is 670 m below their average elevation of 1950 m along the range front. Surface geology and the presence of tuffaceous sediments at a depth of 950 m in Tuscarora 51-9 indicate a graben with subsidence of 1200 m or more between Hot Creek and Harrington Creek (Fig. 3).

A stratigraphic reversal was encountered in Tuscarora 51-9, 1 km east of the hot springs (John Deymonaz, AMAX, 1980, oral commun.). A normal section was penetrated in the upper 722 m of the hole, then bedded tuffaceous sediments were encountered below 119 m of Paleozoic siltstone and shale (Fig. 3, C-C'). A reverse fault seems unlikely in Tertiary rocks when the dominant tectonic force was Basin and Range extension. Also a reverse fault, which would require over 300 m of vertical displacement, does not fit with the surface geology. A low-angle normal fault could produce the observed stratigraphic reversal, assuming a deep graben formed during deposition of the tuffaceous sediments. The sequence of events may have been subsidence of about 700 m along fault F1 followed by a block sliding off the upthrown side onto or into tuffaceous sediments along low-angle fault F2 (Fig. 3, C-C). The west boundary of the slide block was probably controlled by the faults along Hot Creek. The graben and the gap west of the slump block would then be rapidly filled with reworked and new tuffaceous sediments. Detailed gravity data indicates a low-density trough between the high along the basaltic-andesite intrusions near Hot Creek and a weak high under drill hole 51-9 (Fred Berkman, AMAX, 1981, oral commun.). The gravity low may be the sediment-

filled gap west of the slump block.

On the west side of the study area faults trending N 10°E and N 40° W bound a horst which exposes the tuff-breccia vent and extends north to Lime Mountain (Fig. 2). The vent area has been uplifted relative to the rest of the horst, and the bounding faults, where well exposed, are convex upward. This evidence and the massive quartz veins within the vent and along some bounding faults suggest that an intrusion at depth may have uplifted the tuff-breccia (Fig. 2). The top of the tuff-breccia in Tuscarora 66-5 is about 600 m lower than the top of the eroded outcrop in the horst (Fig. 2, section B-B'). Part of this may be due to original relief if the event was a cinder cone. The outcrop of Paleozoic rocks along Skull Creek, within the horst, is 490 m above the Paleozoic rock in Tuscarora 66-5.

In section 30, on the east side of the horst, a fault-line collapse graben has formed (Fig. 2). This fault-produced graben is only slightly modified by erosion. A similar but more poorly defined graben is present a mile to the east in section 29.

A third major structure, trending north to N 20° E, consists of faults and basaltic-andesite plugs along Hot Creek (Fig. 2). This structure is poorly exposed but has controlled emplacement of several plugs on a N 10° W trend and the surface expression of the geothermal system trending N 20° E.

Subordinate to the north-south structures are N 20° W to N 40° W faults. As mentioned above, a set of N 30° W faults offset the range boundary fault between Bull Creek and Marsh Creek (Fig. 2). This trend is continued into the Tertiary rocks, and to the northwest a N 40° W fault offsets the east boundary of the horst (Fig. 2).

The third and least developed fault trend is N 30° E to N 45° E. Faults of this trend extend northeast from the east side of the horst and also occur in the foothills of the Independence Mountains (Fig. 2).

Folding

Several folds, all with north-south axes, are present in the Tertiary rocks (Fig. 2). The glacial outwash gravels (Qg) in sections 3 and 10 along Harrington Creek have been deformed into a south-plunging syncline. The gravel deposit clearly originates from the terminal moraine at its north end and is therefore Pleistocene in age. The southern component of tilt may be a depositional slope but the east-west downwarp of the uneroded surface has been produced by deformation. The syncline was produced by sag of the underlying tuffaceous sediments along the range boundary fault. The anticlines may have formed as a result of the tuffaceous sediments draping over small horsts in the Paleozoic basement rock. Another possible mechanism is slump folding due to the tuffaceous sediments sliding down the east-tilted fault block. Although the folding in the Tertiary units is more pronounced than in the Pleistocene deposits, the fold structures are continuous.

A belt of gravel deposits lapping onto the Tertiary rocks extends along the northwest side of the recent alluvial fan formed by Harrington Creek (Fig. 2). Although bedding orientation is not easily determined in the field due to the coarse boulders and unconsolidated nature of the gravels, the outcrop pattern and photo analysis suggest a southeast dip. This is compatible with the interpretation that the syncline in sections 3 and 10 continues to the southwest and broadens. Harrington Creek's alluvial fan has filled this large structural depression. This interpretation would suggest a considerable thickness of Quaternary alluvium in the north end of Independence Valley and a

major southwest-trending fault which controlled formation of the syncline. Some evidence of the thick alluvium is given by the thermal gradient hole 34 drilled in the SW1/4 SW1/4, Sec. 14, T41N, R52E (Fig. 2). This hole penetrated 317 m of alluvial gravels and conglomerate without encountering Tertiary volcanic rocks or Paleozoic rocks (Fig. 5). Interpretation of dipole-dipole resistivity data across the Harrington Creek alluvial fan indicates a thick section of conductive materials which could be water-saturated alluvium (personal comm., C. E. Mackelprang, 1980).

Thermal Phenomena

Numerous hot springs and extensive sinter deposits occur at Hot Sulphur Springs (Fig. 6). The main sinter mound is 1000 m by 330 m and 35 m high, is covered with sagebrush, and has no active springs on it. The siliceous sinter mound extends down a west-facing slope from several faults and the sinter thickness at any one point probably does not exceed 10 m. At the west foot of the mound, three springs in the alluvium are currently depositing silica (Fig. 6).

Fig. 6

Most of the active springs occur in a small area 400 m upstream from the large sinter mound. The springs form a roughly triangular pattern and spring temperatures are 55° to 95°C. The hotter springs issue directly from tuffaceous sediments exposed in Hot Creek's active channel. These springs are depositing both siliceous and calcareous sinter, sulfur and sublimates. A few of the springs are boiling at the surface and there is a small steam vent.

The Na/K/Ca geothermometer indicates a reservoir temperature of 181° to 228°C. A Cl-SiO₂-enthalpy mixing model indicates an equilibrium temperature for the reservoir of 216°C (Pilkington and others, 1980).

The mapped calcareous sinter in Hot Creek consists of 0.3 to 1 m thick, coarse-grained, white calcite blocks which are currently being eroded. The calcite blocks lie on multi-colored, hematite-stained clay which is probably altered tuffaceous sediments.

Hot Creek is a perennial, cold-water creek above Hot Sulphur Springs. The stream water is warm below the hot springs due to the addition of the thermal water. Because of the intermixing of stream and thermal waters in the thin alluvium, the volume of water discharged by the thermal springs alone can not be estimated.

A few small thermal springs occur to the south and southwest of the main thermal area. A thermal spring on the west side of Hot Creek (Fig. 6) issues from the top of a low calcite and sediment mound. Two siliceous sinter mounds about 40 cm high are present on the calcareous deposit. An intermittently flowing thermal spring occurs 900 m south of the main sinter mound (Fig. 6), and a spring with a flow of 75 to 100 l/min., 3 km south-southwest of the main sinter mound, has a temperature of 21°C as compared to 10°C for cold springs in the area.

Petaini Springs, near the mouth of Jerriitt Canyon, 11 km southeast of Hot Sulphur Springs, is the only other spring in the valley reported to be warm (Garside and Schilling, 1979).

A detailed chemical study is in progress and indicates that the sodium-bicarbonate thermal waters are chemically distinct from cold spring waters in the area (personal comm., David Cole, 1980).

The subsurface structures and lithologies controlling the movement of the thermal fluids and the location of the reservoir are unknown. Dipole-dipole

resistivity and magnetotelluric data (Berkman, 1981; C. E. Mackelprang, 1980, oral commun.) indicate a deep conductive zone under the valley which approaches the surface at the hot springs, to the northwest. This conductive zone is about 1200 m under the valley and may represent the geothermal system.

CONCLUSIONS

A thick accumulation of Oligocene tuffaceous sediments and tuffs overlain by Miocene lava flows has filled a deep graben bounded by faults trending north to N 10° E. Subsidence has been greatest (over 1200 m) along a 1.5 to 3 km wide trough, bounded on the east side by the range front fault and broadening to the south. Late Tertiary deformation which has continued into the Quaternary has produced north-south-trending synclines and anticlines and faults trending north-south and N 20° W. The folds have probably resulted from fault sag and slump folding.

The surface expression of the Hot Sulphur Springs thermal system is controlled by a fault zone trending N 20° E. Exposed argillic alteration produced by the thermal system is limited to the spring area. Quartz-sericite alteration which predates the present thermal system is present along the fault zone.

The subsurface character of the geothermal system is not known but the geophysical and geologic data are consistent with an interpretation that the reservoir is 3 to 5 km southeast of the hot springs. In this model meteoric water circulates down along the range front fault system and is heated at depth. The thermal waters rise along major fractures, perhaps the intersection of the N 10° E and N 30° W fault zones, into either a solution reservoir in the lower plate carbonates or a fracture reservoir in the

overlying Valmy quartzite. The fracture reservoir and feeder channel ways may have been formed by brecciation along the thrust fault and by formation of the deep graben. The reservoir cap consists of the incompetent and less permeable Tertiary tuffs and tuffaceous sediments, the base of which is 1200 m or more below the surface. Some of the thermal fluids migrate up major fractures within the Paleozoic shale, chert and greenstone unit which overlies the Valmy Group quartzite. The fluids probably move up dip to the northwest along gravel aquifers either at the base of or within the tuffaceous sediments, ultimately reaching the surface along the faults at the hot springs. Cold water aquifers in the thick quartzite gravel overlying the tuffaceous sediments mask the thermal anomaly directly above the reservoir.

ACKNOWLEDGEMENTS

This study of the Tuscarora geothermal area was funded by the Department of Energy, Division of Geothermal Energy Industry Coupled Program under contract no. DE-AC07-80ID12079. The author also wishes to thank Dean H. Pilkington of AMAX Geothermal for the use of their aerial photographs and the subsurface information which greatly aided this study. Thanks is also extended to the Ellison Ranching Company for granting surface access.

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