Reconnaissance Geological Study of the Buffalo Valley Area, Northern Nevada, with Special Emphasis on Problems Related to the Geothermal Potential of the Area: A Preliminary Report

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Introduction

Three geological features are particularly important with regard to the geothermal potential of the Buffalo Valley area. These are: A) a complex graben within the central part of the valley and the late Cenozoic faults which have produced this structure, B) a probably continuous sheet of Cenozoic ash-flow tuff which could act as an impermeable cap for a geothermal reservoir of considerable dimensions, and C) presently active and inactive (or subactive) spring systems in the central part of Buffalo Valley, which indicate the areas over which upwelling is occurring or has occurred in the relatively recent past. The combined data suggest that the greatest geothermal potential is within a north- to northeast-trending graben structure located along the west side of the main complex graben.

Recommendations for Future Work

It is strongly recommended that the following geological and geophysical work be done before a final decision is made on the location of a deep test - production well within Buffalo Valley. The data obtained also would be of considerable value in deciding whether or not to establish a deep test well in the Buffalo Valley area.

1) A restudy of the fault patterns utilizing then available NASA and other aerial photography. Ideally, this study should be done when the data from 2, below, is available for simultaneous interpretation.
2) Detailed gravity study of critical portions of the Buffalo Valley graben to better delineate the deep structure and fault patters of the depression.
3) If financially and otherwise feasible, it would be very desirable to obtain a reversed north-south trending refraction profile of the deepest part of the Buffalo Valley graben so as to provide quantitative depth control for the model discussed in 4, below.
4) Preparation of a detailed three-dimensional model of Buffalo Valley utilizing data from 1, 2, and 3, above. This will allow a much better inference of the location and geometry of possible reservoirs and zones of high permeability.
5) A stratigraphic study of the Oligocene and early Miocene ash-flow sheets exposed in the Fish Creek Mountains - Jersey Valley divide area should be made so as to better predict the thickness and physical properties (permeability, etc.) of the ash-flow sequence inferred to cap pre-Tertiary bedrock in the central part of Büffalo Valley.

These studies - exclusive of the seismic refraction work - would cost in the neighborhood of $15,000 to $20,000. They should significantly (perhaps 2 to 5+ percent) improve the probability of encountering the requisite hot water. Considering the cost of a single deep test well, the expenditure for such basic scientific and engineering geological studies would appear to be clearly justified.

Location of a Deep Test-Production Well

The resistivity and other electrical measurements in Buffalo Valley fail to outline any specific areas of markedly superior geothermal potential in Buffalo Valley. Although adequate geophysical data are not presently available to quantitatively define the subsurface configuration of the Buffalo Valley graben, the geologic and gravity data now at hand place marked constraints on the areas which should be considered for future geothermal exploration.

It would appear that the most favorable locations would be within the deepest part of the complex graben; that is, east of the west-side fault system and west of the inferred playa hot springs fault. Perhaps the most favorable location would be at, or west of, the intersection of the playa hot springs fault with the top of an inferred geothermal reservoir. Assuming a sixty degree dip on the fault plane, and a depth of 6,000 feet to the reservoir, the hole should be located about 3,500 feet west-northwest of the inferred trace of the playa hot springs fault plane. (Clearly, quantitative knowledge of the depth of alluvium in the graben, as well as the fault structures at the surface and at depth, is required to most adequate site a deep hole.) One potential location would be in NW$\frac{1}{4}$, SW$\frac{1}{4}$, Sec. 33, T.30N., R.41E. In any case, it would appear highly desirable to site the drill hole sufficiently towards the center of the graben so that the hole remains within the graben over most, if not all, of its projected depth.

Late Cenozoic Basalts along the East Side of Buffalo Valley

Petrographic (thin section) and field examination strongly suggests that the various cinder cones, domes, and dikes of basalt exposed along the western margin of the Fish Creek Mountains and in the southeastern part of Battle Mountain near the Duval property belong to a single period of volcanic activity. If these basalts are very young, then the hot waters in Buffalo Valley could be the result of heating of ground water by still hot subsurface equivalents of these rocks. Radiometric (potassium-argon) ages obtained on these rocks, however, rule out this possibility.

An age of 3.05 ± 0.6 m.y. has been determined by E. H. McKee of the U. S. Geological Survey on a plagioclase phenocryst separate from a basalt specimen collected by Harold Wollenberg at approximately $40^{\circ}22'$N., $117^{\circ}16.5'$W. In addition, an age of 2.7 ± 0.3 m.y. has been obtained on a specimen of dense, holocrystalline, nearly aphyric basalt from about $40^{\circ}19.5$N., $117^{\circ}19.5'$W. by Douglas Archibald of Queen's University. These ages agree well within the limits of analytical error. (The quoted error is a one-sigma estimate of the total variance involved in the various analytical and calibration prodedures.) The fact that the effectively same age was obtained on two very different types of material - plagioclase phenocrysts and whole-rock basalt - argues rather strongly that the K-Ar ages are geologically real, and that the basalts are about 2.8 ± 0.4 m.y. old.

This is too great an age for any of the high-level subsurface equivalents of the basalts to retain significant amounts of original magmatic heat. However, the dates do not rule out the possibility that the high regional heat flow in the Buffalo Valley area, and perhaps other parts of the Battle Mountain high, are the result of major diapiric upwelling of mantle material about 3 m.y. ago beneath northern Nevada, the basalts in Buffalo Valley being one reflection of this mantle event.

Buffalo Valley Hot Springs, as discussed above, appears to be localized by an intricate system of intersecting faults. Some of the individual springs indeed form linear arrays along these faults.

Buffalo Valley Hot Springs has been in existence for at least several thousand years. This is shown by reentrants in the old shorelines on the southeastern margin of the spring area, which demonstrate that the hot springs were an active feature when the shorelines were in the process of formation. The area - and presumably the total discharge - of the spring system appears to have been appreciably larger in former times. This inference is based on the existence of a large northwest-elongate area , with the present Buffalo Valley Hot Springs at its southeastern end, which has the appearance of a large extinct field of hot springs. Field checking of this feature is very desirable.

Active and Inactive Spring Systems within the Playa of Buffalo Valley

The springs in Buffalo Valley can be subdivided into three catagories. These are: A) numerous cold springs with low geochemical temperatures located along the frontal fault scarp of the Tobin Range and along the west-side fault system, B) The springs of Buffalo Valley Hot Springs, and C) Active and inactive (or subactive) spring systems with, at least in part, thermal character, within the Buffalo Valley complex graben.

Springs of group A probably represent relatively shallow aquifer systems that recharge in the Tobin Range to the west of Buffalo Valley. The springs themselves are localized by high-angle faults of the range front and west-side fault systems.

The locations of the active and inactive (subactive?) spring systems of group C are shown on my fault map of the Buffalo Valley quadrangle. That the mounds and mound complexes which mark the inactive systems (indicated by inward-pointing hachures) are indeed the reflection of upwelling waters in indicated by A) the association of several of the mound complexes with active springs, B) the high water table in the vicinity of the mounds, as shown by the presence of remarkably lush growths of grass around the margins of the mounds (for example, the mound in the northeastern quarter of section 4, T.29N., R.41E.), and C) the general similarity in morphology of the mounds to the Buffalo Valley Hot Springs area.

It therefore is not unlikely that within the Buffalo Valley graben a horizon of relatively impermeable ash-flow tuff several hundred or more feet in thickness forms a cap on a geothermal reservoir as much as 20 to 25 square miles in areal extent. The reservoir presumably would be located in fractured pre-Tertiary bedrock beneath the tuff cover.

Some thermal water would be expected to escape upward along the north-trending faults within the complex graben. Such ascending waters would produce the springs with high silica and Na-K-Ca termperatures which we have found in the central part of Buffalo Valley playa. Other thermal waters would migrate up-dip to the east. Buffalo Valley Hot Springs here is provisionally interpreted as resulting from thermal waters which have migrated up-dip to the southeast from the central part of the hypothetical reservoir. These hot waters then have ascended to the surface taking advantage of the many faults and fault plane intersections in the vicinity of the hot springs area (see map).

Ash-Flow Tuffs at Depth in Buffalo Valley and Their Significance for Geothermal Potential

Great thicknesses of ash-flow tuff of the early Miocene Fish Creek Mountains Tuff are exposed to the west of Buffalo Valley in the Fish Creek Mountains (McKee, 1970). The greatest thickness of tuff is found in the southern Fish Creek Mountains, where McKee (1970) infers the source of the unit. The ash-flow sheet appears to thin markedly outward from this source area. This can be observed with binoculars under appropriate lighting conditions along the west face of the northern part of the Fish Creek Mountains. The ash-flow sheet probably also thins to the west, but there has not yet been opportunity to study the unit in the vicinity of the saddle between Buffalo Valley and Jersey Valley, and to the west of this area.

The Fish Creek Mountains Tuff is underlian by a thick sequence of ash-flow tuff assigned to the Oligocene Caetano Tuff.

Based on presently available information, it is highly probable that in the central part of Buffalo Valley the pre-Tertiary basement is overlain by 50 to 200 feet or more of moderately to densely welded Caetano Tuff, which in turn is overlain by 100 to 200 feet or more of nonwelded, partly welded, and in places probably densely welded Fish Creek Mountains Tuff.

Ash-flow tuff tends to be relatively impermeable and plastic. Nonwelded glassy tuff, such as that exposed at the bottom of the Fish Creek Mountains Tuff on the west side of the Fish Creek Mountains, on compaction by several thousand feet of overburden become dense and extremely impermeable. This is especially true where the glassy tuff has been altered to zeolite or argillic material during compaction, a change which can readily be expected to have taken place in the elevated temperature conditions beneath Buffalo Valley. Rxperience at the Pahute Mesa test area of the Nevada Test Site of the U. S. Atomic Energy Commission testifies to the extremely impermeable nature of such tuff horizons.

The southeasternmost limit of this belt of faulting is unclear. It appears most likely, however, that it trends approximately northeastward from a point about one mile southeast of Buffalo Valley Hot Springs to about $40^{\circ}24.5'$ north latitude at longitude $117^{0}15'$W. However, faults locally are present southeast of this line.

As discussed above, the greatest displacement is along the western and northwestern margins of the graben. The gravity data of Grannell (1974; unpub. data) demonstrate that the deepest part of the graben is within several miles of the west-side fault system. From here, the elevation of the basement surface gradually rises to the east and southeast. General stratigraphic considerations, for example, Thompson and Burke (1973) and some very preliminary unpublished gravity data of Grannell (oral commun., 1974) suggest that this rise is mainly the result of relatively small displacements along north-northeast to northeast-trending normal faults down to the northwest.

An important inferred fault of this group may intersect the surface of the playa at the line of springs trending north-northeast along the west center of the Buffalo Valley playa. This fault is here informally terned the "playa hot springs fault". If this fault exists, and has a significant amount of displacement, then the deepest part of the Buffalo Valley complex graben is a graben to to two and one-half miles in width located between the playa hot springs fault and the west-side fault system.

The faults bounding the graben will converge with depth. Assuming a reasonable dip of 60 degrees (the dips of Basin-Range faults vary from about 55 to 70 degrees from the horizontal), the location of the fault surface will be displaced inward about 580 feet for each 1,000 feet of depth. As will be discussed elsewhere, probably the most favorable location for a deep test-production well would be within this graben, and perhaps at the intersection of the inferred playa hot springs fault and the base of the Tertiary ash-flow sheet inferred to overly the pre-Tertiary basement beneath Buffalo Valley.

The faults shown in red by dot-dashed limes on the preliminary fault map of Buffalo Valley were obtained by rather hurried photo interpretation of the low-altitude, high sun angle aerial photography obtained by Lawrence Berkeley Laboratory for the Buffalo Valley area. All lineaments noted which appear to be of fault origin were ploted. Most did not possess scarps as seen in the high sun angle imagery. Most of the lineaments plotted are faults. Some unquestionably have other origins, for example, shore-line features. Nevertheless, in spite of these uncertainties, I believe that the results give a semiquantitatively accurate picture of the fault patterns along the southern and southeastern margins of the Buffalo Valley graben.

Along the southern boundary of the graben, a system of lineaments trends about north 80 degrees west, parallel to and just south of the main graded road to the Saval Buffalo Ranch. Except to the southeast, no lineaments were observed south of this belt. I thus conclude that the southern margin of the Buffalo Valley graven is located about one-half mile south of the east-trending highway to the Buffalo Ranch. It is presently unclear whether this boundary is marked by a single fault, or by a fault zone as much as one-half to one or more miles in width. Displacement must increase to the west, as a result of the assymmetry of the graven, as discussed below. The apparent dying out of the west-side fault system at about the latitude of the Saval Buffalo Ranch raod would appear to be consistent with the above structural interpretations.

The lineaments along the southeastern side of Buffalo Valley are more complex. A zone of lineaments one and one half to two miles wide approximately parallel to the northeast-trending graded road along the east side of the valley is present at and to the northwest of this road. The fault pattern is complex. In the vicinity of Buffalo Valley Hot Springs, and to the north, there are many interesections of north, northeast, and east trending fault swarms.

Subsurface Structure of Buffalo Valley

The central part of Buffalo Valley is underlain by a major asymmetrical complex graben closed at the southern end.

The faults on the west side of the graben are the most readily apparent and unambiguous. The west side of the graben is defined by a system of north-trending faults - here informally termed the "west-side fault system" - which approximately follow the main road on the west side of the Valley. To the west of this fault system the alluvial cover is very thin, as shown by gravity data (Grannell, 1974, unpub. data). The geothermal potential of the area between the west-side fault system and the range fromt fault system is very poor. The west-side fault system has a displacement of about 3,000 to 5,000 plus feet, as shown by the gravity data of Grannell. The uncertainty in this estimate largely reflects the uncertainty of the density contrast between alluvium and bedrock assumed. North of about 40°25' N. to 40°26' N. latitude the trend of the west-side fault system swings to about N.45°E. The system also appears to diverge into two or more parallel branches, presumably with the displacement being taken up more-or-less equally by the several individual faults.

The southern and southeastern margins of the Buffalo Valley graben also are defined by fault systems. Whereas the faults mapped along the west side of the Valley exibit definite, although rather highly eroded, scarps, the faults on the southern and southeastern margins are, with few exceptions, much less well developed.

References Cited

Grannell, R. B., 1974, A regional gravity survey of the Fish Creek Mountains and surrounding area, north-central Nevada: Geol. Soc. America Abs. with Programs, v. 6, p. 183-184.

McKee, E. H., 1970, Fish Creek Mountains Tuff and volcanic center, Lander County Nevada: U. S. Geological Survey Prof. Paper 681, 17 p.

Thompson, G. A., and Burke, D. B., 1973, Rate and direction of spreading in Dixie Valley, Basin and Range Province, Nevada: Geol. Soc. America Bull., v. 84, p. 627-632.