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# Late Quaternary Tectonic Controls of Occurrence of Geothermal Systems in Gerlach-Hualapai Flat Area, Northwestern Nevada

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## ABSTRACT

The Gerlach hot spring system is localized by the intersection of three major and one minor concurrently active normal fault zones which effect quasiradial spreading. The Fly Ranch hot spring system is localized mainly by Late Holocene and historic faulting and rifting along a north-south normal fault zone where it is believed to intersect older fault zones. Late Quaternary deformational features occur abundantly in the region. Extension of these features within fracturable rocks beneath thermally insulating layers may point up locations of hidden geothermal reservoirs.


## INTRODUCTION

In tectonically active spreading regions where volcanism is older than Pliocene, where regional heat flow is above normal, and where thermally insulating layers exist, the occurrence of geothermal convection systems is largely controlled by recurrent tensional faulting and rifting. These processes must recur at frequent intervals, a few thousand years or less, to keep fractures open and to create new fracture systems that will allow continuing circulation of hydrothermal fluids through heated crustal rocks. However, geothermal convection cells may not persist very long if the fracturing creates too much permeability. Too much fracturing permits thermal waters to escape rapidly and thus to disperse heat and cause rocks to cool by inflow of cold waters. On the other hand, if no effective fracturing occurs repeatedly, hydrothermal circulation will be retarded or prevented (unless intergranular or intercrystalline permeability remains effective); geothermal convection cells will tend not to form, or will remain small, or will quickly cease to function. A natural balance between maintenance of fracture permeability, rate of fluid recharge-discharge, and heat storage-heat loss seems essential for persistence through thousands of years of geothermal convection systems. Probably the most favorable tectonic conditions for the occurrence of commercial geothermal systems in nonvolcanic portions of the Basin and Range province are those in which relatively deep and brittle rocks sustain open fractures from repeated fracturing while overlying thermally and hydraulically insulating layers yield to the same tectonic stresses plastically or by quickly sealing fractures. Deep convection cells may persist because of partial or complete trapping. Surface delineation of Late Pleistocene and Holocene (including historic) tensional fault zones in insulating layers and in adjacent fracturable bedrock that projects beneath the insulating layers should assist in locating fracture-controlled geothermal systems from which little, if any, heat is escaping (the hidden geothermal system).

Late Quaternary deformational features occur abundantly around the Gerlach and Fly Ranch hot spring areas and in the extended region as well. Studies of these fractures indicate that they control the hot spring locations and they may point up locations of geothermal systems not leaking to the surface.

## TECTONICS OF HUALAPAI FLAT

Geologic and tectonic features of Hualapai Flat are incorporated on plate I (see last page of this volume for plate I, the geologic map and cross sections). Photogeologic and field mapping uncovered a remarkable array of Holocene faults and tectonic cracks — rifts — in the tectonic zone of Fly Ranch hot spring (figs. 1 and 2; Grose and Sperandio, fig. 6). Some of the faults were

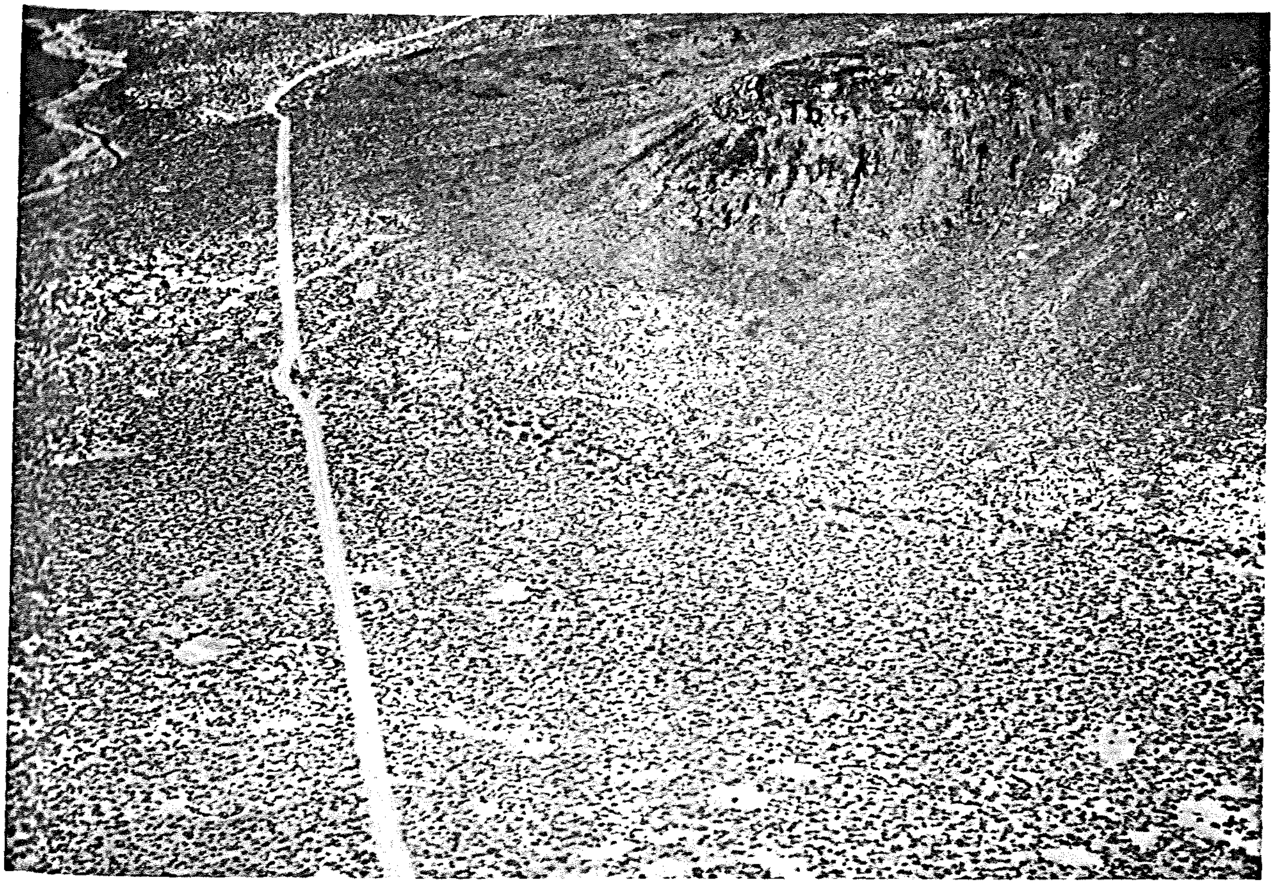


Figure 1.—Oblique air view westward of fault scarp expressed in Lake Lahontan clays and by linear vegetation anomaly along western side of Hualapai Flat. Tb — Tertiary basalt flows. (Photo: LTG 17675) (Note: Fault activity does not offset or bend the road!)

first mapped by Harrill (1969). The particular air photos that reveal tectonic rifts were taken in 1954. Their numbers are DTU 41L nos. 9-12, 35-37, and 56; DTU 40L nos. 159-160; and DTU 50L 118-119. These photos illustrate the natural surface of Hualapai Flat prior to leveling and scraping for irrigation and cultivation in the northern half of the Flat which began in 1960 (Harrill 1969; Sinclair 1962). Agricultural development destroyed the numerous faults, rifts, and slightly tilted surfaces on the Hualapai Flat ground surface that are recorded on the 1954 air photos, but now are largely lost. Although most of the more spectacular neotectonic rifts have been filled in, for example in the area 1 to 2 miles (1.6 to 3.2 km) south of the southwest corner of Humboldt County (pl. I), some rifts escaped the scrappers (when last observed in 1977), such as those 2 to 3 miles (3.2 to 4.8 km) south and ½ mile (1.0 km) east of the northwest corner of Pershing County, and can be observed in their natural state (fig. 2). However, most of the fractures within the northern half of Hualapai Flat have been wiped out, but many of those in the southern half and along the west side are still there.

Characteristics of the rifts cutting the surface of Hualapai Flat are summarized as follows:

(1) They are almost entirely restricted to the northern third of the Flat.
(2) They range in length from tens of feet to about 4 miles.
(3) They are mostly straight with only several feet departure from linear.
(4) Width ranges from fractions of an inch to over 5 feet, and depth of rift or crack may locally exceed 10 feet depending on slumping.
(5) Prevailing strike is north-northeast; dip is vertical; and local *en echelon* pattern consists of northeast striking segments.
(6) No dip-slip or strike-slip offset occurs; rifting is horizontal and perpendicular to the walls of the rift.
(7) The age of the rifts is Holocene and historic with an undetermined Quaternary ancestry. Many were opening (in 1974) as evidenced by splitting of still-live sagebrush and by freshness and sharpness of cracks completely unmodified by wind and water erosion and by slumping across active arroyos. Others are in different stages of infilling by unconsolidated soil and sand. Therefore, the rifting process is dynamic and continuous rather than the result of a single earthquake event.
(8) That they are tectonic in origin is proven by their persistent geometry in plan unrelated to the slope and the fill of the basin and their existence long before groundwater pumping activities of man.
(9) The rifts reveal an environment of pure tectonic tension and suggest that the northern part of Hualapai Flat rela-

Figure 2.—View north-northeastward along a portion of a 1,200-ft-long (360 m) tectonic rift (surface crack) in central part of Hualapai Flat. Photo taken in summer 1975. (Photo: LTG 24775)

tive to the middle and southern parts is in its earliest stage of deformation and opening.

Characteristics of the Late Quaternary faults cutting the surface and marginal areas of Hualapai Flat are summarized as follows:

(1) They are absent in the northern third of the Flat except along the west, and, to a minor extent, the east side. They are best developed in the central third where the Fly Ranch hot spring system occurs, and poorly preserved in the southern third where the Alkali playa is located.
(2) Their length and strike are about like that of the rifts to the north, up to 4 miles (6.4 km) and north-northeasterly to northeasterly.
(3) Height of fault scarp ranges from about 1 to over 20 feet (0.3 to 6 m). The highest scarp passes just east of the Fly Ranch hot spring group. (Grose and Sperandio, fig. 6). No dips could be measured. The faults are probably normal.
(4) Pattern in plan shows *en echelon* tendency to northeast strike and minor convexity to the northwest.
(5) Throw relationships reveal a northeast-trending horst, which includes the Fly Ranch hot spring system, and a graben block to the northwest.
(6) The age of the faults is Holocene and Late Quaternary as determined by a variety of microgeomorphic features. The different stages of preservation of fault scarps indicate an environment of tensional deformation continuing over a period of tens or hundreds of thousands of years.

The rifts and faults together indicate active tectonic spreading along a west-northwest axis. The overall *en echelon* pattern suggests a component of right lateral displacement on the regional north-south fault zone.

Hualapai Flat is basically a north-south-trending graben of intermediate level between the Granite Range horst and elevated volcanic plateau to the west and the Calico Mountains uplift and low horst to the east. It may be divided into three tectonic units on the basis of the nature of Holocene deformation, that most recent deformation which may exert control on the occurrence of geothermal systems there. The northern third contains mostly rifts; the middle third contains mostly normal faults; the southern third contains normal faults and rifts and is an area of most recent subsidence. The northern unit is undergoing horizontal rifting or extension. The middle unit is rifting and undergoing differential vertical displacement. The southern unit is undergoing both horizontal and vertical displacements and is subsiding on the east side where the lowest part of the playa is juxtaposed against an inferred fault scarp. Degree of development of the structures in the three units suggests that the southern unit began deforming earliest, that the middle unit followed, and that the northern unit is the latest to begin deforming. This time-space tectonic evolutionary trend within Hualapai Flat is based on a commonly observed sequence of events within many evolving rift zones in the world: rifting, followed by normal faulting, and then general subsidence.

One or more geothermal systems may underlie the active fault zone along the entire length of the western margin of Hualapai Flat. Hot water and steam were encountered in a shallow geothermal exploratory hole in the southwest part of Hualapai Flat near Granite Ranch (Garside, 1974; Harrill 1969). Fly Ranch hot spring system occurs in the central part of the zone, and warm waters are encountered in irrigation wells in the northern part of Hualapai Flat. The area of youngest (on-going) tectonic deformation lies at Fly Ranch hot spring and northward, and within this zone occur an electrical conductivity high and a near-surface temperature anomaly described elsewhere in this volume.

Fly Ranch hot springs are situated within a major north-south fault zone. Projections of a northeast-trending fault from the Calico Mountains and a northwest-trending fault from the Granite Range (pl. I) would intersect the north-south fault zone in the area of the hot springs.

# TECTONICS OF GERLACH AREA

The Gerlach area is characterized by Holocene (post-Lahontan) fault scarps that trend in many directions: northeast, north-south, northwest, and east-west (pl. I). Tectonic tilting and faulting of Lahontan sands and clays can be observed 1 mile west of

Gerlach. A cold, dry, elevated fault block containing the "stockworks" of an "ancestral Gerlach hot springs" occurs about ½ mile west of the modern hot springs (Romberger 1978, this volume). This spring system was active in Lahontan and Early Holocene time and has since been tectonically uplifted several tens of feet relative to the modern spring system. It also suggests an eastward migration of surface thermal activity, though not necessarily the reservoir.

Gerlach hot springs are at the intersection of three regionally prominent and active normal fault zones (Grose and Sperandio 1978, this volume). The northeast-trending Black Rock Desert zone effects extension in a northwest-southeast direction. The northwest-trending Granite Range zone, having a component of right-lateral slip, is causing extension in a southwesterly and westerly direction. The north-south zone, also having a component of right-lateral slip, is causing extension in a west-northwesterly direction. Locally in the Gerlach area, east-west normal faults effect a north-south extension. Three major grabens — the Black Rock, Smoke Creek, and San Emidio — as manifestations of the three major fault zones, join and terminate in the Gerlach area (Grose and Sperandio, fig. 1). All three fault zones and the local east-west zone display evidence of Holocene activity. Therefore, for a period of at least 10,000 years, crustal extension in the Gerlach area has not been unidirectional, as believed the case in most areas of western Nevada, but has been in several directions which collectively implies radial or quasiradial spreading. Such a tectonic regime without associated igneous activity implies that the area of quasiradial spreading would probably be subsiding. However, the Granite Range uplift is the greatest, most abrupt, and probably the youngest in northwestern Nevada. These characteristics imply active tectonic uplift in an absolute sense. In the Gerlach area of abnormally large and hot thermal springs, quasiradial spreading and local uplift may have had a particularly favorable role in localizing heat in relatively shallow portions of the crust.

# REGIONAL SYNTHESIS

In addition to the Quaternary tectonic features discussed and illustrated (pl. I), microseismic activity was detected (Kumamoto 1978, this volume) along the northwest margin of the Black Rock Desert southeast of Hualapai Flat. Fault plane solutions indicate west-northwest-east-southeast extension in that area. Also, along the same zone a few miles northeast of the seismicity, a several-mile-long zone of cracks appeared in the playa parallel to the margin (Willden and Mabey 1961). Although these fissures were interpreted to be caused by dessication, it is herein suggested that they may have had a tectonic origin particularly in view of similar fissures in nearby Hualapai Flat. Holocene normal faulting, modern rifting, and microseismicity attest to active tensional tectonism in the Gerlach-Hualapai Flat area. The two hot spring clusters in the area are localized by virtue of intersection of major regional fracture systems. The one system that passes through both hot spring areas, the north-south system, is the most recently active.

The localization of recoverable heat comprising the individual geothermal prospect is controlled by convection which in turn is permitted and controlled by recurrent fracturing. The thermal springs represent surface leakage, usually of short time duration, caused by tectonic breaching of a local convection cell which is part of a large heat reservior that has been growing for a long time beneath insulating layers contained in deep grabens.

Some insight into the occurrence of geothermal systems in the region may be gained from consideration of possible longevity of geothermal systems as presented by J. Goguel and A. J. Ellis and summarized by Banwell (1970). The longevity of individual hot springs in the Gerlach-Hualapai Flat area may range from $10^4$ to $10^5$ years as estimated from tectonic-sedimentational history and amount of hot spring deposit. Heat has been accumulating in the Black Rock Desert and Hualapai Flat grabens for an estimated 2 x $10^6$ to $10^7$ years. If the frequency of faulting and surface thermal activity has not appreciably changed, there may be many geothermal convection systems in the region in various stages of evolution for which there is no surface manifestation.

# REFERENCES


Banwell, C. J., 1970, Geophysical techniques in geothermal exploration: Rapporteur's Rept. U.N. Symp. Dev. and Util. of Geothermal Resources, Pisa, Italy.

Garside, L. J., 1974, Geothermal exploration and development in Nevada through 1973: Nev. Bur. Mines and Geology Rept. 21.

Harrill, J. R., 1969, Hydrologic response to irrigation pumping in Hualapai Flat, Washoe, Pershing, and Humboldt counties, Nevada: Nev. Div. Wtr. Resources Bull. 37, 75 p.

Sinclair, W.C., 1962, Ground-water resources of Hualapai Flat, Washoe, Pershing, and Humboldt counties, Nevada: Nev. Dept. Conservation and Natural Resources, Ground-water Resources — Reconn. Series Rept. 11.

Willden, R. and Mabey, D. R., 1961, Giant dessication fissures on the Black Rock and Smoke Creek deserts, Nevada: Science, v. 133, p. 1359-60.