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GEOLOGY AND GEOTHERMAL POTENTIAL OF SUSANVILLE, CALIFORNIA

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The Geology and Geothermal Potential of Susanville, Lassen County, California

Prepared for

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MAPS

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NOTICE

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Introduction

The city of Susanville, located in southern Lassen County, California, is underlain by low temperature geothermal groundwater of limited areal extent. The geothermal fluids occur in fractured volcanics and interbedded sediments, and appear to be heated by either shallow magmatic bodies or radioactive decay. Maximum temperatures measured in water wells and geothermal test holes range from 32 to 66°C and are typically encountered at depths of 30-45 meters; locally as deep as 90 meters. A decrease in the thermal gradient at depths greater than 45 to 90 meters indicate that horizontal and vertical groundwater flow controls the upward migration of the warm water. Faults and fractures have greatly increased the permeability of the reservoir rocks and provide conduits for the fluids. However, they appear to block the lateral migration of the geothermal fluids at shallow depths.

Renewed interest in known geothermal resource area's (KGRA's), and evaluation of them as potential sources of energy, has been stimulated by the 'energy crunch' of the early and middle 1970's. At present, State and Federal agencies and private firms are conducting geophysical investigations at Susanville and throughout Honey Lake Valley.

The reliability of the geophysical interpretations can be greatly enhanced by supplementing them with accurate geologic maps and an appraisal of subsurface structure and hydrology. No detailed geologic map has been published for the northern Honey Lake Valley. A reconnaissance geologic map is available from the Westwood Sheet of the Geologic Map of California (California Division of Mines and Geology,

1960) at a scale of 1:250,000. Later reports by the California Department of Water Resources (1963) and U. S. Bureau of Reclamation (1976) have slightly more detail than the State Sheet. Detailed geologic maps in rock types similar to those which crop out at Susanville are included in reports by: Diller (1908) and Durrell (1959a, 1959b, 1966) in areas to the south, Russell (1928) and Powers (1932) in areas to the north and MacDonald (1966) in the area immediately to the northwest.

Purpose

This investigation is intended to provide a detailed geologic map in, and immediately surrounding, the City of Susanville in order to determine the pattern of complex faulting controling the subsurface hydrologic character of the area, and to explore for hot springs or areas of hydrothermal mineral alteration, which might suggest additional geothermal systems.

Location and Accessibility

The study area (Fig. 1) is approximately 5 miles east of the steep eastern escarpment of the Sierra Nevada. It is situated at the northwestern edge of Honey Lake Valley, and lies approximately midway between Eagle Lake and Honey Lake. The mapped area consists of approximately 35 square miles, bounded on the northwest by Susanville Peak, on the northeast by Antelope Mountain, on the west by basaltic plains of the Modoc Plateau, and on the south and east by Honey Lake Valley. The City of Susanville, the county seat of Lassen County and the major population center in the region, is the only incorporated city within the study area. The towns of Litchfield, Johnstonville and Westwood are to the east, south and west respectively.

The area is 84 miles north of Reno via U.S. 395, and east of Red Bluff, Chester and Westwood on state highway 36. State highways 36 and 139, and unimproved logging and ranch roads provide good access throughout the area, with few points more than 2 miles from serviceable roads.

Field Work

Most of the field work for this report was completed during a two-month period in the summer of 1977. The geology was plotted directly on the U.S. Geological Survey 1954 Susanville 15-minute quadrangle, which had been enlarged to a scale of 1:25,344 (2 1/2 inches to the mile). Faults, structural lineations and contacts of geologic units were further refined by use of aerial photographs provided by the U.S. Bureau of Reclamation and the U.S. Bureau of Land Management in scales ranging from 1:20,000 to 1:25,000.

Geologic Setting

The Susanville area lies at the intersection of three major physiographic provinces. The granitic rocks exposed along Antelope Mountain and extending northwest to Eagle Lake mark the northern terminus of the Sierra Nevada. The Tertiary and Quaternary volcanic rocks, which form a dissected upland surface immediately to the north and west of Susanville, are correlative with the extensive flows of Modoc Plateau basalt. The sharply defined graben structure of Honey Lake Valley to the southeast is topography characteristic of the Basin and Range province.

The study area and most of northeastern California is underlain by a pre-Tertiary basement complex of igneous and metamorphic rocks. Metamorphosed sandstone, shale and limestone of Paleozoic and Mesozoic age were intruded by granitic to granodioritic plutonic rocks during major deformational events in late Jurassic to Cretaceous time. These rocks were repeatedly folded, faulted, uplifted and eventually eroded to a fairly flat to gently undulating topographic surface prior to the deposition of the overlying sedimentary and volcanic rocks that are Eocene and younger in age.

Rocks of Tertiary age are characteristically unmetamorphosed, and consist of gold bearing conglomerates and extensive volcanic flows reflecting several episodes of volcanic activity. Siliceous sand and conglomerate of the middle Eocene Auriferous gravel accumulated in Tertiary flood plains and river channels. Erosion and minor block faulting significantly reduced the areal extent of the Auriferous gravel prior to the eruption of the middle to upper Eocene lava flows of the Lovejoy Formation. Much of the northern and central Sierra Nevada was subsequently covered by a thick sequence (up to 1300 m.) of andesitic mudflow breccia, rhyolitic tuff and associated gravel of Miocene to Pliocene age. These extensive debris flows have been assigned to the Cedarville Series in the Warner Mountains to the north (Russell, 1928), the Ingals, Deleker, Bonta and Penman Formations in the northern Sierra (Durrell, 1959a), and the Valley Springs and Mehrten Formations in the central Sierra Nevada (Durrell, 1966). Unconformably overlying the andesitic mudflows are flows of the Warner Basalt. The Warner Basalt consists of up to 1200 meters of relatively thin olivine basalt flows with interbedded mudflows, pyroclastics and sediments (Department of Water Resources, 1963). Eruption of the Warner Basalt commenced in the upper Pliocene and probably continued into the Quarternary.

During the Pleistocene epoch, extensive lake deposits associated with Lake Lahonton covered much of northeastern California and northern Nevada. Major tectonic uplift and orogenic activity in the Pleistocene created the Sierra Nevada, a huge tilted block of the earth's crust forming a strongly asymmetric mountain range with a gentle western slope and a steep eastern escarpment. Possible correlative movements along parallel faults to the east formed Antelope Mountain and the large graben structure of Honey Lake Valley. Subsequent block faulting, glaciation, erosion and deposition of Quaternary sediments further modified the landscape into the rugged mountainous terrain presently found in this portion of the Western Cordillera.

For a more comprehensive review of the geologic history of northern California, refer to Geology of Northern California, California Division of Mines and Geology bulletin 190 (1964).

Geothermal Potential

Geothermal fluids come to the surface in a roughly rectangular-shaped area in the south part of Susanville (the approximate limits of this area are shown on Plate IV). Percolating groundwater comes in contact with a heat source (hot magmatic body and/or radioactive decay), and is heated. The hot water is less dense than the cold ground water, and rises to the surface along faults and fractures within the Pliocene and Pleistocene basalt flows. The conduit or "piping" system through which the hot water flows is bounded by faults which block horizontal movement of the water.

The geothermal area is bounded on the west by the series of faults along the edge of the basaltic upland just west of Lassen Memorial Hospital and Richmond Road (Plate IV). It is postulated that the geothermal area is bounded on the south by a northeast trending fault which separates Cretaceous granitic rocks on the east from Tertiary volcanics to the northwest. A test hole a mile south of the proposed geothermal area was drilled into granitic rocks and cold groundwater was encountered. It appears, therefore, that the fault boundary between the igneous and volcanic rocks is also the southern boundary of the geothermal area.

The fault(s) which form the north and east boundaries of the geothermal area as shown on Plate IV are purely speculative. They are buried under Quaternary alluvium and their exact location cannot be determined by conventional mapping techniques. The two faults which offset basalt in the Susan River at Witherlow Street, and the lake deposits along the Southern Pacific Railroad tracks, may provide a passageway for the upward movement of warm water, but do not form boundaries of the geothermal area. The eastern boundary is possibly located along a structural feature which controls or is parallel to the course of Piute Creek north of Main Street.

The water quality, temperature and thermal gradient within warm water wells and geothermal test holes were determined by the U.S. Bureau of Reclamation (1976). This investigation indicates a reversal of the thermal gradient and a corresponding decrease in water temperature within the warm wells. This reversal suggests that horizontal as well as vertical flow controls the migration of geothermal fluids.

Active faulting throughout northern Honey Lake Valley has further complicated subsurface hydrologic conditions.

Two additional thermal areas were discovered during the present study which are worthy of additional attention. Warm water occurs in a domestic well along Piute Road, north of Susanville (Plate IV). Hydrothermal mineral alteration resulting in the formation of opal, kaolinite and distinctive orange to red mineralization were observed along a fault between Piute Creek and the Susan River west of the city, and along Piute Creek near the western edge of map area (stippled pattern on Plate IV). A small mine has been dug into the hydrothermally altered rocks just above the Susan River. Migration of geothermal fluids responsible for the mineral alterations could have been initiated by fault movements, or the fluids may have moved upward along the fault from a geothermal system. No mineralization or alteration was observed in the rocks a few feet to either side of the fault.

Most of the mapping was done in the summer of 1977 when drought conditions greatly reduced the flow of springs. None of the springs tested were more than 2-3°C above the average temperature of springs in the study area. The location and temperature of springs are plotted on Plate I.

Descriptive Geology

Summary of Geologic Units

A brief summary of the units found on the Geologic Map (Plate I) and their potential as reservoir rocks for geothermal systems is given immediately below. For more detailed information on the physical properties, distribution and correlation of the units, please see the rock descriptions following this brief summary, and the Columnar Section (Plate III) located in the folder at the end of the report. Descriptions are based on field observations and microscopic analysis of representative samples.

Granitic rocks (gr) are highly weathered and decomposed quartz monzonite to quartz diorite. When well jointed these rocks may yield small to moderate quanities of groundwater. They do not, however, appear to be reservoir rocks associated with the geothermal system (see Geothermal Potential).

Andesitic breccia and mudflows of the Bagwell Springs Formation (Plbs) are poorly jointed, poorly bedded, and for the most part impermeable. These rocks may form the cap rocks above the geothermal system.

Flows of the Warner Basalt undifferentiated (Plw) are thin, typically well-jointed olivine-rich basalts with interbedded sediments and mudflows. When well developed columnar joints exist, these basalts form good geothermal reservoir rocks. The interbedded sediments contained within all members of the Warner Basalt provide excellent hydrologic conduits and reservoirs.

The Inspiration Point member (Pli) of the Warner Basalt consists of well-foliated, moderately to well jointed plagioclase-rich basalt flows. These rocks exhibit hydrothermal mineral alteration west of Susanville (see Geothermal Potential) and when well jointed could yield moderate quantities of (geothermal) groundwater.

Rocks of the Susanville member (Pls) form thin, texturally distinctive olivine and plagioclase-rich basalt flows which crop out within the proposed geothermal area. They are undoubtedly reservoir rocks for the existing geothermal system.

The Gold Run member (Plr) consists of well-jointed, plagioclase-rich basalts and andesites. These rocks appear to underlie the basalt flows of the Susanville member within the geothermal reservoir (Plate II).

Welded tuff beds of the Quarry member (Plq) are moderately to well jointed and may yield small quantities of groundwater. Their limited areal extent and the impermeable nature of the groundmass, however, make these rocks insignificant relative to the geothermal reservoir.

The plagioclase-rich basalts of the Piute Creek member (Plpc) are volcanic intrusives which crop out in the northwest corner of the geologic map and are probably not associated with the geothermal area.

The Antelope Mountain member (Pla) forms thin, typically massive olivine basalt flows. These rocks would yield only small quantities of groundwater, and do not appear to be related to the geothermal area.

Andesitic mudflow breccias and autobreccias of the mudflow member (Plm) have low permeability except where extensively jointed. Like the Bagwell Springs Formation, these rocks are more likely to be cap rocks than reservoir rocks.

The small exposures of tuff, pyroclastic rocks and volcanically derived sandstone of the pyroclastic member (Plp) could act as buried aquifers within the basalts and could significantly affect the groundwater flows at depth within the geothermal area.

Rocks of the brecciated member (Plb) are highly sheared, decomposed and moderately permeable. Similar types of (fault) breccia occur along faults within the geothermal reservoir.

The Quarternary alluvium (Qal) and lake deposits (Ql) consist of nonconsolidated, moderately to well bedded gravel, sand and silt with moderate to high permeability. The ocurrence of clay-rich lenses or beds of low permeability would locally decrease groundwater flow rates or alter the path of groundwater movement. These sediments interfinger with basalts along the edge of Honey Lake Valley and form a major component of the geothermal reservoir.

Pre-Tertiary

Granite rocks - Gr

The granitic rocks along highway 139 in the northern portion of the mapped area crop out as windows of basement rocks that were brought up by movement along the Antelope Mountain Fault and exposed by subsequent erosion of the overlying Tertiary cover. The igneous rocks are biotite-rich quartz monzonite to quartz diorite with minor amounts of diorite. They are highly weathered (locally spheroidally weathered) and moderately to deeply decomposed. In outcrop the rocks are moderately well jointed and are locally cut by small (2-5 cm) quartzose-feldspathic dikes. Granitic exposures are distinguished by their tan to white, very granular soil, and their gently undulating to rolling topography.

The medium to coarse grained texture of the granitic rocks indicate that the rocks crystallized deep within the earth's crust.

These rocks are associated with the widespread Jurassic - Cretaceous plutonism in the western United States. They are tenetatively assigned on age of Cretaceous (?).

Tertiary Rocks

Bagwell Springs Formation - Plbs

The Bagwell Springs Formation crops out northwest of Susanville along Piute Creek, and extends north to Bagwell Springs, the feature after which the formation name is here established. Due to the incompleteness of section, no type area can be designated. The formation consists of hornblende andesite flows, mudflows and mudflow breccia. The flows are crumbly to hard, light grey to tan in color, and contain large phenocrysts of hornblende, plagioclase, augite and pumice fragments in a fine grained, glassy groundmass. Mudflows and mudflow breccia are matrix supported, with locally abundant, subangular to subrounded, andesitic to basaltic clasts. The rocks are poorly bedded, poorly to moderately well jointed, and form low, hummocky surfaces characterized by sparse vegetative cover and locally resistant, craggy structures.

The mudflows of the Bagwell Springs Formation are distinguished from the younger mudflow member of the Warner Basalt by their abundance of hornblende phenocrysts and pumice fragments, their light grey goundmass, and a greater abundance of andesitic flows and lower percentage of heterolithic clasts.

The Bagwell Springs Formation occurs as local erosional remnants of the once extensive Miocene to Pliocene andesitic flows from volcanic centers. They are debris flows that originated from many local fissures which formed massive sheet-like bodies unconformably deposited upon the basement rocks and post-Eocene volcanic rocks (Durrell, 1959a). The hornblende-rich character of the groundmass and its stratigraphic position beneath the Warner Basalt suggest a possible correlation of the Bagwell Springs with the Penman Formation described in the Blairsden quadrangle to the south (Durrell, 1959a). Based upon this potential correlation, the Bagwell Springs Formation is assigned an age of Pliocene.

Warner Basalt

The flows of the Warner Basalt form flat-lying, to gently dipping plateaus and volcanic domes with widespread distribution in central Oregon and northeastern California. The formation was named for its occurrence in the Warner Mountains by R. J. Russell (1928). Durrell (1959a) has examined the olivine basalt in the Warner Mountains, and correlates the olivine basalt at Susanville, those in the Blairsden quadrangle and those that lie as far south as Truckee with the basalt in the Warner Mountains.

In areas of apparently homolithic volcanism, such as the Warner basaltic plateau, subtle differences within a magma chamber could result in visibly distinctive rock types. During the repeated extrusion of lava flows, the composition of the siliceous melt can change as a result of magmatic differentiation, the assimilation of wall rock, the additional injection of parental magma into the magma chamber, and changes in the temperature, pressure, convection circulation systems, and in the concentration of dissolved oxygen, carbon dioxide and other gasses. This slight variation in magmatic composition, coupled with changing depositional conditions, will give rise to mineralogically and texturally distinctive basalt flows or groups of flows. Within the Susanville area, the Warner Basalt has been divided into nine texturally and mineralogically distinctive members, and one 'catch all' unit (Warner Basalt undifferentiated). By identifying individual or distinctive flows, an approximate stratigraphic sequence has been developed for the flows of the Warner Basalt. Offset of units within this sequence can then be used to confirm faults or indicate the direction of movement along the faults.

Warner Basalt is the dominant rock type in the study area. It underlies the upland surfaces surrounding the city of Susanville, the volcanic domes (?) of Susanville Peak and Antelope Mountain, and the low hills and ridges south of Hidden Valley. Most of the Warner rocks are porphyritic olivine basalt with distinctive yellow to reddish-brown olivine phenocrysts, and subhedral to euhedral plagioclase laths in a grey to black groundmass. Lithologic variation within the unit included basalt, basaltic andesite, andesitic flows, mudflow breccia and pyroclastic rocks. Interbedded sediments occur throughout the Warner Basalt, becoming increasingly abundant as one approaches Honey Lake Valley. The Warner Basalt typically exhibits poorly to moderately developed columnar jointing, horizontal sheeting, and pronounced vesicularity at the top and bottom of individual flows. Foliation is locally well developed.

The total thickness of the Warner is uncertain due to the repetition of the section by faulting. Estimates of the thickness range from 4,000 feet (Bureau of Reclamation, 1976) to 1,000 feet (Durrell, 1959a). A thickness of 1500 to 2000 feet is suggested for the Warner Basalt within the Susanville area.

Warner Basalt undifferentiated - Plw

Undifferentiated Warner Basalt is exposed along the entire northern boundary of the mapped area, cropping out on the flanks of Susanville Peak, in Hidden Valley and north of the Antelope Mountain fault. Olivine basalt predominates, with minor amounts of andesite flows and mudflows. Plagioclase phenocrysts are common, locally forming large (.5-1 cm) glomeroporphyritic masses growing around olivine cores. Quartz, opal and zeolite form fillings in vesicules.

This map unit is the 'catch all' member of the Warner Basalt containing rocks which could not be distinctively separated texturally and mineralogically. Rocks of the undifferentiated member crop out at virtually all stratigraphic horizons within the Warner Basalt.

Inspiration Point Member - Pli

The well foliated basalt flows of the Inspiration Point member are named for exposures along the flanks of Inspiration Point Lookout, immediately west of downtown Susanville. These rocks underlie the elongated ridge separating Piute Creek and the Susan River, west of Susanville. These rocks also form a series of small, northwest-trending knobs north of the Susanville Indian Rancheria, and a thin belt overlying the mudflow member (Plm) at the base of the southern flank of the Susanville Peak.

Well developed foliation, defined by the subparallel elongation of plagioclase laths, and a greenish, augite-rich goundmass distinguishes this unit from other members of the Warner Basalt.

The best exposure of the Inspiration Point basalt are the vertical cliffs along the Susan River. These rocks exhibit well developed columnar jointing with individual columns 1-2 m thick and 2-5 m high. The Department of Water Resources (1963), postulated that the homogeneous basalt exposed in this vertical cliff is Pleistocene in age, and filled an ancestral canyon of the Susan River.

Susanville Member - Pls

The basalt flows of the Susanville member were named after the city of Susanville, which they underlie. Within the city limits, these rocks crop out along the Susan River, form the basaltic cliff behind Lassen Memorial Hospital, and are exposed along highway 139 north of Fifth Street. This unit occupies the flat lowland surface extending from Susanville to Hidden Valley and to the south and east where it is overlain by and interfingers with the alluvium of Honey Lake Valley.

Susanville basalt flows are typically fine grained, rich in olivine, and characterized by a fine vesicular (diktytaxitic) texture and random orientation of plagioclase laths. The basalt occurs as thin (1-4m) flows forming small benches on hummocky plateau surfaces, and low-lying, elongate ridges. Outcrops exhibit well-developed columnar jointing and horizontal sheeting. The soil developed on the basalt flows supports a sparse vegetative cover of small bushes and trees.

Gold Run Member - Plr

The plagioclase-rich basalt flows of the Gold Run member were named for their occurrence along the north side of the Gold Run Creek Canyon. The distribution of these rocks is limited to the southwest corner of the map, where they are in fault contact with rocks of the Susanville member.

Rocks of the Gold Run member include porphyritic plagioclase and olivine basalt, with minor amounts of interbedded andesitic mudflow. This member forms well- jointed, elongate knobs and ridges which typically trend to the northeast. Hills underlain by Gold Run basalt flows are covered with abundant vegetation, which distinguishes them in the field from the sparsely vegetated areas of Susanville basalt. These flows are distinguished from other flows by their abundance of plagioclase phenocrysts, and their field association with interbedded andesitic flows and mudflows.

Quarry Member - Plq

The welded tuff beds of the Quarry member are so named because of the massive outcrops in the open pit at the top of Quarry Street on the west side of Susanville. Blocks of this welded tuff were used as building stone during construction of the city hall and numerous other buildings throughout the city.

The unit is divided into a 2m thick basal section of plagioclase and sanidine-rich rhyolite (?) tuff, a 17m thick middle section of welded tuff rich in plagioclase, lithic fragments and pumice clasts, and a 2-5m thick upper baked zone.

Well-defined foliation is seen in the elongation of vesicules and the preferred orientation of pumice clasts and crystals. The unit is moderately to well jointed, and typically is well indurated.

The rocks of the Quarry member crop out at approximately the same elevation on both sides of the Susan River, and appear to have accumulated in a fairly localized topographic low. They are both underlain and overlain by basalt of the Susanville member.

Piute Creek Member - Plpc

The prophyritic basalt and andesite flows of the Piute Creek member are exposed in the northwest corner of the map, north of Piute Creek, and occur locally within the Bagwell Springs Formation and the undifferentiated rocks of the Warner Basalt. Piute Creek basalt flows contain abundant phenocrysts and crystal masses of plagioclase in a grey, glassy groundmass. The roughly circular outcrop patterns, and the steep topographic expression of the knobs and ridges underlain by the Piute Creek, suggest an intrusive origin, but no confirming evidence was obtained.

Rocks of the Piute Creek member contain much larger plagioclase phenocrysts than do rocks of the Gold Run member (2-8mm vs 1-4mm), and underlie much steeper topography. Microscopically, however, the two rock types are similar, and may in fact be correlative.

Antelope Mountain Member - Pla

The olivine basalt flows of the Antelope Mountain member crop out locally in the north-central and northeastern portions of the map. North of the Susanville Indian Rancheria, they occur as thin, flat-lying flows unconformably overlying the mudflow member of the Warner Basalt. Along the northwestern flank of Antelope Mountain, they unconformably overlie the Mesozoic grantic rocks and undifferentiated Warner Basalt. They are in fault contact with the mudflow member.

Olivine Basalt of the Antelope Mountain member is easily distinuishable by its large, typically altered, golden-yellow olivine and hypersthene phenocrysts in a black to dark green, aphanitic, nonvesicular groundmass. Moderately developed foliation is defined by the subparallel orientation of elongate plagioclase, olivine and pyroxene phenocrysts, and is parallel to locally developed columnar joints.

Mudflow Member - Plm

The andesitic mudflows, mudflow breccia and autobreccia of the mudflow member crop out extensively along the west and south flanks of Antelope Mountain. They occupy irregular-shaped patches north of the Susanville Indian Rancheria, and cap a small ridge south of Hidden Valley.

Within the mudflow member, basaltic, andesitic and scoriaceous clasts range in size from 5 cm to 1.5m, averaging 7-25 cm, and comprise from 20-50 percent of the outcrop. These clasts are supported in a matrix of euhedral plagioclase, pyroxene, and hornblende crystals surrounded by a multicolored, vesicular, glassy to muddy groundmass.

At all outcrops, the mudflow member is associated with or bounded by faults. For example, along the west flank of Antelope Mountain, a deeply incised fault-controlled canyon separates 30m-high vertical cliffs and pillars of andesitic mudflow breccia from olivine basalt. Along the south flank of Antelope Mountain, the mudflow member is truncated by the Antelope Mountain Fault. Antelope Mountain is a fault-dissected volcanic cone (Department of Water Resources, 1963), and the andesitic mudflows probably originated locally from faults and fissures along the flanks of the mountain.

The mudflows exposed north of the Indian Rancheria and in Hidden Valley are of similar composition and texture to those which crop out at Antelope Mountain. These local occurrences may either have been extruded along local faults they contact, or are erosional remnants of fissure eruptions from Antelope Mountain.

Pyroclastic Member - Plp

The pyroclastic member consists of tuff, pyroclastic rocks and volcanically derived sandstones which are interbedded among the basalt flows. Rocks of the pyroclastic member are confined to two small areas of outcrop. Along the Susan River channel, approximately 1500 feet west of the city limit, well bedded tuffaceous sandstone alternates with pebbly conglomerate rich in basalt clasts and pumice fragments. These reworked pyroclastic rocks are in fault contact with and underlain by basalt flows of the Susanville member.

On the western flank of Antelope Mountain, two elongate patches or lenses of well-bedded, poorly indurated volcanically derived sandstone, rich in feldspar and mafic lithic fragments, are interbedded within flows of the undifferentiated Warner Basalt. One of these exposures, in a road cut along highway 139, is offset by a number of right-lateral faults of small (1-3m) displacement.

Brecciated Member - Plb

The brecciated member is a map unit which is based mainly on textural characteristics, and consists of highly weathered, sheared and decomposed basaltic material. This unit is limited to scattered outcrops along a fault north of the hospital, and in road cuts along highway 139 northeast of Hidden Valley.

Within the brecciated areas, the basalt flows are weathered into roughly spherical core stones, surrounded by highly granular to sheared volcanic sands. This intense weathering is interpreted as fault induced brecciation.

Quaternary Deposits

Lake Deposits-Ql

The elevated sedimentary mounds exposed along the Susan River, cuts for the Southern Pacific Railroad and due east of Inspiration Point, are underlain by Quarternary lake deposits. These rounded topographic surfaces, varying in elevation up to 50 feet above the valley floor, are erosional remnants of a large delta, built out into Pleistocene Lake Lahonton (Department of Water Resources, 1963). The medium to coarse grained feldspathic sands and pebbly conglomerates are typically well bedded and poorly indurated. Minor amounts of fine grained sands, silts or clays were observed, but the majority of the material is medium grained sand or larger. Quarternary lake deposits are correlative with the near-shore facies of Lahonton lake deposits (Department of Water Resources, 1963).

Alluvium - Qal

Alluvial deposits occur in recent stream channels along Piute Creek, the Susan River, the stream cut basaltic plateau south of Hidden Valley and mantle the valley floor throughout Honey Lake Valley. The deposits consist of nonconsolidated, poorly sorted, subrounded to rounded silts, sands and gravels, typically of volcanic or plutonic origin.

Structure

The major geomorphic features of the Susanville area are the result of recent movements along steeply dipping faults. A fault dissected basaltic plateau to the west and north of the city is separated from the valley floor by normal faults northwest, north and northeast with vertical displacement ranging from five to several hundred meters. This basaltic upland surface is truncated to the north and south by major northwest trending faults which form the graben shaped Honey Lake Valley. To the south, the Valley floor is separated from the Diamond Mountains and the Sierra Nevada proper along the complex Honey Lake fault zone. This fault zone consists of parallel or en echelon faults which dip steeply toward the Valley. The Honey Lake fault zone forms the steep eastern escarpment of the Sierra Nevada, with a total vertical displacement of more than 2400 meters (Department of Water Resources, 1963). The Honey Lake Valley is bounded on the north by the Antelope Mountain fault, a vertical to steeply southwest-dipping normal fault with 600 to 1200 meters of total displacement (Department of Water Resources, 1963). The Antelope Mountain fault extends to the northwest at least as far as Eagle Lake. To the southeast it terminates at the east-trending Litchfield fault. The Antelope Mountain fault forms the steep escarpment in the northern part of the map area.

The basalt flows surrounding the city were deposited on an essentially horizontal or slightly undulated topographic surface. Block faulting with predominantly vertical movements has tilted the basalt flows so that now they typically dip less than 15° toward the valley. These fault blocks are step-down structures, with the down-thrown blocks progressing toward the valley (Plate II). Locally, some fault blocks step down in the opposite direction. All faults have major components of vertical movement, but some have minor components of right lateral (along highway 139, west of Antelope Mountain) and left lateral (northwest corner of area, in lake deposits immediately northeast of Susanville) movement.

Durrell (1959, 1966) stated that periods of minor faulting and erosion occurred between the deposition of the Tertiary units. The major tectonic uplift of the present day Sierra Nevada, and probable correlative movements along the Antelope Mountain fault, occurred in Pleistocene time. Block faulting which has offset both the Warner and Lahonton lake deposits is also indicative of Pleistocene movement. Within the Susanville area, fault activity occurred as early as Mesozoic or Paleozoic time and has continued into the Pleistocene, and probably into recent time.

The relative alignment of streams, hills and ridges, or the abrupt bending of these features, is suggestive of structurally controlled topography. It is important to realize that the controlling structures may be faults, joints, fractures, or foliations. Slickensides, fault gauge or brecciation are rare. Therefore faults were mapped only where definite offset of units could be determined. Structural lineations identified in the field or during air photo interpretation are presented on Plate IV, along with known faults. Many of these linear features appear to be faults, but field evidence was insufficient to make conclusive determinations. This map depicts the major northeast, northwest and east structural trends in the Susanville area. Plate IV also shows the location of warm water wells and approximate limits of the geothermal area.

Geologic cross sections (Plate II) transect the mapped area in northeast (sections A-A' and C-C') and northwest (section B-B') directions. The exact locations of geologic cross sections are plotted on Plates I and V. Please note the fault induced offset of the depositional or unconformable contacts between the essentially flat lying basalt flows. All faults are steeply dipping and are represented as vertical on the cross sections.

The Warner Basalt flows are typically jointed and locally foliated. Mudflows, pyroclastic rocks and lake deposits are poorly to well bedded. The attitude of these structural and textural features are shown on the map of Joints, Foliations and Bedding (Plate V). Joint surfaces are typically arcuate or wavy, and joint orientations can vary 20-30 degrees at a single outcrop. Therefore, joints within 10 degrees of vertical are plotted as vertical joints on Plate V. Both a Geologic Map (Plate 1) and a Map of Joints, Foliations and Bedding (Plate V) are contained within this report so that the numerous attitudes would not add confusion to the geologic map.

Conclusions

The only proven geothermal reservoir within the Susanville area is located in the southwest corner of the city (Plate IV). With maximum temperatures unlikely to exceed 150-160°F (65-70°C), power generation will not be possible. The geothermal reservoir appears sufficient, however, to support additional wells without a drastic reduction in the temperature or yield to existing wells. This hot water can be used commercially for additional space heating, agriculture, and tourism or recreational purposes.

Small areas to the north and west of the city (see Plate IV and Geothermal Potential) exhibit conditions suggestive of the geothermal circulation of warm water. The warm water well along Piute Road is apparently independent of the geothermal reservoir in the south part of Susanville. Structural conditions controlling the migration of warm water to this well must be determined prior to additional development. Additional field mapping and possible geophysical investigations must be conducted to determine the size and geothermal potential of the hydrothermally altered area between Piute Creek and the Susan River.

Warm water may occur at the intersection of faults and lineations (Plate IV) where the rocks are sufficiently fractured to allow geothermal fluids to reach the surface. Additional field work can determine the degree of rock jointing and fracture, the presence of hydrothermal alteration and the possible occurrence of hot springs at structural intersections. These studies are required to totally evaluate the geothermal potential within the Susanville study area.

Recommendations

Geophysical investigations centered around the city should be conducted to determine the surface expression, size, depth and capacity of the known geothermal reservoir. A gravity survey currently underway, and proposed paleomagnetic and possible seismic surveys to be conducted by the author, should generate some of this information.

Correlation of stratigraphic units observed in drill cores and electric logs obtained from deep drilling programs conducted by the U.S. Bureau of Reclamation in the summer and fall of 1977, and by Lassen College in 1978, will help to more accurately determine the migration of groundwater flows within the reservoir rocks.

Finally, additional field investigations as outlined above are needed for an accurate appraisal of geothermal conditions at potential sites surrounding Susanville.

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