UNITED STATES DEPARTMENT OF INTERIOR

GEOLOGICAL SURVEY

Mineral and geothermal resource potential of Wild Cattle Mountain and Heart Lake Roadless Areas Plumas, Shasta, and Tehama Counties, California

by

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STUDIES RELATED TO WILDERNESS

The Wilderness Act (Public Law 88-577, September 3, 1964) and related acts require the U.S. Geological Survey and the U.S. Bureau of Mines to survey certain areas on Federal lands to determine their mineral resource potential. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of geological, geochemical, and geophysical surveys of Wild Cattle Mountain (5093) and Heart Lake (5096) Roadless Areas in Lassen National Forest, Plumas, Shasta and Tehama Counties, California. These two roadless areas were classified as further planning areas during the Second Roadless Area Review and Evaluation (RARE II) by the U.S. Forest Service, January 1979.

SUMMARY

The results of geological, geochemical, and geophysical surveys in Wild Cattle Mountain and Heart Lake Roadless Areas indicate no potential for metallic or non-metallic mineral resources in the areas and no potential for coal or petroleum energy resources. However, Wild Cattle Mountain Roadless Area and part of Heart Lake Roadless Area lie in Lassen Known Geothermal Resources Area, and much of the rest of Heart Lake Roadless Area is subject to non-competitive geothermal lease applications. Both areas are adjacent to Lassen Volcanic National Park, which contains extensive areas of fumaroles, hot springs, and hydrothermally altered rock; voluminous silicic volcanism occurred here during late Pleistocene and Holocene time. Geochemical data and geological interpretation indicate that the thermal manifestations in the Park and at Morgan and Growler Hot Springs (immediately west of Wild Cattle Mountain Roadless Area) are part of the same large geothermal system. Consequently, substantial geothermal resources are likely to be discovered in Wild Cattle Mountain Roadless Area and cannot be ruled out for Heart Lake Roadless Area.

INTRODUCTION

Wild Cattle Mountain Roadless Area is in the southernmost part of the Cascade Range 49 miles east of Redding, California, in Lassen National Forest (figure 1). The roadless area is contiguous to the north with Lassen Volcanic National Park and lies entirely within Lassen Known Geothermal Resources Area (Lassen KGRA). Wild Cattle Mountain Roadless Area comprises 5440 acres (8.5 mi^2) at elevations between 4960 and 7680 feet (1512 and 2345 meters) above sea level. Access to the roadless area from the west is via dirt roads through private and National Forest Service land along Mill Creek, and from the southeast via cindered roads and logging tracks between the South Arm of Rice Creek and Wild Cattle Mountain (figure 2). The summit of Wild Cattle Mountain is actually 1.5 miles south of Wild Cattle Mountain Roadless Area.

Heart Lake Roadless Area also is in the southernmost part of the Cascade Range, 42 miles east of Redding, California (figure 1). The roadless area comprises 8960 acres (14 mi^2) at elevations between 5600 and 7555 feet (1706 and 2302 meters) above sea level. Access to the area from the west is by logging and unimproved dirt roads along the North and South Forks of Bailey Creek, along Onion Creek, and along the South Fork of Digger Creek (figure 3). Access from the south is by logging roads in the vicinity of Martin Creek. Access from the southeast is by California Highway 89 (which traverses Lassen Volcanic National Park) and by a dirt road extending west from Highway 89 to McGowan Lake.

Geologic maps (figures 2 and 3) of both roadless areas were prepared by L. J. Patrick Muffler and Michael A. Clynne in 1979-81 as part of a USGS project to evaluate the volcanic setting and the geothermal potential of the Cascade Range south of the Pit River. Previous geological investigations include the pioneering work of Williams (1932) in Lassen Volcanic National

Park, an unpublished Masters thesis by Wilson (1961), and unpublished geologic mapping by P. A. Bowen. Bowen's work in particular focused on the northern part of Wild Cattle Mountain Roadless Area and the southeastern part of Heart Lake Roadless Area.

Geochemical work on waters and gases from thermal features near Wild Cattle Mountain Roadless Area has been carried out by the USGS (Thompson, 1982; J. M. Thompson, written communication, 1982; N. L. Nehring, written communication, 1982). Studies of Hg, As, Sb, Cs, and Rb in surficial deposits in and around Lassen Volcanic National Park have been carried out by J. C. Varekamp and P. R. Buseck (written communication, 1982) under contract from the USGS. In addition, 29 stream-sediment samples were collected by the authors and analyzed for 32 elements by the USGS Branch of Exploration Research.

Substantial geophysical investigations have been carried out by the USGS in connection with pre-lease evaluation of Lassen KGRA (Christopherson, 1980; Christopherson and Pringle, 1981; Christopherson and others, 1980; Mase and others, 1980; Christopherson and Hoover, 1981; Dighem, Ltd., 1982). In addition, the USGS maintains an eight-station seismic network in and around the Park (Klein, 1979; D. A. Stauber, written and oral communications, 1982) and has conducted several passive seismic surveys (Monfort, 1980; 1982). Regional gravity data are available (Pakiser, 1964; LaFehr, 1965; Oliver and others, 1975; Oliver and others, 1980; Griscom, 1980), and high-quality areomagnetic data have been acquired recently by Couch (1982) under contract from the USGS.

GEOLOGIC SETTING

Wild Cattle Mountain and Heart Lake Roadless Areas lie on the southeast and southwest flanks, respectively, of an eroded andesitic composite volcano. Potassium-argon ages on several samples from this volcano indicate that it was formed between 0.6 to 0.35 m.y. ago (unpublished data of G. B. Dalrymple, USGS). Remnants of the composite volcano are overlain on the northeast by an extensive field of late Pleistocene and Holocene dacites and andesites (Williams, 1929, 1931, 1932; Macdonald, 1963); historic volcanic eruptions occurred in 1915-1917 at the summit of Lassen Peak (Day and Allen, 1925) and in 1851 at Cinder Cone (James, 1966).

To the south, the andesitic composite volcano overlaps older volcanic rocks of the Maidu volcanic center (Lydon, 1961; Wilson, 1961). Several potassium-argon dates reported by Gilbert (1969) and by G. B. Dalrymple (unpublished data, 1982) suggest that the main part of this volcanic center was constructed 1.8 m.y. ago, but that late silicic activity extended to approximately 1.2 m.y. ago. The Maidu volcanic center has been interpreted by Lydon (1961) to be the source of much of the Tuscan Formation, a sequence of andesitic breccias and flows that crops out extensively on the northeast side of the Sacramento Valley (Anderson, 1933). The nature of the basement under the Maidu volcanic center is uncertain; Cretaceous marine sedimentary rocks (the Chico Formation) and Mesozoic granitic and metamorphic rocks are exposed sporadically in canyons to the south, and Mesozoic granitic and metamorphic rocks of the northernmost Sierra Nevada crop out extensively 19 miles to the southeast of Wild Cattle Mountain and Heart Lake Roadless Areas. These basement rocks probably pass under the volcanic rocks of the region around Lassen Volcanic National Park to appear again to the northwest in the Klamath Mountains (Heitanen, 1981, figure 2).

Regional geologic structure south and southeast of Lassen Volcanic National Park is dominated by northwest-trending high-angle faults (Lydon and others, 1960), none of which are expressed in the young volcanic rocks of Wild Cattle Mountain and Heart Lake Roadless Areas. The nearest faults that the authors have been able to confirm are in the vicinity of Devils Kitchen and Terminal Geyser (figure 1). North of the Park, faulting trends northerly; this direction is also expressed by a line of small basaltic cinder cones just east of Wild Cattle Mountain Roadless Area.

All of Wild Cattle Mountain and Heart Lake Roadless Areas have been glaciated, and till of Tahoe and Tioga ages covers most of both roadless areas (Crandell, 1972; Kane, 1975). This till is shown on the geologic maps (figures 2 and 3) only where it is of sufficient thickness to obscure the underlying volcanic rock.

TRACE ELEMENT GEOCHEMISTRY

Twenty-nine samples of silt- or sand-sized sediment from all significant perennial and ephemeral streams draining Wild Cattle Mountain and Heart Lake Roadless Areas were collected for trace-element analysis. Samples were not taken from Mill Creek, a large stream traversing Wild Cattle Mountain Roadless Area from north to south. This stream is the major drainage of the southwestern part of Lassen Volcanic National Park, and virtually all of the sediment in the streambed is derived from the eroded core of the andesitic composite volcano entirely within the Park. Hence, analyses of the sediment of Mill Creek are not relevant to the mineral resource potential of the roadless area.

The stream-sediment samples were dried, sieved to minus-80 mesh, split, pulverized, and analyzed by standard semiquantitative emission spectrography for 31 elements and by instrumentation methods for Hg (tables 1 and 2). The results are within the expected ranges for sediments derived from volcanic rocks (cf. Turekian and Wedepohl, 1961, table 2). In addition, no individual samples stand out as anomalously enriched in any element or set of elements.

GEOTHERMAL RESOURCES

The region around Lassen Volcanic National Park has been long recognized for its substantial geothermal potential (Renner and others, 1975; Brook and others, 1979), and an area of 141 mi^2 just south of the Park is classified by the Minerals Management Service as a Known Geothermal Resources Area (Godwin and others, 1971). This classification is based on the extensive vapor-dominated thermal manifestations present just to the north in Lassen Volcanic National Park and on the presence of boiling Cl^-- and SiO_2-bearing thermal waters at Morgan and Growler Hot Springs. The presence of siliceous sinter at Morgan and Growler Hot Springs indicates that the thermal waters at depth are almost certainly over 180°C (White, 1974), and Na-K-Ca, sulfate-isotope, and mixing-model geothermometers indicate that the deep thermal water feeding these springs may have a temperature approaching 240°C (Brook and others, 1979; J. M. Thompson, oral communication, 1982).

Observations of the thermal features in and around Lassen Volcanic National Park suggest that the fumarole areas within the Park as well as at Morgan and Growler Hot Springs are manifestations of a single, large geothermal system whose focus and major thermal upflow is under Bumpass Hell (figure 1). Bumpass Hell contains numerous superheated fumaroles, the hottest of which had a surface temperature of 159°C in 1976. Superheated fumaroles of temperatures up to 125°C in 1976 also occur in Little Hot Springs Valley, but steam being discharged from other fumarole areas in the Park is either saturated or only slightly superheated. Furthermore, Devils Kitchen has old sinter in two places along Hot Springs Creek, indicating hot-water discharge in the recent past. These observations all fit a model originally suggested by D. E. White (written communication, 1971) of a single geothermal system with a vapor-dominated reservoir centered on Bumpass Hell and surrounded by a peripheral zone of hot water. Figure 4 shows an idealized cross-section of this system. Temperature of the upflowing deep water under Bumpass Hell is likely to be about 240^{o}C, as in most vapor-dominated geothermal systems (White and others, 1971).

This interpretation of the thermal features in and around Lassen Volcanic National Park is strongly corroborated by recent studies of gases from the thermal areas (N. L. Nehring, written communication, 1982). The gases sampled at Bumpass Hell are rich in H_2S, whereas those from the other thermal areas are progressively depleted in H_2S and enriched in CO_2 and N_2 with increasing distance from Bumpass Hell. These chemical changes are due to reaction of H_2S with oxygen in groundwater and admixed air, and to dilution with atmospheric N_2.

J. C. Varekamp and P. R. Buseck (written communication, 1982) have conducted an intensive study of Hg and other trace elements in the superficial deposits (soils, muds, alteration halos) of Lassen Volcanic National Park and vicinity. They find strong enrichment of Hg in the vapor-dominated part of the geothermal system (i.e., the fumarole areas in the Park) and moderate enrichment of Hg at the hot-water manifestations at Morgan and Growler Hot Springs. In addition, they find depletion of As, Sb, and Cs in the vapor-dominated areas and enrichment in the hot-water areas. These relations are due to the preferential fractionation of Hg into the vapor phase and As, Sb, and Cs into the liquid phase. Hence, at areas of solely steam discharge (i.e., the fumarole areas in the Park) one would expect a positive anomaly only for Hg. At areas of mixed water and steam discharge (as in the boiling thermal springs at Morgan and Growler Hot Springs) one would expect moderate Hg (from the steam phase) and enrichment in As, Sb, and Cs (from the water phase).

In addition to the areally restricted trace-element anomalies in the thermal areas, the maps of Varekamp and Buseck show a belt of anomalously high Hg extending from the fumarole areas in the Park south-southeasterly through Morgan Hot Springs. Much of this anomaly is undoubtedly due to mechanical transport of Hg along with the rock that is being rapidly eroded from the altered core of the andesitic composite volcano and transported southward along Mill Creek by alluvial and debris-flow processes. Significantly, however, this Hg anomaly does not extend southwesterly down Mill Creek but instead continues to the south-southeast along Childs Meadows. Accordingly, this belt of anomalous Hg can not be due solely to mechanical transport of Hg adsorbed on clays in the sediment of Mill Creek but may be due in part to addition of Hg accompanying steam boiling off the hot thermal water moving to the south-southeast from the center of the geothermal system.

Nine shallow heat-flow holes have been drilled in Lassen KGRA (figures 1, 2 and 3). Holes C and E, located in the southern part of the KGRA (figure 1), yielded consistent linear temperature gradients at depths below a zone of near-surface water movement (figure 5) and are interpreted by Mase and others (1980) to give a regional heat flow of 65-75 mWm^{-2}, transitional between low heat flow (40 mWm^{-2}) in the Klamath Mountains and Coast Ranges to the west and high heat flow (70-100 mWm^{-2}) in the Basin and Range province to the east. The temperature gradients for the remaining 7 holes are quite variable with depth, due to complex near-surface convection of water; meaningful regional conductive heat flows can not be calculated for these holes. Hole F has a gradient of $94^{o}C/km$ between the depths of 50m and 250 m and is probably influenced by the hot water flowing south at depth beneath Mill Creek. Three other holes (B, G, and H) and possibly a fourth (D) show high gradients at depths greater than 100 m (figure 5), suggesting that thermal water may extend under much of the northern part of Lassen KGRA.

Audio-magnetotelluric, telluric, self-potential, magnetotelluric, and airborne electromagnetic surveys have been conducted in Lassen KGRA (Christopherson, 1980; Christopherson and others, 1980; Christopherson and Pringle, 1981; Christopherson and Hoover, 1981; Dighem Ltd., 1982). These surveys all display a complex pattern of resistivity reflecting primarily near-surface variations in lithology, porosity, and temperature. The known thermal areas in and adjacent to Lassen Volcanic National Park all show up as resistivity lows (figure 6). Other conspicuous resistivity lows, however, may not be due to upflow of thermal waters. In particular, the resistivity lows in the area west of Rice Creek and near Domingo Spring may be due to near-surface porous aquifers in alluvium, glacial deposits, and young basalts. Chemical analyses of Domingo Spring by J. M. Thompson (oral communication, 1982), however, show a minor thermal component.

In summary, geological, geochemical, and geophysical evidence indicates a single geothermal system centered on the Bumpass Hell area of Lassen Volcanic National Park. The system is represented by a vapor-dominated reservoir within the Park and hot-water outflow to the south along Mill Creek and probably to the southeast to the area of Terminal Geyser. The high thermal gradients at depths greater than 100 m in heat-flow holes G, H, and possibly D suggest that this lateral flow of hot water may not be confined only to the valleys of Mill and Hot Springs Creeks. Accordingly, the entire Wild Cattle Mountain Roadless Area could be underlain by thermal waters. This speculation can not be confirmed without deep exploratory drilling.

The evidence for possible geothermal resources under Heart Lake Roadless Area is scanty, particularly because pertinent geophysical data are are almost completely lacking. The area is indeed adjacent to the southwest part of Lassen Volcanic National Park, and lateral flow of thermal water from the main upflow zone at Bumpass Hell is by no means impossible. Although there are no thermal manifestations in or immediately adjacent to the area, heat-flow hole B (just south of the area) does show a high temperature gradient at depths greater than 158 m (figure 5). Accordingly, at least the southern part of Heart Lake Roadless Area is likely to contain geothermal resources, and the existence of such resources under the rest of the roadless area can not be precluded.

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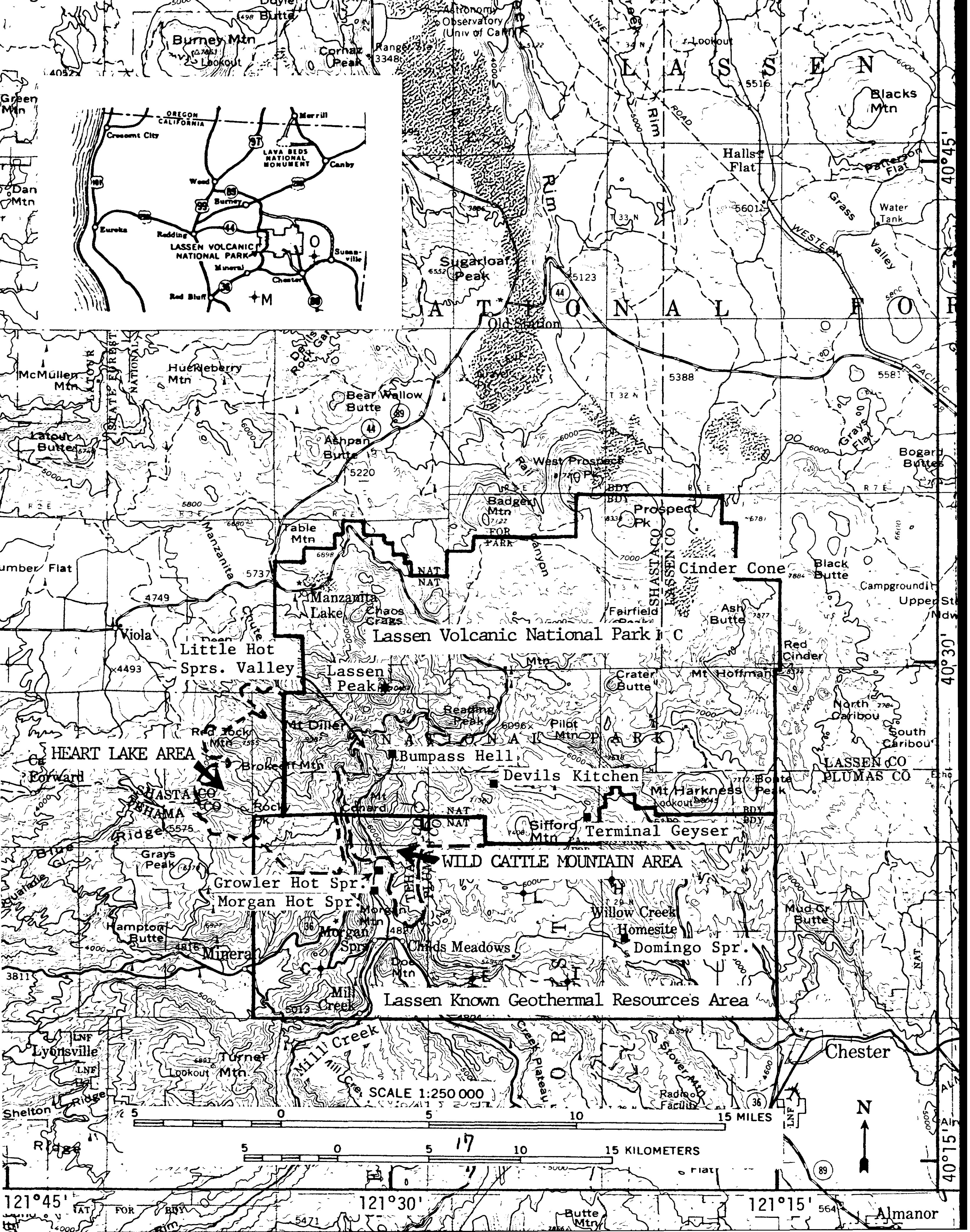
FIGURES

Figure 1.



Lassen Volcanic National Park
Lassen Known Geothermal Resources Area
HEART LAKE AREA
WILD CATTLE MOUNTAIN AREA
Little Hot Sprs. Valley
Lassen Peak
Cinder Cone
Bumpass Hell
Devils Kitchen
Terminal Geyser
Growler Hot Spr.
Morgan Hot Spr.
Domingo Spr.
Willow Creek Homesite
Chester
Mineral
Viola
Manzanita Lake
Old Station
Mill Creek
SCALE 1:250 000
15 MILES
15 KILOMETERS
N
121°45'
121°30'
121°15'
40°45'
40°30'
40°15'
OREGON
CALIFORNIA
Crescent City
Merrill
LAVA BEDS NATIONAL MONUMENT
Canby
Wood
Burney
Eureka
Redding
LASSEN VOLCANIC NATIONAL PARK
Mineral
Susanville
Chester
Red Bluff

17

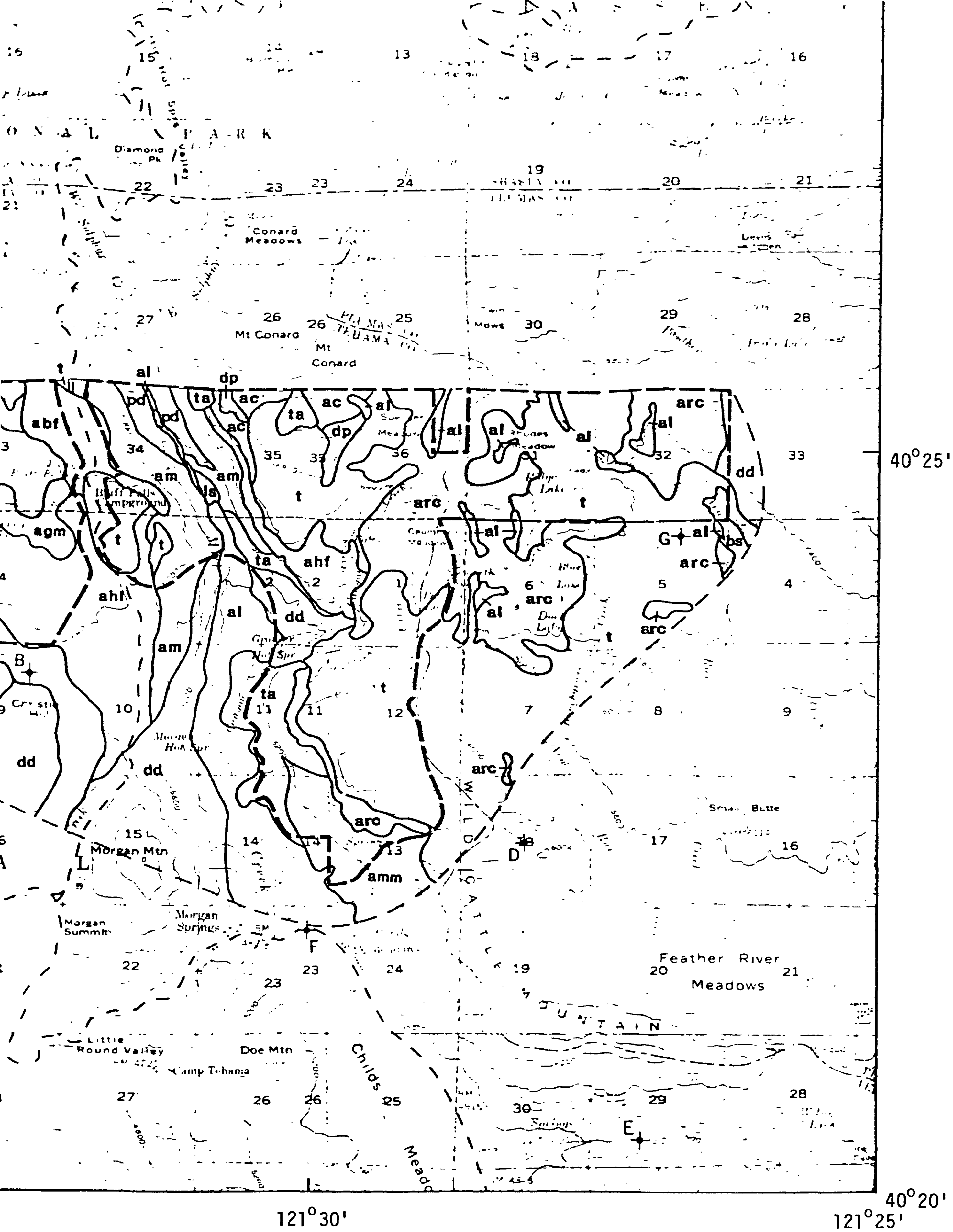
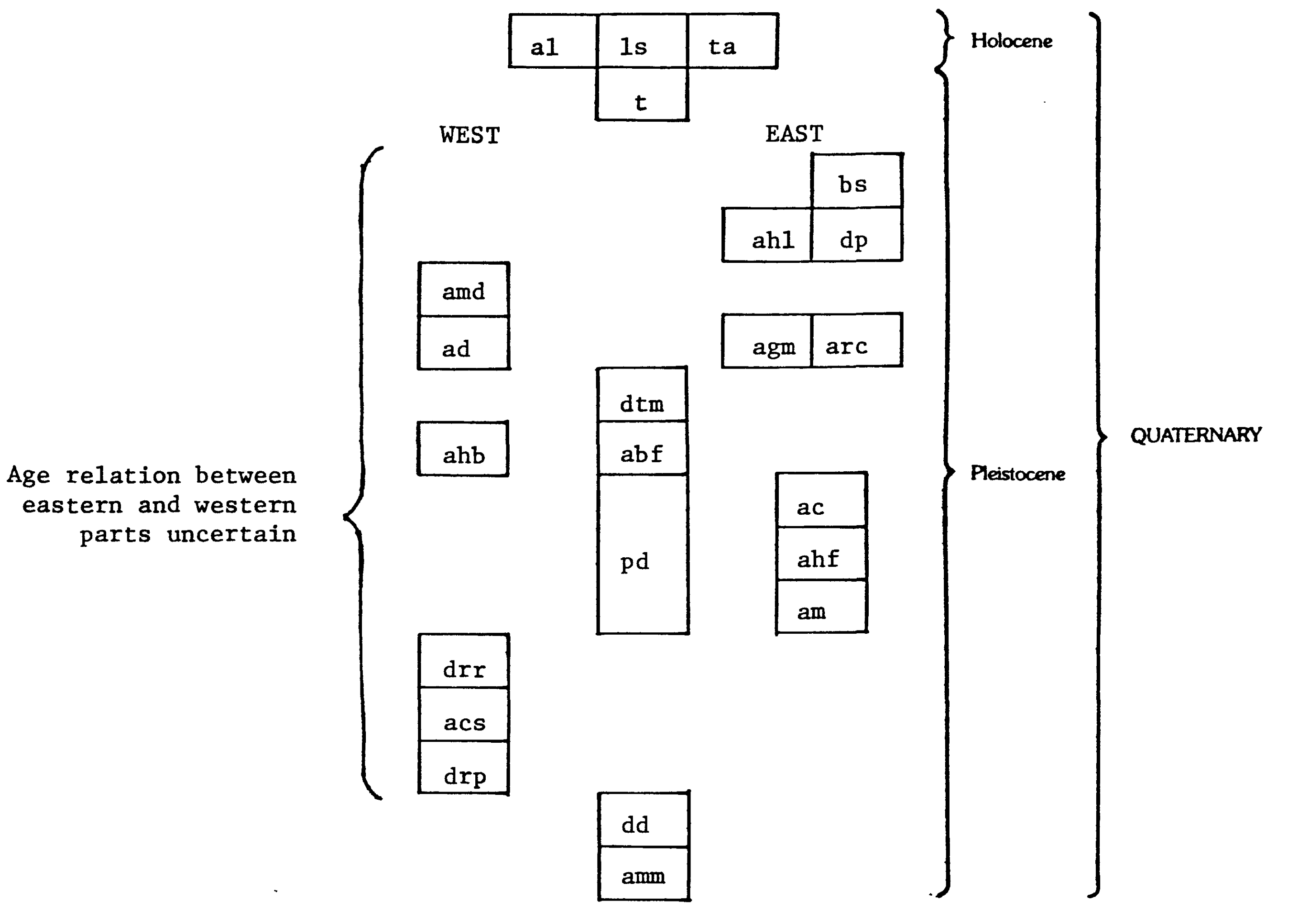


Figure 2. Geology of the Wild Cattle Mtn. Roadless Area

SCALE 1:62500

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

al Alluvium

ls Landslide

ta Talus and colluvium

t Undivided till of Tahoe and Tioga age

bs Basalts of Sifford Mountain--Dark-gray basalt and mafic andesite flows containing variable amounts of olivine, hypersthene, augite, and plagioclase phenocrysts.

ahl Andesite of Huckleberry Lake--Thin, light- to dark-gray mafic andesite flows, containing 10-20% phenocrysts of olivine and plagioclase with sparse orthopyroxene and clinopyroxene crystals. Glomeroporphyritic clots of plagioclase and pyroxene are occasionally present.

dp Pre-Lassen Dacite of Williams (1932)--Black, glassy, flow-banded dacite containing 15-20% phenocrysts, dominantly plagioclase and hornblende, with lesser amounts of hypersthene and biotite.

amd Andesite of Mount Diller--Thin flows and interflow breccias of light-gray to black, porphyritic, 2-pyroxene, silicic andesite containing 30% phenocrysts of plagioclase, and 5% each of augite and hypersthene. Glomeroporphyritic clots of plagioclase, augite, and hypersthene $\pm$ Fe-Ti oxide and olivine are abundant.

ad Andesite of Digger Creek--Thick flows of light- to dark-gray, occasionally black, porphyritic, 2-pyroxene, silicic andesite. Plagioclase is the dominant phenocryst; pyroxene proportions are variable, but generally hypersthene and augite are present in subequal amounts. Xenocrystic olivine is usually present in small amounts. Glomeroporphyritic clots of plagioclase and pyroxene $\pm$ Fe-Ti oxide and olivine are abundant, and gabbroic inclusions of similar mineralogy and partially digested inclusions of sedimentary and volcanic rocks are locally common.

agm Andesite of Glassburner Meadows--Thick flows of light-gray, porphyritic, 2-pyroxene, silicic andesite containing phenocrysts of plagioclase (30%), hypersthene (5%), and augite (5%). Resorbed hornblende and xenocrystic olivine are usually present as minor components. Glomeroporphyritic clots of plagioclase and pyroxene $\pm$ Fe-Ti oxide and olivine are abundant.

arc Andesite of Rice Creek--Light-gray, conspicuously porphyritic andesite flows with phenocrysts of plagioclase, augite, hypersthene, and rare olivine. Plagioclase and pyroxene commonly occur as characteristic glomeroporphyritic aggregates. Forms a major flow complex from a vent in the vicinity of Bumpass Mountain.

ahb Andesites of Heart Lake and Bailey Creek--The andesite of Heart Lake consists of thick flows of porphyritic, 2-pyroxene andesite containing 30% phenocrysts of plagioclase with augite and hypersthene present in subequal proportions. Serpentinized olivine xenocrysts are a characteristic minor component. The andesite of Bailey Creek is a medium-gray, porphyritic, 2-pyroxene, andesite flow. Subequal amounts of augite and hypersthene phenocrysts are subordinate to plagioclase.

dtm Dacite of Twin Meadows--Medium-gray to black, hornblende-pyroxene and pyroxene dacite flows containing variable amounts of phenocrysts. Hornblende-pyroxene dacites contain 20% phenocrysts, dominantly plagioclase and hornblende with minor amounts of augite and hypersthene. Pyroxene dacites are less porphyritic and hornblende is absent or completely resorbed. Microvesicular mafic inclusions of skeletal plagioclase and hornblende with glass and Fe-Ti oxide are abundant.

abf Andesite of Bluff Falls quarry--Thick flows of light- to medium- gray, porphyritic, 2-pyroxene andesite with plagioclase as the dominant phenocryst and augite greatly exceeding hypersthene in abundance. Xenocrystic olivine is sparsely present and glomeroporphyritic clots of plagioclase and pyroxenes ± Fe-Ti oxide and olivine are common.

pd Pyroclastic debris from the andesitic composite volcano--Dominantly lithic pyroclastic flows (block-and-ash flows) of andesitic composition, with subordinate interlayered andesite flows. Phenocrysts are dominantly plagioclase, hypersthene, and augite.

ac Andesites of Mount Conard--Medium-gray andesite flows with 10-20% phenocrysts of plagioclase, hypersthene, and augite plus 0-5% olivine.

ahf Andesite and mafic andesite of Hanna Falls--Conspicuous ledge-forming andesite flow with 15-20% phenocrysts of plagioclase, hypersthene, augite, and olivine, overlying a mafic andesite flow containing 10-15% phenocrysts of plagioclase and olivine plus subordinate hypersthene and augite.

am Andesite of Mill Canyon--Medium-gray andesite flows from flank vents of Tehama Volcano. Approximately 15% phenocrysts of plagioclase, olivine, hypersthene, and augite.

drr Dacite of Red Rock Mountain--dome of mafic dacite containing 5% phenocrysts, dominantly plagioclase and resorbed hornblende. Minor hypersthene as well as quartz phenocrysts surrounded by reaction rims of fine-grained augite are also present. The rock is typically oxidized to shades of red.

acs Andesite of Cabin Spring--Medium-gray, 2-pyroxene andesite flows containing conspicuously color-zoned augite phenocrysts with lesser amounts of hypersthene and small plagioclase. Milky quartz inclusions with fine-grained augite rims are locally common.

drp Dacite of Rocky Peak--Light-gray dacite dome and thick flow containing 20% phenocrysts, dominantly of plagioclase (15%) and resorbed hornblende (0-5%) with hypersthene and augite as minor components.

dd Dacite domes of Maidu volcanic center--Dacite containing 15-25% phenocrysts, predominantly plagioclase and hypersthene or hornblende, with minor augite and occasional quartz or olivine.

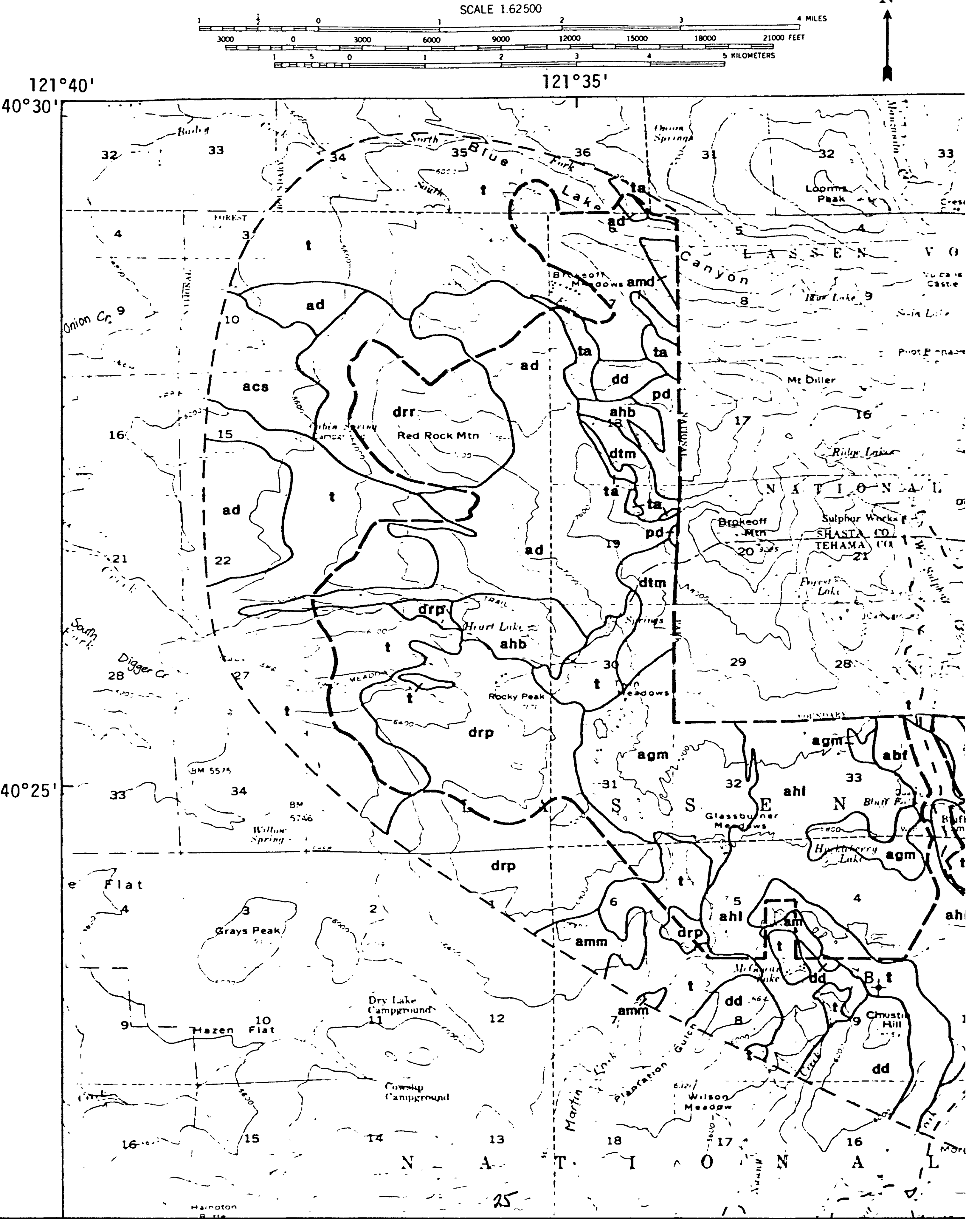
amm Andesites of Maidu volcanic center--Conspicuously porphyritic andesite flows and breccias with phenocrysts dominantly of plagioclase, hypersthene, and augite with sporadic olivine. In contrast to younger units, displays no constructional topography.

— — Boundary of Roadless Areas

— — Boundary of area mapped

B✦ Approximate location of heat-flow holes with letter designation

Figure 3. Geology of the Heart Lake Roadless Area



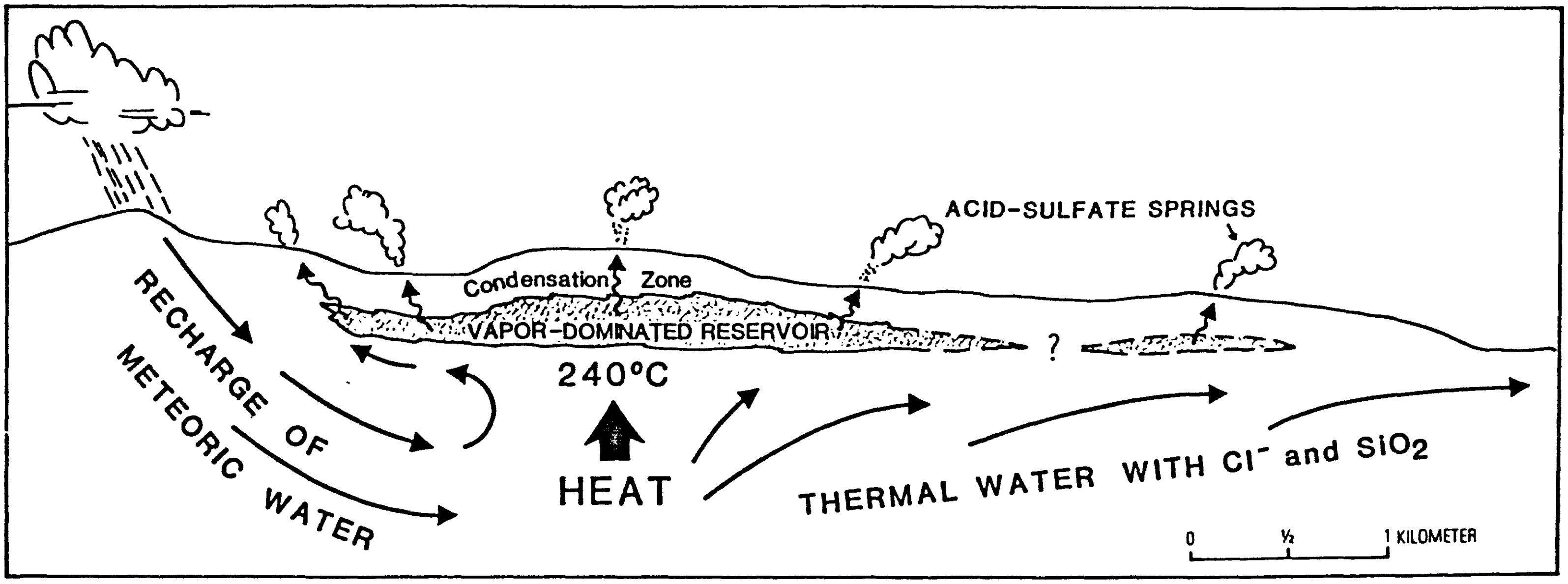

ACID-SULFATE SPRINGS
Condensation Zone
VAPOR-DOMINATED RESERVOIR
?
240°C
RECHARGE OF METEORIC WATER
HEAT
THERMAL WATER WITH Cl⁻ and SiO2
0 ½ 1 KILOMETER

Figure 4.

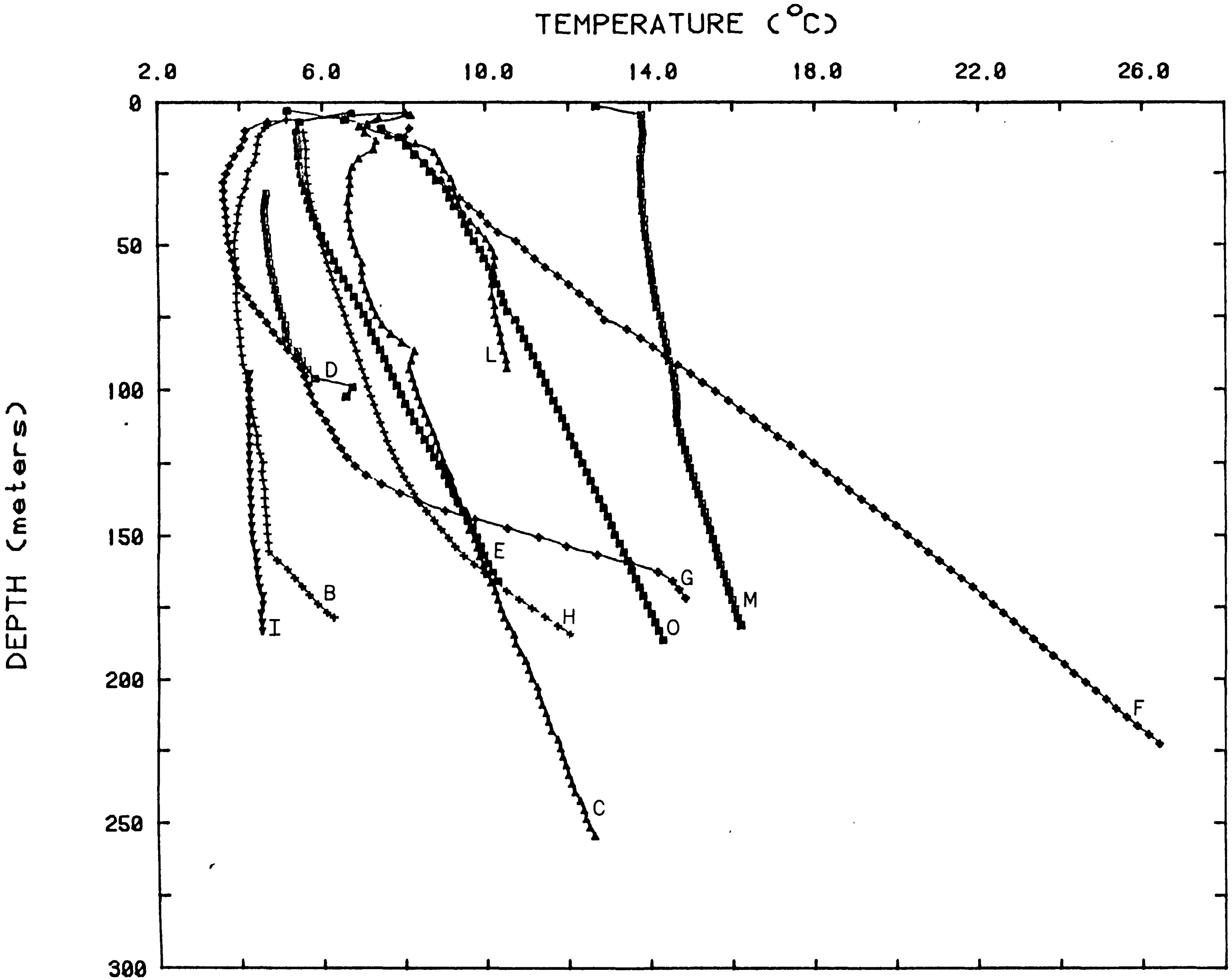


Figure 5. Temperature profiles from USGS wells in the Lassen area (adapted from Mase and others, 1980).

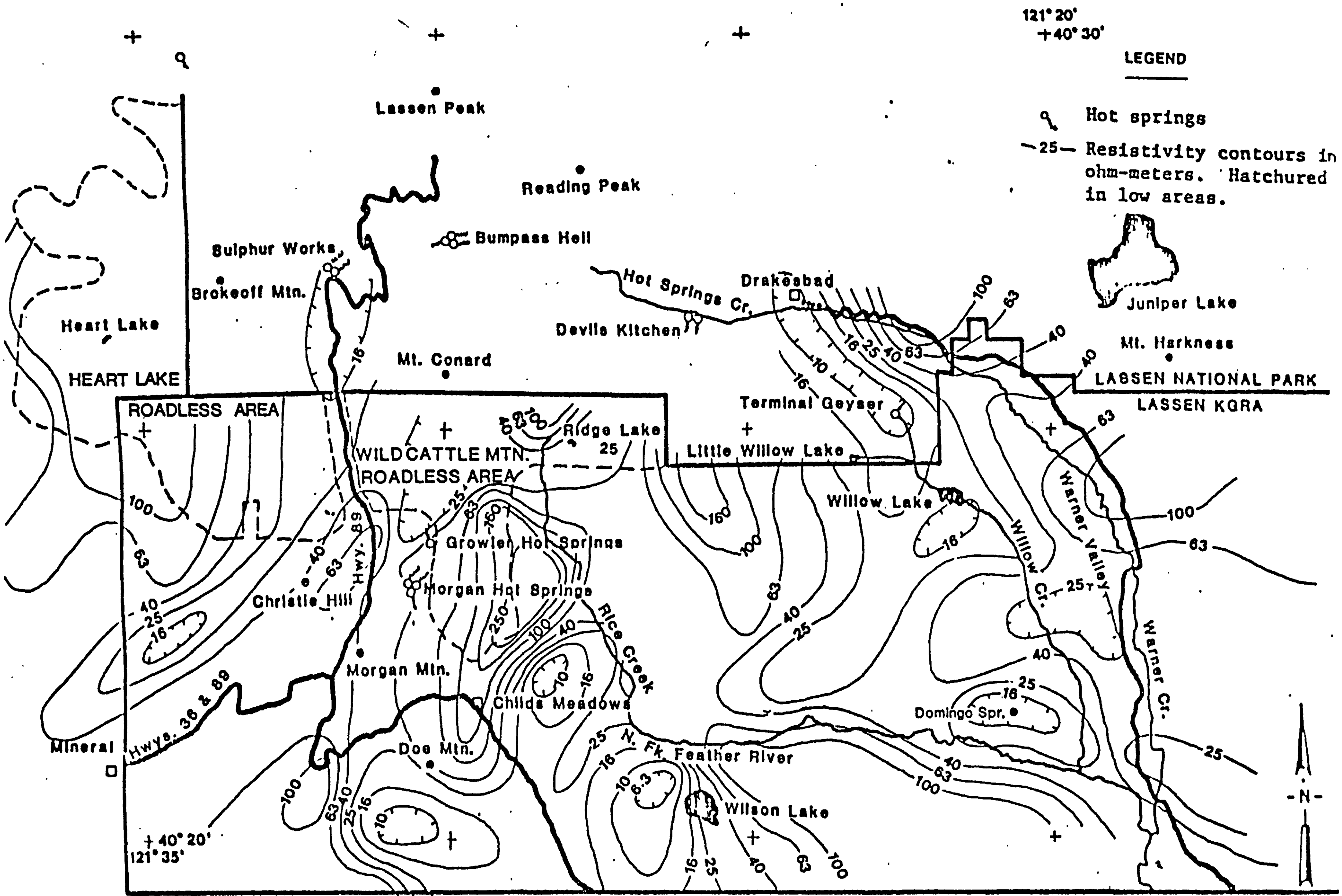


Fig. 6 : Audio-magnetotelluric apparent resistivity map at 7.5 hertz, electric line oriented east-west (adapted from Christopherson and Pringle, 1981).

TABLES

Table 1. Geochemical analyses of stream sediments from Wild Cattle Mountain Roadless Area. Semi-quantitative spectrographic analysis by USGS Branch of Exploration Research, Report no. 73164. The following elements were analyzed for but not detected (detection limits in ppm given in parentheses): Ag (.5), As (211), Au (11), Bi (11), Cd (21), Mo (5), Nb (21), Sn (111), W (51), and Th (111)

	Percent				ppm																
Lower limit of detection	.15 Fe	.12 Mg	.15 Ca	.112 Ti	11 Mn	11 B	21 Ba	1 Be	5 Co	11 Cr	5 Cu	21 La	5 Ni	11 Pb	5 Sc	111 Sr	11 V	11 Y	211 Zn	11 Zr	Hg
Sample Number																					
LM81-788	11	2	1	.7	1111	11	211	L	51	311	51	L	111	21	31	211	211	21	211	71	.18
LM81-789	7	2	1	.5	1111	15	511	1	31	211	71	21	71	15	15	311	211	21	N	151	.91
LM81-793B	11	2	1.5	.7	1111	11	311	L	51	311	51	L	111	11	21	211	311	21	211	111	.26
LM81-812	5	1	1	.5	711	21	511	1	21	71	51	21	31	21	15	511	111	15	N	111	.24
LM81-817	7	2	1.5	.5	1111	21	511	1	31	211	31	21	51	21	15	311	151	15	N	71	.31
LM81-818	5	2	1	.5	1111	21	311	1	31	211	31	21	71	21	15	211	151	21	N	71	.61
LM81-821	5	2	1.5	.5	1111	21	511	1	31	311	71	21	71	21	21	311	151	15	N	111	.61
LM81-839	5	2	1.5	.5	1511	31	511	1	31	211	51	21	71	21	21	511	151	21	N	111	.41
LM81-845	2	.5	.7	.2	1111	31	211	1	15	51	21	31	31	21	11	151	111	15	N	51	.51
LM81-848	3	1.5	1	.3	711	15	311	1	21	111	51	31	51	21	15	311	111	15	N	111	.41
LM81-849	5	1.5	1	.5	711	21	311	1	21	151	71	31	51	21	15	311	111	15	N	111	.28
LM81-858	3	1	1	.3	711	11	311	1	15	71	31	21	31	15	11	311	111	11	N	51	.41
LM81-864	5	1	.7	.5	1111	15	311	1.5	21	211	71	31	71	15	15	211	151	21	N	71	.65
LM81-879	5	1.5	1.5	.5	711	21	311	1	21	211	51	21	71	21	15	311	111	15	N	111	.35
LM81-885	5	1	1	.7	511	15	311	1	21	151	31	21	51	15	15	311	151	15	N	111	.55

Table 2. Geochemical analyses of stream sediments from Heart Lake Roadless Area. Semi-quantitative spectrographic analysis by USGS Branch of Exploration Research, Report no. 73165. The following elements were analyzed for but not detected (detection limits in ppm given in parentheses): Ag (.5), As (211), Au (11), Bi (11), Cd (21), Mo (5), Nb (21), Sn (111), W (51), and Th (111)

	Percent				ppm																
Lower limit of detection	.15 Fe	.12 Mg	.15 Ca	.112 Ti	11 Mn	11 B	21 Ba	1 Be	5 Co	11 Cr	5 Cu	21 La	5 Ni	11 Pb	5 Sc	111 Sr	11 V	11 Y	211 Zn	11 Zr	Hg
Sample Number																					
LC81-123	2	.7	1	.2	711	15	211	1	21	151	31	21	51	15	15	211	111	11	N	51	1.1
LC81-169	1.5	.5	1	.15	711	21	511	1.5	15	51	21	31	31	21	11	211	111	11	N	71	.41
LC81-174	5	2	2	.5	1111	21	311	L	31	211	51	L	71	31	21	311	151	15	L	111	.31
LC81-175	5	1.5	1.5	.7	1111	31	511	1	21	111	31	21	51	21	21	311	151	15	N	111	.35
LC81-392	7	1	1	.5	1111	31	511	1	51	151	51	21	71	21	21	311	151	21	L	111	.41
LC81-418	3	1	1	.5	1111	21	511	1	31	311	51	21	71	21	21	311	151	21	N	71	.75
LC81-421	5	2	1	.7	1111	21	311	L	51	511	71	21	111	21	21	311	211	15	N	71	.91
LC81-466	3	1	1	.5	1111	21	311	1	31	111	51	21	71	15	15	311	151	15	N	71	.41
LC81-473	5	3	2	.7	1511	11	311	L	51	311	51	L	111	21	31	311	151	15	211	71	.31
LC81-474	3	2	2	.5	1111	15	311	L	31	211	51	21	111	21	21	511	151	15	N	71	.41
LC81-513	2	1	.7	.3	711	21	311	1	21	211	51	31	51	15	15	311	151	15	N	71	.41
LC81-515	3	3	1.5	.5	711	11	311	L	51	511	71	21	211	11	21	311	151	15	N	71	.31
LC81-516	5	3	2	.7	1511	11	211	L	51	311	51	21	111	15	31	311	211	15	211	71	.61
LC81-517	2	1	1	.2	711	15	311	1	21	71	21	21	31	15	11	311	111	15	N	71	.28