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Additional audio-magnetotelluric soundings in the Lassen Known Geothermal Resource Area, Plumas and Tehama Counties, California

by

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During the summer of 1980, 16 audio-magnetotelluric stations were occupied near Lassen National Park in northern California. This work was additional to work done in 1979 (Christopherson and others, 1980) to assess the geothermal and mineral potential of the Lassen Known Geothermal Resource Area (KGRA) and of the proposed Heart Lake and Wild Cattle Mountain Wilderness (fig. 1).

The 16 stations were located mostly within the proposed wilderness boundaries (fig. 2). Their locations are designated by letters A through P. Their locations are listed by Range, Township, and Section (Table I) and scalar resistivities in ohm-meters for orthogonal electric field line (E-line) orientations are given in Table II. At some frequencies and orientations data were unobtainable due to local cultural interference or instrumentation problems. The scalar resistivities were contoured at 7.5 and 27 hertz for both the N-S and E-W E-line orientations (figs. 3 thru 6). A description of the equipment and technique used is given by Hoover and others (1978).

The geology of the area is not well mapped in detail. Information is available in Lydon and others (1960) and Schulz (1957). At present mapping is being done by Patrick Muffler and others of the USGS and is concentrated mostly in the western part of the KGRA and National Park. A generalized geology map is shown in fig. 7. The Lassen area is covered mostly by Quaternary (Pleistocene) and Tertiary (Pliocene) volcanics of basaltic and andesitic composition. Extensions of andesite and dacite approximately 500,000 years ago from an ancient volcano, Mt. Tehama, (now a caldera feature) in the southwest corner of the park cover most of the Heart Lake and Wild Cattle Mountain Wilderness. The southern part of Wild Cattle Mountain is older, mostly Pliocene andesite. The basalt of Red Mountain and to the south is about 20,000 to 10,000 years old. (Patrick Muffler, oral communication, 1981).

Two other calderas, evidence of older volcanic centers, have been described in literature. Mount Midou, a center near the town of Mineral, has mostly been eroded but evidence of it exists as flows and hydrothermal alteration (Wilson, 1961). Another larger caldera encircles the site of an ancient volcano called Mt. Yana. The caldera is about 23 miles in diameter and centers about a point 15 miles due south of Stump Ranch (Lydon, 1968).

Quaternary dacite domes are exposed at Lassen Peak, Reading Peak, Morgan Mountains, Doe Mountain, and Christie Hill. Faulting occurs in the southern part of Lassen Park and the eastern part of the KGRA either following the regional northwest trend or as ring fractures encircling in part what is proposed to be a large caldera feature covering most of the KGRA. This caldera is approximately 14 miles in diameter. Its existence is supported by geomorphologic patterns (Jules Friedman, USGS, oral communication, 1981), self-potential anomalies mapping ring dikes on the eastern side of the caldera (Christopherson and others, 1980) and low resistivity trends found in this study. As of yet there is little geologic evidence for this caldera, but with the other volcanic activity and caldera features in the surrounding region, its existence is highly plausible.

As shown by the AMT data, all soundings made at or near areas of known thermal manifestations show associated low resistivities as would be expected to result from thermal waters and concommittant alteration. This is shown at the two soundings near Sulphur Works, three soundings near Morgan and Growler

Hot Springs, and each sounding at Drakesbad and Terminal Geyser. At these sites the lowest 7.5 hertz apparent resistivities generally range from 7 to 16 ohm-meters. Other areas where apparent resistivities approach these values can be inferred to have significant potential for thermal waters and/(or) alteration even though no surface manifestations are present.

The 7.5-hertz east-west map (fig. 5) shows an arcuate low resistivity trend defined by a series of closed lows from Drakesbad to Terminal Geyser and south along Willow Creek. In part these lows correspond with mapped faults (fig. 3) and also with the approximate locations of the northern and eastern inner edges of a proposed collapse structure centered over the middle of the KGRA (Jules Friedman, oral communication, 1981). From Willow Lake, near the center of the arc, a southwesterly low resistivity trend is shown on both 7.5-hertz maps. This same trend is also shown by data in the western part of the KGRA from north of Mineral to Highway 89. No well-defined major geological trends are known having this direction but the electrical data suggests that they may be present. Regional gravity data show a similar trend through the middle of the KGRA.

The low resistivity areas seen in the western part of the KGRA do not form a consistent picture which correlates with known geologic structures. Sulphur Works and Bumpass Hell are thought to be located on a ring fracture associated with the large collapse feature to the southeast along whose eastern edges lie the lows of the Willow Lake area. The low resistivity areas near Morgan and Growler Hot Springs trending south and branching to the southwest and southeast of Childs Meadows could also be associated with the inner caldera margins.

The 27-hertz maps (figs. 6 and 7) show approximately the same trends as the 7.5-hertz maps, although at 7.5 hertz the skin depth or depth of investigation is about twice as deep. Differences in resistivity values between the two E-line orientations can usually be attributed to local variance in structure. The 27-hertz maps define essentially the same borders for the collapse structure as defined by the 7.5-hertz data.

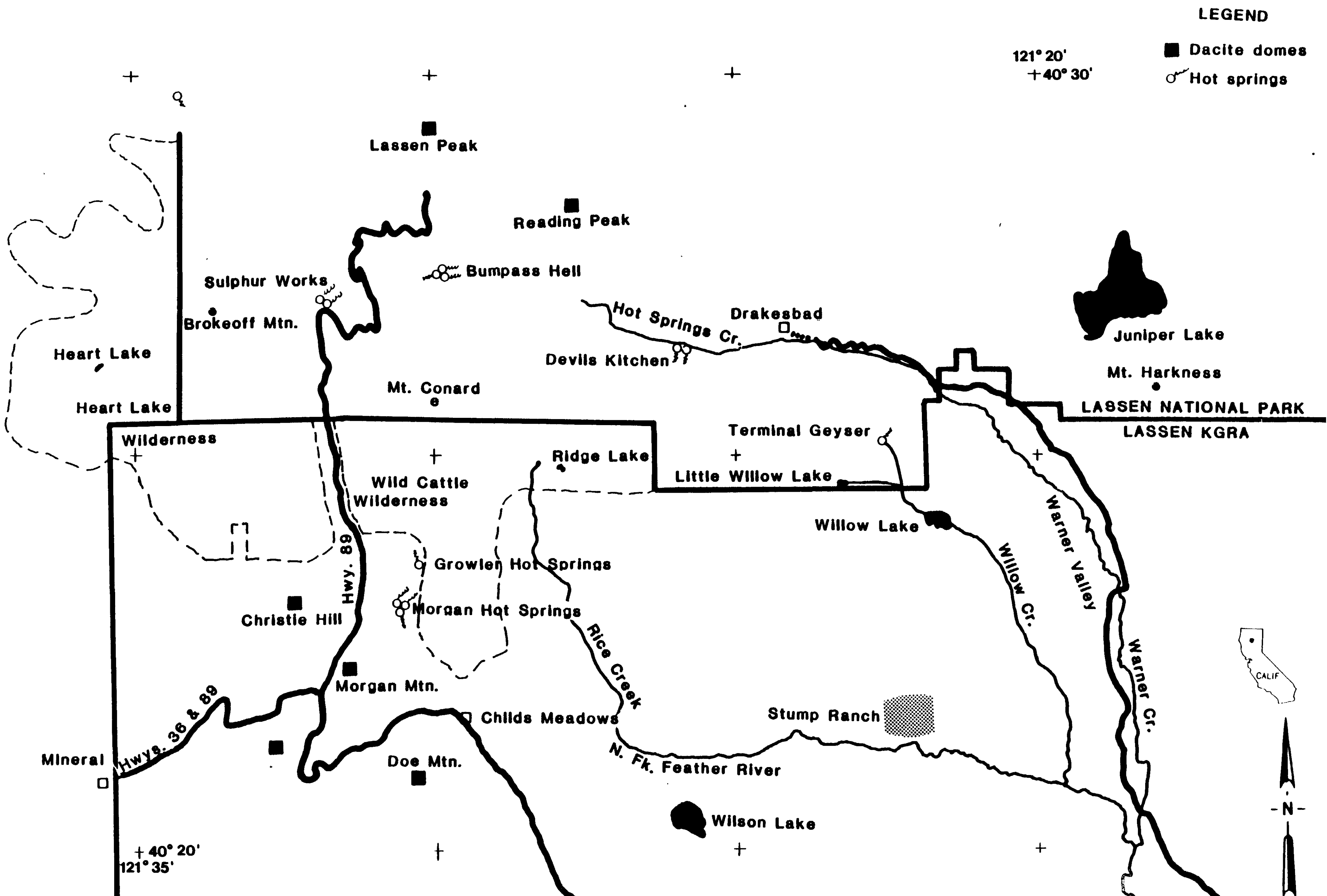


Fig. 1 · Location map showing proposed wilderness boundaries.

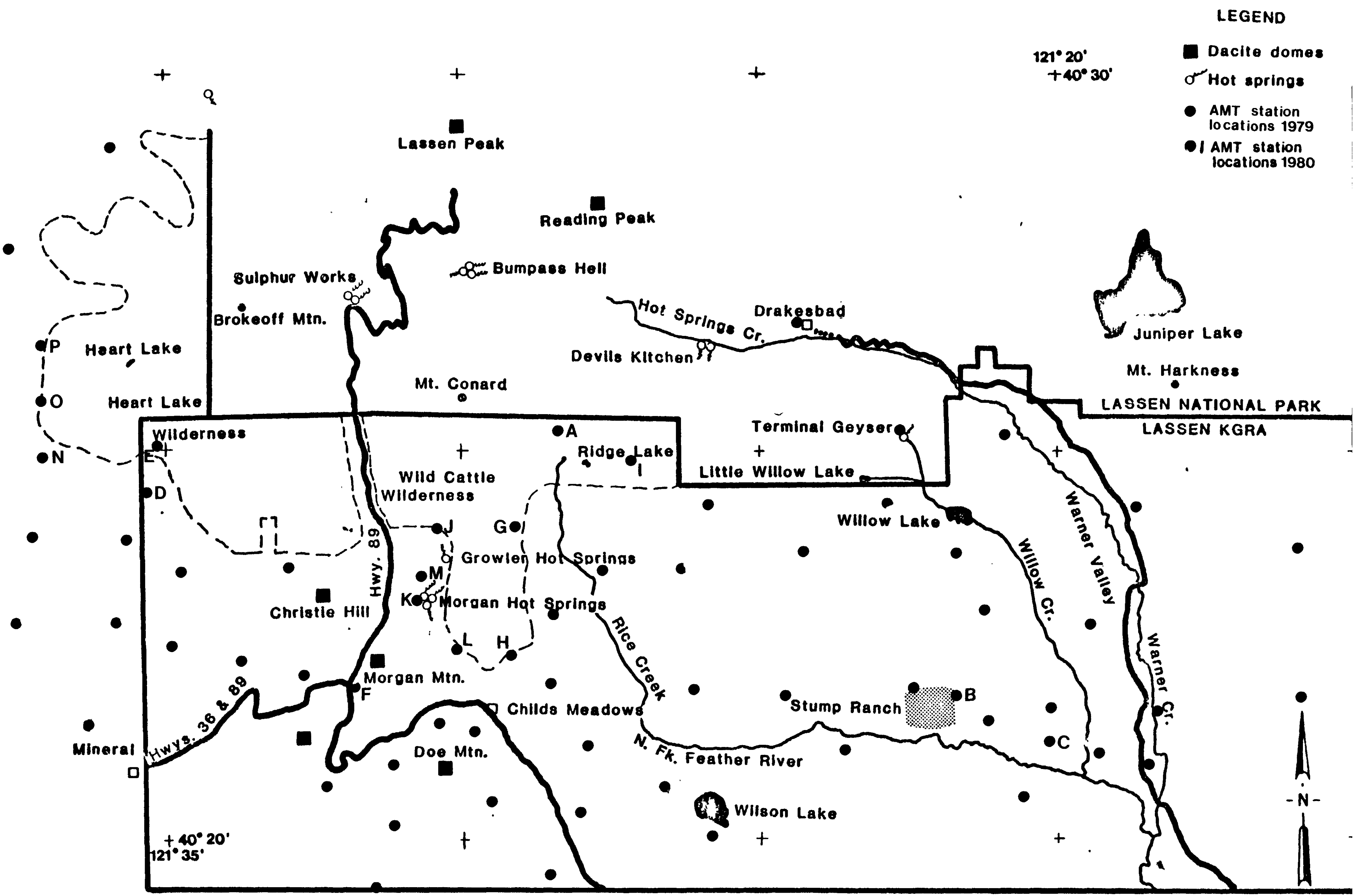


Fig. 2: Audio-magnetotelluric station location map.

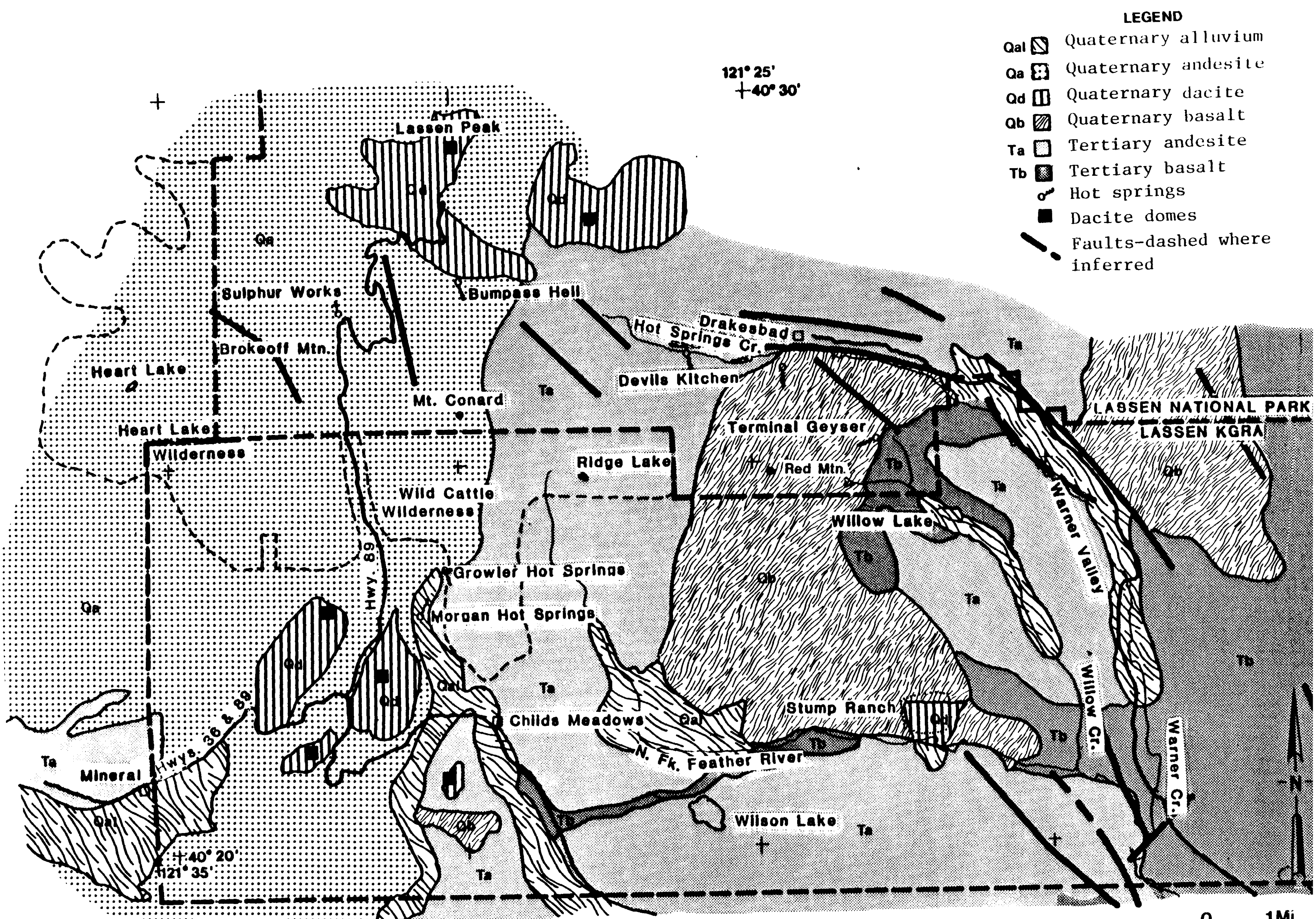


Fig. 3: Generalized geologic map, Lassen Known Geothermal Resource

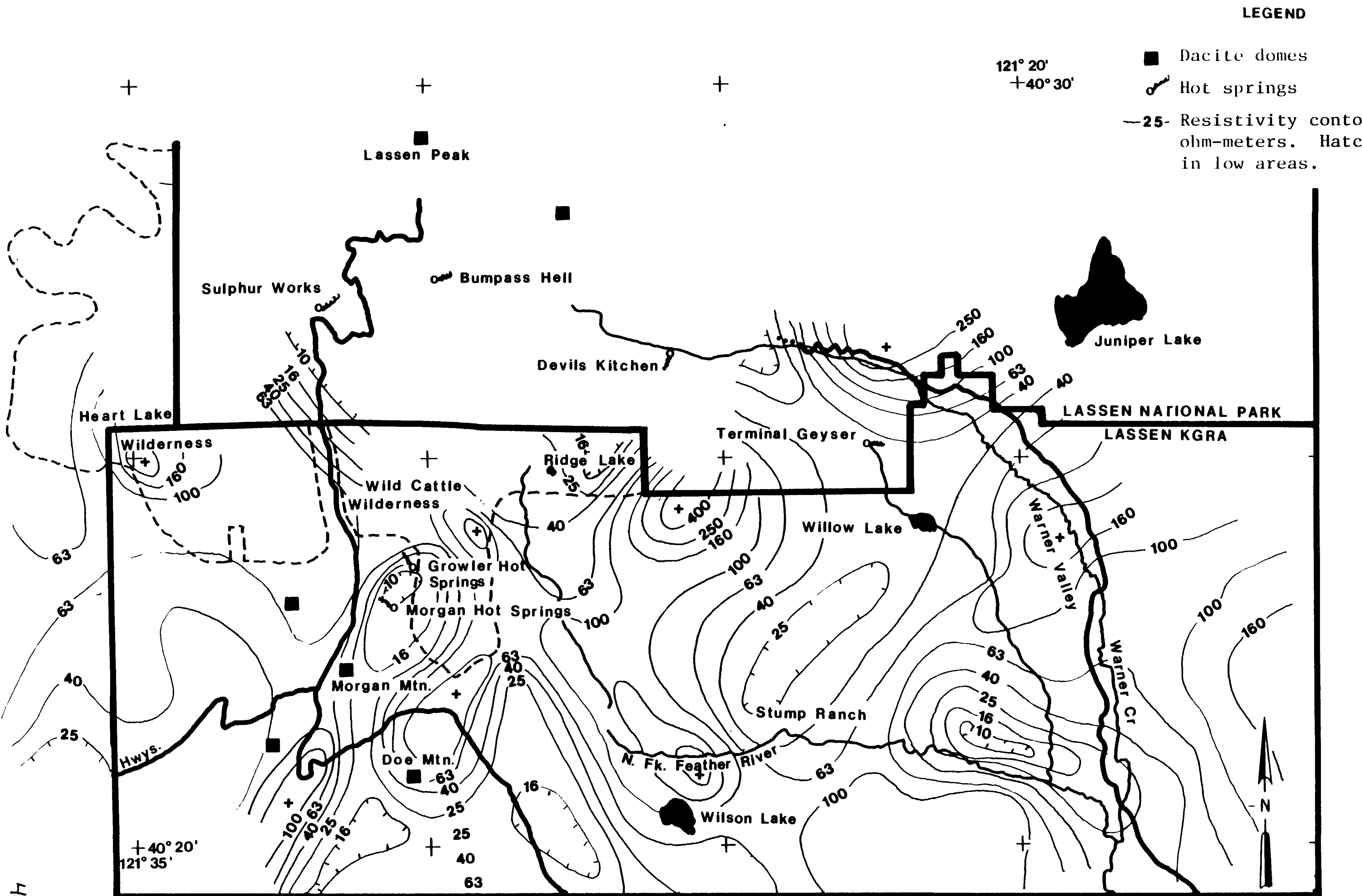


Fig. 4: Audio-magnetotelluric apparent resistivity map at 7.5 hertz,

4d

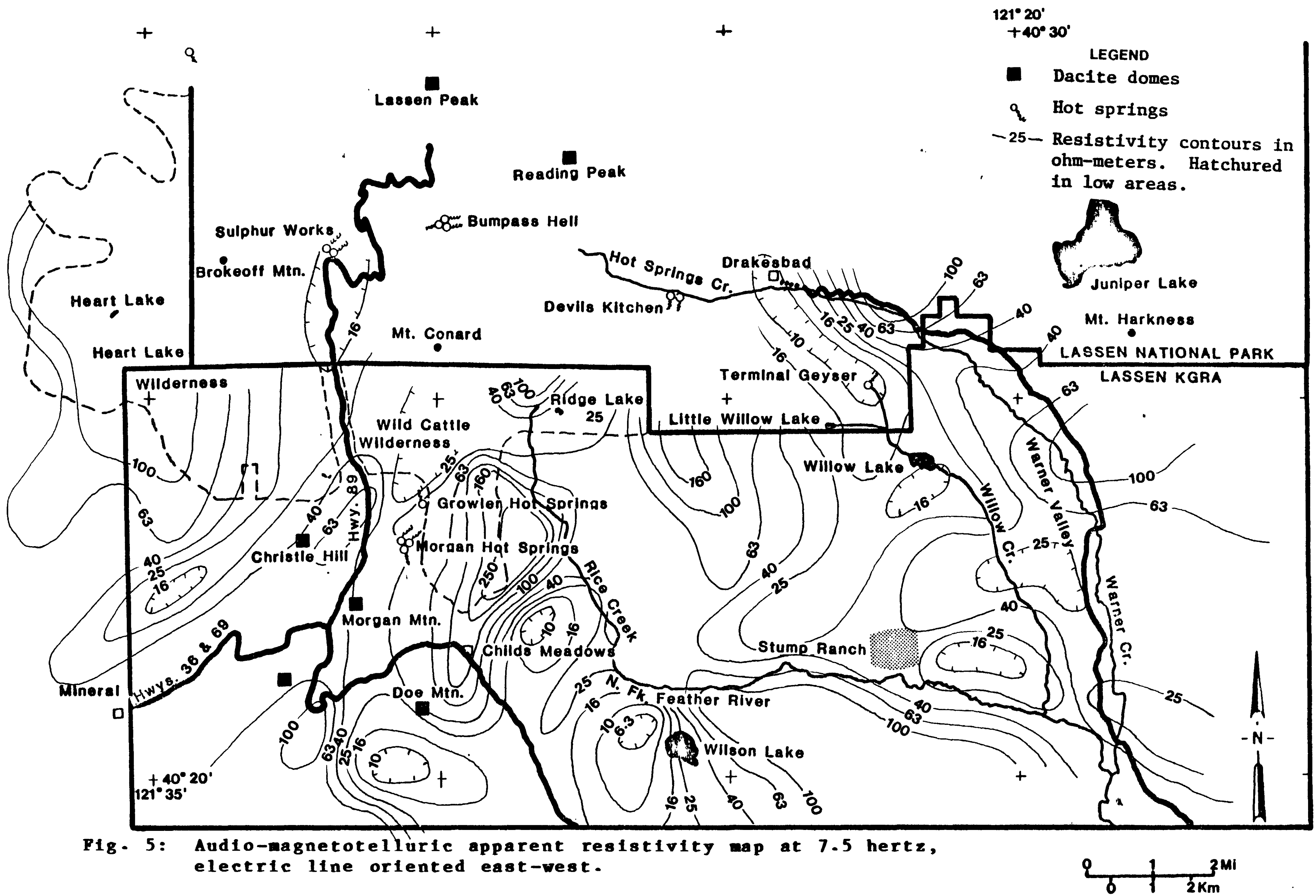


Fig. 5: Audio-magnetotelluric apparent resistivity map at 7.5 hertz, electric line oriented east-west.

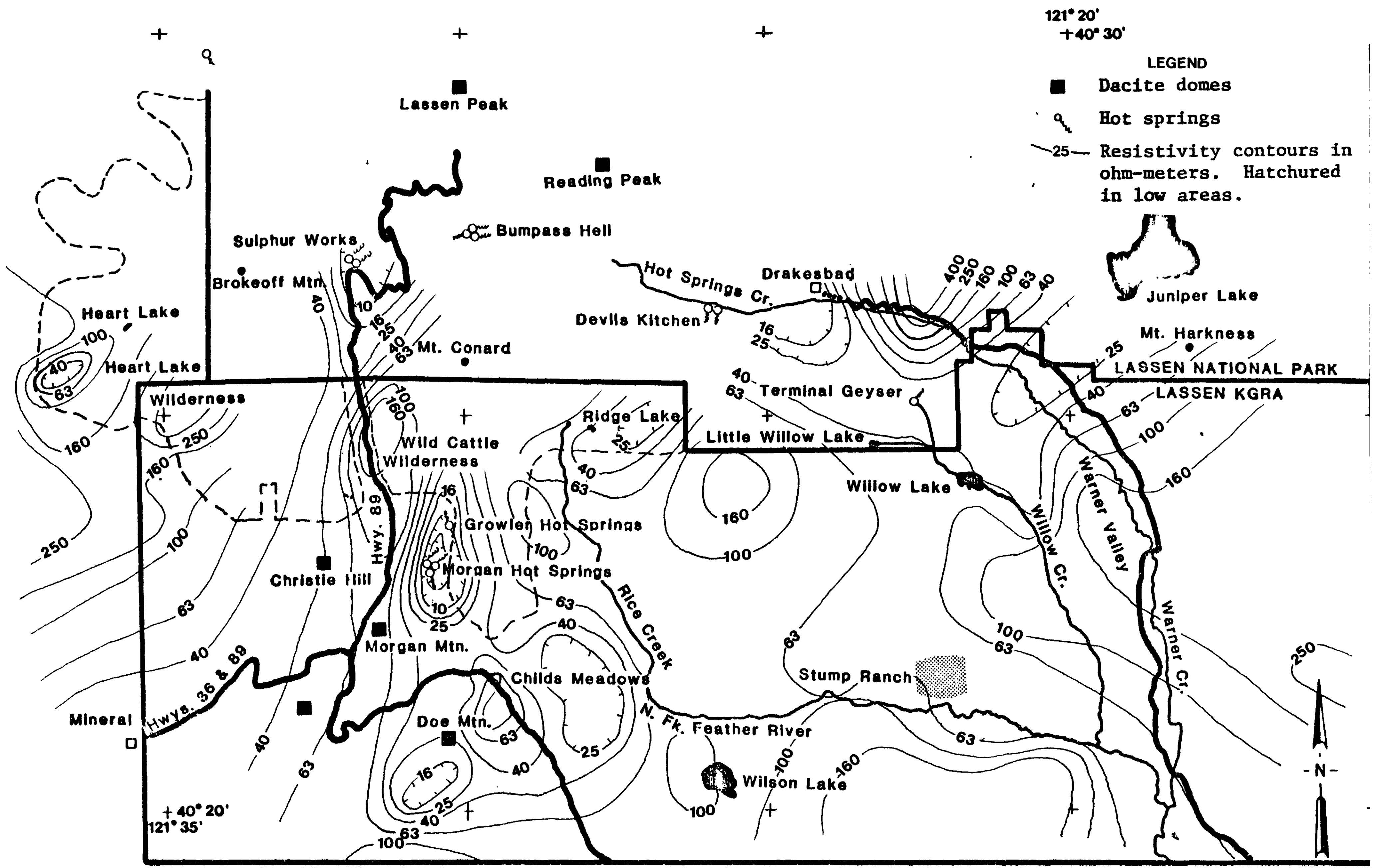


Fig. 6: Audio-magnetotelluric apparent resistivity map at 27 hertz, electric line oriented north-south.

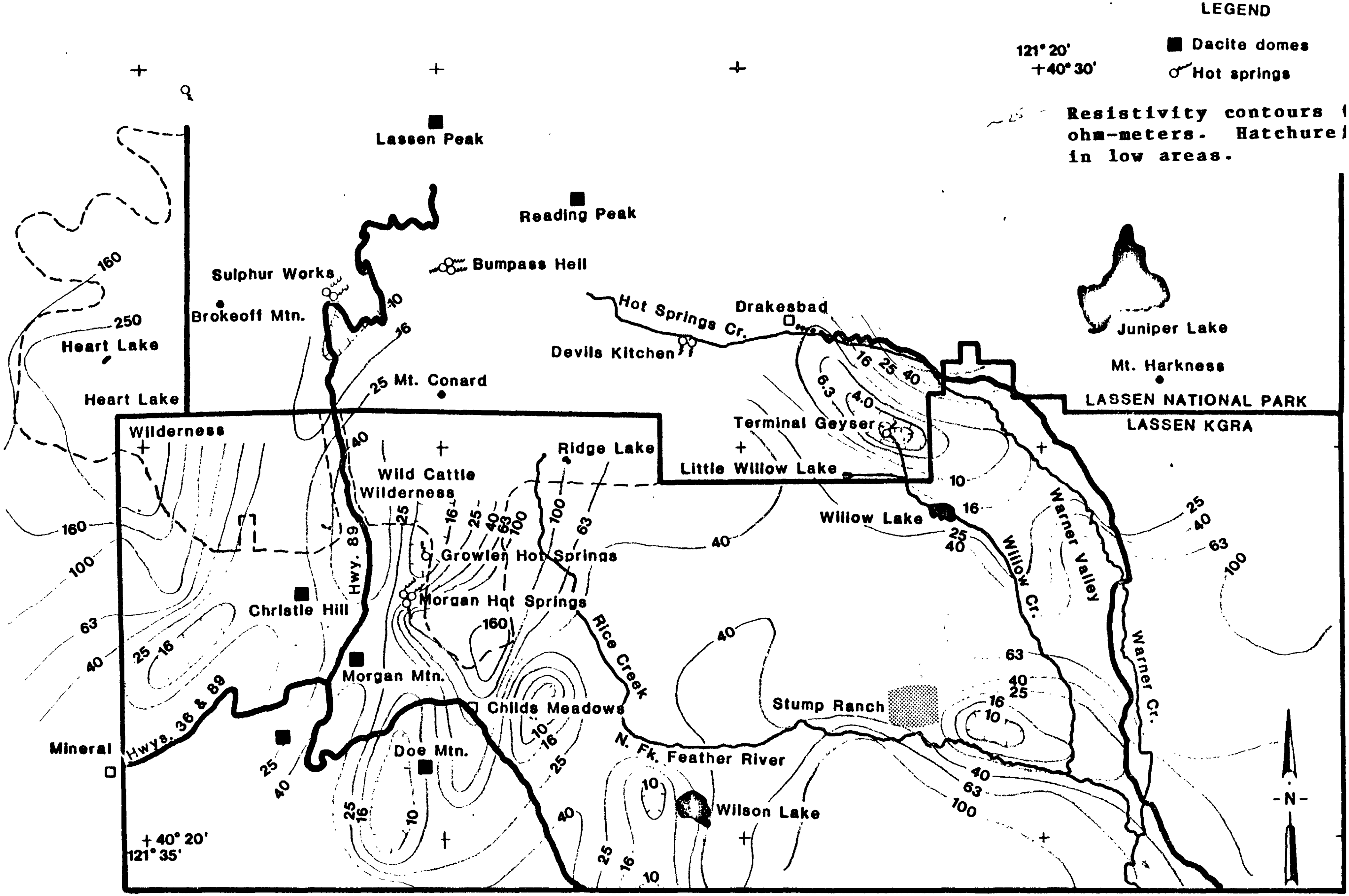
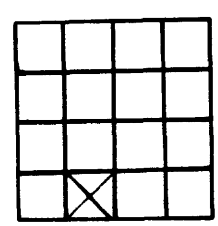


Fig. 7: Audio-magnetotelluric apparent resistivity map at 27 hertz, electric line oriented east-west.

Table I: AMT station locations

Station	Range	Township	Section location
A	5E	30N	NW NW 31
B	5E	29N	NE NE 24
C	6E	29N	SE SW 20
D	4E	29N	NW NW 6
E	4E	30N	SE NW 31
F	4E	29N	SW SW 15
G	4E	29N	NW SE 1
H	4E	29N	NE SW 13
I	5E	30N	NE SW 32
J	4E	29N	NE SW 2
K	4E	29N	NW SW 11
L	4E	29N	SW NE 14
M	4E	29N	SW NW 11
N	3E	30N	NW SE 35
O	3E	30N	SW SE 26
P	3E	30N	SW SE 23

Note: Section location gives the quarter-quarter section first, followed by the quarter section, and section number. Example - Station C would be located in section 20 as shown in this diagram.



pa = observed apparent resistivity in ohm-metres
N = number of observations
Err = standard error in ohm-metres — = no data

"NOTE" - Telluric line orientation indicated with station numbers

Table II: AMT Scalar Resistivities

Sta. No.		FREQUENCY 4.5	7.5	13.6	27	45	75	136	270	450	750	1.36K	2.7K	4.5K	7.5K	10.2K	12.5K	13.6K	18.6K	23K
A N-S	pa	25.9	29.0	17.6	75.3	—	—	—	—	144.	218.	88.3	164.	—	—	—	—	—	—	—
	N	6	8	2	6					7	7	5	6							
	Err	4.67	1.34	10.7	7.64					23.4	38.1	22.2	28.4							
A E-W	pa		227.	52.4	104.	126.	225.	344.	545.	716.	1050.	396.	506.	910.	660.	—	—	—	—	371.
	N		4	8	6	8	8	7	8	8	8	9	9	12	10					5
	Err		26.9	3.76	5.32	4.08	17.8	20.3	44.6	26.9	53.1	42.3	37.8	36.4	20.5					15.5
B N-S	pa		39.3	64.1	41.0	—	—	—	—	133.	117.	117.	139.	—	—	—	—	—	—	—
	N		7	8	9					7	9	9	7							
	Err		3.14	6.15	3.12					3.02	10.7	10.1	23.4							
B E-W	pa		205?		48.9	51.7	69.8	106.	139.	169.	314.	172.	269.	331.	365	—	—	209.	—	217.
	N		5		11	12	10	11	11	10	9	12	7	6	6			8		4
	Err		20.7		2.21	2.87	2.82	4.29	5.61	9.11	27.5	9.25	2.34	23.5	23.3			8.05		5.10
C N-S	pa		9.56	10.9	9.44	—	—	—	—	27.1	18.3	17.6	43.4	—	—	—	—	—	—	—
	N		8	9	9					7	6	5	7							
	Err		1.64	0.88	0.77					3.40	2.61	1.99	2.16							
C E-W	pa	11.9	13.0	11.7	15.2	17.3	20.6	25.0	22.1	40.5	47.9	34.4	30.2	68.1	66.3	—	—	69.2	—	44.4
	N	10	12	11	10	10	13	9	11	13	10	10	8	8	7			9		7
	Err	1.20	0.61	0.44	0.66	0.84	0.73	0.59	3.07	1.13	2.56	3.62	2.71	1.95	3.09			1.12		1.60
D N-S	pa	65.8	76.4	110.	126.	—	—	—	—	245.	174.	162.	370.	—	—	—	—	—	—	—
	N	7	10	9	11					6	4	4	7							
	Err	10.5	12.5	12.8	7.12					49.8	21.4	41.0	22.0							
D E-W	pa	41.7	147.	110.	273.	204.	441.	630.	888.	745.	906.	519.		1075.	1035.	—	—	—	—	140.
	N	6	7.	8	8	8	8	10	8	9	7	9		9	11					1
	Err	5.69	8.95	7.43	17.7	20.6	26.3	65.3	133.	87.9	75.3	84.6		74.6	65.2					—

Table II (cont'd)

pa = observed apparent resistivity in ohm-metres
N = number of observations
Err = standard error in ohm-metres —— = no data

"NOTE" - Telluric line orientation indicated with station numbers

Sta. No.		FREQUENCY 4.5	7.5	13.6	27	45	75	136	270	450	750	1.36K	2.7K	4.5K	7.5K	10.2K	12.5K	13.6K	18.6K	23K
E_{N-S}	pa	885.	257.	319.	426.	—	—	—	—	2014.	1413.	2360.	4187.	—	—	—	—	—	—	—
	N	7	8	8	10					6	8	5	6							
	Err	95.5	24.9	54.2	39.6					308.	252.	705.	370.							
E_{E-W}	pa	194.	112.	208.	289.	369.	537.	722.	880.	953.	1191.	515.	828.	1976.	1462.	—	—	1309.	—	485.
	N	5	7	9	9	9	11	11	10	9	12	9	4	14	7			8		7
	Err	25.6	16.6	23.1	41.3	8.55	44.7	37.3	65.4	45.3	80.0	48.2	69.4	51.8	155.			50.8		22.8
F_{N-S}	pa		43.2	—	74.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	N		8		4															
	Err		3.08		3.81															
F_{E-W}	pa	33.3	41.1	26.0	49.2	43.3	62.0	75.2	86.4	74.0	82.2	48.2	162.	289.	440.	—	—	238.	—	26.6
	N	7	10	10	10	12	9	10	11	7	11	9	9	10	11			9		1
	Err	2.47	3.27	1.19	3.22	2.81	4.91	5.68	6.05	3.98	15.0	8.18	18.6	22.2	30.5			4.94		—
G_{N-S}	pa	—	168.	154.	159.	—	—	—	—	172.	152.	248.	320.	—	—	—	—	—	—	—
	N		9	8	9					8	8	8	7							
	Err		19.4	5.85	14.4					10.2	13.7	17.6	30.5							
G_{E-W}	pa	—	232.	101.	98.0	89.2	90.6	159.	281.	83.8	168.	32.5	205.	286.	791.	—	—	388.	—	—
	N		5	7	10	8	9	7	10	6	7	4	4	6	10			9		
	Err		17.4	9.94	9.45	20.1	7.69	15.1	46.6	22.7	26.1	14.2	9.71	23.5	41.7			13.0		
H_{N-S}	pa	—	116.	59.1	53.7	—	—	—	—	99.7	55.9	37.1	41.9	192.	40.2	—	—	2.07	—	0.24
	N		8	10	7					9	10	9	8	10	8			9		7
	Err		9.47	4.54	6.66					13.8	2.08	2.95	3.52	16.4	5.93			0.09		0.04
H_{E-W}	pa	—	270.	71.4	207.	44.3	48.1	54.9	61.4	66.2	98.4	61.4	26.8	167.	135.	—	—	62.0	—	25.5
	N		8	8	9	8	9	11	10	8	9	9	10	5	10			10		5
	Err		32.0	3.62	29.3	2.26	0.98	2.08	1.55	1.69	5.43	2.98	2.82	22.0	13.9			3.95		0.75

Table II (cont'd)

pa = observed apparent resistivity in ohm-metres
N = number of observations
Err = standard error in ohm-metres — = no data

"NOTE" - Telluric line orientation indicated with station numbers

Sta. No.		FREQUENCY 4.5	7.5	13.6	27	45	75	136	270	450	750	1.36K	2.7K	4.5K	7.5K	10.2K	12.5K	13.6K	18.6K	23K
I_{N-S}	pa	42.9	13.9	10.7	18.8	—	—	—	—	139.	226.	129.	128.	—	—	—	—	—	—	—
	N	8	4	4	6					7	10	4	2							
	Err	5.07	2.50	0.87	2.45					17.2	22.7	15.9	14.5							
I_{E-W}	pa	44.2	18.6	19.9	46.0	40.4	49.8	93.2	101.	131.	121.	86.9	—	286.	487.			316.		152.
	N	3	4	5	10	10	8	11	9	6	6	6		6	9			9		1
	Err	10.9	2.85	2.10	4.39	3.58	3.47	5.97	16.5	11.1	12.6	7.63		26.4	27.1			9.15		—
J_{N-S}	pa	18.0	60.8?	11.5	14.0	—	—	—	—	—	—	—	—	2.31	0.1	—	—	0.12	—	0.47
	N	5	8	7	7									8	8			6		5
	Err	4.04	14.5	1.02	1.32									0.14	0.01			0.01		0.04
J_{E-W}	pa	8.69	13.5	10.5	12.9	0.87	3.50	2.34	3.10		24.7									
	N	7	5	9	9	7	4	6	1		1									
	Err	1.06	1.37	0.81	1.30	0.14	0.88	0.18	—		—									
K_{N-S}	pa	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	N																			
	Err																			
K_{E-W}	pa	—	48.9	25.3	111.	11.4	38.5	—	—	—	—	—	—	—	—	—	—	—	—	—
	N		10	11	4	7	4													
	Err		7.11	2.59	18.5	1.26	5.74													
L_{N-S}	pa	17.0	24.5	32.0	26.7	—	—	—	—	49.6	40.5	42.4	39.9	—	—	—	—	—	—	—
	N	6	11	8	11					11	10	9	10							
	Err	2.44	3.12	2.85	2.50					1.43	1.46	2.54	2.56							
L_{E-W}	pa	26.8	61.3	98.6	84.4	119.	121.	126.	91.9	86.3	262.	61.3	56.6	95.5	140.			53.4		29.0
	N	9	9	9	9	9	10	12	12	9	10	12	11	8	9			8		1
	Err	2.48	8.46	13.1	7.76	9.65	4.55	7.35	4.81	5.91	20.0	3.36	3.02	5.33	3.95			1.41		—

Table II (cont'd)

pa = observed apparent resistivity in ohm-metres
N = number of observations
Err = standard error in ohm-metres — = no data

"NOTE" - Telluric line orientation indicated with station numbers

Sta. No.		FREQUENCY 4.5	7.5	13.6	27	45	75	136	270	450	750	1.36K	2.7K	4.5K	7.5K	10.2K	12.5K	13.6K	18.6K	23K
M_{N-S}	pa	7.66	7.98	7.56	5.93	—	—	—	—	5.63	6.27	14.7	10.8	—	—	—	—	—	—	—
	N	8	8	10	10					6	8	9	8							
	Err	0.48	0.62	0.10	0.28					0.37	0.45	0.42	0.75							
M_{EW}	pa	35.0	45.4	42.7	17.6	11.7	7.41	7.03	9.02	8.88	11.4	6.27	13.4	—	1.17			4.84		12.1
	N	9	9	8	10	9	10	12	8	4	4	7	8		6			4		1
	Err	5.58	3.05	5.40	0.82	0.64	0.26	0.21	0.21	0.99	1.96	1.90	0.46		0.12			0.65		—
N_{NS}	pa	70.5	44.5	77.6	105.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	N	5	9	8	9															
	Err	16.8	5.48	12.0	33.4															
N_{EW}	pa	40.3	48.3	140.	233.	330.	588.	625.	446.	58.8	61.6	—	—	101.	304.			194.		33.9
	N	5	6	7	8	8	9	10	8	3	6			7	13			1		1
	Err	9.54	5.22	26.0	33.4	26.5	35.1	30.0	28.5	19.4	10.3			20.0	20.9			—		—
O_{NS}	pa	4.37	6.35	7.42	26.3	—	—	—	—	11.9	3.08	0.71	—	—	—	—	—	—	—	—
	N	6	9	7	9					7	7	1								
	Err	0.39	0.34	1.01	2.28					0.87	0.53	—								
O_{EW}	pa	9.04	47.5	84.8	174.	266.	386.	554.	82.5	205.	40.7	14.9	—	78.4	147.			65.6		65.0
	N	6	7	8	10	9	10	12	10	7	5	3		5	12			1		1
	Err	0.62	4.11	17.9	20.3	9.76	21.9	19.6	3.20	24.7	15.8	0.62		7.83	8.13			—		—
P_{NS}	pa	—	46.9	80.8	194.	—	—	—	—	606.	364.	91.7	—	—	—	—	—	—	—	—
	N		10	9	9					9	10	8								
	Err		2.76	6.95	17.8					44.8	8.60	6.83								
P_{EW}	pa	148.	117.	74.7	271.	428.	417.	705.	462.	421.	248.	66.5	235.	211.	545.			413.		333.
	N	6	8	9	9	9	9	7	7	6	8	8	4	8	9			4		1
	Err	29.6	11.0	6.04	18.3	33.0	56.3	81.1	87.8	129.	60.9	9.95	25.1	38.8	48.8			14.1		—

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