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GEOTHERMAL POTENTIAL
OF THE
SULPHUR CANYON AREA
SODA SPRINGS, IDAHO

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SUMMARY

1. The Soda Springs area is geologically, geophysically and geochemically favorable for the existence of a geothermal resource.
2. Thermal phenomena, a heat source, porous and permeable reservoir rocks, adequate recharge, and microseismically active fault conduits have been noted.
3. Thermex has leased approximately 8,862 acres of fee land and has applied for noncompetitive geothermal leases on about 6,684 acres of Federal land. The aggregate 15,546 acres cover the most prospective region and could support economically viable geothermal development.
4. The power demand in the area now exceeds the available service capacity and is on an "interruptible" basis with the supplier, Utah Power and Light. The growing phosphate industry will require supplementary power in the near future and would welcome a supply of geothermally generated electricity.
5. The State of Idaho has a positive attitude toward geothermal development and has had experience writing rules and regulations that are consistent with such development by private industry.

ADDENDUM

LAND STATUS

Thermex's land position has been augmented by 8,110 acres as shown on Plate V. Additionally, we are in the process of leasing 9,534 more acres that will fill in a northwest trending zone that is approximately 3.2 km (2 miles) wide and 19 km (12 miles) long. Thus, Thermex now has under lease and/or application for lease 25,754 acres and will shortly have a total of approximately 33,190 acres.

The 17,644 acres being added overlie a very prominent aeromagnetic anomaly that may signify the presence of a major fault conduit, originating near China Hat, that could "feed" the Sulphur Canyon area.

Of the additional 17,644 acres, only 400 are Federal applications and only 280 are Idaho State applications.

LAND STATUS SUMMARY

	Fee	Federal (Pending)	State (Pending)
October 29, 1976	16,972	6,683.97	
Ultimate	25,826	7,083.97	280

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GEOTHERMAL POTENTIAL OF THE SULPHUR CANYON AREA
NEAR SODA SPRING, IDAHO

INTRODUCTION

Thermex has studied the geothermal potential of southeast Idaho ever since 1972. Though Thermex acquired land positions as a result of these studies, other companies created sufficient evidence of competitive interest in the region so that KGRA's were eventually delineated in several interest areas including Grandview, Raft River, Indian Hot Springs, Preston and Island Park. (Figure 1) Following the acquisition of land positions at Grays Lake, Idaho and Afton, Wyoming, Thermex directed exploration efforts into the Soda Springs region in September 1975. Passive microearthquake monitoring was conducted in several locations within a radius of approximately 29 km (18 miles) the town of Soda Springs and ultimately a strong fee lease position was taken at and north of the mouth of Sulphur Canyon 6.4 km (4 miles) east of Soda Spring. (Figure 2)

Geologic mapping, structural analysis of LANDSAT imagery, and hydrochemical analyses of surface and spring waters were undertaken concurrently with the microearthquake studies. The data from these surveys synthesized with data available from published sources constitutes the basis upon which Thermex leased fee lands and made application for Federal lands in the Soda Springs Area.

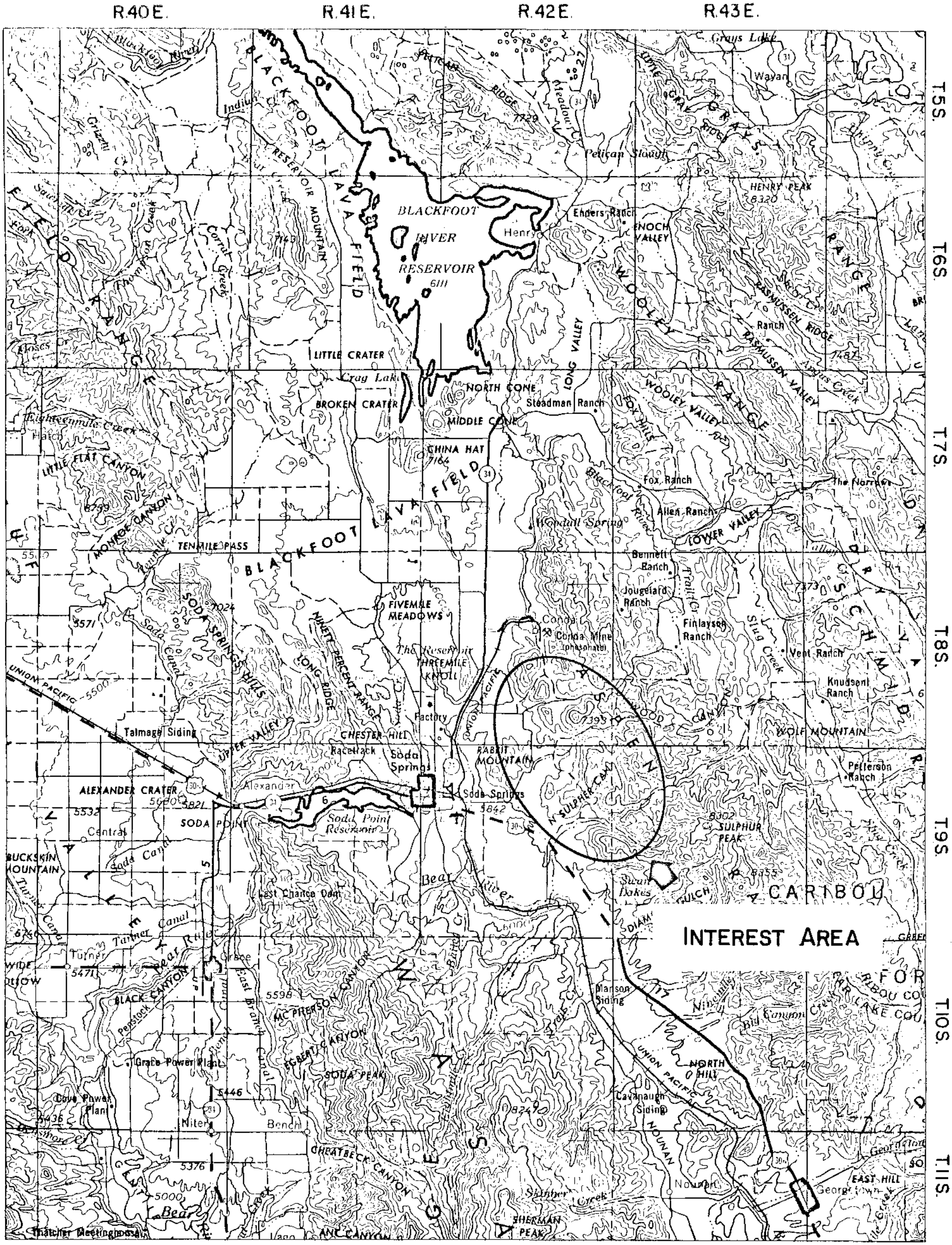
Presented in this report are the data and geothermal interpretations made therefrom.

Appended is a brief report on the seismicity of the region by Microgeophysics Inc.

Attached are Plates depicting the microseismicity, the geology, and the Thermex land position in the interest area.

REGIONAL INDEX MAP

Fig. 1



INDEX MAP - SODA SPRINGS

Fig. 2

LOCATION AND ACCESS

The Soda Springs geothermal prospect is within Townships 8 and 9 South, Ranges 42 and 43 East, Boise Principal Meridian. The area is in Caribou County, Idaho approximately 72 km (45 miles) north of the Utah-Idaho border and 40 km (25 miles) west of the Wyoming-Idaho border. (Figure 1,2)

Access to the region is excellent at all times of the year, from the north, via Idaho Route 34, from the south via U.S. Highway 30 N and from the west via both routes U.S. 30 N and Idaho 34. The mountainous parts of the prospect are accessible on fair to poorly maintained dirt and gravel roads some of which are passable by sedan and some of which can be traversed only by 4-wheel drive vehicles. Winter access to the mountains is limited due to deep snow.

GEOGRAPHY

The interest area lies along the western base of the Aspen Range, which bounds the Bear River Valley, south of Soda Springs, on the east. Relief between the valley and the mountain tops averages 760 meters (2500 feet). The peak elevations in the Bear River Valley are approximately 1770 meters (5800 feet) and at Sulphur Peak about 2530 meters (8300 feet) above M.S.L.

The regional climate is quite variable with summer temperature maxima of $43^{o}C$ ($109^{o}F$) and winter lows to $-40^{o}C$ ($-40^{o}F$). The valley climate is semi arid and supports a short (100 day) growing season. Precipitation averages 48 cm (19 inches) annually. In excess of 115 cm (45 inches) of precipitation, chiefly snow, falls on the mountains where access and work can be inhibited from November through late May.

The valleys adjacent to the prospect are used for farming, ranching, recreation, and mineral processing. The mountains in the region lie within the Caribou National Forest and are utilized for recreation, the lumber industry, and for mining of phosphates. The mining and some small farms and ranches are on enclaves of fee land inside the forest boundaries.

Soda Springs, the county seat of Caribou County, Idaho, has a population of approximately 3000, most of whom provide services to the ranching and mining industries. The town and surrounding region are within the electric power province of Utah Power and Light Company whose several transmission lines transect the area as part of the Bonneville Power Association network.

At present approximately 51.5 megawatts is available to users in the region, generally on a low priority, interruptible basis. The power demand in Southeast Idaho led by the growing phosphate industry exceeds that currently available and is expected to increase in the immediate future.

GEOLOGY

Regional Setting

The Soda Springs interest area is near the divide between the Columbia River drainage to the north and the Basin and Range region of internal drainage to the southwest. These drainages, within the Snake River Geologic Province and the Basin and Range geologic provinces respectively, are just to the east of the "Overthrust Belt" characterized by severe tectonic deformation. As might be expected in such a situation, the area contains geologic conditions typical of those found in each of the surrounding provinces. There are Quaternary Snake River type basalts, miogeosynclinal sediments folded and faulted to varying degrees, and imbricately thrust faulted Paleozoic through Mesozoic sediments.

LOCAL STRATIGRAPHY

Rocks exposed in the immediate vicinity of the geothermal target area include limestones, sandstones, siltstones and siliceous, phosphatic shales of Mississippian through lower Triassic age. In areas just to the north, and west are Quaternary age basalts, rhyolites, and tufa deposits together with Tertiary continental deposits.

The sediments in and near the heart of the interest areas have been mapped by Gulbrandsen et al (1956). The following descriptions, from oldest to youngest, are synthesized from their publication. The hydrologic inferences are those of this author.

Mississippian: Brazer Limestone - Massive gray limestone containing some gray and brown sandstone in the lower parts. At least 300 meters (1000 feet) thick. Probably a good aquifer for reservoir purposes.

Pennsylvanian: Wells Formation - About 600 meters (2000 feet) of interbedded brown and gray sandstones and distinctive gray, fossiliferous limestone. Locally containing blue and black chert lenses. Capable of being a geothermal reservoir rock with abundant intergranular porosity and permeability.

Permian: Phosphoria Formation - 90-150 meters (300-500 feet) of medium gray to black, unexposed phosphatic shale and ledge forming chert. This unit would be an aquiclude and might act as a sealing unit above older geothermal reservoir rocks.

Triassic: Dinwoody Formation - Thick bedded gray limestone interbedded with olive gray siltstone in the upper 245-365 meters (800-1200 feet); yellow to olive gray interbedded siltstone, thin limestone and black shale in the lower 300-425 meters (1000-1400 feet). A moderate to poor choice for a geothermal reservoir rock.

Thaynes Formation - Mainly calcarious siltstones intercalated with thin limestone streaks. More than 915 meters (3000 feet) thick. This unit is producing gas from subcrops in the southern part of the Overthrust Belt so it may be porous enough to constitute a geothermal reservoir. Whether or not it is may depend on depth of burial.

Armstrong (1969) has mapped the Soda Springs 15' quadrangle and he described the Tertiary and Quaternary rocks adjacent to the primary interest area as follows:

Tertiary (Pliocene): Salt Lake Formation - Sandstones, conglomerates and lacustrine limestones, all of which may be variable tuffaceous, intercalated with beds of rhyolitic ash and tuff. This is a widespread continental deposit that produces variable quantities of water from shallow depths for domestic and stock use.

Quaternary (Recent): Calcarious tufa and travertine - Extensive, moundlike to elongate deposits formed by effusions of CO_2 rich spring waters originating along valley bounding fault zones. These deposits are so extensive along a trend extending from Bear Lake 70 km (45 miles) to the south to and beyond

Blackfoot Reservoir north of Soda Springs that one can postulate the existence of a major, Yellowstone-like environment in the region in the not-to-distant past.

<u>Quaternary</u> (Recent): Rhyolitic lavas and pumice at China Hat and at Middle Cone 19 km (12 miles) north of the prospect site have been age dated at 0.04, 0.08, and 0.1 million years (Armstrong 1975). These rocks are evidence for the existence of a contemporary, acidic heat source very near by.

GEOLOGIC STRUCTURE

Mansfield (1927) was the first to produce detailed geologic and structural maps of the interest area. His most important interpretation was for the existence of several major thrust faults, exposures of which were reported throughout the Overthrust Belt.

More recent work (Cressman et al, 1955; Gulbrandsen, 1956; Armstrong, 1969) has led to the conclusion that the thrust faulting is not nearly as extensive as previously thought. Most of the stratigraphic disruption can be explained by normal faulting or even by more careful detailed field mapping than was accomplished by Mansfield during his regional study of mineral resources.

The geologic structure in the interest area is characterized by broad folds that are crazed by normal faults (and a few minor reverse faults) whose strike is typically parallel and subparallel to the axial trends of the major folds.

Some slightly curvilinear faults and some faults orthogonal to the predominant trends exist, and these appear to be the youngest deformities.

It is likely that thrust faulting from west to east, of older over younger rocks, was the earliest structural deformational event. This probably occurred during and after development of broad folds in the Paleozoic and Mesozoic rocks and was caused by compressional plate tectonic forces in effect at the time.

When the Basin and Range region begin to undergo tensional stresses in the late Mesozoic and early Tertiary, normal faults fractured both the folded sediments and the older thrust planes. These normal faults were numerous and created the basis for much of the contemporary topography. They also constitute an extensive "plumbing" network for transportation of thermal waters to the surface.

Finally, perhaps in conjunction with tensional stresses related to development of the Snake River downwarp in the Late Tertiary, normal faults developed, nominally parallel to the downwarp. These are the youngest faults in the area and cut across the regional trend commonly offsetting the older faults with left lateral movement.

The western front of the Aspen Range is determined by erosion along a series of subparallel normal faults that strike about N30W. These faults transect the sulfur bearing, H_2S, SO_2 and CO_2 rich areas at the Dewey and Idaho Sulfur mines and can probably be traced northwestward on the same strike directly to the vicinity of and China Hat Middle Cone. LANDSAT imagery shows this trend to be persistent throughout the region.

The faults referred to above constitute the eastern boundary of the "Bear River Valley Graben" of Armstrong (1969) which is one of a series of alternating horsts (mountains) and grabens (valleys) west of the Aspen range.

HYDROLOGY

Groundwaters in the Soda Springs region have been studied by numerous workers including Stearns (no date, unpublished USGS manuscript), Mansfield (1927) and Bright (1963). Because a complete discussion is beyond the scope of this report, only geothermally significant aspects will be summarized.

The aquifers that have been studied are those that yield significant quantities of water to wells drilled for irrigation, domestic stock and industrial purposes. These aquifers are the Quaternary basalt flows, the Tertiary Salt Lake formation and the Recent alluvial materials. Pre-Tertiary bedrock yields water to the regimen through numerous springs, but is not a primary source of appropriated waters.

The hydrolic system in the region is a "gaining" one and is recharged via precipitation, snow melt and downward percolation of spring and irrigation waters. Groundwater that enters the interest area from the north originates in the Blackfoot Reservoir (Snake River Drainage) from which it flows down a 150 meters (500 feet) differential gradient along fractures, cinder beds and interflow contacts in the olivene basalts. Waters to the south and west originate in the north flowing Bear River drainage saturating the Tertiary Salt Lake formation and younger alluvial materials.

The Recent alluvium is 0-30 meters (0-100 feet) thick and yields 25-500 gpm to domestic and stock wells. The basalt which may be over 330 meters (1000 feet) thick, is a major aquifer and yields 500-3500 gpm to domestic, stock, irrigation and industrial wells. The Salt Lake formation is a highly unpredictable aquifer 0-200 meters (0-600 feet) thick that yields 0-1500 gpm to domestic and stock wells.

Bedrock permeability is largely within fractures and joints. Solution cavities in limestones give rise to numerous springs.

HYDROCHEMISTRY

The predominant groundwater types in the prospect vicinity are magnesium bicarbonate, calcium magnesium bicarbonate, calcium sulfate, and magnesium bicarbonate sulfate. Dissolved solids content ranges from 422 to 998 mg/l and the water temperature averages 12.2°C (54°F). Table 1, below, presents data gathered by IEC in the vicinity of Soda Springs.

TABLE 1

SELECTED GEOCHEMICAL DATA - SODA SPRINGS VICINITY

	pH	SiO_2	SO_4	Ca	Mg	Tot. Hrdns	Na	K	F
Supper Club.	7.2	85	> 400	50	20.3	180	3.8	1.4	1.4
Town Geyser	7.4	80	∿ 300	35	14.5	130	3	.25	1.2
Hooper Spr.	7.0	110	60	58	8.7	50	9	.5	1
Id. Sulphur Mine	1.3	90	> 400	10,000	8.7	70	1000	2.1	.68
N. Side, Sulphur (Canyon)	7.5	45	43	18	11.6	60	.8	.15	1
S. Side, Sulphur (Canyon)	7.9	40	< 20	18	8.7	50	.8	.1	1
Sulphur Can. Mine (S. Side)	6.6	60	> 400	26	8.7	70	5.5	1.4	1
Formation Cave	7.2	-	< 20	12	5.8	50	-	-	-

Thermal waters have been reported and/or measured from Corral Creek, northwest of the interest area (38°C), on the east side of Fivemile Meadows (18-21°C), from wells southeast of Sulphur Canyon (18°C) and at the town geyser (27°C). It is believed that thermal waters in this area are much diluted by throughflows of cold meteoric and irrigation waters causing all geochemical and geothermometry to be highly suspect.

One unusual and geothermally significant groundwater characteristic is the great quantity of CO_2 emitted from many of the springs. Locally the CO_2 is mixed with H_2S and/or SO_2 and can be under considerable pressure. Geysers exist where drill holes have penetrated gasseous formations at Corral Creek and at the Soda Springs town well. Additionally, gas lifted artesian flow exists at Sulphur Canyon and was encountered in a well drilled southwest of Sulphur Canyon.

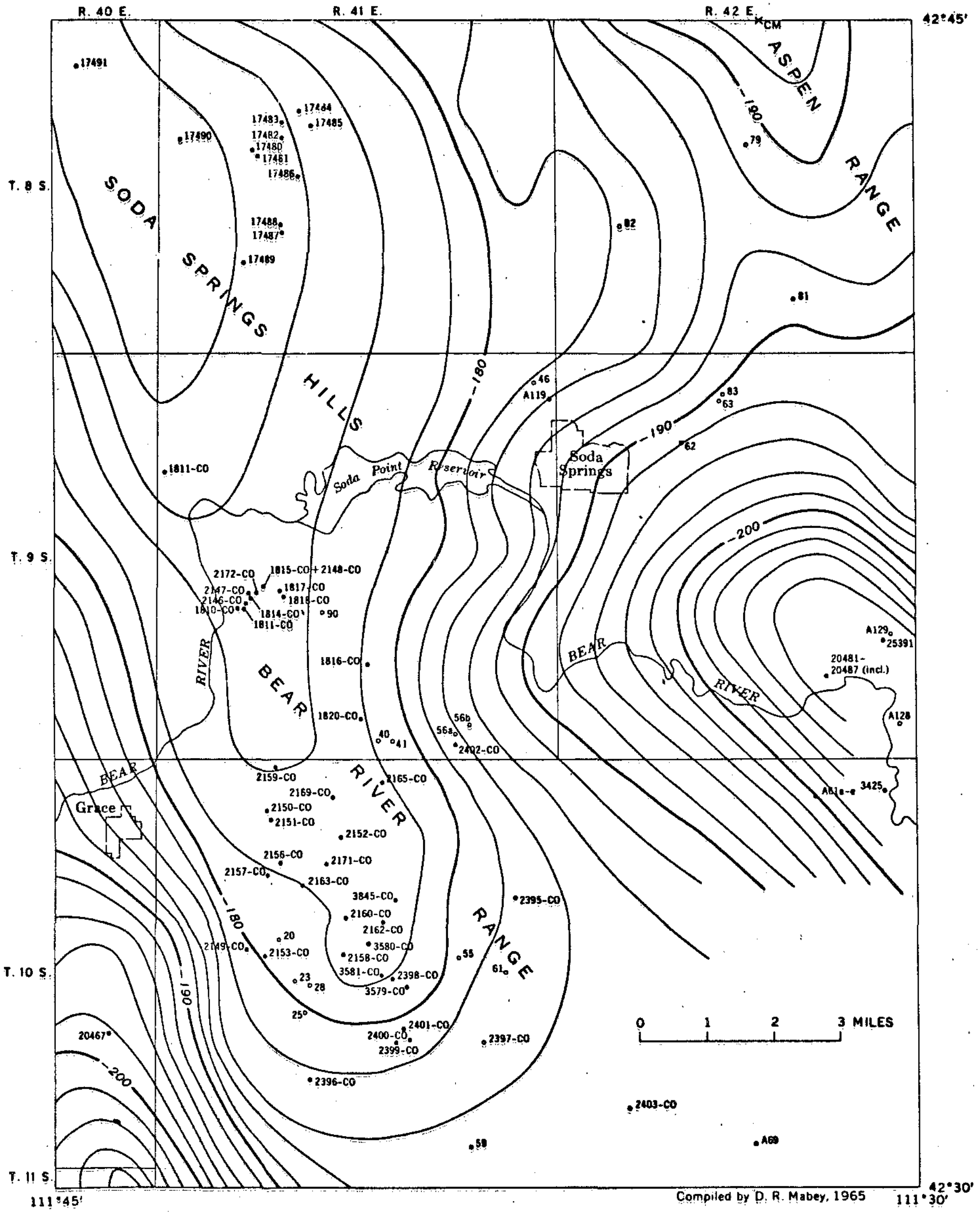
CO_2 can be liberated by 1) the action of acid with carbonate rocks, 2) the application of heat to CO_2 rich waters or 3) via direct magmatic emanations. Present interpretations incorporate a combination of all three mechanisms at work. The waters are enriched in CO_2 by the action of acid (H_2SO_4 or H_3PO_5) on carbonate bedrocks. Then heat transported either convectively by open faults leading to great depths or by conduction from shallow intrusives liberates CO_2 from the charged waters. It is possible that direct emanations from a shallow buried intrusive could be causing the intense solfataric alteration present at the Idaho and Dewey Sulphur mines.

GEOPHYSICAL INVESTIGATIONS

Aeromagnetics - Mitchel et al (1965) have studied the regional aeromagnetics. Analysis of their map (Plate IV) indicates a very pronounced magnetic low zone trending approximately N30W from Sulphur Canyon across Fivemile Meadows past the southwest flanks of China Hat and Broken Crater into Corral Creek. This low zone may reflect destruction of magnetic minerals by thermally related alteration acting along a major fault system. The low trend is bounded by magnetic highs of the type that one would expect over volcanic terrain and it stands out in its persistent contrast to the background signatures.

Gravity - Mabey and Oriel (1965) have conducted gravity analyses of the region. The Bouger anomaly map (Figure 3) indicates the existence of a deep 1525 meter (5000 feet) structural depression within the Bear River Valley south of Soda Springs. The map is not detailed enough to localize structural features that might be caused by individual fault zones such as the one referred to above. The geothermal significance of the gravity data is that a thick sequence of potential reservoir rock may exist above a bedrock assemblage that can itself constitute a viable geothermal reservoir.

Seismicity - The intermountain seismic belt, extending northward along the Wasatch front through the Overthrust Belt to and slightly beyond Yellowstone Park has a long history of recorded macroseismic activity. Persistent earthquake activity exists, west of Yellowstone along the Snake River and Starr Valley grabens in western



Compiled by D. R. Mabey, 1965

BOUGUER ANOMALY MAP OF SODA SPRINGS QUADRANGLE

Wyoming, in the vicinity of Grays Lake, Idaho and along the west side of the Bear River Valley graben near Soda Springs and Montpelier.

Thermex has conducted field surveys of the microseismicity in several of these areas and undertook such studies near Soda Springs for 25 days between August 22 and September 19, 1975. During this period ten sites were occupied, in groups of three at a time, utilizing Sprengnether MEQ-800 portable seismographs. In order to maintain continuity, one site in a three-component array was held constant while the other two sites were changed.

More than sixty (60) events were recorded during the observation period and of these, thirty-three (33) were close enough laterally or shallow enough to have s-p times under 3.0 seconds. Plate I, attached, depicts the epicenters of these events. The shallow events are those clustered spacially beneath the Aspen Range, while the deeper events lie west of the National Forest boundary. This would be the expected result of movement on a west dipping range front fault or on a zone of stress relief east of and parallel to the range front fault. Microgeophysics Inc. of Golden, Colorado was contracted to analyze the Thermex field data as a double check. As can be seen in their appended report, MGI arrived at essentially the same conclusions as did Thermex.

In light of our interpretations of the aeromagnetic and surface geologic expressions of the local geologic structure, we believe that the microseismicity beneath the Aspen Range may be due to strain on range front faults caused by the proximity of an upward stopping intrusive or by a combination of regional tectonic forces coupled with thermal stresses created by local magmatic intrusions.

Inasmuch as geothermal resources throughout the world. almost without exception, are associated with anomalous microearthquake activity clustered both spacially and temporarily, the intense microseismicity recorded just northeast of Sulphur Canyon is considered to be of great geothermal significance.

THERMAL PHENOMENA

The most spectacular thermal phenomenon in the interest area is the intense solfataric alteration present within and both north and south of Sulphur Canyon for a distance in excess of 14 km (9 miles). The heart of this linear zone is north of Sulphur Canyon at the Idaho Sulphur Mine were 40+ acres are totally altered, at the Dewey Sulphur Mine on the north side of Sulphur Canyon where an estimated five acres are intensely altered and at an unnamed area on the south side of Sulphur Canyon where ~10 acres are affected. The solfataric alteration in these areas is virtually complete with total acidization of limestone, replacement of acid created solution cavities with massive and crystalline sulphur and intense brecciation of altered limestones. Noxious fumes that permeate the air at these solfataras are probably CO_2, H_2S, SO_2 and possibly some HF and/or boric acid derivative. The areas are devoid of plants and animals. Smaller solfataras which exist north and south of the zone of the most intense alteration testify to past thermal activity along a large portion of the Bear River Valley graben.

Other thermal phenomena in the region include the very young Rhyolites (0.01, 0.04 and 0.10 million years) at China Hat and Middle Cone, the abundant slightly thermal (18-20°C) carbonated springs in the region and finally, the extensive tufa and travertine deposits exposed throughout the region which suggest a Yellowstone-like thermal regime in the recent past.

In addition to these overt thermal indicators one should appreciate the significance of the geothermometric indicators which, through greatly diluted by flows of fresh meteoric waters, suggest anomalous base level temperatures in the area.

LAND STATUS

Thermex has obtained leases on 8,862.33 acres of fee land and has pending applications to the U.S. government (BLM) for non-competitive geothermal leases on 6,683.97 acres within the Caribou National Forest.

These leases and applications were delineated on the basis of the microearthquake investigations, surface geologic mapping, analysis of airphotos and LANDSAT imagery and interpretation of published geophysical data.

The land position controlled by Thermex is depicted on Plate III and is believed to cover the most potential part of the Soda Springs geothermal interest area. It is considered to be adequate to insure the ability to develop an economically viable geothermal resource.

The State of Idaho has had experience formulating rules and regulations pertaining to geothermal development in connection with Federally sponsored research in the Raft River Valley. The State has a positive attitude toward geothermal development that will be helpful should a resource be discovered at Soda Springs. Though no applications for geothermal leases have been issued in the Caribou National Forest yet, the pressures upon the State, brought to bear by encroaching petroleum industry exploration in the Overthrust Belt, should prompt some geothermal leasing soon.

CONCLUSIONS

A viable geothermal resource requires the presence of a heat source, a reservoir and conduits along which thermal fluids can convect and by which reservoir recharge can be effected. All of these parameters exist in the Soda Springs prospect area.

The exposure of very young (40,000 year old) extrusive rocks of acidic (rhyolitic) composition constitutes evidence for a heat source nearby. The thick unconsolidated Tertiary sediments and permeable pre-Tertiary bedrock sequences can both be adequate reservoirs for thermal fluids and finally, the anomalous microearthquake activity indicates that fracture systems are moving and are therefore permeable.

Thermex has leased and/or applied for leases on 15,546.3 acres of fee and Federal lands that overlay the area considered to be most geothermally prospective on the basis of geologic, geophysical and geochemical data.

SELECTED REFERENCES

Armstrong, F. C., 1969, "Geologic Map of the Soda Springs Quadrangle, Southeastern Idaho": U.S. Geol. Survey Misc. Inv. Geol. Map I-557.

Armstrong, R. L., 1975, "The Geochronometry of Idaho": Isochron/West, No. 14.

Cressman, E. R., and Gulbrandsen, R. A., 1955, "Geology of the Dry Valley Quadrangle, Idaho": U.S. Geol. Survey Bull. 1015-I.

Dion, N. P., 1969, "Hydrologic Reconnaissance of the Bear River Basin in Southeastern Idaho": Idaho Department of Reclamation Water Information Bulletin 13.

Dion, N. P., 1974, "An Estimate of Leakage from Blackfoot Reservoir to Bear River Basin, Southeastern Idaho": Idaho Department of Water Administration. Water Information Bulletin 34.

Gulbrandsen, R. A., McLaughlin, K. P., Honkala, F. S., and Clabaugh, S. E., 1956, "Geology of the Johnson Creek Quadrangle, Caribou County, Idaho": U.S. Geol. Survey Bulletin 1042-A.

Mansfield, G. R., 1927, "Geography, Geology and Mineral Resources of Part of Southeastern Idaho": U.S. Geol. Survey Prof. Paper 152.

Mitchell, C. M., Knowles, F. F., and Petrafeso, F. A., 1965, "Aeromagnetic Map of the Pocatello - Soda Springs Area, Bannock and Caribou Counties, Idaho": U.S. Geol. Survey Geophysical Investigations Map GP 521.

Young, H. W., and Mitchell, J. C., 1973, "Geothermal Investigations in Idaho", Part I: Idaho Department of Water Administration Water Information Bulletin 30.

APPENDIX A

μ∫ Geophysics Corporation

SEISMICITY OF THE SODA SPRINGS AREA

EASTERN IDAHO

MICRO GEOPHYSICS CORPORATION

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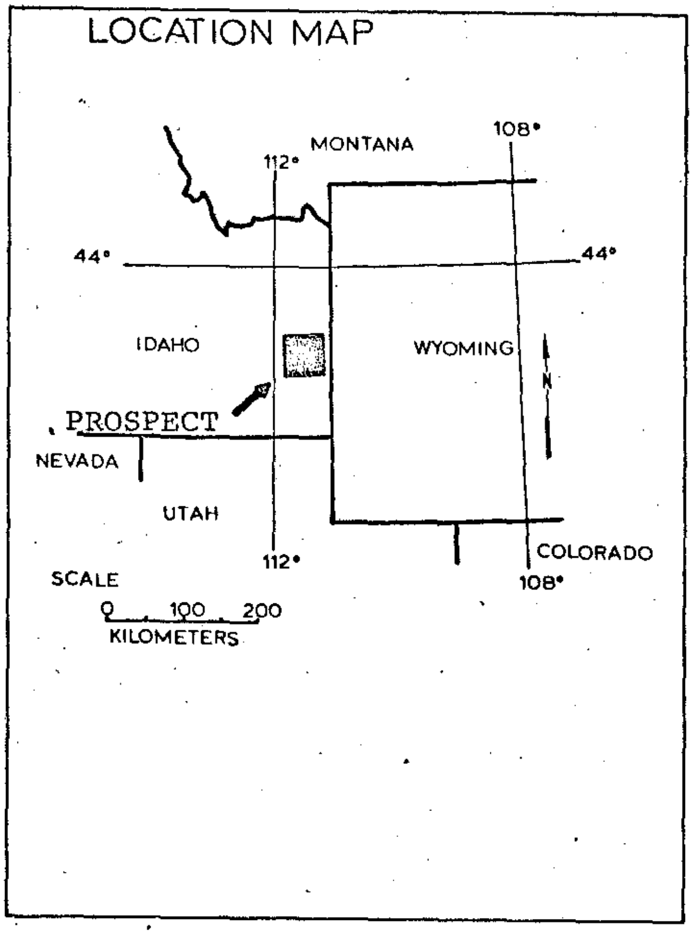
INTRODUCTION

Microgeophysics in late October, 1975 calculated hypocenters of microearthquakes that were recorded on a three station network deployed near Soda Springs in Eastern Idaho (see location map figure 1).

Figure 1



Three station networks can be used effectively as an economic tool in the search for areas of high microearthquake activity. Microearthquakes are indicative of active tectonic processes. With a heat source and a sufficient source of water in the area, the permeability and porosity associated with an active tectonic process is an attractive target for geothermal exploitation. In fact, microearthquakes can be considered an essential ingredient of a commercial geothermal occurrence.

ANALYSIS

Three station networks produce the minimum number of data needed to uniquely locate a microearthquake. The location errors of three station location methods depend on the errors of the two main location parameters. One of the main parameters is the model velocity and the second is the body wave velocity ratio. Typical errors in these values produce locations errors of ± 3 - 5 km in plan, and the calculated depth of the microearthquakes is totally up to the model used for location and is normally very poorly controlled. These values increase rapidly as distance from the array increases with ± 5 - 10 km errors at distances of greater than 5 aperatures.

Since even very high quality three station data will produce location errors of 3 - 5 km, then special consideration should be paid to insuring that only the best quality is used in location estimates.

The following results include location of microearthquakes where first arrivals could be picked with a precision of ± .030 sec and whose origin times could be calculated to ± 0.25 sec. Since location error is a severe function of distance from the array, only microearthquakes with S - P times of 3.0 sec and less were used in the analysis. With assumed velocity of 4.5 km/sec in a half space and a 1.74 velocity ratio, a S - P time of 3.0 sec would correspond to a distance of 18 km.

RESULTS

Thirty-three microearthquakes of the approximately sixty events analyzed were of high enough quality to locate. The station and epicenter locations are shown on Plate 1. The coordinates of the stations and epicenters are listed in Table 1 and Table 2 respectively.

Plate 1 shows that the epicenters can be separated into three groups (A, B, C). Group A is northwest of the origin, Group B is northeast of the origin and Group C is southeast of the origin. Each epicenter within each group is shown with a ± 3 km error bar. These are the expected error limits for each event.

The most significant group with respect to activity and concentration in space is Group B. Area B is twice as active and twice as arealy concentrated than either of the other areas.

CONCLUSIONS

1. Three areas of interest are indicated by the three station reconnaisance survey near Soda Springs, Idaho.
2. Area B is approximately three times more active and arealy concentrated than areas A and C (see Plate 1).
3. Detailed spacial relationships of the microearthquake activity could only be made from data collected from a multi component seismic network.

RECOMMENDATIONS

1. A phased geothermal exploration and exploitation program is indicated for this area.
2. A detailed microearthquake survey would provide invaluable information with respect to use and expected returns for other geophysical methods and be an invaluable guide in setting priorities in land acquisition.

Table 1

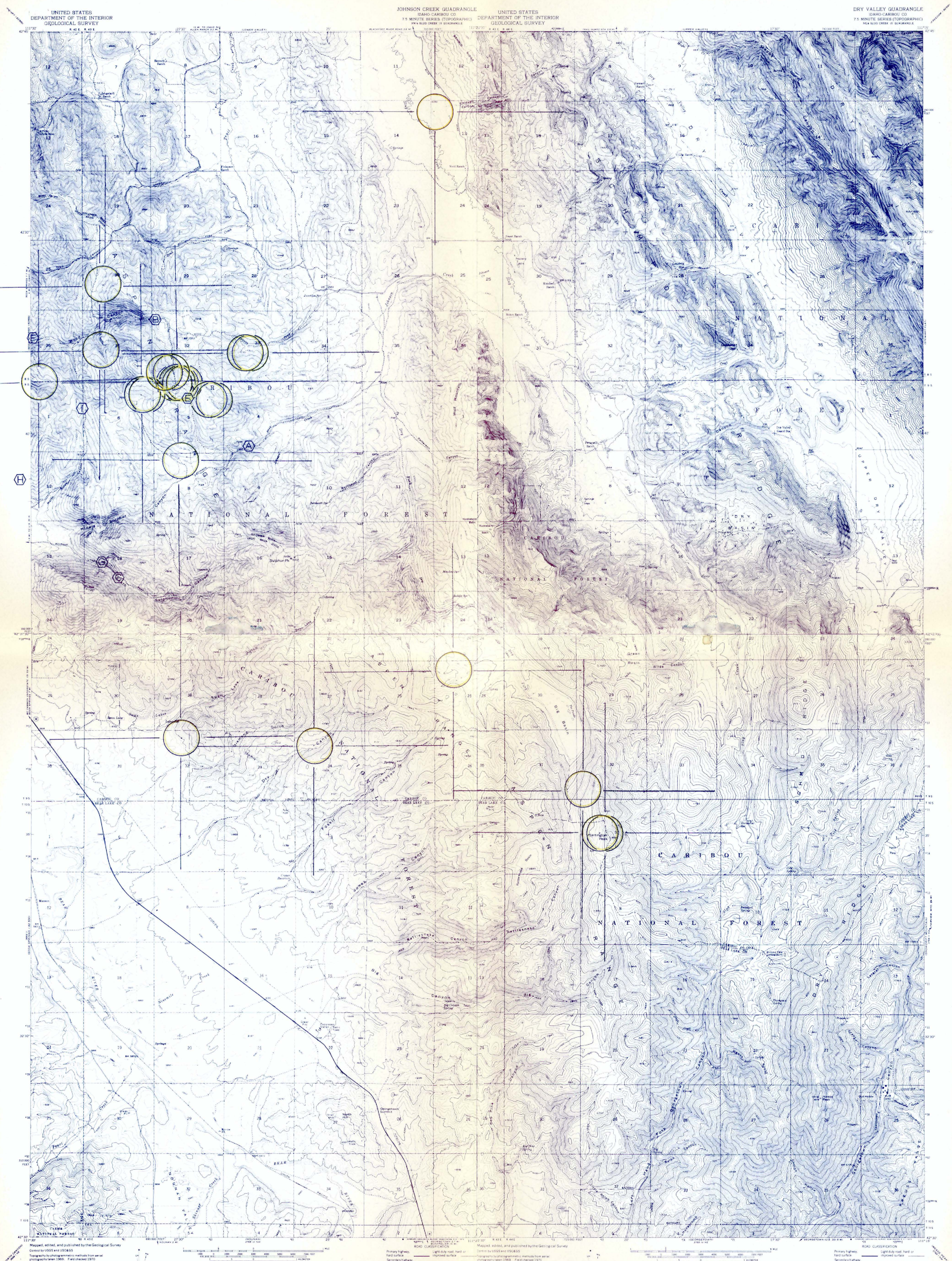
	Station Locations		
Station	X^x (km)	Y^x (km)	Z^x (km)
A	4.96	4.34	0.57
B	2.83	7.25	0.64
C	2.01	1.35	0.46
E	3.55	5.42	0.45
F	0.05	6.84	0.47
G	1.59	1.66	0.43
H	-0.27	3.59	0.52
I	1.11	5.23	0.67

*positive X is east, positive Y is north and Z is altitude above datum. X, Y and Z are in km from an origin located at latitude 42°37'30" North and longitude 111°30' west.

Table 2

Event #	Day	Time	$X^{(km)}$	$Y^{(km)}$	$Z^{(km)}$
1		2:40	3.3	5.8	3.4
2		2:40	3.3	5.8	3.4
3		3:55	5.3	6.5	2.5
4		5:29	3.3	5.8	3.4
5		7:43	3.3	5.8	3.4
6		7:52	-6.0	3.2	9.0
7		10:03	-10.0	5.4	0.0
8		2:49	6.4	-2.6	13.0
9		3:19	2.5	5.5	3.5
10		12:56	2.5	5.5	3.5
11		13:42	9.6	-0.9	0.0
12		16:39	1.5	6.5	3.4
13		1:10	4.0	5.4	3.7
14		7:22	3.0	6.0	3.0
15		10:52	4.0	5.4	3.7
16		12:13	3.0	6.0	3.0
17		1:41	3.4	-2.4	9.0
18		1:46	12.6	-3.6	0.0
19		6:16	-2.0	3.0	0.0
20		8:50	13.0	-4.6	0.0
21		9:30	13.0	-4.6	0.0
22		11:44	0.8	8.0	3.0
23		12:49	-2.0	3.0	0.0
24		13:19	-5.0	2.4	0.0
25		4:59	-5.0	6.4	0.0
26		4:59	-5.0	6.4	0.0
27		12:46	-16.0	16.0	0.0
28		14:59	-16.0	16.0	0.0
29		11:25	-1.4	5.4	6.0
30		11:43	0.2	5.8	5.0
31		6:35	9.2	12.0	0.0
32		8:47	3.0	6.5	6.4
33		11:23	3.4	4.0	0.0

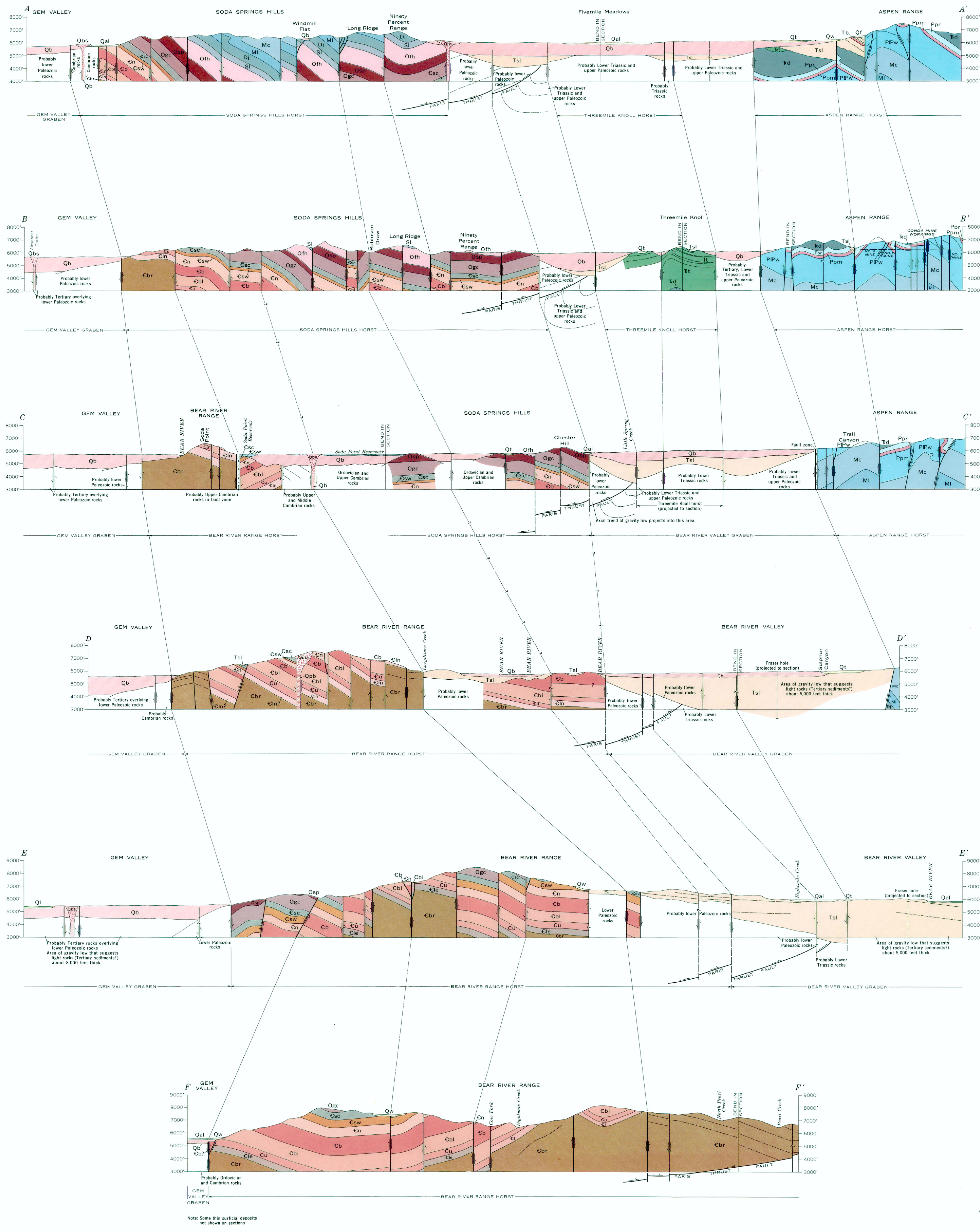
*positive X is east, positive Y is north and Z is altitude above datum. X, Y and Z are in km from an origin located at latitude 42° 37' 30" North and longitude 111° 30' west.



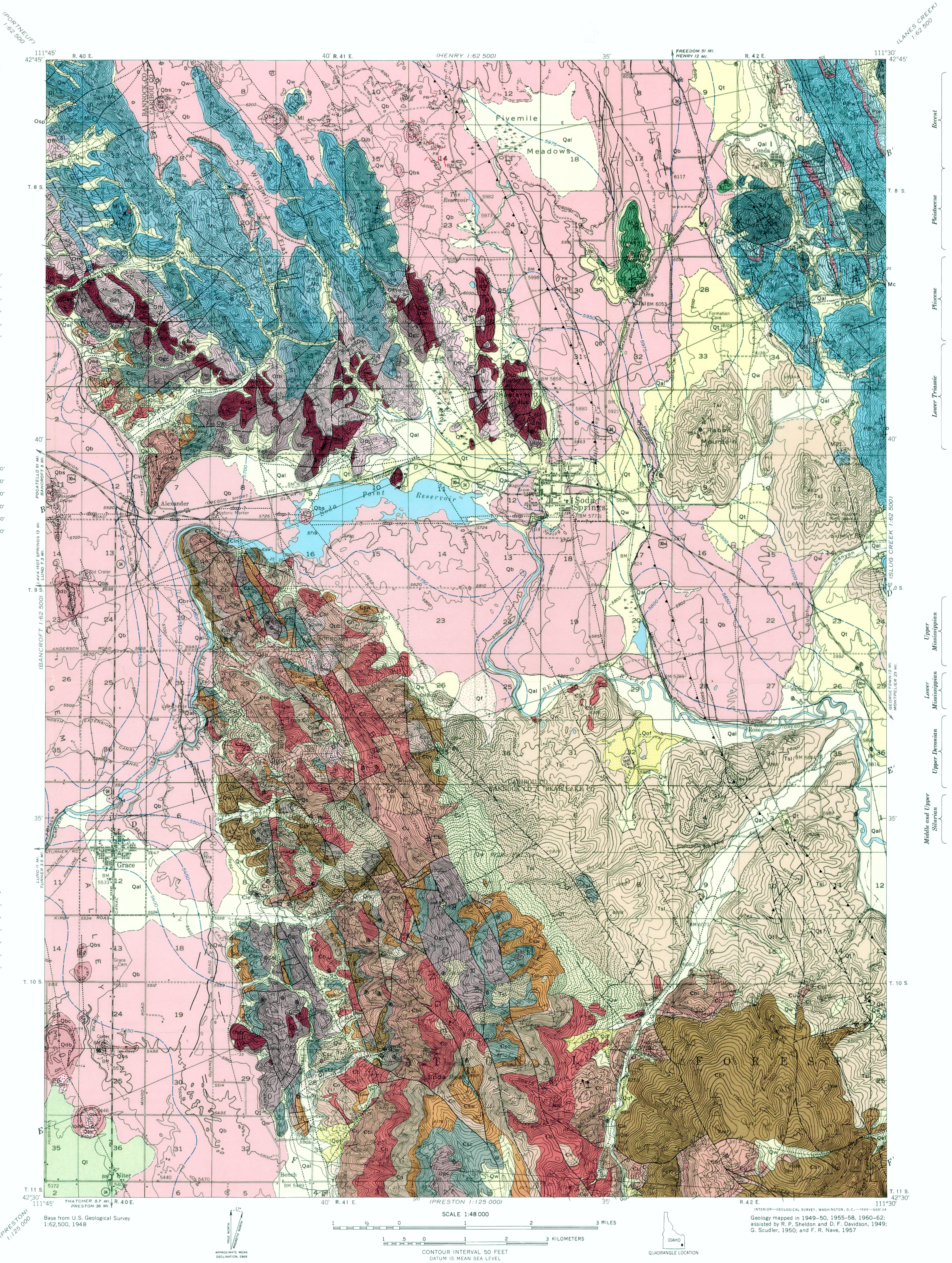
Microearthquakes **Plate I**

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

MISCELLANEOUS GEOLOGIC INVESTIGATIONS
MAP I–557 (SHEET 1 OF 2)



Note: Some thin surficial deposits not shown on sections



Base from U.S. Geological Survey 1:62,500, 1948

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1969—G68134

Geology mapped in 1949–50, 1955–58, 1960–62; assisted by R. P. Sheldon and D. F. Davidson, 1949; G. Scudler, 1950; and F. R. Nave, 1957

GEOLOGIC MAP OF THE SODA SPRINGS QUADRANGLE, SOUTHEASTERN IDAHO

By

Frank C. Armstrong

1969

EXPLANATION

QUATERNARY

Recent

Qal Qf Qls

Gravel, sand, and silt

Qal, *alluvium*
Qf, *fan deposits*
Qls, *landslide deposits*

Qt

Calcareous tufa and travertine

Hot and cold spring deposits

Qpb Qpbs

Porphyritic basalt

Qpb, *porphyritic basalt*
Qpbs, *porphyritic basalt scoria*

Pleistocene

Qw Qof

Sand, gravel, and silt

Qw, *hill wash and older alluvium; stippled where mass-wasting has deposited lag gravel from Salt Lake Formation on hill wash*
Qof, *old fan deposits being dissected by present cycle of erosion*

Qb Qdb Qbs Qbc

Olivine basalt

Qb, *olivine basalt*
Qdb, *domed olivine basalt containing collapsed areas*
Qbs, *basalt scoria*
Qbc, *basalt cinders*

Ql

Lake deposits

Silt and marl; poorly exposed and probably thin

TERTIARY

Pliocene

Tsl

Salt Lake Formation

Sandstone, conglomerate, lacustrine limestone, all of which may be tuffaceous, and rhyolitic vitric volcanic ash and tuff
Stippled where particle size ranges from large boulders to silt; characterized by large boulders from Swan Peak Quartzite and from other Paleozoic formations; in most places boulders concentrated as lag gravel in upper part of unit

Tb

Olivine basalt

TRIASSIC

Lower Triassic

Ꝛt

Thaynes Limestone

Tan silty and sandy limestone, tan calcareous siltstone and sandstone, light-gray finely crystalline limestone, some Pentacrinus*-bearing, and a little red calcareous sandstone;* Meekoceras*-bearing limestone at base*
lt, *(in structure sections only), Lanes Tongue of the Ankareh Formation; contains a few red beds*

Ꝛd

Dinwoody Formation

Brown, silty, medium-crystalline limestone and light-gray finely crystalline limestone

PERMIAN

Ppr
Ppm

Phosphoria Formation

Ppr, *includes massive Rex Chert Member and cherty shale member*
Ppm, *Meade Peak Phosphatic Shale Member; phosphorite, phosphatic mudstone, and phosphatic limestone*

PENNSYLVANIAN

PℙPw

Wells Formation and associated rocks

Includes Grandeur Tongue of Park City Formation at top. Interbedded sandstone, some of which is calcareous, quartzitic, or dolomitic, and light-gray limestone and brownish-gray medium-crystalline dolomite. Dolomite more abundant in upper half; limestone in lower. Beds of limestone in lower half composed almost wholly of flattened oolites

MISSISSIPPIAN

CARBONIFEROUS

Upper Mississippian

Mc

Chesterfield Range Group
(Brazer Limestone of older reports)

Upper half is thick bedded limestone that forms bold outcrops; lower part, interbedded thin-bedded limestone and buff fine-grained sandstone; at base, a phosphatic chert zone that contains a few thin beds of black petroliferous-smelling limestone; chert weathers a distinctive blotchy tan and black

Lower Mississippian

Ml

Lodgepole Limestone

Medium- to dark-gray thin-bedded very fossiliferous, locally cherty limestone

DEVONIAN

Upper Devonian

Djb
Dj

Jefferson Dolomite

Djb, *Beirdneau Sandstone Member; buff fine-grained sandstone*
Dj, *dark-brown medium-crystalline petroliferous-smelling dolomite; sandy and more finely crystalline near top; near base, a few white coarsely crystalline dolomite beds similar to underlying Laketown Dolomite*

SILURIAN

Middle and Upper Silurian

Sl

Laketown Dolomite

White coarsely crystalline dolomite; in upper part a few dolomite beds similar to overlying Jefferson Dolomite; in lower part contains dolomite beds similar to underlying Fish Haven Dolomite

ORDOVICIAN

Upper Ordovician

Ofh

Fish Haven Dolomite

Medium-brownish-gray to gray finely to medium crystalline dolomite; chert nodules and lenses in lower part

Middle Ordovician

Osp

Swan Peak Quartzite

White fine-grained pure quartzite composed of well-rounded frosted grains of high sphericity; some sandy limestone near base

Lower Ordovician

Ogc

Garden City Limestone

Interbedded light-gray finely crystalline limestone and intraformational limestone conglomerate; matrix is coarse and locally appears to be composed of fossil fragments; abundant chert nodules and lenses near top and in lower part

CAMBRIAN

Upper Cambrian

Ꞓsc
Ꞓsw

St. Charles Formation

Ꞓsc, *dolomite, medium-brownish-gray to gray, finely to medium crystalline; poorly defined bedding;* Girvanella *in dolomite; distinctive peppered and streaked texture; medium-gray finely crystalline limestone near base*
Ꞓsw, *Worm Creek Quartzite Member; interbedded arkosic quartzite, quartzite and arkose*

Ꞓn

Nounan Limestone

Upper part light- to dark-gray and tan-gray finely to coarsely crystalline limestone, locally oolitic and blotchy and tan silty partings; a few red beds
Lower part white coarsely crystalline dolomite and medium-gray finely to medium crystalline dolomite; weathers light tan gray

Middle Cambrian

Ꞓb

Bloomington Formation

Interbedded olive-drab to tan finely micaceous shale and thin-bedded limestone; limestone most abundant near middle. Much coarsely oolitic limestone; oolites tan, red, and black. Much intraformational limestone conglomerate; pebbles have pink margins. Apple-green aphanitic limestone concretions in shale

Ꞓbl

Blacksmith Limestone

Blotchy oolitic medium- to light-gray limestone; thick beds make bold outcrops; Girvanella *up to 1 inch; tan silty partings and streaks; middle part of facies of Nelson Creek contains dolomite similar to Fish Haven Dolomite*

Ꞓu

Ute Limestone

Tan-gray and pinkish-gray thin bedded finely crystalline limestone; weathers into platy float; some beds oolitic; sparse Girvanella *up to ½ inch; tan silty partings. Limestone interbedded with tan sandy micaceous shale and sandy shale and a little calcareous sandstone. Distinctive red oolitic limestone at base of facies on Nelson Creek*

Ꞓln Ꞓle Ꞓl

Langston Formation

Ꞓln, *facies in Nelson Creek area; tan-weathering white coarsely crystalline dolomite; forms cliffs; medium- to dark-gray limestone locally at base*
Ꞓle, *facies in Egbert Canyon area; upper part like Ute Limestone with less limestone and more tan and olive-drab micaceous shale and siltstone; more olive-drab shale downward; olive-green micaceous shale and black fissile shale at base*
Ꞓl, *area southeast of Eightmile Creek; upper part greenish-tan micaceous sandstone and phyllitic siltstone; grades downward into green, reddish-gray and brown micaceous sandy quartzite and quartzite in lower part*

Ꞓbr

Brigham Quartzite

Upper part tan and olive-drab micaceous sandstone and sandy quartzite; grades downward into tan and green quartzite interbedded with micaceous quartzitic sandstone, a few dolomite beds locally underlain by red, brown, and purplish-brown quartzite
Lower part lighter shades, tan, and white crossbedded quartzite and conglomerate
Quartzites in upper and lower parts have wide range of grain size from bed to bed and within each bed
Base of formation not exposed in Soda Springs quadrangle. Lower part of formation may include Lower Cambrian and upper Precambrian rocks

Contact

Dashed where approximately located; short dashed where gradational, indefinite, or inferred; dotted where concealed

U D ?

Fault

Dashed where approximately located or inferred; dotted where covered; queried where doubtful. U, *upthrown side;* D, *downthrown side; arrows indicate relative movement. Structure sections show most faults as vertical although map patterns and field measurements show that locally many have steep dips to the east or west*

Concealed thrust fault

Sawteeth on side of upper plate

Linear feature on photograph

May coincide with or be extensions of mapped faults; all are interpreted as faults

Anticline

Showing trace of axial plane and direction of plunge. Dashed where approximately located; dotted where concealed

Overturned anticline

Showing trace of axial plane. Dashed where approximately located

Syncline

Showing trace of axial plane and direction of plunge. Dashed where approximately located

Syncline

Showing trace of axial plane and direction of shallow plunge. From aerial photographs

15

Strike and dip of beds

45

Strike and dip of overturned beds

14

Strike and dip of beds

Computed by photogrammetric methods

Inferred strike and direction of dip of beds

From aerial photographs

Inferred trend of beds

From aerial photographs

⊕

Horizontal beds

Fossil collection site

See Bouguer anomaly map for locality numbers

Lava tube

Dashed where inferred. Arrow indicates direction of emptying

PR

Pressure ridge

Topographic depression

Hachures on low side; hachures outline sag troughs along faults, crater rims in volcanic cones, collapsed areas and topographic depressions in basalt

⚒ lms

Quarry

lms, *limestone*
qtz, *quartz*
To avoid overcrowding, phosphate mines have not been shown; outcrops of Meade Peak Phosphatic Shale Member of the Phosphoria Formation have been mined by surface and/or underground methods

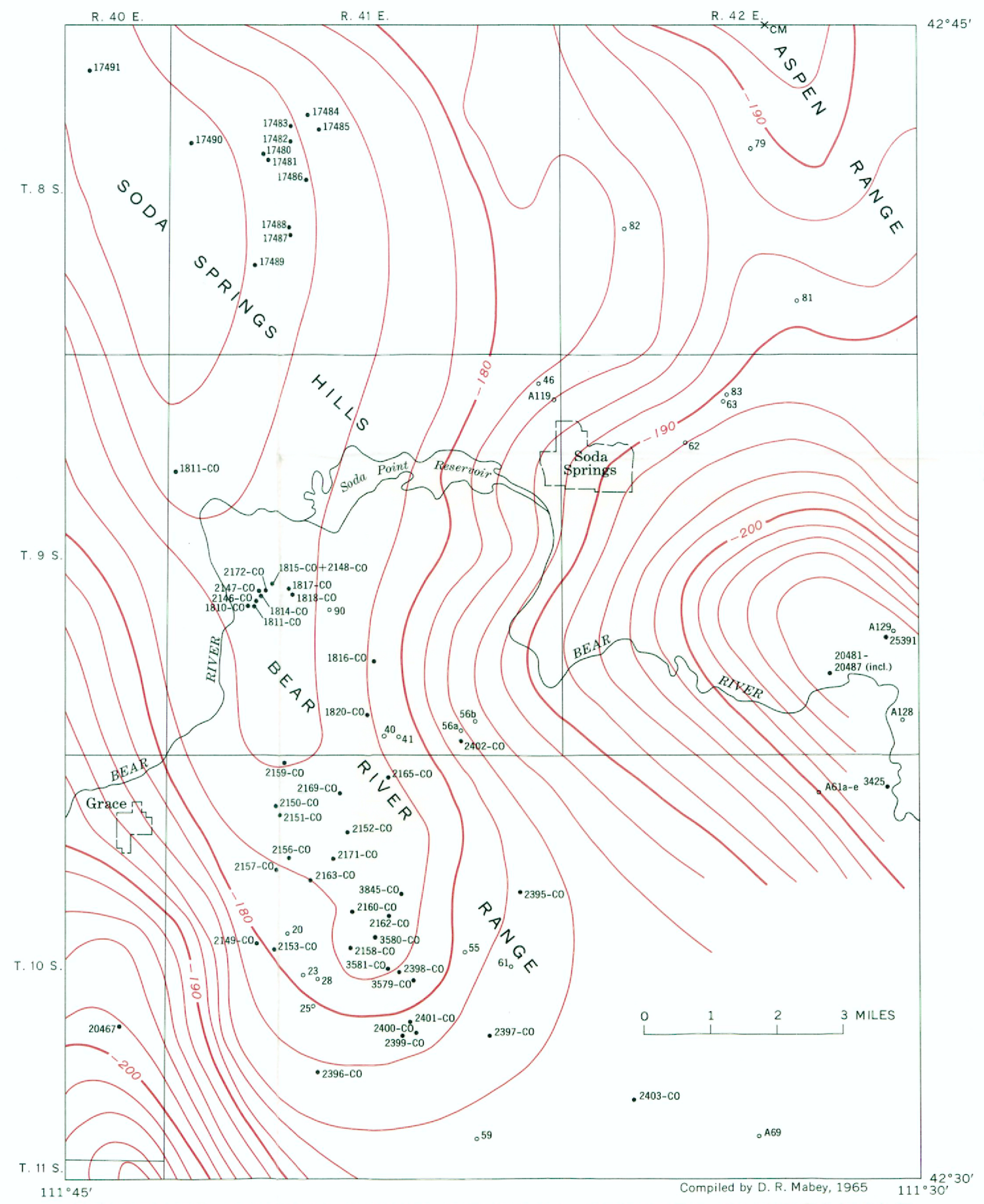
Dry hole drilled for oil

Hole drilled by J. M. Fraser Enterprises

6000

Approximate altitude of the piezometric surface

Contour interval 25, 50, and 100 feet as indicated; datum is mean sea level. At many places the principal aquifers are at a lower altitude than the piezometric surface (in part from U.S. Geological Survey Water-Supply Papers Nos. 774 and 775)



Compiled by D. R. Mabey, 1965

BOUGUER ANOMALY MAP OF SODA SPRINGS QUADRANGLE

EXPLANATION

—190—

Gravity contours

Contour interval 2 milligals

17491 28

Fossil collection localities

Solid dot indicates U.S. Geological Survey collection number
Open dot indicates Frank C. Armstrong's field collection number
See geologic map for exact positions of collection sites

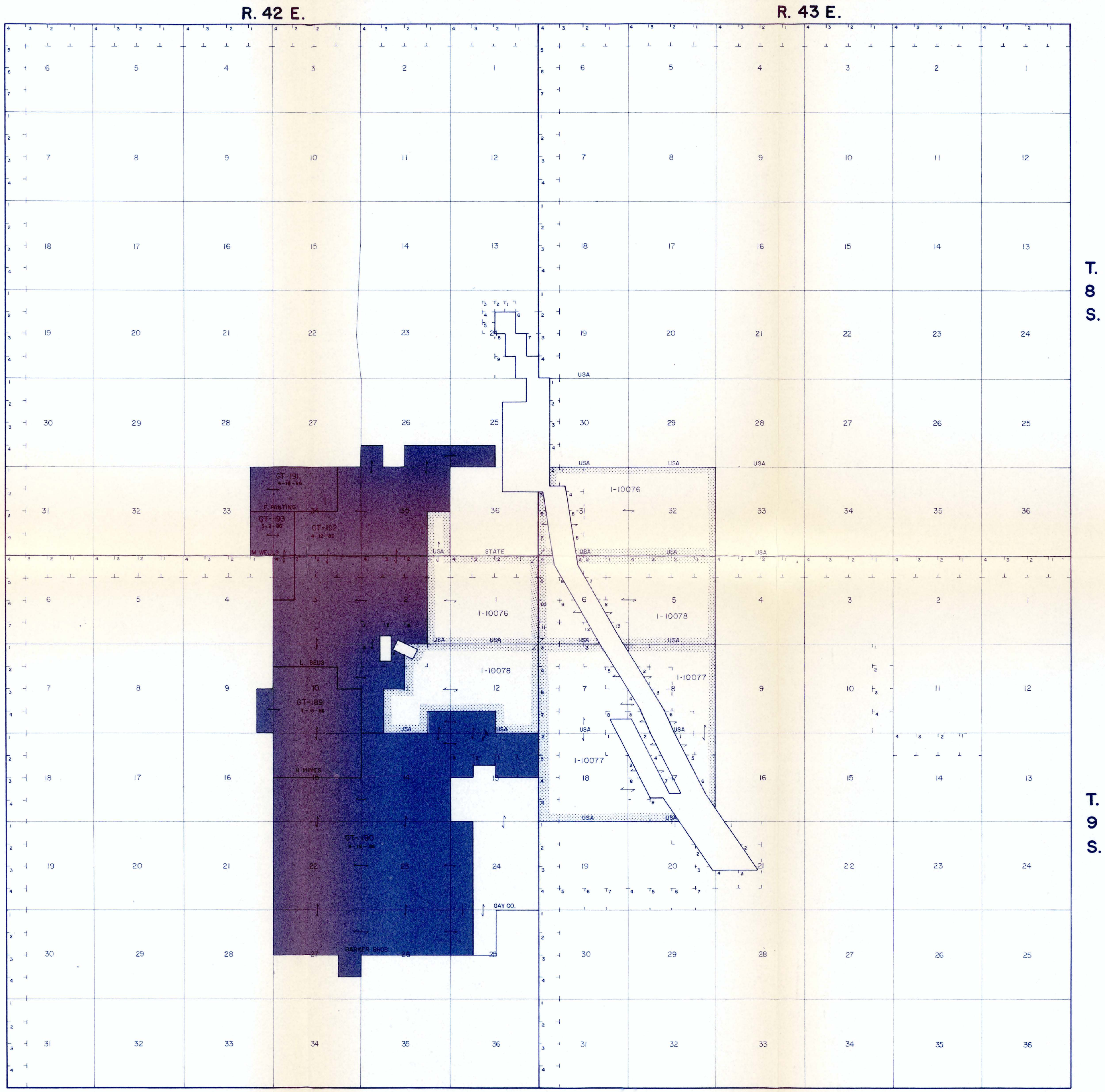
CM

Fossil site of Columbia mammoth

For sale by U.S. Geological Survey, price $1.50 per set

Plate III

SODA SPRINGS



LEASE DATA

▨	Intercontinental Energy Corp. 100%
░	IEC, Federal Application

Date Revised

September 2, 1976

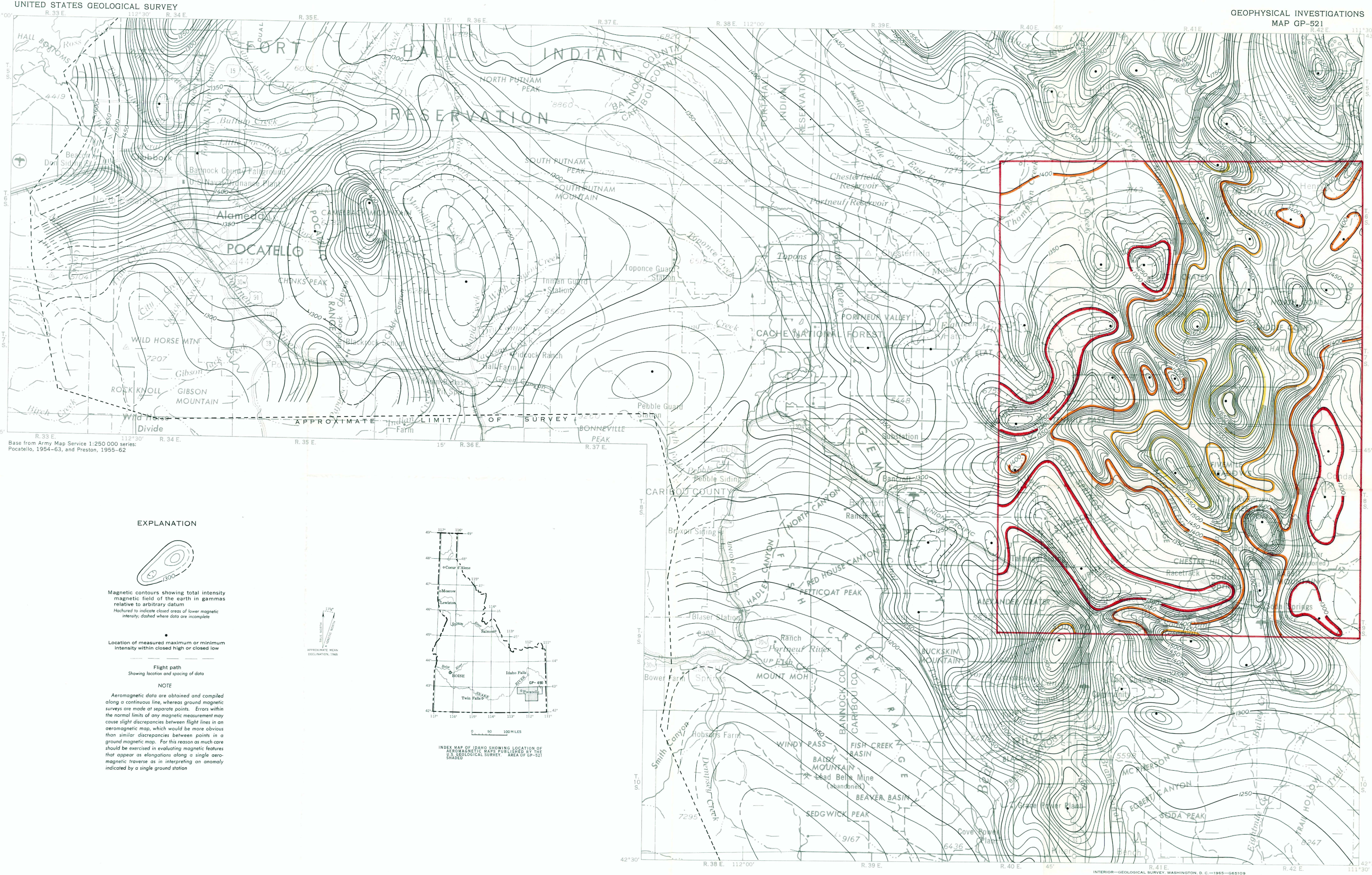
N

0 1/2 1 2 3 4 miles

SCALE 1 inch = 3,960 feet.

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

GEOPHYSICAL INVESTIGATIONS
MAP GP-521



Base from Army Map Service 1:250 000 series:
Pocatello, 1954–63, and Preston, 1955–62

EXPLANATION

Magnetic contours showing total intensity magnetic field of the earth in gammas relative to arbitrary datum
Hachured to indicate closed areas of lower magnetic intensity; dashed where data are incomplete

●
Location of measured maximum or minimum intensity within closed high or closed low

— — — — —
Flight path
Showing location and spacing of data

NOTE

Aeromagnetic data are obtained and compiled along a continuous line, whereas ground magnetic surveys are made at separate points. Errors within the normal limits of any magnetic measurement may cause slight discrepancies between flight lines in an aeromagnetic map, which would be more obvious than similar discrepancies between points in a ground magnetic map. For this reason as much care should be exercised in evaluating magnetic features that appear as elongations along a single aeromagnetic traverse as in interpreting an anomaly indicated by a single ground station

INDEX MAP OF IDAHO SHOWING LOCATION OF AEROMAGNETIC MAPS PUBLISHED BY THE U.S. GEOLOGICAL SURVEY. AREA OF GP-521 SHADED

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.—1965—G65109

Aeromagnetic survey flown at 9000 feet barometric elevation, 1963

AEROMAGNETIC MAP OF THE POCATELLO-SODA SPRINGS AREA, BANNOCK AND CARIBOU COUNTIES, IDAHO

By

C. M. Mitchell, F. F. Knowles, and F. A. Petrafeso

SCALE 1:125 000

2 0 2 4 6 8 10 MILES

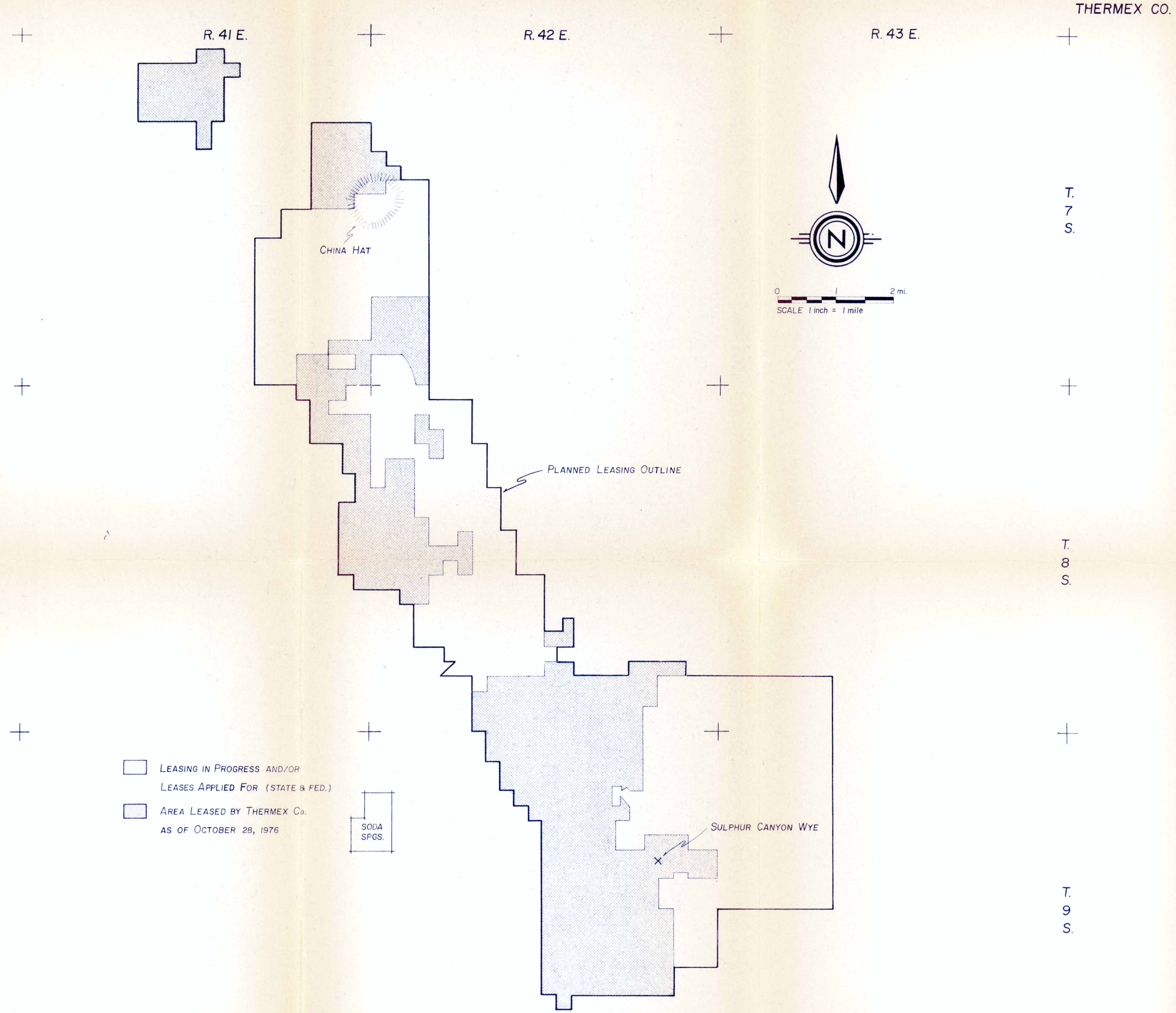
2 0 2 4 6 8 10 KILOMETERS

CONTOUR INTERVALS 10 AND 50 GAMMAS

1965

For sale by U.S. Geological Survey, price 50 cents

Plate V



SODA SPRINGS

LAND STATUS MAP