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EVALUATION

OF

GEOTHERMAL PROSPECTS

AND

GEOTHERMAL EXPLORATION PRACTICE

for

AMAX EXPLORATION, INC.

DENVER, COLORADO

by

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Introduction

This report summarizes the findings of a 3-day evaluation of AMAX's geothermal prospects held in Denver on June 2-5, 1980. Eight of 17 prospects were discussed in detail, these being located in diverse geologic terrain in 4 states (California, Nevada, Utah and New Mexico). Time did not permit evaluation of the other prospects, but it is not anticipated that the findings of this study would be modified significantly in the event that all were studied.

AMAX staff members H. J. Olsen, A. Lange, D. Pilkington and F. Berkman were present throughout the evaluation process and provided invaluable insight and explanation. W. M. Dolan and W. Lodder provided additional support and commentary.

In the following pages, a brief description is given of each prospect, followed by a critique of AMAX exploration program and results. Recommendations are offered for future action.

Project Descriptions

Tuscarora, NV. Tuscarora is in the Basin and Range province of northern Nevada. It is characterized by boiling springs of projected reservoir temperatures 150°-210°C. There has been extensive geophysical exploration and temperature gradient drilling, culminating in drilling of a 5,500 foot test near the boiling springs.

Structural and stratigraphic geology is complex. Most information comes from modeling of gravity and aeromagnetic surveys. Possible geothermal targets are identified by temperature-gradient and geoelectrical (resistivity, magnetotelluric and SP) anomalies.

The 5,500 foot hole experienced a sharp temperature reversal at relatively shallow depth, and was abandoned prematurely without equilibrium temperature logging, because of drilling problems. Another target is perceived in geoelectrical data to the southeast, beneath a resistive caprock.

Geologic data are inadequate for the complex situation. Geochemical data are surprisingly sparse. Geophysical data are abundant, including heat flow and temperature gradient data in holes to 1,500 feet.

Land position and the drilling requirements imposed via a USGS Geothermal Unit (requested by AMAX) have led to selection of a second

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drill site southeast of the original hole and at a distance from the thermal springs. This would go to 4,000-4,500 feet, hopefully to penetrate an upwelling thermal plume offset from the thermal springs, as seen in geoelectrical data.

Were it not for the Geothermal Unit and lease position, I would recommend a 2,500 foot hole approximately half-way between the original geothermal test and the proposed test. This could probe the upwelling thermal plume at shallower depth. Somewhat reluctantly I concur with the 4,000-foot-hole plan. Depth to magnetotelluric anomalies is not well constrained. 4,000 feet may be too shallow (or unnecessarily deep). However, I see no reasonable alternative, unless Supron and USGS can be brought to accept a 2,500 foot hole on Supron property. Another 2,000-2,500 foot hole would be desirable about an equal distance west of the hot springs.

Tuscarora is a very mature prospect in need of definitive drilling. Only additional geologic and geochemical modeling appear worthwhile at this time.

Deeth, NV. Deeth is a geochemical and gradient prospect in an immature state of development. Detailed geologic mapping is needed, as well as further geochemical surveys and hydrologic modeling of flow regime. These should follow drilling of a planned set of gradient holes designed to pinpoint the anomaly at 500 feet. AMAX holds a scattered lease position, some of which (to the southwest) may be abandoned even at this time.

More definition of the prospect is required before deep drilling can be contemplated. It remains attractive enough to pursue to completion. Dropping or adding of lease acreage may be desirable as exploration proceeds. Additional geophysical surveys should follow the definition stage and precede deep drilling.

McCoy, NV. McCoy is a geochemical and gradient anomaly in a mature state of development. However, the fundamental nature of the prospect remains uncertain, despite extensive geophysical surveys. Here, too, I perceive a lack of adequate geologic control, although geochemical data appear more adequate.

Gradient holes to 2,000 feet have not identified either a heat source or a reservoir. It appears possible that additional gradient and/or geophysical anomalies will be discovered with continued exploration along structural trend, again without yielding clear information on reservoir or heat source.

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Given this, I recommend a careful geologic study, including cross-sectional modeling of a possible volcanic collapse center. A few additional gradient holes are warranted to explore the significance of a magnetotelluric low in the region to the south.

Despite the extensive work to date, there is no clear basis on which to select a deep drilling site. If careful geologic study does not provide an answer, a single blind hole to 6,000 feet may be the ultimate action.

Mayacmas Mountains, CA. This very mature prospect has been drilled to some 8,700 feet, with unsatisfactory results. Drilling problems precluded equilibrium temperature logging. Existing gradient data (60°C/km to 5,000 feet; 40°C to TD) suggest an 10,000-11,000 foot objective for adequate temperature. This is deep, but not unheard of, at The Geysers.

Geologic, geochemical and geophysical work appear to be detailed and fully adequate. A second drill site has been selected, for which the gradient is thought to be somewhere in the range 60°-90°C/km. The higher range would yield adequate temperature conditions by 2 km (6,500 feet); the lower range by 3 km (10,000 feet). However, permeability remains a moot point.

The Mayacmas Mountains prospect is on trend several miles southeast of The Geysers steam field. Uncertainties as to whether steam or hot water may be present beneath the prospect have complicated and clouded geophysical and geochemical interpretations. Farther south, at Calistoga, a hot-water field is present at shallow depth. AMAX leases extend into the Calistoga area. However, strong opposition by county and local government agents probably would preclude any drilling near Calistoga. Therefore, the present drill site remains the best achievable test.

If a carefully drilled and adequately logged hole to 9,000-10,000 feet proves unattractive, the prospect may be shelved, farmed out or released. No further geophysical or geological exploration is recommended.

A final effort may be made to obtain a drilling permit for a 6,000 foot hole near Jericho Canyon, in the hottest portion of the anomaly near Calistoga, despite local opposition.

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Cove Fort, UT. Cove Fort is AMAX's principal prospect having a possible active magmatic heat source. Magmatic heat sources appear to be higher-temperature and economically more attractive than non-magmatic fields. Therefore, exceptional efforts should be devoted to Cove Fort.

Geology, geochemistry and geophysics appear adequate for the prospect area. Gradient drilling, although widespread, is shallow in AMAX's principal lease area. Elsewhere locally, 5 or 6 holes have been drilled to at least 2,000 feet, by Union, Hunt and Phillips. The best of these, at Sulphurdale by Union, went to about 8,000 feet, encountered 325°F temperature, and bottomed in metamorphosed Paleozoic rock. Lost circulation was a problem in all deep tests, possibly precluding adequate temperature logging.

A broad graben structure is recognized, terminated by important cross trends, and containing a central, youthful horst block. Along the margin of this horst and a reactivated, smaller marginal graben, the potentials appear to be best.

Drilling into young volcanic rock and into Paleozoic carbonate rock promises to be extremely difficult. A plan for continuous coring of a slim hole is attractive, although difficult, and offers better and cheaper potentials for reaching an objective than does rotary drilling of a standard diameter hole.

A set of 3 such holes east-west across the graben and near Cinder Crater to depths of perhaps 2,500-3,500 feet each should serve to resolve difficult and important questions of deep gradient, rock type, and possibly fluid chemistry. The slim diameter is adequate for passage of logging tools, including downhole fluid samplers.

Until this is done and results evaluated, all leases should be held, and leases dropped by other parties should be sought after. Because of the possible active magmatic heat source, the prospect should continue to receive high priority.

Burning Stone, UT. This gradient anomaly is in an immature state of exploration. Shallow anomalies in temperature gradients are not reflected in geoelectrical data, especially in the absence of a deep-seated magnetotelluric low. There appears to be no recourse, other than dropping the prospect, to drilling a deeper gradient hole into the middle of the anomaly: 1,500 feet appears adequate, 2,000 feet is generous. If gradients do continue to be attractive at that depth range, some care must be given to designing an exploration program and to explaining physical controls over the system.

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No other work is warranted until a single deep gradient hole has been drilled.

Black Mountains, UT. This prospect is characterized by temperature gradient, chemical and structural anomalies. It has been drilled at its most obviously attractive surface manifestation by Republic, to over 8,000 feet. That hole was hot (≳350°F) and dry, probably bottoming in a Paleozoic sedimentary section. However, unlike Cove Fort, no magmatic heat source is foreseen.

The widespread, high amplitude nature of temperature gradient anomalies suggests that hot water is moving convectively at relatively shallow depths. However, except for Thermo Springs, no temperatures much over 120°F are recorded in shallow gradient holes. Parts of the gradient anomaly are not well constrained.

Structural complexities have been modeled by combined use of gravity, aeromagnetics and other data. Intersections of north-south and northeast-southwest structures appear to control the anomaly or anomalies. Further geologic or geochemical work does not now seem valuable. Further geophysical work also should await results of drilling deeper gradient holes.

Gradient holes should be of 2 types: (1) those to constrain the thermal anomaly on its borders; and (2) those to determine downward continuation of the anomaly. The former should be 300-500 feet in depth; the latter need to be 1,000-1,500 feet deep. Exact locations must depend upon land position and access. However, several companies, including GRI and Earth Power, might be interested in a shared program that includes their lands.

The suspicion remains that Republic has taken the best shot at this area. However, its areal extent and the possibility of local structural control warrant continued drilling.

Animas, NM. This is a very mature prospect in need of definitive drilling on a small but very well-defined anomaly. If deep drilling (5,000-8,000 feet) cannot be accomplished, then a set of 3 east-west gradient holes to 2,000 feet is recommended across the prospect.

Additional geologic mapping in nearby hills and cross-sectional modeling beneath the prospect might profitably be done. However, this would best benefit from data from the 2,000 foot holes, and should so be postponed.

No additional geophysical work is recommended.

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A Critique of AMAX's Exploration Program

Geologic, geochemical and geophysical exploration practice appears to be thorough and detailed, and generally has yielded interpretable results. There is a tendency to employ a very wide range of geophysical techniques, verging on overkill in some cases. Although there has been extensive geochemical exploration, for most prospects AMAX does not have adequate geochemical reports on file. It may be that the raw chemical data have not been digested, or that final reports have not been prepared. This should be done. Geologic work has varied from cursory to excellent. Additional effort should be given in the future to detailed geologic mapping and construction of cross-sections and other models earlier in the prospect evaluation process.

AMAX has received very good value from its efforts in modeling gravity and aeromagnetic data. It is less demonstrable to me that the SP work has been valuable in many prospects. The dc-resistivity and magnetotelluric work also has its limitations, but appear to be effective in certain terrains.

However, my principal critical comment regards the lengthy shelf-life of almost every prospect. AMAX seems to be unable to decide whether to drill or abandon, and as a result requires very many years of exploration, evaluation and negotiation before a prospect has been resolved. Put simply, AMAX is holding its prospects too long without drilling them.

Obviously, there are considerations of land position, permits, financing and third-party negotiation to be considered. However, in a 7 or 8 year period, AMAX itself has drilled only 2 deep exploratory holes, one each at Tuscarora (with partners) and at Mayacmas Mountains (with partners). During the same period, other companies of equal size have drilled many more prospects and total holes. For example, Sun since 1976 has drilled 7 prospects (11 holes), making a discovery in Dixie Valley of significant proportion (3 completions out of 4); and Phillips (excluding Roosevelt Hot Springs) has drilled at least 7 separate prospects in that time, with perhaps 3 of these being of commercial importance.

There may be special reasons for AMAX holding its prospects for longer times prior to drilling. These did not become evident in the discussions held with the geothermal group.

Similarly, AMAX has been timid in developing and using deep gradient drilling techniques. For many prospects, no holes are drilled

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deeper than 300-500 feet. This depth usually is inadequate to penetrate through shallow convective aquifers. Many other companies routinely drill gradient holes to 1,000-2,000 feet for every attractive prospect. Phillips, Union and Chevron regard 2,000 foot holes as a routine step in the exploration process. Anadarko, Sun, Occidental and others commonly drill to 1,000-1,500 feet, or deeper.

Some companies have tried to go to depths of 2,500-3,500 feet in gradient drilling. This usually has not been cost effective. However, with AMAX's pioneer efforts in continuous coring of slim holes to depths over 2,000 feet, it may be possible to develop this as an effective procedure.

It is very difficult to compare staff practice from company to company, because of policy differences. For example, Phillips maintains a staff at least as large as AMAX's, but with at least one branch office. Chevron also has a large geothermal group, and with a high proportion of staff as compared with line workers. Alternatively, Sun keeps a small exploration staff, and contracts out almost all of its exploratory effort. Republic has developed a much larger staff, but regularly serves as a U.S. government contractor, complicating the picture.

It would appear that Phillips and Union must be considered as having had the most productive exploration program to date. They can be evaluated as follows: strongly staffed; very active exploration program; wide use of a variety of techniques; competitive bidding in selected lease sales; willingness to drill deep gradient holes (to 2,000 feet routinely); willingness to drill exploratory holes to great depth; moderate to strong support by home office.

AMAX has to its credit a participatory interest in the Roosevelt Hot Springs geothermal field in Utah. When compared to Phillips or Union, however, AMAX does not have a significant discovery record. This in part, of course, reflects AMAX's hesitancy to drill deep wells, even on mature prospects. Other companies can be faulted for having drilled weak prospects (such as Hunt at Monte Neva, NV, or McCulloch at several of its locations); but at least they have explored and gotten out.

In evaluating prospects for this project, the following was considered:

- Is there clear evidence of temperatures over 200°C at drillable depth?
- Is there a well-defined reservoir objective?

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- Is land position adequate?
- Will exploration, drilling and completion costs and problems be within manageable limits?
- Does the potential resource appear large enough to justify development?
- Are environmental, legal, access and land-use problems manageable?

Where all or most of these can be given a clear yes! answer, the prospect is Class A. Where the resources appears to be at least adequate, but severe land and environmental problems exist, Class B. If resource is marginal, but land and environmental problems are manageable, Class C. Where both resource is marginal, and land and environmental problems are great, Class D. Thus, the evaluation is not made on resource characteristics alone. If only resource characteristics are considered, Class A and B are often of approximately equal merit. Where information is inadequate, but land is available, the prospect is placed in Class C.

The 8 prospects evaluated in this study are listed in the following table:

Tuscarora	Class B	Geochemically, electrically attractive; moderate to complex land position; probably not magmatic heat source
Deeth	Class C	Immature prospect; adequate land position
McCoy	Class C	No obvious heat source; moderate to poor exploration results; good land position
Mayacmas Mountains	Class B	Potential magmatic heat source; could even by dry steam field; very difficult environmentally; moderate to poor exploration results
Cove Fort	Class A	Potential magmatic heat source; difficult to explore; adequate land and environmental position
Burning Stone	Class C	Immature prospect; adequate land position

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Black Mountains	Class C	No obvious heat source; moderate exploration results; complex land position; may be off the main anomaly
Animas	Class B	Unknown heat source; moderate exploration results; good land and environmental position; requires exploratory drilling

The prospect mix represented herein probably is typical of the range of prospects being explored by other large companies. What is noteworthy is that there are few plays on the margins of discovered fields. Also, about half of the prospects have come as farm-outs from third parties, and about half have been developed by AMAX staff. Perhaps the percentage of self-developed prospects is higher with companies like Phillips, Union, Chevron and Sun.

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Recommendations

1. Attempt to bring prospects to the point of drilling in less time than previously; drill a higher percentage than previously.

2. Routinely drill gradient holes in range of 1,500-2,000 feet on every attractive prospect.

3. Attempt to develop slim hole continuous coring technique for deep gradient drilling in selected areas.

4. Have existing geochemical data brought to completion. This will require preparation of detailed reports and maps on each prospect.

5. Introduce detailed geologic mapping and construction of cross-sections and other models at an earlier stage in prospect evaluation.

6. Consider limiting geophysical exploration to gravity, magnetics and one geoelectrical technique, except in unusual cases. Consider diverting additional geophysics dollars into deeper gradient drilling.

7. Consider lessened involvement with partners and third party farm-outs. Attempt to develop own prospects more routinely. Consider exploring locations at margins of other discoveries.

8. Other recommendations are shown within the body of this report, pertaining to individual prospects.

1978 Recce Program

Deeth

Four high heatflow holes were probed north of the Deeth interchange on Interstate 80, about 32 km northeast of Elko (Figure 2).

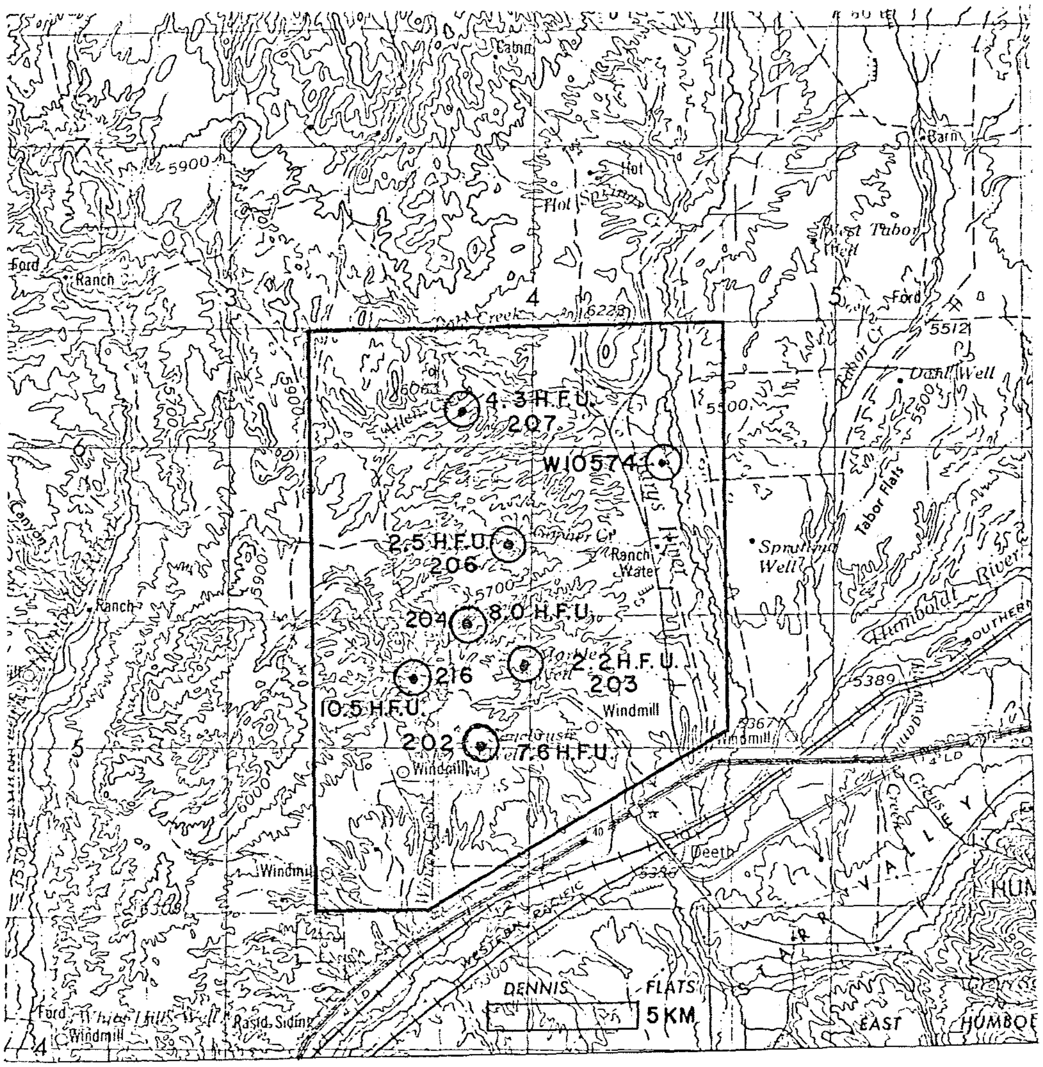

Figure 2. Deeth Prospect with Buy Line, Heatflow and Hot Spring Locations.

Table 2 is a list of specific heatflow data. The data is very credible and delineates a narrow north-south trending heatflow anomaly. Hole 204 (Plate 1) is 140 meters deep and has a gradient and bottom hole temperature of 134°/km and 45.52°, respectively.

Table 2. Deeth Heatflow Data

ΔNumber	Depth(m)	BHT°C	Q H.F.U.	ΔT°C/km
202	21	17.96	7.6	218
203	42	16.38	2.2	64
204	140	45.52	8.0	134
206	40	17.20	2.5	71
207	40	17.70	4.3	122
216	60	27.61	10.5	301

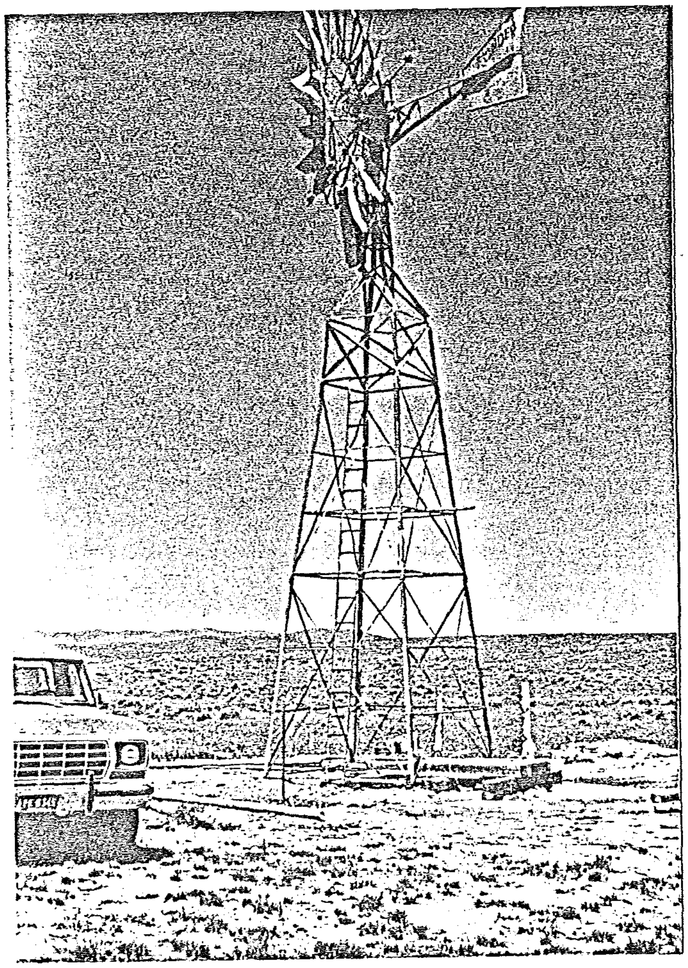

Plate 1. Deeth Hole 204 Salt Block Well

The Tertiary lacustrine Humboldt Formation dominates the local geology; however, small outcrops of Pennsylvanian Diamond Peak and Permian Gerster Formation are in sections 2 and 11 of T38N R58E. A small outcrop of highly crystalline rhyolite is exposed in sections 26 and 35 of T38N R58E. The Humboldt Formation obscures most local structure, except for the north-south trending Mary's River Fault.

The Mary's River Hot Springs are in sections 11 and 14 of T38N R59E (Figure 2 and Plate 2). The springs have deposited siliceous sinter in the

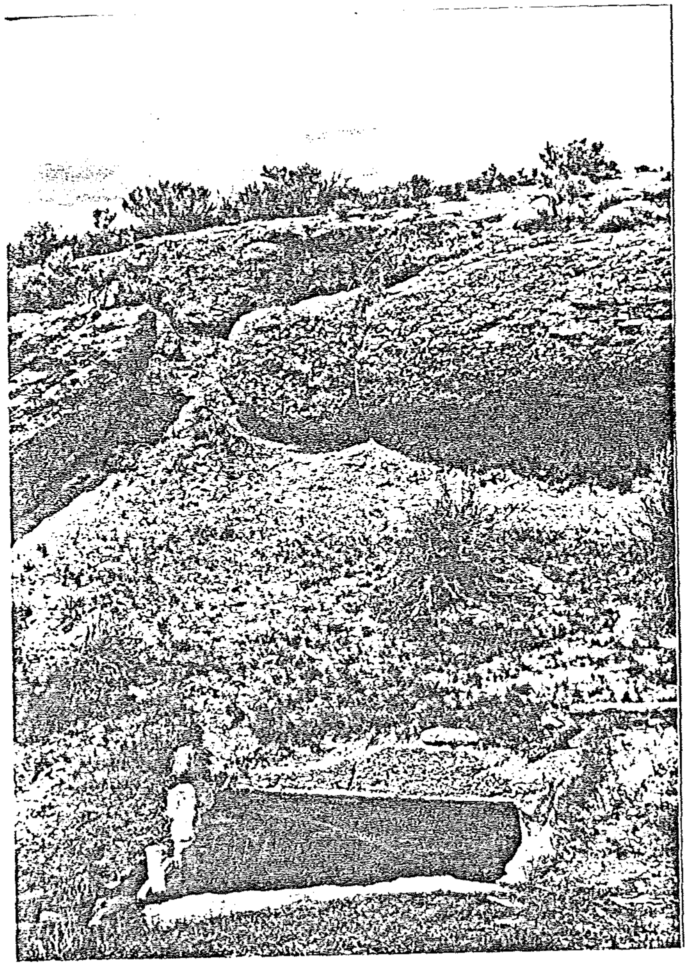

Plate 2. Mary's River Hot Spring

recent past. Major ions are distributed as follow:

$$HCO_3 > Cl > SO_4 \quad Na > K > Ca > Mg.$$

The waters are rich in fluoride and depleted in lithium, boron and ammonia (Table 3). The subsurface geothermometers should be reliable, owing to the low calcium concentration. Temperatures range from 161° to 197°C.

The prospect is located within the railroad land grant corrider so sections are alternately Federal and fee. The railroad has title to about half of the fee land while the remaining quarter is held by a diversity of individuals. Figure 2 shows a very liberal buy line which should include the majority of the north-south trending heatflow anomaly.

W-10574	
County	Elko
Temp (C)	38.
Flow (GPM)	5.
pH	8.15
Cl	29.
F	22.
SO_4	5.
HCO_3	988.
CO_3	0
SiO_2	150.
Na	500.
K	34.
Ca	3.
Mg	.4
Li	0
Cu	0
B	0
MO	15.
NH_3	.2
TDS	1741.7
$TSiO_2$	161.
TNa-K	143.
TNa-K-Ca	197.

Table 3. Analysis of Mary's River Hot Springs.