THE CARSON LAKE GEOTHERMAL PROSPECT

by

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Reno, Nevada

April 19, 1990

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INTRODUCTION AND HISTORY

A relatively large and intense thermal anomaly, referred to as the Carson Lake anomaly or prospect, was discovered southeast of the Fallon Naval Air Station (NAS) by Phillips Petroleum Co. in 1973. There are no natural active thermal features in the area but a 163' deep drillhole is flowing thermal water with a temperature of 162 °F (Bruce 1980). Phillips drilled 28 temperature-gradient holes to a maximum depth of 500' covering an area of 5 or 6 townships. Phillips did not perform any additional exploration as the more attractive Desert Peak and Soda Lake thermal anomalies were identified shortly thereafter and the twenty thousand acre Federal acreage limitation per state in force then did not allow Phillips to lease the Carson Lake prospect.

In the late 1970's the U. S. Navy embarked on a program of evaluating selected facilities for their geothermal potential. Geothermal data from the Fallon NAS and some surrounding bombing ranges were first published by the Navy in May 1980 (Bruce 1980). This appears to have instigated the nearby Unocal activity in the early 1980's.

In 1980 and 1981 Unocal obtained 5 leases on BLM acreage east of the NAS and performed a significant amount of exploration work which has recently become publicly available. The existence of most of this work was unknown to Oxbow until late October 1989 when it was obtained from the BLM state office in Reno. The most important of the Unocal exploration was the drilling of a 2892' deep slim hole, 72-7 in mid 1981. Surprisingly, Unocal did not drill any shallow temperature-gradient holes to assist in locating 72-7. Well 72-7 was simply located close to the thermal artesian well in the expectation that a large high-temperature geothermal reservoir could be easily discovered and understood later. Unocal was not then interested in reservoirs with capabilities below the hundreds of megawatts. Unocal also ran gravity and aeromagnetic surveys but later relinquished the leases, presumably due to the less than exciting results of 72-7 which has a maximum temperature of 268 ^{o}F. In hindsight, well 72-7 was poorly located, the result of a rather limited exploration program not designed to deal with laterally flowing thermal water at shallow depths.

In 1982 additional Navy data, including detailed gravity and ground magnetic surveys, part of an aeromagnetic survey, and results from a 2025' observation hole (OH-1) were published (Katzenstein and Danti, 1982). Between 1983 and 1985 the abortive General Ener-Tech - Helioscience venture occurred and no new exploration work was performed.

In 1986 the Navy drilled OH-2, a core hole, to a depth of 4485' near the southeastern corner of the NAS (Katzenstein and Bjornstad, 1987). This hole had a more or less linear gradient to total depth and a maximum temperature of 310 ^{o}F at 4485'. This is the hottest temperature yet measured at Carson Lake. Currently the Navy has released a draft environmental impact statement covering potential production of 160 MW from the NAS.

As a result of renewed Navy interest in the geothermal potential of the NAS in late 1987, and publication of the results of OH-2, Oxbow took notice of the area. After temperature data showing most of the thermal anomaly lay off the base were presented to Oxbow management the decision was quickly made to lease both Federal and fee acreage in the spring of 1988. In August 1989 Oxbow applied for additional Federal leases to the south of their existing lease block but withdrew these applications prior to issuance. In October 1989 Oxbow drilled 11 additional shallow temperature-gradient holes from 200 to 500' deep to further outline and define the thermal anomaly. After this drilling was completed Oxbow obtained the Unocal data. The most recent exploratory work was the drilling of two additional shallow holes in January 1990.

This report was prepared at this time to take a hard look at the prospect and its existing data base. The next major step in the development of this prospect will involve deeper drilling with costs increasing from tens to hundreds of thousands of dollars. Prior to undertaking this deeper drilling it is essential to take the time and effort to draw together all existing data to obtain as complete an understanding of the area as possible. This will hopefully result in thoroughly considered recommendations for future work that are most cost effective yet offer the best chances for discovering a viable resource.

REGIONAL SETTING

Geothermal Areas

The Carson Lake prospect is located near the southeastern corner of the Carson Sink, the largest basin in northwestern Nevada (Figure 1). Within the Carson Sink the Soda Lake (3.6 MW) and Stillwater (11 MW) geothermal reservoirs are currently being produced by Ormat. Ormat is also undertaking additional exploratory drilling for a possible 12 MW expansion of the Soda Lake reservoir. The Desert Peak plant at the northwest margin of the Carson Sink produces 10 MW for Chevron and the Oxbow Dixie Valley plant northeast of the Sink is currently producing 62 MW. Other potentially productive geothermal areas in or near the Carson Sink include Brady's, Salt Wells, Hazen, Lee, and New York Canyon.

The existing fields produce from a wide variety of depths and rock types. Desert Peak and Dixie Valley produce primarily from metamorphosed Mesozoic rocks with lesser production from siliceous and mafic Tertiary volcanic rocks. Brady's and Salt Wells produce from mafic Tertiary volcanic rocks. Soda Lake produces from siliceous Tertiary volcanic rocks and from Quaternary sediments. Stillwater produces from Quaternary sediments. About the only major unit missing from this list is production from granitic rocks which occurs at Steamboat, Roosevelt, and Coso. There is no reason why granitic production should not be possible in the Carson Sink region.

Stratigraphy

The regional stratigraphy can be obtained both from geology surrounding the Carson Sink and from deep wells drilled in the sink. Both types of information are available for Carson Lake and agree reasonably well.

Granitic rocks are absent in the ranges immediately surrounding Carson Lake but Anadarko's 8500' deep well 14-36 near Simpson Pass in the Bunejug Mtns. encountered 2200' of volcanic rocks, mostly or entirely basaltic, overlying 6300' of granite. At Soda Lake, Tertiary volcanic rocks also overlie granitic and gabbroic intrusives. In neither field have any Mesozoic sedimentary rocks been encountered and the mountain ranges surrounding the southern part of the Carson Sink (southern Stillwater Range, Bunejug, Blowsand, White Throne, and Dead Camel Mtns.) all conspicuously lack large Mesozoic or other pre-Tertiary outcrops. Thus there is reason to expect the "basement" rocks beneath Carson Lake

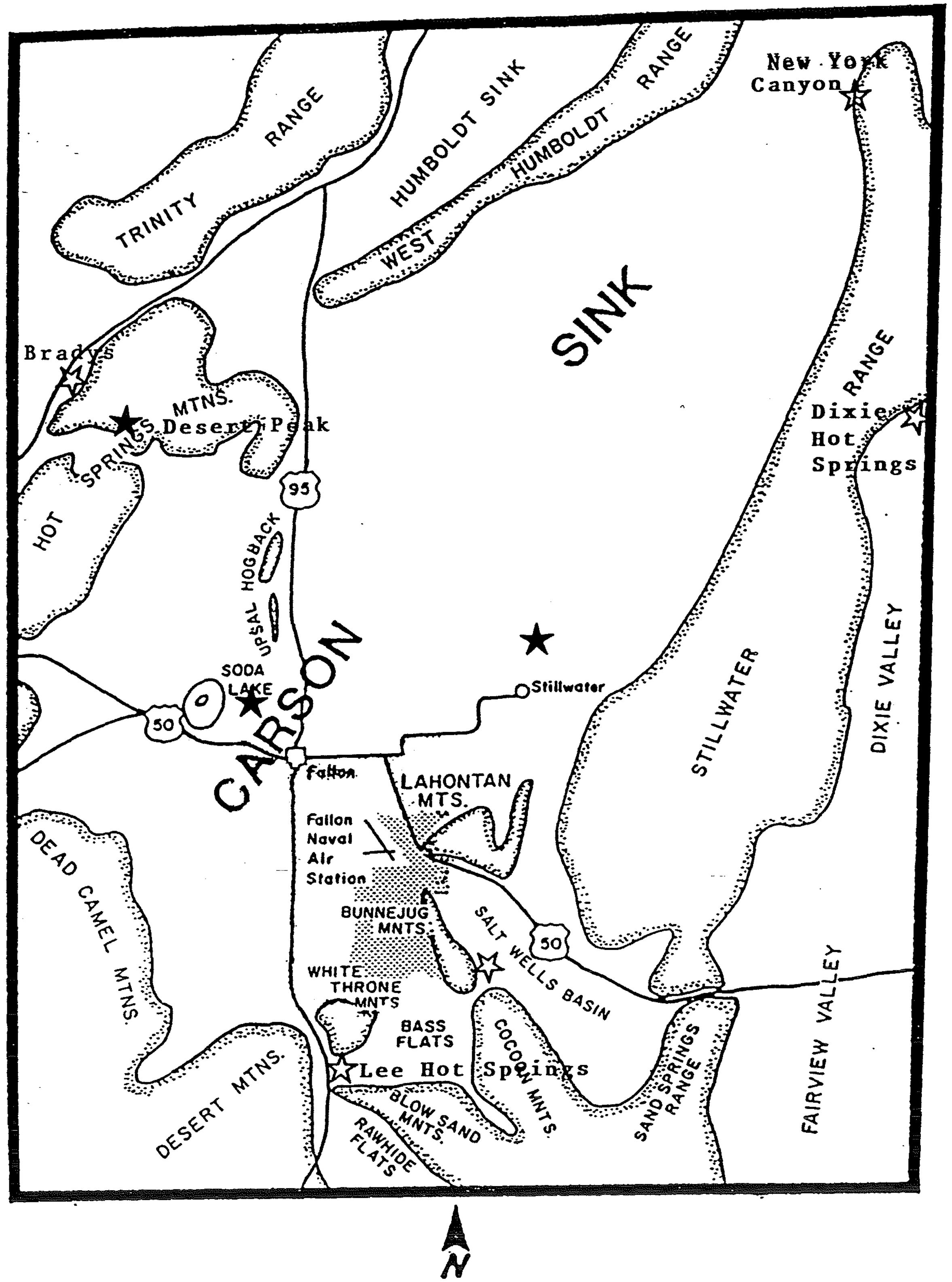


Figure 1. Location map (after Bruce, 1980)

★ Producing Geothermal Power Plant

☆ Potential Geothermal Areas

Carson Lake Prospect

will be igneous intrusives. Mesozoic rocks such as largely define the Dixie Valley and Desert Peak reservoirs are likely to be absent.

Overlying the basement rocks the typical sequence in the Carson Sink area is a highly variable Tertiary rhyolitic sequence being in turn overlain by a basaltic sequence. This is the case at Desert Peak, Dixie Valley, and to a lesser extent at Soda Lake. Both the rhyolitic and basaltic units can vary greatly in thickness and be locally absent as the rhyolites are at Salt Wells. The Unocal 72-7 hole encountered rhyolitic rocks below 2700′ while the OH-2 hole bottomed in basalts. Thus we know the rhyolitic unit is present beneath at least part of the Carson Lake anomaly. Its thickness remains unknown.

Above the basalts a highly variable layer of Tertiary tuffs and/or sedimentary rocks is locally present as at Desert Peak and Dixie Valley. This unit may be largely absent near Carson Lake as shown by the Anadarko and Navy OH-2 holes. Alternatively this unit could be largely sedimentary in nature here and easy to lump together with the overlying Quaternary alluvium. Unocal reports some tuffs in the 72-7 hole above basalts and below the alluvium but it does not appear to be a major unit in the Carson Lake area.

The uppermost formation is the Quaternary alluvium consisting of debris flushed into the Carson Sink ranging from coarse gravel to fine clay in size and texture. These unconsolidated Quaternary sediments can vary from a few feet to several thousand feet thick. At Soda Lake and near Fallon, Quaternary basalt flows are locally interbedded with the unconsolidated sediments but these basalts were not encountered by the OH-2 or 72-7 holes. There are no Quaternary basalts present in the ranges surrounding the southern Carson Sink.

In summary, the regional geology expected beneath the Carson Lake prospect consists of four gross units, all of which are suitable for containing a geothermal reservoir. The deepest is a crystalline basement of Mesozoic or Tertiary granitic rocks. Depths to this granitic unit are probably going to vary from about 2000′ beneath the surrounding ranges to over 5000′ in the deeper parts of the southern Carson Sink. Above the granite a sequence of Tertiary rhyolite of unknown thickness is likely to be present. Tertiary basalts at least 1650′ to 2200′ thick overlie the rhyolite. The uppermost unit is relatively unconsolidated Quaternary sediments with a range in thickness from nothing over the ranges to at least 2200' locally beneath Carson Lake.

Structure

The dominant structures in the Carson Sink area are north-south to northeast-southwest trending normal faults which can have vertical displacements of as much as 12,000' (Figure 2). The prospect area is about 13 miles northeast of the margin of the Walker Lane and presumably little affected by its right lateral wrench faulting. Extensional faulting in the region is ongoing as demonstrated by the 1954 north-south to north-northeast trending surface ruptures on the east side of Rainbow Mountain about 6 miles east of the Carson Lake anomaly (Figure 3, Bell 1984). Five northeast trending Quaternary scarps are present in Wyemaha valley. A curved fault appears to bound the southeastern corner of Carson Lake.

These recent features are outside the thermal anomaly and can not control or localize the thermal anomaly. They are minor structural features when compared with the Stillwater fault in Dixie Valley. Major Quaternary structural features are lacking at Desert Peak and Stillwater so the lack of major features should not downgrade the quality of this prospect. Lineament studies by Trexeler and others (1981) also show no recently active structural features within the thermal anomaly. The only lineaments reported within the thermal anomaly come from a 1983 (?) GeothermEx report for Helioscience Inc. and show three intersecting lineaments at the southeast corner of the NAS (Figure 4). The author briefly examined two sets of air photos at the University of Nevada for lineaments in the thermal anomaly and could find no definite or easily visible lineaments in Quaternary alluvium in or near the Carson Lake thermal anomaly.

A striking north-northeast trending lineament as defined by a steep, narrow, smooth-sided valley spliting Eetza Mountain is approximately on strike with the thermal anomaly. This feature was also noted by Trexler and others (1981). While apparently not Recent in age, this feature is the most conspicuous surface feature within the Carson Lake thermal anomaly.

The drilling data to date indicate that major range-front faults do not occur at the bases of the ranges such as Eetza Mtn. or the Bunejug Mtns. Instead basalt extends out from the hills beneath a thin veneer of alluvium for as much as

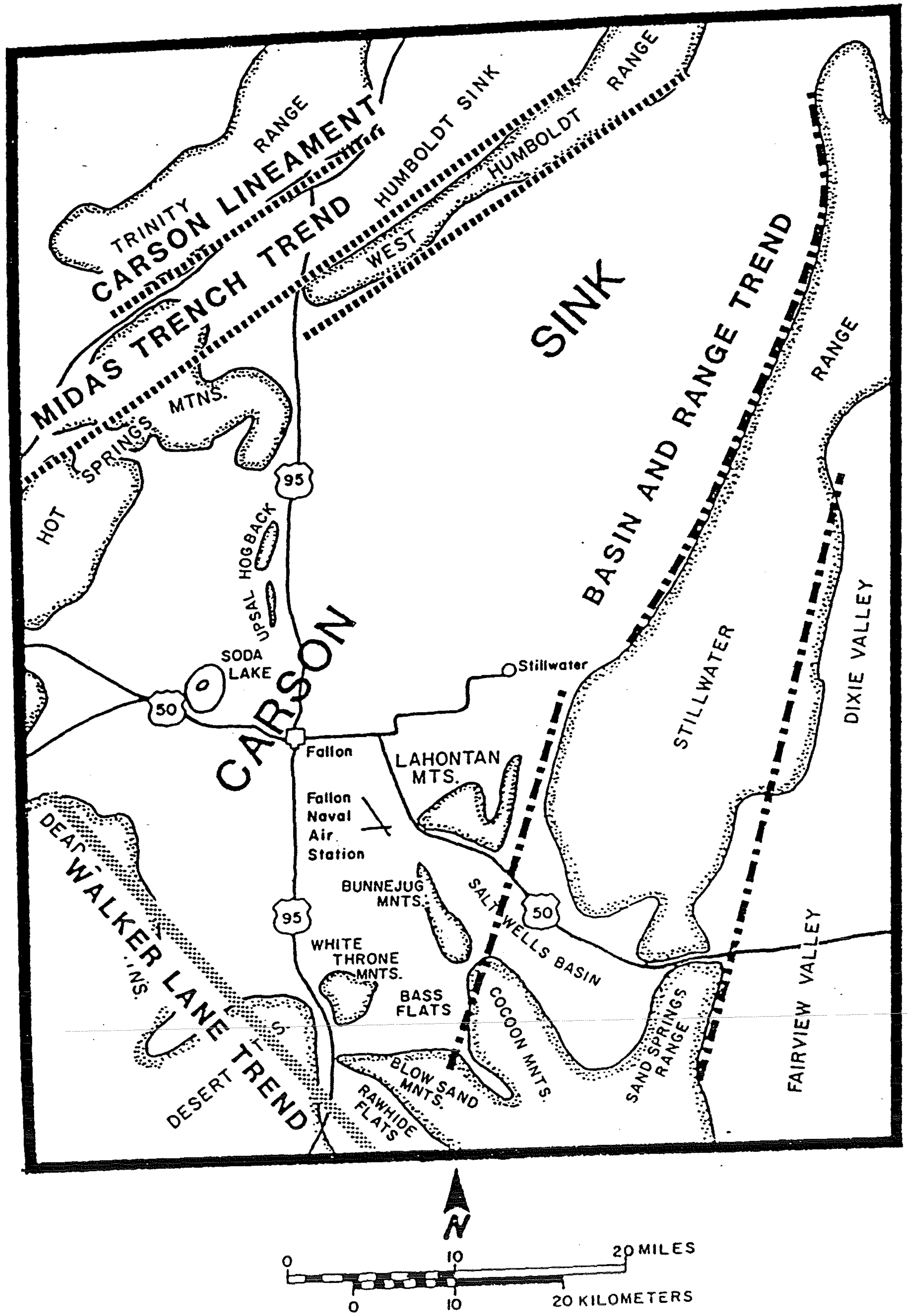


Figure 2. Regional Structural Map (after Bruce, 1980)

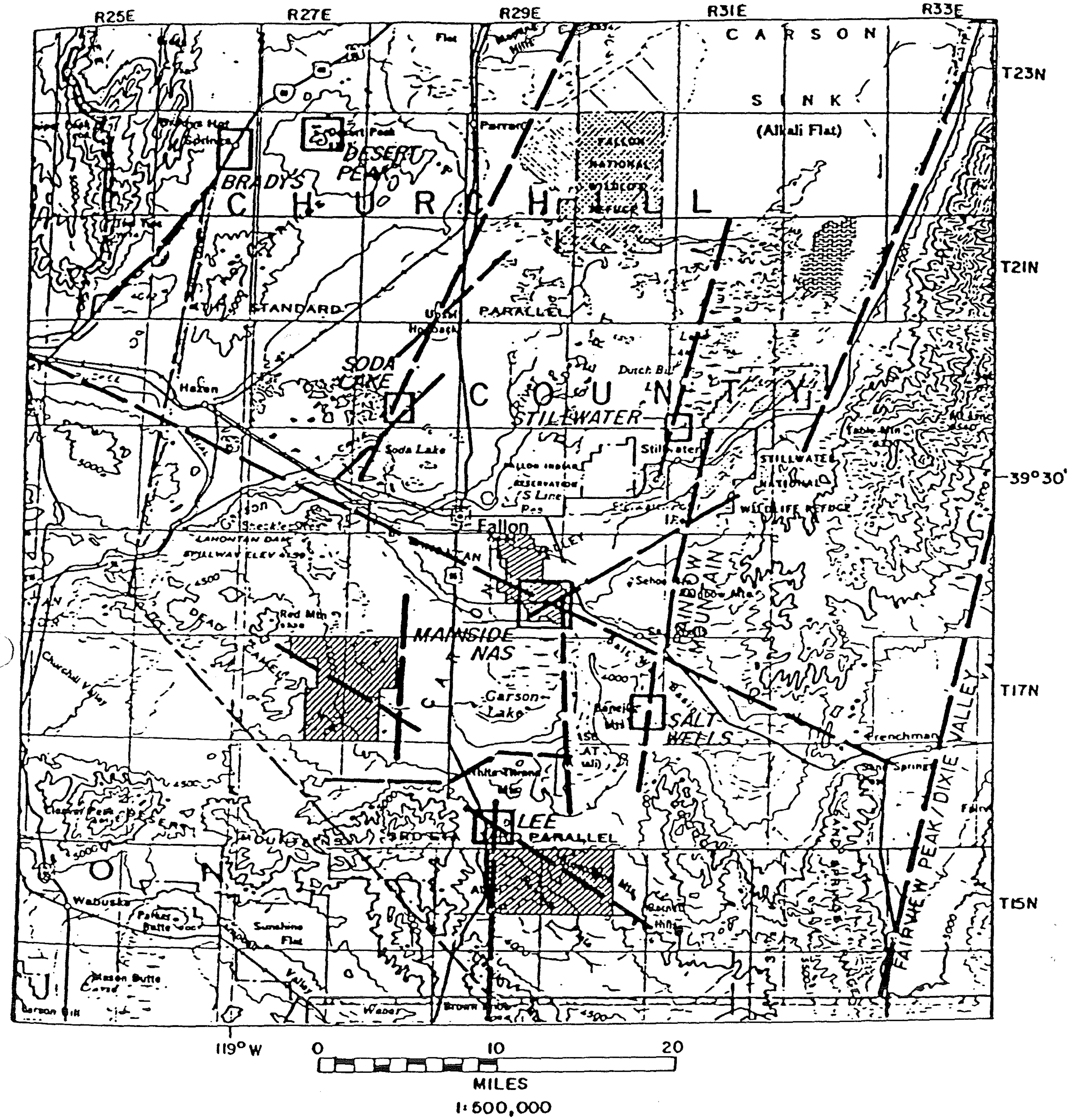
Figure 3. Quaternary Fault Map (after Bell, 1984)

Historic Surface Rupture

Holocene Fault

Pleistocene Fault

Lineament



Generalized trend of major Quaternary fault

Geothermal prospect

Naval reservation

Figure 4. Major Quaternary Fault Map (after GeothermEx, 1983)

half a mile. However, once out in the sink the alluvium does thicken quite rapidly so perhaps significant faults are present but are located in the basin and concealed by alluvium. The lack of surface expression would indicate they are not currently active. Alternatively Eetza Mtn and the Bunejug Mtns may simply be constructional volcanic features more or less lacking nearby large-displacement normal faults. In this case the rapidly thickening alluvium may just represent the ongoing burial of a steep-sided volcanic highland.

In summary no obvious structural targets have been identified within the Carson Lake thermal anomaly. Within 10 miles of the NAS recent structural trends can be found in almost any direction. This permits any controlling structural features within the thermal anomaly to have almost any strike direction.

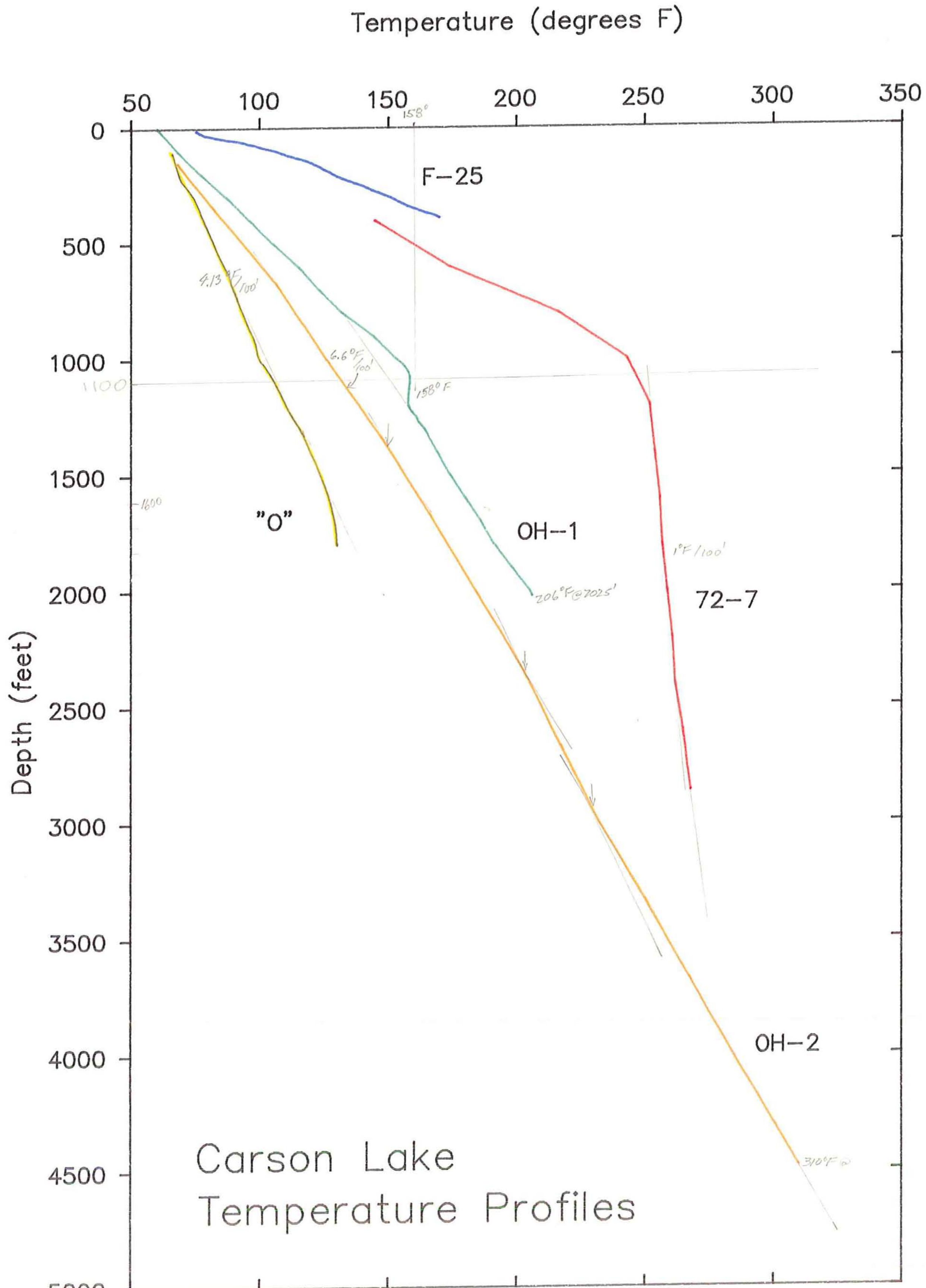
DRILLING RESULTS

Two types of temperature-gradient holes have been drilled in the vicinity of Carson Lake. About 60 holes from 100 to 500' deep have been drilled in the Carson Lake region. Many of these are shown on Plates 1, 2, and 3. Those holes not shown on the plates are simply beyond the margins of the plates. The actual temperature measurements from these holes are contained in Appendix 1.

Four holes from 1800 to 4485' deep have also been drilled and they are described in greater detail below. No deep, large diameter test wells have been drilled.

Well 0

Well 0 was apparently drilled as a deep water well on the NAS a number of years ago. It is not located within the shallow thermal anomaly and has a gradient of 4.13 ^{o}F/100' over most of its length (100' to 1600'). This gradient is probably representative of regional background thermal conditions away from any of the surrounding mountain ranges. Below 1600' well 0 shows a decreasing temperature gradient (Figure 5), for unknown reasons. There are no lithologic data available for well 0 but given its proximity to OH-2 it can be reasonably assumed the well bottomed in alluvium. Aside from defining the background thermal conditions and demonstrating that shallow temperature gradients near 4 ^{o}F/100' do continue to much greater depths, well 0 has little geothermal significance.



Temperature (degrees F)
50
100
150
200
250
300
350
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Depth (feet)
F–25
"O"
OH–1
72–7
OH–2
Carson Lake
Temperature Profiles

Figure 5

OH-1

Hole OH-1 was drilled to a depth of 2025′ in alluvium by the Navy in 1981 as a geothermal exploratory hole. It is located in the extreme southeastern corner of the NAS and has a bottomhole temperature of 206 °F.

There is a 158 °F thermal aquifer at a depth of 1100′ (Figure 5) in alluvium. This aquifer is the major feature on the temperature profile and certainly controls the 9.4 °F/100′ thermal gradient at shallower depths. This shallow gradient is about double the background as defined by well 0. The thermal aquifer is only about 10 °F above the background gradient trend in OH-1, suggesting it is really not a major feature at this location. At other locations this aquifer is a much more significant thermal feature. Below the aquifer the temperature gradient averages 6 °F/100′ which is 50 % above background and definitely indicative of anomalous thermal conditions at greater depth.

OH-2

Hole OH-2 was drilled about 800′ west-northwest of OH-1 on the FASGE #1-36 pad in 1986. It is a core hole with a depth of 4485′. At a depth of 2223′ the hole penetrated into Tertiary basaltic rocks where it remained until its total depth.

The temperature profile of OH-2 can be broken into two linear segments. Above about 1500′ the temperature gradient is 6.6 °F/100′ which is intermediate between well 0 and OH-1 (Figure 5). Below 1500′ the gradient is 5.1 °F/100′, again intermediate. The change in gradient probably results from either changes in thermal conductivity of the formation and/or represents an edge effect of the thermal aquifer noted in OH-1 at a depth of 1100′.

The bottomhole temperature in OH-2 is 310 °F, the highest temperature measured in the area. This is 65 °F above the expected background conditions. This excess heat presumably results from conductive heat flow above a deeper and hotter aquifer which hopefully is capable of functioning as a viable geothermal reservoir. At this stage of exploration there is no way to reliably extrapolate the temperature gradient to reservoir conditions. Pessimistically it is possible that a few feet deeper the gradient could become isothermal. Optimistically it could continue on to temperatures over 400 °F. The available geochemically predicted temperatures probably do not apply to this suggested deeper aquifer.

There is little or no evidence for movement of thermal fluid in the OH-2 temperature profile. This is good evidence that the aquifer seen in OH-1 does not extend as far northwest as OH-2, although its lateral conduction effects might. Thus OH-1 can be interpreted as being close to the margin of the shallow aquifer but over it and OH-2 can be interpreted as being just off the edge of it.

Well 72-7

Well 72-7 was drilled by Unocal in 1981 to a depth of 2892'. The Union lithologic log shows alluvium to a depth of 560' followed by clays, tuffaceous sediments, and tuffs to a depth of 1000'. Below 1000' both mafic and siliceous hard volcanic rocks are present. Between 1000 and 2200' basaltic or andesitic compositions dominate. Below 2200' the formation is generally more siliceous, possibly even being rhyolite below a depth of 2750.

The hole contains numerous permeable intervals. At 565 and 725' the well flowed. Below 1395' some large fractures (up to 6' thick) were encountered and there was much lost circulation, indicating high permeability.

Well 72-7 presents the most striking case for major near-surface movement of thermal fluid within the Carson Lake thermal anomaly (Figure 5). Above a depth of 1000' the temperature gradient is about 15 ^{o}F/100'. Below 1000' the gradient quickly declines to about 1 ^{o}F/100'. At about 1000' the lithology changes from alluvium or tuff to basalt. However, the gradient change is far too great to be explained by just the change in thermal conductivity. Most of the change must result from fluid movement in the formation given the abundant evidence of permeability encountered while drilling.

Well 72-7 convincingly demonstrates that the high near-surface temperature gradients measured in alluvium in the interior of the thermal anomaly are unreliable for extrapolation to significantly greater depths. It also demonstrates the presence of a relatively thick aquifer with a local temperature of 255 to 268 ^{o}F. The temperature of the aquifer is expected to be highly variable with temperatures increasing toward its source.

Accurately predicting the shape of the temperature profile beneath 72-7 is impossible given the available nearby information. The temperature gradient can carry on at 1 ^{o}F/100' for thousands of feet, it can actually reverse, or it can markedly increase.

Shallow Thermal Anomaly

A relatively intense thermal anomaly has been outlined by 30 shallow temperature-gradient holes up to 500′ deep with an approximate spacing of one hole per square mile near the center of the anomaly (Plates 1, 2, and 3).

Only the northeastern margin of the anomaly has not been adequately defined. The cause being access problems, both archaeological and topographic on or near Eetza Mtn., and difficult drilling conditions involving shallow basalt flows. Irregular temperature-gradients above depths of 200′ in these basalt flows further complicate the interpretation of the northeastern edge of the thermal anomaly. Hole Cl-12 is a classic example of this (Appendix 1). Similarly the temperature profiles in holes Cl-7, 8, and 13, which were intended to outline the northeastern margin of the anomaly, are nonlinear and too shallow. As such they can not be reliably extrapolated to greater depths. One additional 500′ hole is needed for increased definition of the northeastern margin of the anomaly at some future time.

Nearly all of the thermal anomaly lies within the boundaries of the Carson Sink where the geology can be simply treated as a homogeneous sedimentary unit. Complicating concerns such as changes in thermal conductivity and refraction of heat can be ignored except in the vicinity of Eetza Mtn. where the temperature data above a depth of 300′ are already of questionable quality.

The simplest thermal data are shown on Plates 1 and 2, maps showing the temperatures at depths of 200 and 400′. The 200 ′ depth was selected because nearly all the holes in the area reached this depth. The 400′ depth was selected because many of the holes reached this depth and it is believed that extrapolations from 100 to 200′ in length do not introduce significant errors. Also a depth of 400′ gets below the shallow irregularities found near Eetza Mtn. These plates contain no interpretation other than the detailed locations of the contour lines between the data points. Due to the relative simplicity of the shallow geology Plates 1 and 2 show similar contour patterns. There are no major temperature gradient reversals or isothermal intervals above a depth of 500′ in most of the prospect area (Appendix 1).

The thermal anomaly is highly elongated in a northeast-southwest direction, generally parallel to the regional structural grain. This can be interpreted in two ways. The first is that a northeast-southwest trending structure is transmitting thermal fluid upward along a strike length of several miles, in a manner similar to Dixie Valley. The second, and preferred interpretation, is that thermal fluid is rising near one end of the anomaly and flowing laterally toward the other end. This situation has been encountered at many thermal areas in Nevada. The most logical flow direction is from Eetza Mountain down the regional hydrologic gradient toward Carson Lake. The shallow thermal aquifer probably underlies most of the thermal anomaly and their boundaries are largely the same.

Normally at this stage of exploration the thermal aquifer has been penetrated by several intermediate depth holes and it is a simple matter of following the aquifer upstream via increasing maximum temperatures. However, in this case due to Unocal's refusal to drill shallow holes and the Navy being confined to the NAS the normal exploration progression has not occurred and deeper holes have been drilled only along opposing lateral margins of the aquifer.

In spite of this, secondary information exists to document the flow direction is most likely from near Eetza Mtn. to the south. Near Eetza Mtn. the temperature contours tend to be closely spaced while in the southern part of the anomaly the contours are significantly further apart. As thermal fluid rises steeply along a structure and then flows laterally in one direction this type of pattern is expected. Contours near the upwelling area will be closely spaced as the aquifer is both hot and confined to a relatively small area. As the fluid moves laterally down the hydrologic gradient it cools by conduction, mixes with cool groundwater, and spreads out, becoming more diffuse. The margins become less distinct and this shows up as more widely spaced contours.

Additional evidence for the general flow direction comes from comparing the flowing temperature of the artesian well and the hottest shallow temperature-gradient hole. The hot artesian well has a fluid exit temperature of 163 ^{o}F which is less than the 170 ^{o}F temperature measured at a depth of 390' in hole F-25. Had hole F-25 been drilled slightly deeper even hotter shallow temperatures would undoubtedly have been measured.

The shallow temperature gradient map (Plate 3) is based on data between depths of 100 and 500' and shows the same pattern as the 200 and 400 foot isothermal maps. The highest gradients and highest shallow temperatures are found in hole AN-SW-1, less than one mile south of Eetza Mtn. The maximum gradient in hole AN-SW-1, 31.4 °F/100', is about 9 times the regional background in the Carson Sink.

The shallow temperature data provide little information on which to base the possible source temperature of the aquifer. It must exceed the 170 °F measured in hole F-27 and presumably exceeds the aquifer temperature of 255 to 268 °F measured in hole 72-7. A crude estimation of a possible aquifer temperature is to extrapolate the maximum shallow temperature gradient to the expected depth of the aquifer. The aquifer has been found at a depth near 1000' in both OH-1 and 72-7. If the gradient in AN-SW-1 is linearly extrapolated to 1000' the aquifer temperature would be 374 °F. For F-7 (the second hottest hole) this estimated temperature of 303 °F. These are admittedly crude estimates but they do give an indication that shallow temperatures over 300 °F are possible.

Another qualitative indication of significantly higher than measured aquifer temperatures comes from the Desert Peak area. Desert Peak well 1-29 encountered a similar thermal aquifer at a depth of 700' with a temperature of 240 °F. The aquifer was traced upstream for 1.4 miles and a reservoir temperature of 406 °F was encountered. The source of the aquifer at Carson Lake may be as much as 3 miles northeast of well 72-7 so there is potential for aquifer source temperatures significantly above 268 °F.

In summary, the shallow thermal water is probably rising from depth near the south side of Eetza Mtn. It appears to make its closest and hottest approach to the surface near hole AN-SW-1. The exact location and attitude of the feature transmitting the thermal fluid to the near-surface environment has not been determined. After the fluid reaches the near-surface environment it quickly loses heat as it spreads out and flows down the hydrologic gradient toward Carson Lake. This shallow thermal aquifer lies below the total depth of all the shallow temperature-gradient holes. Experience has shown that it is generally necessary to obtain production from the source area supplying the shallow aquifer. Thermal fluid flow within the laterally flowing portions of these aquifers is often too dispersed and/or too cool to support high-productivity geothermal wells. A notable exception to this is the Ormat plant at Steamboat Springs, Nevada.

<u>Deeper Thermal Anomaly</u>

Data on the deeper thermal anomaly in the prospect area are confined to three holes on the Naval Air Station. Well 72-7 provides no information on this topic. Moving southeast from well 0 the deeper temperature gradients show a consistent increase to OH-1 (Figure 5). Presumably this increase continues at least a short distance into the lands outside the NAS. This is solid evidence that the majority of the deeper thermal anomaly also lies outside the NAS. If not, the deeper thermal anomaly becomes very limited in extent.

The other boundaries of the deeper thermal anomaly are obscured by the shallow thermal aquifer. There is room for a large deep thermal anomaly to be present beneath the shallow thermal aquifer. However, there is no evidence proving the deeper anomaly is large.

The ultimate temperature of the deeper thermal anomaly is poorly constrained. It must exceed 310 ^{o}F. Comparisons with other reservoirs in the Carson Sink suggest it is unlikely to significantly exceed 400 ^{o}F. Extrapolating the gradient in OH-1 gives a temperature of 400 ^{o}F at a depth of 5260' which is economically feasible. Even shallower depths to the 400 ^{o}F isotherm are possible just southeast of the NAS.

GEOPHYSICS

Gravity

Four gravity surveys have been conducted in the prospect area but only one of these provides detailed coverage of the most interesting portion of the thermal anomaly.

A regional gravity map of the Reno AMS sheet by Erwin and Berg (1977) has very widely spaced stations that are useful primarily for locating regional features such as the deepest parts of the Carson Sink.

In 1981 a subregional gravity survey was performed by Trexler et al (1981 p. 183) covering the Carson Sink area south of Fallon. Spacing of gravity stations was 1/2 to one mile so again only the very large structural features were detected. In this survey the data and corrections are not presented nor are the individual survey points shown on the map.

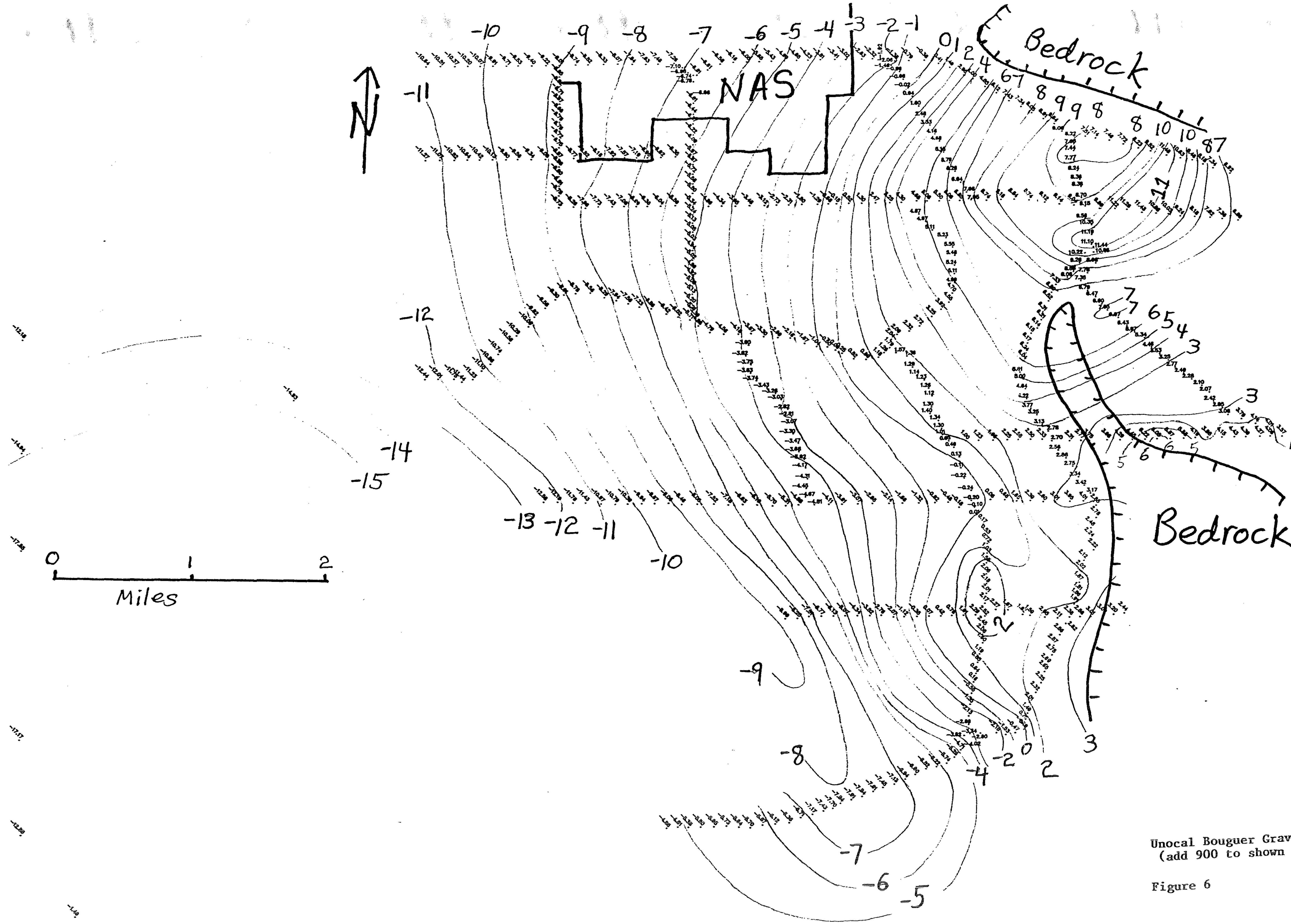
A detailed gravity map of the Fallon NAS published by the Navy (Katzenstein and Danti, 1982 page 19) shows only smooth widely spaced arcuate contours over most of the NAS with increasing valley fill to the southwest. The main feature of interest on this map is located just southeast of the NAS and consists of a tightening of the contours and increasing gravity. Unfortunately this occurs at the very edge of the map. This map shows nothing in the way of structures that might be interpreted as major faults on the NAS.

For Oxbow's purposes the most useful gravity survey is the unpublished data from Unocal that covers much of the thermal anomaly in moderate detail and overlaps the Navy's survey (Figure 6). The survey is confined to roads so there are some rather large localized data gaps. These gaps pose no problem where the gravity contours are relatively straight but in more complicated areas, such as near Eetza Mtn., the gaps do make interpretation of the survey less definitive. This survey shows the valley fill becoming progressively thicker (gravity contours becoming more negative) toward the west with most of the contours trending north to north-northwest. Only locally do the contours tighten indicating possible rapid offsets in the basement topography.

In the northeastern quarter of the survey, which from the temperature data is the expected source area of the thermal aquifer, the contouring is more complicated with much variation in the spacing and strike of the contours. No terrain corrections were performed by Unocal yet the northeastern sites, due to the presence of basaltic hills, are most susceptible to terrain problems. Drilling has shown the alluvium can be less than 100' thick in this area and the relatively high gravity values agree with this. The area between Turupah Flat and Eetza Mtn may be viewed as bedrock that is covered by only thin veneer of alluvium. Within this area the most striking structure is the northeast trending gravity ridge. The meaning or significance of this high is not known.

The gravity data near Eetza Mtn. neither show or allow major structures with large density contrasts to be present. Major structures are not mandatory for movement of thermal fluid. Soda Lake is a good nearby example where a viable reservoir has no obvious gravity signature.

Three things can be done to improve the gravity data near Eetza Mtn. First, the survey needs to be extended to the north and east. Second, some of the gaps between the roads can use a few stations. Third, the data near Eetza Mtn. should be subjected to terrain corrections. However, it is unlikely that these additional data will by themselves result in definition of obvious drilling targets.



Unocal Bouguer Gravity Map
(add 900 to shown values)

Figure 6

Aeromagntics

Unocal and the Navy flew a joint aeromagnetic survey over the region but only the results of the north west part of the survey were ever published by the Navy (Katzenstein and Danti, 1982). The remainder of the data were obtained from the BLM in October 1989 (Plate 4).

Aeromagnetic surveys have not been particularly successful indicators of geothermal reservoirs, especially in basaltic terrains. The reason for this is that basalt is a highly magnetic rock, is generally common in volcanic areas and the Carson Sink, and has great local variations in magnetic susceptibility. For instance, during a ground magnetic survey at Desert Peak it was found that moving the instrument a couple feet could commonly result in readings differing by a few hundred gammas. Thus obtaining reproducible data becomes a problem. Aeromagnetic surveys in basaltic terranes are characterized by the same problems resulting in generally chaotic contour patterns with many small and intense anomalies. In practice these maps are generally most useful in showing generalized structural directions or contacts between basalt and less magnetic rocks.

The Carson Lake aeromagnetic map is easily broken into two halves; the eastern half obviously has basalt at or near the surface and the western half has much more subdued contours indicating a lower magnetic intensity alluvial cover. This interpretation has been confirmed by both deeper and shallow drilling. In the eastern half the dominant structural grain trends both north and north-northeast, as expected. There is a poorly developed northwest trending fabric also. In the western half the main trend appears to be north-south with a subordinate northwesterly trend.

In conclusion, the aeromagnetic data were not expected to offer any new insight into the geology but they are in agreement with the known geological aspects. It is quite unlikely that additional study or interpretation of the aeromagnetic data will result in significant new knowledge of the geothermal system.

The Navy ran a ground magnetic survey over the NAS but it will not be discussed here as it is really of no value in understanding the shallow hydrothermal system.

GEOCHEMISTRY

There is only one thermal occurrence in the Carson Lake area, an artesian well (NW 1/4 Section 7, T 17 N, R 30 E) flowing about 10 gpm of 162 ^{o}F water. Two chemical analyses are available from this well, one collected by Bruce about 10 years ago and one collected by Oxbow and analyzed by UURI late in 1989 (Table 1).

The Carson Lake thermal fluid is a moderately saline sodium chloride water. Figure 7 shows the major chemical relationships and differences between the various thermal fluids in the vicinity of the Carson Sink. In overall salinity and composition the Carson Lake thermal water is remarkably similar to water collected and analyzed by the US Geological Survey from a shallow thermal well at Stillwater. In comparison Bradys and Desert Peak are only about 4 miles apart yet have much greater chemical differences. Carson Lake and Stillwater may have a common deep relationship.

In general the geothermometers work reasonably well at predicting subsurface temperatures in the Carson Sink region, at least where drilling has been extensive enough to discover a reservoir at depth (Table 2). Of the three geothermometers, the Na-K temperatures are consistently too low, a result of relatively high calcium contents in the Carson Sink thermal waters. Consequently the Na-K temperatures will generally be ignored in this discussion.

Drilling at Stillwater has encountered a shallow reservoir with a temperature of 340 ^{o}F that is currently being produced. The geothermometers from the shallow well at Stillwater indicate substantially lower temperatures (284 - 318 ^{o}F) than currently being produced. The shallow well is several miles from the Stillwater power plant so it is possible that the fluid has had an opportunity to reequilibrate and modify its chemistry after presumably leaving the Stillwater reservoir. Similarly the Carson Lake fluid is suspected to have migrated as much as 3 miles laterally since leaving its most likely shallow reservoir site.

The Carson Lake geothermometers indicate temperatures of 283 to 295 ^{o}F which on face value are admittedly not overly encouraging. However, when compared with the nearby Stillwater experience and the fact the Navy has already measured hotter temperatures than predicted, the chemical geothermometers should not be accepted at face value. The similarities in chemistry with Stillwater indicate that any shallow reservoir at Carson Lake is unlikely to have

Table 1

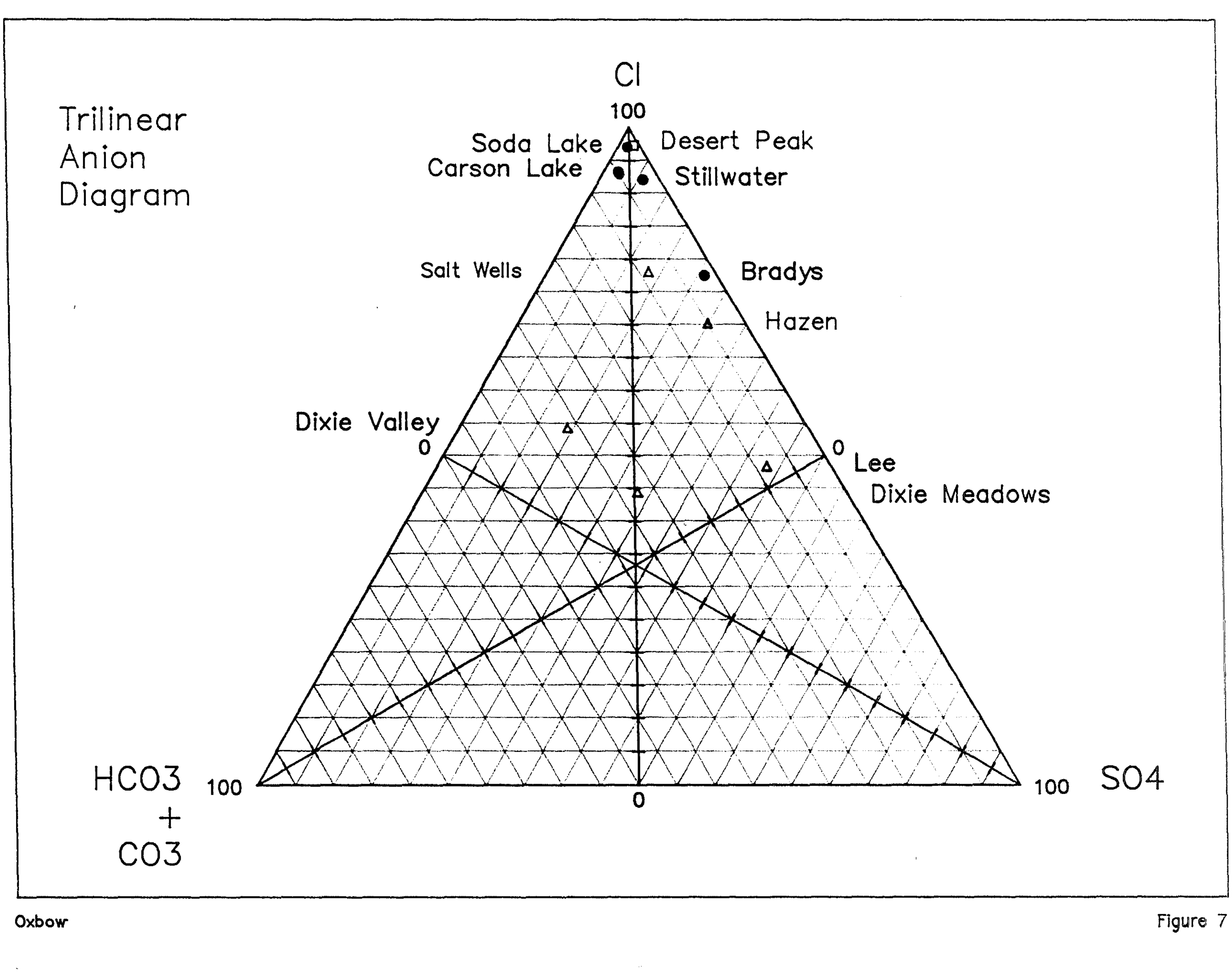
Chemical Analyses of Thermal Fluids in the Carson Sink Area

Sample	Source	Ca	Mg	Na	K	HCO3	CO3	SO4	Cl	F	B	Li	SiO2
Carson Lake Shallow Hot Well	(Oxbow)	60	2.4	1324	29	190		65	2100	1.9	12.3	2.3	119
Carson Lake Shallow Hot Well	(Bruce)	70	3.1	1350	41.5	190	0	58	2138		5.3	2.3	104
Stillwater Shallow Hot Well	(USGS)	108	1.7	1480	42	90	0	190	2200	5.0	15	1.9	170
Soda Lake 84-33	(Chevron)	115		2019	235	106		55	3306		9.3		287
Desert Peak B21-2	(Phillips)	100		2250	250	50		98	3700		16	1.4	350
Bradys Hot Spring	(Phillips)	33		930	72	46		446	1200		5.6	0.8	152
Hazen Hot Spring	(USGS)	70	1.5	620	36	100		400	820	4.2	5.6	1.6	150
Lee Hot Spring	(USGS)	44	0.6	450	26	114	0	470	380	7.9	2.4	0.7	180
Dixie Meadows Hot Spring	(USGS)	3.6	0	190	6.5	111	11	111	126	16.3	0.9	0.4	115
Dixie Valley V-102	(Oxbow)	2.8	0	353	53	228	37	110	304	9.1	7.8	2.3	516
Salt Wells	(Anadarko)	18	2.1	1000	67	130	38	300	1300	8.5	8.1	2	260

Table 2

Geothermometric Data

Location	Sample Collection Temp. (F)	Downhole Production Temp. (F)	Predicted Temperatures Silica (F)	Na-K (F)	Na-K-Ca (F)
Carson Lake (Oxbow)	162		297	239	270
Carson Lake (Bruce)	162		283	271	295
Stillwater (USGS)	205	340	283	271	295
Soda Lake (Chevron)	310	364	403	396	430
Desert Peak (Phillips)	310	390	431	385	431
Bradys (Phillips)	170	340	324	311	300
Hazen (USGS)	187	240 ?	322	346	327
Lee (USGS)	190	?	343	262	324
Salt Wells (Anadarko)	?	265	389	285	378
Dixie Mdws (USGS)	162	288	293	187	290
Dixie Valley V-103+103 (Oxbow)	325	480	491	466	464


Trilinear
Anion
Diagram
Cl
100
Soda Lake
Desert Peak
Carson Lake
Stillwater
Salt Wells
Bradys
Hazen
Dixie Valley
0
0
Lee
Dixie Meadows
HCO3
+
CO3
100
0
100
SO4

temperatures exceeding the mid 300's ^{o}F. Higher temperatures are possible in a deeper reservoir.

The Navy has run a mercury survey over the NAS. While mercury surveys are inexpensive they also tend to produce results that can not be duplicated and are therefore highly suspect. For this reason mercury is not further discussed.

GEOTHERMAL POTENTIAL

The key question in geothermal exploration is - How many megawatts are there and how much will it cost to produce them? This section addresses this question in so far as the existing data permit.

The shallow thermal anomaly most likely has a source temperature in the low to mid 300's ^{o}F and at the present time is best viewed as a binary project. Other binary projects in northwestern Nevada that produce from shallow thermal aquifers range from 2 MW to 12 MW. The shallow thermal aquifer at Carson Lake should not be viewed as exceptional at this time.

There are methods to estimate the amount of energy currently being released by the aquifer. However, experience at Dixie Valley and other places, has shown that there need not be a close relationship between the natural energy loss and the commercially sustainable energy extraction rate over a period of 30 years. An estimate of the natural energy loss at this time would have to be treated as a minimum potential megawatt number and would not be encouraging.

The capability of the deeper reservoir is completely unknown. It will depend to a large extent on the temperature which can range anywhere from 310 to over 400 ^{o}F. This encompasses both binary and flash conversion technology. The depth to the reservoir is unknown but is hoped to be in the 5000 to 6000' range which is relatively deep for northwestern Nevada. However, as compensation the top 2200' of drilling is expected to be inexpensive. The productivity of individual wells can not be predicted nor can the size of the deeper reservoir. In the absence of contradictory data, a best guess is that the deeper reservoir could be capable of a few tens of megawatts.

Drilling costs at Carson Lake are expected to be in the normal range given what is known about the geology. A binary plane would require pumps but the expected temperatures and depths are not viewed as problematical.

FUTURE EXPLORATION STRATEGIES

There are two potential reservoir targets at Carson Lake, the source of the shallow thermal aquifer and the deeper reservoir. Evaluating them requires different strategies. To date Oxbow's efforts have been solely dedicated to evaluating the shallow target.

Shallow Reservoir

The shallow exploration target is the upwelling source feeding the shallow thermal aquifer. In the Basin and Range this target is typically some kind of steeply dipping structure, most commonly a fault, that is transmitting thermal fluid up from depths of several thousand feet. Generally these targets are quite restricted in terms of size when presented on a map but they are characterized by extremely high permeability and the temperatures can be almost as high as the deeper reservoir located thousands of feet deeper. The existing data have not conclusively defined the source area.

Evaluating this shallow target will ultimately require drilling holes to depths of 1000 to 2500'. Two drilling strategies can meet this objective. The first would be to drill another four to eight holes to depths of 200 to 500' in the area south of Eetza Mtn at a cost of $10,000 to $25,000. This may provide enough detail within the thermal anomaly to accurately determine the location of the upwelling fluid. Then a single slim hole approximately 2000' deep could test the source area for both temperature and potential permeability. Depending upon the geology and associated drilling problems encountered, a 2000' deep hole could cost from $100,000 to $200,000. There is always the chance that additional deeper exploratory holes will be required. This is the preferred method.

The second shallow strategy could be to assume that the thermal anomaly is well-enough defined that no additional shallow drilling is necessary. A 2000' slim hole could be located in the vicinity of AN-SW-1. While this hole would likely give reasonable data on the maximum aquifer source temperature that can be expected, actual intersection of permeability would be a matter of luck. Should the temperature be inadequate additional drilling could become unnecessary. Should the temperature be encouraging then more selective drilling can be undertaken to locate permeability. This method is less expensive but has the downside of having a higher probability of not locating a viable reservoir.

If these intermediate depth holes are actually drilled to a depth of 2000' or penetrate beneath the shallow thermal aquifer there is the added bonus that they might provide some information on the deeper target.

Deeper Reservoir

Evaluating this target will ultimately require the drilling of a test well to depths of 5000 to 7000'. Again there are two possible strategies. The first is to just go ahead and drill the smallest diameter and cheapest possible well a short distance southeast of OH-1. A hole located here would probably provide reasonable data on the maximum temperatures that can be expected. It is uncertain if such a wildcat hole could be expected to encounter permeability as no deep structural targets have been identified.

The second deep strategy could be to drill from one to three additional 2000' deep holes to gain a better understanding of the system below the shallow thermal aquifer. Such a program would presumably begin with a hole located east or southeast of the southeastern corner of the NAS. Unfortunately given the current information these 2000' deep holes located to evaluate the deeper target would probably not suffice to locate the source of the shallow aquifer and visa versa.

Obviously dealing with the deeper target is a more expensive proposition than working with the shallow aquifer but the potential rewards are higher.

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CONCLUSIONS

There are two potential reservoir targets at Carson Lake and exploration strategies for dealing with them differ greatly. The cheapest and simplest exploration target is the source area for the shallow thermal aquifer. This is believed to be located near the south side of Eetza Mtn. and probably has a temperature between 300 and 375°F. Currently there is little reason to expect this target will be capable of much over 10 MW.

The second reservoir target lies below a depth of 4500' and has a temperature above 310°F. This area is only known to exist near the southeastern corner of the Fallon NAS. Its potential areal extent is unknown. As it underlies the shallow thermal anomaly its position and outline are completely obscured by the shallower aquifer and it will take holes actually penetrating beneath the shallow aquifer to detect the presence of this deeper target. Currently nothing is known about the potential relationships between these two targets. The megawatt potential of the deeper exploration target is not known but should not be viewed as exceeding 20 or 30 MW.

The geochemistry from a single thermal artesian well indicates the shallow thermal aquifer is closely related to the Stillwater area. Chemical geothermometry suggests reservoir temperatures between 283 and 295 °F. However, the geothermometers at Stillwater understated the actual temperatures by 22 to 56 °F. Thus it is not unreasonable to expect temperatures as high as 340 °F to exist in the prospect at shallow depths. Temperatures as high as 400 °F could exist at greater depths.

The shallow temperature drilling results also indicate that Oxbow's acreage position remains good but can be improved slightly.

RECOMMENDATIONS

The next step in evaluating the shallow aquifer is to drill additional shallow and intermediate depth holes near Eetza Mtn. Additional 500' holes will help in defining the northeastern margin of the shallow thermal anomaly in deciphering the source area for the shallow thermal aquifer. Once these are drilled then holes 1500' to 2000' need to be drilled to confirm the source area and its expected production temperature.

Evaluating the deeper reservoir target will require drilling a 5000' to 7000' hole a short distance east of the southeastern corner of the Fallon NAS.

Six to nine Federal sections in the southwest corner and extreme southeastern corner of the acreage position can be eliminated. Oxbow should make an attempt to lease the 40 acre Truckee Carson Irrigation District parcel near the southeastern corner of the NAS and obtain leases on three additional sections of Federal acreage northeast of Eetza Mtn and over the far southern edge of the shallow thermal anomaly.

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APPENDIX 1

CARSON LAKE PROSPECT

U.S. Navy Temperature Data Base

DEPTH (feet)	TEMPERATURE (1)	(0)	DEPTH	(20)	DEPTH	(21)	DEPTH	(22)	DEPTH	(23)	DEPTH	(24)	DEPTH	(25)	DEPTH	(26)	DEPTH	(27)	DEPTH	(28)	DEPTH	(29)	DEPTH	(30)	DEPTH	(31)
0	60		0	42	0	42	0	51	0	42	0	39	0	46	0	43	0	39	0	42	0	40	0	40	0	41
100	68	65	7.5	43	10	42	12.5	52	5	59	2.5	56	2.5	49	2.5	48	10	61	5	43	7.5	60	2.5	42	7.5	62
200	77	69	12.5	62	12.5	43	15	59	7.5	60	5	57	5	52	5	54	20	60	7.5	46	10	61	5	43	20	61
300	87	74	35	61	17.5	44	17.5	60	10	61	7.5	59	7.5	55	7.5	56	35	59	10	61	15	60	10	44	30	60
400	96	78	50	62	20	45	20	61	15	62	10	61	10	56	10	58	65	60	20	60	17.5	59	12.5	61	50	61
500	105	82	90	63	22.5	46	30	62	22.5	60	40	62	15	57	12.5	59	92.5	61	40	59	25	58	15	62	65	62
600	115	86	130	64	25	50	67.5	63	57.5	61	47.5	64	17.5	58	15	60	120	62	50	60	37.5	59	27.5	61	85	63
700	123	90	177.5	65	27.5	51	87.5	64	80	62	60	65	30	57	20	59	145	63	70	61	55	60	60	62	110	64
800	132	93	205	66	30	52	107.5	65	105	63	70	66	57.5	58	45	60	165	64	85	62	82.5	61	87.5	63	142.5	65
900	144	97	237.5	67	32.5	54	135	66	135	64	80	67	77.5	59	55	61	185	65	115	63	102.5	62	117.5	64	170	66
1000	153	100	267.5	68	37.5	55	165	67	165	65	92.5	68	95	60	65	62	205	66	137.5	64	127.5	63	142.5	65	200	67
1025	156		290	69	40	57	187.5	68	185	66	97.5	69	122.5	61	75	63	225	67	160	65	147.5	64	172.5	66	220	68
1050	157.6		317.5	70	42.5	58	215	69	200	67	102.5	70	140	62	82.5	64	247.5	68	177.5	66	160	65	197.5	67	237.5	69
1075	158.5		355	71	50	59	240	70	225	68	117.5	71	162.5	63	92.5	65	267.5	69	195	67	187.5	66	217.5	68	262.5	70
1100	158.5	106	380	72	62.5	60	277.5	71	242.5	69	122.5	72	190	64	107.5	66	287.5	70	217.5	68	215	67	240	69	292.5	71
1125	158.3		405	73	92.5	61	302.5	72	260	70	127.5	73	220	65	127.5	67	307.5	71	235	69	235	68	262.5	70	310	72
1150	158		442.5	74	95	65	325	73	280	71	137.5	74	240	66	145	68	330	72	267.5	70	247.5	69	292.5	71	342.5	73
1175	157.9		457.5	75	115	66	355	74	292.5	72	145	75	257.5	67	155	69	355	73	287.5	71	270	70	300	72	372.5	74
1200	157.9	110	475	76	157.5	67	385	75	315	73	152.5	76	282.5	68	162.5	70	375	74	310	72	295	71	325	73	392.5	75
1225	159.1				197.5	68	410	76	322.5	74	160	77	297.5	69	177.5	71	395	75	332.5	73	310	72	350	74	412.5	76
1250	161				235	69	432.5	77	350	75	167.5	78	315	70	182.5	72	410	76	347.5	74	350	73	370	75	435	77
1275	162				272.5	70	457.5	78	365	76	175	79	340	71	192.5	73	430	77	372.5	75	365	74	392.5	76	457.5	78
1300	164	116			312.5	71	485	79	397.5	77	182.5	80	355	72	202.5	74	455	78	392.5	76	385	75	412.5	77	482.5	79
1400	169	120			352.5	72			402.5	78	190	81	365	73	210	75	477.5	79	412.5	77	405	76	432.5	78		
1500	174	124			380	73			417.5	79	197.5	82			222.5	76	497.5	80	432.5	78	425	77	452.5	79		
1600	180	127			410	74			437.5	80	200	83			235	77			455	79	447.5	78	470	80		
1700	186	129			442.5	75					207.5	84			247.5	78					465	79	495	81		
1800	191	130									217.5	85			257.5	79					482.5	80				
1900	198										227.5	86			267.5	80					505	81				
2000	205										235	87			277.5	81										
2025	206										245	88			285	82										
											252.5	89			295	83										
											260	90			305	84										
											267.5	91			317.5	85										
											275	92			332.5	86										
											285	93			342.5	87										
											292.5	94			355	88										
											300	95			367.5	89										
											307.5	96			375	90										
											317.5	97			385	91										
											325	98			395	92										
											335	99			407.5	93										
											345	100			420	94										
											352.5	101			430	95										
											360	102			440	96										
											370	103			450	97										
											380	104			460	98										
											387.5	105			467.5	99										
											397.5	106			480	100										
											405	107			490	101										
											415	108			502.5	102										
											425	109														

CARSON LAKE PROSPECT

Phillips Petroleum Co. Temperature Data Base

DEPTH (feet)	(F1)	(F2)	(F3)	(F4)	(F5)	(F6)	(F7)	(F8)	(F9)	(F10)	(F11)	(F12)	(F13)	(F14)	(F15)	(F16)	(F17)	(F18)	(F19)	(F20)	(F21)	(F22)	(F23)	(F24)	(F25)	(F26)	(F27)	(F28)
TEMPERATURE (°F)																												
10	60.8	67.6	66.2	64.9	66.1	60.4	68.4	59.6	67.2	63.7	64.4	65.2	68.2	67.6	63.3	64.2	66.2	72.3	61.7	61.3	65.5	66.2	63.5	63.3	75.4	60.2	63.5	62.8
20	56.2	61.2	61.0	59.8	60.2	59.2	64.1	58.9	60.4	61.0	60.0	61.2	62.2	63.5	62.8	59.8	63.8	74.8	59.9	59.3	59.2	63.2	61.0	62.9	76.8	60.1	63.3	63.5
30	56.8	64.0	61.2	59.9	59.0	59.4	66.2	59.2	60.1	61.0	59.6	60.8	61.1	62.0	62.8	59.6	66.8	80.0	59.8	59.3	59.0	63.7	60.8	62.6	78.7	60.0	63.3	62.7
40	57.4	65.3	62.2	60.1	59.8	59.8	67.2	60.1	60.8	61.3	59.8	60.8	61.1	62.1	63.5	60.0	67.9	86.0	60.3	59.7	59.6	64.8	60.0	63.1	83.0	60.1	64.0	64.1
50	57.8	66.8	62.4	60.3	60.2	60.2	68.0	60.5	61.2	62.0	59.8	60.7	61.6	62.0	63.8	60.2	68.1	91.0	60.7	60.4	60.0	65.7	60.5	63.5	87.4	60.1	64.2	63.7
60	58.2	68.4	63.0	60.6	60.6	60.6	69.6	60.1	61.5	62.2	59.9	60.7	61.7	62.0	64.0	60.8	69.8	93.9	61.2	60.9	60.3	66.5	60.6	64.2	93.2	60.2	64.4	64.5
70	58.8	69.6	63.2	61.0	61.0	60.8	70.5	61.8	62.1	62.6	60.0	60.6	61.9	61.9	64.3	61.0	71.0	96.5	61.6	61.1	60.8	67.2	60.6	64.5	96.1	60.6	65.0	64.7
80	59.2	70.8	63.5	61.4	61.5	60.9	71.4	62.2	62.4	63.1	60.3	60.8	62.0	62.0	64.4	61.6	72.0	99.8	62.0	62.0	61.6	68.6	60.8	65.0	99.7	60.7	65.8	65.0
90	59.8	71.8	64.0	62.0	62.0	61.2	72.8	63.0	63.0	63.5	60.6	60.8	62.1	62.0	64.5	62.2	73.1	102.5	62.9	62.2	62.0	70.0	61.02	65.3	102.8	60.8	65.0	65.5
100	60.0	72.6	64.4	62.2	62.2	62.0	74.1	63.5	63.4	64.0	61.0	61.0	62.2	62.0	64.6	62.8	74.4	106.2	63.7	62.5	62.9	71.4	61.2	65.7	106.3	60.9	66.0	66.0
110	60.6	74.2	64.8	62.5	62.8	62.4	75.2	64.0	63.8	64.3	61.2	61.1	62.3	62.1	64.8	63.2	75.8	110.5	64.5	63.0	63.5	72.3	61.02	66.1	108.7	61.2	66.1	66.1
120	61.0	75.2	65.4	63.2	63.4	62.9	76.5	64.4	64.2	64.7	61.8	61.4	62.5	62.2	65.2	63.6	77.6	116.6	64.8	63.4	64.0	73.3	61.7	66.7	111.2	61.5	66.8	66.6
130	61.4	76.2	66.0	63.5	63.5	63.2	78.1	64.8	64.5	64.9	62.2	61.7	62.8	62.3	65.6	64.0	80.0	121.7	65.2	63.9	64.3	74.2	61.8	67.0	114.5	61.7	67.2	66.9
140	62.0	77.4	66.2	64.2	64.0	63.5	80.1	65.0	64.9	65.1	62.6	62.0	63.0	62.6	66.1	64.5	82.1	126.8	66.0	64.2	64.7	75.3	61.95	67.3	117.6	62.0	67.8	67.3
150	62.4	78.9	66.4	64.8	64.5	64.0	81.6	65.8	65.1	65.6	63.1	62.2	63.2	63.1	66.3	65.0	84.0	130.6	66.3	64.7	65.5	76.0	62.1	67.9	119.8	62.2	67.0	67.8
160	62.8	81.6	66.8	65.4	64.8	64.2	83.0	66.2	65.4	66.0	63.9	62.5	63.5	63.6	66.6	65.5	85.8	137.2	66.7	64.9	65.7	77.0	62.2	68.3	121.7	62.4	68.1	68.0
170	63.2	82.8	67.1	65.8	65.2	64.6	84.6	66.8	66.0	66.3	64.0	63.0	63.9	63.8		66.2	87.1	140.4	67.1	65.1	66.1	77.9	62.3	69.1	123.6	62.5	68.0	68.1
180	63.6	83.8	67.4	66.4	66.0	65.0	86.0	67.2	66.5	66.8	64.5	63.2	64.4	64.2	67.0	66.5	88.8	145.0	67.8	65.6	66.4	79.3	62.5	68.7	125.0	62.7	68.4	68.9
190	64.0	85.1	67.8	66.6	66.4	65.4	88.0	67.9	66.8	67.1	65.0	63.8	64.8	64.4	67.2	67.0	90.0	148.4	68.0	66.0	66.7	80.5	62.7	70.3	127.1	63.0	68.1	69.2
200	64.4	86.2	68.0	67.0	66.6	65.9	89.4	68.2	67.2	67.3	65.4	64.0	65.1	63.8	67.4	67.2	91.0	152.2	68.6	66.4	66.8	82.0	63.0	71.1	128.5	63.3	69.5	69.3
210	64.8	87.3	68.8	68.2	66.9	66.2	91.0	69.1	67.5	67.9	66.1	64.2	65.5	64.0	67.6	67.8	92.8	156.0	69.0	66.5	67.0	83.2	63.1	72.0	130.1	63.6	70.0	69.4
220	65.0	88.8	69.0	67.6	67.2	66.5	92.6	69.8	67.8	68.2	66.4	64.4	65.9	65.2	67.9	68.0	94.2	161.0	69.6	66.7	67.3	84.2	63.2	72.5	132.2	63.7	70.1	69.5
230	65.4	89.5	69.5	69.9	67.8	66.9	93.8	70.4	67.9	69.0	66.8	64.2	66.2	65.6	68.2	68.2	94.8	167.8	70.5	66.9	67.8	85.6	63.4	73.2	134.6	63.8	70.4	69.5
240	65.6	90.8	69.8	68.2	68.0		94.8	70.8	68.1	69.4	67.0	65.0	66.4	66.0	68.6	69.0	97.2	172.0	71.0	67.0	68.1	86.5	63.6	74.0	136.8	64.2	70.0	69.5
250	66.1	92.0	70.2	69.0	68.4	67.8	96.2	71.4	68.2	69.8	67.3	65.2	66.7	66.2	69.0	69.5	98.5	177.0	71.8	67.2	68.8	88.0	64.0	74.5	139.8	64.5	70.4	69.7
260	66.4	93.2	70.5	69.6	68.7	68.0	97.5	72.0	69.8	70.2	67.9	65.6	66.9	66.5	69.4	70.2	100.2	181.0	72.3	67.5	69.3	89.2	64.08	75.2	141.7	64.7	72.3	69.8
270	66.5	94.0	70.8	70.2	69.2	69.2	99.4	72.8	70.4	70.8	68.3	66.1	67.0	66.7	69.6	70.9	102.0	184.0	73.4	67.9	70.0	91.2	64.2	75.8	143.6	64.9	71.5	69.9
280	66.8	95.1	71.2	70.5	69.6	69.6	100.8	73.8	71.0	71.1	69.0	66.5	67.3	67.0	69.8	71.8	103.0	187.5	73.7	68.2	70.4	91.4	64.5	76.0	146.0	65.0	71.3	69.9
290	66.9	95.8	71.8	71.0	70.1	70.0	102.0	74.4	71.8	71.6	69.6	66.8	67.9	67.2	70.2	72.1	104.2	190.5	74.3	68.6	70.7	92.8	64.6	76.5	148.2	65.4	73.3	69.9
300	67.0	96.8	72.0	71.4	70.6	70.4	102.8	75.0	72.1	72.0	70.1	67.1	68.2	67.4	70.5	72.4	106.0	193.5	75.0	69.0	71.6	93.7	64.8	77.0	150.4	65.8	74.0	70.0
310	67.2	97.9	72.5		71.0	70.6	104.0	75.6	73.0	72.6	70.9	67.2	68.8	67.8	70.8	73.3	107.4	196.6	75.7	69.3	71.9	94.6	65.0	78.2	152.2	65.9	74.3	
320	67.4	99.2	72.9	72.2	71.8	71.2	105.0	76.0	73.8	73.2	71.0	67.8	69.2	67.9	71.2	74.0	109.5	201.5	76.0		72.3	95.6	65.3	78.4	154.0	66.1	73.5	
330	67.6		73.4	72.9	72.0	71.8	106.5	76.8	74.2	73.9	71.3	68.0	69.6	68.2	71.5	74.5	110.8	204.0	76.8	70.1	73.0	96.8	65.5	79.3	155.8	66.2	75.2	
340	67.8		74.0	73.4	72.2	72.2	108.0	77.5	74.9	74.4	71.7	68.2	69.9	68.8	72.0	75.2	111.6	207.5	77.5	70.7	73.4	97.6	66.0	80.2	157.6	66.4	75.5	
350	68.0		74.4	74.0	72.6	73.0	109.5	78.8	75.2	75.0	71.9	68.6	70.2	69.0	72.2	75.5	112.8	208.5	78.1	71.0	74.0	98.8	66.1	81.0	160.1	66.7	75.7	
360	68.2		75.0	74.2	73.0	73.5	110.2	79.4	75.5	75.3	72.1	69.0	70.8	69.4	72.6	76.0	114.5	210.5	79.2	71.6	74.6	100.0	66.3	81.9	162.4	67.0	75.8	
370	68.5		75.6	75.0	73.4	74.2	111.3	80.0	76.0	75.5	72.5	69.3	71.1	69.6	73.0	76.2	117.0	216.5	79.8	71.9	75.0	101.5	66.5	82.6	165.0	67.2	76.0	
380	68.9		75.8	75.4	73.9	74.8	112.8	80.4	76.2	75.8	73.1	69.8	71.8	69.8	73.5	76.8	118.8	219.5	80.8	72.3	75.5	102.5	66.8	83.2	168.2	67.4	75.7	
390	69.1		76.0	75.8	74.3	75.2	114.0	81.2	76.8	76.0	73.7	70.1	71.9	70.2	73.8	77.3	120.1	221.0	81.7	72.8	75.8	103.5	67.0	83.4	170.0	67.6	76.9	
400	69.4		76.2	76.2	74.8	75.6	115.8	82.0	77.2	76.1	74.1	70.8	72.1	70.6	74.0	78.0	121.2	221.8	82.3	73.2	76.2	104.2	67.2	84.2		67.8	77.0	
410	69.6		77.0	76.6	75.2	75.9	117.0	82.4	77.8	76.5	74.8	71.0	72.6	70.8	74.4	78.5	123.0	223.3	83.0	73.7	76.7	105.7	67.3	85.0		68.0	77.5	
420	69.8		77.2	77.0	75.5	76.0	118.5	83.0	78.0	76.9	75.0	71.3	72.9	71.0	74.8	79.0	124.8	226.4	83.6	74.1	78.2	106.8	67.8	85.5		68.2	77.8	
430	70.1		77.8	77.2	75.8	77.0	119.5	83.8	78.4	77.2	75.2	71.8	73.1	71.2	75.2	80.2	126.0	228.1	84.4	74.4	78.7	108.4	67.95	86.0		68.4	78.2	
440	70.5		78.1	78.2	76.2	77.2	120.8	84.2	79.2	77.6	75.5	72.0	73.8	72.0	75.5	81.0	127.5	229.0	85.0	75.0	79.3	109.8	68.15	86.3		68.8	78.5	
450	70.7		78.8	78.8	76.6	77.6	121.8	85.4	80.1	78.9	75.8	72.2	74.0	72.2	75.8	81.3	129.2	231.2	85.5	75.2	78.8	111.0	68.3	87.1		69.1	78.9	
460	70.9		80.8	79.1	77.0	78.0	123.0	86.0	80.8	79.1	76.0	72.4	74.7	73.0	76.0	82.2	130.8	235.0	86.2	75.7	80.4	112.2	68.9	88.0		69.4	79.3	
470	71.0		81.2	80.0	77.4	78.2	124.0	86.2	81.2	79.5	76.2	73.0	75.0	73.2	76.2	82.8	132.5	237.5	87.0	75.9	81.0	114.0	69.1	88.8		69.8		
480			81.8	80.6	77.9	78.8	125.0	87.0	81.6	81.2	76.8	73.4	75.2	73.8	76.8	83.4	134.5	238.0	87.5	76.1	81.5	115.0	69.3	89.4		70.0		
490			82.2	81.2	78.0	79.2	126.2	87.4	82.8	81.6	77.8	73.6	75.8	74.0	77.0	84.0	136.5	239.0	88.1	76.9	82.0	116.5	69.8	90.2		70.3		
500			82.2	81.8	78.1	79.6	127.0	88.0	83.0	82.0	78.2	73.8	75.8	74.0	77.2	84.5	139.5	239.4	88.8	77.5	82.5	117.8	70.0	90.5		70.6		

F7 F8

F24 F25 F27
dT/dz 6.0°F 24.8
F7- 11.2 F-8 6.0
350
390
460

APPENDIX I
Carson Lake Prospect
Oxbow Temperature Database

Feet	CL-1(b)	CL-2(a)	CL-3(a)	CL-4(b)	CL-5(b)	CL-6(b)	CL-7(b)	CL-8(b)	CL-9(b)	CL-10(b)	CL-11(b)	CL-12(b)	CL-13(b)
									12.9	9.7			
	10-24-89	10-12-89	10-16-89	10-27-89	10-24-89	10-24-89	11-9-89	11-9-89	10-27-89	10-27-89	10-27-89	3-16-90	3-13-90
10			65.7										55.4
20	60.8	85.4	67.5	70.9	60.3	60.3	64.2	64.6	64.4	61.1	67.6	69.6	62.8
30			68.2										64.6
40	60.9	86.6	68.7	78.7	59.7	60.5	67.9	64.8	59.1	59.7	71.2	75.4	65.8
50	61.2	87.5	69.8	82.8	60.5	61.5	69.3	65.5	58.5	60.4	74.1		67.3
60			72.9									77.7	68.4
70	63.0	89.3	74.7	87.3	62.0	64.0	72.0	67.0	59.0	60.9	76.1		69.3
80			76.6									77.5	70.2
90	64.6	90.6	77.9	94.0	63.7	65.6	74.1	68.3	59.9	61.7	79.2		71.2
100	65.3	91.3	79.7	97.8	64.4	66.6	74.8	69.0	60.2	62.4	80.5	77.4	
110			80.8										
120	67.0	93.9	82.2	104.9	66.4	68.7	75.5	70.4	60.7	62.9	84.3	77.4	
130			83.7										
140	68.8	99.5	85.1	111.3	68.4	70.7	76.0	71.9	61.9	63.7	87.9	78.3	
150	69.7	102.4	86.2	114.5	69.4	71.9	76.0	72.6	62.3	64.1	89.5		
160			87.6									83.8	
170	71.5	108.4	88.7	119.7	71.2	74.2	76.0	73.7	63.3	65.3	92.2		
180			90									88.7	
190	73.1	113.4	91.2	123.9	72.8	76.8	79.6	74.0	64.3	66.7	94.1		
200	73.8	116.3	92.45		74.0	77.9					95.0	91.9	
210													
220	75.4	121.7			76.1	80.3					97.0	94.5	
230	76.0	123.3			77.2	81.5							
240												97.2	
250	77.6	128.5			79.5	83.9							
260												100.2	
270	79.1	133.5			81.5	86.4							
280	79.9	136.0			82.4	87.5						103.3	
290													
300	81.3	141.9			84.0	89.8						106.7	
310													
320	82.7	148.4			86.0	92.1						110.5	
330	83.3	151.5			87.0	93.3							
340												114.3	
350	84.7	156.2			88.9	95.8							
360												118.2	
370	86.0	161.7			90.9	98.1							
380	86.7	164.3			91.8	99.2						122.2	
390													
400	88.1	169.1			93.7	101.8						125.8	
410	88.8	171.8			94.7	103.0							
420												129.7	
430	89.9	175.1			96.7	105.6							
440												133.7	
450	91.3	179.3			98.6	108.3							
460	92.0				99.7	109.6						137.8	
470													
480	93.3				101.5	112.0						141.8	
490												143.6	