**GED STUDIES AND DRILLING OF
AMERICULTURE STATE 2,
AMERICULTURE TILAPIA FARM
LIGHTNING DOCK KGRA, ANIMAS
VALLEY, NM**

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FINAL TECHNICAL REPORT

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1.0 INTRODUCTION

1.1 PURPOSE

This report summarizes the GRED drilling operations in the AmeriCulture State 2 well with an overview of the preliminary geologic and geothermal findings, from drill cuttings, core, geophysical logs and water geochemical sampling.

1.2 LOCATION AND SETTING

The Lightning Dock KGRA is located in the Animas Valley, Hidalgo County, New Mexico near Cotton City (Figure 1-1). The area lies within the Mexican Highland section of the southern Basin and Range Province. The known productive portion of the KGRA is characterized by an elongate heat-flow anomaly that apparently represents outflow and a localized upflow zone of unknown characteristics at the southern end of the anomaly. A shallow north-flowing plume underlies the tapered northern end of the heat-flow anomaly (Witcher, 2002). Production wells that tap the outflow plume are used to heat 30 acres of the Burgett geothermal greenhouses and the AmeriCulture Tilapia Farm.

Figure 1-1. Location map of Lightning Dock geothermal area.

2.0 DRILLING AND SITE OPERATIONS

1.1 OBJECTIVES AND SCOPE

The purpose for deepening the AM-2 well was to confirm hypothesized subsurface structure and stratigraphy and determine if inferred higher temperature (~300° F) outflows exist in the Upper Jurassic - Lower Cretaceous Bisbee Group and possibly the Pennsylvanian Horquilla Formation. Geologic and temperature logs in nearby AMAX 55-7 exploration hole indicated that potential existed for a deep outflow plume with temperatures around 300° F in the Lower Cretaceous rocks. Core drilling reached all planned stratigraphic targets by 1,687.5 ft depth and the follow on reverse circulation rotary drilling continued the exploration into the Pennsylvanian Horquilla Formation at the planned TD of 2,100 ft.

2.2 DRILL SITE LAYOUT AND WATER

The AM-2 well site is within the Lightning Dock Known Geothermal Resource Area (KGRA) in the northeast quarter of the northeast quarter of section 7, Township 25 South, Range 19 West, approximately 825 ft from the east section line and 319 ft from the north section line at an approximate elevation of 4,217 ft. The drill site is located on private surface, owned by AmeriCulture, Inc., adjacent and east of the AmeriCulture Geothermal Tilapia Farm complex. Access to the drill site is via a graded dirt road.

No dirt work was required to build a level and stable drilling pad. A backhoe was used to create small mud pits. Approximately 1,300 ft of pipeline from an AmeriCulture water supply well provided water for all drilling operations to a large portable 20,000-gallon storage tank at the drill site. Overall layout provided for efficient water, mud, and equipment resupply, drilling operations, and well site geotechnical operations.

2.3 DRILLING EQUIPMENT

Boart Longyear provided their wireline core-drilling unit LS 244EC. The drilling rig is basically a Longyear 44 size unit that is enhanced with computerized controls for a pneumatic top drive, draw works, and other advanced features. The final recovery of lost fish during coring and reaming of the hole to the 2,100 ft TD was done with the Lang LK-23 drill rig built in 1990. The LK-23 rig is a Drilltech DH-3 series platform that is equipped with a hydraulic tophead drive on a 52 ft mast. Pullback is rated at 90,000 lbs, pulldown at 30,000 lbs, and rotary tork at 13,000 ft/lbs. A 900 cfm @350 psi compressor provides nominal compressor air capability. While over the AM-2 borehole, the LK-23 rig used rig and auxiliary air compressors in a reverse rotary drilling mode.

2.4 WELL CONTROL

In the event that pressured fluids, gas, or rapidly boiling or flashing superheated water entered the AmeriCulture well while drilling, several steps were taken to insure that well discharges would be controlled. Well control consisted of a well head with valved flow and kill line ports, a frac tank with 20,000 gallons of water on site, and the monitoring of bottom-hole temperatures (BHT) and blooie line temperatures. A rotating head was installed over the diverter. The kill line port was connected to the auxiliary water tank via a pump.

2.5 HYDROGEN SULFIDE MONITORING

Industry-standard, continuous-monitoring, hydrogen sulfide detectors, equipped with automatic visual and audio alarms, were installed at suitable locations to include the drill rig operators console, on the rig floor near the rotating head and diverter, and at the flow or blooie line discharge. Alarms were set to trigger visual alarms at 10-ppm hydrogen sulfide and audio alarms at 15 ppm. A windsock was also installed at the location entry where it was visible to

all site personnel. Self-contained breathing equipment was placed for emergency use at two different briefing area locations. The briefing areas were situated to provide one area that would be upwind of the hole at any given time. A warning and status sign was also placed at the entry to the drill site.

2.6 WELL SITE GEOLOGY AND OPERATIONS MONITORING

Well site geotechnical operations included making field geologic logs of core and cuttings and archiving core and cuttings for future reference or study. Currently, the core is stored at the AmeriCulture facility. Geophysical and temperature logs completed the geotechnical operations.

Operations monitoring included daily well history report log, daily cost tabulation. A summary daily well history report log is listed in **Appendix 1**. The daily report log was used to document footage per shift, blooie temperature measurements, all drilling activities, and materials used in drilling.

2.7 DRILLING SUMMARY AND ANALYSIS

Drilling and casing depths in this report are referenced to the ground surface. The deepening of the AM-2 borehole was done with wireline core drilling tools above 1,687 ft depth feet depth and with reverse circulation rotary tools between 1,687 and 2,100 ft depth.

The GRED II project drilling and deepening of the existing 910 ft deep AmeriCulture State 2 (AM-2) began on 13 August 2003 and reached total depth (TD) of 2,100 ft on September 28, 2003 (**Table 2-1**). **Appendix 1** is a Summary Geologic Log of the AM-2 well. **Appendix 2** is Core Run Log and **Appendix 3** is a Daily Report Log with detail on drilling operations and events.

On August 11, 2003 Boart Longyear began rigging up the continuous wireline core drilling unit LS 244EC. This drilling rig has computerized controls for a pneumatic top drive and draw works. While cleaning the hole of thick mud from earlier rotary drilling, a 4 ½ -inch drilling liner was hung inside a 12 ¾ -inch

casing from the surface to 907 ft depth without tag cementing the liner shoe in place. After preparing the wellhead with a diverter, HQ coring began at 906.5 ft depth (GL elevation 4,217) on 13 August 2003. The first 40 ft was cored with a "fast" rotation of 500 to 550 rpm. Due to the gritty nature of the rhyolite

Table 2-1 Summary well drilling history.

DATE	DEPTH	ACTIVITY
	ft	
8/11/2003	n/a	Boart Longyear rigging up continuous wireline rig LS244EC. Install new well head flange.
8/12/2003	906.5	Cleaning and conditioning hole; run 4 1/2 HWL inch liner; hung with no tag cement at shoe.
8/13/2003	937.5	Prepare well head and diverter, make up core tools, trip in hole, begin coring.
8/14/2003	1117.5	Core ahead, with high rpm (500 to 550) rpm. Clean desanders.
8/15/2003	1274.5	Core ahead
8/16/2003	1481.0	Core ahead. Lost circulation Trip to replace core bit.
8/17/2003	1529.0	Trip tools back bottom; core ahead. Twist off. Fish. Trip in; core ahead; twist off. Fish.
8/18/2003	1617.5	Trip in; core ahead. Reduce rotation 550 rpm to 300 rpm; lost circulation.
8/19/2003	1687.5	Core ahead; rods torque; trip out; check bit reamer shell; trip in; liner slips; twist off.
8/20/2003	1687.5	Fishing rods; drill liner slipped into hole to 123.3 ft depth.
8/21/2003	1687.5	Fishing; wash hole and run Welenco camera survey.
8/22/2003	1687.5	Continue to wash hole and run Welenco camera survey. Start single 12-hour tower.
8/23/2003	1687.5	Fish out centralizers for drill liner.
8/24/2003	1687.5	Fish out more centralizers with missing setscrews.
8/25/2003	1687.5	Fish out more centralizers and biotite rhyolite cave from estimated 870 ft depth.
8/26/2003	1687.5	Fish out more centralizers and more rhyolite.
8/27/2003	1687.5	Continue fishing; no recover.
8/28/2003	1687.5	No borehole activities. Rig computer controls inoperative.
8/29/2003	1687.5	No borehole activities. Rig computer controls inoperative.
8/30/2003	1687.5	Continue fishing; run mill at 1001.4 ft to 1014.5 ft; run spear pull back 10,000 lbs, no fish.
8/31/2006	1687.5	Trip in magnet; no fish
9/1/2003	1687.5	Drill bridge 910 to 989 ft; wash down 1005 ft, mud up hole; lay down tools; demob core rig.
9/16/2003	1687.5	Rig up Lang rig #LK-23 with top drive. Trip in washover bit and drill to 992 ft, top of fish.
9/17/2003	1687.5	Drill from 992 to 1045 ft with washover bit. Condition hole.
9/18/2003	1687.5	Fish out liner, ream to 1187 ft. Trip out ream 11 7/8 to 1175.5 ft and tag HQ rods.
9/19/2003	1687.5	Grab HQ fish with overshot and trip out.
9/20/2003	1687.5	Continue to fish HQ tools, recover core barrel and core.
9/21/2003	1687.5	Ream hole to 1385 ft (10 5/8 in tricone).
9/22/2003	1687.5	Ream hole to 1460 ft; run geophysical logs, and run 8 5/8 in casing.
9/23/2003	1687.5	Continue casing; add cement basket; land casing with grout shoe. Tremie cement in hole.
9/24/2003	1687.5	Cement bottom 1460 ft to 1355 ft; WOC. Run AQ tremie annulus cement basket at 735 ft.
9/25/2003	1455.0	Tremie annulus cement; make up BHA; WOC. Trip in, tag cement grout shoe; drill out.
9/26/2003	1770.0	Drill ahead reverse circulation with water; steel cuttings bottom of core hole at 1687 ft
9/27/2003	1975.0	Drill ahead reverse circulation with water.
9/28/2003	2100.0	Drill ahead reverse circulation with water; 7 7/8 in hole to TD, trip BHA and lay down tools
9/29/2003	2100.0	Trip in air tube, airlift 20 gpm; W.L below 1400 ft, temp 137 °F; cut 8 5/8 in casing 470 ft.
9/30/2003	2100.0	Release rig and demob.

ash flow tuff units and volcanoclastic sediments between 906.5 ft and 1,334 ft depth, coring stopped several times to adjust the mud and clean the desanders. At 1,481 ft on August 16, 2003, the hole was tripped to replace the bit. The gauge of the inner cutting surface was worn out of specification. A new bit was tripped into the hole and coring resumed in the morning of August 17, 2003.

On the afternoon of 17 August 2003 drilling problems began to occur. At 1,527 ft, depth the drill rods twist off leaving 940 ft of rods in the hole. The rods and core tools were recovered with a spear. The core in the tube was also recovered. After tripping to the bottom while circulating and washing, coring again commenced with another twist off at 1,529 ft depth. Again the rods, core tools, and core were retrieved. Coring resumed at 1,529 ft with a reduction in rotation from 550 to 300 rpm. At 1,559 ft, circulation was lost with no returns in the Lower Cretaceous Hell-to-Finish Formation, a limestone boulder conglomerate. On 19 August 2003 at 1,620 ft with lost circulation and no returns, the torque on the drill string became excessive. While tripping out of the hole to check the bit and reamer shell, the 4 1/2 -inch drill liner slipped into the hole. The rods were tripped back to bottom and disconnected and a spear was used to pull the 4 1/2 -inch liner back into place. Welded "ears" were placed at the surface on the liner to hold it in place. At 1,687.5 ft the drill rods twisted off again. Only 1,180 ft of drill rods were recovered above the twist off, leaving 508 feet of rods and core tools in the hole. On August 20, 2003, while attempting to trip a fishing spear into the hole, an obstruction was encountered at 890 ft. After tripping out with the fishing tools, the driller discovered that the 4 1/2 -inch liner had slipped into the hole. An impression tool located the top of the liner casing at 123.3 ft depth. Later in the day, 778 ft of 4 1/2 -inch liner was recovered. On August 21, 2003 another 100 ft of 4 1/2 -inch liner was recovered, but an attempt to spear the core rods and core tools through the remaining liner in the hole was unsuccessful because of an obstruction at 887 ft depth. The remainder of August 21 and 22, 2003 was spent conditioning the hole for camera survey and conducting multiple Welenco camera surveys. On August 23, 2003 the drill crew changes to one 12 hr tower per day while attempting to recover fish in the hole.

Between August 23, 2003 and August 31, 2003, eight centralizers were recovered leaving 29 ft of 4 1/2 -inch liner with a shoe and two centralizers and 508 ft of rods and core tools (core barrel, reamer shell, and bit) in the hole. On 1 September 2003, the Boart Longyear LS 244 EC was demobilized after conditioning the hole and drilling out a bridge of cave at 910 to 989 ft.

On 16 September 2003 the Lang Exploration Drilling Rig #LK-23 top drive rotary rig was mobilized on to the site from Albuquerque. The next three days were spent clearing the hole of the remaining 4 1/2 -inch liner, drill rods and drill tools. However, during fishing operations, the open borehole from 908 to 1,203 ft was enlarged with an 11 7/8 -inch washover bit. All fish except half a centralizer, the core reamer shell, core bit, and a broken off part of a Bowen spear were recovered.

After the reverse-circulation drill string and supporting equipment had arrived, the hole was reamed ahead to 1,200 ft on 21 September 2003 with a 10 5/8 -inch full-face rock bit across the previous core-hole (HQ). Later in the day, a severe loss zone was encountered between 1,355 and 1,374 ft depth. However, the reverse-circulation (RC) (air-assisted fluid lift inside a dual-wall drill pipe) drilling system allowed drilling ahead. About 7,000 gal of drilling mud was initially lost in this zone. After drilling ahead 3 ft more, another 7,000 gal of drilling mud was lost. Drilling continued ahead to 1,385 ft without returns. At 1,400 ft, circulation returned with full returns and the loss zone temporarily healed.

On 22 September 2003 at an interim depth of 1,460 ft, a solid formation suitable for setting casing was reached. A string of 8 5/8 -inch welded casing was run into the hole with a cementing shoe on the bottom and an annular cement basket welded at 753 ft below ground level. The casing specifications are 28.58 lb/ft with a wall thickness of 0.322 inch and an internal pressure at minimum yield of 2,610 psi. The casing was landed on 23 September at a depth of 1,455 ft.

The casing was tag cemented through the cement shoe from 1,455 ft up to the loss zone at 1,355 to 1,374 ft with 300 gal of cement. The 300 gal volume

of cement was enough to have theoretically cemented up the annulus to 1,255 ft. However, a fall-off in fluid returns to zero at the surface during cement pumping indicates that the cement had probably reopened the lost circulation zone at 1,355 to 1,374 ft.

A cementing tremie pipe was run down the annulus between the 8 5/8-inch and 12 3/4 -inch casing on 24 September 2003. The annulus was cemented in stages up to about a depth of 492 ft below ground level. On 25 September 2003, a 7 7/8 -inch drilling assembly was tripped into the hole and tagged good cement at 1 1/2 ft above the cement shoe. The cement shoe was drilled out and cement was drilled out to 1,455 ft inside casing shoe. The 7 7/8-inch hole was completed on 28 September to a total depth (TD) of 2,100 ft. An hour-long airlift pump test was performed on 29 September 2003 and showed an initial flow rate 50 gpm at 154 °F that dropped to 20 gpm and 137 °F. The temperatures reflect cooling disturbance from lost circulation and drilling. The 8 5/8 -inch casing was also cut off at 470 ft depth below the surface on 29 September, 2003 and removed from the hole leaving an inside diameter of the 12 3/4 -inch to 470 ft depth.

2.8 WELL COMPLETION

Tables 2-2 show the initial completion of the AM-2 well prior to GRED II drilling operations over the hole. Table 2-3 adds the changes to the AM-2 well after GRED II drilling. The completed AM-2 well will allow perforating of the 12 3/4 -inch casing with a mill to allow production of the productive outflow plume reservoir between 280 and 492 ft depth. The 8 5/8 -inch casing below 470 ft depth may require plugging or setting a packer to cap off deeper formations. Perforation and production of the 753 to 1,355 ft interval with the 8 5/8 -inch casing with a pump set in the 12 3/4 -inch casing is another option for AM-2. The last option would produce from the 7 7/8 -inch open-hole at 1,455 to 2,100 ft through the 8 5/8 -inch casing with the pump in the 12 3/4 -inch casing. However, the poor airlift test results make the later option highly unlikely.

Table 2-2. Original AmeriCulture State 2 well construction.

ITEM	HOLE	TOP	BOTTOM	CASING	WT	CEMENT
	in	ft	ft	in	lbs/ft	ft ³
rotary mud	20	0	280			
surface		0	280	16	42	
cement		0	280			192 (pumped/shoe)
rotary air	14 3/4	280	580			
intermediate		0	580	12 3/4	36	
cement		520	580			33 (tag/shoe)
rotary mud	11 7/8	580	910			

Table 2.3. Final Americulture State 2 well construction.

ITEM	HOLE	TOP	BOTTOM	CASING	WT	CEMENT
	in	ft	ft	in	lbs/ft	ft ³
rotary mud	20	0	280			
surface		0	280	16	42	
cement		0	280			192 (pumped/shoe)
rotary air	14 3/4	280	580			
intermediate		0	580	12 3/4	36	
cement		520	580			33 (tag/shoe)
rotary mud	11 7/8	580	910			
wirelinecore	HQ	910	1687			
ream	11 7/8	910	1203			
ream	10 5/8	1203	1455			
intermediate		470	1455	8 5/8	29	
cement		492	753			134 (basket/annulus)
cement		1355	1455			40 (tag/shoe)
rotary mud	7 7/8	1445	2100			

2.9 GEOPHYSICAL AND TEMPERATURE LOGGING

The AM2 well was geophysically logged several times before the well was finally completed to current depth. Several temperature and gamma logs have been done on the hole at different stages in the history of the well (Table 2-4). Sandia National Laboratory (SNL), Albuquerque, New Mexico provided high quality equilibrium temperature logs in addition to a gamma log during the first phase of drilling of the AM-2 well to 910 ft. Welaco, a wireline geophysical firm

from Bakersfield, California performed temperature and gamma logs during reaming operations and prior to setting an intermediate casing string to 1,460 ft depth after Welaco had logged a nearby exploration borehole drilled by Lightning Dock Geothermal on an nearby Federal geothermal lease.

The SNL temperature logs were done with a conventional wireline thermocouple tool or with the temperature sensor and memory imbedded in the SNL Dewared core tube logger (CTL) tool. The Welaco temperatures were with conventional thermister wireline tools.

Table 2-4. Geophysical and temperature logs of the AmeriCulture State 2 well.

LOG	DATE	INTERVAL ft	LOGGER	REMARKS
temperature	Dec-01	0-910	Sandia	original hole
gamma	Dec-01	0-910	Sandia	original hole
temperature	Sep-03	0-1455	Welaco	during ream
gamma	Sep-03	0-1455	Welaco	during ream
temperature	Dec-03	0-2100	Sandia	equilibrium ?

The gamma logs have a maximum sampling radius of about 1 to 2 ft into the formation. A logging rate of about 30 feet per minute was used. As with temperature logs, the wireline signal is digitally converted into ASCII files for plotting, analysis, and interpretation.

The gamma log measures gamma radiation from naturally occurring uranium, thorium, and potassium. Because different rock types have different radioactivity levels, the gamma log is a very useful lithology correlation tool. For instance, shale and clay may have higher natural radioactivity than sandstone and sand.

2.10 SITE CLEANUP

Site cleanup of the AM-2 well pad at the end of drilling operations consisted of removing all trash and any oil contaminated soil to approved disposal sites. All equipment was removed from the site.

3.0 GEOLOGY AND THERMAL REGIME

3.1. SUMMARY GEOLOGIC LOG OF WELL

The AmeriCulture State 2 (AM-2) well was initially drilled with both rotary air and rotary mud. Except for major zones of lost circulation in the lower part of the hole, cuttings quality was very good with both air and mud drilling (Witcher, 2002).

Figure 3-1 is a summary geologic log that is plotted alongside the Welaco gamma log. This short summary will begin in reverse order of deposition, contrary to typical geologic report convention, as this is the sequence encountered while drilling. The upper 645 ft of the hole consists of alluvial basin fill deposits. From the surface down to 280 ft, the sandy gravel, clayey gravel, and minor clay deposits are largely unconsolidated. This unit probably represents uppermost Miocene to Quaternary mid and distal alluvial fan deposits mostly shed from the Pyramid Mountains to the east. At about 280 to 284 ft, thick and gravely orange gummy clay rests upon highly silicified sandy conglomerate. The silicified sandy conglomerate contains rounded clasts of andesite, ash flow tuff, and aphanitic rhyolite. Clasts in this volcanolitharenite are generally floating in a brick red and silicified silty to fine sand matrix. The highly indurated nature of the unit and clasts of ash flow tuff have resulted in an erroneous label for the unit in past drilling and geologic logs of wells at Lightning Dock. These logs call this unit "rhyolite or lithic tuff". The highly silicified nature of the unit is most intense between 284 and about 400 ft depth. Below 400 ft, the unit is indurated, but not as strongly silicified. The sandy conglomerate from 284 to 570 ft depth probably represents an earlier phase of basin fill sedimentation that is called the Gila Conglomerate in southwest New Mexico and southeast Arizona. The Gila Conglomerate at Lightning Dock may range in age from Oligocene to late Miocene.

At about 570 ft the alluvial deposits, become generally coarse-grained with much less fine and medium sand and silt. The coarse deposits are found to a total depth of about 645 ft. The coarse unit may represent a basal unit

Figure 3-1. Summary geologic unit well log of AM2 with natural gamma log.

of the Gila Conglomerate and record sedimentation associated with the initial extension in the Basin and Range Province or the unit may represent late sedimentary fill of the Muir Cauldron. In that case, these rocks may represent a post volcanism "ring fracture" moat fill.

At 645 ft a biotite rhyolite was identified in drill cuttings. This unit could be a latite as no "megascopic" quartz phenocrysts are observed. The only other phenocrysts are plagioclase. No sanidine or "moonstone" was observed. This unit bottoms out at about 860 ft. The upper part of the unit from 645 to about 730 ft consists of white and apple green, altered rhyolite. Alteration preserved the biotite but no matrix textures. The apple-green color may represent reduced iron or a trace of microscopic chlorite or epidote. From 730 to 830 ft the unit is not altered and displays some very diagnostic features. From 730 to 760 ft, a vitrophyre with perlitic texture is observed. The perlitic texture is pervasive even across devitrified zones developed around glassy cores. The perlitic texture shows more blocky elongated fractures (banded perlite) than arcuate or circular microcracks (classic perlite) (McPhie and others, 1993). In the lower part of this unit from 760 to 830 feet, the volcanic glass is either completely devitrified or absent. A few isolated spherulites, abundant lithophysae, and abundant extremely fine-grained, gray granophyric patches that appear to be lithophysae fill occur in a light brown aphanatic matrix. The lower part of the unit from 830 to 860 ft closely resembles the upper part of the unit from 645 to about 660 feet and is altered. Because no eutaxitic textures or fiamme are observed in the biotite rhyolite from 645 to 860 ft, the unit may represent a rhyolite flow (Cas and Wright, 1988). The abundant biotite, 3 to 10 percent, also places this unit in the volcanic episode associated with the Muir cauldron. Studies by Elston and others (1983) and McIntosh and Bryan (2000) indicated that siliceous rocks with abundant hydrous mineral phases such as biotite are mostly observed in the early phase of silicic volcanism in the region (such as the Muir Cauldron suite of volcanic rocks). Caving of the lower part of this unit during GRED drilling activities may have contributed to some of the drilling problems.

Below the rhyolite, an ash flow tuff was drilled. While cuttings returns were poor due to lost circulation in the biotite rhyolite flow, sufficient returns allow a log and an interpretation. This unit, from about 860 to 958 ft is a welded vitric crystal ash flow tuff with a matrix texture of devitrified granophyre. A ghost eutaxitic texture is clear and is outlined by abundant hematite in the matrix. About 10 to 20 percent of the rock contains crystals of plagioclase, quartz, and biotite. No sanidine or "moonstone" crystal fragments are positively identifiable under the binocular scope or hand lens. Total thickness of this unit is unknown. However, the tuff of Graham Well on the northern slopes of Lightning Dock Mountain ESE of the AM-2 well has similar attributes (Elston and others, 1976). The Tuff of Graham Well is an upper cauldron facies tuff of the Muir cauldron.

The thickest ash flow tuff unit was cored from 957.5 to 1,104.6 ft depth. This unit is a light brown to buff heterolithic tuff that is partially welded with lapilli mostly between ¼ to ½ -inch size. Pumice is altered and shows weak to moderate eutaxitic texture. It is likely that this unit is correlative with the tuff of Woodhaul Canyon, one of the lower cauldron fills of the Muir cauldron (Elston and others, 1976).

Between 1,104.5 and 1,325.9 ft depth a sequence of volcanic mudflow (lahars) and mud-supported tuffaceous volcanoclastic sand and gravel was cored. Clasts in the units range from felsite to basalt with andesite predominating. These units probably represent debris shed from mostly intermediate composition eruptive centers prior to the Muir cauldron silicic eruptions and caldera collapse and may be correlative with the Rubio Peak Formation or older andesite units of Eocene to Paleocene age. Core in this interval shows several fault zones. The most notable zones are from 1,169 to 1,175 ft and 1,255 to 1,275 ft. The fault zone fractures are mostly healed with calcite and several thin zones of fault gouge were present in each zone.

From 1,325.9 to 1,334 ft depth, a porphyritic andesite flow was cored. The base of this unit is missing and cut by a fault at 1,334 ft. The andesite may be Eocene or upper Cretaceous-Paleocene age (Laramide).

The Upper Jurassic to Lower Cretaceous Bisbee Group is encountered below the fault at 1,334 ft depth. From 1,334 to 1,456 ft, the Bisbee Group is characterized by interbedded calcareous sandstone, calcareous shale, shale and dolomite. This interval is tentatively assigned to the Hell-to-Finish Formation. A fault zone at 1,392 to 1,397 ft shows a 35° to 40° dip.

At 1,456 to 1,653 ft, a well-indurated or lithified sandy, cobble-to-boulder, clast-supported conglomerate was cored. Clasts consist mostly of Pennsylvanian limestone and some chert. This unit is assigned to the conglomerate facies of the Hell-to-Finish Formation of the Bisbee Group. A fault zone dipping at about 69° cuts this unit between 1,594 and 1,607 ft depth.

From 1,653 to 2,100 ft the Pennsylvanian Horquilla formation was cored. The lower 70 ft from 2,030 to 2,100 feet consists of fine gray sandstone to siltstone. The rest of the Horquilla is a fossiliferous gray to dark gray limestone (biomicrudite to intramicrudite) with some chert. Fusulinids were observed in some of the core. Between 1,850 and 1,990 ft, the Horquilla is intruded by a dacite to dacite porphyry dike or sill of probable Tertiary (Eocene) age.

3.2 DISCUSSION AND SYNTHESIS OF GEOLOGY

The uppermost shallow "bedrock" unit at Lightning Dock has previously been identified as "rhyolite". This unit is actually a silicified older Tertiary basin fill unit. This unit is correlated with the Gila Conglomerate, a catchall term for older indurated, alluvial sand and gravel packages that are found in southwestern New Mexico and southeastern Arizona. The Gila Conglomerate is actually a unit that should have group status rather than formation status and probably represents several formations which may be separated by major unconformities and have greatly different provenance for clasts among local sequences. In fact, not all Gila Conglomerate is accurately ascribed to represent older Tertiary graben or extensional basin fill of the Basin and Range Province. At the base of the Gila Conglomerate in the AM-2 well, a package of gravels with different provenance and gamma log signature overlies Tertiary volcanics. This lower unit may not be basin fill. Instead, the lower gravel may represent a remnant moat fill

of the ring fracture zone of the Oligocene Muir cauldron of Elston and others (1983).

The base of the upper basin fill or top of the Gila Conglomerate contains a thick (about 4 to 5 ft) unit of gummy orange clay with clasts of gravel that may be interpreted as a "paleosol." This would indicate an unconformity and a local and stable structural high at Lightning Dock for a period of time during the late Miocene or early Pliocene. Regional gravity and aeromagnetic data back up this hypothesis. The Lightning Dock geothermal system occurs in this intra basin horst block.

Rhyolite and thicker ash flow tuff units encountered in the AM-2 well are probably Muir cauldron related extrusions. Several lines of evidence lead to this conclusion. First, the uppermost rhyolite is relatively rich in biotite, but poor in overall phenocryst percentage. Along with a general absence of lithic fragments, no quartz or sanidine is observed. Where plagioclase is observed, the phenocrysts are euhedral or sheared apart in place. Biotite is usually euhedral in hexagonal plates or smeared out in linear or curvilinear patches suggestive of forced flow or mechanical flow banding. A suite of silicic volcanic rocks blankets the region; but, these rocks represent ash flow tuffs erupted from distance caldera sources and have very little or no biotite and are generally relatively crystal and lithic rich (Elston and others, 1983 and McIntosh and Bryan, 2000). Non-euhedral or embayed crystal fragments in Rim Rock ash flow tuffs are usually represented by at least some sanidine ("moonstone") and quartz. The upper rhyolite also has vitrophryric zones that show perlitic textures. Where devitrification is prominent a few radial spherulitic textures are developed. In other areas of devitrification, lithophysae are well developed along with very fine-grained granophyritic devitrification textures. At the base of the rhyolite, much "crackle breccia" occurs. This is interpreted as rhyolite flow autobrecciation rather than fracturing associated with a nearby fault. The rhyolite probably represents a late phase ring fracture zone flow. No typical ash flow tuff features such as eutaxitic texture or fiamme were observed. Hydrothermal alteration at the top and bottom of the rhyolite further implicates a flow rather than an ash flow

tuff. Coupled with the fact that biotite is common, some phenocrysts appear sheared out (mechanical flow banding), and strong hydrothermal alterations exist on the top and bottom of the rhyolite, all pointing to a ring fracture rhyolite flow with an associated dike or dome complex. A correlation with a ring fracture eruptive unit, the rhyolite of Pyramid Peak, is provisionally given.

The upper ash flow tuff encountered in the AM-2 well may correlate to the tuff of Graham Well. The unit has quartz and has an unusual granophyric texture with hematite in the groundmass. Elston and others (1983) describe the tuff of Graham Well as having a strong hematite dusting in the groundmass.

The thick ash flow tuff below the Tuff of Graham Well is probably the tuff of Woodhaul Canyon and represents the main collapse cauldron fill of the Muir cauldron. The moderate thickness indicates a position at least in the Muir cauldron or outer ring fracture zone rather than an outflow facies.

While the Upper Jurassic to Lower Cretaceous Bisbee Group is inferred from poor geologic logs of the Steam Reserve 55-7 well, the AM-2 confirms the presence of the Hell-to-Finish Formation of the Bisbee Group. The Hell-to-Finish fanglomerates indicate a proximal location to a major WNW-striking late Jurassic to early Cretaceous normal fault of the Bisbee rift, a Mesozoic analog of today's Rio Grande rift. These faults were later reactivated during compression of the Laramide Orogeny with a reversed sense of motion.

The importance of the WNW trending basement structure is very apparent from a field reconnaissance of the mineralization along the western and southwestern slopes of Lightning Dock Mountain in the Pyramid Mountains ESE of the Lightning Dock thermal anomaly. All of the mineralized sites are within the basement trend highlighted by the aeromagnetic lineament. The first feature, a calcite vein zone (CVZ) with a width greater than 200 ft, has an orientation that is on strike with the thermal anomaly in the Animas Valley to the WNW. The Doubtful Mine site at the western base of Lightning Dock Mountain is a second site that contains light green fluorite mineralization in wide shear or fault zone that trends NNW. Elston and others (1983) report fluid inclusion data that indicates 249 to 297°F temperatures and fall within the same range of

temperatures that can be inferred from geothermometry and measured temperatures with today's thermal anomaly at the KGRA. The CVZ southeast of the mine on the southwestern slopes of Lightning Dock Mountain has the following paragenesis:

- a) early white coarsely crystalline calcite that is weakly banded.
- b) brecciation, deposition of black manganese minerals and dark manganiferous calcite.
- c) brecciation, deposition of gray and white-banded calcite.
- d) brecciation, silica quartz deposition in breccia spaces and along calcite cleavage planes.
- e) brecciation, and calcite dissolution in silicified zones to create "honeycomb" spaces that are filled with euhedral quartz. The dissolution cavities frequently have the shape of rhombohedral calcite cleavage fragments.

Elston and others 1983) describe the paragenesis of the Doubtful Mine, which contains fluorite. No fluorite was observed during the reconnaissance of the CVZ. Propylitic alteration is apparent in the tuff of Woodhaul Canyon country rock that surrounds the CVZ. The overall dimensions and character of the Doubtful Mine and the CVZ may provide a clue as to the dimensions and character of the upflow zone for the Lightning Dock KGRA thermal anomaly. The main upflow may be concentrated in a relatively small area and be characterized by repeated episodes of mineralization and fracturing. As indicated by the CVZ, a particular fault may not host the upflow zone.

Elston and others (1983) show outcrops in the Threemile Hills in an area south of the KGRA as the Mojado and U-Bar Formations. A field investigation of outcrops discovered that these units are probably not autochthonous. While exposures are poor, the site identified as the Mojado Formation actually has lithology more typical of the Hell-to-Finish Formation. The unit is probably allochthonous and has no systematic bedding orientation. Boulders up to 1-to-4 ft across of Pennsylvanian Horquilla limestone, Hell-to-Finish sandy chert conglomerate, and Mojado (?) indurated quartz sandstone are all jumbled up on

a low relief, poorly exposed hill slope beneath ash flow tuffs of the Rimrock Mountain sequence. The outcrop identified a U-Bar Formation is poorly exposed along the Old Lordsburg road. Again, the exposures of U-Bar may not be in place. The outcrop shows abundant calcite-healed fracturing and weak marblization and no consistent orientation or bedding strike and dip. Again, ash flow tuffs of the Rimrock Mountain sequence overlie the outcrops. These outcrops could be interpreted as landslide deposits that are older than the Rimrock Mountain sequence.

A field investigation of Table Top Mountain south of the KGRA thermal anomaly and northwest of the Threemile Hill area reveals that this outcrop consists of Gila Conglomerate (?) and has been hydrothermally silicified. This outcrop is similar to lithology from the AM-2 well from 280 to 400 ft depth. Most curiously, Table Top Mountain is teardrop shaped and has the same approximate size, shape, and orientation as the 800- to-1000 mW/m² heat flow contour closure at the Lightning Dock KGRA. The shape and size may not be a coincidence. In fact, Table Top Mountain may represent the fossil expression of a former hydrothermal outflow plume from a late Miocene or early Pliocene geothermal system. Local Neogene uplift of the area allowed erosional stripping of unaltered gravels, leaving the hydrothermally silicified gravels of Table Top Mountain preserved as an inselberg. Also of interest, Table Top Mountain has an analogous tectonic setting to the Lightning Dock KGRA. In fact, another WNW trending structure zone slices this area of the Muir cauldron fracture zone (Lawton, 2000; and Bayona and Lawton, 2000). The area lies within the accommodation zone between the upper and lower Animas grabens and regional gravity data shows the area to be structurally high. Available temperature gradient information indicates enhanced heat flow. None of the temperature gradient holes is located properly to assess whether or not an active geothermal systems exists beneath Table Top Mountain today.

Field investigation of the Pleistocene “Animas” fault shows that only about 6 to 8 ft of displacement have occurred north of the KGRA. In a discussion of the fault by Stephen Wells in Elston and others (1983), a maximum of 16 ft relief is

reported for the fault. The scarp breaks a piedmont fan surface with Stage 2 to Stage 3 caliche development with a late Pleistocene age (Gile and others, 1981). The relatively steep profile of the scarp qualitatively indicates an age between about 100 and 10 ka. This fault appears to indicate only one or two displacement events. The lack of a major gravity geophysical expression indicates that this fault is not a major bounding fault of the Animas graben. The fault is a young incipient structure. The eastward embayment of low gravity across the fault north of the KGRA backs this conclusion (O'Brien and Stone, 1983 and 1984). The major graben structures are east of this fault and have not been active in the Quaternary. The importance of the "Animas" Pleistocene fault for geothermal conditions in the KGRA is not clear. Because the fault ends at thermal anomaly, tectonism may have reopened or enhanced fracture permeability in the upflow zone. Fault tips are favorable sites for enhanced fracture permeability.

Elston and others (1983) argue that a northeast-trending structure plays a major role in providing geothermal fluids into the Lightning Dock KGRA where the northeast structure intersects the ring fracture zone of the Muir cauldron. Temperature and oxygen isotope data do show a trend that supports the Elston and others (1983) argument. Gas studies of fluids at Lightning Dock and the Animas Valley by Norman and Bernhardt (1982) also show the same trend. Elston and others (1983) further argue that the northeast trend is a crustal structure or weakness that allows leakage of basaltic magmas to the surface and shallow crust. Basaltic flows near Animas and Rodeo, which are northeast of the basaltic volcanic field of the San Bernardino Valley in Arizona, suggest the possibility of northeast-trending structure with an imbedded magmatic heat source. Another interpretation is also valid that is not discussed by Elston and others (1983) or Norman and Bernhardt (1982). The area of discussion lies along the structurally high accommodation zone, separating the upper and lower Animas grabens. South flowing ground water in the deeper alluvial fill of the upper Animas graben is forced upward over the northeast-trending accommodation zone by structurally high bedrock. The older and deeper source waters will have slightly higher temperature, somewhat lighter oxygen stable

isotope ($^{18}\text{O}/^{16}\text{O}$) ratios, and gas compositions much different than shallow and young basin-fill waters. These waters probably represent upwelling older alluvial basin water rather than leakages of deep-seated magma-heated geothermal water in bedrock along a hypothetical northeast-trending fault.

Elston and others (1983) suggest that a basaltic magma in the deep subsurface of the region along the northeast-trending structure provides a heat source for the Lightning Dock geothermal system. While accommodation zones are favorable sites for basaltic volcanism in rift settings, this hypothesis is highly unlikely as basaltic magmas in a continental setting are not of sufficient volume and intrusive duration for magma replenishment to provide a sustained heat source for a hydrothermal system (Smith and Shaw, 1975; and Jaeger, 1964).

O'Brien and Stone (1982) present a lithology log for the Cockrell Pyramid well. The Gila Conglomerate overlies Tertiary volcanic rocks at 1,890 ft depth. Tertiary volcanics are at 645 ft depth in the AM-2 well. Therefore, a fault with more than 1,200 ft of throw has displaced the geologic section between the two wells. One of the most interesting features of the Cockrell Pyramid log is the thick "Tertiary" volcanic section from 1,890 to 5,795 ft depth. Two things are striking. First is the fact that the volcanic section overlies Mississippian rocks instead of Pennsylvanian or Cretaceous rocks, indicating Laramide (Late Cretaceous to Eocene) inversion of structure along the WNW structure zone when compared to the Steam Reserve 55-7 well. Second, the column of Tertiary volcanic rocks is very thick. A thick Eocene (Laramide) sequence of andesite is observed in the Peloncillo Mountains to the west between Granite Gap and Road Forks and in the northern Pyramid Mountains. Volcanics in the Cockrell Pyramid well may be dominated by the Eocene andesite sequence. Tectonic inversion would support a thick section of andesite. On the other hand, much of the sequence may be represented by the Rimrock tuffs and Muir cauldron affinity volcanics.

3.3 TEMPERATURE LOGS AND INTERPRETATION

Several temperature logs have been run on the AM-2 well at various stages of the well history. Figure 3-2 compares the disequilibrium Welaco log on 20 September, 2003 with equilibrium logs taken in December 2001 and 2003. The difference in temperatures for the upper 500 ft for the two equilibrium logs is believed to be the affect of cooling on the 2003 log by convection in the borehole that is aided by the 8 5/8-inch casing that is open to the formation below 1,455 ft rather than a cooling of the shallow reservoir. The Welaco log shows much lower temperatures because it represents a disequilibrium log before the well had recovered from cooling disturbance from drilling. A very minor temperature deviation is observed in the December 2003 log of AM-2 at about 1,203 ft. This could be a very small-lost circulation zone. If so, it correlates with the deep outflow zone observed in the Steam Reserve 55-7 well (Figure 3-3).

Clearly, the AM-2 well does not show an important reservoir below the shallow outflow plume reservoir. After the temperatures roll over the temperature gradient is largely linear. Apparently none of the fault zones encountered below 1,150 ft are conducting up flow of hot water and the major lost circulation zones between 1,300 and 1,400 ft not appear to be transmitting hotter water upward or allowing down flow of cooler water.

An hour long air-lift pump test was performed on 29 September, 2003 and showed a maximum flow rate 50 gpm which dropped to near 20 gpm while the water level fell below 1,400 ft depth. After the well fully recovered, static water levels average around 54 ft, similar the those in the Steam Reserve 55-7 well; but higher than the nearby AM-1 production well which averages around 70 ft.

The Lower Cretaceous Hell-to-Finish and the Pennsylvanian Horquilla Formations apparently do not have enough permeability beneath the AM-2 site to act as reservoirs for outflow of fluids. Equilibrium temperatures are only slightly higher than the temperatures observed in the shallow outflow plume reservoir.

Figure 3-2. Temperature logs of the AM-2 well.

Figure 3-3. Temperature logs showing the relationships between the AM-2 well and the Steam Reserve 55-7 well prior to thermal equilibrium and after thermal equilibrium.

4.0 GEOCHEMISTRY

4.1 PURPOSE

Groundwater chemistry in geothermal wells at the Lightning Dock KGRA is investigated to in order to obtain information on possible flow paths (such as the nature of the upflow zone host), deep reservoir hosts, mixing, subsurface boiling, and deep reservoir temperature.

4.2 PREVIOUS STUDIES

The main aqueous geochemical studies performed at the Lightning Dock KGRA area include include Cuniff and Bowers (1988), Dellechiaie (1977), Swanberg and others (1977), Logsdon (1981), Norman and Bernhardt (1982), O'Brien and Stone (1982) Elston and others (1983), Hawley and others (2000), and Hibbs (2000). Logsdon (1981) and Elston and others (1983) discuss a mixing model that predicts a deep reservoir of 250 °C. Logsdon (1981), Elston and others (1983), and Norman and Bernhardt (1982) use groundwater chemistry and groundwater gases to infer a deeply penetrating, southwest-striking structural zone host for a deep high-temperature reservoir and possibly basaltic magma southwest of the area of hot wells (the heat-flow anomaly). Logsdon (1981) and Elston and others (1983) argue for a 165 °C shallow reservoir consisting of mixture of 25 percent deep geothermal fluids and 75 percent cold groundwater.

4.3 APPROACH

The chemical and isotopic character of the geothermal waters is related to flow path length or age of water since recharge, climate and geographic area of recharge, the type of rocks that host water flow and react chemically with the water, and temperature. The processes of cation exchange, hydration reactions, mixing, dissolution, precipitation, and boiling can all play specific roles.

Geochemical fingerprints comprise two general categories. The first uses the ratios of conservative ions such as chloride (Cl), boron (B), bromide (Br), and

lithium (Li). These ions are highly soluble or conservative and are, therefore, unlikely to be involved in precipitation of minerals and can be applied to study mixing, evaporative (boiling) concentration, and dissolution of salts (Hem, 1985).

A second category involves the isotopic characteristics of the water and dissolved chemical constituents. Isotopic information is useful to characterize temperature, recharge source and paleoclimate, age since recharge, and the type of rock that hosts water flow (Mazor, 1997). Isotopic signatures, in conjunction with conservative dissolved ions, can also be used to investigate mixing of waters with different flow domain heritage or to delineate other geochemical processes such as boiling.

Aqueous geochemical models that define chemical and isotopic equilibrium or saturation indices with solid mineral phases provide additional interpretative tools to characterize chemical evolution and sources (Bethke, 1996).

Several isotopic systems when combined with solute chemistry, allow cross checking of results and interpretations. The first and most commonly used system uses fractionation ratios of natural stable isotopes such as oxygen ($^{18}\text{O}/^{16}\text{O}$), hydrogen ($^2\text{H}/\text{H}$), carbon ($^{13}\text{C}/^{12}\text{C}$), and sulfur ($^{34}\text{S}/^{32}\text{S}$) (Clark and Fritz, 1997). Recharge source and timing, temperature, rock-water reactions, organic processes, and evaporation can have an important impact on these ratios. In addition, the sulfur and carbon isotopes may point to specific geologic formations as chemical sources.

The second isotopic approach uses radiogenic stable-daughter isotope ratios such as the strontium (Sr) system of $^{87}\text{Sr}/^{86}\text{Sr}$ (Banner and others, 1989; Johnson and DePaolo, 1994). The Sr system is useful to fingerprint the flow path and type of rock that the groundwater has predominantly encountered. The Sr isotope systematics can provide a proxy for the ultimate source(s) of calcium (Ca) and potassium (K) in mixed geothermal waters.

Four samples were taken from a range of geothermal wells found in different areas of the Lightning Dock KGRA as defined by the heat flow anomaly. In addition to field sample filtering and preservation, the pH, and conductance

were immediately determined. High-temperature (>90 °C) samples were retrieved at discharge ports in the greenhouse-heating loop of each production well so that cooled and unboiled samples could be obtained. Analysis of dissolved ions included:

Na, Ca, Mg, Sr, K, HCO₃, SO₄, Cl, SiO₂, Br, Li, B, F, and TDS

Samples taken for chemistry were also isotopically analyzed for:

¹⁸O/¹⁶O, ²H/H, ¹³C/¹²C, ³⁴S/³²S, and ⁸⁷Sr/⁸⁶Sr.

Charge and mass balance were used to evaluate the quality of the results from sampled fluids (Reed and Mariner, 1991).

An integrated approach of traditional solute chemistry and isotopic systematics was employed. Water temperature and hydrogeologic information complemented geochemical and isotopic interpretations. Data interpretation focused on flow path sources, mixing, possible subsurface boiling, and chemical geothermometry.

4.4 METHODS

Sampling was accomplished after allowing the discharge sampling point to flow for at least 15 minutes. A 5-gallon (19.2 liter) plastic pail (well rinsed with the sample water) was used to take a grab sample. Temperature was determined using a digital thermometer. Aliquots were taken for determination of pH with an Oakton pH 10 series meter, and conductivity using an Oakton Con5 Acorn series meter. Alkalinity was determined using a Hach digital titrator. A 50 mL sample was pipetted into a beaker with a magnetic Teflon stirring rod and placed on a “homemade” portable field magnetic stirrer. A pre-measured packet of Bromcresol Green-Methyl red reagent was added and the solution was titrated by drops with 0.1600N H₂SO₄ until the color changed to pink. The amount of acid required times 2 gives a direct reading of mg/L total alkalinity (as CaCO₃).

Six water samples were collected for laboratory analysis. The ²H/¹H and ¹⁸O/¹⁶O samples were collected in amber glass bottles with septum caps, rinsed with sample water. All other samples were collected in high-density polyethylene bottles (HDPE), which were washed with soap, rinsed with tap water to remove the soap, and rinsed three times with distilled/deionized water (DDIW). The last

rinse was left in the bottles and emptied just prior to sampling. After the preceding wash and rinse, the $^{87}\text{Sr}/^{86}\text{Sr}$ sample bottles were placed in a 10 percent ultra pure nitric acid bath for a minimum of 24 hours, followed by three additional rinses with DDIW. Filtration was accomplished on site with a 0.45-micron filter and vacuum flask. A “homemade” vacuum pump, constructed from a small marine bladder pump with cigarette lighter power supply, was connected to the vacuum flask for rapid and efficient filtering. Table 4-1 shows the amounts and treatments of the samples collected.

Table 4-1. Field Sample Preparation.

SAMPLE	AMOUNT	FILTERED	TREATMENT
anions	250 ml	yes	none
cations	250 ml	yes	acidified to pH<2 with HCl
$^2\text{H}/^1\text{H}$ and $^{18}\text{O}/^{16}\text{O}$	60 ml	no	none
$^{13}\text{C}/^{12}\text{C}$	250 ml	no	sodium azide
$^{34}\text{S}/^{32}\text{S}$	1L	yes	BaCl w/ BaSO_4 filtrate
$^{87}\text{Sr}/^{86}\text{Sr}$	250 ml	yes	acidified to pH<2 with ultrapure H_2NO_3

4.5 DATA

Field measurements taken during sampling are shown in Table 4-2. Temperatures represent wellhead discharge. The AM4 sample has a much lower temperature and a higher alkalinity than the other wells sampled.

Table 4-2. Sample Field Measurements.

SAMPLE	SITE	TEMP °F	TEMP °C	pH	COND	ALK- HCO3	DATE
AM1	Burgett #1	208	97.8	8.26	2090	172	1/16/2003
AM2	Burgett #C	224	106.7	7.10	1932	178	1/16/2003
AM3	Burgett #6	224	106.7	7.47	1515	174	1/16/2003
AM4	AmeriCulture Fed	118	47.8	7.47	1661	316	1/16/2003

Cation and anion chemistry is shown in Table 4-3. Samples, AM1, AM3, and AM2 all have similar chemistry; however, chloride (Cl), silica (SiO₂), fluoride (F), sodium (Na), sulfate (SO₄) and potassium (K) show slight systematic changes in concentrations.

Table 4-3. Cation and Anion Chemistry.

SAMPLE	SITE	pH	Na	K	Ca	Mg	Sr	Cl	SO ₄	HCO ₃	F	SiO ₂	B	Br	Li	TDS
AM1	Burgett #1	8.40	377	22	22	0.1	1.4	98	543	101	9.8	144	0.4	0	1	1180
AM2	Burgett #C	8.10	325	15	24	0.1	1.2	89	493	113	8.9	113	0.4	0	0.5	1050
AM3	Burgett #6	8.00	314	15	24	0.2	1.2	86	482	113	8.3	111	0.4	0	0.6	1030
AM4	AmeriCulture Fed	8.00	314	11	44	0.8	1.2	90	444	195	5.6	55.2	0.1	0	0.9	1000

Isotopic analyses are shown in Table 4-4. Insufficient sample was available for analysis of carbon isotopic ratio in AM3 due to making splits of the sample during changes of analytical labs. Interpretation of the isotopic analyses is done in tandem with cation and anion chemistry and with published groundwater isotopic data for the Animas Valley.

Table 4-4. Isotopic Analyses. See Appendix 4 for explanation of delta (δ).

SAMPLE	SITE	δ ² D	δ ¹⁸ O	δ ¹³ C	δ ³⁴ S	⁸⁷ Sr/ ⁸⁶ Sr
AM1	Burgett #1	-76	-9.9	-10.6	8.50	0.728344
AM2	Burgett #C	-76	-10.0	-8.6	8.55	0.725616
AM3	Burgett #6	-77	-10.8	n/a	8.34	0.727433
AM4	AmeriCulture Fed	-70	-10.1	-10.0	8.84	0.728861

4.6 CATION AND ANION SYSTEMATICS

4.61 Piper Diagram

Piper diagrams (Piper, 1944) provide an initial graphic display of geochemical data from the geothermal wells. A Piper diagram shows major cation and anions in terms of millequivalent percentages on cation and anion trilinear plots. The anion and cation percentages are projected from the respective triangle plots on to a central diamond plot. As whole, the Piper diagram allows immediate recognition of chemical type and some basic

processes that may be occurring such as mixing, dissolution of evaporate minerals, and cation exchange between water and clay or silicate minerals.

A Piper diagram plot of sampled waters is shown in Figure 4-1. The Lightning Dock geothermal waters are sodium sulfate with total dissolved solids (TDS) ranging from 1,000 to 1,180 mg/L. The Piper diagram shows an apparent mixing trend in the thermal waters with AM1 as end-member geothermal water. The AM4 well appears to have a small fraction of non-thermal water mixed with thermal water.

Figure 4-1. Piper Diagram of Samples Lightning Dock wells.

4.62 Bromide and Chloride/Bromide Ratio

Typically Cl acts as the most conservative major ion in groundwater and is not directly involved in most chemical reactions except for the dissolution of soluble minerals that are contained in evaporate rocks such as halite. Therefore,

where evaporates are absent, Cl variation is largely the result of mixing of young low TDS waters and older thermal waters. Bromide (Br) acts much like Cl in solution; however, Br is considerably less abundant in natural groundwater. In addition, Br is very conservative and even more soluble than Cl (Davis and others, 1998).

The Cl/Br ratio is sensitive to mineral and chemical sources or provenance. The Cl/Br ratio is very low in most natural systems like seawater (290), meteoric water (50-180), organic materials (20-200), and igneous and metamorphic rocks (100-500) (Davis and others, 1998). Higher Cl/Br ratios are generally associated with anthropogenic sources such as road salt, sewage, industrial chemicals or waste, agriculture processes, and with the natural dissolution of evaporate minerals or release of salts in mineral fluid inclusions during water-rock equilibration.

High Cl/Br ratios in evaporates are a result of the differential solubility between Br and Cl. Since Br is much more soluble than Cl, halite forms as a nearly pure NaCl crystal with most Br remaining in the brine. Dissolution and re-precipitation results in even higher Cl/Br ratios in the solid precipitate (Davis and others, 1998; Hounslow, 1995; and Hanor, 1988 and 1994).

At Lightning Dock, the highest Cl/Br ratios (328 to 376) are found in the hottest geothermal wells and the variation of the Cl/Br ratios is relatively low. In the Rio Grande rift, geothermal water generally has highly variable and much higher Cl/Br ratios (800 to 1,361) (Witcher and others, 2004). The high Cl/Br ratios relate to geochemical processes along deep regional flow paths, in which water typically progresses from HCO₃ through SO₄ to Cl in anion character with increasing time, depth and flow path length (Mazor, 1997). Processes may include dissolution of evaporate minerals from Paleozoic marine rocks. The large differences in Cl/Br between non-thermal and thermal water can be used to fingerprint flow paths of geothermal waters and to identify mixing with shallow non-thermal groundwater.

Bromide (Br) concentrations show little variation from 0.26 to 0.27 mg/L in the hottest geothermal waters (AM1, AM2, and AM3). The coolest thermal water

(AM4) has a higher Br concentration of 0.37 mg/L. Figure 4-2 is a plot of Cl/Br versus Cl. The apparent vertical trend in the Cl/Br ratio with increasing Cl between AM3 and AM2 may be interpreted as a boiling trend. In other words, Cl and Br are both concentrated at the same rate by loss of water by boiling. With mixing the Cl/Br ratio would change. Sample AM3 is located up hydraulic

Figure 4-2. Cl/Br ratio versus Cl.

gradient from AM2 and AM3 is located over the most intense area of the Lightning Dock heat flow anomaly.

Samples AM3 and AM4 may be mixtures of geothermal water with the composition of AM1 and shallow cold groundwater. If this is true, then two end members of cold groundwater with different chemistry may be involved. The local hydrogeology appears to support this hypothesis. The hot wells AM2 and AM3 are located on the eastern half of the heat flow anomaly on the toe of the alluvial apron or alluvial fan shed from the Pyramid Mountains to the east. Pump

test results indicate that a hydraulic barrier separates AM4 from AM1, AM2, and AM3 (Witcher, 2001). Gravity data suggests the barrier may represent a major basin-bounding fault zone (Kucks and others, 2001). In other words, AM2 and AM3 have a mixed component of cold water recharged from the coarse-grained alluvial fan deposits and Pyramid Mountains to the southeast and AM4 has a cold-water mix component from the fine-grained basin-fill deposits to the south and southwest.

When the Cl/Br ratios are plotted against SiO_2 , a linear trend from AM4 through AM2 and AM3 to AM1 (Figure 4-3) is observed. The trend may be further evidence for mixing of thermal and non-thermal water and have use in a geothermometer-mixing model to predict deep subsurface temperatures. However, silica is not a conservative chemical species and further analysis is required.

Figure 4-3. Cl/Br ratio versus SiO_2 .

4.63 Silica Concentrations

Silica (SiO_2) concentrations are temperature dependent and can be used to quantify subsurface temperatures (Fournier, 1960 and 1977). This is because of the slow kinetics of dissolved SiO_2 equilibrium with quartz at lower temperatures below 150 °C (Rimstidt and Barnes, 1980). In other words, high SiO_2 concentrations may be retained at low temperatures for long periods of time after the geothermal fluids have cooled below 150 °C.

Dissolution of aluminosilicate minerals such as potassium feldspar (orthoclase or sanidine) can release K and SiO_2 to solution and result in higher alkalinity or bicarbonate (HCO_3) concentrations. Feldspar-rich rhyolite ash flow tuff and rhyolite is common in the subsurface at Lightning Dock. Figure 4-4 and 4-5 are comparisons of K and HCO_3 concentrations respectively versus dissolved SiO_2 . A negative trend of higher SiO_2 with a correlative lower HCO_3 is observed. This suggests that SiO_2 concentrations are temperature dependent rather than the result of dissolution of aluminosilicate minerals. The high K concentrations are a common result of geothermal processes (Fournier and Truesdell, 1973; and Giggenbach, 1988).

Figure 4-6 is a plot of log SiO_2 concentration versus temperature. The temperature dependent equilibrium curves for the solid silica species of quartz, alpha-cristobalite, chalcedony, and amorphous silica are shown. Sampled wells plot near the chalcedony curve with much scatter. This would suggest mixing at temperatures below 150 °C with no equilibration of the SiO_2 concentrations in the waters with respect to chalcedony (or quartz).

Figure 4-4. K versus SiO₂.

Figure 4-5. HCO₃ versus SiO₂.

Figure 4-6. Temperature ($1000/T$ (°K) versus $\log \text{SiO}_2$ showing temperature-dependent equilibrium curves of solid silica phases.

4.7 ISOTOPE SYSTEMATICS

4.7.1 Introduction

Isotope systems analysis helps to identify sources and processes associated with water chemistry and salinity. For ease of discussion, delta (δ) notation is used with the stable isotopes. Delta (δ) is the per thousand (per mil) comparison of the ratio of heavy to light isotopes in a sample compared to a standard. Appendix 4 details the nomenclature used for reporting isotope analyses.

4.7.2 Hydrogen and Oxygen (δD and $\delta^{18}O$)

The stable isotopes of hydrogen (1H) and deuterium (2H), and oxygen (^{16}O and ^{18}O) are the most common isotopes in water (H_2O). In water, the light isotopes of hydrogen (1H) and oxygen (^{16}O) comprise more than 99% of a water molecule, while the heavier isotopes comprise less than 1%. Because atomic mass is almost entirely protons and neutrons, addition of a neutron in a hydrogen (1H) nucleus to form deuterium (2H or D) practically doubles the mass. Addition of two neutrons to form ^{18}O increases the oxygen atomic mass by approximately 12.5%. Isotopic mass differences are significant enough to cause different chemical and physical reaction rates and allow measurable fractionation or separation of heavy and light water. For instance, the hydrologic cycle fractionates light and heavy water during evaporation and condensation. Lighter water evaporates more easily and heavy water condenses more readily (Faure 1986; Clark and Fritz, 1997; Gat, 1996; and Mazor, 1997). Enrichment of the heavy isotope with respect to the standard is indicated by increased values of δD and $\delta^{18}O$, and depletion of the heavy isotope is noted by decreased values.

Relative enrichment and depletion of isotope ratios in water can be characterized by plotting δD versus $\delta^{18}O$ (Figure 4-7). Data is from this study and Elston and others (1983). Based on a large number water stable isotope analyses of precipitation from around the world, Craig (1961) found a systematic worldwide variation that described a sloping line or Global Meteoric Water Line (GMWL). The GMWL is quantified by the equation: $\delta D = 8 \delta^{18}O + 10$. The intercept (10) is referred to as deuterium excess. Dansgaard (1964) found that temperature was a major determining factor in precipitation (meteoric water) isotope depletion. Other important factors include: 1) altitude, 2) storm duration, 3) a continental effect, 4) a seasonal effect, and 5) a paleoclimate effect (Fontes 1980). Higher altitudes and continental interiors receive isotopically lighter precipitation. In general, winter precipitation is isotopically lighter than in summer and longer storm events result in relatively lighter isotopic precipitation. Cooler paleoclimatic conditions also result in isotopically lighter meteoric water.

Figure 4-7. $\delta^{18}O$ versus δD with diagram showing general trends for various geochemical physical processes. GMWL is the Global Mean Water Line (Craig, 1961).

Two processes can cause isotope values to plot to the right of the meteoric water line or GMWL. With evaporation or boiling, residual waters attain heavier isotopic composition due to preferential evaporation of lighter molecules. Normally, residual waters plot as an “evaporation line” with a slope between two and five (Clark and Fritz 1997). Second, “old” groundwater and geothermal waters will gain heavy oxygen (^{18}O) from rocks by exchange processes associated with water-rock interaction and hydrothermal alteration. These waters typically plot horizontally to the right of the meteoric source water because rocks contain very little hydrogen for exchange and the δD value remains constant. The amount of oxygen exchange or change in $\delta^{18}O$ is a function of rock

composition, texture, temperature and length of contact (Fontes, 1980; Nicholson, 1993; Gat, 1996; and Mazor, 1997).

Because of arid climate in the region, surface water and shallow groundwater is subject to evaporation processes. With time and distance along the flow path, some shallow groundwater, especially in playa areas, becomes progressively heavier in δD and $\delta^{18}O$ with a trend that is upward and to the right because of evaporation. Without evaporative fractionation, most non-thermal water in the Animas Valley is heavier than the geothermal waters. In order to obtain the lighter δD and $\delta^{18}O$ observed in Lightning Dock geothermal waters, precipitation and recharge must have occurred during a much cooler climate. The Lightning Dock geothermal waters show a $\delta^{18}O$ shift to the right from hydrothermal alteration processes and appear to show an upward to the right shift in δD and $\delta^{18}O$ from minor subsurface boiling.

Sample AM4 and AM3 plot along the GMWL. AM4 probably represents a mixture of geothermal water and cold water. Alternatively, AM4 may represent cold groundwater that is conductively heated from below. A plot of δD versus Cl/Br ratio provides additional evidence that minor subsurface boiling is occurring (Figure 4-8).

Figure 4-8. Cl/Br ratio versus δD .

Samples AM3 (up gradient) and AM2 (down gradient) show a shift to heavier δD with no change in the Cl/Br ratio that is consistent with fractionation of δD by boiling. Residual fluids (AM2) show increased Cl and Br, but the Cl/Br ratio remains the same.

4.7.3 Strontium ($^{87}\text{Sr}/^{86}\text{Sr}$) Ratio

Strontium (Sr) frequently replaces Ca in mineral structures because of similar ionic radius. Strontium has four stable isotopes, ^{84}Sr , ^{86}Sr , ^{87}Sr , and ^{88}Sr . With time the natural reservoir of ^{87}Sr is slowly increasing due to beta decay of ^{87}Rb (rubidium), with a half-life of 48.8×10^9 years to form ^{87}Sr . Isotopes of Sr are reported as mass ratios such as $^{87}\text{Sr}/^{86}\text{Sr}$ (Faure 1986, Capo and others, 1998, and Stewart and others, 1998).

Because of very small mass differences between the isotopes of Sr, the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio is not changed by fractionation during chemical or physical processes as observed with lighter isotopic systems such as H and O. An Sr ratio ($^{87}\text{Sr}/^{86}\text{Sr}$ initial) is set at the time of mineral formation. Because Rb has an ionic radius similar to K, K-rich rocks may be enriched in ^{87}Rb . With sufficient time, a rock with high K content may have high ^{87}Sr as a result of ^{87}Rb beta decay.

The $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of the Lightning Dock geothermal wells reflects the flow paths and rock and mineral sources in the region. These sources may include Precambrian granite and metamorphic rocks, Paleozoic carbonate rocks, Tertiary and Quaternary mafic and intermediate composition volcanic rocks and intrusions, Tertiary silicic volcanic and plutonic rocks, and Quaternary eolian dust. Flow paths through Tertiary and Quaternary Animas Valley sediments can reflect a mixture of all sources as these sedimentary units have varied mineral and rock provenance. Older (>1.5 Ba) Precambrian granites have initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios between 0.700 and 0.708 while the younger (<1.5 b.y.) Precambrian K-rich granites in the region have initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios between 0.705 and 0.728 (Condie and Budding, 1979). Today, measured Precambrian $^{87}\text{Sr}/^{86}\text{Sr}$ ratios may range up to 0.81 (Butcher, 1990). Important variations in the initial $^{87}\text{Sr}/^{86}\text{Sr}$

ratio occur in marine carbonate rocks during the Phanerozoic (Burke and others, 1982; McArthur and others, 2001; and Veizer and others, 1999). The ratio changes reflect large-scale plate tectonic related variance in weathering rates and terrestrial sources for initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in Paleozoic seas. During the Pennsylvanian, the average Sr ratio was generally between 0.7080 and 0.7085. Because of low K content and high Ca content, the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of today's Pennsylvanian rocks (such as the Horquilla Formation at Lightning Dock) probably remains below 0.710. Tertiary and Quaternary basalts have initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of 0.703 to 0.704 (Elston, 1976). Mid-Tertiary basaltic andesites have initial $^{87}\text{Sr}/^{86}\text{Sr}$ between 0.707 and 0.708 (Elston, 1976). Because of low K content and relatively high Ca content compared to K and likely low Rb content, the basalt and basaltic andesite initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are valid today. On the other hand, Tertiary silicic volcanics and plutons have initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios ranging from 0.71 to 0.73 (Elston, 1976). Because these rocks may have high Rb contents as a consequence of high K, measured $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of today are higher. Butcher (1990) reports present day $^{87}\text{Sr}/^{86}\text{Sr}$ values up to 0.7488 for mid-Tertiary silicic rocks in the Organ Mountains. The Organ Mountain rhyolites are close in age to the silicic volcanics of the Pyramid Mountains. Caliche provides a proxy for the Quaternary eolian dust $^{87}\text{Sr}/^{86}\text{Sr}$ ratio source reservoir. Caliche $^{87}\text{Sr}/^{86}\text{Sr}$ ratios range from 0.708 to 0.716 (Van der Hoven, 1994; and Capo and others, 1998). However, the contribution of Sr dissolved from eolian dust is probably minor when accounting for the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of groundwater of the Animas Valley.

Figure 4-9 shows the Cl/Br ratio versus the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio for the Lightning Dock geothermal wells. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are very close and only range between 0.7274 and 0.7288.

Figure 4-9. $^{87}\text{Sr}/^{86}\text{Sr}$ versus Cl/Br.

Geothermal groundwater at Lightning Dock has probably flowed through Precambrian granite and/or possibly mid-Tertiary silicic volcanics and granite plutons in order to acquire $^{87}\text{Sr}/^{86}\text{Sr}$ ratios greater than 0.725. Long-term flow through aquifers with a provenance that is dominated by Paleozoic carbonate and mid-Tertiary mafic to intermediate volcanic rocks will have ratios below 0.710.

4.7.4 Carbon ($\delta^{13}\text{C}$)

Carbon (C) has three common isotopes; ^{12}C and ^{13}C are stable, while the ^{14}C isotope is radioactive. In this study, only the stable isotopes are discussed. The abundance of C stable isotopes is ^{12}C (98.89 %) and ^{13}C (1.11%). Carbon isotopes are fractionated by a variety of natural processes, including plant photosynthesis and isotope exchange reactions between carbonate minerals.

Plant photosynthesis can be important and result in ^{12}C enrichment of organic carbon inclusions in sediments, petroleum and coal (Faure 1986). Hoefs (1997) describes two separate pathways for sediment diagenesis, a shallow meteoric pathway and a burial pathway for deep-sea environments. The burial

pathway creates carbonates enriched in ^{13}C from methane production even when ^{12}C enriched organic carbon is present in the original sediment. The resulting carbonates can have high $\delta^{13}\text{C}$ values (Faure 1986 and Hoefs 1997).

At Lightning Dock, thermal waters have $\delta^{13}\text{C}$ values of (– 8.6 to –10.6). The $\delta^{13}\text{C}$ values in the thermal water are probably too light for water-rock equilibration along a deep regional flow path through marine carbonates of Cambrian to Pennsylvanian age. Marine carbonate rocks typically have $\delta^{13}\text{C}$ values from –4 to 6 (Clark and Fritz, 1997; and Veizer and others, 1999). Early Mississippian (Alamogordo Member of the Lake Valley Formation) in south central New Mexico has average $\delta^{13}\text{C}$ at 2.7 (Stanton and others, 2002). Algeo (1996) presents carbon isotopic data on the Middle Pennsylvanian Gobbler Formation in the Sacramento and San Andres Mountains of south central New Mexico. While $\delta^{13}\text{C}$ ranges from 5 to –5, most $\delta^{13}\text{C}$ values for the Gobbler Formation are 2 to 4.

Waters with significant atmosphere-derived fractions of dissolved carbonate species will have $\delta^{13}\text{C}$ values lower than –4 but probably greater than –15. Average atmospheric $\delta^{13}\text{C}$ is about –7. Calcite and carbonate in the upper basin fill deposits of south central New Mexico have $\delta^{13}\text{C}$ between –2.2 and –5.5 (Mack and others, 1994; and Mack and others, 2000); while surface carbonate soils (caliche) $\delta^{13}\text{C}$ range between – 0.6 and –11 (Monger and others, 1998). Monger and others (1998) report organic carbon $\delta^{13}\text{C}$ between –15.7 and –25 in near surface soils.

Like the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, the $\delta^{13}\text{C}$ values suggest that the Lightning Dock waters have not had a flow path through Paleozoic carbonate rocks and have retained a meteoric water $\delta^{13}\text{C}$ that is consistent with flow through silicic volcanic rocks and granite.

4.7.5 Sulfur $\delta^{34}\text{S}$

The main sources of sulfur for Animas Valley groundwater are probably dissolution of gypsum and weathering of sulfide minerals such as pyrite. Gypsum

and anhydrite (CaSO_4) are associated with several Pennsylvanian and Permian rock units and with Tertiary-Quaternary playa deposits. Pyrite occurs as an accessory mineral in many rock units in the subsurface of the area, especially the mid-Tertiary silicic rocks. Dissolution and weathering releases sulfur into groundwater as a sulfate (SO_4) anion. Where acid geothermal conditions or subsurface boiling occurs and biogenic reducing processes are active, some sulfur may occur as dissolved hydrogen sulfide (H_2S). However, no significant amount H_2S has been measured at Lightning Dock (Norman and Bernhardt, 1982).

Stable sulfur isotopic ratios ($\delta^{34}\text{S}$) can reflect source and geochemical processes such as biogenic reduction of sulfur. Marine evaporates of Permian age in west Texas typically have $\delta^{34}\text{S}$ of 9.6 to 12.5 (Thode and Monster, 1965; and Hill, 1996). Late Permian brines in southeast New Mexico have $\delta^{34}\text{S}$ of 7.4 to 9.8 (Hill, 1996). Where sulfur of biogenic heritage occurs, $\delta^{34}\text{S}$ can range downward to -30.

The Lightning Dock geothermal waters show a tight distribution of $\delta^{34}\text{S}$ values between 8.50 and 8.84. The thermal waters may have a component of late Paleozoic dissolved sulfate, although slightly lower than the $\delta^{34}\text{S}$ of Permian brines and gypsum in southeast New Mexico. The tight distribution of values suggests that most sulfate is derived from a single source. Sulfate derived from oxidation of disseminated pyrite in mid-Tertiary silicic rocks is the most likely source of sulfur.

4.8 GEOTHERMOMETRY

Table 4-5 shows the results of geothermometry calculations for the Lightning Dock samples. Table 4-6 is a list of the geothermometers with literature references. The general use and assumptions that are inherent in chemical geothermometer interpretations are discussed by Fournier and others (1974). Inspection of Table 4-5 shows that the alpha-cristobalite, beta-cristobalite and amorphous silica geothermometers are not useful to predict subsurface temperature at Lightning Dock because the predicted temperatures

are less than measured values. Since the waters show close equilibration to chalcedony (Figure 4-6), chalcedony predicts the maximum shallow reservoir temperatures.

Table 4-5. Geothermometer calculations (°C) for geothermal wells. Underlined and italic values are less than measured well temperatures and are not valid indicators of subsurface temperature.

SAMPLE	TEMP	QRTZ	QRTZ(STM)	A-CRIST	B-CRIST	CHAL	AMORPH	Na/K/Ca
AM1	97.8	159	151	108	<u>59</u>	134	<u>32</u>	166
AM2	106.7	144	138	93	<u>45</u>	118	<u>19</u>	151
AM3	106.7	143	138	92	<u>44</u>	117	<u>18</u>	152
AM4	47.8	106	107	56	<u>9</u>	77	<i>n/a</i>	132

SAMPLE	Na/K/Ca(Mg)	Na/K(1)	Na/K(2)	Na/Li(>)	Na/Li(<)	Na/Li	Mg/Li	K/Mg
AM1	159	168	347	95	93	198	173	149
AM2	144	151	314	<u>74</u>	<u>68</u>	173	147	135
AM3	149	153	318	<u>80</u>	<u>75</u>	180	147	132
AM4	<i>n/a</i>	131	277	103	102	208	134	98

Table 4-6. Geothermometer references.

TYPE	LABEL	NAME	REFERENCE
SILICA			
	QRTZ	quartz	Fournier (1977)
	QRTZ(STEAM)	quartz (maximum steam loss)	Fournier (1977)
	A-CRISTO	alpha-cristobalite	Fournier (1977)
	B-CRISTO	beta-cristobalite	Fournier (1977)
	CHAL	chalcedony	Fournier (1977)
	AMORPH	Amorphous silica	Fournier (1977)
CATION			
	Na/K/Ca	Na/K/Ca	Fournier and Potter (1979)
	Na/K/Ca (Mg)	Na/K/Ca (Mg correction)	Fournier and Potter (1979)
	Na/K(1)	Na/K	Fournier (1979)
	Na/K(2)	Na/K	Fournier and Truesdell (1973)
	Na/Li (>)	Na/Li (>10,000 mg/L)	Fouillac and Michard (1981)
	Na/Li(<)	Na/Li(<7,000 mg/L)	Fouillac and Michard (1981)
	Na/Li	Na/Li	Kharaka and others (1982)
	Mg/Li	Mg/Li	Kharaka and Mariner (1989)
	K/Mg	K/Mg	Giggenbach (1988)

Quartz and Na/K/Ca-Mg (correction) geothermometers agree very closely in AM1, AM2, and AM3. Because of possible equilibration of dissolved silica with respect to chalcedony and the fact that the waters show overall partial cation equilibration (Figure 4-10), the quartz and Na/K/Ca-Mg(correction) probably represent the minimum “deep” reservoir temperature (143 to 159 °C). The temperature predicted by the Na/K of Fournier and Truesdell (1973) is not

Figure 4-10. Giggenbach Ternary Diagram showing relative equilibrium maturity of geothermal well water and geothermometer estimates at full equilibrium. Line projection from the Mg apex through sample chemistry gives estimated geothermometer temperature (°C) range on the chemically mature curve (Giggenbach, 1988).

realistic for a non-magmatic heat source geothermal system such as Lightning Dock. On the other had the Na/K of Fournier (1979) and the Na/K/Ca show close agreement and probably show the maximum temperatures of the “deep” reservoir (152 to 168 °C). The Na/Li geothermometers of Fouillac and Michard

(1981) do not appear to be useful at Lightning Dock as these geothermometers are generally used for lower temperature geothermal systems (<100 °C). The Na/Li geothermometer of Kharaka and others (1982) may predict “very deep or base” reservoir conditions; however, this geothermometer predicts temperatures 20 to 30 °C higher than other maximum cation geothermometers and the quartz geothermometer. However, the Na/Li geothermometer falls within the maximum temperatures indicated on the equilibrated or mature water line in the Giggenbach Ternary Diagram (Giggenbach, 1988) (Figure 4-10). The generally lower temperature Mg/Li and K/Mg geothermometers (132 to 173 °C) may reflect partial equilibrium conditions as shown in Figure 4-10. However, they generally bracket the minimum “deep” reservoir temperatures predicted by the quartz and the Na/K/Ca-Mg(correction). A Cl/Br versus enthalpy may have use as a mixing model calculation of subsurface temperature (see Figure 4-3). This analysis was not done as sampling for Cl/Br and SiO₂ of additional Lightning Dock geothermal wells is probably needed.

4.9 SYNTHESIS AND INTERPRETATION

A limited, but up to date, geochemical analysis of chemistry, isotopic variation, and geothermometry of four geothermal wells at Lightning Dock, KGRA yields the following interpretations:

- 1) The shallow reservoir chemistry is sodium sulfate with total dissolved solids (TDS) between 1,000 and 1,180 mg/L.
- 2) The waters appear to have mixed with groundwater at shallow depth and are not equilibrium with any silica phases except possibly chalcedony and do not show geochemical equilibrium maturity (Giggenbach Ternary).
- 3) Two end-member non-thermal groundwater mixes may be indicated by comparison of cation and isotopic ratios with the Cl/Br ratio. One end member may flow in from southeast (Pyramid Mountains) and the other may flow in from the southwest (Animas Valley).

- 4) Minor water table boiling is possible at sample site AM3 because of isotopic fractionation of $\delta^{18}\text{O}$ and δD (heavier) without a change in the Cl/Br ratio of down gradient compositions at AM2.
- 5) The δD and $\delta^{18}\text{O}$ show that the thermal waters represent old meteoric water that recharged in a cooler climate than today.
- 6) Isotopic information argues for an isolated flow path (reservoir and upflow zone) through silicic rocks such as granite and rhyolite and no reservoir chemical or isotopic equilibration with Paleozoic rocks (such as the Pennsylvanian Horquilla Formation) and basalts and andesite of Quaternary to Late Cretaceous age. The high $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, depleted $\delta^{13}\text{C}$, and the relatively low values and small variation in Cl/Br (compared to most geothermal waters) support this hypothesis.
- 7) The $\delta^{34}\text{S}$ values show very little variation and may indicate a single source or mineral phase such as pyrite disseminated in mid-Tertiary rhyolite.
- 8) The minimum “deep” reservoir temperature ranges from 143 to 159 °C and the maximum “deep” reservoir temperature most likely ranges from 152 to 168 °C)
- 9)

5.0 CONCLUSIONS AND DISCUSSION

While many wells have been drilled at the Lightning Dock KGRA over the years, the subsurface geology of the area is not well defined. Recent studies of Witcher 2001b and 2002 point to that the following factors are important to understanding the Lightning Dock geothermal system. An outflow plume, flowing north in silicified and fractured Tertiary Gila Conglomerate and Tertiary rhyolite and silicic ash flow tuff, underlies the tapered north end of the heat-flow anomaly (Witcher, 2002). The heat-flow anomaly occurs over a buried intra-basin horst block at the intersection of an incipient Pleistocene fault, the ring fracture zone of a mid-Tertiary ash flow tuff cauldron, and a major regional northwest-striking basement structure that shows major inversion tectonism (ie. normal faulting that is followed by reverse or transpressional faulting of the same structure zone) during the Mesozoic (Witcher, 1988, 2001b, and 2002).

Previous geophysical studies and exploration efforts at Lightning Dock have used a simple Basin and Range fault zone model to explain the dynamics of the system. The Lightning Dock system is not contained in a major basin bounding fault zone. In fact, the Lightning Dock geothermal reservoir(s) is contained within a bedrock high or small intra graben horst block, at the intersection of four regional tectonic features: 1) a major WNW striking basement structure zone with repetitive compression and extensional deformation since Precambrian; 2) a mid-Tertiary caldera ring fracture zone; 3) a rift accommodation zone in the Animas graben complex; and 4) a small incipient and late Pleistocene normal fault that ends in the area of the thermal anomaly. The Pleistocene fault tip may enhance or open previous fracture permeability. The volcanic rocks drilled in the AmeriCulture AM-2 well place the geothermal system inside the mid-Tertiary Muir cauldron outer ring fracture. Ground water geochemical anomalies have been used to argue for a poorly defined northeast-trending feeder source for hot water. These geochemical anomalies are probably the result of upwelling older deeper alluvial basin water over a bedrock high or constriction between the upper and lower Animas grabens as ground water flows southward, and not leakage from a high temperature “feeder zone” southwest of Lightning Dock.

Available geochemical information for the geothermal fluids suggests that the fluids have flowed through silicic rocks (Dellechiaie, 1977). Low TDS and low bicarbonate concentration is not typical of hot water flow through limestone (ie Paleozoic carbonate rocks). This is an argument for three possibilities. First, a deep-seated basement (granite-metamorphic) circulation is implied. Second a “granite or rhyolite or silicic” upflow channel is implied. Third, a long-term or periodic flow regime may also be assumed. In the paragenesis of the calcite vein zone (CVZ) at Lightning Dock Mountain the last two mineral phases were quartz. In other words, out flow from silicic basement may cross carbonate domains that have been silicified or jasperized by earlier late Tertiary or Quaternary hydrothermal systems.

Field investigation of Miocene and Pliocene (?) hydrothermal fluorite and calcite veins (CVZ) at Lightning Dock Mountain indicates that a major fault may not be required for the upflow zone of the Lightning Dock thermal anomaly. The Tertiary hydrothermal veins at Lightning Dock Mountain have a nearly identical tectonic setting to the present day Lightning Dock geothermal system. A mid-Tertiary Muir cauldron ring fracture rhyolite dike and flow complex may host the upflow zone at Lightning Dock. The juxtaposition of a WNW regional structure, a caldera ring fracture zone, and an intrabasin horst block (accommodation zone) points to intense fracturing and “ground preparation” to host outflow of geothermal water. Stress associated with the Pleistocene fault tip has locally opened older fractures. Upflow along a fractured Tertiary rhyolite dike in association with Pleistocene faulting and a rift accommodation zone is well characterized at Radium Springs, New Mexico (Witcher, 2001a)

Two stratigraphically controlled outflow plumes may exist at Lightning Dock. The shallow outflow plume is mostly contained in silicified and fractured Gila Conglomerate. Previous studies have erroneously interpreted the silicified Gila Conglomerate as “rhyolite.” Limited deep outflow maybe is hosted the upper Jurassic to Lower Cretaceous rift fan conglomerate (Hell-to-Finish Formation?) with solution and fracture permeability.

Heat flow and temperature gradient data indicate a total heat loss for the system less than 12 MWt and a northward outflow (Witcher, 2001 and 2002). A base reservoir or upflow zone temperature of 160° C is determined from silica geothermometry and the temperature profile of the Steam Reserve Animas 55-7 well. A total natural mass flux of about 210 gpm of water at 160° C into the base of the upflow zone is estimated by energy and mass balance of the Lightning Dock heat flow anomaly (Witcher, 2001b and 2002).

Drilling during GRED II studies confirms that the Lightning Dock geothermal system is structurally coincident with a buried, small intra-basin horst block that cross cuts the mid-Tertiary Muir cauldron outer ring fracture zone. The sequence of ash flow tuffs is interpreted to represent a Muir cauldron facies and the overlying biotite rhyolite may represent ring fracture zone flows or rhyolite

dome. The intrusive source for the ring fracture zone rhyolite flow may provide the upflow path for the system. Temperature logs indicate the main outflow is within highly silicified Gila Conglomerate that is preserved on the top of the horst block. A probable paleosol at the top of the Gila Conglomerate sequence suggests that the horst block age is post Gila Conglomerate and that bounding faults have not been active since late Miocene or early Pliocene. Younger largely unaltered basin fill deposits buried the paleosol developed on the Gila Conglomerate on the uplift block.

Upper Jurassic- Lower Cretaceous sedimentary packages (Bisbee Group) drilled during GRED II confirmed the presence of a major WNW structural zone inferred from aeromagnetic data, Tertiary-Mesozoic subcrop relationships observed on the Paleozoic rocks between the Steam Reserve 55-7 and Cockrell Pyramid wells, and the close relative elevation of the Precambrian-Paleozoic contact between the 55-7 and Cockrell wells.

The 55-7 well subsurface geology and temperature logs indicate a deep outflow (about 150° C) in the Bisbee Group. Temperature logs in the AM-2 well show that this deep outflow does not flow laterally to the north. It is believed that this deeper outflow probably leaks to the WNW into the older late Miocene to early Pliocene fault zone(s) bounding the west side of the buried horst block and then flows northward along the fault in fractures contained in the hanging wall Gila Conglomerate or Tertiary volcanics with possible minor upward leakage. The AmeriCulture Federal well (geochem sample AM4) probably overlies this deeper outflow as the AmeriCulture Federal well is west of the fault as determined by drawdown during a pump test of the AM-1 State well (Witcher, 2001b). The main upward leakage (upflow zone) is probably located in a rhyolite intrusion or WNW fracture (or shear) zone beneath the southeast portion of the Burgett greenhouse complex closest to the termination of the last surface break of the incipient Pleistocene Animas fault on the east side of the buried horst block. The deep basement structure of the WNW zone probably plays a role in the termination of the last surface break on the Pleistocene Animas fault and the south boundary of the Lightning Dock geothermal anomaly.

Temperature logs and a short airlift test of the Horquilla Formation indicate elevated temperature but no permeability. Apparently, the sedimentation of the Bisbee Group rift deposits were not preceded by significant karst (solution permeability) development within the underlying Paleozoic carbonate rocks. This is consistent with geochemical evidence that precludes flow (and chemical equilibrium) with Paleozoic limestone for the geothermal fluids at Lightning Dock. The elevated temperatures represent a thermal areole around the upflow. The roll over in shallow temperature logs would indicate that the shallow outflow has relatively young geologic age. The larger thermal areole suggests an over all longer lived system (in the last 1 Ma) that is periodically very active (10's Ka) at a shallower depth. The relationships of fluorite mineralization and a fairly wide belt of hydrothermal calcite in the Pyramid Mountains to the east indicates that the regional WNW zones can be active at tectonically favorable locations on the order of several Ma intervals. Table Top Mountain may represent another.

The conclusions drawn from the GRED II drilling is that while many details of the Lightning Dock geothermal system remain to be determined, the system is relatively small, is relatively long-lived with periodic spurts in activity, has deep flow roots in either Precambrian "granite" or mid-Tertiary rhyolite cauldron complexes along a WNW-trending regional structural weakness. An incipient Pleistocene fault zone (Animas Fault) serves to open up deep-seated flow in these rocks. The upflow is probably contained in a small window of vertical permeability opened by the Pleistocene fault that ends at the deep-seated WNW shear zone. A Muir cauldron ring fracture zone rhyolite intrusive contained within a small-buried horst block maybe cross cut by the Pleistocene fault zone to provide the vertical permeability window. The major shallow outflow is within a remnant Gila Conglomerate section preserved at the top of the horst block and minor deep outflow may be channeled first by permeable WNW fractures in Bisbee Group sediments in the horst block that are connected to inactive Miocene to Pliocene fault zones with remnant permeability on the west side of the horst block. In any case, the flow system is predominantly contained in mid-Tertiary rhyolite or detritus derived from the mid-Tertiary rhyolite (Gila

Conglomerate) at shallow and intermediate depth and either Precambrian granite or mid-Tertiary plutons at great depth. There is no productive reservoir present in either the Mesozoic or Paleozoic rocks beneath Lightning Dock.

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APPENDIX 1 SUMMARY GEOLOGIC LOG

SUMMARY GEOLOGIC LOG - AmeriCulture State 2		
TOP	BOTTOM	FORMATION
ft	ft	lithology, unit, age, structure
0	270	Upper basin fill alluvium (Quaternary-Tertiary)
270	284	Paleosoil (?) top of Gila Conglomerate (Tertiary)
284	570	Gila Conglomerate (highly silicified) (Tertiary)
570	645	Conglomerate (caldera moat fill ?) (Tertiary)
645	730	Altered biotite rhyolite (ring fracture flow or dike) (Tertiary)
730	830	Vitrophyric biotite rhyolite (ring fracture flow or dike) (Tertiary)
830	860	Altered biotite rhyolite (ring fracture flow or dike) (Tertiary)
860	958	Rhyolite ash flow tuff (upper cauldron fill) (Tertiary)
958	1105	Rhyolite lithic ash flow tuff (lower cauldron fill) (Tertiary)
1105	1145	Volcanic mud flow (lahar) (Tertiary)
1145	1151	Matrix-supported volcanic gravel (Tertiary)
1151	1212	Tuffaceous volcanoclastics and interbedded ash flow tuff
		(Tertiary?) (fault zone 1169 to 1175 ft)
1212	1238	Sandy boulder to gravel volcanoclastics (Tertiary?)
		(fault zone 1255 to 1275 ft, dip about 60°)
1238	1296	Tuffaceous sandy volcanoclastics (Tertiary?)
1296	1326	Pumaceous mud flow (Tertiary?)
1326	1334	Porphyritic andesite (Late Cretaceous? Tertiary?)
		(fault zone at 1334 to 1344 ft, dip 35° to 40°)
1334	1456	Interbedded calcareous sandstone, calcareous shale, shale,
		and dolomite (Early Cretaceous) Bisbee Group
		(fault zone at 1392 to 1397 ft, dip 35° to 40°)
1456	1653	Lithified sandy limestone cobble-to-boulder clast-supported
		conglomerate (Early Cretaceous) Bisbee Group
		(fault zone 1594 to 1607 ft, dip about 60°)
1653	1850	Limestone (Paleozoic) Horquilla Formation
1850	1990	Dacite, porphyritic dacite, and dacite porphyry
		(Tertiary ? sill or dike)
1990	2030	Limestone (Paleozoic) Horquilla Formation
2030	2100	Interbedded fine sandstone and siltstone (Paleozoic)
		Horquilla Formation

APPENDIX 2 CORE RUN LOG

CORE RUN	DATE	BEGIN	END	TIME	TOP	BOTTOM	DRILLED	CORE	REMARKS
		hrs	hrs	min	ft	ft	ft	ft	
1	13-Aug	1945	2010	25	906.5	912.5	6.0	6.0	
2		2030	2050	20	812.5	917.5	5.0	4.3	
3		2117	2247	30	918.5	927.5	10.0	10.0	
4		2303	2333	30	927.5	937.5	10.0	10.0	
5	14-Aug	0056	0122	26	937.5	947.5	10.0	10.0	
6		0208	0306	58	947.5	957.5	10.0	10.0	BHT 184 °F
7		0401	0429	28	957.5	967.5	10.0	10.0	
8		0500	0526	26	967.5	977.5	10.0	10.0	
9		0615	0637	22	977.5	987.5	10.0	10.0	
10		0720	0741	21	987.5	997.5	10.0	10.0	
11		0802	0825	23	997.5	1007.5	10.0	10.0	
12		0846	0919	33	1007.5	1017.5	10.0	10.0	
13		0942	1014	32	1017.5	1027.5	10.0	10.0	BHT 204 °F
14		1045	1118	33	1027.5	1037.5	10.0	10.0	
15		1144	1215	31	1037.5	1047.5	10.0	10.0	
16		1305	1340	35	1047.5	1057.5	10.0	10.0	
17		1420	1458	38	1057.5	1067.5	10.0	10.0	
18		1530	1618	48	1067.5	1077.5	10.0	10.0	
19		1715	1750	35	1077.5	1087.5	10.0	10.0	
20		1839	2022	36	1087.5	1097.5	10.0	10.0	
21		1950	2322	32	1097.5	1107.5	10.0	8.0	BHT 210 °F
22		2255	0245	37	1107.5	1117.5	10.0	10.8	
23	15-Aug	0210	0425	35	1117.5	1120.5	3.0	3.0	
24		0325	0600	60	1120.5	1127.5	7.0	6.7	
25		0540	0710	20	1127.5	1129.5	2.0	2.0	
26		0650	0825	20	1129.5	1137.5	8.0	8.0	
27		0745	0915	40	1137.5	1147.5	10.0	10.0	BHT 210 °F
28		0928	1002	30	1147.5	1157.5	10.0	8.5	
29		1032	1118	50	1157.5	1167.5	10.0	10.0	
30		1305	1348	43	1167.5	1177.5	10.0	10.0	
31		1423	1520	63	1177.5	1187.5	10.0	10.0	
32		1625	1650	25	1187.5	1197.5	10.0	10.0	BHT 216 °F
33		1741	1810	31	1197.5	1207.5	10.0	10.0	
34		1835	1903	32	1207.5	1217.5	10.0	10.0	
35		1923	1946	23	1217.5	1227.5	10.0	10.0	
36		2004	2038	34	1227.5	1237.5	10.0	10.0	
37		2055	2120	25	1237.5	1247.5	10.0	10.0	BHT 221 °F
38		2142	2208	20	1247.5	1257.5	10.0	10.0	
39		2227	2255	32	1257.5	1264.0	6.5	6.5	
40		2328	2354	26	1264.0	1274.5	10.5	10.5	
41	16-Aug	0219	0249	30	1274.5	1285.0	10.5	10.5	
42		0312	0345	33	1285.0	1295.5	10.5	10.5	BHT 200 °F

43		0428	0502	34	1295.5	1306.0	10.5	10.5	
44		0530	0605	35	1306.0	1316.5	10.5	10.5	
45		0640	0717	37	1316.5	1327.0	10.5	10.5	
46		0801	0825	24	1327.0	1337.5	10.5	10.5	
47		0845	0910	25	1337.5	1347.5	10.0	5.0	
48		0930	0947	24	1347.5	1353.0	5.5	10.5	BHT 214 °F
49		1010	1032	22	1353.0	1363.5	10.5	10.5	
50		1055	1125	30	1363.5	1373.5	10.0	10.0	
51		1147	1218	31	1373.5	1384.0	10.5	10.5	
52		1253	1325	32	1384.0	1394.5	10.5	10.5	
53		1350	1430	40	1394.5	1405.0	10.5	10.5	
54		1500	1530	30	1405.0	1415.5	10.5	10.5	
55		1558	1630	32	1415.5	1426.0	10.5	10.5	BHT 220 °F
56		1650	1730	40	1426.0	1436.5	10.5	10.5	
57		1745	1818	33	1436.5	1447.0	10.5	10.5	
58		1841	1912	31	1447.0	1457.5	10.5	10.5	
59		1925	2006	31	1457.5	1467.5	10.0	10.0	
60		2032	2120	52	1467.5	1477.5	10.0	10.0	BHT 226 °F
61		2145	2218	33	1477.5	1480.0	2.5	2.5	
62		2230	2240	10	1480.0	1481.0	1.0	1.0	
63	17-Aug	0700	0805	65	1481.0	1487.5	6.5	6.5	
64		0818	0925	67	1487.5	1497.5	10.0	10.0	
65		0950	1117	87	1497.5	1507.5	10.0	10.0	
66		1153	1253	60	1507.5	1517.5	10.0	10.0	
67		1326	1430	64	1517.5	1527.0	9.5	9.5	
68		2020	2125	65	1527.0	1529.0	2.0	2.0	
69	18-Aug	0920	1020	60	1529.0	1537.5	8.5	8.5	
70		1048	1140	52	1537.5	1547.5	10.0	10.0	BHT 206 °F
71		1242	1402	20	1547.5	1557.5	10.0	10.0	
72		1432	1556	84	1557.5	1567.5	10.0	10.0	lost circulation
73		1615	1715	60	1567.5	1577.5	10.0	10.0	lost circulation
74		1743	1912	89	1577.5	1587.5	10.0	10.0	lost circulation
75		1940	2050	70	1587.5	1597.5	10.0	10.0	BHT 218 °F; lost circulation
76		2122	2222	60	1597.5	1607.5	10.0	10.0	lost circulation
77		2240	2330	50	1607.5	1617.5	10.0	10.0	lost circulation
78	19-Aug	0040	0145	65	1617.5	1627.5	10.0	10.0	lost circulation
79		1042	1265	83	1627.5	1637.5	10.0	10.0	lost circulation
80		1307	1427	80	1637.5	1647.5	10.0	10.0	lost circulation
81		1456	1550	66	1647.5	1657.5	10.0	10.0	lost circulation
82		1609	1718	69	1657.5	1667.5	10.0	10.0	lost circulation
83		1737	1810	93	1667.5	1657.5	10.0	10.0	lost circulation
84		1930	2103	93	1667.5	1687.5	10.0	10.0	lost circulation

APPENDIX 3 DAILY DRILLING REPORT LOG

DAILY REPORT LOG			
AM-2 GRED II			
DATE	8/11/2003		
FOOTAGE	START ft	END ft	
	906.5	906.5	
TOOLS IN HOLE	N/A		
GEOLOGY	N/A		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	1200	Rigging up; cutoff old flange; install and weld new flange.	
DATE	8/12/2003		
FOOTAGE	START ft	END ft	
	906.5	906.5	
TOOLS IN HOLE	N/A		
GEOLOGY	N/A		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	1200	Finish rigging up; run 4 1/2 inch HWL casing and wash down from 720 to 910 ft to remove heavy mud from last drilling.	
	2000	Rotation speed controls on rig not functioning properly; needs reprogramming computer	
	2400	Tower change.	

DATE	8/13/2003		
FOOTAGE	START ft	END ft	
	906.5	937.5	
TOOLS IN HOLE	4/12 inch casing with centralizers and shoe; HQWL core barrel, HQWL reamer shell, and HQWL series 7 diamond bit.		
GEOLOGY	Ash flow tuff.		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	0030	Pull casing; rerun 4 1/2 inch casing with shoe and stabilizers to 910 ft.	
	0840	Install diverter, hang and secure 4 1/2 inch drill liner, mixing mud.	
	1600	Conditioning hole, running core tools into hole.	
	1845	At 100 ft from bottom, mud returns 130 °F	
	1945	Begin coring at 906.5 ft GL; first two runs broken core	
	2203	Pullback, slowly rotate, hookup backside mud to lubricate rubbers at top of diverter	
	2222	Back to bottom, coring ahead, 500 to 550 rpm	
	2400	Tower change, pull back slowly rotate and circulate at 937.5 ft.	

DATE	8/14/2003		
FOOTAGE	START ft	END ft	
	937.5	1117.5	
TOOLS IN HOLE	4/12 inch casing with centralizers and shoe; HQWL core barrel, HQWL reamer shell, and HQWL series 7 diamond bit.		
GEOLOGY	Ash flow tuff.		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	0046	Resume coring 937.5 ft.	
	0230	Pull back off bottom, adjusting mud pit system.	
	0245	Resume coring 952 ft.	
	0324	Hole producing about 20 gpm mud, pull back off bottom and circulate.	
	0330	Disconnect, call Ralph Jecks, flowing 20 gpm of "hot mud".	
	0355	BHT 957.5 ft is 184 °F	
	0430	Disconnect, pull core tube 967.5 ft, flowing 20 gpm of "hot mud".	
	0520	Disconnect, pull core tube 977 ft, flowing 20 gpm of "hot mud".	
	0530	Pull back off bottom, stop drilling for thunderstorm and lightning.	
	0615	Resume coring.	
	0800	Cleaning mud desanders.	
	1013	Mixing mud.	
	1045	BHT at 1027.5 ft is 204 °F.	
	2108	Pull back off hole, wiring tangled in rig works on run #21, core falls out of tube, formation change in box 22	
	2230	Recovered core run #21 lost 1.2 ft.	
	2235	BHT at 1107.5 ft is 210 °F.	
	2335	Adjusting mud system.	

DATE	8/15/2003		
FOOTAGE	START ft	END ft	
	1117.5	1274.5	
TOOLS IN HOLE	4/12 inch casing with centralizers and shoe; HQWL core barrel, HQWL reamer shell, and HQWL series 7 diamond bit.		
GEOLOGY	Volcanoclastic sediments.		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	0015	Continue to adjust mud system, rig maintenance.	
	0210	Resume coring at 1117.5 ft.	
	0345	Adjusting mud system, mud pump maintenance.	
	2135	BHT at 1247.5 ft is 221 °F, serviced fuel line.	
DATE	8/16/2003		
FOOTAGE	START ft	END ft	
	1274.5	1481.0	
TOOLS IN HOLE	4/12 inch casing with centralizers and shoe; HQWL core barrel, HQWL reamer shell, and HQWL series 7 diamond bit.		
GEOLOGY	Volcanoclastic sediments and Cretaceous shale and sandstone.		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	0015	Change out core tube head.	
	0216	Resume coring at 1264 ft.	
	0400	BHT 200 °F, mud discharge temp is 151 °F.	
	2300	Trip out of hole to change bit, inner cutting surface of bit out of guage.	
	2330	Hole unloading drill mud from formation, mud temp is 191°F, 800 gpm of mud lost in hole during last 24 hrs.	

DATE	8/17/2003			
FOOTAGE		START ft	END ft	
		1481.0	1529.0	
TOOLS IN HOLE		4/12 inch casing with centralizers and shoe; HQWL core barrel, HQWL reamer shell, and HQWL series 7 diamond bit.		
GEOLOGY		Cretaceous shale, sandstone, and limestone conglomerate with some chert gravel.		
MUD PROPERTIES		N/A		
EVENT LOG				
	TIME hrs	NARRATIVE		
	0700	Trip new bit to bottom and resume coring		
	0722	About a 1 ft of hard lithology cave recovered in core run #63.		
	1437	Drill depth 1527 ft. Drill rods twist off. 940 ft of rods pulled from hole. Fish drill rods and core with spear.		
	1830	Recovered core, tripping core tools.		
	2000	Tripping in 20 ft from bottom; difficult trip washing to bottom.		
	2020	Resume coring at 1527 ft.		
	2125	Cored to 1529 ft and twist off. Fish drill rods and core with spear. Hole unloading "hot mud".		
DATE	8/18/2003			
FOOTAGE		START ft	END ft	
		1529.0	1617.5	
TOOLS IN HOLE		4/12 inch casing with centralizers and shoe; HQWL core barrel, HQWL reamer shell, and HQWL series 7 diamond bit.		
GEOLOGY		Cretaceous limestone conglomerate with chert gravel and sandstone.		
MUD PROPERTIES		N/A		
EVENT LOG				
	TIME hrs	NARRATIVE		
	0920	Resume coring at 1529 ft. BHT is 209°F, change bit rotation for 500 to 550 rpm to 300 to 350 rpm with less bit weight.		
	1427	Lost circulation at 1559 ft.		

DATE	8/19/2003			
FOOTAGE		START ft	END ft	
		1617.5	1687.5	
TOOLS IN HOLE		4 1/2 inch casing with centralizers and shoe; HQWL core barrel, HQWL reamer shell, and HQWL series 7 diamond bit.		
GEOLOGY		Cretaceous limestone conglomerate with chert gravel and Paleozoic limestone.		
MUD PROPERTIES		N/A		
EVENT LOG				
	TIME hrs	NARRATIVE		
	0100	Lost cricutlation with no returns at 1620 ft and coring ahead.		
	0145	Hole torque, trip out of hole to check bit and reamer shell for guage. Drill liner (4 1/2 in) slipped into hole.		
	0600	Rods tripped to bottom; disconnect; use spear to pull casing back; weld on surface "ears" to stabalize 4 1/2 in casing.		
	1042	Resume coring, bit was good.		
	2200	At 1687.5 ft cavern encountered; tag bottom of void (18 ft) at about 1705 ft; attempt to core and twist off.		
	2300	Trip out 1180 ft of core rods above twist off.		

DATE	8/20/2003		
FOOTAGE	START ft	END ft	
	1687.5	1687.5	
TOOLS IN HOLE	910 ft of 4 1/2 in casing, shoe w/ 10 centralizers, and 530 ft of core tools (core barrel, reamer shell, bit and twisted off rods).		
GEOLOGY	Paleozoic limestone.		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	0120	Trip fishing spear into hole and hit obstruction about 890 ft inside casing (parted casing).	
	0138	Trip fishing tools out of hole and discovered that 4 1/2 in casing had slipped into hole.	
	0300	Fishing tools out of hole. Make impression tool and trip into hole.	
	1450	Impression tool locates top of casing at 123.3 ft. Trip into hole with spear to recover casing.	
	1700	Trip back with first string of 20ft casing.	
	1830	Laid down 39 strings of casing recovered (778 ft). Welded tabs or ears at surface missing.	
	2000	Tripping back to bottom with impression tool to locate casing fish left in hole.	
	2045	Tag casing fish in hole at 887 ft and trip out impression tool.	
	2200	Impression tool on surface, casing string fish laying against SE side of hole.	
	2210	Tripping into hole with spear to recover core tools fish at bottom through 4 1/2 in casing.	

DATE	8/21/2003			
FOOTAGE		START ft	END ft	
		1687.5	1687.5	
TOOLS IN HOLE		122 ft of 4 1/2 in casing, shoe w/ 10 centralizers, and 530 ft of core tools (core barrel, reamer shell, bit and twisted off rods).		
GEOLOGY		Paleozoic limestone.		
MUD PROPERTIES		N/A		
EVENT LOG				
	TIME hrs	NARRATIVE		
	0135	Unable to get past 4 1/2 in casing fish at 887 ft with spear to recover coring tool fish at bottom.		
	0800	Recovered 5 strings of 20 ft 4 1/2 in casing.		
	1515	Lay down fishing tools to wash hole for camera survey.		
	1600	Trip HQ rods to 875.4 ft flush hole with high pressure, low volume pump and then low pressure, high volume pump.		
	2039	Welenco (Peter Godfrey - logger) on site for camera survey.		
	2300	Welenco camera survey out of hole, continue to flush hole.		
DATE	8/22/2003			
FOOTAGE		START ft	END ft	
		1687.5	1687.5	
TOOLS IN HOLE		22 ft of 4 1/2 in casing, shoe w/ 10 centralizers, and 530 ft of core tools (core barrel, reamer shell, bit and twisted off rods).		
GEOLOGY		Paleozoic limestone.		
MUD PROPERTIES		N/A		
EVENT LOG				
	TIME hrs	NARRATIVE		
	0100	trip into hole with HQ to 887.7 ft, pump for 1/2 hour, pull back to 885.7 ft and pump two Baker tanks loads		
	1130	Welenco on site for additional camera survey.		
	1500	Welenco completes survey, no fish observed to 886 ft, HQ rods strike fish at 889.6 ft with 10.6 ft stickup from 910 ft.		
	1600	Drill crew goes on one 12 hour tower beginning at midnight.		

DATE	8/23/2003		
FOOTAGE	START ft	END ft	
	1687.5	1687.5	
TOOLS IN HOLE	22 ft of 4 1/2 in casing, shoe w/ 10 centralizers, and 530 ft of core tools (core barrel, reamer shell, bit and twisted off rods).		
GEOLOGY	Paleozoic limestone.		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	0100	trip in to fish for centralizers.	
	0810	One centralizer recovered. Set screws missing on stabilizers	
	1030	One half centralizer recovered. Set screws missing on stabilizers	
	1300	One centralizer recovered. Set screws missing on stabilizers	
DATE	8/24/2003		
FOOTAGE	START ft	END ft	
	1687.5	1687.5	
TOOLS IN HOLE	22 ft of 4 1/2 in casing, shoe w/ 7 centralizers, and 530 ft of core tools (core barrel, reamer shell, bit and twisted off rods).		
GEOLOGY	Paleozoic limestone.		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	0850	Two centralizers recovered. Set screws missing on stabilizers.	

DATE	8/25/2003		
FOOTAGE	START ft	END ft	
	1687.5	1687.5	
TOOLS IN HOLE	22 ft of 4 1/2 in casing, shoe w/ 5 centralizers, and 530 ft of core tools (core barrel, reamer shell, bit and twisted off rods).		
GEOLOGY	Paleozoic limestone.		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
		One and one half centralizers removed along with altered white biotite rhyolite boulder cave from about 870 ft depth.	
		Mud up hole to prevent further formation cave into hole	
DATE	8/26/2003		
FOOTAGE	START ft	END ft	
	1687.5	1687.5	
TOOLS IN HOLE	22 ft of 4 1/2 in casing, shoe w/ 2 centralizers, and 530 ft of core tools (core barrel, reamer shell, bit and twisted off rods).		
GEOLOGY	Paleozoic limestone.		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	N/A	Wash hole with mud, temp 158 °F at surface discharge, trip in with hooks to 910.5 ft and pull out 2 centralizers and 10 in rock	

DATE	8/27/2003		
FOOTAGE	START ft	END ft	
	1687.5	1687.5	
TOOLS IN HOLE	22 ft of 4 1/2 in casing, shoe w/ 2 centralizers, and 530 ft of core tools (core barrel, reamer shell, bit and twisted off rods).		
GEOLOGY	Paleozoic limestone.		
MUD PROPERTIES	mud viscosity, 42 sec		
EVENT LOG			
	TIME hrs	NARRATIVE	
	N/A	Wash hole, run spear in hole, tag bottom at 1001.7 ft, trip out	
DATE	8/28/2003		
FOOTAGE	START ft	END ft	
	1687.5	1687.5	
TOOLS IN HOLE	22 ft of 4 1/2 in casing, shoe w/ 2 centralizers, and 530 ft of core tools (core barrel, reamer shell, bit and twisted off rods).		
GEOLOGY	Paleozoic limestone.		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	N/A	No borehole activity, rig computer controls down	

DATE	8/29/2003		
FOOTAGE	START ft	END ft	
	1687.5	1687.5	
TOOLS IN HOLE	22 ft of 4 1/2 in casing, shoe w/ 2 centralizers, and 530 ft of core tools (core barrel, reamer shell, bit and twisted off rods).		
GEOLOGY	Paleozoic limestone.		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	N/A	No borehole activity, rig computer controls down	
DATE	8/30/2003		
FOOTAGE	START ft	END ft	
	1687.5	1687.5	
TOOLS IN HOLE	22 ft of 4 1/2 in casing, shoe w/ 2 centralizers, and 530 ft of core tools (core barrel, reamer shell, bit and twisted off rods).		
GEOLOGY	Paleozoic limestone.		
MUD PROPERTIES			
EVENT LOG			
	TIME hrs	NARRATIVE	
	N/A	Run in hole with mill tool to 1001.4 and mill to 1014.3 ft, run in hole with spear, pulled back to 10,000 lbs, no fish	

DATE	8/31/2003		
FOOTAGE	START ft	END ft	
	1687.5	1687.5	
TOOLS IN HOLE	22 ft of 4 1/2 in casing, shoe w/ 2 centralizers, and 530 ft of core tools (core barrel, reamer shell, bit and twisted off rods).		
GEOLOGY	Paleozoic limestone.		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	N/A	Conditioned hole viscosity from 59 to 42 seconds, trip in magnet to 905 ft, trip out with magnet, not fish, condition hole	
DATE	9/1/2003		
FOOTAGE	START ft	END ft	
	1687.5	1687.5	
TOOLS IN HOLE	22 ft of 4 1/2 in casing, shoe w/ 2 centralizers, and 530 ft of core tools (core barrel, reamer shell, bit and twisted off rods).		
GEOLOGY	Paleozoic limestone.		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	N/A	Conditioned hole, drilled bridge in hole from 910 to 989 ft and washed hole to 1005 ft. Trip out of hole, lay down rods.	
	N/A	Prepare to demob core rig	

DATE	9/16/2003			
FOOTAGE		START ft	END ft	
		1687.5	1687.5	
TOOLS IN HOLE	22 ft of 4 1/2 in casing, shoe w/ 2 centralizers, and 530 ft of core tools (core barrel, reamer shell, bit and twisted off rods).			
GEOLOGY	Paleozoic limestone.			
MUD PROPERTIES	N/A			
EVENT LOG				
	TIME hrs	NARRATIVE		
	0600	Rig up Lang Exploration Drilling Rig #LK-23 topdrive rotary rig.		
	1230	Trip in 7 in washover to 910 ft.		
	1415	Drill 908 ft to 920 ft with washover bit.		
	1515	Circulate hole for 15 minutes and setup to trip in 4 1/2 in rods.		
	1600	trip in 4.5 in rods to 920 ft inside 7in.		
	1700	Drill from 920 ft to 992 ft to top of casing fish and clean hole.		
	1800	End tower.		
DATE	9/17/2003			
FOOTAGE		START ft	END ft	
		1687.5	1687.5	
TOOLS IN HOLE	22 ft of 4 1/2 in casing, shoe w/ 2 centralizers, and 530 ft of core tools (core barrel, reamer shell, bit and twisted off rods).			
GEOLOGY	Paleozoic limestone.			
MUD PROPERTIES	N/A			
EVENT LOG				
	TIME hrs	NARRATIVE		
	0600	Drill 992 ft to 1040 ft with 5 in tricone, top of casing fish at about 992 ft.		
	0715	Condition hole for 15 min and trip in 7 in washover bit.		
	0745	Drill 920 to 992 ft with washover bit and condition hole.		
	1045	Trip in 4.5 in and trip out 4.5 in and trip in 7in washover bit.		
	1215	Drill 992 ft to 1045 ft with washover bit.		
	1445	Condition hole.		
	1600	Stand by for parts.		

DATE	9/18/2003		
FOOTAGE	START ft	END ft	
	1687.5	1687.5	
TOOLS IN HOLE	22 ft of 4 1/2 in casing, shoe w/ 2 centralizers, and 530 ft of core tools (core barrel, reamer shell, bit and twisted off rods).		
GEOLOGY	Paleozoic limestone.		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	0600	Standy by	
	0645	Trip in 4.5 in with fishing tool to 980 ft.	
	0800	Attempt to hook casing fish and trip out.	
	0915	Retrieve 20 ft casing fish and cut casing from fish tool.	
	0945	Trip in 4.5 in with fishing tool to 1000 ft.	
	1030	Attempt to hook last 20 ft casing fish and trip out.	
	1200	Last 20 ft casing fish on surface and breakdown fishing tools and make up 5 in tricone bit.	
	1215	Trip in to 1040 ft.	
	1315	Ream to 1187 ft and seem to drilling along side HQ rod fish.	
	1545	Run in 7 in washover bit and continue washover to 1200 ft.	
	1615	Drill 11 7/8 in from 1045 to 1175.5 ft (GL) and tag HQ rods.	
	2300	Set 7 in washover on bottom and switch over to 4 1/2 in.	
	2315	Trip out 4 1/2 in rods.	
	2400	Tower change.	

DATE	9/19/2003		
FOOTAGE	START ft	END ft	
	1687.5	1687.5	
TOOLS IN HOLE	Casing centralizer, and 530 ft of core tools (core barrel, reamer shell, bit and twisted off rods).		
GEOLOGY	Paleozoic limestone.		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	0000	Finish trip out 4 1/2 in rods.	
	0100	Trip in 7 in washover bit.	
	0130	Drill 1175 ft to 1200 ft with 7 in washover bit.	
	0230	Condition and circulate hole.	
	0300	Land 7 in washover bit and trip in 4.5 in rod with grapple to 1180 ft.	
	0430	Hook HQ fish and trip out with weight of fish but fail to retrieve.	
	0645	Trip in to 1180 ft and fail to grab HQ fish.	
	0800	Trip out with fish with approximately 8,000 lbs over string weight and break pin on sub with grapple.	
	1015	Break down subs, pump fuel, and clean site, wait on overshot.	
	1200	Tower change, wait on overshot	
	2145	Overshot arrives, make up fishing tools.	
	2215	Trip in to top of HQ fish.	
	2315	Overshot over fish, trip out.	
	2400	Tower change	

DATE	9/20/2003		
FOOTAGE	START ft	END ft	
	1687.5	1687.5	
TOOLS IN HOLE	Lost fish (casing centralizer, reamer shell, bit and bowen spear).		
GEOLOGY	Paleozoic limestone.		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	0000	Continue trip out washover tools.	
	0145	Trip out 4 1/2 in rods with 490 ft (50 joints) HQ and 1 core barrel, reamer shell, HQ bit, and bowen spear.	
	0545	Remove core from core barrel, load HQ rods with crane, prepare to trip out 7 in.	
	0645	Circulate and condition hole.	
	0715	Trip out 7 in rods.	
	0915	Clean site and pump fuel.	
	1045	Wait on supply truck.	
	1200	End Tower.	

DATE	9/21/2003		
FOOTAGE	START ft	END ft	
	1687.5	1687.5	
TOOLS IN HOLE	(1) Bit 10 5/8 tricone carbide (0.95 ft), (2) Reamer (5.61 ft), (3) Stabilizer (20.04 ft), (4) Reamer (6.13 ft), (5) Collar (20.00 ft), (6) Collar (20.00 ft), (7) Collar (19.65 ft), (8) Collar (20.10 ft), (9) Collar (20.01ft), (10) Collar (20.08 ft), (11) Collar (19.97 ft), (12) Topsubs (4.50 ft)/// 177.04 ft total drill tools///Lost fish (casing centralizer, reamer shell, bit and bowen spear).		
GEOLOGY	Paleozoic limestone.		
MUD PROPERTIES	wt - 8.8, visc- 38 sec., pH - 9, wall cake - 2/32, temp -150 °F, wl - 13.6 cc, solids -0.5% time 1030 hrs.		
EVENT LOG			
	TIME hrs	NARRATIVE	
	0430	Unload supply truck, make up drilling tool assembly.	
	0630	Trip in drilling tools to 1200 ft.	
	0930	Ream from 1200 ft to 1255 ft.	
	1200	Tower change, ream ahead.	
	2015	Ream to 1374 ft, loose 3/4 tank of mud, pull back 3 rods, mix mud, trip back to bottom.	
	2200	Ream ahead to 1377 ft and loose another 3/4 tank of mud.	
	2215	Mix mud, hook up 5X6 mud pump.	
	2300	Ream ahead.	
	2400	Tower change, reamed to 1385 ft.	

DATE	9/22/2003		
FOOTAGE	START ft	END ft	
	1687.5	1687.5	
TOOLS IN HOLE	(1) Bit 10 5/8 tricone carbide (0.95 ft), (2) Reamer (5.61 ft), (3) Stabilizer (20.04 ft), (4) Reamer (6.13 ft), (5) Collar (20.00 ft),		
	(6) Collar (20.00 ft), (7) Collar (19.65 ft), (8) Collar (20.10 ft), (9) Collar (20.01ft), (10) Collar (20.08 ft), (11) Collar (19.97 ft),		
	(12) Topsubs (4.50 ft)/// 177.04 ft total drill tools///Lost fish (casing centralizer, reamer shell, bit and bowen spear).		
GEOLOGY	Paleozoic limestone.		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	0000	Ream from 1385 ft to 1445 ft	
	0615	Out of mud and water, fix water line, mix mud.	
	0700	Ream from 1445 ft to 1460 ft.	
	0845	Condition and circulate hole.	
	0915	Trip drill rods and three drill collars.	
	1200	Tower change.	
	1315	Finish tripping out drilling assembly, break down tools and load tools with crane, begin geophysical survey.	
	1630	Complete geophysical survey, setup to run casing and weld casing grout shoe.	
	1750	Run 8 5/8 in casing w/centralizer every 80 ft (76 joints on site)	
	2400	Tower change.	

DATE	9/23/2003		
FOOTAGE	START ft	END ft	
	1687.5	1687.5	
TOOLS IN HOLE	Lost fish (casing centralizer, reamer shell, bit and bowen spear).		
GEOLOGY	Paleozoic limestone.		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	0000	Run 8 5/8 in casing, run out of welding argon.	
	0245	Wait on argon	
	1000	Supply truck arrives, unload argon tank and 13 "super sacks" Halliburton cement	
	1030	welder on site, resume run 8/5/8 in casing	
	1235	cement basket (OD 17 in) welded to 8 5/8 in casing, 1ft above weld connection on joint 35 (698.3ft bot and 758.2 ft top)	
	2215	land casing at 1455.25 ft GL (69 joints 8 5/8 in 1456.14 ft w/ 2.25 ft grout shoe	
	2220	Run cement tremie (73 joints BQ drill tube)	
	2400	Tower change	

DATE	9/24/2003		
FOOTAGE	START ft	END ft	
	1687.5	1687.5	
TOOLS IN HOLE	Lost fish (4 1/2 in casing centralizer, reamer shell, bit and bowen spear)///NOT RECOVERED		
	Casing (27 8/5/8 in centralizers, 8/ 5/8 in cement basket, 2.25 ft 8/5/8 in grout shoe, 1456.54 blank 8 5/8 in casing)		
GEOLOGY	Paleozoic limestone.		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	2400	fill inside 8 5/8 in casing w/mud, stab into grout shoe w/tremie, circulate annulus while mixing 300 gal cement	
	0051	annular returns	
	0115	finish pump cement, cement going into loss zone (1355-1375 ft ??) WOC	
	1445	unloading AQ drill pipe as tremie for cement basket cement job	
	1515	Run AQ tremie pipe	
	1600	Tag cement basket at 753 ft GL, mix 2 1/2 sacks (50 lb) bentonite chip hole plug to seal basket and run into hole	
	1644	"Dry" hole plug (bentonite chips) tagged above cement basket	
	1717	Pump 326 gal, 15.8 ppg cement w/ backside AQ tremie pipe	
	1800	Pump 375 gal, 15.75 ppg cement w/ backside AQ tremie pipe, trip tremie, and WOC	

DATE	9/25/2003		
FOOTAGE	START ft	END ft	
	1455.0	1505.0	
TOOLS IN HOLE	(1) Bit 7 7/8 tricone carbide (0.72 ft), (2) Reamer (8.37 ft), (3) Collar (19.72 ft), (4) Reamer (8.40 ft), (5) Collar (20.00 ft), (6) Collar (19.99 ft), (7) Collar (19.99 ft), (8) Collar (19.98 ft), (9) Collar (20.01ft), (10) Collar (20.01 ft), (11) Collar (19.82 ft), (12) Collar (20.00), (13) Collar (19.85), (14) Top Sub (2.50)////Total BHA 219.36 ft		
GEOLOGY	Paleozoic limestone.		
MUD PROPERTIES	Drilling RC water		
EVENT LOG			
	TIME hrs	NARRATIVE	
	0215	Tag backside cement behind basket at 601 ft GL, and WOC	
	0600	Tag backside cement behind basket at 601 ft GL	
	0700	Trip in AQ tremie and mix 300 gal, 15.7 ppg cement (one super sack Halliburton class G plus 15 sacks of Portland	
	0743	Pump 3rd cement basket batch and trip out AQ tremie	
	0830	WOC	
	1100	Trip in AQ tremie to 460 ft	
	1145	Tag cement at 492 ft with wireline	
	1200	Trip out AQ tremie, cut 8 5/8 in casing and dress up diverter	
	1330	Make up bottom hole assembly (BHA) (see above Tools In Hole)	
	1700	Trip in to 1435 ft, add discharge hose, test cyclone seperatore, continue WOC	
	1953	Washing to bottom	
	2000	Tag 1.5 ft cement above grout shoe, drill out cement at 1455 ft (8 5/8 in casing shoe at 1455 ft)	
	2030	Drill ahead at 1460 ft (drilling reverse w/ air turnaround at 580 ft below GL and 880 ft above bit	
	2400	Tower change, 1505 ft	

DATE	9/26/2003			
FOOTAGE		START ft	END ft	
		1505.0	1770.0	
TOOLS IN HOLE		(1) Bit 7 7/8 tricone carbide (0.72 ft), (2) Reamer (8.37 ft), (3) Collar (19.72 ft), (4) Reamer (8.40 ft), (5) Collar (20.00 ft), (6) Collar (19.99 ft), (7) Collar (19.99 ft), (8) Collar (19.98 ft), (9) Collar (20.01ft), (10) Collar (20.01 ft), (11) Collar (19.82 ft), (12) Collar (20.00), (13) Collar (19.85), (14) Top Sub (2.50)////Total BHA 219.36 ft		
GEOLOGY		Paleozoic limestone.		
MUD PROPERTIES		Drilling RC water		
EVENT LOG				
	TIME hrs	NARRATIVE		
	1200	Drilling ahead at 1665 ft		
	1328	Bottom of core hole at 1687 ft, steel cuttings from drilled up fish (bowen spear)		
	2400	Drilling ahead at 1770 ft		
DATE	9/27/2003			
FOOTAGE		START ft	END ft	
		1770.0	1975.0	
TOOLS IN HOLE		(1) Bit 7 7/8 tricone carbide (0.72 ft), (2) Reamer (8.37 ft), (3) Collar (19.72 ft), (4) Reamer (8.40 ft), (5) Collar (20.00 ft), (6) Collar (19.99 ft), (7) Collar (19.99 ft), (8) Collar (19.98 ft), (9) Collar (20.01ft), (10) Collar (20.01 ft), (11) Collar (19.82 ft), (12) Collar (20.00), (13) Collar (19.85), (14) Top Sub (2.50)////Total BHA 219.36 ft		
GEOLOGY		Paleozoic limestone.		
MUD PROPERTIES		Drilling RC water		
EVENT LOG				
	TIME hrs	NARRATIVE		
	1200	Drilling ahead at 1870 ft		
	1230	WL at 520 ft (electric)		
	1242	Drilling at 1875 ft, 290 psi to unload hole		
	1916	Drilling ahead at 1915 ft, 255 psi to unload hole		

DATE	9/28/2003		
FOOTAGE	START ft	END ft	
	1975.0	2100.0	
TOOLS IN HOLE	(1) Bit 7 7/8 tricone carbide (0.72 ft), (2) Reamer (8.37 ft), (3) Collar (19.72 ft), (4) Reamer (8.40 ft), (5) Collar (20.00 ft), (6) Collar (19.99 ft), (7) Collar (19.99 ft), (8) Collar (19.98 ft), (9) Collar (20.01ft), (10) Collar (20.01 ft), (11) Collar (19.82 ft), (12) Collar (20.00), (13) Collar (19.85), (14) Top Sub (2.50)////Total BHA 219.36 ft		
GEOLOGY	Paleozoic limestone and Tertiary intrusive (dacite)		
MUD PROPERTIES	Drilling RC water		
EVENT LOG			
	TIME hrs	NARRATIVE	
	0748	Drilling ahead at 2035 ft	
	1127	Drilling ahead at 2055 ft	
	1653	TD 2100 ft, 7 7/8 in hole from 1455 to 2100 ft	
	2130	Finish tripping rods, BHA, and laying down tools	
	2400	Trip in to 1540 ft with lift tube 40 ft uphole from lead rod, tower change	

DATE	9/29/2003		
FOOTAGE	START ft	END ft	
	2100.0	2100.0	
TOOLS IN HOLE			
GEOLOGY	Paleozoic limestone.		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	0045	Finish trip to 2100 ft, WL at 772.5 ft, hook up discharge and prepare to air lift	
	0100	Start airlift, unload at 680 psi, temp 154 °F, pumping 210 psi at about 50 gpm	
	0205	Temp at 137 °F, discharge decreased to under 20 gpm, stop airlift, trip out	
	0515	Run WL sounder to 1400 ft (no water), remove diverter, set up to trip in casing cutter	
	0645	Trip in casing cutter to about 480 ft	
	0700	Begin cutting 8 5/8 in casing at about 470 ft below ground surface	
	0815	Cutting unsuccessful, trip out	
	0930	Add stabilizer, trip back to 480 ft.	
	1000	Begin cutting 8 5/8 in casing at about 470 ft below ground surface	
	1045	Cutting unsuccessful, trip out	
	1145	Remove casing cutter tool, rebuild casing cutter knives	
	2000	Trip in casing cutter to about 480 ft	
	2130	Begin cutting 8 5/8 in casing at about 470 ft below ground surface	
	2215	Casing pulls back 1800 psi, trip out casing in 12 pieces (470 ft)	

DATE	9/30/2003		
FOOTAGE	START ft	END ft	
	2100.0	2100.0	
TOOLS IN HOLE			
GEOLOGY	Paleozoic limestone.		
MUD PROPERTIES	N/A		
EVENT LOG			
	TIME hrs	NARRATIVE	
	0245	Finish trip out of 8 5/8 in casing (470 ft)	
	0300	Release rig, begin rig tear down and demobilization of site	

APPENDIX 4 ISOTOPE NOMENCLATURE

Hydrogen stable isotopes (δD)

δD analyses reported in ‰ (permil) notation

$$\delta D (‰) = ((^2H/^1H_{\text{sample}})/(^2H/^1H_{\text{standard}}) - 1) \times 1000$$

$^2H/^1H_{\text{standard}}$ is VSMOW

(Vienna Standard Mean Ocean Water)

Oxygen stable isotopes ($\delta^{18}O$)

$\delta^{18}O$ analyses reported in ‰ (permil) notation

$$\delta^{18}O (‰) = ((^{18}O/^16O_{\text{sample}})/(^{18}O/^16O_{\text{standard}}) - 1) \times 1000$$

$^{18}O/^16O_{\text{standard}}$ is V-SMOW

(Vienna Standard Mean Ocean Water)

Carbon stable isotopes ($\delta^{13}C$)

$\delta^{13}C$ analyses reported in ‰ (permil) notation

$$\delta^{13}C (‰) = ((^{13}C/^12C_{\text{sample}})/(^{13}C/^12C_{\text{standard}}) - 1) \times 1000$$

$^{13}C/^12C_{\text{standard}}$ is PDB = 0.011237

(Pee Dee Belemnite)

Sulfur stable isotopes ($\delta^{34}S$)

$\delta^{34}S$ analyses reported in ‰ (permil) notation

$$\delta^{34}S (‰) = ((^{34}S/^32S_{\text{sample}})/(^{34}S/^32S_{\text{standard}}) - 1) \times 1000$$

$^{34}S/^32S_{\text{standard}}$ is CDT = 0.0450045

(Canyon Diablo Troilite)

Strontium isotopes ($^{87}Sr/^{86}Sr$)

$^{87}Sr/^{86}Sr$ analyses reported as ratio $^{87}Sr/^{86}Sr$

NIST SRM 987 Sr standard = 0.710265