CALPINE

MEMORANDUM

Date: February 3, 2003

To: Tom Box

From: Mitch Stark

Subject: Fourmile Hill Resource Evaluation

1 SUMMARY AND RECOMMENDATIONS

During the 2002 field season the first exploration well in Fourmile Hill, 88A-28, was drilled, completed and flowtested. Table 1 compares the performance of 88A-28 against the three existing productive wells in the Telephone Flat area. 88A-28 can produce 22 kph steam and 81 kph brine at a wellhead pressure of 15 psig, with little change during a 34 day flowtest. The source of this production is primarily from a single entry at a depth of 6,360′ and temperature of 411°F. At this temperature, even if future Fourmile Hill wells could produce mass flows comparable to those at Telephone Flat (300 kph TMF at 90 psig), 19 production wells and six injection wells would be required to support the approved Fourmile Hill 49.9 mw development. This is not practical for three reasons: the likely resource volume is not large enough to sustain such high mass flow rates; the approved development plan does not include enough wells; and the economic results would be poor.

Table 1. Key drilling and testing results, Fourmile Hill 88A-28 vs Telephone Flat wells (Telephone Flat data from Nordquist and Thompson, 1990).

	88A-28	Telephone Flat
Total depth (ft)	8,503	6,935 – 8,417
Maximum Temperature (°F)	443*	542 – 556
Fluid entry depths (ft)	5,100 – 6,700	2,600 – 5,700
Total mass flow (kph @ psig whp)	103 @ 15	260 – 340 @ 120
Steam flow (kph @ psig whp)	22 @ 15	44 – 61 @ 120
Enthalpy (total discharge, btu/lb)	390	435 – 480
Entry temperatures (°F)	397 – 440	475 – 514
kh (md-ft, assuming no skin)	2,500	4,800 – 17,500
Kh (md-ft) (Pingol, 2002a; 2002b)	2,573	12,000 – 75,000
Skin factor (Pingol, 2002a; 2002b)	1.7	10 – 60
Total Dissolved Solids (ppmw, flash-corrected)	2,200	2,300 – 3,100
Noncondensible gas (wt % in steam)	0.07%	0.07 – 0.15
H_2S (ppmw in steam)	65	43 -- 93

* 88A-28 temperature as of 1/14/03 may not be stabilized.

---

cc: 88A-28 well file
ec (w/o appendices): Glass Mtn team Resource Dep't

The fluid chemistry and temperature data from 88A-28, and temperature data from nearby gradient hole 88-28, indicate a possible resource of at least 460°F at a depth of about 3,000'. Although the well was designed in part to explore that target, it failed to encounter significant permeability in that depth range. Any further exploration drilling in Fourmile Hill should focus on finding permeability and delineating reservoir volume associated with this shallower, hotter target.

The Fourmile Hill project is still an attractive prospect, with important commercial and regulatory advantages. But from a pure resource perspective, the 88A-28 results downgrade Fourmile Hill to a third-rate status among prospect areas in the Glass Mountain KGRA. Telephone Flat, with its proven commercial production, is certainly the top priority, and the Pumice Mine and Arnica Sink areas, with their proven temperatures of ≥ 500°F, are next.

2 INTRODUCTION

2.1 Geologic Setting

The Glass Mountain Unit (Figure 1) is centered on the Medicine Lake volcano, a broad shield volcano built up over the last 500 ka, with a long history of bimodal and andesitic eruptions as young as 900 years. (Donnelly-Nolan, 1988; 1990). At the summit is an elliptical ring of volcanic edifices which form a basin, measuring approximately 7.1 miles east-west and 4.4 miles north-south. The basin encloses Medicine Lake, which measures about 1.2 mi east-west by 0.7 miles north-south. Geologists have debated whether the elliptical basin is truly a caldera or just the result of surrounding constructional edifices, but there is little doubt that some kind of ring fault system has controlled the extrusion of the elliptical ring of volcanoes. Other important structural elements are three throughgoing northeast-trending fault zones, evident from ground fissures and alignments of volcanic vents.

Underlying the Medicine Lake Volcano are older volcanics, including the Pleistocene Warner Basalts and Miocene Cedarville series, that are exposed in the surrounding Modoc Plateau.

Subsurface data (Carrier, 1989) from 26 temperature gradient holes (mostly cored and extending to depths of 2,000' to 4,000') and five deep exploration wells show a varied volcanic stratigraphy which has been correlated from well to well by Nordquist and Thompson (1990) (Figure 2a). Two wells encountered an altered granitic intrusion which has been K-Ar dated at approximately 300 ka (Lowenstern, 2001). Numerous younger, unaltered granitic xenoliths dated at 20 ka to 100 ka have been found within surfacial lavas (Lowenstern, 2001). These samples were found mostly in and around the Medicine Lake Glass Flow, just north and northwest of Medicine Lake. Geophysical data suggest that such intrusions may underlie much of the volcano, producing a broad NE trending resistivity and gravity high (Nordquist and Thompson, 1990).

2.2 Geothermal Resource

Based primarily on the extensive Recent volcanism, and a lone, weak fumarole area known as the Hot Spot (shown on Figure 1), the USGS defined the Glass Mountain KGRA in 1971. Since that time the 26 TGH's and exploration wells have delineated an extensive thermal anomaly with measured and extrapolated temperatures of 450°F at depths as shallow as 3000 ft (Figure 1). Geophysical exploration, including over 100 MT soundings and hundreds of TDEM soundings, has delineated three areas where low resistivities in the upper 5000', primarily due to intense clay alteration, coincide with high temperatures (Nordquist and Thompson, 1990). These areas occur roughly where the northeast-trending fault zones come near the elliptical ring fault system, and are dubbed the Telephone Flat, Fourmile Hill and Southwest anomalies.

The best information on the resource comes from three exploration wells drilled in the 1980's by Unocal in the Telephone Flat area, along the southeastern margin of the volcanic depression. As shown in Table 1, these wells produced sufficient steam for 3 to 5 MW each, with dilute, alkaline chemistry and low non-condensable gas concentrations. Interpreted reservoir temperatures ranged from 470ºF to 515ºF. All encountered temperatures exceeding 500°F, with thick sections of intense propyllitic alteration (Figure 2b), but rather mediocre deliverability. The sub-par permeability is partially explained by the intense hydrothermal alteration, much of it deposited by older, hotter systems (Hulen, 2002b) which may have plugged up fracture pathways. Review of drilling and flowtest histories (Walters, 2002a; Walters, 2002b) indicates that well performance has also been damaged due to lost circulation while drilling, and/or the practice of injecting drilling sump contents into the well. Acid stimulation was needed to get 31-17 to flow, and was probably successful in approximately doubling the flowrate of 68-8. Recent analysis by Pingol (2002a) indicates that all three wells still had significant skin damage, suggesting that improved stimulation or drilling practices could result in much higher production from these wells or future wells.

A fourth well located northwest of Telephone Flat, 17A-6, also encountered temperatures approaching 500ºF, but could not be fully evaluated because of drilling problems (Smith, 1985).

Because the Telephone Flat wells are over five miles from the approved Fourmile Hill project area, it has been uncertain whether the Fourmile Hill resource would share these same characteristics. With the completion and testing of 88A-28 it appears that the geologic section and fluid chemistry there are similar to those at Telephone Flat, but temperatures are lower at Fourmile Hill. Permeabilities were also lower in 88A-28 compared with the Telephone Flat wells, but higher permeabilities may exist elsewhere in Fourmile Hill.

3 Fourmile Hill Background

The Fourmile Hill block (Figure 3) was defined in 1995, based on Calpine's land situation and measured temperatures of >450ºF at 3000' in TGH 88-28. Although six sections were carved out to form the block, the TGH and geophysical data show that only the southeastern half of section 28 is highly prospective. A 49.9-mw project development proposal was submitted for NEPA and CEQA certification, and in May 2000 a positive Record of Decision (ROD) was issued. Subsequent appeals to the ROD were denied in May 2002. Meanwhile talks with BPA led to a long-term PPA for the entire 49.9-mw planned output, and the CEC awarded to Calpine a five-year production incentive adder from its New Renewable Account. Both the BPA and CEC agreements require plant start-up by December 2005. These regulatory and commercial realities set the stage for the 2002 exploratory drilling program.

In 2001 CEC awarded a Geothermal Research and Development Account (GRDA) cost-share grant toward the drilling of a deep exploration well in Fourmile Hill. In 2002 DOE extended its Geothermal Resource Exploration and Definition (GRED) program at Fourmile Hill, committing to cost-share funding for a geophysical survey and a small contribution toward delineation drilling.

3.1 Strategy

With the major exception of 88-28, the TGH's in the Fourmile Hill vicinity (Figure 3) all show rather uninteresting bottom hole temperature due to deep "rain curtain" effects extending 1,500' to 2,500' below the surface (Figure 4). Below the rain curtain these TGH's show good gradients that can be extrapolated to commercial temperatures at depths of 4,000' to 5,000'. But TGH 88-28 shows a much thinner rain curtain and higher temperature gradient, reaching temperatures of 460°F at a depth of 3,000'. Below 3,000', there is a gentle reversal and an isothermal interval to its original TD of 3,604'. In 2001, 88-28 was deepened from to 4,417' (Stark, 2001), demonstrating near-isothermal conditions at 430°F continuing at least to that depth.

Figures 3 and 4a shows the major prospective indications as of the end of 2001:

- The 88-28 temperature profile, suggesting two potential reservoir targets: a lateral 460°F outflow underlain by a thicker isothermal zone at 430°F.
- The conductance anomaly extending southwest from 88-28.
- The northeast structural trend, well defined in this area by ground fissures and volcanic vents.
- Proximity to the inferred ring-fault.

Together these features support the model depicted in Figure 4a, where the geothermal upflow zone is controlled by the northeast-trending structures and/or the ring fault.

However, there remained several uncertainties regarding this model:

- High permeability would be needed to prove a commercial resource given the reservoir temperature and thicknesses implied by the 88-28 profile.
- The conductance anomaly was poorly defined, with only three TDEM stations located inside.
- Only a small part of the conductance anomaly overlapped with the approved Fourmile Hill project area. If the resource is located directly underneath the anomaly, long-reach directional drilling and/or an expanded project area would be required to develop the 49.9 mw project.

4 WORK COMPLETED IN 2002

Given the favorable commercial and regulatory situation, the contractual deadline for full development, availability of cost-share funding, and the state of knowledge of the resource, Calpine's goal for 2002 was to discover a resource and prove sufficient acreage to establish the viability of a full 49.9 mw development at Fourmile Hill.

Table 2 shows the planned and actual accomplishments for the year. The somewhat disappointing performance reflects a broad range of logistical difficulties including permitting, pad construction and drilling problems. Then the puzzling and ambiguous results from 88A-28 made contiinued drilling look like a risky proposition. On the bright side, the most important task for 2002, drilling and testing 88A-28, was accomplished.

Table 2. 2002 Fourmile Hill resource evaluation program

Planned	Accomplished
Infill TDEM coverage	38 soundings acquired during 6/02
Drill TGH at 18-28 pad	Cancelled due to drilling priorities
Drill 88A-28 exploration well	Built location, spudded 7/21, completed 9/19 to 8,503', recompleted 10/8.
Test 88A-28	Two short-term tests after completion and recompletion, long-term test 10/29 – 12/2
Drill and test 85-33 exploration well	Built location, moved rig onsite, deferred drilling to 2003 due to ambiguous results from 88A-28 and onset of winter.
Drill and test 18-28 exploration well	Built location, deferred drilling to 2003 due to ambiguous results from 88A-28 and onset of winter.

Below are some details of the program.

4.1 Time-Domain Electromagnetic Survey

During an 11-day period from June 18 to June 29, Quantech (2002), under contract to Calpine, acquired 38 concentric-loop TDEM soundings in the Fourmile Hill vicinity. The goal was to improve coverage of the conductance anomaly shown in Figure 1 and thereby guide the casing and directional program for drilling 88A-28. Although logistical obstacles (primarily the lava flow in Section 33) limited coverage in certain areas, the survey greatly improved our knowledge of the size and shape of this important geophysical feature. Figure 3 shows the resultant resistivity contours, using both the new and pre-existing TDEM data.

Figure 5 shows a preliminary cross-section through the anomaly. In the near future, a consultant will undertake more detailed analysis and interpretation of the TDEM data. This work will include better integration of the new data with existing TDEM and MT data, to produce more accurate geo-electrical cross-section. The goal will be to provide a farther-reaching and more accurate interpretation.

4.2 88A-28 Drilling

The drilling of 88A-28 was carried out by Nabors Drilling Inc, using their Rig #92. Directing the operation for Calpine were Marc Steffen and Tim Smith, with additional field supervision by contractors Russ Silva and Keith Powers. Figures 6a and 6b show the initial completion and subsequent recompletion of the well.

Snow clearing and pad construction began in mid-May. Construction went very slowly due to the large extent of extremely hard rock just below the surface. This led to delays in rig mobilization. The well was spudded on July 21, 2002. Total lost circulation was encountered almost immediately, at 87', then later at 330' and at 540'. In the young volcanic rocks (alternating unconsolidated cinders and fractured lava flows), plugging tactics such as lost circulation material and cement plugs were not very effective. Twenty-five cement plugs were set in the upper 540', with only partial success. Eventually the decision was made to drill ahead without returns. Daily drilling footage increased immediately and dramatically, and cementing costs plummeted. Despite the failure to cure lost circulation zones, sloughing problems were non-existent, and both casing strings (13 3/8" to 1,109' and 9 5/8" to 2,927') were cemented in place with the help of minor top jobs. Directional drilling was carried out primarily in the 2,000′ to 2,800′ interval.

Following the setting of the 9 5/8″ casing, a balanced aerated mud system was used to drill through the prospective reservoir section. This system was successful in minimizing lost circulation and thereby preventing stuck pipe and potential formation damage. The well reached a total depth of 8,503' (8,026' vertical) on September 15, 2002. TD coordinates were 2,339′ S14E of the wellhead, reasonably close to the original target of 9,000′ measured depth and 2,000′ S30ºE deviation. On September 19 the well was completed by running 7-inch slotted liner from 2,689' to 8,468' to prevent bridging. This initial completion is shown schematically in Figure 6a.

After an initial airlift-assisted flowtest September 21 – 23 failed to stimulate unassisted flow, a number of temperature, pressure and spinner logs indicated a significant leak in the 9-5/8 inch casing at approximately 1,900'. Water at 390° F was entering the well at this depth and flowing down to at least 6,000-6,500 feet. This diagnosis was confirmed by pressure-testing the casing, and on October 1 a cement squeeze job was implemented to plug the leak. On October 3 flow was again initiated by airlifting. After 24 hours of airlift the well began to flow unassisted, and continued to do so for an additional 8 hours until it was shut-in. Subsequent TP logs and pressure testing verified that the leak had been plugged, so to make the repair permanent a 7″ liner was cemented in place from 1,553′ to the top of the 7″ slotted liner at 2,689′. This remedial work was completed on October 7, and the rig was then demobilized to the 85-33 location. On October 24, during coil-tubing airlifting operations, 1,550′ of tubing was dropped in the hole. By October 28 the top of the fish had been pushed down to 6,885′, where it was left. Figure 6b shows the final configuration of the well, with the remedial cemented liner and the fish.

Figure 7 shows key features of the wellsite geology log compiled by Tecton Inc, modified based on Hulen's (2002b) ongoing studies of 88A-28 cuttings and core from the nearby TGH 88-28. Prior to drilling 88A-28, Hulen and the Tecton geologists met to review Hulen's (2002a) detailed core log of 88-28 and establish wellsite logging priorites and conventions. Tecton's wellsite rock descriptions were based primarily on binocular microscopy and the methylene-blue method to analyze for smectite clay. Tecton also monitored drilling parameters such as mud losses and rate of penetration. Hulen's post-drilling analysis of the 88A-28 cuttings, aided by x-ray diffraction and petrographic microscopy of thin sections, has identified important minerals (e.g. laumontite and actinolite) and lithologies (e.g. a diabase dike) that were not identified by the Tecton geologists.

4.3 Wireline logs

Temperature-pressure (TP) logs were acquired by two different providers: Calpine Wireline Services (CWS) headed by Clarence Reams, and the contractor Welaco Inc. In addition, Welaco provided spinner and gamma logs. Table 3 lists all the logs acquired during and since the drilling program. The most important of these logs are shown in Figures 8 and 11. Appendix 1 provides complete data printouts and plots of all the logs, and electronic data files may be found on the accompanying CD.

Table 3. TP and TPS logs

Date and provider	Logs Acquired	Well Status	Comments
9/2 Welaco	PT, 162 minute buildup at 6072′	POOH, TD at 6074′	Required by BLM to continue drilling. T buildup extrapolated to 440°F.
9/7 CWS	PT, 185 minute buildup at 7324′.	POOH, TD at 7368′	Required by BLM to continue drilling. T buildup extrapolated to 415°F.
9/19 CWS	PT, 183 minute buildup at 8460′	POOH, TD at 8503′	Decision to quit drilling.
9/23 Welaco	PTS + gamma to 8451′.	Shut-in 5 hrs after airlift	Detected cool downflow.
9/25 CWS	PT to 8460′	Shut-in 2 days after airlift	Detected 390°F downflow originating from 1900′.
9/27 Welaco	PTS to 8450′	Shut-in 4 days after airlift	Confirmed 390°F downflow originating from 1900′.
10/2 CWS	PT to 8432′	POOH after casing repair	Demonstrated successful casing repair.
10/4 CWS	PT to 8435′	Shut-in 1 hr after flowtest	
11/6 Welaco	PTS to 6803′	Flowing 7 days	Spinner logs on 11/5 failed. 11/6 log showed main entry: 410°F at 6360′
12/2 CWS	PT to 6800′, 44-hr buildup at 6300′	Shut-in 4 hrs after flowtest	P buildup yielded kh = 2573, skin = 1.7.
1/14/03	PT to 6800′	Shut-in 34 days after flow	T peaks – 443°F at 2860′, 439°F at 5400′.

Data quality and agreement among the logs was very good overall, consistent with an estimated temperature accuracy of ± 2°F. The CWS logs were acquired using a Kuster memory tool. Depth control to an estimated ± 20 ft was maintained with the help of carefully synchronized operator's logs and stops every 1,000 ft to establish depth markers. Welaco's rig provided real-time data readout and depth control to an estimated ± 10 ft.

4.4 Flowtests

Design and construction of the flowtest apparatus was supervised by Tom Bahning, with input from consultant Doug Jung, under the direction of Tom Conant. The skid-mounted apparatus includes a high-pressure separator, metering runs to measure separated brine and steam flows, injection ports for H_2S abatement (although abatement was never required because of low flowrates and low H_2S concentrations), a low-pressure flash vessel, and a drain line out to the 750,000 gallon testing sump. From the sump, the produced brine was conducted via a temporary 7-mile aluminum victaulic 6″ pipeline, to be injected in well 68-8 at Telephone Flat. Flowtest operations were staffed by Denis Henn, Jay Hepper, Craig Stankoweicz and Dennis Campbell. Metering instrumentation and pneumatically controlled valves were monitored and operated from an adjacent trailer, where data was electronically logged and routed to a computer for analysis and archiving. Data was generally sampled at one-minute intervals and eventually decimated to 10-minute intervals for easier handling. A satellite data link allowed for daily email data deliveries to Geysers staff. Complete electronically gathered flowtest data are included on the CD that accompanies this report.

Overall this system functioned quite well, providing excellent abatement of noise and high-quality data. However, during the early testing stages, the data acquisition system was difficult to understand and use, leading to several unrecoverable data gaps, so Al Pingol created some Excel macros that allowed for smoother and more reliable data acquisition. The satellite data link also had some start-up bugs, but by 11/4 data emails were being dispatched daily. As the weather grew colder, problems due to freezing and plugging of control valves had to be solved. Other modifications included: a weir box installed inside the low-pressure vessel to enable measurment of total brine flow; and an acid drip system that maintained the sump pH below 8.5 to protect the aluminum victualic pipe.

Table 4. 88A-28 Flowtests

Start	Duration	Comments
9/21 15:00	50 hrs	Airlifted at 90′ intervals from 2,698′ to 8,445′; well would not flow unassisted.
10/3 09:15	36 hrs	Airlifted at various depths for first 28 hrs, then flowed unassisted final 8 hrs.
10/29 12:00	34 days	Mixed airlift and unassisted flow first two days, then unassisted flow for 32 days. Stable flowrate was 22 kph steam + 83 kph brine at 15 psig WHP, 4 psig separator pressure.

Table 4 shows the operational parameters of the three time intervals during which the well was flowed. All three tests were initiated by air lift. During the first test self-sustained flow was never achieved. Air was injected into open-ended drillpipe at a given depth for about an hour, then shut off to run the drillpipe 90′ deeper, where the air was restarted. This sequence was repeated at 90′ intervals. Each time the air was shut off the well died in less than one hour, sometimes after just a few minutes. The test was terminated after 50 hours. Subsequently the casing leak was discovered and repaired.

The second test was again carried out by rig air lift, successively running drillpipe, airlifting, then shutting off the air to run more drillpipe. After 16 hours of this routine, with the well dying each time the air was shut off, the pipe was being pulled out to terminate the test. A last airlift stop was made at a relatively shallow depth of 2,603′, and this time the well continued to flow unassisted as the drillpipe was removed. It continued to flow for 8 hours until the test had to be terminated because the sump was full (the injection line had not yet been completed due to permitting delays).

For the third test, the injection system was available, allowing a long-term test. The rig had been moved off site, and a coil tubing unit was brought in to run air. This time the well kicked off easily after a few hours of shallow airlift. The coil tubing was then run to 6,000′ in order to stimulate deeper zones to flow. That tactic backfired as the well died after the deeper airlift. Self-sustained flow was reinitiated by again airlifting shallow (at 2,200′). The tubing was then removed and the well continued to flow unassisted for the remaining 33 days of the test. As was later determined, cooler fluids, entering the wellbore from the deepest feed zones, were the reason that deeper airlift consistently failed to initiate self-sustained flow.

Figure 9 shows the data acquired during the long-term test. The flow was weak but very steady, stabilizing at 22 kph steam and 81 kph brine at a wellhead pressure of 14 psig and separation line pressure of about 4 psig. No decline or incline was discerned. At these low flowrates, there was no point in trying to impose higher wellhead pressures to get points for a deliverability curve. However on a couple of occasions when the flow line was pinched back or shut-in wellhead pressures rose to over 40 psig.

Following the 34-day flowtest, a 48-hour pressure buildup survey was conducted to assess permeability and skin (Pingol, 2002b). The buildup results are presented in Figure 12.

4.5 Geochemical Data

Flowtest geochemistry was coordinated by Joe Beall, with assistance from Dustin Cox and contractor Bob Wiley. Brine, steam, and steam condensate samples were gathered for chemical analysis. Field brine analyses of conductivity, pH, Cl^-, and SiO_2 were carried out twice daily (more often during the early hours of each test), using meters for conductivity and pH, and Hach titration kits for Cl^- and SiO_2. Field analysis of H_2S in the steam was generally carried out once per day, using the titration method as required for determination of abatement requirements. During the last couple weeks of the testing, steam condensates were also measured for pH and conductivity. Brine, steam and condensate samples for lab analysis were collected approximately twice weekly (again more frequently during the early days), including acidized samples to preserve SiO_2 and samples with copper wire for stable isotope analyses. Only a subset of these samples have been analyzed to date, based on the need for the data. Appendix 2 lists the samples acquired and the field and lab analyses carried out to date. Lab analyses were conducted by ThermoChem Inc. Calculated reservoir concentrations incorporate a constant 22% flash correction. There was no evidence for steam dilution, so no excess steam correction was attempted. Geothermometry values were calculated based on published formulas using SiO_2, Na-K, and Na-K-Ca.

The field analyses of conductivity and Cl^- were consistent and were later validated by lab data. The field pH measurements were affected by minor instrument calibration problems, so those values are uncertain to approximately $\pm$ 0.2 units. The field SiO_2 analyses were afflicted with two problems. The first and most critical of these was an evident tendency for the SiO_2 to polymerize very rapidly and unpredictably after sampling, leading to significant under-estimation of dissolved SiO_5. Unfortunately, this problem was not recognized until 11/29, when analyses of the same sample 5 minutes, 30 minutes and 60 minutes after sampling yielded values of 540 ppm, 360 ppm and 240 ppm respectively. Another problem was a bad batch of de-ionized water which led to large over-estimates of SiO_2 from 11/11 to 11/18. Because of these problems, only the lab SiO_2 data were used. Gas bomb samples analyzed to date showed extremely variable air contamination, ranging above 50% in one case. The reasons for this are unclear, but are probably linked to the very low flowing pressure of the well. The line pressure, measured in the inlet pipe near the base of the riser, was only about 4 psig, so it is possible that pressure where the pipe enters the separator, 20 ft higher up, was less than atmospheric, allowing air to leak in. Anyway, the O_2-based air corrections done on the gas data were apparently very effective and accurate, even for the highly contaminated samples.

Figures 10a and 10b show plots of the key brine geochemical and geothermometric results. More advanced analysis of the geochemical data will be undertaken by an outside consultant.

4.6 Other Work Completed

Drilling locations for two additional Fourmile Hill wells, 85-33 and 18-28, were built in 2002. The reason for doing this work was to make it possible to drill these additional wells in 2002 had the results from 88A-28 warranted such a program. The rig was actually mobilized from 88A-28 to the 85-33 location, and was prepared for winter drilling conditions. But as the 88A-28 flowtest data came in, it became apparent that more time was needed to determine whether, and where, to drill a follow-up well.

5 DATA ANALYSIS AND INTERPRETATION

5.1 Resource Location, Conceptual Model and Extent

As discussed above, the best clues on the location and extent of resources at Glass Mtn come from the temperature gradients, resistivity data and structural trends. In the Fourmile Hill area (Figure 3), high temperatures found in the 88-28 TGH occur near the northeast end of a northeast-trending low resistivity anomaly. That anomaly coincides with a portion of the Little Glass Mtn fault zone, parallel with the local ring fault trend. As seen in cross-section (Figure 5) the top of the low-resistivity zone occurs at a depth of about 1200′, consistent with the top of intense smectite clay alteration comprising the cap of the geothermal reservoir. To the northwest and southeast the anomaly falls off symmetrically, showing no dip or connection to a deeper root, thus offering no preferred direction for deep drilling.

Figure 4a shows how these elements were combined to form the conceptual model which guided the 88A-28 drilling program. The resistivity low from 1,200′ to 1,700′ is interpreted as the clay cap separating the rain curtain from the deeper geothermal system. The 88-28 temperature profile, with its peak of 460°F at 3,000 ft depth, and reversal below, suggested outflow from a deeper, hotter source (Stark, 2002), inferred to be an upflow zone along the ring fault system. Two major objectives guided the 88A-28 drilling program: setting casing above 3,000′ to test for permeability at the peak temperature; and deviating the wellcourse southeast to cross the structural grain and reach toward the ring fault and hypothesized upflow zone.

Figure 4b shows how the conceptual model has changed based on the results from 88A-28. The main surprise was the long deep temperature reversal below 5,400′. This contradicts the idea of an upflow zone associated with the ring fault and suggests the source of the high-enthalpy system may be from another direction, or perhaps confined to a narrow zone directly beneath the low-resistivity anomaly. The likely reservoir volume is also much smaller in the revised model, because the ring fault area is not considered part of the commercial reservoir volume.

Another surprise was the failure to encounter permeability in the 3,000′ depth range. It is doubtful that any fractures were undetected or cased off in this depth range. As seen in Figure 7, no lost circulation was experienced from 2,560′ to the casing point at 2,930′, even though the drilling mud was not aerated and was thus substantially overbalanced. Below the casing shoe, although it is possible that lost circulation zones were suppressed due to the balanced aerated mud system, the production logs (Figures 12a and 12c) showed little or no contribution above 5,100′. One possibility is that 88A-28 simply missed the fracture zones which conduct the 460°F fluid. Initial shut-in temperature logs since the flowtest (Figure 8) indicate that this temperature peak is somewhat shallower and cooler in 88A-28 compared with that in 88-28.

This suggests that the hypothesized deeper source liies in the opposite direction, very roughly west. The stability of the latest temperature data from 88A-28 must be confirmed to support that idea.

The new TDEM data pins down the location of the low-resistivity anomaly and allows a much improved estimate of its area. The area inside the 50 ohm-m contour is 0.9 square miles. Experience with high-enthalpy geothermal fields worldwide shows that a reservoir area of 1 square mile is roughly adequate to support a 50 mw development for 30 years (for comparison, The Geysers was mostly developed at 110 mw per square mile, and is currently still producing about 50 mw per square mile). If the resistivity low is taken as a rough estimate of the reservoir area, then its extent is a positive indication of the feasibility of the approved 49.9 mw project at Fourmile Hill. In the case of a lower-enthalpy resource requiring more mass flow, a larger area, or smaller plant capacity, would be required.

5.2 Resource Temperature

5.2.1 Subsurface Temperature

Figure 8 shows the key temperature logs available to date from 88A-28, with the stable 88-28 profile shown for comparison. While flowing, the temperature profile was controlled by the 411°F fluid entering the main feedzone at 6,360′. Near-isothermal single-phase flowing conditions prevailed up to 3,700′. From that point to the surface, temperatures and pressures followed a two-phase saturation relationship, with temperatures and pressures monotonically decreasing (and steam fraction increasing) to a surface value of about 240°F. This flowing temperature profile wiped out the static profile, which otherwise should have closely matched that of the 88-28 TGH, located only 250 ft away. The shut-in temperature log of 1/14/03, taken 44 days after terminating the flowtest, indicates a cooler and shallower peak temperature: 443°F at 2,700′ in 88A-28 vs. 460°F at 3,000′ in 88-28. However at least one future temperature log will be needed to confirm that the 1/14/03 profile represents stable conditions.

Much smaller fluid entries were detected above and below the main zone at 6,360′. Approximately 10 kph comes from below 6,800′ (because of the fish, the TPS log could not go deeper), at a temperature of 397°F. Logs taken shortly after drilling, along with formation mineralogy, suggest that at greater depth formation temperatures continue to decrease, perhaps down to 350°F at 8,503′ TD. A very small entry was detected at 6,700′, and is interpreted as approximately 6 kph at 403°F. At 5,100′ is another small entry that showed up as a temperature kick only. The 1/14/03 temperature log indicates that its temperature must be at least 439°F, so its calculated mass flow works out to about 3 kph.

5.2.2 Geothermometry

As shown in Figure 10b, chemical geothermometer values fell in a range from 410°F to 480°F, with the more reliable Na-K-Ca and SiO_2 geothermometers in the range 440°F to 480°F. These values are higher than the measured main feedzone temperature of 411°F. A number of hypotheses could explain the discrepancy. One possibility is that something unusual about the fluid chemistry (e.g. high pH) or formation mineralogy (e.g. laumantite) could distort the geothermometry. Another possibility is that the fluid originated at higher temperature but cooled conductively in transit to the production zone, while retaining its high-temperature geochemical signature. More detailed geochemical analysis may help to resolve this puzzle.

5.3 Permeability and Flow

Overall, the drilling and logging data suggest that the Fourmile Hill geothermal system, like that of Telephone Flat, is low in permeability due to extensive mineral deposition from earlier, hotter systems. Unlike the Telephone Flat wells, there is no evidence for damaged permeability in 88A-28.

5.3.1 Drilling Data – Geology, Lost Circulation, Alteration Mineralogy

Figure 7 shows the composite geologic log of 88A-28. Lithologically, the entire section is volcanic, covering a full range of compositions (basaltic to rhyolitic) and textures (lavas to pyroclastic). No granitic intrusive rocks were identified, despite the numerous granitic xenoliths found at the surface by USGS scientists (Lowenstern, 2001). A distinctive felsic volcanic unit was drilled from 1,270′ to 2,900′. Detailed study of core from the neighboring 88-28 temperature gradient hole (Hulen, 2002a) showed that this unit is dominated by lahars. Lahars were also logged at the same elevation at the 36-28 temperature gradient hole, located about 3000 ft to the northwest. Hulen (personal communication) has speculated that such a thickness of lahar could have originated from the slopes of Mt. Shasta.

Hulen (2002b) reviewed the 88A-28 cuttings in the vicinityof the known productive zones at 5,100′ and 6,360′. At 5,100′ the lithology is andesite, near the base of a probable diabase dike intrusion. At 6,360 the lithology is basaltic andesite, intruded by rhyolite, and heavily microbrecciated.

Mineralogically, the log shows thick intervals remarkable for their intensity of smectite and propylitic alteration. Smectite dominates from 1,120′ to 1,364′, with x-ray diffraction data from the nearby 88-28 TGH (Hulen, 2002a) indicating as much as 75% of the rock mass altered to the soft swelling clay. Below the smectite zone is a great thickness of very intense propylitic alteration, dominated by chlorite, clay minerals, actinolite (as much as 13% of rock mass) epidote. The propylitic alteration is evidently a relic of older, hotter systems. The last alteration mineral deposited throughout much of the propylitc section is laumontite. This zeolite mineral has been identified in a number of other geothermal systems and is stable at temperatures up to about 440°F, consistent with current measured temperatures.

While drilling, Tecton identified distinctive zones of "bleached and leached" plagioclase at the depth intervals 5060′ – 5110′, 5900′ – 6030′, 6140′ – 6160′, and 6320′ – 6360′, flagging them as potential permeable zones. These observations proved quite accurate, insofar as TPS logging later verified production from zones at 5,100′ and 6,360′.

Below about 7,800′, Tecton geologists noted a marked decrease in alteration intensity, extending down to the TD of 8,503′. This correlates with a decrease in measured temperature and little or no fluid flow into the well.

Aside from the massive losses in the upper 1,100′, zones of partial lost circulation were few and minor, detected while drilling at depths of 1,780′, 2,435′ and 7,080′ and 7,480′. The LCZ at 1,780′ was probably the source of a 390°F flow that leaked through a casing break at 1,900′ and down the wellbore (until the casing was repaired). Regarding the LCZ's below 7,000′, there has been no confirmation of significant permeability at those depths, so probably those losses exited into shallower permeable zones. Below the casing shoe (2,930'), the aerated balanced drilling mud system certainly minimized circulation losses which would have otherwise accompanied the penetration of permeable zones. But in this highly underpressured resource it is likely that encountering a zone of high permeability would have resulted, at least temporarily, in massive or total losses, regardless of efforts to balance the column.

5.3.2 Flowtest, Pressure, Temperature and Spinner Data

The overall message from these datasets is that production is predominantly from a single low-permeability feedzone at a depth of 6,360', flowing into the wellbore as a single-phase 411°F liquid. Low wellbore skin suggests that acid stimulation would not be effective in improving the well's performance.

Figure 11a shows the interpreted flowing spinner log. Four passes at different line speeds were run, allowing calibration of the spinner by cross-plotting line speed vs spinner rate at a number of specific depth points. The linear fit yielded a coefficient of 24.3 fpm line speed (or fluid velocity) per spinner rps. Using this coefficient, the spinner rps data from the best pass was corrected for line speed and converted to fluid velocity, as plotted in Figures 11a, 11b and 11c.

Figure 11b shows the portion of the log below 3,700'. In this depth range, single-phase flow prevailed, making interpretation fairly straightforward and allowing a simple conversion to mass flow. Approximating the 6.375" liner ID as the effective hole diameter, and using a fluid density of 53.6 lbs per cf, a conversion of 0.91 kph per fpm fluid velocity is obtained. Starting from the bottom, the cumulative mass flows and enthalpies were modeled as the product of four discrete entry zones annotated in Figure 11b and shown in Table 5.

Table 5. Fluid entries interpreted from 11/6/02 flowing PTS log

Depth (ft)	Mass Flow (kph)	Temperature (°F)	Enthalpy (btu/lb)	Comments
>6800	10	397	373	PTS log depth 6800' due to fish.
6700	6	403	380	
6360	89	411	388	Main entry
5100	3	440	419	Inflow too small for spinner. Based on T logs only.
Total	**108**		**386**	Compare with 107 kph, 390 btu/lb measured at surface.

The major fluid entry at 6,360' shows up as a kick in both fluid velocity and temperature. A smaller, cooler entry shows up at 6,700'. Due to the fish, the hole could not be logged to TD, but it is clear that only about 10 kph comes from below 6,800', and that flow is even cooler, 397°F. At 5,100', the temperature log shows a definite kick, but with insufficient mass flow to show up in the spinner data. The 1/14/03 temperature log (Figure 8) indicates that its temperature must be at least 439°. At 440°F its calculated mass flow works out to about 3 kph.

In the two-phase flow above 3,700', it is more difficult to detect feed zones. There are no major kicks evident (see Figure 11a), just a monotonic increase in fluid velocity and decrease in temperature toward the surface, due to increasing steam fraction. The only depth interval where a feed zone might be suspected is right below the casing shoe, from 3,000' to 3,100'. This interval is shown at expanded scale in Figure 11c. The spinner rate fluctuated wildly in this zone, dropping to near zero at 3,060' and 3,095'. The accompanying decrease in pressure gradient suggests that the spinner behavior is due to borehole washouts, and not due to fluid entry zones. A thief zone might even be hypothesized, but this explanation is highly unlikely given the flowing pressure of 140 psig vs the static pressure of 650 psig.

The total downhole mass flows and enthalpies interpreted from the PTS data (bottom row of Table 5) agree very well with those measured at the surface, confirming that virtually all the flow is accounted for by the identified entries in the single-phase liquid zone. The spinner-derived mass flows add up to 108 kph, in close agreement with the orifice meter readings which averaged 107 kph during the PTS log. The maximum flowing temperature of 411°F corresponds to a liquid enthalpy of 386 btu/lb. This is slightly lower than the 390 btu/lb flow measured at the surface during the PTS log. This small discrepancy may be just data noise, or due to undetected addition of higher-enthalpy fluid in the two-phase section of the production hole (3,700′ to 2,930′). Al Pingol has also mentioned that under certain conditions two-phase fluid can gain enthalpy, by losing entropy, as it flows to the surface.

Figure 12 shows Pingol's (2002b) interpretation of the pressure build-up test. The results show very low transmissivity of 2,583 md-ft, and very low skin factor of 1.71. Additional evidence for low permeability is seen by comparing flowing and static pressure data; at the main feedzone depth of 6,360′, the flowing pressure was 525 psi lower than the static pressure.

5.4 Fluid Chemistry

As seen in Figure 10a, Table 1 and Appendix 2, the produced fluid is a dilute, alkali sodium chloride brine, with low non-condensible gas. This fluid is similar to those produced from the Telephone Flat wells, but is somewhat more dilute, with a flash-corrected TDS of 2,200 ppmw, vs. 2,300 to 3,000 at Telephone Flat. The 88A-28 steam contained 0.6% NCG by weight, significantly higher than the Telephone Flat average of 0.15% by weight. However the 88A-28 NCG numbers are questionable due to severe air contamination of the samples (discussed in section 4.6). A better indication may be the field measurements of H_2S concentrations, which averaged about 60 ppmw in 88A-28 steam, similar to the range of 43 to 93 ppmw analyzed in Telephone Flat steam samples. The overall chemical similarity may reflect a hydrologic connection between the two resource areas, or may simply mean that these two systems evolved in similar geologic and mineralogic environments, and have been exposed to similar fluxes of gas.

6 FEASIBILITY OF 49.9 MW PROJECT

Table 7 contrasts the 88A-28 testing results with those from the Telephone Flat wells. The drilling of 88A-28 failed to discover a high-enthalpy resource as planned. Instead, the well encountered a 411°F reservoir, and even this produced at a disappointing total mass flow rate of only 105 kph. However, it is still important to evaluate whether it could be practical to develop this lower-enthalpy resource to support the approved 49.9 mw Fourmile Hill project.

Brady (2001) calculated that for a 490°F resource, total mass flow of 3,150 kph would be consumed to produce 50 mw, using a double flash system. Assuming 300 kph TMF per production well, 900 kph per injection well (based on Telephone Flat data), and 12% mass loss in the cooling tower, then 12 production wells and 3 injection wells would be required. In contrast, a 410°F resource would consume 5,700 kph to produce 50 mw, so 19 production wells and 6 injection wells would have to be drilled. Given the estimated reservoir area of 0.9 square miles, based on the TDEM anomaly, it is doubtful that this higher level of drilling and extraction could be sustained. This number of wells is also not covered by the existing EIR, which allows for up to 11 initial production wells and 3 intial injection wells. And of course, drilling that many extra wells greatly detracts from the economic outlook for the project.

These calculations assume Telephone Flat-like mass flow rates of 300 kph per well, at a separator pressure of 90 psig. This is far better than the actual performance of 88A-28, which flowed 105 kph at 4 psig separator pressure. So even if such enormous production increases could be realized by finding better permeability and/or pumping the wells, it is doubtful that the resource discovered in 88A-28 could support the approved 49.9 mw project.

7 CONCLUSIONS AND RECOMMENDATIONS

The first deep exploration well drilled in Fourmile Hill, 88A-28, encountered a geothermal resource at a temperature of 411°F. The source of this production is predominantly from a single feed zone at 6,360′. Due to low permeability, the well can only produce 22 kph steam and 105 kph total mass flow at a wellhead pressure of 14 psig. There is no evidence that any better production potential was cased-off or damaged during drilling.

This performance falls far short of justifying development of the approved 49.9 mw project. Even if wells with much better flowrates could be drilled or engineered, developing a 411°F resource here would be problematic in terms of reservoir volume, permitting, and economics.

From a pure resource perspective, these results have downgraded Fourmile Hill to third-rate status among Glass Mountain prospect areas. The proven resource at Telephone Flat is the top area. The nearby Pumice Mine and Arnica Sink prospects, with their proven temperatures of > 500°F, are now clearly superior to Fourmile Hill. The main reasons to continue prioritizing exploration at Fourmile Hill are the favorable PPA and ROD attached to the project.

There remains substantial geophysical, geochemical and temperature evidence of a hotter, shallower resource at Fourmile Hill – at least 460°F at 3,000′ – and sufficient reservoir volume to support the 49.9 mw project. The best reason to consider new drilling in 2003 is to search for this superior resource.

8 REFERENCES

Brady Engineering Services, 2001, "Glass Mountain plant configuration study", report to Calpine.

Carrier, D. L., 1989, "Glass Mountain borehole and well data", Unocal memo to D. Sussman, Calpine Geolib file# GM.42.03.

Donnelly-Nolan, J., 1988, "A magmatic model of Medicine Lake Volcano, California", Journal of Geophysical Research, v. 93, p. 4412.

Donnelly-Nolan, J., 1990, "Geology of Medicine Lake Volcano, Northern California Cascade range", Transactions Geothermal Resources Council, v. 14, p. 1395.

Hulen, J., 2002a, "88-28 Core Log", in 88-28 TGH file.

Hulen, J., 2002b, "Preliminary Description of Selected Cuttings Samples from Calpine Corporation Well GM-88A-28, Fourmile Hill, Glass Mountain Area, California", proprietary memo to Calpine, in 88A-28 well file.

Lowenstern, J.B., Donnelly-Nolan, J., Wooden, J.L., Lanphere, M., 2001, "Volcanism, Plutonism and Hydrothermal Alteration at Medicine Lake Volcano, California: Revelations from U-Pb, U-Th and Ar-Ar geochronology", Penrose Conference abstracts. http://wrgis.wr.usgs.gov/docs/geologic/jlwnstrn/medlake/mlhome.html

Nordquist, G. and R.C. Thompson, 1990, "Integrated geophysical and geological interpretation of the Glass Mountain prospect, California", Unocal memo, Calpine Geolib file# GM.30.05.

Pingol, A.S., 2002a, "Telephone Flat Wells, Pressure Transient Analysis", Calpine memo to W.T. Box and M.A. Stark.

Pingol, A.S., 2002b, "88A28 Pressure Buildup Results", Calpine memo to W.T. Box and M.A. Stark.

Quantech, 2002, "TEM Surveys Conducted at the Fourmile Hill Project", report to Calpine, Calpine Geolib file# GM.38.10.

Smith, K.W., 1984, "Report on Medicine Lake 17A-6 well test, October 21-22, 1984", Phillips memo to R.C. Lenzer & J.J. Beall, in Calpine 17A-6 well file.

Stark, M.A., 2001, "Temperature Logs from Deepened Glass Mountain 88-28", Calpine memo to W.T. Box Jr., in 88-28 well file.

Stark, M.A., 2002, "June 12 Log of Temperature Gradient Hole 88-28", Calpine memo to W.T. Box Jr., in 88-28 well file.

Walters, M., 2002a, "Glass Mountain Federal 68–8 Well Drilling and Completion: Factors Affecting Flow Rate of Deepened Well", Calpine memo to M.A. Stark, in 68-8 well file.

Walters, M., 2002b, "Glass Mountain Federal 31–17 Well Drilling and Completion: Factors Affecting Flow Rate of Deepened Well", Calpine memo to M.A. Stark, in 68-8 well file.

LIST OF FIGURES

APPENDICES

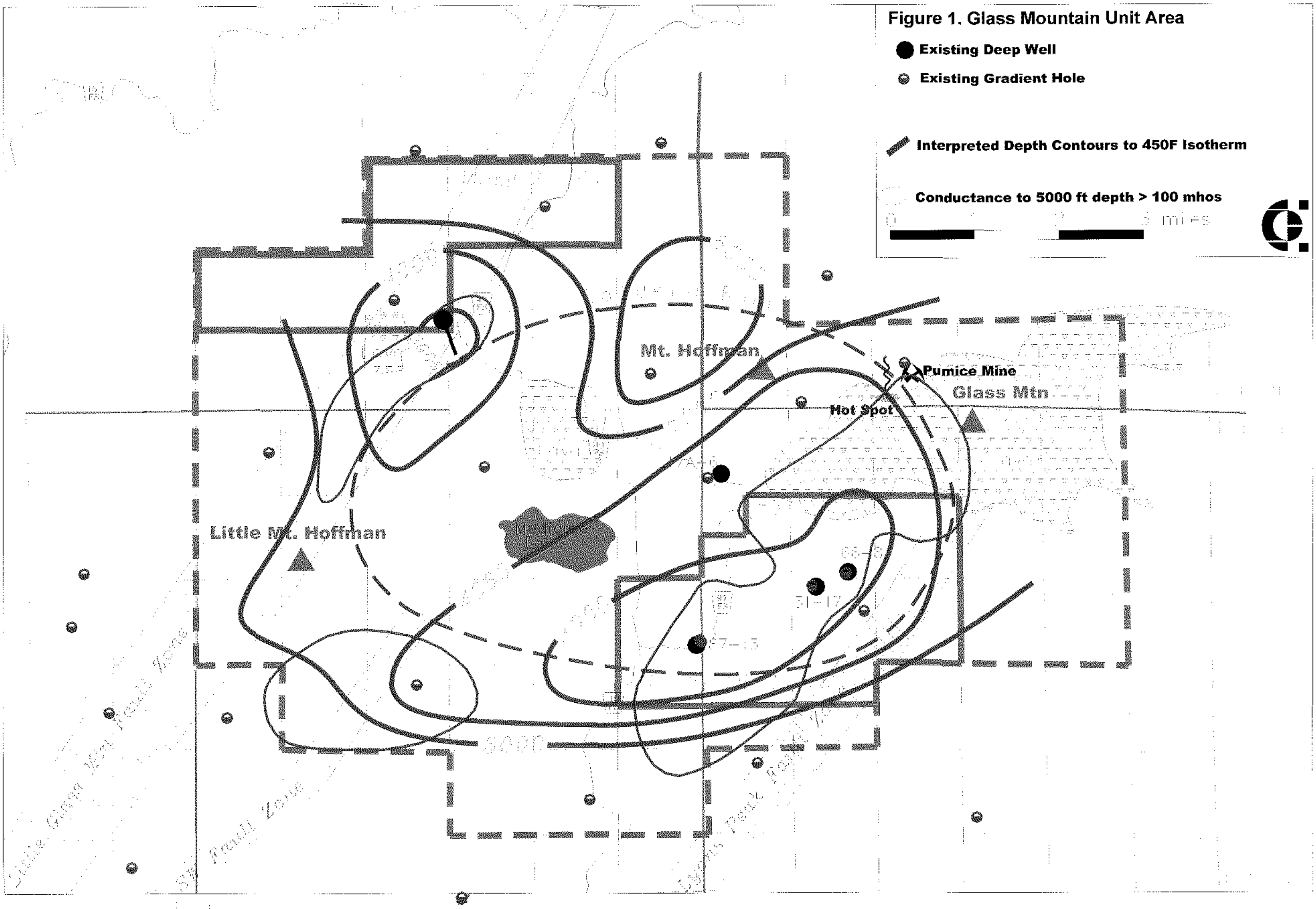
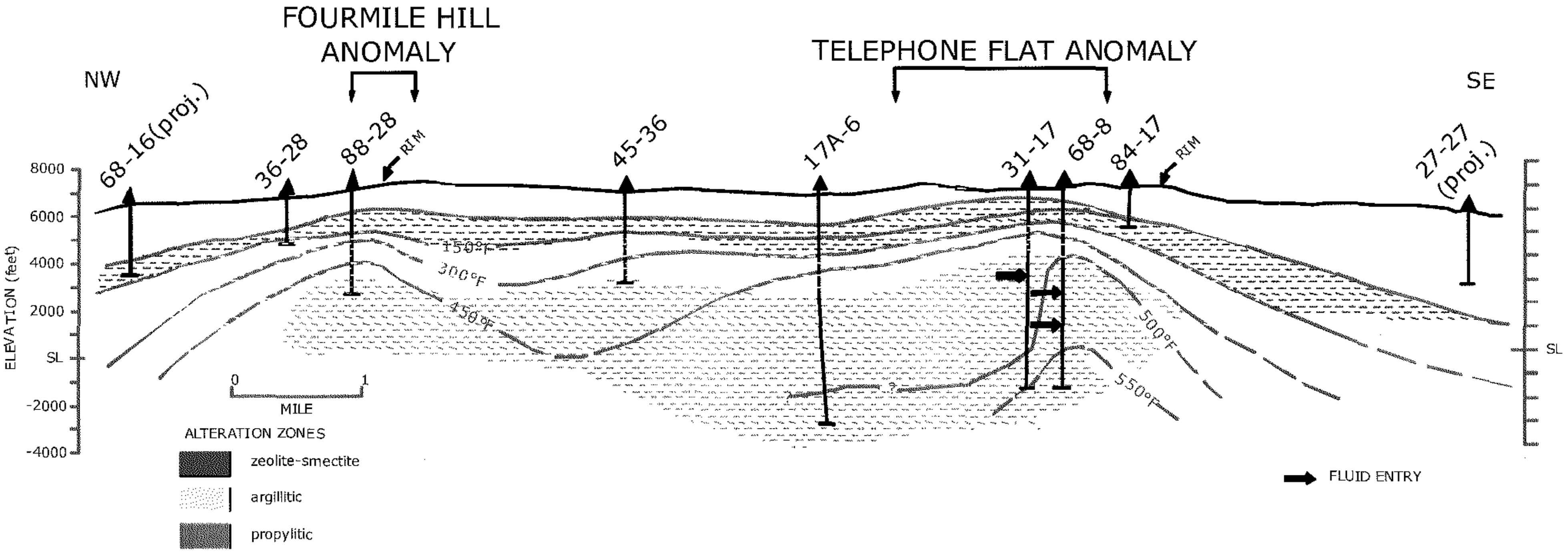


Figure 1. Glass Mountain Unit Area

Figure 2. Glass Mtn temperature and alteration cross-section (modified from Nordquist and Thompson, 1990)



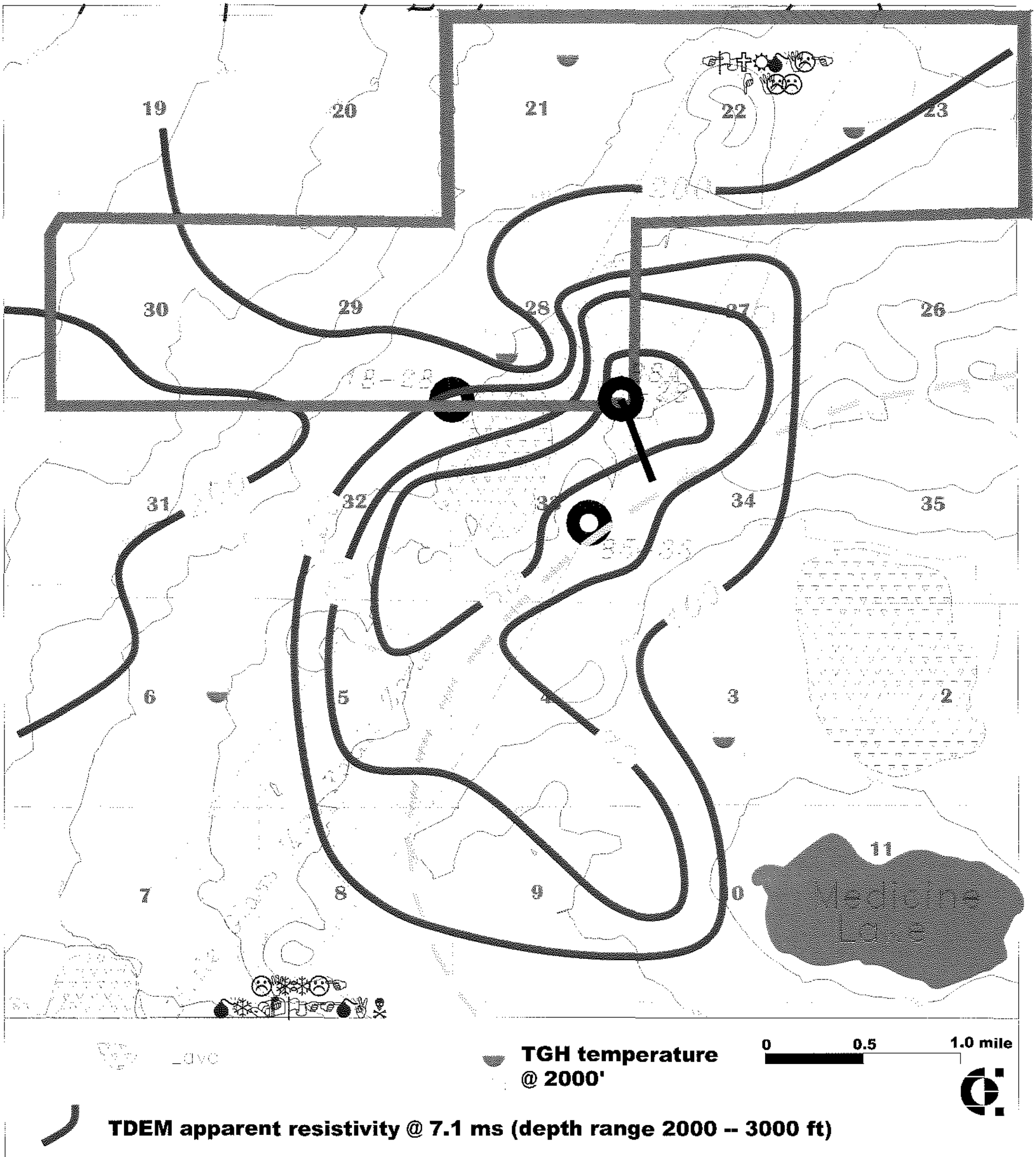


Figure 3. Fourmile Hill area, showing key geoscientific features.

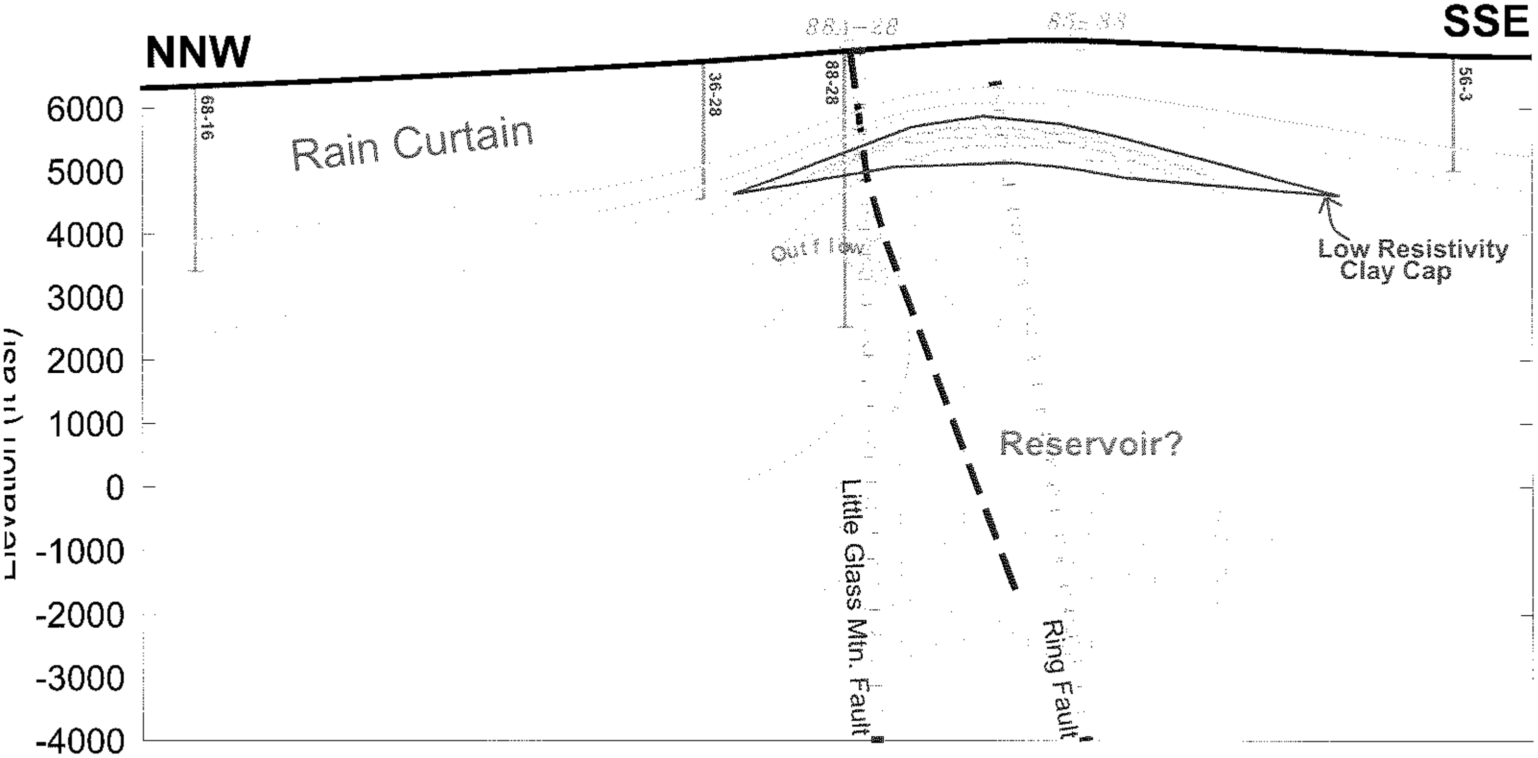


Figure 4a. Fourmile Hill conceptual model cross-section, prior to drilling 88A-28

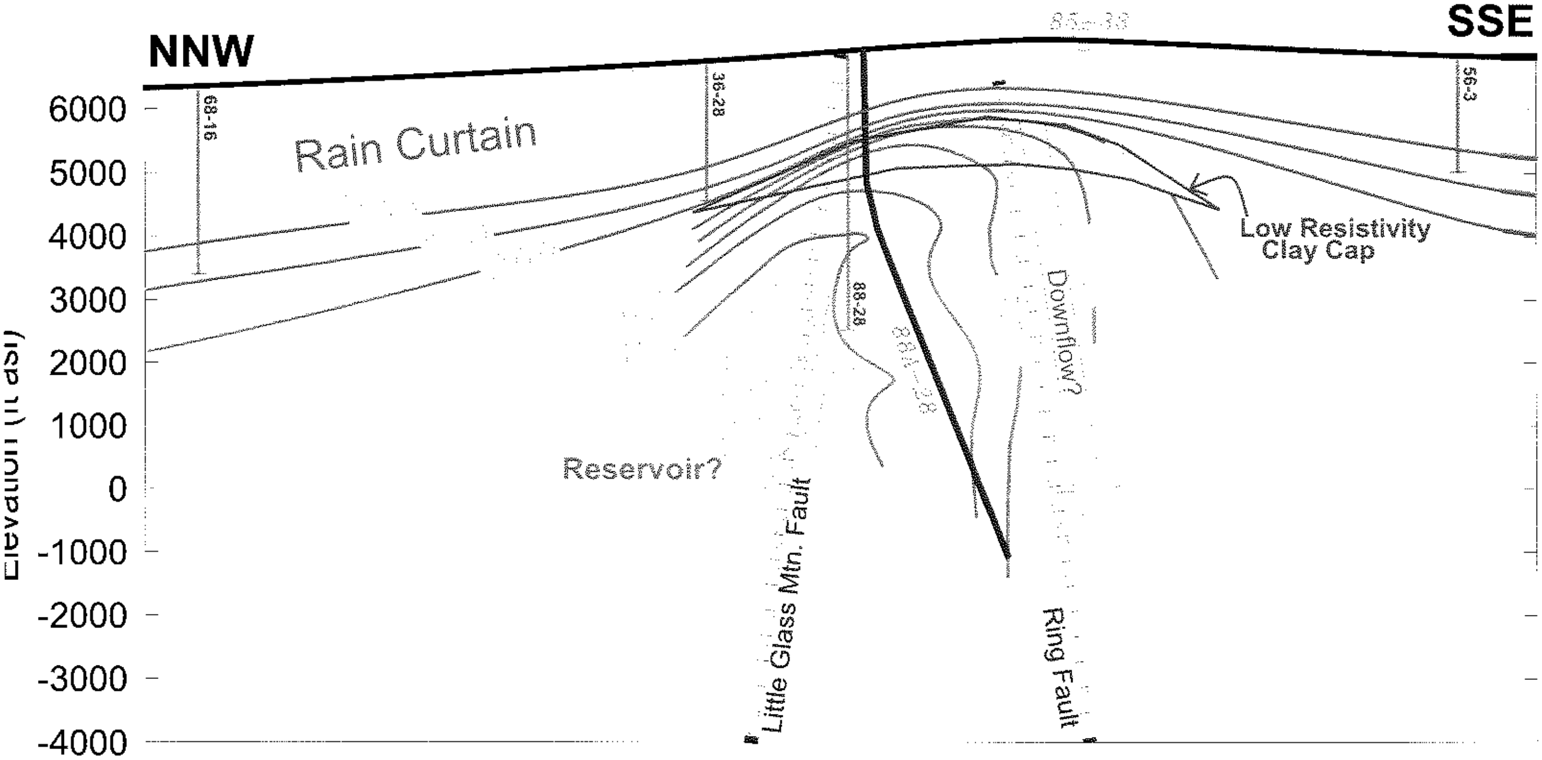


Figure 4b. Revised Fourmile Hill conceptual model cross-section

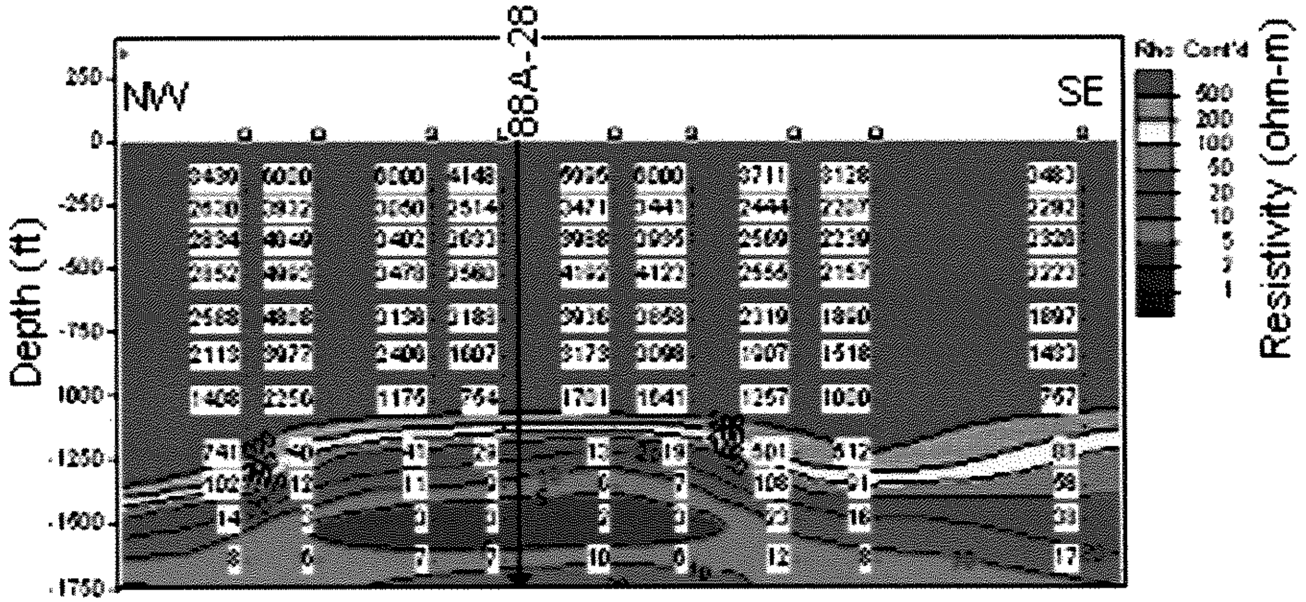


Figure 5. Preliminary resistivity cross-section, developed from TDEM data

2000 ft
Horizontal Scale

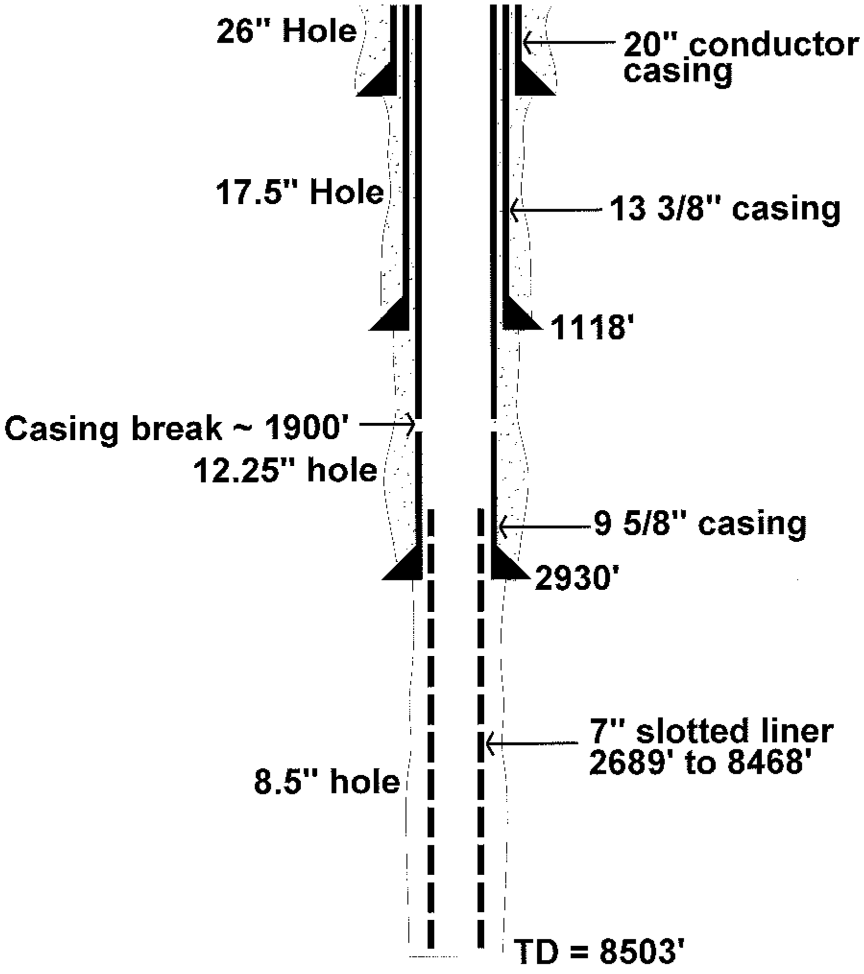


Figure 6a. Schematic diagram, Fourmile Hill 88A-28, as completed on 9/19/02.

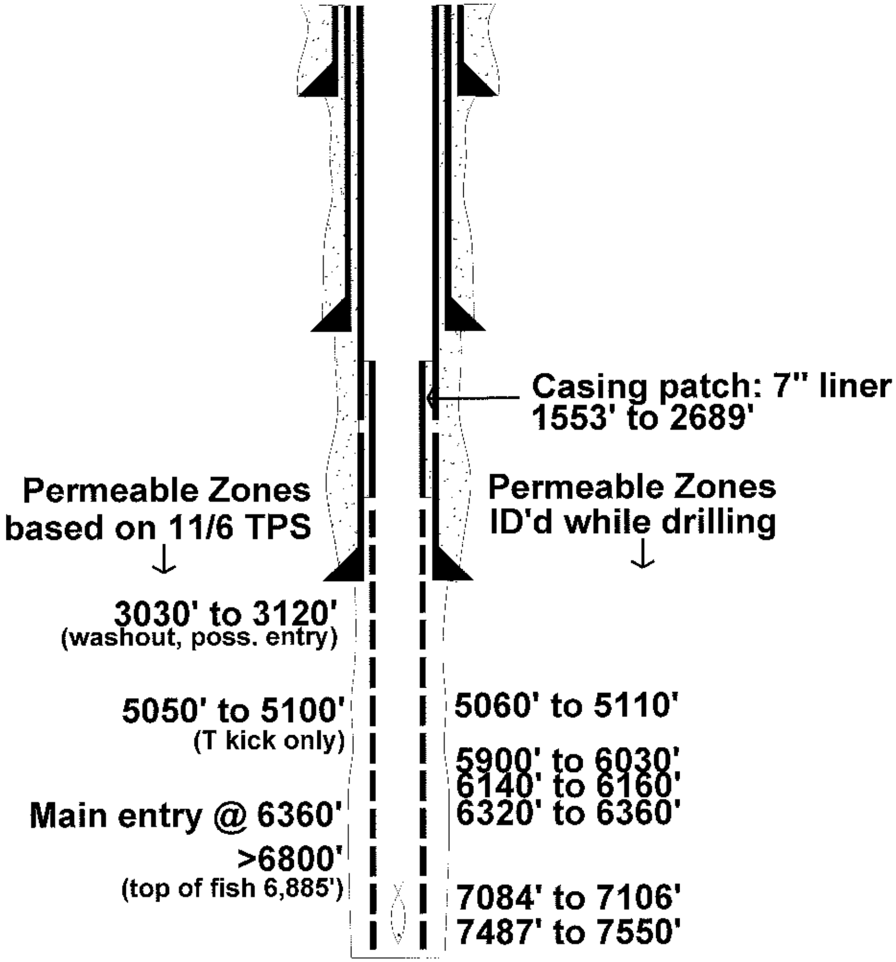


Figure 6b. Schematic diagram, Fourmile Hill 88A-28, as of 10/28/02.

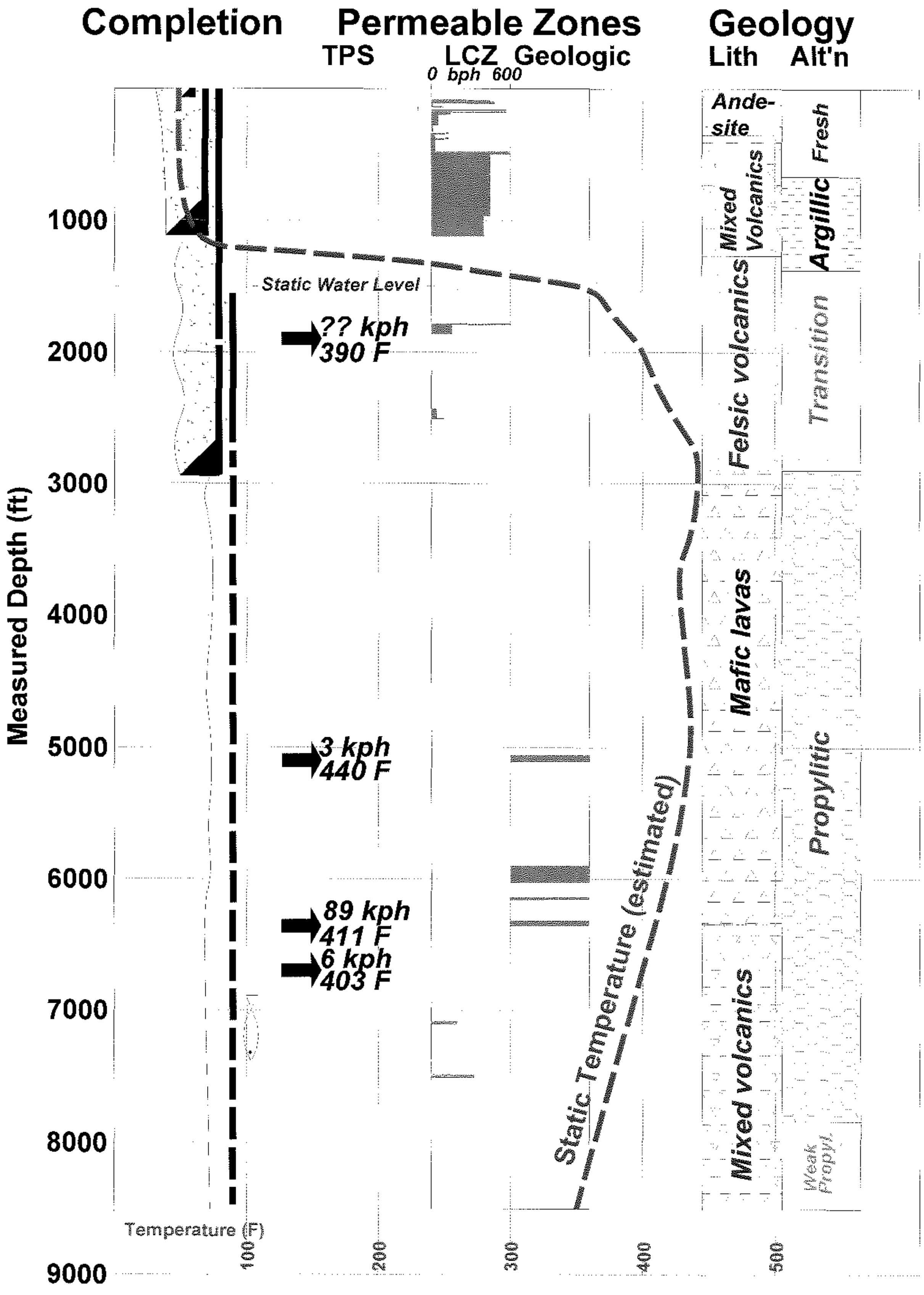


Figure 7. Simplified 88A-28 geologic log.

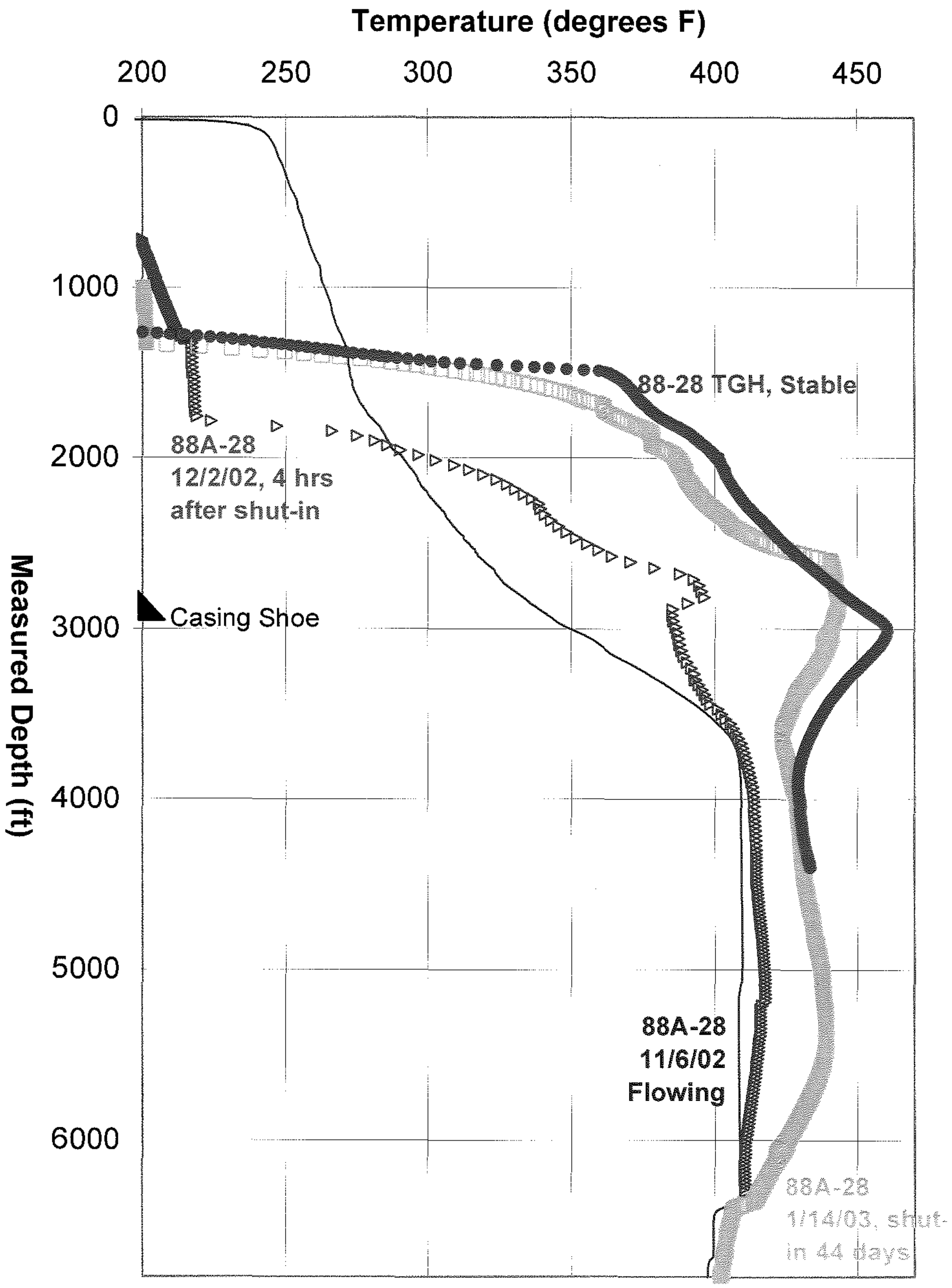


Figure 8. Key Temperature Logs

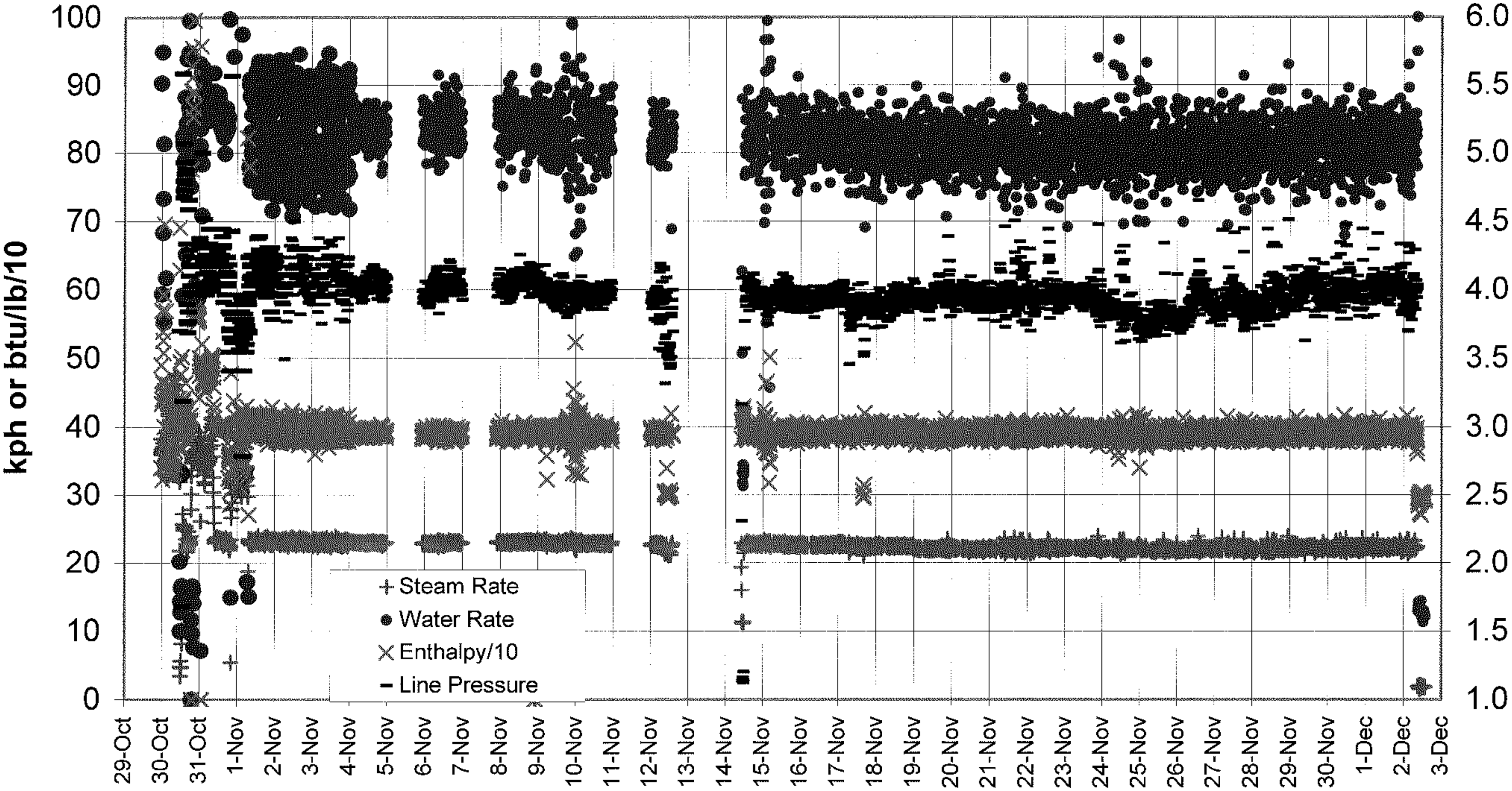
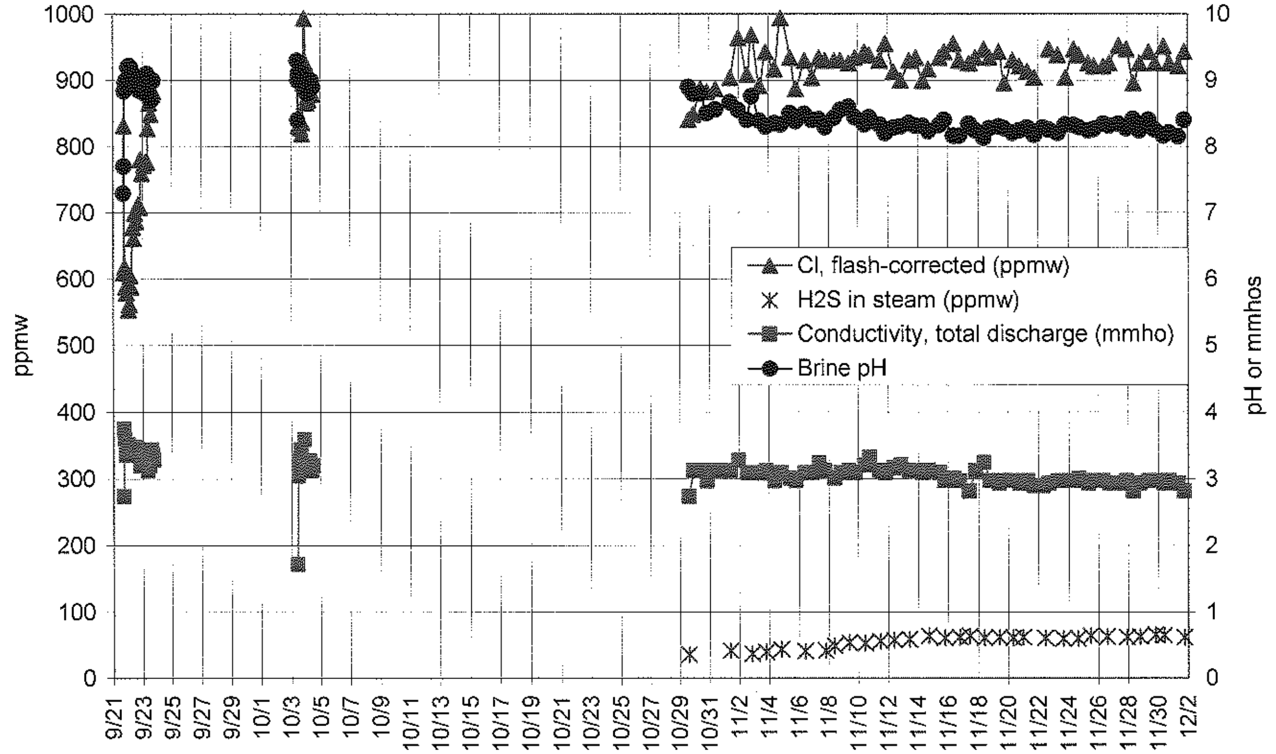


Figure 9. 88A-28 long-term flowtest data, 10/29/02 – 12/2/02. Early data (10/29 – 11/2) affected by airlifting.

Figure 10a. 88A-28 Flowtest Geochemical Data



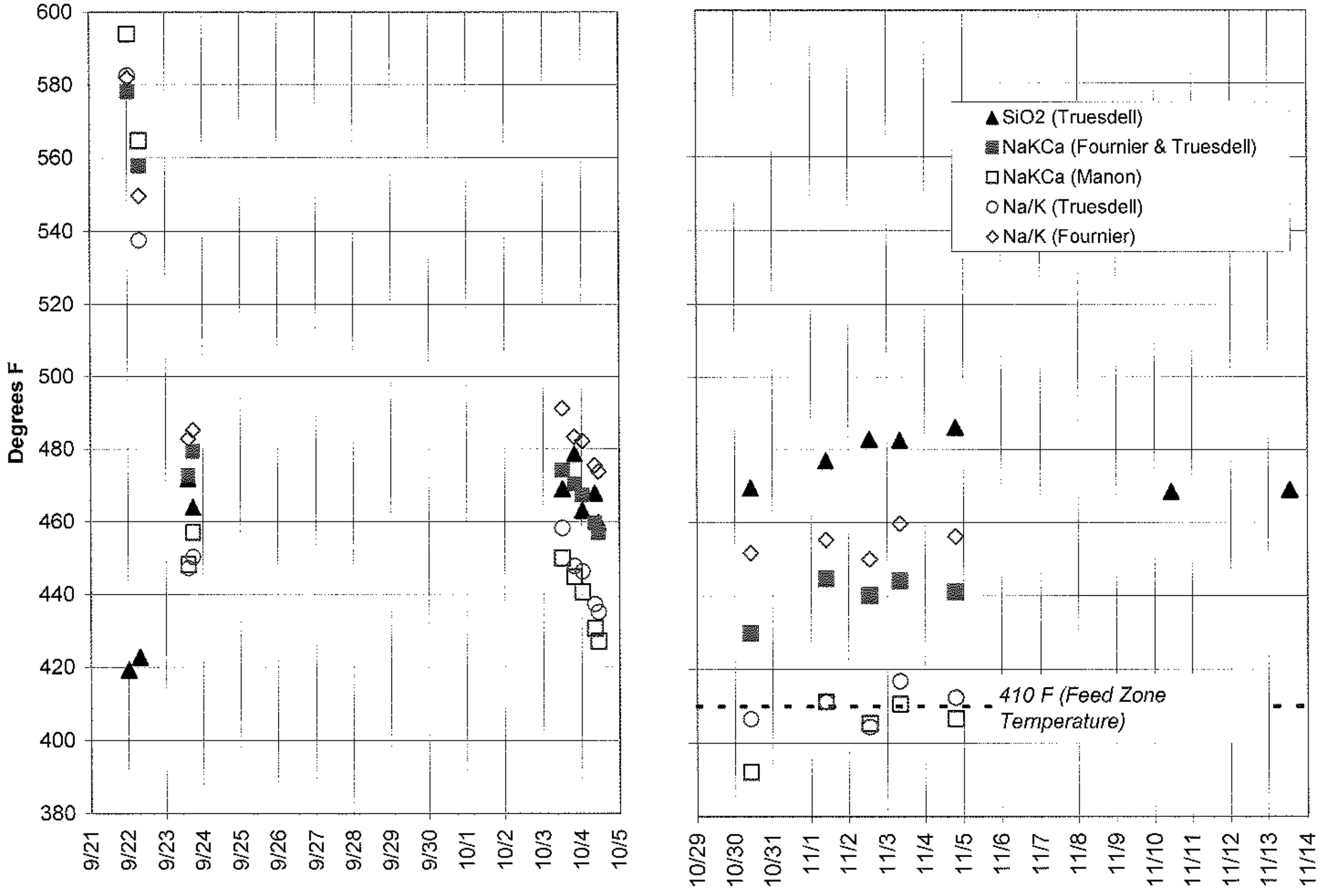


Figure 10b. Geothermometry Values, 88A-28 Flowtests

Figure 11a. 88A-28 TPS Log, 11/6/02. Fluid velocity (7-point moving averages) calculated based on 24.3 fpm per Spinner rps.

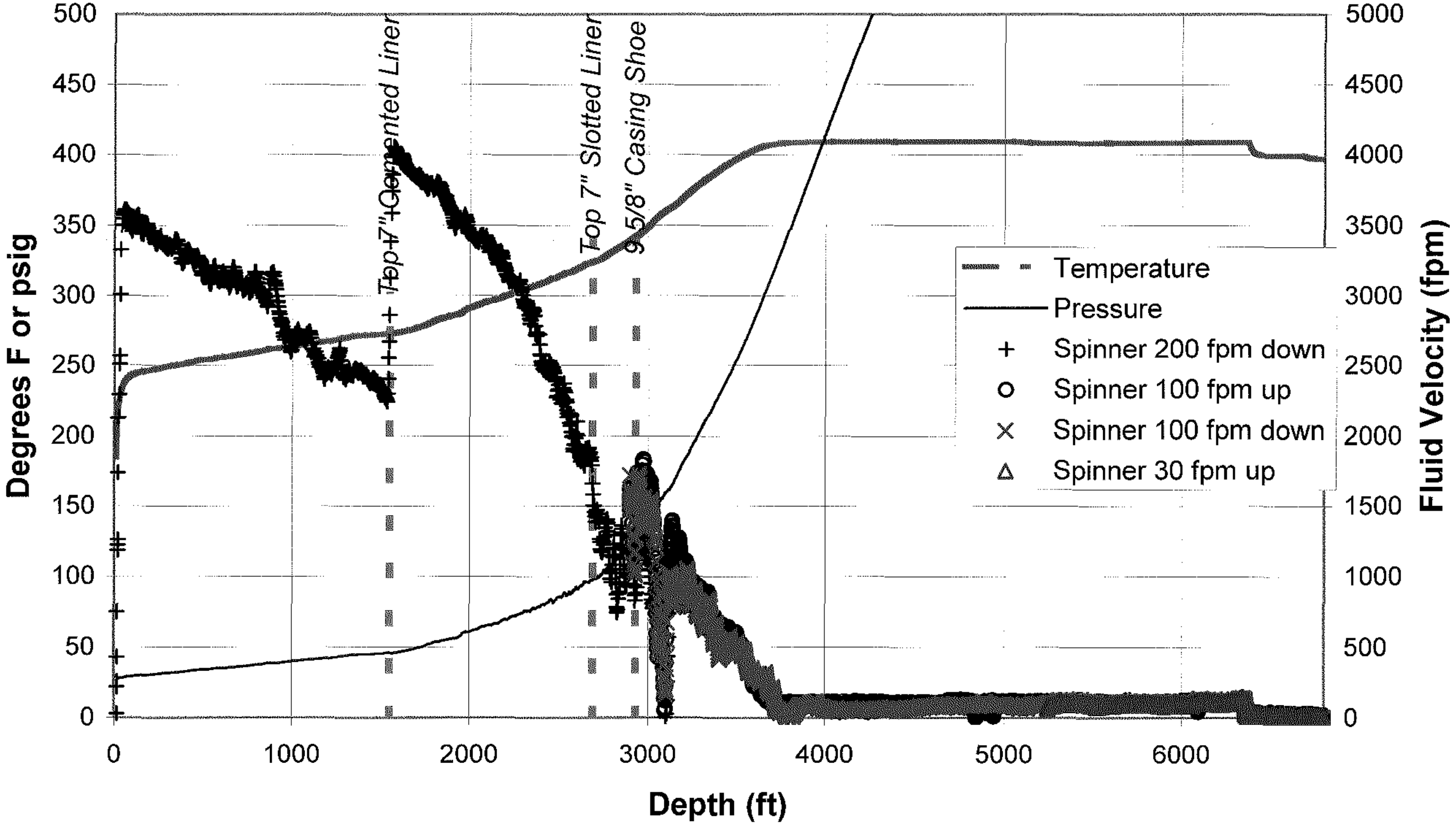


Figure 11b. 88A-28 TPS log, 11/6/02. Details of single-phase flow interval, 4,500' -- 6,800'.

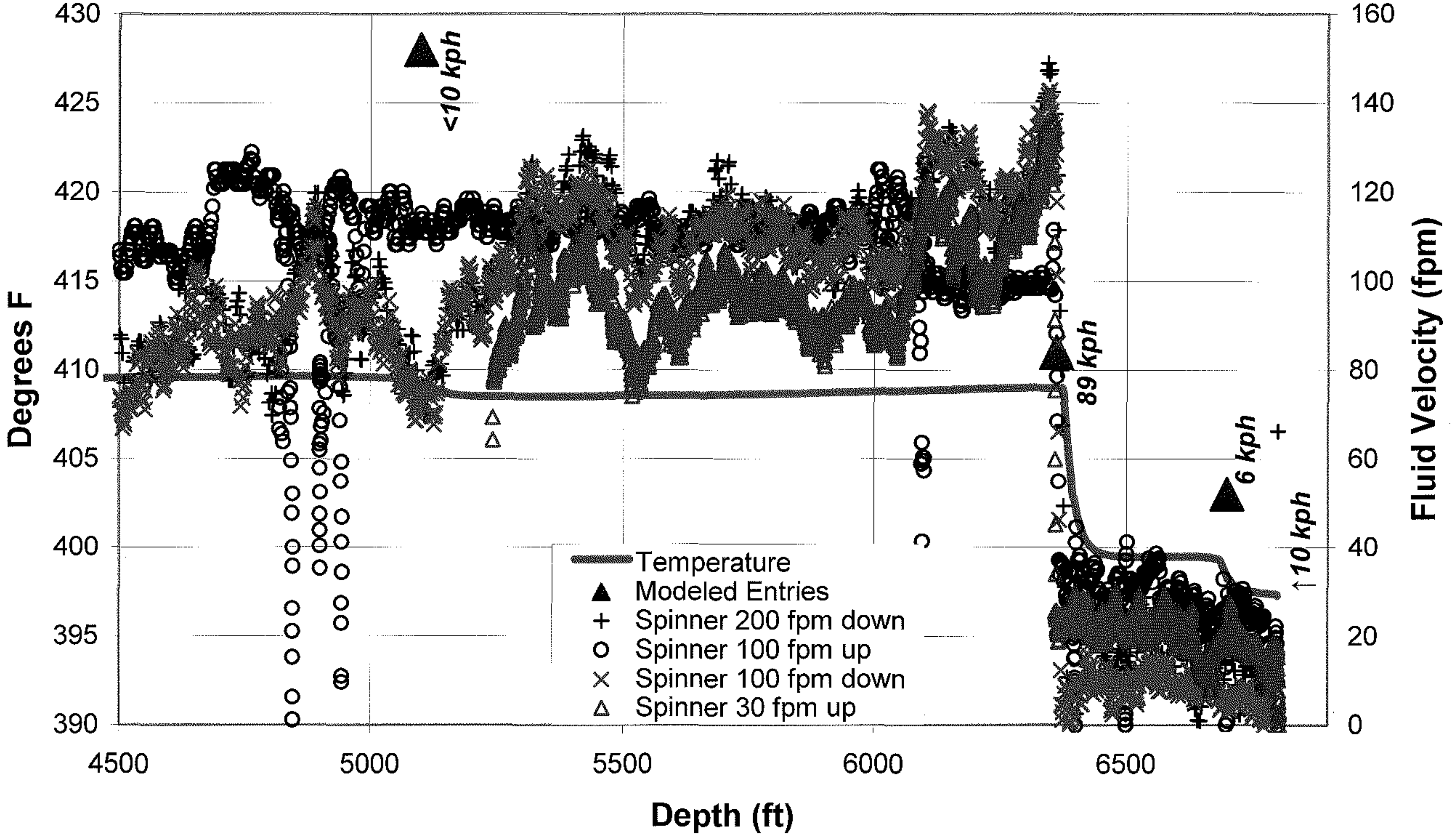


Figure 11c. 88A-28 TPS log, 11/6/02. Detail of 2,900' -- 3,200' interval. Fluid velocity and pressure gradient in interval 3,040' to 3,120' indicate major washouts, not fluid entries or thief zones.

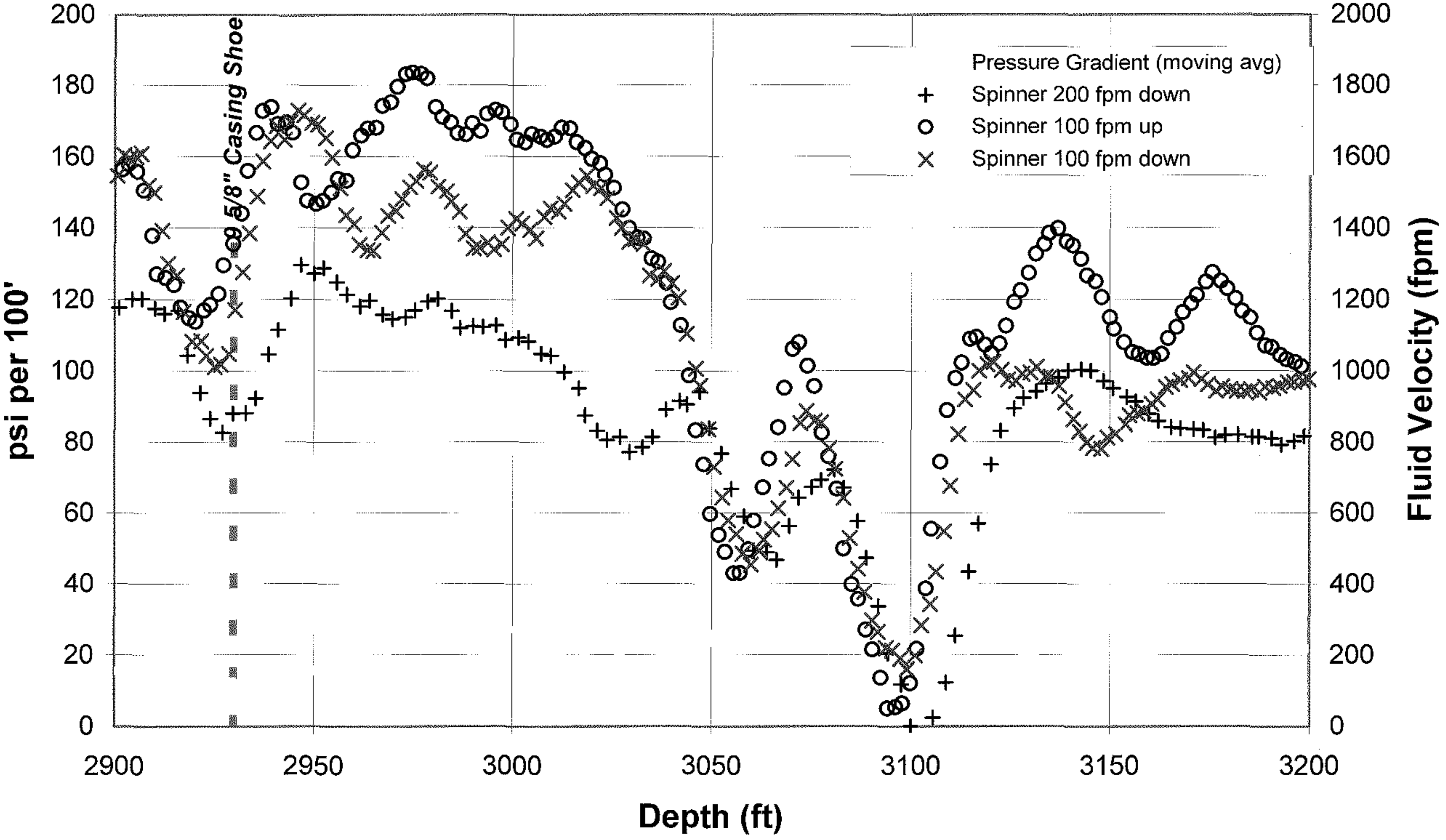
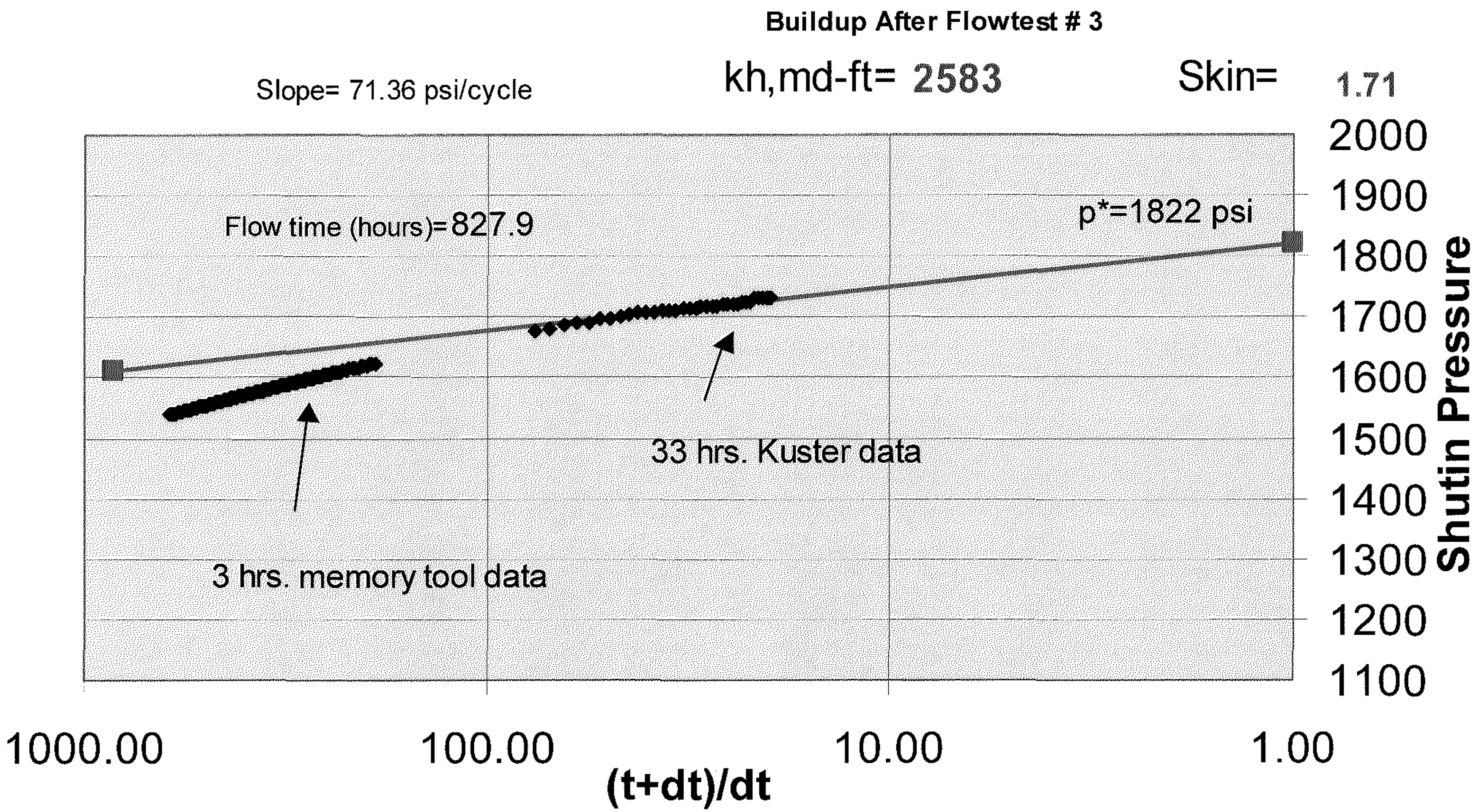


Figure 12. Pressure build-up plot, from Pingol (2003).



APPENDIX 1. PT and PTS logs.

The table below shows facts and figures on the 11 pressure-temperature (PT) and pressure-temperature-spinner (PTS) logging projects completed during and after the drillling of 88A-28. In the following pages are the operator reports and plots for all the logs. Complete data files may be found on CD (Appendix 3).

Date and provider	Logs Acquired	Well Status	Comments
9/2 Welaco	PT, 162 minute buildup at 6072′	POOH, TD at 6074′	Required by BLM to continue drilling. T buildup extrapolated to 440°F.
9/7 CWS	PT, 185 minute buildup at 7324′.	POOH, TD at 7368′	Required by BLM to continue drilling. T buildup extrapolated to 415°F.
9/19 CWS	PT, 183 minute buildup at 8460′	POOH, TD at 8503′	Decision to quit drilling.
9/23 Welaco	PTS + gamma to 8451′.	Shut-in 5 hrs after airlift	Detected cool downflow.
9/25 CWS	PT to 8460′. Also re-logged 88-28 TGH.	Shut-in 2 days after airlift	Detected 390°F downflow originating from 1900′.
9/27 Welaco	PTS to 8450′	Shut-in 4 days after airlift	Confirmed 390°F downflow originating from 1900′.
10/2 CWS	PT to 8432′	POOH after casing repair	Demonstrated successful casing repair.
10/4 CWS	PT to 8435′	Shut-in 1 hr after flowtest	
11/6 Welaco	PTS to 6803′.	Flowing 7 days	Spinner failed on 11/5 runs. 11/6 log showed main entry: 410°F at 6360′
12/2 CWS	PT to 6800′, 44-hr buildup at 6300′	Shut-in 4 hrs after flowtest	P buildup yielded kh = 2573, skin = 1.7.
1/14/03	PT to 6800′	Shut-in 34 days after flow	T peaks – 443°F at 2860′, 439°F at 5400′.

Appendix 2. Geochemical Data Tables

Appendix 3. Data Files on CD