DEMONSTRATION OF A LOW-COST 2-TOWER MICRO SCALE N_2 REJECTION SYSTEM TO UPGRADE LOW-BTU GAS FROM STRIPPER WELLS

Type of Report: Final
Reporting Period Start Date: 8/1/2007
Reporting Period End Date: 12/31/2008

Principal Author: Saibal Bhattacharya
Contributors: Dr. Lynn Watney, Dr. Dave Newell, & Mike Magnuson
Kansas Geological Survey

Date Report was issued: May 2009
DOE Award No: DE-FC26-04NT42098
[Subaward No: 3447-UK-DOE-2098]

Name of Submitting Organization:
Kansas Geological Survey
University of Kansas Research Center
2385 Irving Hill Road
Lawrence, KS 66047

ABSTRACT

Pipeline companies buy natural gas usually with the stipulation that its heat content is at least 950 BTU/cu ft. As a result, 32 tcf (17% of known U.S. reserves) are categorized as low-BTU natural gas. N_2 is thus a target for removal to upgrade low-BTU natural gas. A significant portion of the nation's N_2-rich low-BTU gas is isolated behind pipe in small fields owned by stripper operators. These small fields are not amenable to upgrading technologies such as cryogenic separation and conventional pressure swing adsorption because these technologies require large feed volumes that small fields can not deliver.

This project is a joint effort by the Kansas Geological Survey (University of Kansas) and American Energies Corporation (AEC), a company that primarily operates stripper wells in Kansas. AEC operates several fields where wells have tested or produce low-BTU gas. Much of this low-BTU gas cannot be produced due to limited supply of richer gas necessary for blending. The intent of this project is, therefore, to design, construct, and successfully demonstrate a micro-scale N_2 Rejection Unit (NRU) to upgrade low-BTU natural gas to pipeline quality (>950 BTU/cu ft). The proposed plant was constructed and successfully operated at the Elmdale field, Chase County, Kansas.

Operating parameters, such as tower charge and vent pressures, were optimized to upgrade two different low-BTU feed to pipeline quality. For a feed gas averaging 35% N_2 (i.e., ~715 BTU/cu ft; C_2H_6+/CH_4+ = 7.9%), the plant was able to deliver ~57% of the feed volume as pipeline-quality sales gas (at >950 BTU/cu ft). When the feed composition deteriorated to ~40% N_2 (i.e., ~630 BTU/cu ft; C_2H_6+/CH_4+ = 3.9%), the plant was optimized to deliver 39% of the feed volume as pipeline quality sales gas. The

sales/feed ratio was critically influenced by the amount of heavy hydrocarbons (C_2H_6+/CH_4+) in the feed stream.

Commonly available non-patented activated carbon (made from coconut husks) was used in the NRU towers as adsorption media, which preferentially adsorbed hydrocarbons under pressures while rejecting the entrained N_2. The unadsorbed N_2-rich gas was vented from the tower, and then the hydrocarbons adsorbed on the charcoal were recovered under vacuum. The towers were alternatively charged for continuous plant operation. The adsorbent bed was very effective in removing high-BTU-content hydrocarbons (C_2H_6+) from the feed stream. This removal of heavy hydrocarbons effectively stripped the vent stream of most of the high heat content components except methane. Thus, vent gas may not be rich enough for secondary capture and upgradation to pipeline quality.

An appropriately sized screen filter placed in the vent stream successfully stopped bed blowout during repeated venting. The current design of the NRU could also be improved so that unnecessary space at the base of each tower is minimized. With the present design, this space remains filled with feed gas at the end of the vent phase, and this lowers the heat content of the sales stream at the end of its flush from the towers.

Wireline logs from 26 wells in and around the Elmdale Field were analyzed to evaluate their gas-producing potential. Produced water from 3 wells was analyzed for resisitivity for use in the Archie equation. Most wells currently produce pipeline quality gas from the Lansing-Kansas City (LKC) Group. Initial log analyses revealed that several shallower sandstones have potential to produce gas. However, in each sandstone layer, the low-BTU gas potential is limited to pockets and is not widespread across the field.

Select candidate wells need to be recompleted in shallower sands to validate log analyses estimates and to better determine the potential of low-BTU reserves in and around the Elmdale field.

Compositional analyses (of 54 samples) of gas produced around the Elmdale field indicated the following: a) shallower zones tend to produce low-BTU gas, b) hydrocarbon-wetness increased with the depth and age of the formation, c) nitrogen-to-helium ratios were unaffected by the age of the producing zone, and d) deeper formations displayed a greater compositional range for hydrocarbon and non-hydrocarbon gases.

TABLE OF CONTENTS **PAGE**

LIST OF FIGURES **PAGE**

INTRODUCTION

Local pipeline specifications vary, but most companies buy natural gas with the stipulation that its heat content is at least 950 BTU/cu ft. As a result, 32 tcf (17% of known reserves in the U.S.) are categorized as low-BTU "sub quality" natural gas. N_2 is thus a major target for removal to upgrade significant volumes of otherwise unsalable natural gas to pipeline quality. A significant portion of the nation's N_2-rich low-BTU gas is trapped in modest to small fields owned by stripper operators, or isolated behind pipe. These small fields are not amenable to upgrading technologies such as cryogenic separation and conventional pressure swing adsorption (PSA) because these fields cannot usually deliver the large feed volumes necessary for profitable operations of these technologies.

The objectives of this project were a) to design, construct, operate, and optimize a micro-scale N_2 rejection unit (NRU) to economically upgrade low-BTU gas from stripper wells, b) to evaluate the potential of low-BTU gas production from the neighboring Elmdale field (Chase County, Kansas), and c) to conduct a regional analysis of low-BTU gas composition around the site of the NRU.

EXECUTIVE SUMMARY

In an attempt to encourage economically viable upgrading of low-volume low-BTU gas from stripper wells, a demonstration project that encompasses the planning, design, construction, operation, and optimization of an easily built, low-cost, 2-tower micro-scale PSA (pressure swing adsorption) plant for N_2-rejection using non-patented processes and commonly available equipment was proposed as a joint project between the Kansas Geological Survey (KGS, University of Kansas) and American Energies Corporation (AEC), Wichita, Kansas.

Three major issues were studied as in this project: a) design, construction, operation, and optimization of a micro-scale nitrogen rejection unit (NRU) with commonly available activated carbon to upgrade low-BTU gas to pipeline quality, b) undertake a resource evaluation of low-BTU potential around the NRU site in the Elmdale field, Chase County, Kansas, and c) regional (statewide) analyses of low-BTU gas composition.

The NRU was operated using two types of low-BTU feed gas with average heat contents of 715 (37% N_2) and 630 BTU/cu ft (40% N_2), respectively. The plant settings were modified to upgrade the two different feed gas (compositions) to pipeline quality (>950 BTU/cu ft). Under optimum running conditions, the plant operator could sell at least 54% and 39% of feed gas volumes as upgraded pipeline quality gas for feed gas compositions having 37% and 40% N_2, respectively. The sales/feed ratio varied significantly (from 54% to 39%) despite small changes in the nitrogen composition (from 37% to 40%) because of variation in the ratio of heavy to total hydrocarbons (from 7.9% to 3.9%) in the feed. Thus, both nitrogen content and the fraction of heavy hydrocarbons

in the feed affect the optimum plant settings and determined its efficiency. The bed of commonly available activated carbon, made from coconut husks, was effective in adsorbing the heavy hydrocarbons (C_2H_6+) in the feed, leaving the vent stream stripped of any hydrocarbon other than methane. This puts in question the viability of further upgrading the vent gas by a secondary tower. An appropriately sized screen filter placed within the top flange of each tower (i.e., the mouth of the vent stream) proved effective in preventing bed blow-out due to repeated tower pressurization and venting.

When compared to the costs of and conditions for using a local commercial low-BTU upgradation plant, this micro-plant was found to be more economic to producers of low-volume, low-BTU gas from isolated gas fields/wells. Assuming a gas price of $4/mcf and feed volumes of 150 mcf/d, the calculated pay out time for the micro-plant was 17 and 12 months when the feed gas was rated at 615 and 715 BTU/cu ft, respectively.

A flaw was found in the current design of the NRU. Significant dead space volume exists at the bottom of each tower because the grate supporting the bed of activated carbon was placed above the tower access hole. This dead space remained filled with low-BTU feed gas even after the vent phase, and this untreated feed gas ended up in the surge tank (sales stream), thus lowering its average heat content. Minimizing the dead-space volume, with respect to the tower volume will result in a) minimal volume of feed gas entering the sales stream, and b) greater bed volume with increased adsorption capacity.

Wireline logs from 26 wells located in and around the Elmdale field were analyzed to evaluate the potential of low-BTU gas in the area using resistivity values obtained from produced water samples from 3 wells in the field. Shallower sandstones show pockets of low-BTU gas. Additional wells need to be selectively recompleted and tested to validate the logs analyses and help determine the available low-BTU potential.

Fifty-four gas sample analyses from the area around the Elmdale field were analyzed to identify characteristics of low-BTU gas production. It was found that the shallower sandstones tend to produce low-BTU gas and that hydrocarbon wetness increased with depth and the age of the producing formation. However, the nitrogen-to-helium ratios remained unaffected by the age and depth of the pay zone. Finally, gases from the deeper formations appear to display greater variations in compositional range.

The project web-site, which can be accessed at http://www.kgs.ku.edu/PRS/Microscale/index.html, has been updated with results obtained from plant optimization tests. Technology transfer of best practices was carried out by oral presentations at various industry and professional meetings and a publication in the E&P journal. A technical manuscript summarizing the plant design and optimization and lessons learned is currently under preparation for publication in a trade journal that has wide circulation in the small producer community. Publication is expected in the fall of 2009.

MICRO-SCALE N_2 REJECTION PLANT – BLUE PRINT & OPTIMIZATION

N_2 REJECTION UNIT (NRU) CHARACTERISTICS

The micro-scale nitrogen rejection unit (NRU) constructed and successfully demonstrated in this project to upgrade low-BTU gas to pipeline quality has the following characteristics:

a) Uses non-patented processes and commonly available equipment to minimize construction costs.

b) Uses easily obtained and inexpensive activated charcoal as the adsorbent bed.

c) Is designed as skid-mounted modular units so that the plant is mobile and scalable as per changing feed volumes.

d) Has a small environmental foot print (400 sq. ft).

e) Does not emit any volatile organic compounds (VOCs).

f) Has few moving parts (other than the engine and compressor) to reduce labor and maintenance costs.

g) Can operate in remote locations without being connected to the electric grid by being powered by solar panels and low-BTU feed gas.

h) Can economically upgrade low-volume (<250 mcf/d) and low-pressure (<100 psi) feed gas.

NRU DESCRIPTION

The nitrogen rejection unit (NRU) built in this project is located in the Elmdale field, Chase County, Kansas (Figure 1). The general layout of the plant (Figure 2) is compact thus minimizing its environmental foot print, which is important since it is located in Kansas farm land. The (2 inch) feed gas line (Figure 3) enters the plant passing through a scrubber for removal of entrained moisture. The dehydrated feed gas then passes through a flow meter that records the rate and pressure and then into the adsorption/desorption towers (Figure 4). Each of these towers, made of carbon steel, has a 48-inch diameter and is 8 feet tall (seam to seam). Electronically controlled solenoid valves (colored in red) allow feed gas to flow into one tower for adsorption while isolating the other tower for desorption under vacuum. These valves also enable venting of unadsorbed gas from each tower at the end of the adsorption phase. A small fraction of the (N_2-rich) waste gas is utilized as instrument gas and is cleaned by the instrument gas scrubber before entry to the control panel. Access ports located at the base of the towers (Figure 4) allow removal of spent bed materials and cleanup. Commercially available granulated carbon (Figure 5A), made from coconut husks, was used to charge the towers (Figures 5B and 5C). The activated carbon was purchased in 1100 lb bags. Each tower was charged with about 2200 lbs of activated carbon costing around 7 cents/lb. Figures 6A and 6B show the front and the rear views of the towers. Adsorbed methane is desorbed from the bed under vacuum and flows to the compressor through the upgraded gas line (Figure 6B). The (2 inch line) lines (Figure 6B) carrying N_2-rich vent (effluent) gas from each tower connect to the vent tower (Figure 7A). The bull nipple and the hopper used to load the towers with activated carbon are shown in Figure 7B.

A 6-cyclinder 50 HP VGG-330 gas-fired engine (Figure 8), operating on the low-BTU feed gas, drives the compressor which pulls a vacuum on each tower during desorption. The desorbed (upgraded) gas is cleaned by the gas scrubber before entering the compressor via a 3-inch line. The compressor used (Figure 8) is an Ingersoll-Rand unit that is designed for vacuum service, and was modified to run a strong vacuum. The compressed (upgraded) gas passes through a condensate removal tower (Figure 9) before flowing into a surge tank (Figure 9) that is designed to have a 1 hour holding capacity for maximum flow rates of 150 mcf/d. Upgraded gas is held in the surge tank (5 feet diameter and 25 feet long) for about an hour so that output from the tank can mix to achieve a uniform composition with a heat value greater than 950 BTU/cu ft. The upgraded gas from the surge tank passes through the sales gas meter (Figure 9) before connecting to the nearby pipeline.

PRESSURE TESTING NRU

The plant was put through a pressure test to see if any vessels, pipe, fittings, and instrumentations leaked. The maximum operating pressure is expected to be around 75 psi. Thus for reasons of safety, the plant was pressure tested at 105 psi and was found to hold the pressure without any leaks. Thereafter, the plant was tested by pulling a vacuum of 28 inches (mercury). The plant held the vacuum during the 2-day test period.

NRU OPERATION - STAGES

STAGE 1 - The first step in the sequence of operation of the NRU is depicted in Figure 10. The low-BTU feed gas travels (by the line shown in red) to the bottom of Tower 1 and charges it to the requisite pressure. The optimum tower charge pressure is primarily dependent on the feed composition (i.e., N_2 and heavy hydrocarbon content. A process of trial and error was used to determine the requisite tower charge pressure necessary to attain pipeline quality heat content for the specific feed gas composition. Thus, the plant is run by charging up Tower 1 to different pressure settings, and the pressure at which the sales stream achieves pipeline quality is deemed as the requisite tower pressure. During this first step, Tower 2 is under desorption (i.e., its bed is desorbed under a vacuum of 22 to 25 inches of mercury). The compressor that pulls this vacuum is run by an engine that operates on the low-BTU feed gas. The time taken to charge Tower 1 to requisite pressure depends on the flow rate and pressure of the incoming feed gas and the fill-up volume of the tower. During this charging period, hydrocarbons are preferentially adsorbed in the bed of activated carbon inside Tower 1, while gas in the free space (existing between the carbon particles and in the dead space) is made up primarily of N_2 for which the activated bed has significantly less adsorption affinity.

STAGE 2 – In second step, Tower 1 is vented from the top to atmosphere until the pressure inside it reaches 2 psi while Tower 2 is kept under vacuum (Figure 11). The length of the venting period is proportionate to the magnitude of the Tower 1 charge pressure. During this period, the N_2-rich gas in the free space (inside Tower 1) is vented to atmosphere, thus preventing its entry into the sales stream and resultant dilution of its heat content.

STAGE 3 - During the third stage (Figure 12), the Tower 1 is connected to the compressor to undergo desorption, while the desorbed Tower 2 is connected to the low-BTU feed stream for charge up to the same pressure as Tower 1 (as described in stage one). During the counter current desorption stage, the pressure in Tower 1 is reduced from 2 psi to 22 to 25 inches mercury, which results in extraction (desorption) of hydrocarbons that had been adsorbed in the bed of activated carbon (during the Stage One). The desorbed gas, rich in hydrocarbons and leaves Tower 1 from the bottom, will be of pipeline quality when the plant settings (i.e., charge-up pressure and final vent pressure) are optimally set with respect to the feed composition. The desorbed gas from the NRU is stabilized in the surge tank before flowing out as upgraded pipeline quality sales stream (at > 950 BTU/cu ft). The desorbed gas is minimally contaminated with unadsorbed N_2 when the tower design is such that the dead space is minimized with respect to the tower volume. Larger dead-space causes the N_2-rich unabsorbed (feed) gas trapped in the dead space to go into the sales stream during the desorption process.

NRU THROUGHPUT BOTTLENECK

The bottleneck affecting the NRU sales (volume) throughput is primarily the time to desorb a tower from vent pressure (2 psi) to 22 to 25 inches of (mercury) vacuum. The tower evacuation time depends on the tower (or bed) volume and the compressor capacity, and is normally longer than the tower charge-up time, given sufficient pressure and flow rate in the feed line. Thus, the tower charging process commonly has to be adjusted (slowed) to make the charge time equal to the evacuation time for continuous operation of the NTU. Thus, one of the critical lessons from this project is that the operator should employ a strong compressor that is capable of evacuating the tower (volume) in as short a time as possible so that the process cycle time is reduced and the plant throughput is maximized (assuming that the feed line pressure and rate are sufficient for quick charging of the towers).

GAS ANALYSES

A potable gas meter (Figure 13A) that detected total hydrocarbon concentration (CH_4+ %) was used to take readings from the feed, vent, and sales streams entering and exiting the plant. The portable meter played an indispensible role in taking quick readings (Figure 13B) of gas compositions from different parts of the plant under various field operating conditions. Recordings from this portable gas meter (referred as handheld-CH_4+ %) were calibrated (Figure 13C) with the total hydrocarbon content determined from gas-chromatographic (GC) analyses (referred as GC-CH_4+ %) of the same samples. Furthermore, these GC-analyses of gas samples taken from the plant helped establish correlations (Figure 13D) between hydrocarbon content (GC-CH_4+ %) and the heat content of the gas (BTU dry). Equations encapsulating these correlations proved useful for quick determination of N_2 % and BTU content in any gas stream into and out of the NRU under different operational settings. It is critical to note, however, that these correlations are specific to a handheld (portable) gas meter and its calibration, and the correlations need to be reestablished when a new (different) portable gas meter is used. For example, the red-filled squares and the blue triangles (Figures 13C and 13D) represent two sets of data representing feed gas of different composition and measurements carried out using two different handheld gas meters.

BED BLOWOUT

Initial testing at the NRU commenced on May 31, 2008, after both towers were topped with activated carbon and their respective top flanges sealed. Results from the tests carried out at the NRU are summarized in Figure 14. The first test was carried out between from May 31 and June 3, 2008, when the towers were charged to 34 psi and then vented (to 2 psi) from the top. The average feed entering the plant had 63% hydrocarbons (CH_4+), which the plant was able to upgrade to 84% (CH_4+). The corresponding sales/feed ratio (i.e., the ratio between the sales to feed volumes) was 0.54 (i.e., 54% of the feed gas by volume was upgraded by the plant). The sales/feed ratio critically affects the volume of saleable gas from the plant, or inversely the volume of gas lost during the venting process. The volume of gas lost during the venting process depends on the pressure differential between the tower charge pressure and the vent pressure (here set at 2 psi) and the N_2 (%) content of the feed. The greater the N_2 content in the feed, the greater the volume of unabsorbed gas inside the tower, and the plant controls need to be optimized to efficiently reject most of this gas during the venting process.

With minor fluctuations in the feed stream composition, a second test was carried out (from June 4 to June 6, 2008) with the towers charged to 20 psi followed by venting to 2 psi to reduce the pressure differential between charge and vent pressures. The feed and sales gas during this second test, respectively, averaged 66% and 85% hydrocarbons, both of which were slightly higher than that observed during the first test. The sales/feed ratio during the second test was around 58%, a value slightly higher (and therefore better) than the first test. However, due to feed quality improvement (from 63% to 66% hydrocarbons), it is difficult to know if this increase in the sales/feed ratio (from 0.54 to 0.58) is solely due to reduced vent volumes as a result of lower differential between charge and vent pressures. Under real-life operating conditions in marginal environments where the feed stream is a mixture of production from different wells, it is not uncommon for the feed composition to fluctuate over time.

Another factor that affected plant performance is the dead-space volume that was inadvertently left at the base of each tower (Figure 15A). The gas remaining in the dead space is the low-BTU feed gas that never contacted the bed even after the end of the vent phase. Upon desorption (i.e., tower evacuation to vacuum) this N_2-rich low-BTU feed gas (with as much as 35 to 37% N_2) ended up in the surge tank, where it lowered the heat content of the sales stream. To better vent this feed gas accumulating at the base of each tower, the plant was run by simultaneously venting the towers from both the top and bottom during the vent phase under the assumption that such dual venting might improve the purging of N_2-rich gas and as a result improve the BTU content of the gas desorbed from the bed and stored in the surge tank for sales.

During the third test period (from 7 to June 10, 2008), the towers were alternatively charged to 20 psi with feed gas, the composition (Figure 14) of which showed minor variation from the previous two tests, and then vented simultaneously from top and bottom to 2 psi before being desorbed under vacuum. Though the feed composition changed slightly from the second test (i.e. average total hydrocarbons increased from 66% to 68%), the sales stream showed a small reduction in the hydrocarbon content from 85% to 83%. Contrary to expectations, the sales/feed ratio decreased between the second and third tests, from 0.58 to 0.51, especially when the tower charge pressure remained unchanged at 20 psi and the feed had slightly higher hydrocarbon content. It is counter-intuitive for the average hydrocarbon content in the sales stream to decline as a result of simultaneous venting from top and bottom of the towers because it was assumed that such dual venting would be more effective in purging unadsorbed low-BTU feed gas from the tower and thus increase the heat content (or CH_4+ %) in the sales stream.

The decline in the sales/feed ratio was exacerbated during the fourth test period from 11 to June 14, 2008, when the towers were charged to 30 psi followed by venting to 2 psi from top and bottom and desorption under vacuum. The feed composition was very similar to that during the third test (i.e., 67% hydrocarbons as compared to 68%). However, the sales/feed ratio (Figure 14) decreased significantly from 0.51 to 0.44 during this test. Also, the tower charge pressure (i.e., 30 psi) during the fourth test was close to that of the first test (i.e., 34 psi). However, the sales/feed ratio in the fourth test (i.e., 44%) was significantly lower than that obtained during the first test (i.e., 54%) despite similar differential between the tower charge and vent pressures.

Other interesting data include the near constant hydrocarbon content (varying between 83 to 85%) in the upgraded sales gas (extracted from the bed under vacuum) despite slight changes in the feed hydrocarbon content and major variations in the sales/feed ratio recorded during these four tests. The consistent hydrocarbon content of the sales gas may be indicative of the unchanging effectiveness of the bed in adsorbing the hydrocarbons from the feed stream. The decline in the sale/feed ratio over time may indicate bed blow-out during the venting process, especially because it was visually evident that carbon particles were ejected from the vent tower during each venting phase. Lacking any screen filter placed inside the vent valve located inside the top flange, it is reasonable to expect that minute particles of charcoal (bed) were ejected during the vent process when the charged tower is suddenly allowed to expand against atmospheric pressure. With bed material blown out, the dead-space increased inside each tower and this resulted in poorer performance of the plant.

The flange atop each tower was opened to visually check for bed blowout, and each of the towers was found to have lost about 18 inches of bed from the top of the column (Figure 15A). The towers were refilled (topped off) with fresh activated carbon (Figure 15B), and an appropriately sized screen filter was set below the top flange to prevent future bed blowouts.

PLANT PERFORMANCE – Average feed: 715 BTU/cu ft & C_2H_6+/CH_4+ = 7.9%

Initial optimization of the plant was carried out using a feed gas consisting of commingled production from a number of wells. Some wells were on pump and were prone to producing slugs of water along with gas. These varying production conditions resulted in changes in the gas composition feeding to the plant. Also the valves in the production lines, carrying gas from different wells to a central manifold downstream to the plant, had to be adjusted to maintain feed flow rate and pressure within a range, and these changes in the valve settings resulted in variation in the feed compositions.

At first, the low-BTU feed gas averaged around 687 BTU/cu ft with the ratio of the heavy to total hydrocarbons (C_2H_6+/CH_4+) around 7.9%. Under this feed condition, the plant was optimized to output pipeline quality gas (> 950 BTU/ cu ft) by charging the towers to 34 psi and then venting (from the top) to 2 psi to remove the unabsorbed N_2-rich gas from the tower followed by desorption of the bed to around 25 inch of Hg (vacuum). These settings (Figure 16) resulted in a sales/feed ratio of 0.54, i.e., 54% of the low-BTU feed gas (by volume) was upgraded to pipeline quality. Thus a feed gas with an average hydrocarbon content of 63% (CH_4+ % mole) was upgraded to a saleable stream containing around 84% of CH_4+ (% mole), thus resulting in 73.2% of hydrocarbon recovery and 75.7 % BTU recovery. The BTU recovery was calculated as the ratio of the product of total BTU coming into the plant (i.e., feed volume times feed BTU/cu ft) and that recovered in the sales stream (i.e., sales volume times sales BTU/cu ft). Under these settings, the vented gas contained about 63.1% N_2 (% mole) resulting in an average N_2 rejection efficiency of 76.7%.

The sales/feed ratio critically determines plant economics. Given unchanging feed composition and bed adsorption characteristics, the sales/feed ratio depends on the following: a) differential between the tower charge pressure (34 psi as stated earlier) and the vent pressure (2 psi), b) the volume of dead space within each tower, c) volume of gas desorbed from the beds during the venting process, and d) volume of N_2 in the feed that is mostly unadsorbed by the bed. The dead space in each tower consists of the volume between the carbon particles in the bed and any other unfilled space within the tower and can not be changed by the operator once the towers are in operation. Under similar feed compositions, higher sales/feed ratios result in greater recovery of the hydrocarbons entrained in the feed gas, and thus higher volumes of pipeline quality gas for sale. Conversely, the sales/feed ratio represents the volume and amount of gas (including N_2 and hydrocarbons) lost from the system as a result of the venting process.

To increase the sales/feed ratio, the pressure differential between tower charge pressure and vent pressure was reduced. As mentioned earlier, it was difficult to maintain a constant feed-gas composition because of commingling production from different wells. Thus by the time the plant could be operated under lower tower charge pressure, the feed gas composition had changed to an average of 743 BTU/cu ft. The plant produced pipeline quality gas (964 BTU/cu ft) at a higher sales/feed ratio of 0.60 (i.e., sales volume was 60% of the feed, see Figure 16) when its towers were charged to 20 psi and then vented to 2 psi (from the top of the tower). It is difficult to determine if the lower tower charge pressure resulted in slightly higher CH_4 recovery efficiencies (of 75.4%) and slightly lower N_2 stripping efficiency (of 72.6%), or if these were the result of better quality feed gas coming into the plant.

PLANT PERFORMANCE – Average feed: 630 BTU/cu ft & C_2H_6+/CH_4+ = 3.9%

Over time, the plant was connected to a different combination of wells including Palmer 1, as the major contributor, to maintain sufficient feed rate and pressure. This resulted in feed-gas composition that was poorer in heat content, with an average of 615 BTU/cu ft (as compared to 715 BTU/cu ft, previously discussed). Also, the ratio of the heavy hydrocarbons to total hydrocarbons in the feed decreased from 7.9% to 3.9%. However, this deterioration in the feed-gas composition provided an opportunity to fine tune the plant settings to see if the plant could upgrade a poorer quality of feed gas than that discussed earlier.

According to a tabulation of the BTU content of different kinds of hydrocarbons (Figure 17), it is evident that small increases in heavy hydrocarbons result in significant increases in the BTU content of the gas. Thus, the reduction in BTU content and halving of heavy hydrocarbon fraction (C_2H_6+/CH_4+) in the feed necessitated dramatic changes in the plant settings so that pipeline-quality sale-gas could be achieved.

The plant was run under different settings and the results are tabulated in Figure 18. The variation in BTU content of the feed gas was less than 5% during this plant optimization study. Initially the plant was run with tower-charge pressures of 15 and 30 psi and vent pressure of 2 psi, values close to settings that resulted in pipeline quality sales stream (i.e., >950 BTU/cu ft) for previously described richer feed gas. However, with these settings and for a feed with heat content around 630 BTU/cu ft and heavy hydrocarbon component fraction of 3.9%, the desorbed gas from the NRU was found to be of sub-pipeline quality (i.e., 831 and 881 BTU/cu ft, respectively). Raising the tower charge pressure to 70 and 65 psi, followed by venting to 13 and 9.5 psi, increased the heat content of the desorbed gas to around 920 BTU/cu ft but also resulted in lower sales/feed ratios, i.e., 45 and 49%, respectively. At the time of these tests, the feed gas had a heat content and heavy hydrocarbon fraction that was 12% and 50% lower than the earlier discussed feed. This deterioration (change) in the feed composition was the main reason for requiring higher tower-charge pressures in order for the desorbed gas to come close to pipeline quality (950 BTU/cu ft). Higher tower-charge pressures result in greater pressure differential during the vent process, and therefore greater loss of hydrocarbons and lower sales/feed ratios. Thus, the vent pressures were set higher (to 13 and 9.5 psi) when the towers were charged to 70 and 66 psi, respectively, to reduce the pressure differential during the vent process, and thus to reduce the adverse impact on the sale/feed ratio. However, these settings failed to produce pipeline quality gas with the heat content of the desorbed gas hovering around 920 BTU/cu ft.

In the current tower design (Figure 15A), an unfilled space about 20 inches from the bottom of the (8 foot) tower remains unfilled by the bed of activated carbon because the grate supporting the bed was incorrectly designed to be located above the tower access hole (port). This dead (space) volume at the bottom of each tower remains filled with N_2-rich feed gas (at 2 psi) after the vent phase when the venting took place solely from the tower top. Thus during the desorption stage, this feed gas, remaining in the dead space, entered the surge tank and lowered the BTU of the sales gas. Hence, attempts were made to see if simultaneously venting from both the top and bottom of the tower would help improve the purging of this (untreated) feed gas present in the bottom dead space.

The sales gas from the plant was found to be of pipeline quality (at 958 BTU/cu ft) when the tower charge pressure was set at 69 psi and vent pressure to 3 psi with venting occurring from both the top and bottom of the tower. This setting resulted in a sales/feed ratio of 0.39. The sales/feed ratio was improved slightly to 0.40 when the tower charge pressure was set to 72 psi and the vent pressure was set at 4 psi with minor variations in the feed gas heat content (i.e., from 633 to 634 BTU/cu ft).

It is apparent from the above results that this plant can upgrade a feed with a heat-content as low as 630 BTU/cu ft and a heavy hydrocarbon fraction of 3.8%. Thus, it is critical to note that both the heat content and the amount of heavy hydrocarbons present in the feed stream dictate the operational settings of the plant for attaining pipeline quality sales gas. Needless to say, any deterioration in the quality of the feed will result in a concatenate reduction in the sales/feed ratio. This is expected because poorer quality of feed gas will naturally contain increasingly higher amounts of non-hydrocarbon components (such as nitrogen), and any upgradation process, such as this plant, is effective only if it can successfully reject most of the increasing volume of non-hydrocarbon impurities in the feed, thus naturally resulting in lower sales/feed ratios.

Also as feed quality deteriorates, the towers must be charged to higher pressures resulting in higher pressure differentials during the venting process, leading to greater volumes of gas lost and lower sales/feed ratios. Also for this poorer quality feed, the BTU-recovery efficiency decreased to around 59% as compared to 75% obtained with a superior feed having an average of 715 BTU/cu ft.

HEAVY HYDROCARBONS ADSORPTION

Figures 19A to 19B display the analyses of gas samples taken from the feed and the upgraded sales stream for a feed gas with heat content of around 746 BTU/cu ft and heavy hydrocarbon fraction of 7.7%. A mass balance on the heavy hydrocarbons (C_2H_6+) made on the feed gas and the upgraded sales gas shows that about 98% of the heavy hydrocarbons entrained in the feed are recovered in the sales stream. Thus, the bed of activated carbon was efficient in capturing the incoming heavy hydrocarbons. The desorption process was equally effective in recovering these adsorbed hydrocarbons. Also, the mass balance calculations show that about 67.7% of the total hydrocarbons (CH_4+) have been recovered at the NRU. Therefore, the vent stream is mostly made up of unadsorbed nitrogen and some methane because most of the heavy hydrocarbons are recovered in the sales stream.

Figures 20A and 20B show the gas analyses of the feed (at 601 BTU/cu ft and heavy hydrocarbon fraction of 3.7%) and the respective upgraded (sales) gas from the plant. As compared to the previous case, the feed-gas composition has deteriorated both in terms of heat content and heavy hydrocarbon fraction. Mass balance calculations on this poorer quality feed gas show that the plant is able to trap and recover around 98.2%

of the entrained heavy hydrocarbons (C_2H_6+). The associated total hydrocarbon recovery (CH_4+) is lower (at 58.6%) for this poorer quality feed.

The above results clearly indicate that an unpatented off-the-shelf bed of activated carbon, made from coconut husks, is effective in adsorbing and then desorbing 98% of the entrained heavy hydrocarbons (C_2H_6+) from a feed stream of low-BTU gas. This effective capture and recovery of the heavy hydrocarbons, where each component has significant heat content, plays a critical role for the plant to upgrade low-BTU gas to pipeline standards. However, the adsorption effectiveness of the bed means that the vent gas contains little to no heavy hydrocarbons, and therefore the only component in the vent gas that has any heat content is CH_4. This calls in question the economic feasibility of upgrading the vent gas to pipeline quality using a secondary tower to improve the total hydrocarbon recovery from the plant.

PERFORMANCE COMPARISON WITH COMMERCIAL PLANT

Figure 21A tabulates the price, in terms percentage of sales volume, that American Energies Corporation (AEC) was offered by a local commercial plant in Kansas to upgrade low-BTU gas. The micro-scale NRU described in this report was designed to handle around 250 mcf/d of low-BTU feed gas. The appropriate seller's percentage offered to AEC for such low volume sales (i.e., <450 mcf/d) was 51% of the total volume of gas sold to the commercial upgradation plant. Thus for every 100 mcf of low-BTU gas that AEC sells to the plant, it gets paid for 51 mcf. Also, the sales contract carried additional constraints (Figure 21B), important among which was that the feed could not have N_2 content >28%. This constraint would disqualify the gas from Elmdale field wells because its N_2 content was 33% or higher. Additionally, AEC had to consider the cost of transporting the low-BTU gas from the production wells (in the Elmdale field) to the commercial plant, provided presence of a nearby pipeline whose operator agreed to transport the low-BTU gas. AEC estimated that the transportation costs would additionally be around 13% of the volume of low-BTU gas that it sold to the commercial upgradation plant.

Figure 21C compares the revenue that AEC would collect if it sold the low-BTU gas to the commercial plant with what it would gain if it processed the same gas using the micro-NRU, assuming that the commercial plant would agree to set aside its refusal to accept gas with greater than 28% N_2. Thus, if AEC were to sell 100 mcf of low-BTU gas to the commercial plant, it would get paid for 38 mcf of pipeline quality gas after deduction of the upgradation and transportation costs (here estimated at 13% of the total gas volume sold). In comparison, if AEC were to use the micro-NRU to treat its low-BTU gas onsite, it could save on the transportation costs. Given the average sales/feed ratio achieved at the micro-NRU, if AEC were to sell 100 mcf of low-BTU gas with an average heat content of 615 BTU/cu ft and 715 BTU/cu ft, it would get paid for 39 and 57 mcf of pipeline quality gas, respectively. Thus, the micro-NRU offers competitive value to low-BTU producers, particularly if available commercial upgradation plants are located far from the production sources and when such commercial plants restrict the maximum amount of N_2 in the feed gas.

PLANT ECONOMICS

Figure 22 summarizes the payout calculations for the micro-NRU whose construction costs totaled to $120,000 including financial support of $60,000 from the Stripper Well Consortium. AEC built the plant using off-the-shelf vessels, pipelines, control valves, engine, and compressor, in their workshop with its own maintenance/service crew. This achievement highlights the simplicity of the plant design, and should therefore provide confidence to other small operators to venture into building a micro-NRU for their own needs without relying on expensive expertise from consultants. The payout calculations were carried out assuming the price of pipeline quality gas to be $4.00/mcf, feed volume of 150 mcf/d, and for two different qualities of feed gas at 615 and 715 BTU/cu ft. Based on average performance (sales/feed ratio) observed at the micro-NRU, the payout time calculates to be 17 and 12 months, respectively, for the above two types of feed.

PLANT CONTROLS

The plant is easily optimized from a central (electronic) control panel that pneumatically opened and shut the different solenoid valves that control the flow of gas in and out of the two towers. The electronic panel allows the operator to input charge and vent times (or pressures) for each tower, which need to be synchronized for continuous operation. For unchanging feed line pressure and composition, the plant will work unattended with one daily check-up visit by the pumper/operator. However if the feed composition changes, the operator needs to re-set the operating conditions of the NRU using the control panel to produce pipeline quality gas at the downstream end. Only two parameters need to be changed in order to re-optimize the plant to upgrade the new low-BTU feed to pipeline quality, and these are the tower charge pressure and the vent pressure. The operator must try different combinations of these two parameters by changing feed and vent pressures (or times) using the control panel to find the new settings that result in pipeline quality sales stream.

Based on experiences from this pilot NRU, the following are suggested general guidelines that an operator can follow to optimize the settings:

a) If the feed BTU and heavy hydrocarbon fraction increases, the towers can be charged to lower pressures to obtain pipeline quality sales stream. Sales/feed ratios tend to improve with higher quality feed.

b) If the feed BTU and heavy hydrocarbon fraction decreases (i.e., feed quality deteriorates), the towers must be charged to higher pressures to upgrade to pipeline quality. Sales/feed ratios will decrease with poorer feed quality.

c) After having attained pipeline quality sales stream with a particular setting, the operator may test for optimum sales/feed ratio by adjusting the tower charge pressure downward to identify the lowest charge pressure, which results in the sales stream to be of pipeline quality.

PLANS

The micro-NRU continued to upgrade low-BTU feed gas at its current location until the beginning of 2009, when the wells supplying the gas had to be shut-in due to production of water and the attendant infrastructure limitations in trucking away this water. Thus, AEC is currently under discussions with other operators of neighboring low-BTU gas wells to relocate the NRU and re-start gas upgradation.

Encouraged by the results of this demonstration micro-NRU, AEC has already built a bigger plant (Figure 23). At the time of writing of this report, this newly built plant (with tower height of 20 feet and diameter of 6 feet) has been moved to location and has been commissioned. The plant is awaiting legal clearance before start of operation. Based on the lessons learned from the demonstration plant, the grate supporting the bed of activated carbon has been placed at the bottom of the tower (just above the feed entry flange) in order to minimize the dead space (volume) in comparison to the volume of the tower. This new plant will mobilize gas from a low-BTU field that is currently shut-in because of lack of a higher BTU-gas necessary for blending. This case thus demonstrates how micro-NRUs can be effective in activating shut-in fields and thereby provide new life to the marginal assets often in isolated locations and owned by small producers. Upgraded gas can either be consumed locally or be assimilated in the nation's gas grid to increase domestic energy supplies.

LOW-BTU GAS POTENTIAL – ELMDALE FIELD, CHASE COUNTY, KS

WATER ANALYSIS

Produced water was analyzed to determine resistivity for use in Archie equation in log analyses. The majority of the wells in and around the Elmdale field produce pipeline quality gas from the LKC Group. Representative water samples are not available from other sandstones (such as the Tecumseh) because they are currently not being produced. Water was collected from 3 wells, namely Davis Giger 1, Kisser 1-29, and Pretzer 3. The Davis Giger 1 and Pretzer 3 produce from the LKC, while AEC suspects that the Kissel 1-29 well is open to some low-BTU gas zones. Water analyses revealed that the resistivity of produced water from the above mentioned wells was 0.079, 0.077, and 0.076 ohm-m respectively. Thus lacking sandstone-specific resistivity data, a resistivity of 0.078 ohm-m was used in the Archie equation for log analyses discussed in the following section.

LOG-ANALYSES – LOCAL LOW-BTU RESOURCE EVALUATION

One of the deliverables for this project was a local resource evaluation of low-BTU reserves around the plant. Wireline logs from 26 wells in and around the Elmdale field were analyzed as a part of the resource evaluation study. Initially, the log analysis was carried out over the Tecumseh interval (Figure 24) in Frankhauser Trust E1 well that produced water-free gas. The Tecumseh interval extends from 704 to 714 ft, where the gas effect is visible on the neutron porosity log. The significant separation between the density porosity and the BVW (bulk volume water), which clusters around 0.12, implies gas production that is water-free or has minimal water. The GR (gamma ray log) indicates relatively lower values. Thus, the wireline log signatures match the production observed at this well from the Tecumseh zone. This exercise was used to define the Archie constants ($m = 1.8$, $a = 1$, $R_w = 0.079$) that were used universally for all the other zones at other wells lacking zone-specific data. The petrophysical cut-off parameters that defined the Tecumseh as a pay zone include the following: porosity > 0.19, $S_w < 0.60$, Vshale < 85%, and BVW < 0.15.

To evaluate the potential of low-BTU reserves in this area, shallower sandstones such as Ireland, Douglas, Tecumseh, Calhoun, Severy, and White Cloud Sandstones were analyzed when present at the well of interest. For each well, the density porosity and neutron porosity logs (run on a limestone matrix of 2.71 g/cc) were corrected for the sandstone matrix density of 2.65 g/cc. Thus, a neutron cross over (where the neutron porosity becomes less than the density porosity log by taking an hour-glass shape) is considered indicative of gas effect. However, note that low porosity zones often result in deeper invasion, which masks the gas effect, which is otherwise visible in high porosity zones with shallower invasion. Presence of gas effect on the neutron log is a strong indicator of presence of gas, but absence of gas effect may not mean that gas is absent because invasion may mask the effect on neutron log. The summary of this log analyses is presented in Figure 25. Based on the log signatures of each of these sandstones, production potential of each of these zones was evaluated and tabulated.

Figure 26 displays strong gas production potential for the Ireland Sandstone (1014 to 1030 feet) in Palmer 1 well – a zone with high porosity, low GR values, clustering of the BVW around a low value of 0.14, and gas effect on the neutron log over the lower part of this interval. Figures 27 and 28 indicate that the Tecumseh interval (744 to 754 feet) has good indications of gas production potential with low BVW values (< 0.1), gas effect on the neutron log, and low GR values. The cut-off parameters defined for the Tecumseh pay zone in the Frankhauser Trust E1 well, when used in this analysis indicate that the Tecumseh interval in Palmer 1 well can be similarly defined as pay. Figure 29 shows that the Calhoun sandstone (654 to 657 feet) in this well may have some gas production potential with low BVW values (< 0.14), low GR values, and minor gas effects on the neutron log, and separation between the density porosity and BVW. However, no gas shows were recorded over this zone during drilling. Figure 30 shows that the Severy sandstone (570 to 578 feet) has gas-bearing potential with gas effect on the neutron log, moderate GR, and significant separation between density porosity and BVW. However, a transition zone is also clearly visible in this zone. This well tested significant volumes of low-BTU gas in both the Tecumseh and Severy zones.

Log analyses of the other wells are detailed in Figures 31 to 78. In each case, the analyzed sandstone is marked by a red rectangle. These results represent the first pass in analyzing wireline log data. Log signatures can be better correlated with production results as wells get recompleted in the shallower sandstones analyzed in this study.

REGIONAL GAS ANALYSIS

LOW-BTU GAS CHARACTERISTICS - KANSAS

Fifty-four gas analyses were collected from published and private sources from the region around the Elmdale Gas field (Chase County) in Kansas (Figure 79), so as to survey the likely range of compositions of natural gas in this region and to determine what strata may contain low-BTU gas resources. Several pay zones, ranging in age from Permian to Mississippian, produce gas in the region. In general, the shallower pay zones contain low-BTU gas (i.e. <950 BTU/scf) (Figure 80). Hydrocarbon wetness, the ratio of heavier molecular-weight hydrocarbons to that of methane plus the heavier molecular-weight hydrocarbons, increases with increasing age and depth of the producing formation (Figure 81). The presence of these heavier-molecular-weight hydrocarbons increase the heating value (BTU content) of the natural gas, and this partly accounts for the better BTU content of the deeper gases, in addition to the greater percentages on nitrogen in the shallower gases (Figure 82).

Nitrogen-to-helium ratios for all the gases essentially remains the same regardless of the age of the pay zone (Figure 83), suggesting a common source for these component gases. The greater percentages of nitrogen and helium in the shallower, low-BTU zones indicates that these zones will have better economics if attempts are made to recover helium from the rejected noncombustible (N_2-rich) gases from the upgrading process. The compositional ranges of hydrocarbon and non-hydrocarbon gases are expressed respectively in Figures 84A and 84B. The deeper formations appear to have a greater range in composition, but this may be due to greater number of samples available from deeper zones.

TECHNOLOGY TRANSFER

A web site (http://www.kgs.ku.edu/PRS/Microscale/index.html) dedicated to this project has been kept updated with pictures, results, cross-sections, log analyses, and other data. All reports and presentations have been posted at this web site including results obtained from the plant optimization studies. Initial results from plant optimization study were published in the trade journal E&P (August 2008) and in the 2008 IOGCC Report "Marginal Wells: Fuel for Economic Growth". A manuscript detailing the overall project results and plant optimization is being written for submission to one of the widely read trade journals in the small producer community (i.e., either Oil & Gas Journal or World Oil). The expected date of publication is early fall 2009.

Also, projects results have been presented at the following industry meetings and technical gatherings:

1. Kansas Geological Society meeting at Wichita, Kansas, on March 25, 2007
2. Stripper Well Consortium meeting at Roanoke, West Virginia, on September 20, 2007
3. Stripper Well Consortium meeting at Wichita, Kansas, on October 20, 2007
4. Fall meeting of the Stripper Well Consortium at Erie, Pennsylvania, on September 8 & 9, 2008
5. Oklahoma Oil & Gas Trade Expo at Oklahoma City, Oklahoma, on October 16, 2008
6. Kansas Geological Society meeting at Wichita, Kansas, on November 10, 2008

CONCLUSIONS

1. It is possible to upgrade low-BTU gas (as low as 630 BTU/cu ft) to pipeline quality (> 950 BTU/cu ft) using a simple, cost-effective micro-scale nitrogen rejection unit (NRU) with an adsorption bed consisting of readily available non-patented activated carbon made from coconut husks.

2. Approximating plant construction costs at $120,000 and assuming gas prices at $4/mcf and a feed of 150 mcf/d, the payout is estimated at 17 months for 615 BTU/cu ft feed, and 12 months for 700 BTU/cu ft feed.

3. The dead space within each tower must be minimized relative to tower volume. Initial operation data indicate that greater bed mass (with minimum dead space) results in larger volumes of adsorbed hydrocarbons and therefore better sales/feed ratio.

4. The off-the-shelf bed of activated carbon is efficient in adsorbing heavy hydrocarbons (C_2H_6+) from the feed stream and desorbing it under vacuum. This efficient removal of heavy hydrocarbons leaves the vent gas poor in constituents with significant heat content, and therefore puts in doubt the viability of upgrading vent gas to pipeline quality.

5. The towers have to be evacuated (desorbed) from vent pressure (around 2 psi) to maximum vacuum (≈25 to 28" Hg) in the shortest possible time to maximize heavy hydrocarbon recovery and to lower cycle time, which is inversely related to plant throughput. Efficient bed desorption results in better adsorption of hydrocarbons in the next cycle and may increase bed life. The compressor capacity is relative to the size of the towers, and thus plant throughput will be compromised if a less-than-appropriate

sized compressor is employed. Despite the cost of the compressor being one of the major expenses in building of the micro-plant, operators should not employ an inadequate compressor if plant efficiency and throughput are valued.

6. Both nitrogen content and the fraction of heavy hydrocarbons in the feed control the optimum plant settings and determine its efficiency.

7. Plant settings, namely tower charge pressure and vent pressure, will have to be adjusted if feed composition (BTU and C_2H_6+/CH_4+ ratio) changes. Greater amounts of heavy hydrocarbons in feed results in higher sales/feed ratio and thus better plant operating economics.

8. Use of a portable hydrocarbon meter is very effective during the process of plant optimization. Correlations developed between portable hydrocarbon meter and gas chromatographic (GC) analyses enable quick estimation of hydrocarbon concentration and BTU value from portable meter readings taken from different sampling points in the plant, particularly during the optimization process.

9. Wireline logs from 26 wells in and around the Elmdale field were analyzed to determine the gas production potential of several sandstone bodies such as the Ireland, Douglas, Tecumseh, Calhoun, Severy, and White Cloud. Gas production potential was identified in several pockets in these sandstones at several wells. Additional production testing needs to be carried out at select wells to validate and refine the log analysis.

10. Regional analyses of low-BTU data was initiated using 54 gas samples and the following trends observed:

a) In general, the shallower zones tend to produce low-BTU gas.

b) Hydrocarbon-wetness increases with age and depth of the producing zone.

c) Nitrogen-to-helium ratios are unaffected by the age of the pay zone.

d) Given the limited data set available, the deeper formations appear to display greater compositional ranges for hydrocarbon and non-hydrocarbon gases.

REFERENCES

1. Low-cost plant upgrades marginal gas Fields: Saibal Bhattacharya, K. David Newell, W. Lynn Watney, and Michael Sigel - E&P, v. 81, no. 8, August 2008

2. A Low-cost micro-scale N2 rejection plant to upgrade low BTU gas from marginal fields: Saibal Bhatttacharya, Lynn Watney, Dave Newell, Rudy Ghijsen, and Mike Magnusen - Marginal Wells: Fuel for Economic Growth 2008 Report, Interstate Oil & Gas Compact Commission

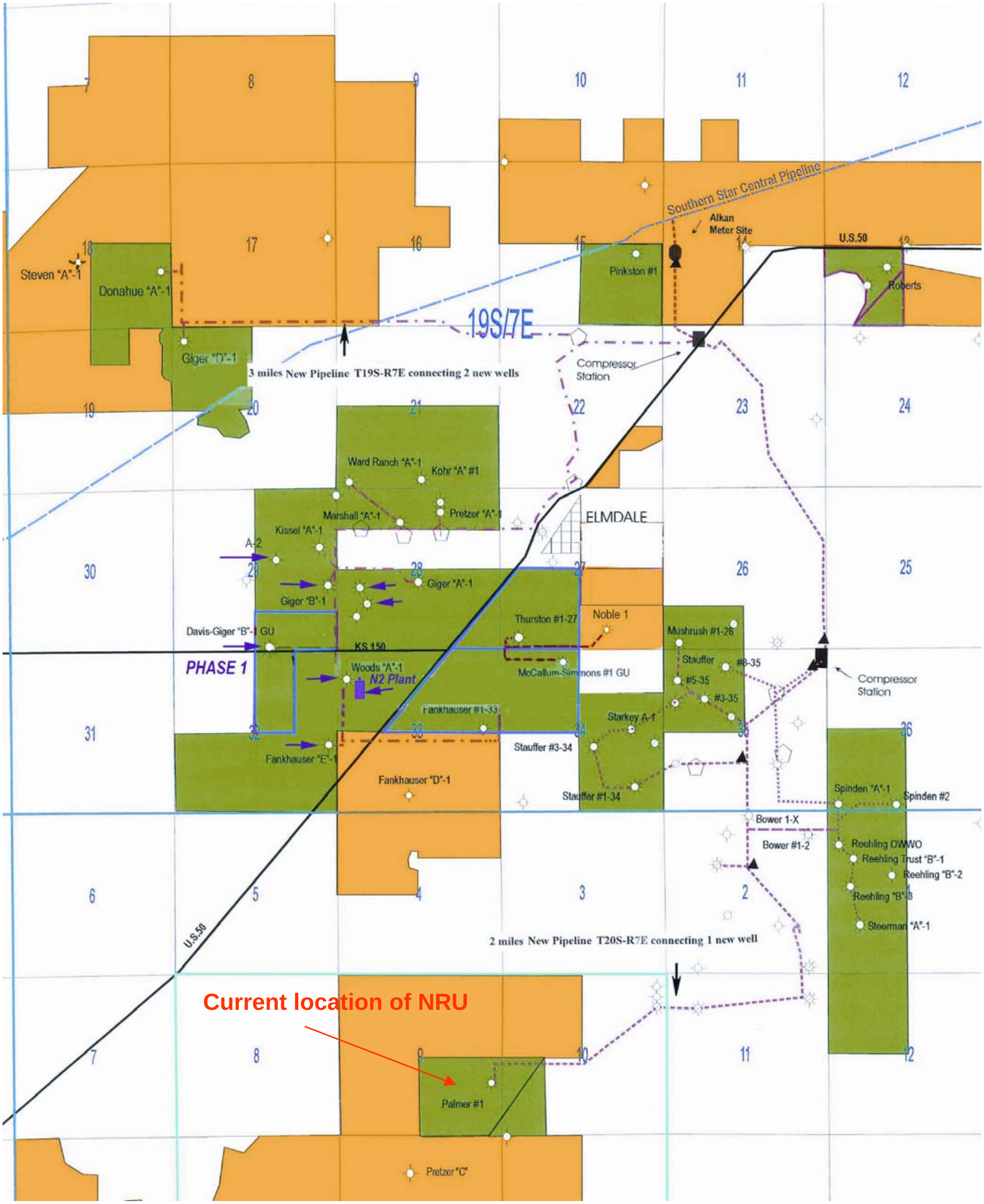


Figure 1. Map showing the location of the Elmdale field, Chase County, Kansas, along with the location of the N_2 Rejection Unit (NRU).

Figure 2: Picture showing the general layout of the nitrogen rejection unit (NRU).

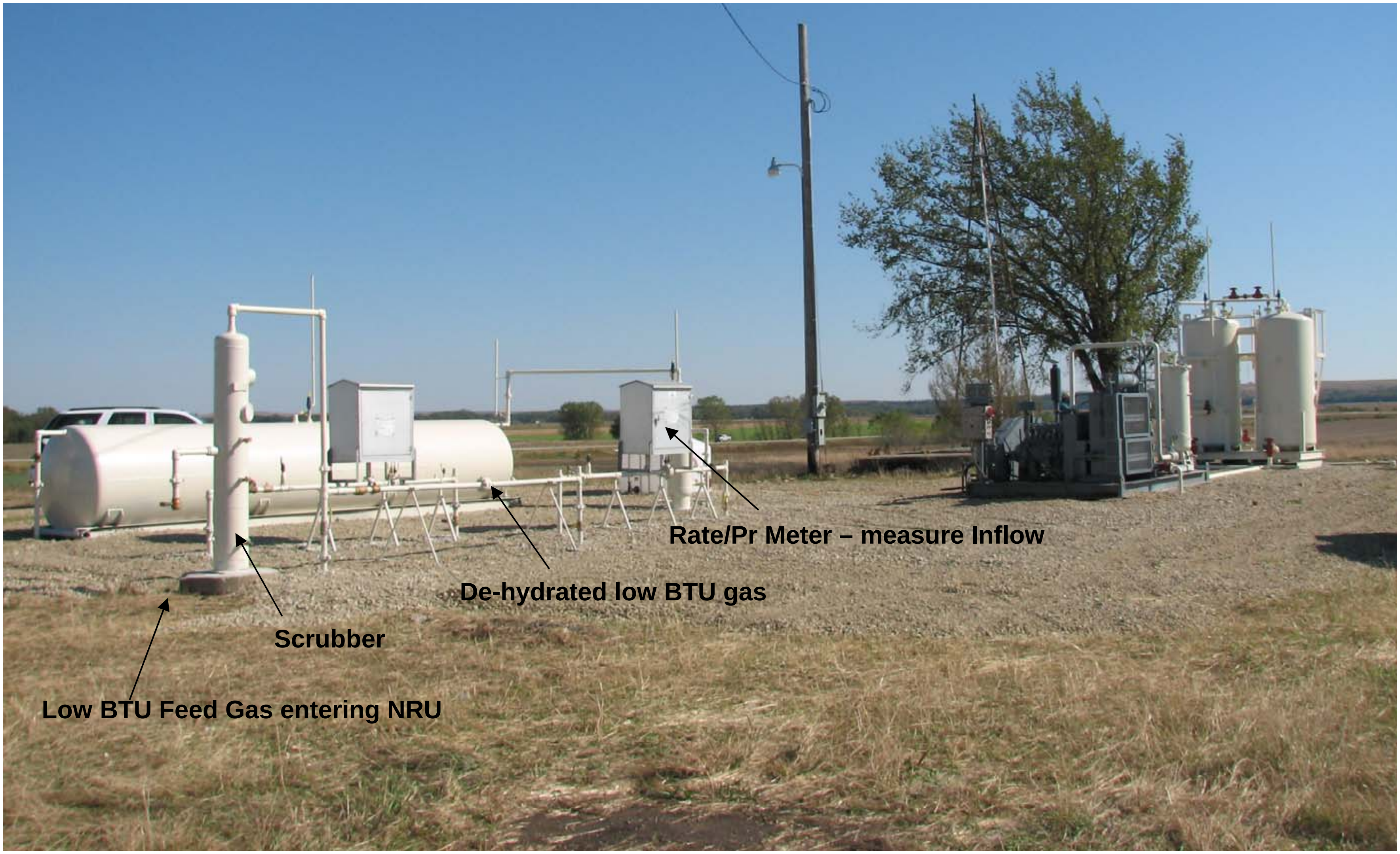


Figure 6: Picture showing the feed gas line connecting to the scrubber to remove moisture and onwards to the flow meter.

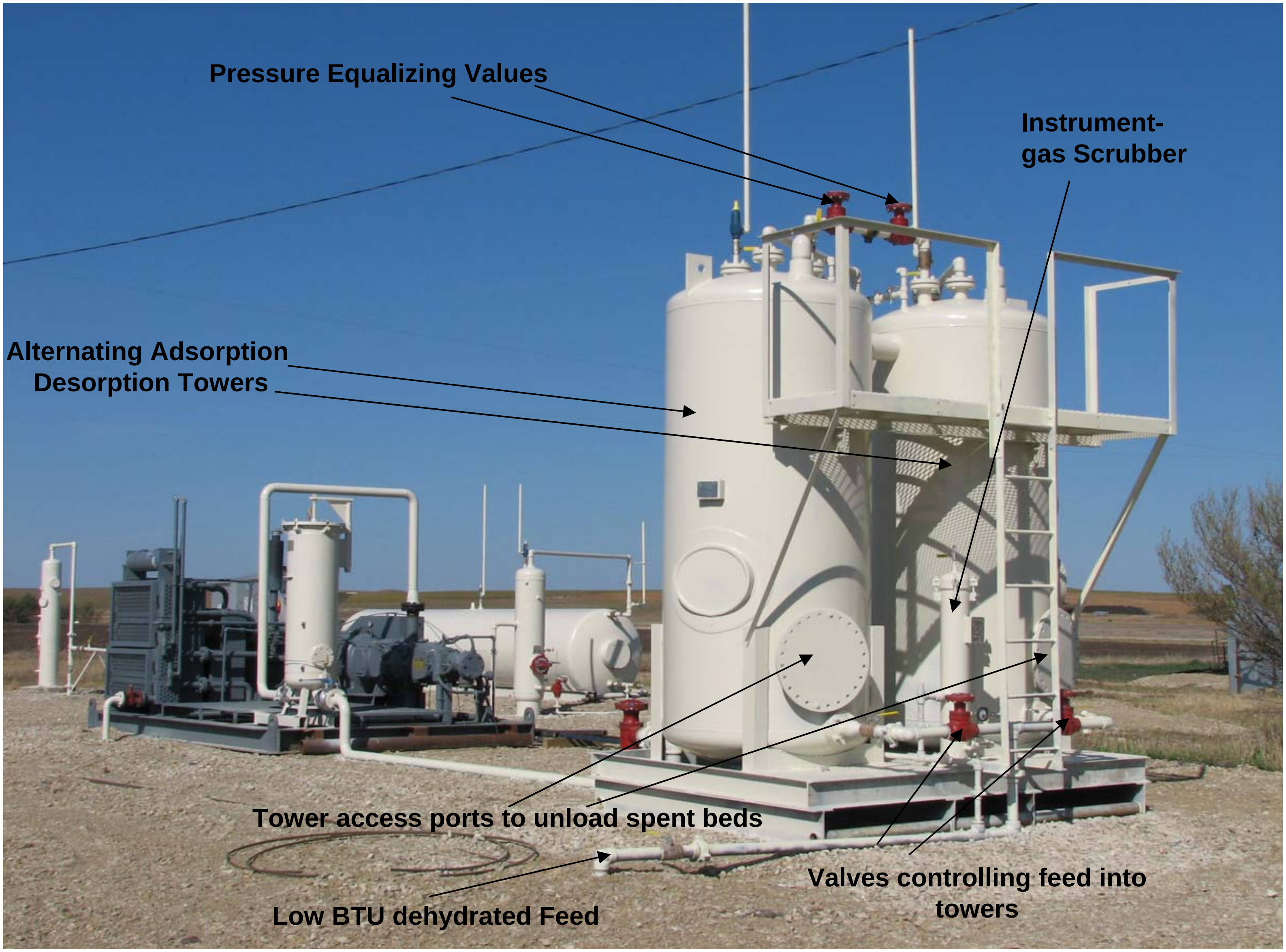


Figure 4: Picture showing the feed gas line connecting to the two towers and the valves controlling flow of gas into the towers.

Figure 5: Pictures showing the following: A) close up of activated carbon granules, B) charging of the towers with activated carbon, and C) leveling the carbon bed after charging towers.

Front side of the Adsorption/Desorption Towers

Rear side of the Adsorption/Desorption Towers

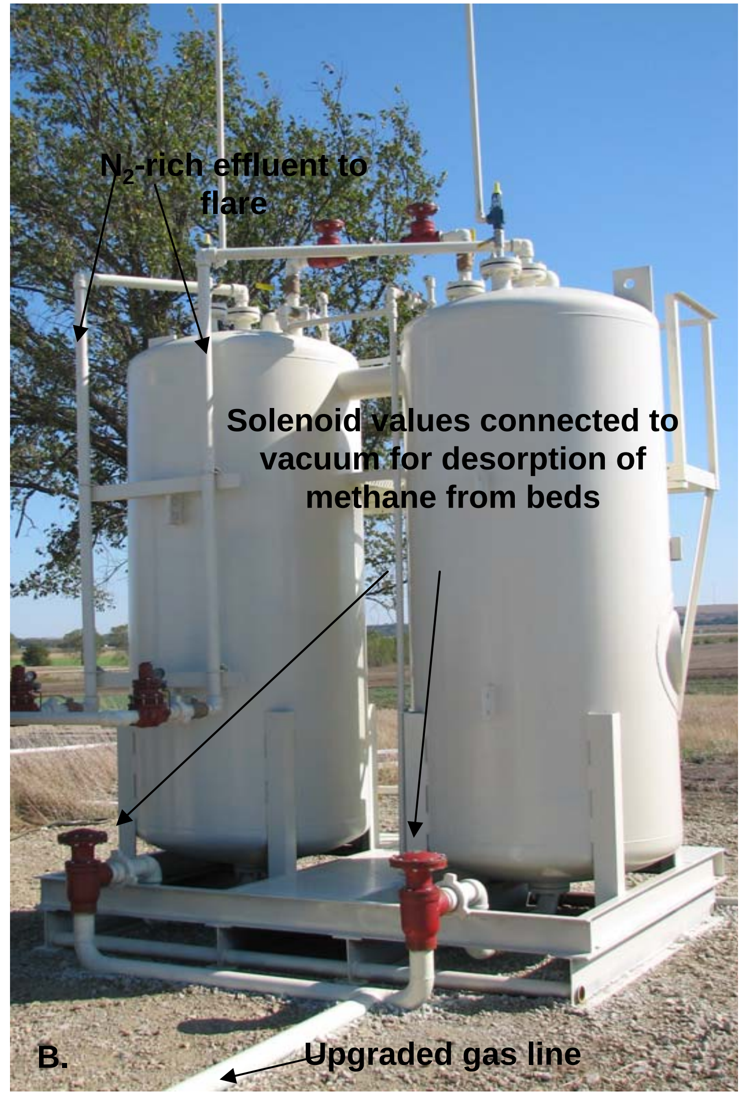
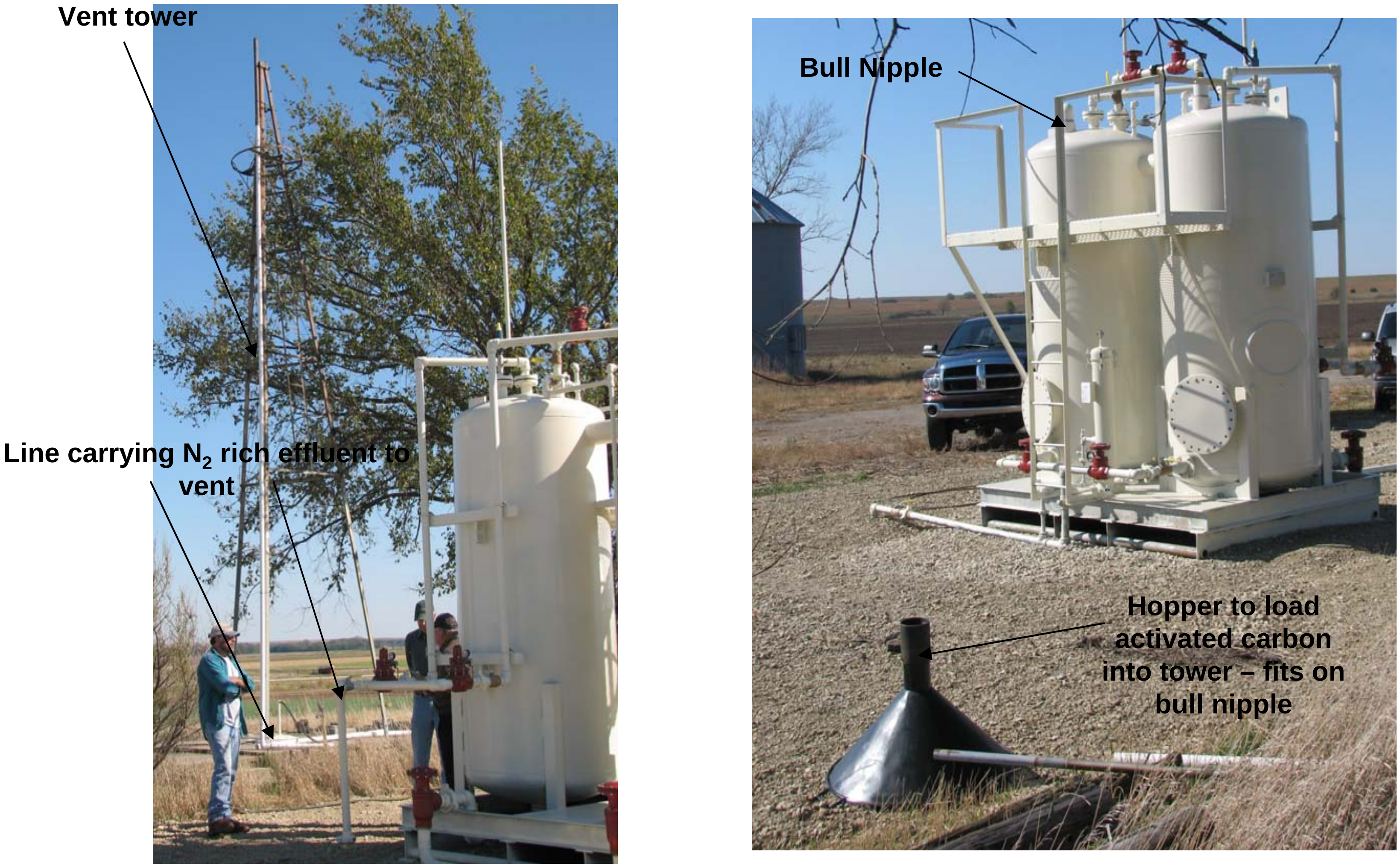


Figure 6: Close up of the two rowers: A) front side and B) rear side.



A. **B.**

Figure 7: A) Picture showing the vent line connecting to the flare. B) Picture showing the bull nipple and the hopper used to load the towers with activated carbon.

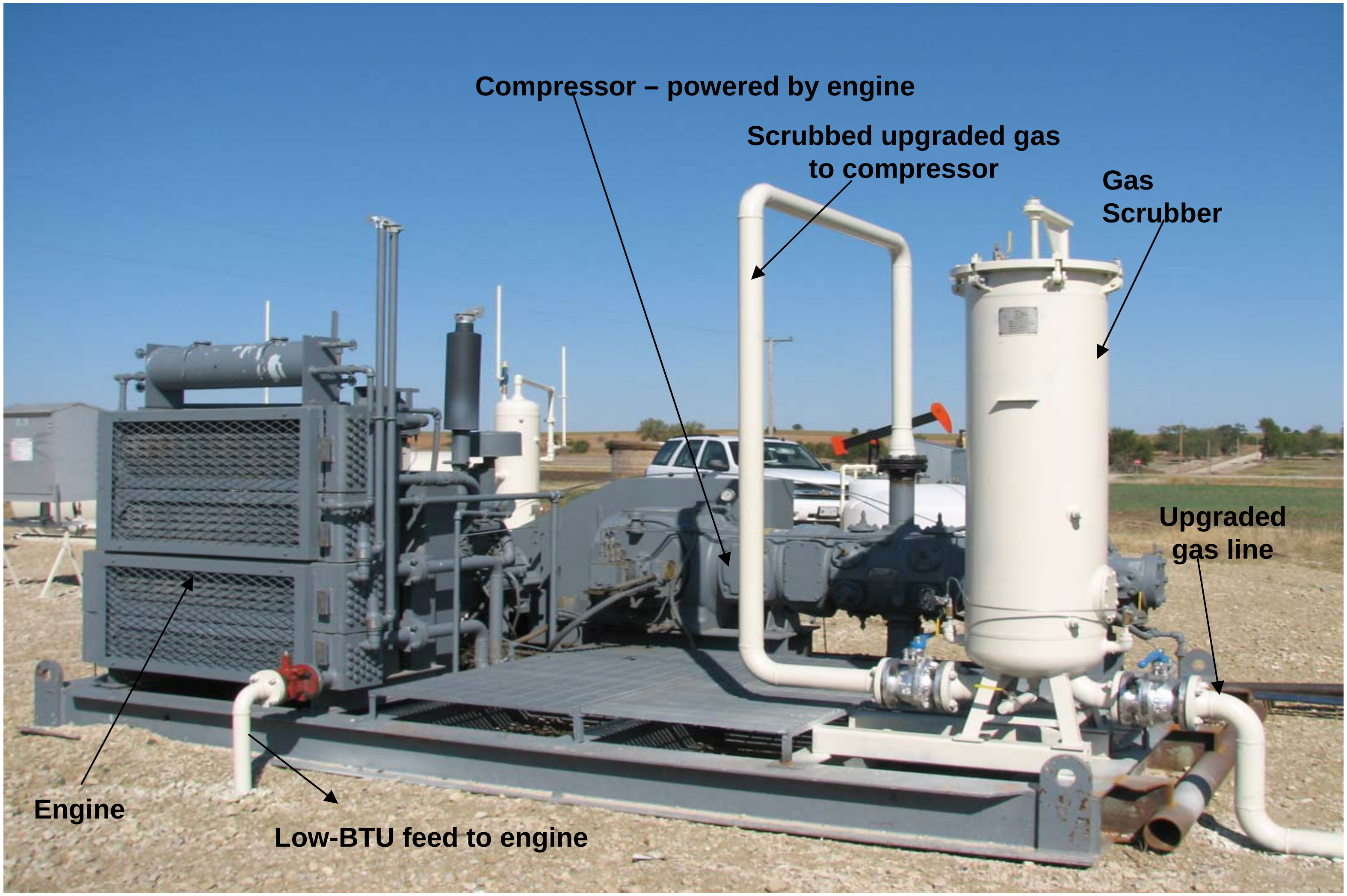


Figure 8: Picture showing the compressor that pulls a vacuum on the desorption tower along with the engine that powers it.

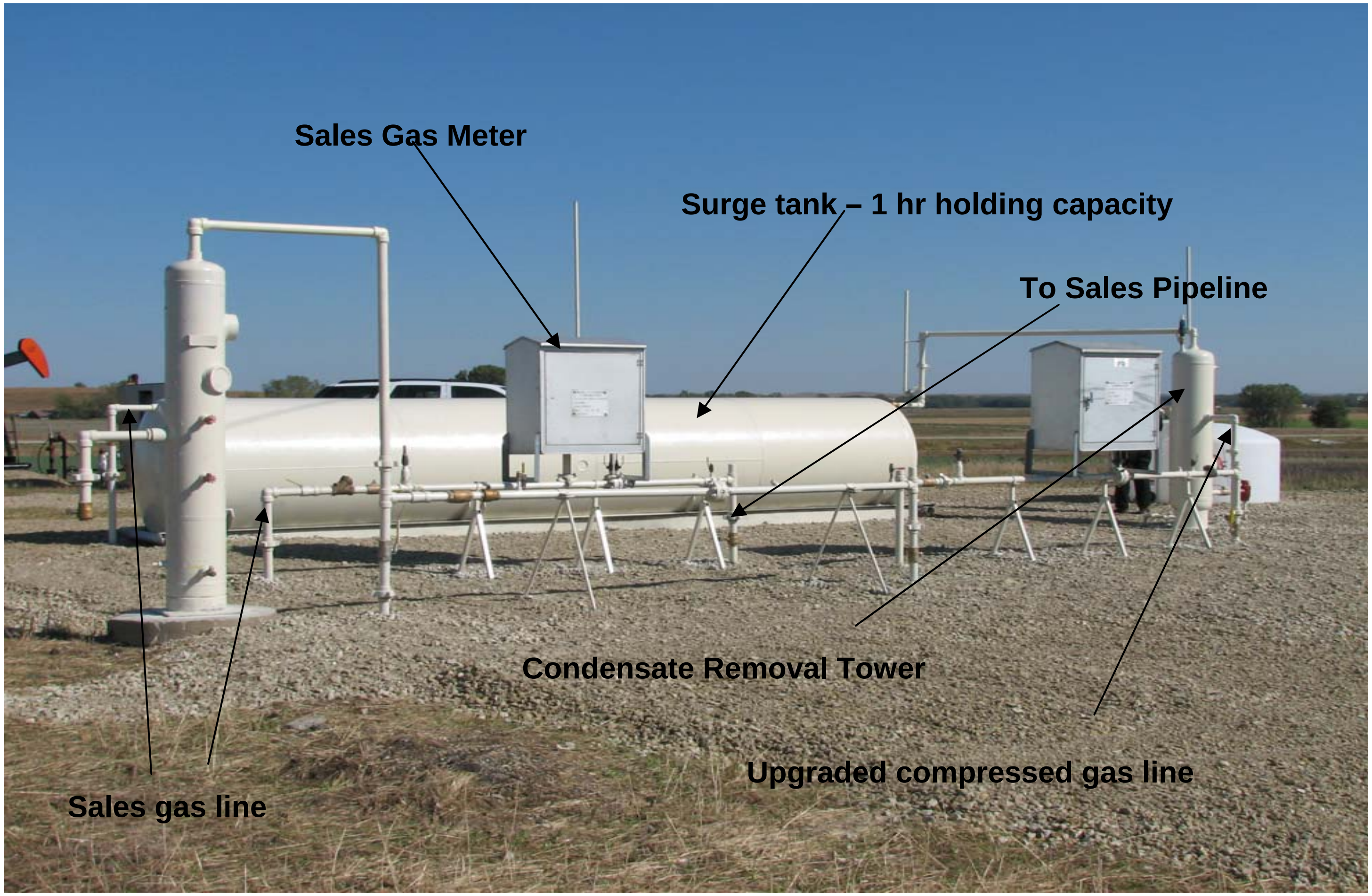


Figure 9: Picture showing the surge tank and the flow lines transferring the upgraded gas.

STEP 1 - Tower 1 Adsorption, Tower 2 Desorption

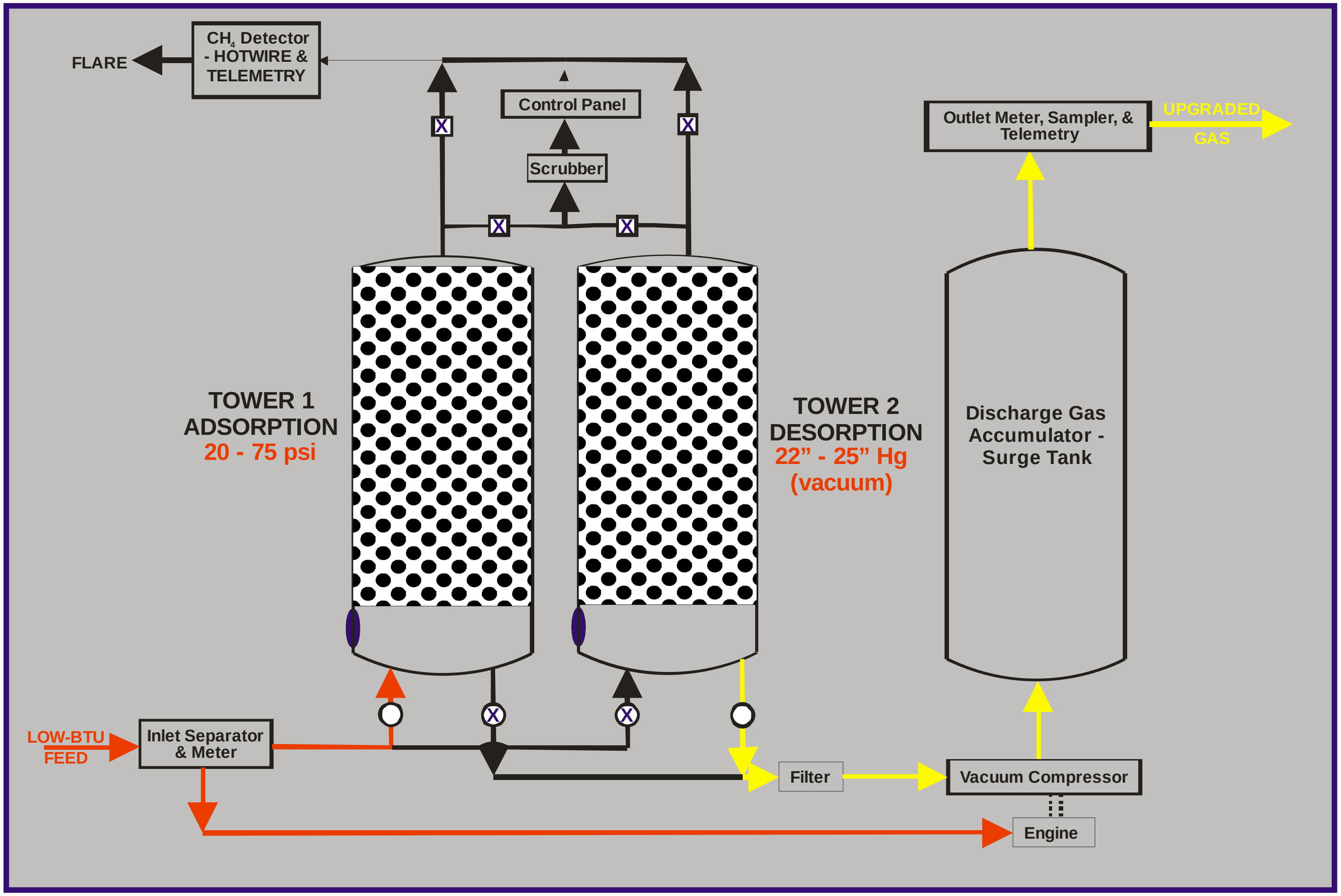


Figure 10: 1st step of operation - the feed gas charges up the evacuated Tower 1 to the set pressure (between 25 to 75 psi) depending on the plant settings determined by the feed gas quality, while Tower 2 is going through the evacuation process to vacuum ranging between 22 to 25 inches of Hg.

STEP 2 - Tower 1 Venting, Tower 2 in Vacuum

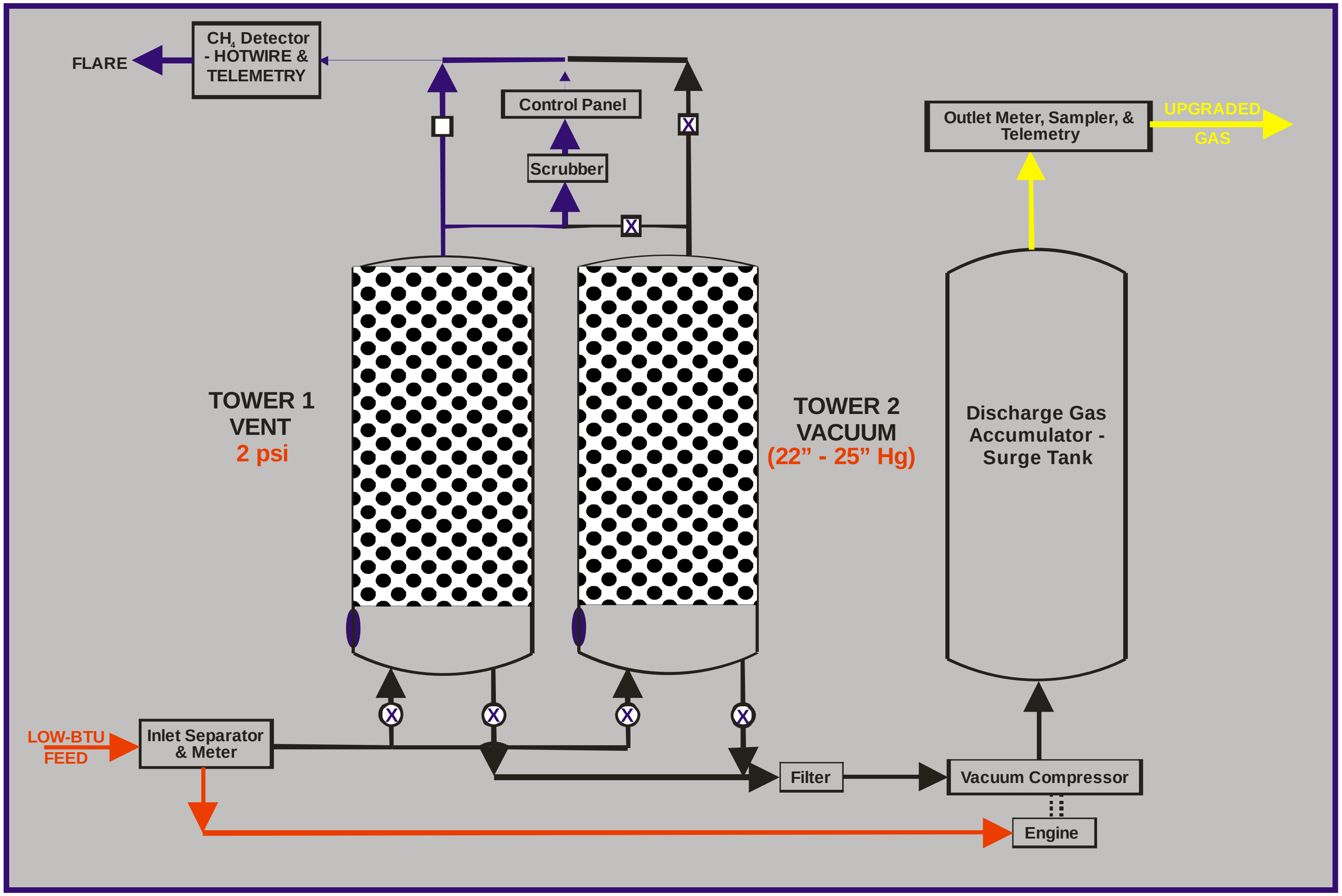


Figure 11: 2nd step of operation - Tower 1 is vented to 2 psi after having been charged to the set pressure thus allowing the removal of N_2-rich unadsorbed gas from the tower. This venting results in some loss of CH_4 but also prevents the unadsorbed N_2 from ending up in the surge tank during the desorption process. The vent period is very short (less than a minute for a plant of this size) and Tower 2 remains under vacuum during this time.

STEP 3 - Tower 1 Desorption, Tower 2 Adsorption

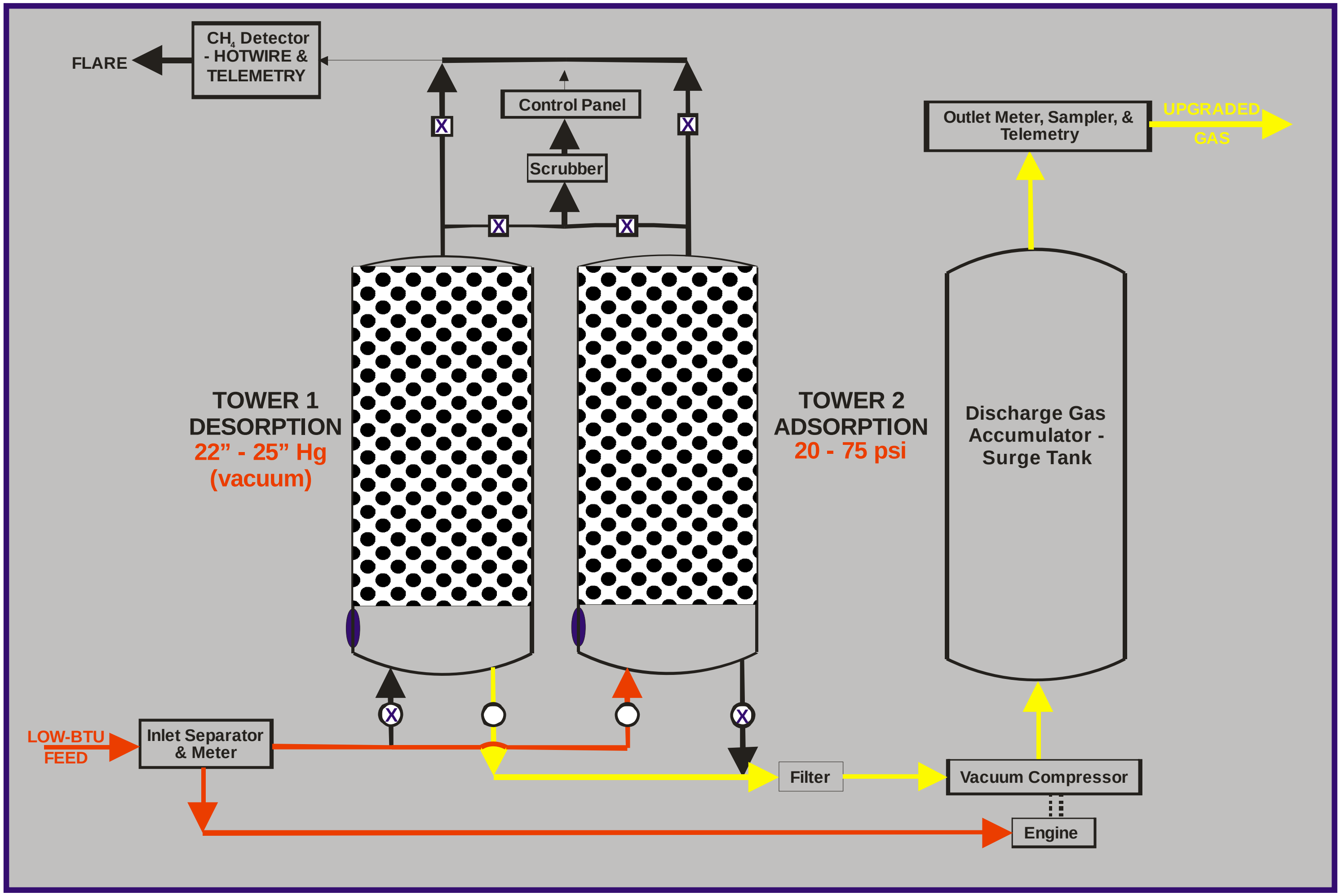
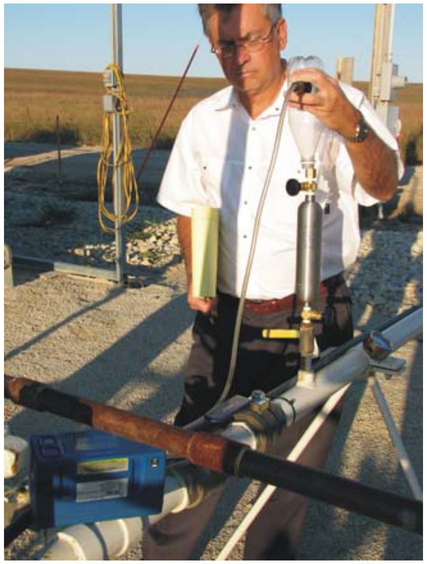


Figure 12: 3rd stage of operation - Tower 1 (after completion of the venting) is put under vacuum to evacuate the CH_4-rich gas adsorbed in the activated bed while Tower 2 is connected to the feed line and gets charged.

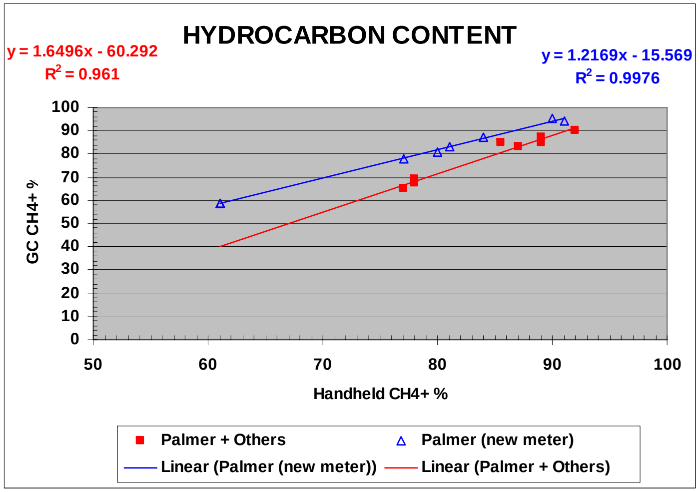
GAS ANALYSIS – PORTABLE GAS CHROMATOGRAPH

A.

B.



C.



D.

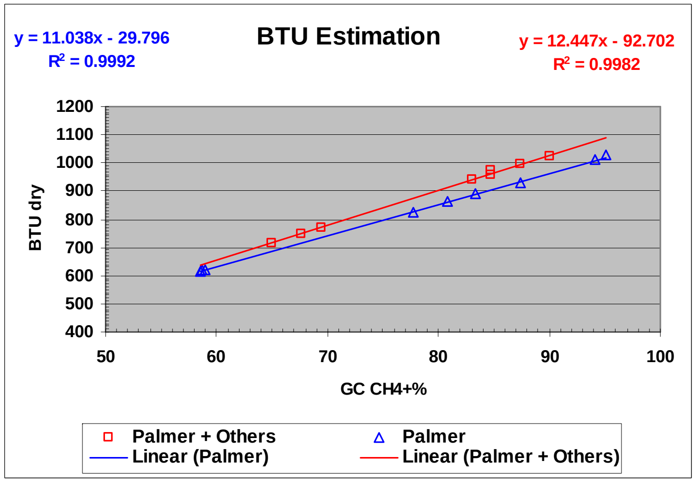


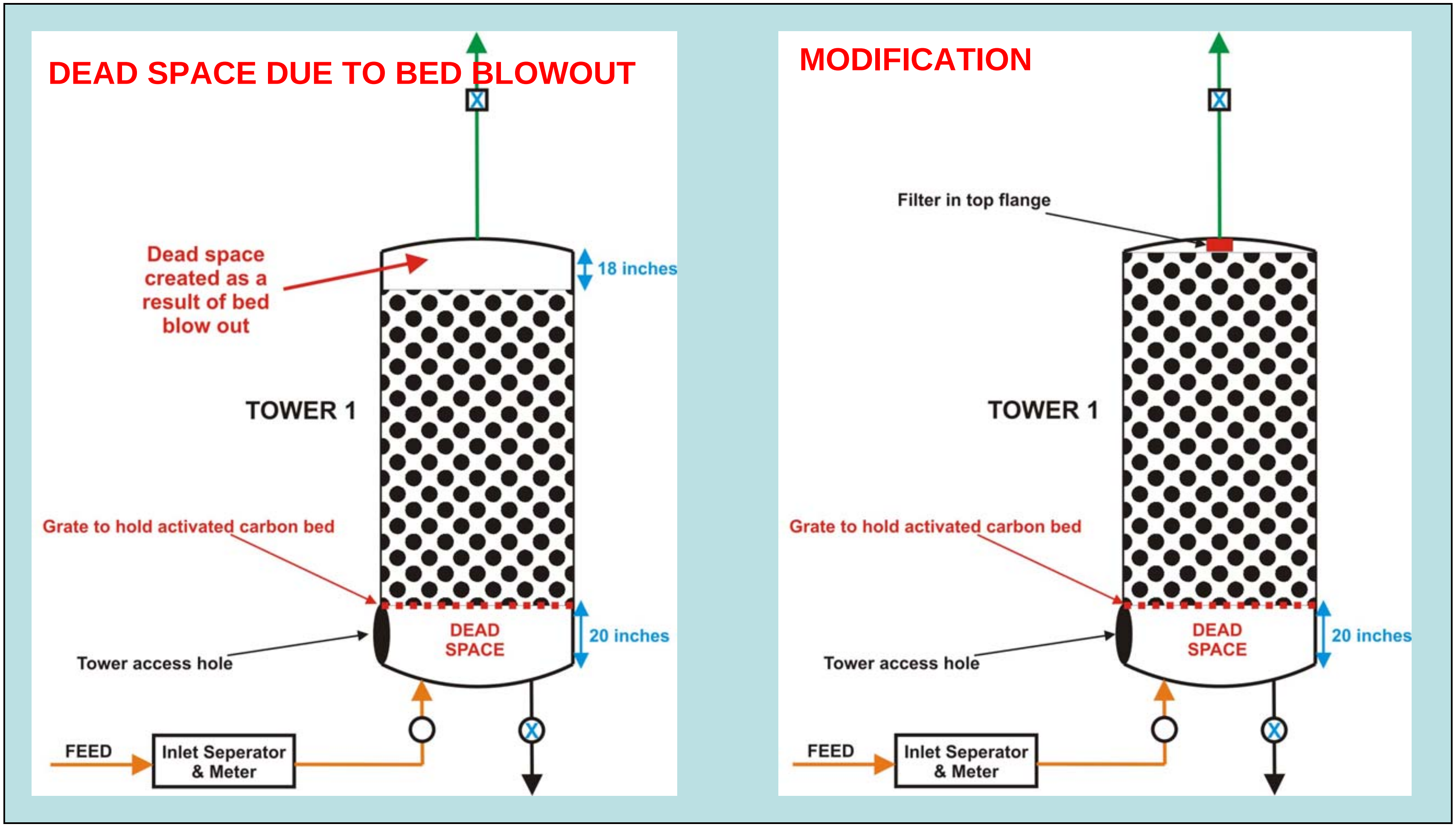
Figure 13: A) Portable gas meter that detects total hydrocarbons (handheld CH_4+ %). B) Field sampling of the feed stream using portable meter. C) Correlation between portable meter (handheld CH_4+ %) and gas chromatographic analyses (GC-CH_4+ %). D) Correlation between gas chromatographic analyses and heat content.

INITIAL TESTING

Test #	From	To	Charge Pr, psi	Vent from	Vent to, psi	Feed CH4+	Avg Sales CH4+	Sales/feed
1	31-May	3-Jun	34	Top	2	0.63	0.84	0.54
2	4-Jun	6-Jun	20	Top	2	0.66	0.85	0.58
3	7-Jun	10-Jun	20	Top & Bottom	2	0.68	0.83	0.51
4	11-Jun	14-Jun	30	Top & Bottom	2	0.67	0.85	0.44

Figure 14: Results from initial tests where the plant was operated under different settings until bed blow out.

BED BLOWOUT



A. **B.**

Figure 15: A) Dead space created at the top of the tower due to bed blowout. Permanent dead space (of about 20 inches) remains at the base of the 8 ft tall tower due an inadvertent design flaw. B) The tower topped with activated carbon and sealed in place by a filter set in the top flange.

Avg Feed @ 715 BTU/cu ft, C_2H_6+/CH_4+=7.9%

Vent from Top

Tower Charge Pr	Vent to psi	Corrected Avg Feed CH4+, %	Corrected Avg Sales CH4+, %	Sales/Feed	Efficiency N2 stripping	Efficiency CH4+ Rec	N2 % in Vent Gas	BTU feed	BTU sales	BTU rec %
34	2	63	84	0.54	76.7	73.2	63.1	687	953	75.7
20	2	67	85	0.60	72.6	75.4	59.2	743	964	77.4

Pipeline Quality

Sales/Feed ratio - indicative of gas (CH_4+ & N_2) lost from the system

- HIGH - tower charge pressure low, dead space volume minimized
- LOW - tower charge pressure high, dead space volume significant

N_2 Stripping Efficiency - % of feed N_2 volume that is rejected (vented)

CH_4+ Recovery Efficiency - % of feed HC captured for sales

BTU Recovery Efficiency - (Sales BTU*Sales mcf)/(Feed BTU*Feed mcf)

- Follows CH_4 recovery efficiency - HCs determine BTU content

Figure 16: Results of upgrading feed with average heat content of 715 BTU/cu ft to pipeline quality under two different plant settings.

BTU CONTENT

	BTU/cu ft
Methane	1010
Ethane	1770
Propane	2516
i-Butane	3253
n-Butane	3264
i-Pentane	4000
n-Pentane	4006
n-Hexane	4722
n-Heptane	5500

Figure 17: Table showing that heavier hydrocarbons significantly contribute to the BTU content of natural gas. Thus, optimum plant settings will change when C_2H_6+/CH_4+ ratio changes.

HOW POOR A FEED CAN THE PLANT UPGRADE?

FEED 630 BTU/cu ft, avg C_2H_6+/CH_4+ = 3.9%

SIMULTANEOUS VENTING - TOP & BOTTOM OF THE TOWER

Pipeline quality

Tower Charge Pr	Vent to psi	Corrected Avg Feed CH4+ %	Corrected Avg Sales CH4+ %	Sales/Feed	Efficiency N2 stripping	Efficiency CH4+ Rec	N2 % in Vent Gas	BTU feed	BTU sales	BTU rec %
15	2 T*	59	78	0.64	66	85	75	619	831	86
30	2 T*	59	82	0.49	79	69	64	622	881	70
70	13 T*	59	86	0.45	85	66	63	621	920	67
66	9.5 T*	59	84	0.49	84	73	68	618	923	74
66	4 T&B**	58	88	0.42	88	64	64	607	940	65
69	3 T&B**	60	89	0.39	90	58	59	633	958	59
72	4 T&B**	60	89	0.40	89	59	59	634	956	60

T - vent from top;*
*T&B** - vent from top and bottom of the tower*

Figure 18: Results of upgrading feed with average heat content of 630 BTU/cu ft to pipeline quality under different plant settings.

ADSORPTION EFFECTIVENESS OF HEAVY HYDROCARBONS

Feed 746 BTU/cu ft, C_2H_6+/CH_4+ = 7.7%

Sample Bottle	KGS 1		
Sample date	Jun 06 2008		
Well	Feed Gas (Replicate)		
Component		Mole %	BTU
Neopentane		0.0000	0.00
CO2		0.1291	0.00
Helium		0.6408	0.00
Hydrogen		0.0000	0.00
Oxygen		0.0000	0.00
Nitrogen		31.4020	0.00
Argon		0.1925	0.00
Methane		62.4206	630.45
Ethane		2.9970	53.04
Propane		1.4761	37.14
i-Butane		0.2061	6.70
n-Butane		0.3663	11.95
i-Pentane		0.0758	3.03
n-Pentane		0.0757	3.03
n-Hexane		0.0143	0.68
n-Heptane		0.0036	0.20
Totals		99.9999	746.2200
Specific Gravity from Composition			0.7198
BTUs @	14.696	Saturated	733.21
BTUs @	14.696	Dry	746.22
Compressibility			0.99846
C2H4+		5.2149	
CH4+		67.6355	
C2H4+/CH4+		7.7	%

A.

Sample Bottle	KGS 5		
Sample date	Jun 06 2008		
Well	Sales Gas		
Component		Mole %	BTU
Neopentane		0.0000	0.00
CO2		0.1820	0.00
Helium		0.1225	0.00
Hydrogen		0.0000	0.00
Oxygen		0.0000	0.00
Nitrogen		14.5400	0.00
Argon		0.3692	0.00
Methane		75.3267	760.80
Ethane		5.2381	92.70
Propane		2.7426	69.01
i-Butane		0.3890	12.65
n-Butane		0.7116	23.22
i-Pentane		0.1574	6.30
n-Pentane		0.1640	6.58
n-Hexane		0.0363	1.73
n-Heptane		0.0205	1.13
Totals		99.9999	974.1200
Specific Gravity from Composition			0.6872
BTUs @	14.696	Saturated	957.11
BTUs @	14.696	Dry	974.12
Compressibility			0.99777
C2H4+		9.46	
CH4+		84.79	
C2H4+/CH4+		11.2	%

B.

	Sales/Feed	0.54		
100	moles of feed has	5.21	moles of C2H4+	
100	moles of feed result in	54	moles of sales	
54	moles of sales has	5.11	moles of C2H4+	
	C2H4+ recovery %	98.0		
100	moles of feed has	67.64	moles of CH4+	
100	moles of feed result in	54	moles of sales	
54	moles of sales has	45.78	moles of CH4+	
	CH4+ recovery %	67.7		

Figure 19: A) GC analysis of feed gas (at 746 BTU/cu ft) and B) GS analysis of sales gas when compared with that of feed shows that most of the heavy hydrocarbons (HCs) are adsorbed in the activated carbon.

ADSORPTION EFFECTIVENESS OF HEAVY HYDROCARBONS

Feed 601 BTU/cu ft, C_2H_6+/CH_4+ = 3.7%

Sample Bottle	KGS 5		
Sample date	Aug 20 2008		
Well	Feed Gas - 2		
Component		Mole %	BTU
Neopentane		0.0008	0.00
CO2		0.0912	0.00
Helium		0.7318	0.00
Hydrogen		0.0000	0.00
Oxygen		0.0000	0.00
Nitrogen		41.8242	0.00
Argon		0.0006	0.00
Methane		55.2329	557.85
Ethane		1.4788	26.17
Propane		0.4625	11.64
i-Butane		0.0721	2.34
n-Butane		0.0758	2.47
i-Pentane		0.0157	0.63
n-Pentane		0.0114	0.46
n-Hexane		0.0021	0.10
n-Heptane		0.0000	0.00
Totals		99.9999	601.6600
Specific Gravity from Composition			0.7372
BTUs @	14.696	Saturated	591.17
BTUs @	14.696	Dry	601.66
Compressibility			0.99885
C2H4+		2.12	
CH4+		57.35	
C2H4+/CH4+		3.7	%

A.

Sample Bottle	KGS 1		
Sample date	Aug 20 2008		
Well	Sales Gas -1		
Component		Mole %	BTU
Neopentane		0.0025	0.00
CO2		0.1811	0.00
Helium		0.0816	0.00
Hydrogen		0.0000	0.00
Oxygen		0.0000	0.00
Nitrogen		11.3093	0.00
Argon		0.0454	0.00
Methane		82.9035	837.32
Ethane		3.7077	65.61
Propane		1.2601	31.71
i-Butane		0.1962	6.38
n-Butane		0.2189	7.14
i-Pentane		0.0473	1.89
n-Pentane		0.0367	1.47
n-Hexane		0.0076	0.36
n-Heptane		0.0022	0.12
Totals		100.0001	952.0000
Specific Gravity from Composition			0.6381
BTUs @	14.696	Saturated	935.41
BTUs @	14.696	Dry	952.00
Compressibility			0.99799
C2H4+, %		5.48	
CH4+, %		88.38	
C2H4+/CH4+		6.2	%

B.

	Sales/Feed	0.38		
100	moles of feed has	2.12	moles of C2H4+	
100	moles of feed result in	38	moles of sales	
38	moles of sales has	2.08	moles of C2H4+	
	C2H4+ recovery %	98.2		
100	moles of feed has	57.35	moles of CH4+	
100	moles of feed result in	38	moles of sales	
38	moles of sales has	33.58	moles of CH4+	
	CH4+ recovery %	58.6		

Figure 20: A) GC analysis of feed gas (at 623 BTU/cu ft) and B) GC analysis of sales gas when compared to that of feed shows that most of the heavy hydrocarbons (HCs) are adsorbed in the activated carbon. This calls in question the feasibility of capturing vent gas for secondary upgradation given that it lacks heavy HCs that significantly add to the BTU of the upgraded gas.

PERFORMANCE COMPARISON WITH COMMERCIAL PLANT

This micro-plant is ideal for upgrading low-volume, low-pressure, low-BTU feed from isolated wells (fields) that are far from any commercial upgradation plants and electric grid.

Daily Feed, mcf	Seller's %
1,300 to 1,750	72
1,100 to 1,299	70
900 to 1,099	68
650 to 899	64
550 to 649	59
450 to 549	55
< 450	51

A.

ADDITIONAL CONSTRAINTS

Feed limitations: Often can't have too high N_2 (< 28% N_2) concentration in the gas sold to the plant

Additional costs related to transportation from low-BTU source to commercial plant estimated at 13% of volume of gas transported

B.

	Max Feed N2 %	Feed BTU/cu ft	Sales Vol mcf/d	Sales/Feed Ratio	Price received mcf/d	Pipeline costs mcf/d	Revenue mcf/d
Commercial Plant	28		100		51	13	38
Micro-Plant	40	615	100	0.39	39	0	39
Micro-Plant	33	715	100	0.57	57	0	57

C.

Figure 21: A) Example of seller's (volume) percentage offered by a commercial low-BTU gas upgradation plant in Kansas. B) Associated constraints related to selling low-BTU gas to the commercial upgradation plant. C) Performance comparison of micro-NRU with commercial upgradation plant.

PLANT ECONOMICS

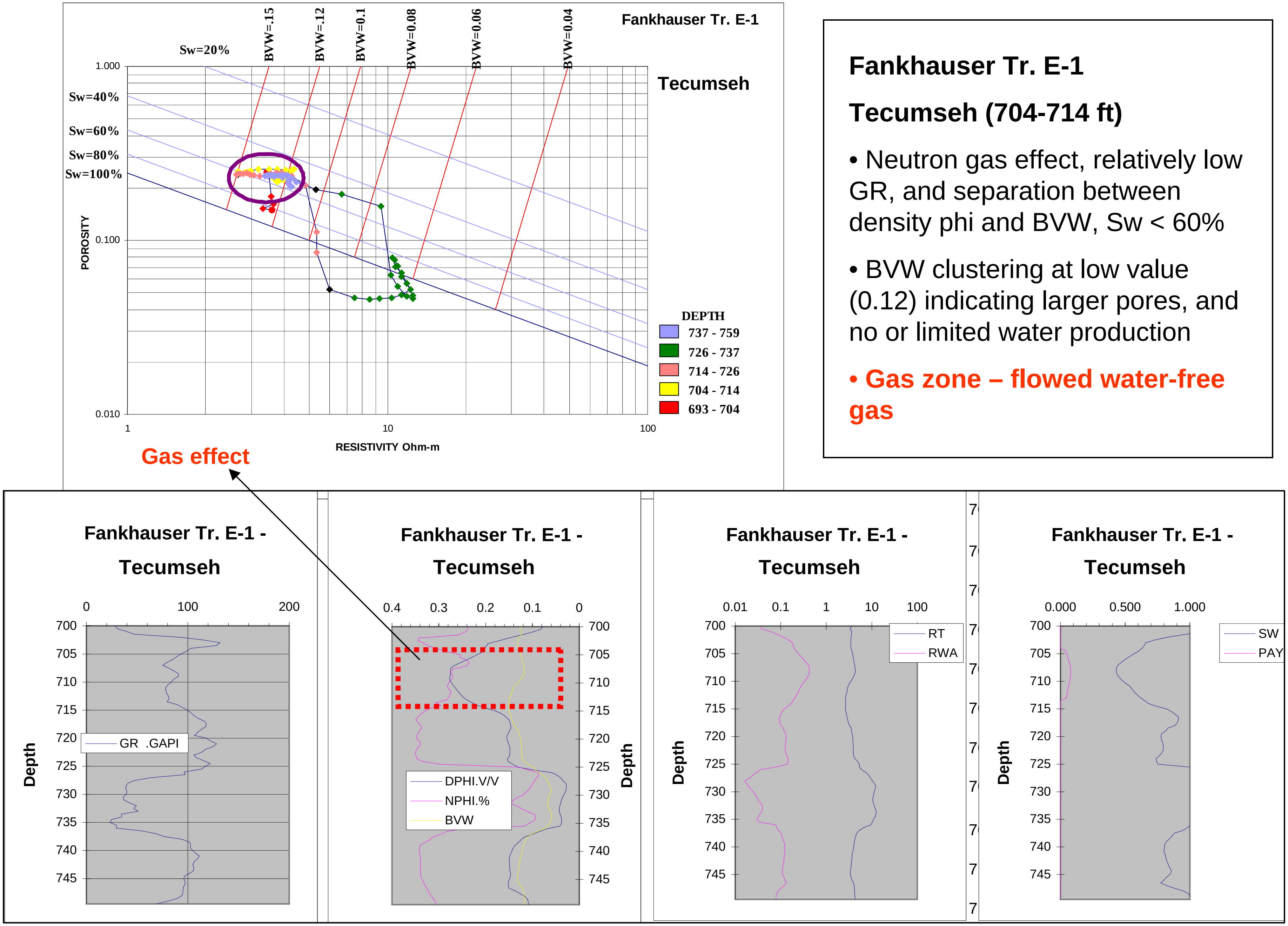
Plant Construction Costs = $120,000

Feed mcf/d	Feed BTU/cu ft	Sales/Feed Ratio	Sales mcf/d	Gas $/mcf	Payout, months
150	615	0.39	58.5	$4.00	17
150	715	0.57	85.5	$4.00	12

Figure 22: Payout calculation for micro-NRU using two different low-BTU feed gas.

CURRENT STATUS

Figure 23: Photograph of the new and larger plant that has been built by American Energies Corporation for installation in one of their low-BTU fields where the wells are currently shut for lack of availability of rich gas for blending.



Fankhauser Tr. E-1

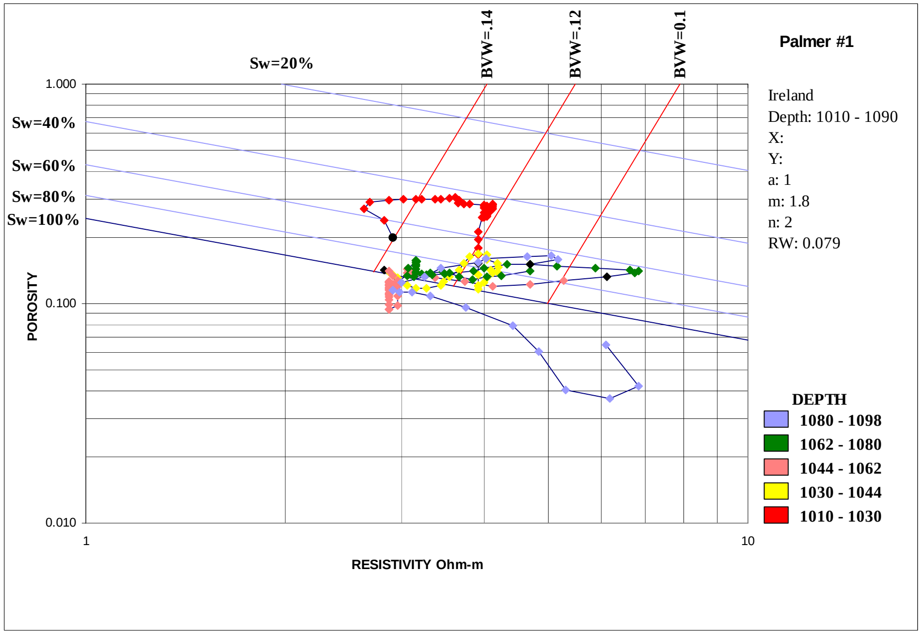
Tecumseh (704-714 ft)

- Neutron gas effect, relatively low GR, and separation between density phi and BVW, Sw < 60%
- BVW clustering at low value (0.12) indicating larger pores, and no or limited water production
- **Gas zone – flowed water-free gas**

Figure 24: Log analysis of Tecumseh Sandstone in Frankhauser Trust E1 well.

Well	API	Operator	Sec	Twn - S	Rng - E	pfeffer	Ireland	douglas	Techumseh	Calhoun	Severy	White Cloud
Palmer 1	15-017-20845	Range Oil Co	9	20	7	yes	gas	wet	gas	gas	gas in transition	wet
Donahue A1	15-017-20846	AEC	18	19	7				wet	wet	wet	
Stevens A1	15-017-20861	AEC	18	19	7		wet		wet	wet	wet	
Giger D1	15-017-20844	AEC	20	19	7	yes			trans	trans	wet	
Kohr A1	15-017-20842	AEC	21	19	7	yes	wet		wet	wet	trans	
Ward Ranch A1	15-017-20816	AEC	21	19	7	yes	wet		wet-coal	wet	wet-coal	
Mushrush B1	15-017-20810	AEC	23	19	7	no Rt						
Mushrush 26-1	15-017-20497-0001	Tejas Energy	26	19	7	yes		wet	wet	wet	wet	
Mushrush 26-2	15-017-20790	AEC	26	19	7	yes	wet		wet	trans-fine	trans & coal	
Noble 1	15-017-20868	AEC	27	19	7	yes	wet		wet	trans-fine	wet	
McCallum A1	15-017-20822	AEC	27	19	7	no Rt						
Thurston 1-27	15-017-20092-0001	AEC	27	19	7		wet		gas?	wet	gas?	
Giger A1	15-017-20823	AEC	28	19	7	yes	wet		wet	Gas+wtr	wet-coal	
Pretzer A1	15-017-20817	AEC	28	19	7	yes	wet		shaly	wet	wet	
Marshall A1	15-017-20811	AEC	28	19	7	yes	wet		shaly	wet	wet	
Davis/Giger B1 Gas Ur	15-017-20860	AEC	29	19	7	yes	wet	shaly	gas + transition	wet	wet + 2 ft coal	
Giger B1	15-017-20824	AEC	29	19	7	yes	wet	shaly	gas but no show	wet	trans + 2 ft coal	
Kissel 1-29	15-017-20081-0001	AEC	29	19	7	yes	gas	gas?	gas?	shaly	gas + 2 ft coal	
Fankhauser Trust E1	15-017-20843	AEC	32	19	7	yes	wet	wet	gas	shaly	shaly	
Fankhauser Trust D1	15-017-20841	AEC	33	19	7	yes	wet	shaly	gas?	wet?	wet-coal	
Wood A1	15-017-20828	AEC	33	19	7	yes	wet	show	gas?	wet	wet-coal	
Fankhauser 1-33	15-017-20091-0001	AEC	33	19	7	no Rt						
Starkey A1	15-017-20800	AEC	34	19	7	yes	wet	gas?	wet	trans-fine	gas+ 3ft+ coal	
McCallum-Simmons Gl	15-017-20858	AEC	34	19	7	yes	wet	trans	wet	wet	wet+coal	
Stauffer 1A-34	15-017-20762	Yellow Rose Energy	34	19	7	**na**						
Stauffer 3-34	15-017-20372	D&F Petr	34	19	7	na						
Stauffer 2-35	15-017-20090	Viking Intl Pet	35	19	7	yes	wet	gas -looks trans	wet	wet	wet	
Stauffer 8-35	15-017-20789	AEC	35	19	7	yes	wet	trans-shaly	tran-wet	trans	gas?	
Stauffer 5-35	15-017-20373-0001	Viking Intl Pet	35	19	7	not logged						
Spinden A1	15-017-20801	AEC	36	19	7	yes	trans	trans	wet	wet	trans	
Stauffer 3	15-017-20126	Jackman & Jackman	35	19	7							
Steerman A1	15-017-20830	AEC	1	20	7							
Reehling Trust B1	15-017-20809	AEC	1	20	7	yes	wet	shaly	wet	wet	wet	wet
Reehling Trust B3	15-017-20826	AEC	1	20	7	yes	wet	shaly	wet	wet	wet	wet

Figure 25: Summary of log analyses for wells in and around the Elmdale field, Chase County, Kansas.



Palmer #1

Ireland (1014-1030 ft)

- **Strong gas indications** with high porosity, low BVW including clustering around 0.12, and lower GR
- Neutron gas effect on cleaner sandstone
- Sw < 60%
- Produces water-free low-BTU gas

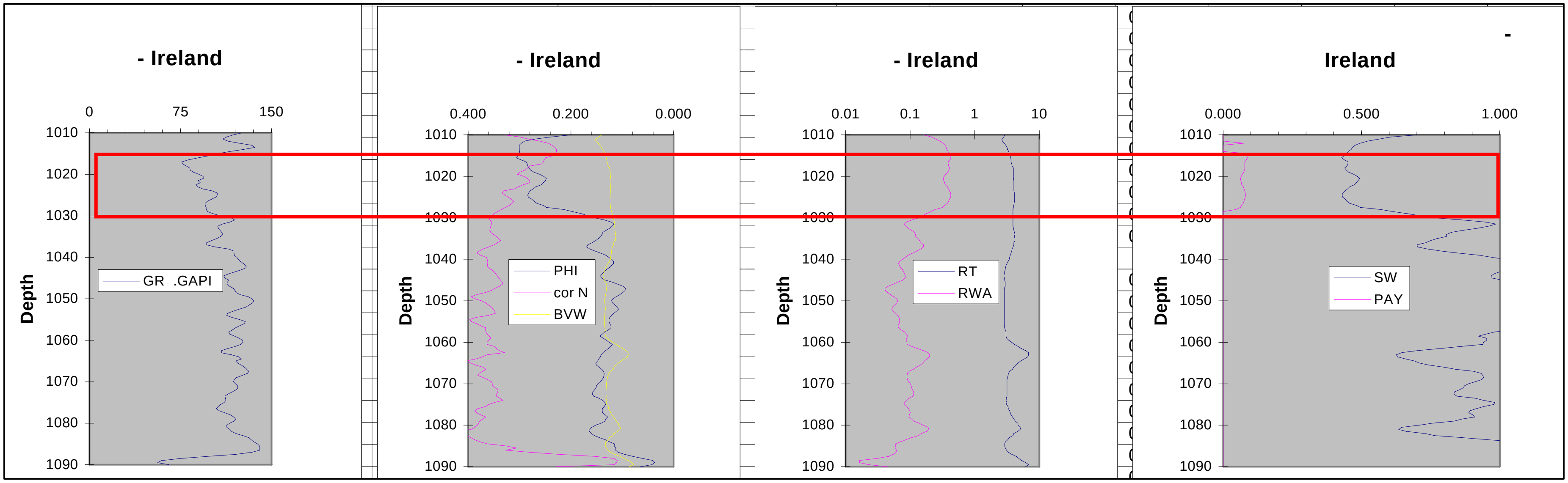
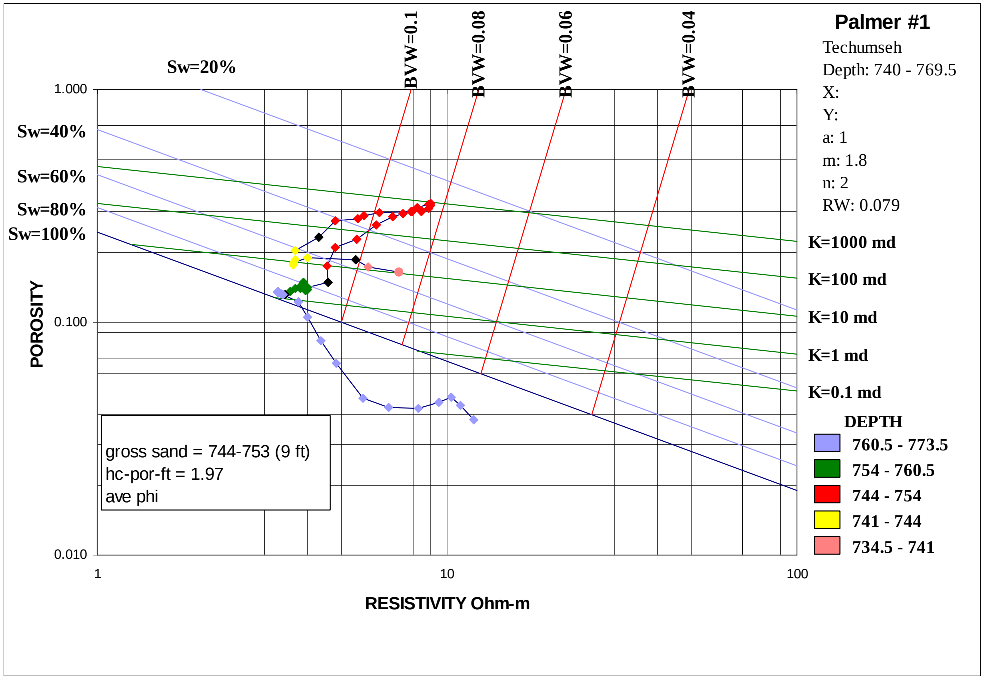


Figure 26: Log analysis of Ireland Sandstone in Palmer #1 well.



Palmer #1

Tecumseh (744-754 ft)

- **Good indications of gas pay** – relatively low GR, BVW cluster ~0.08, high porosity, gas effect on neutron log, Sw < 50%
- Tecumseh identified as pay using cut-offs defined at Frankhauser Trust E1 well

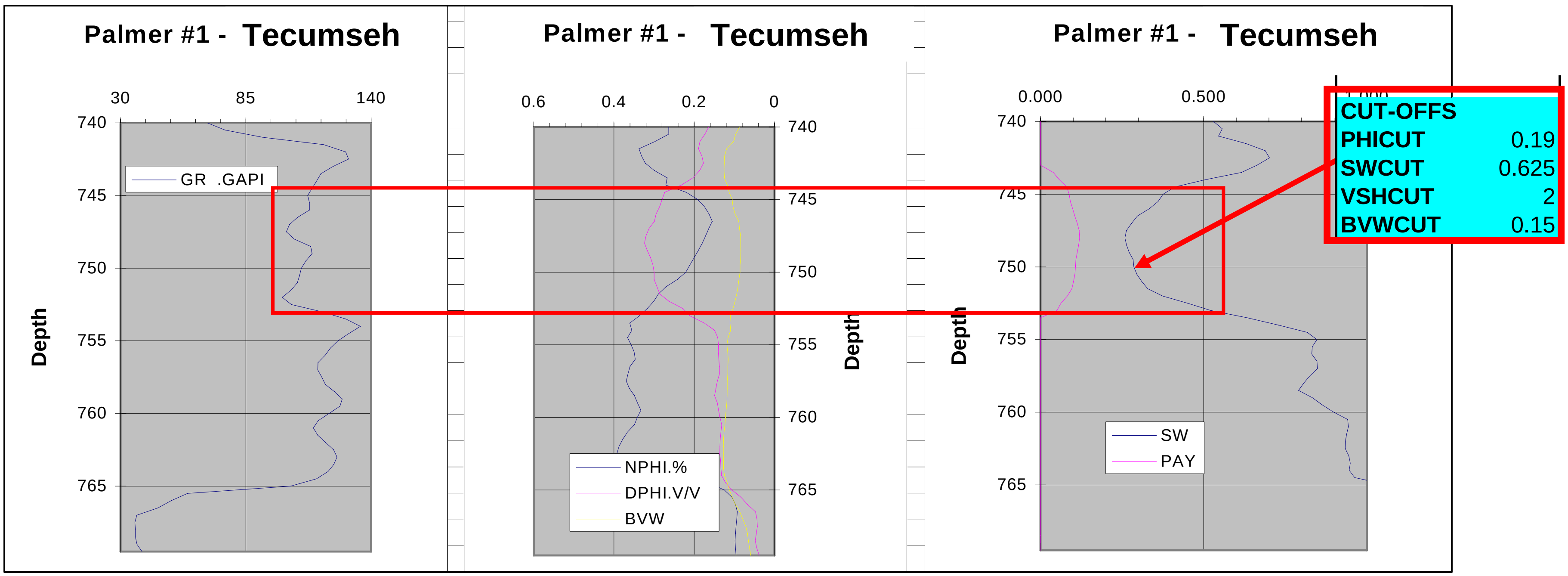
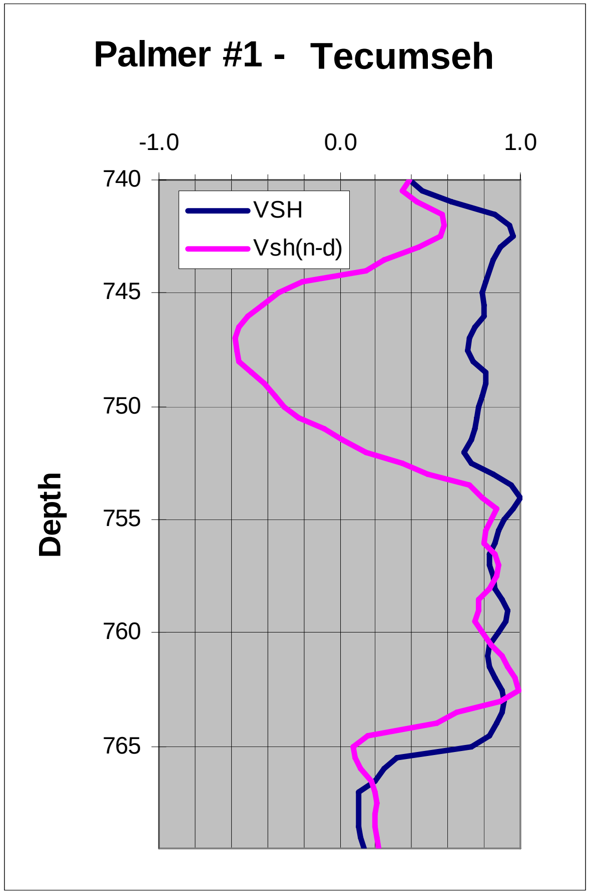


Figure 27: Log analysis of Tecumseh Sandstone in Palmer 1 well.



Palmer #1 – Tecumseh Sandstone

- **Gamma ray** does not recognize the fine-grained, well sorted, porous sand, probably due to K-rich mica content
- **Vsh** from **Neutron-density** overcorrect due to probable gas effect on neutron

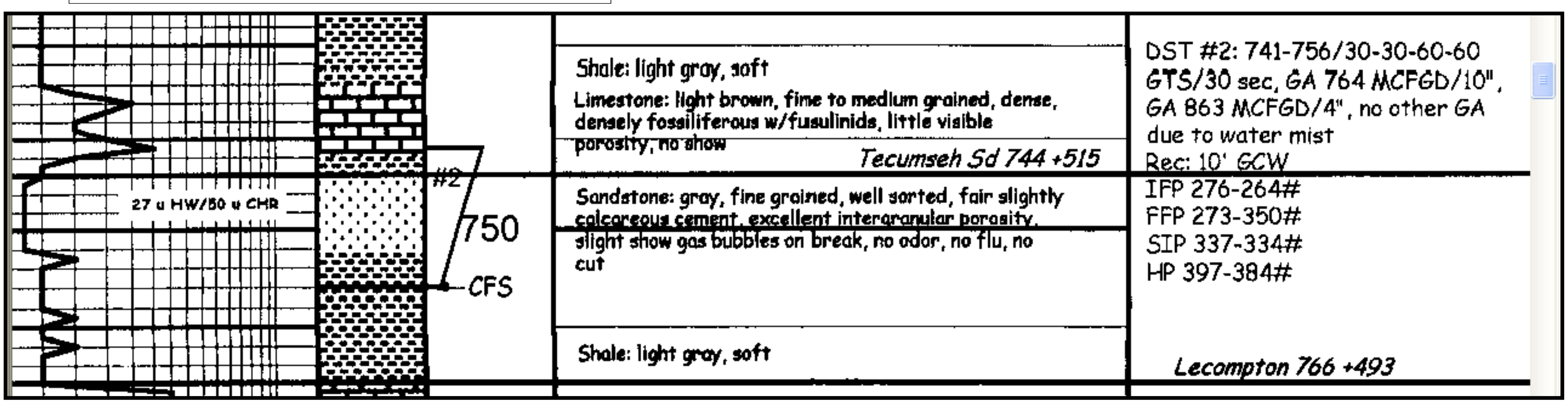
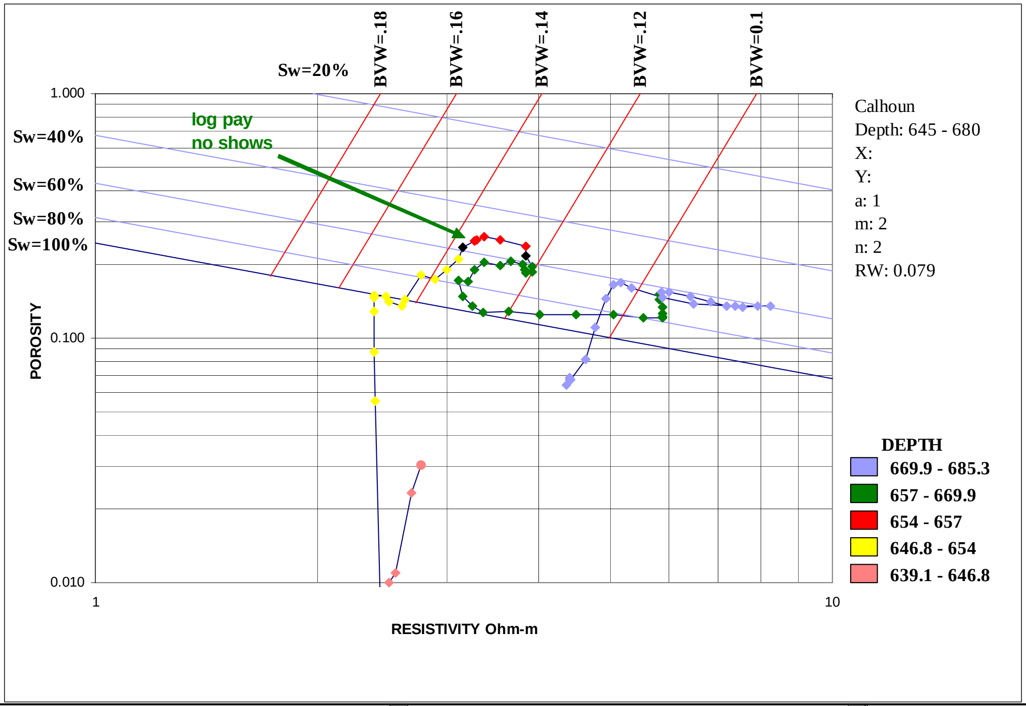


Figure 28: Comparison of Vshale calculated from gamma with that calculated from neutron-density porosities in Tecumseh Sandstone in Palmer 1.



Palmer #1

Calhoun (654-657 ft)

- **Indications of gas pay** with low BVW (~0.13), possible gas effect on neutron log, Sw < 60%, separation between density porosity and BVW
- However, no shows observed during drilling through zone

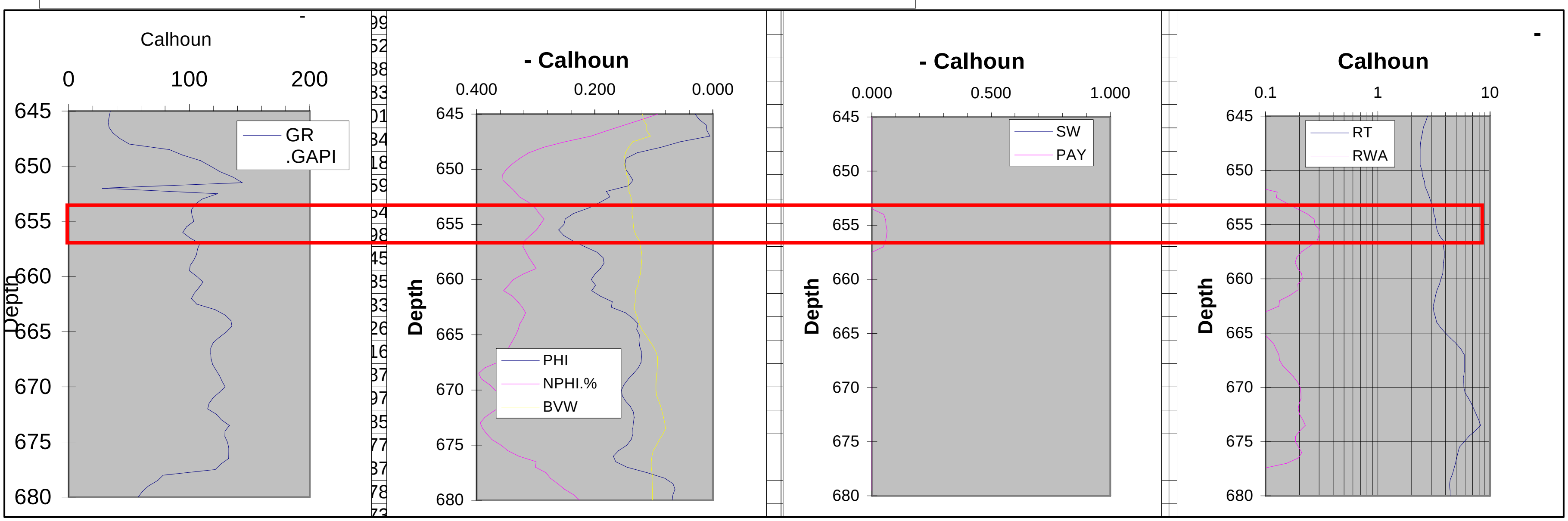
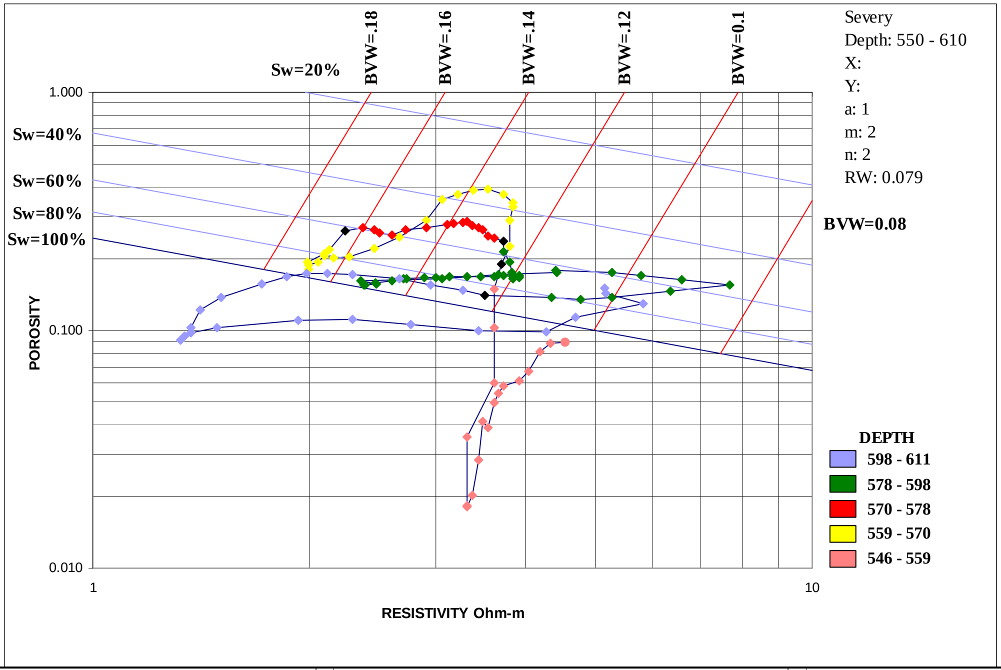


Figure 29: Log analysis of Calhoun Sandstone in Palmer 1 well.



Palmer 1
Severy (570-578 ft)

- Gas effect on neutron, separation between density porosity and BVW, GR ~100 API, Sw < 60%
- Parts of the sand has BVW < 0.14
- **Possibly gas bearing**

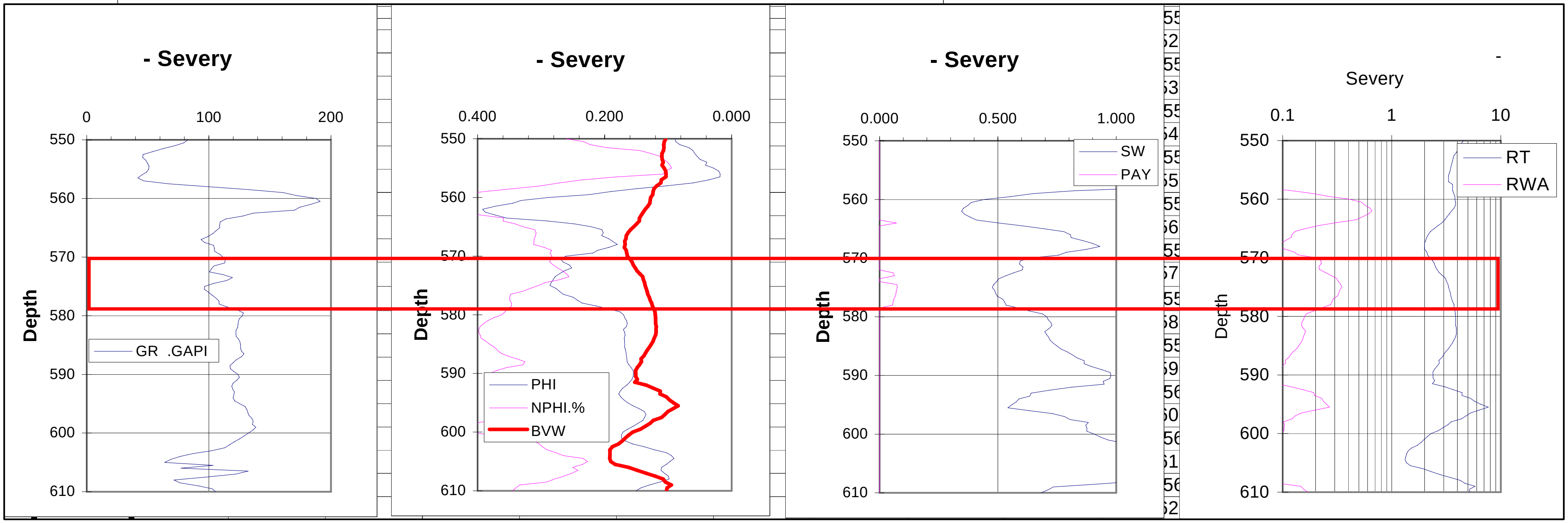
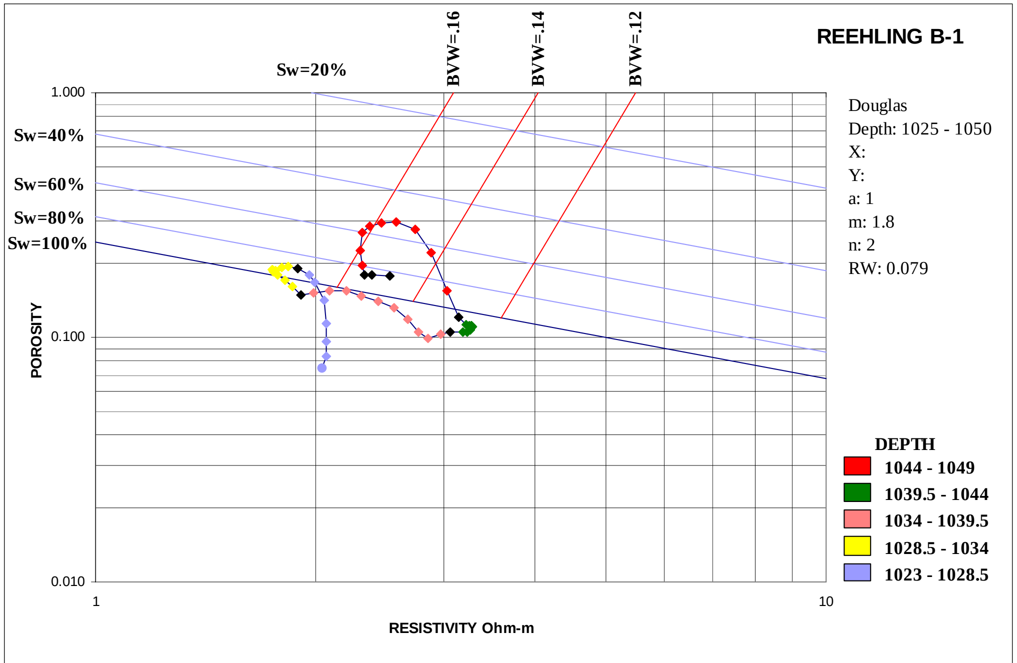


Figure 30: Log analysis of Severy Sandstone in Palmer 1 well.



Reehling B-1

Douglas (1044-1049 ft)

- High porosity and separation between density porosity and BVW
- However, GR is > 100 API
- Zone appears to be shaly. Need to test to validate GR cut-off.
- **Poor prospect for gas - shaly**

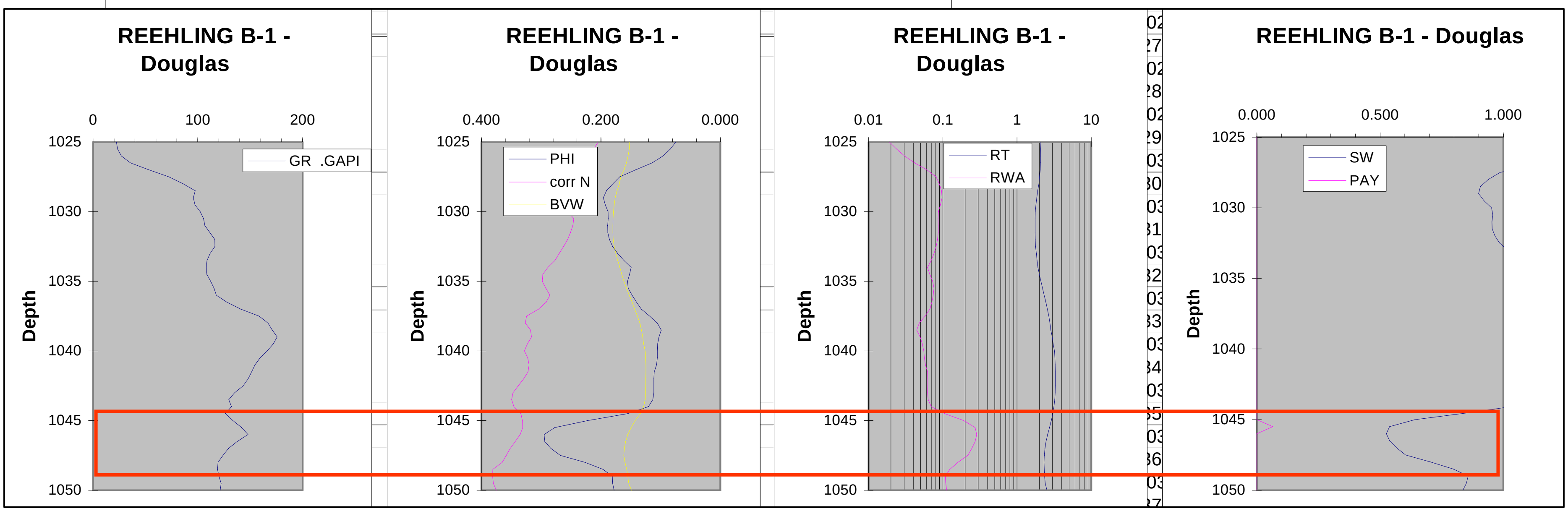
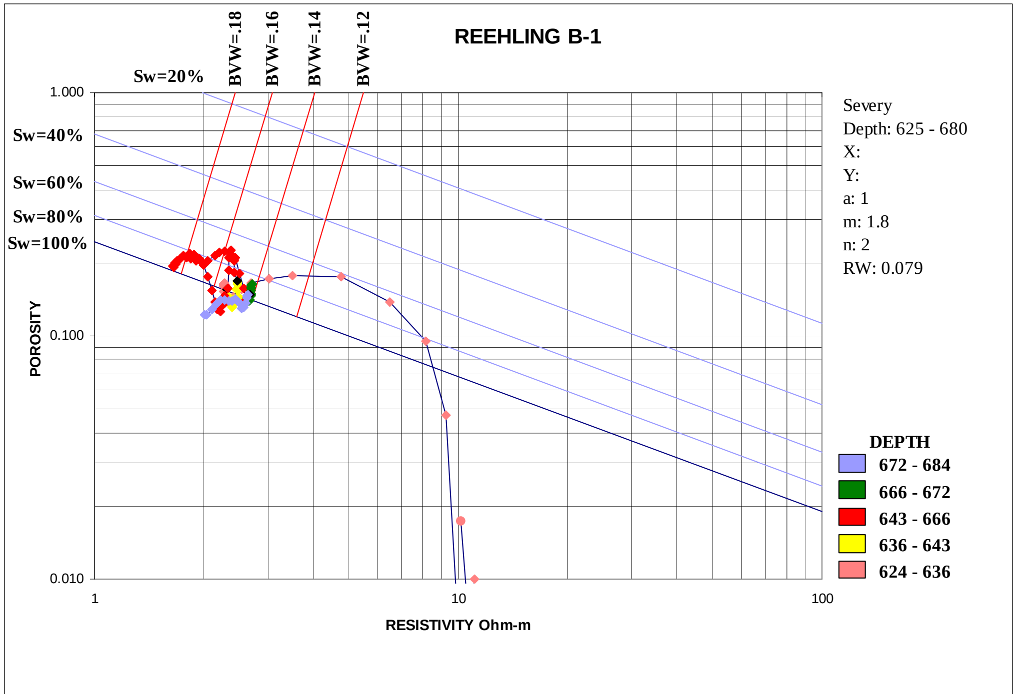


Figure 31: Log analysis of Douglas Sandstone in Reehling B1 well.



Reehling B-1

Severy (643-666 ft)

- High GR
- BVW and density porosity overlap
- Sw > 80%
- **Expected to be wet**

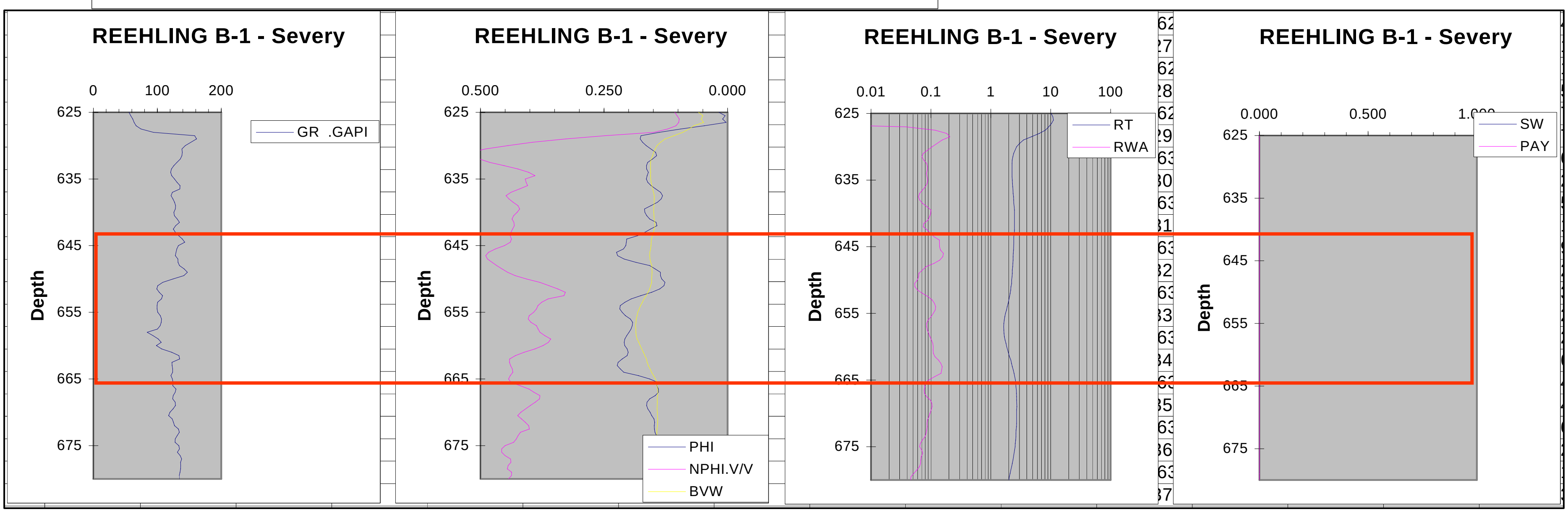
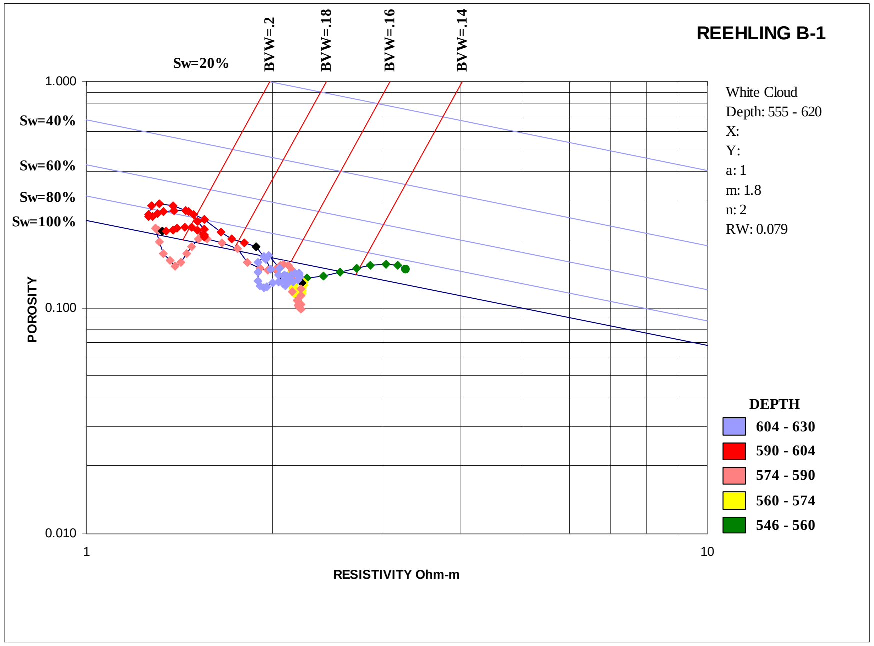


Figure 32: Log analysis of Severy Sandstone in Reehling B1 well.



Reehling B-1

White Cloud (590-604 ft)

- High GR (~100 API), little seperation between density porosity and BVW
- Sw > 80%
- **Expected to be wet**

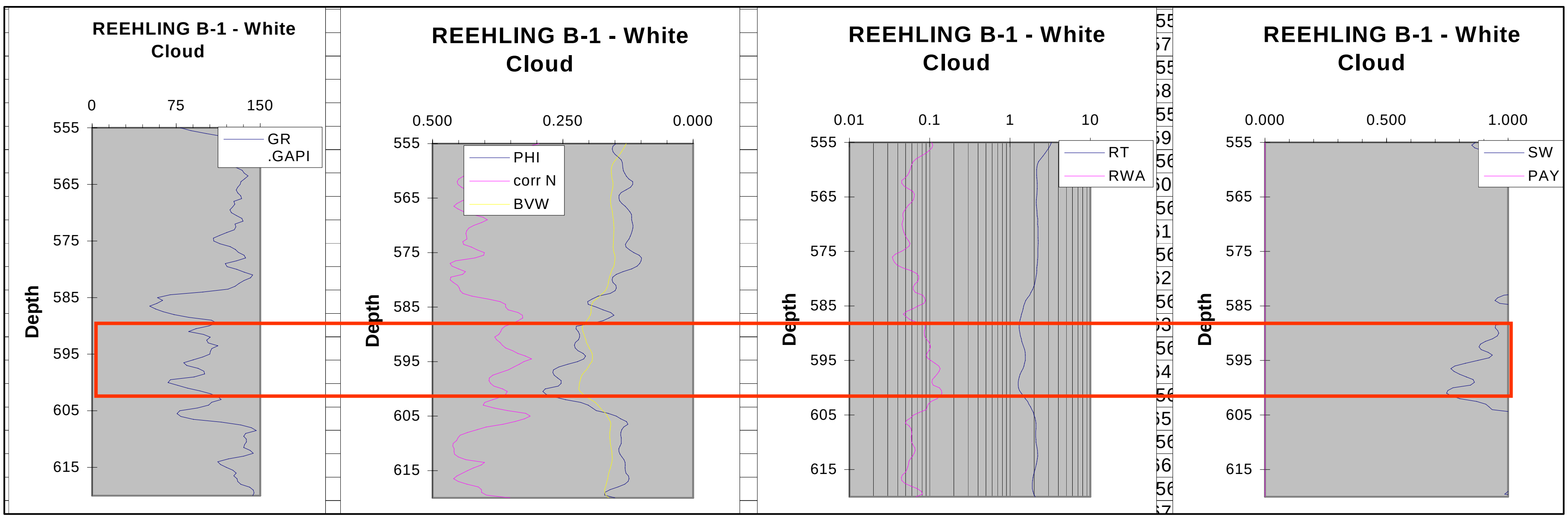
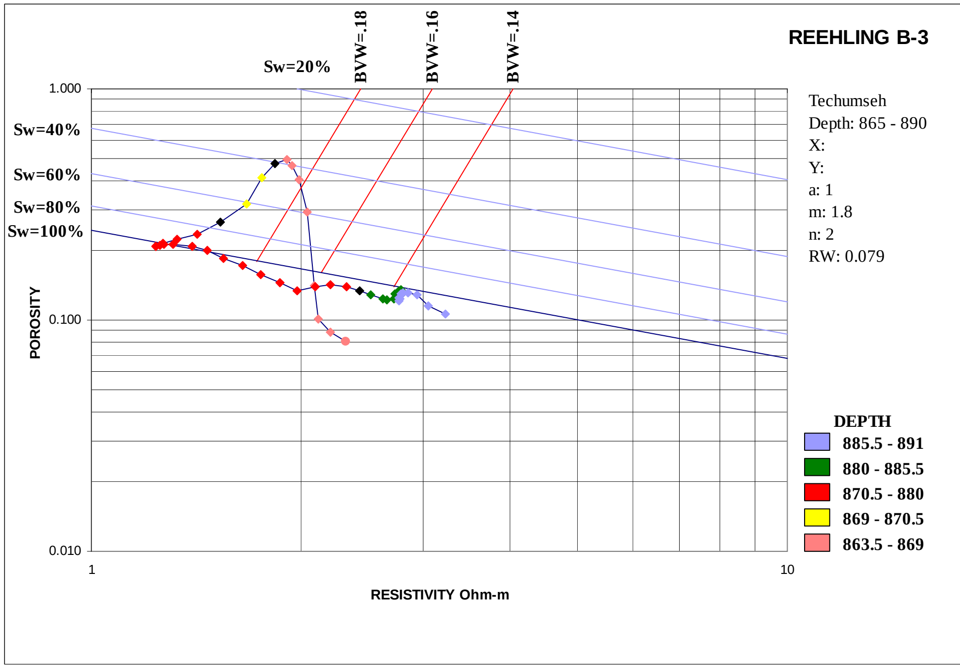


Figure 33: Log analysis of White Cloud Sandstone in Reehling B1 well.



Reehling B-3
Tecumseh (872-880 ft)

- Washout at shale accounting for high porosity on top of sand
- High GR (~100 API), and overlap of BVW and density porosity
- **Expected to be wet**

Density log reading high (~50%) at washout across shale see caliper log

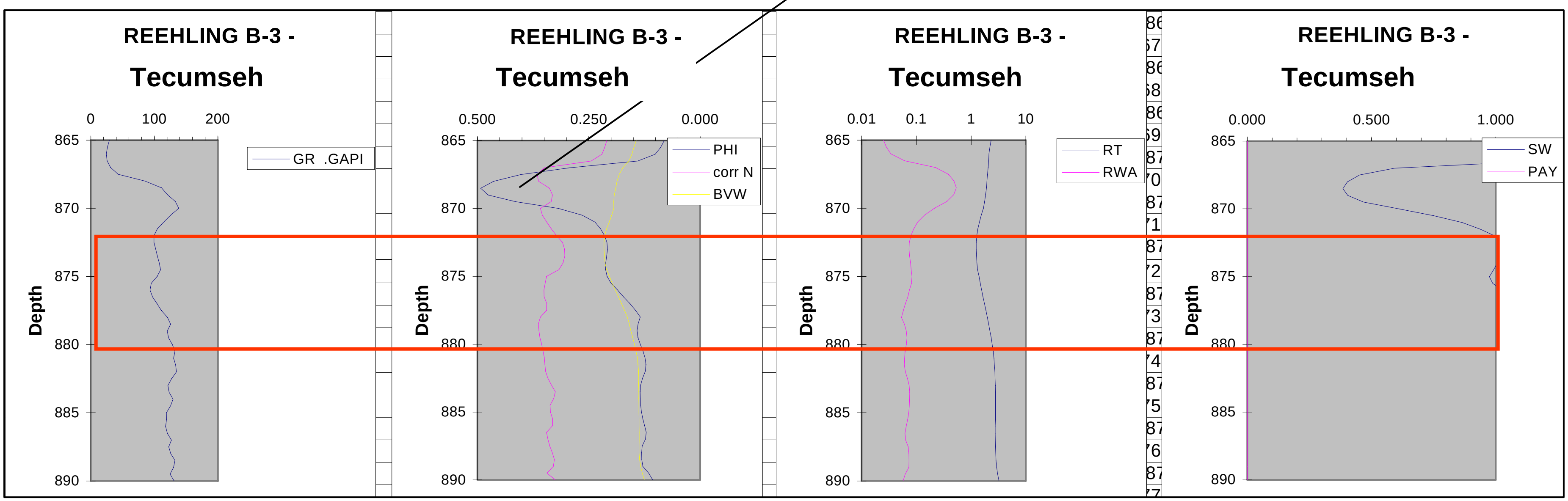
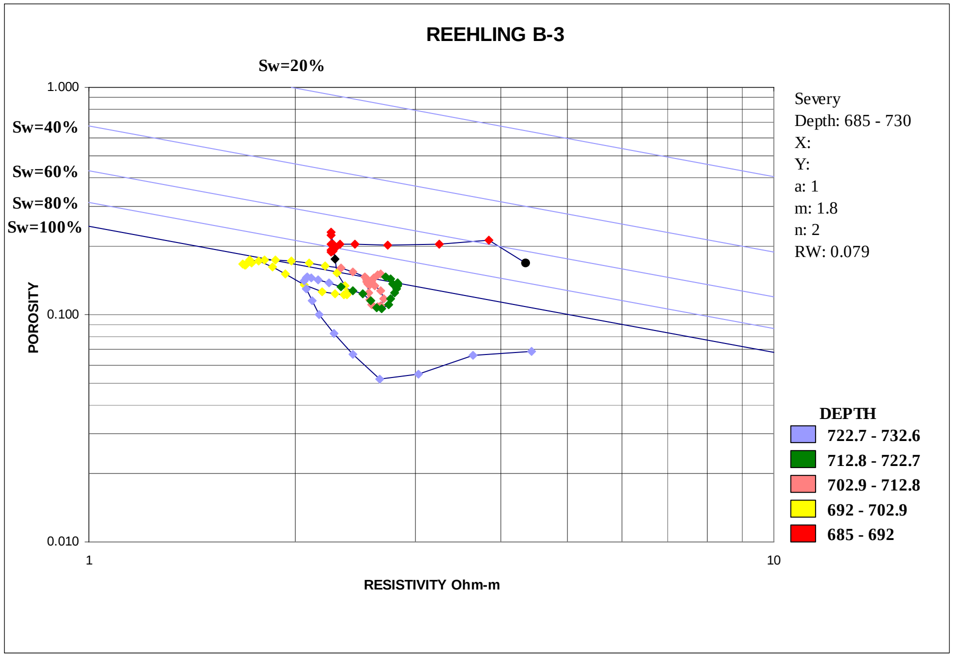


Figure 34: Log analysis of Tecumseh Sandstone in Reehling B3 well.



Reehling B-3
Severy (692-702 ft)

- Overlying coal (690-692 ft) possibly - high porosity combines with slightly lower GR
- Sand - overlap between BVW and density porosity
- **Expected to be wet**

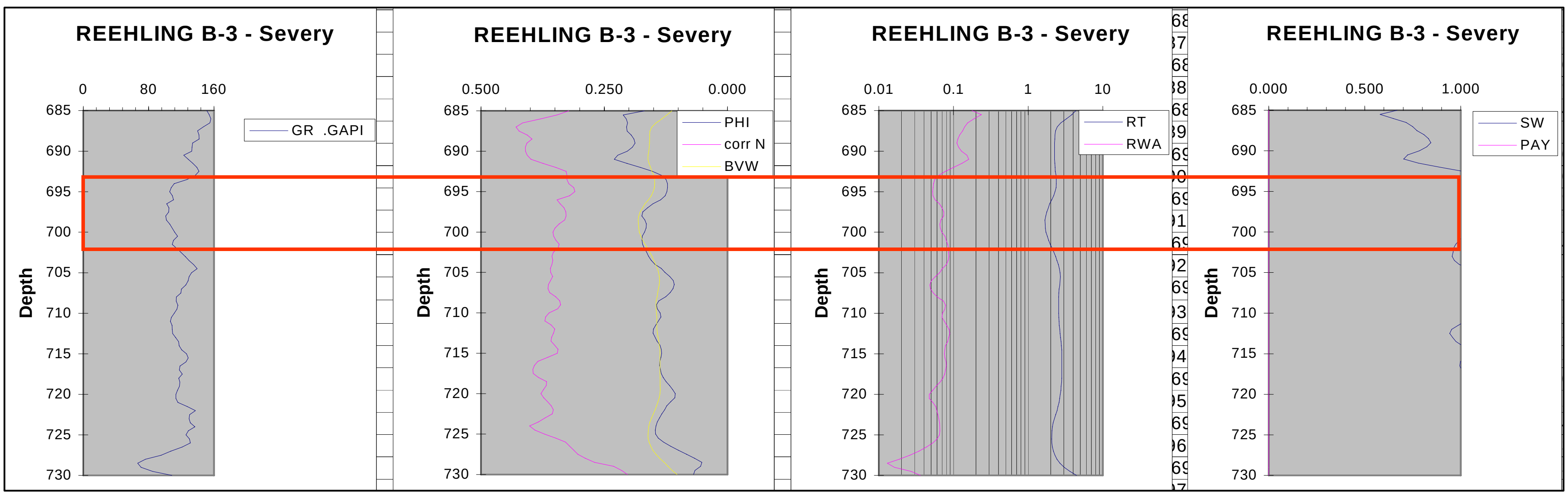


Figure 35: Log analysis of Severy Sandstone in Reehling B3 well.

Reehling B-3

- Coal overlying Severy sand

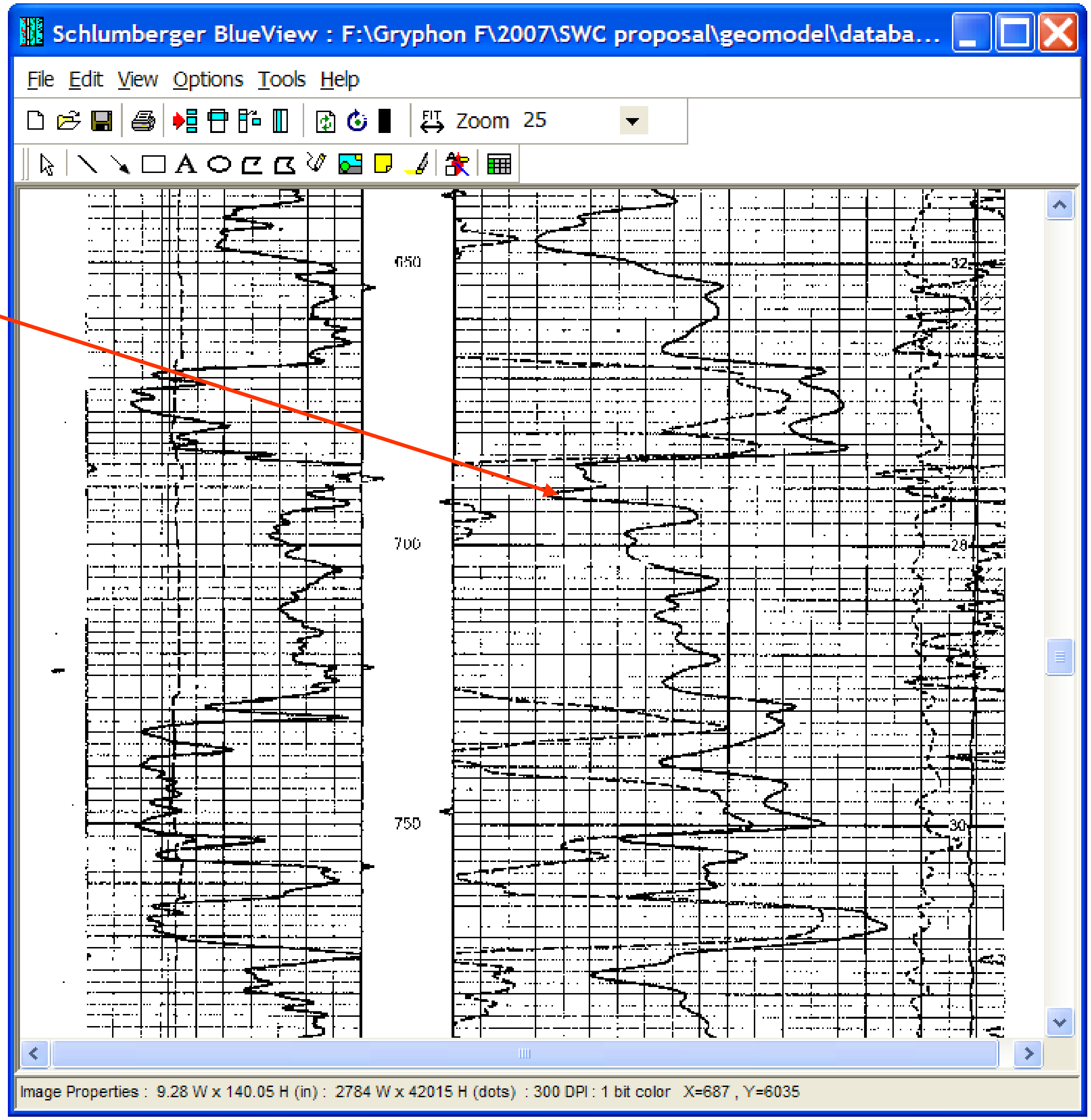
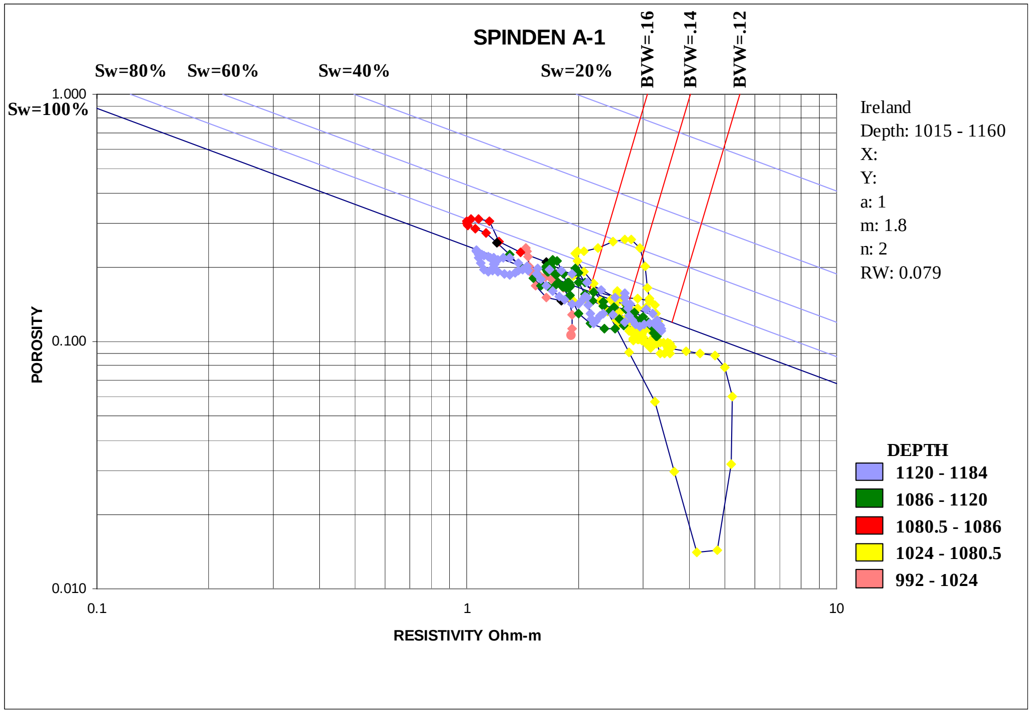


Figure 36: Log showing location of coal bed atop the Severy Sandstone in Reehling B3 well.



Spinden A-1
Ireland (1080-1086 ft)

- Separation between density porosity and BVW
- GR < 100, Sw~80%, BVW high
- **Poor prospect – some gas in transition**

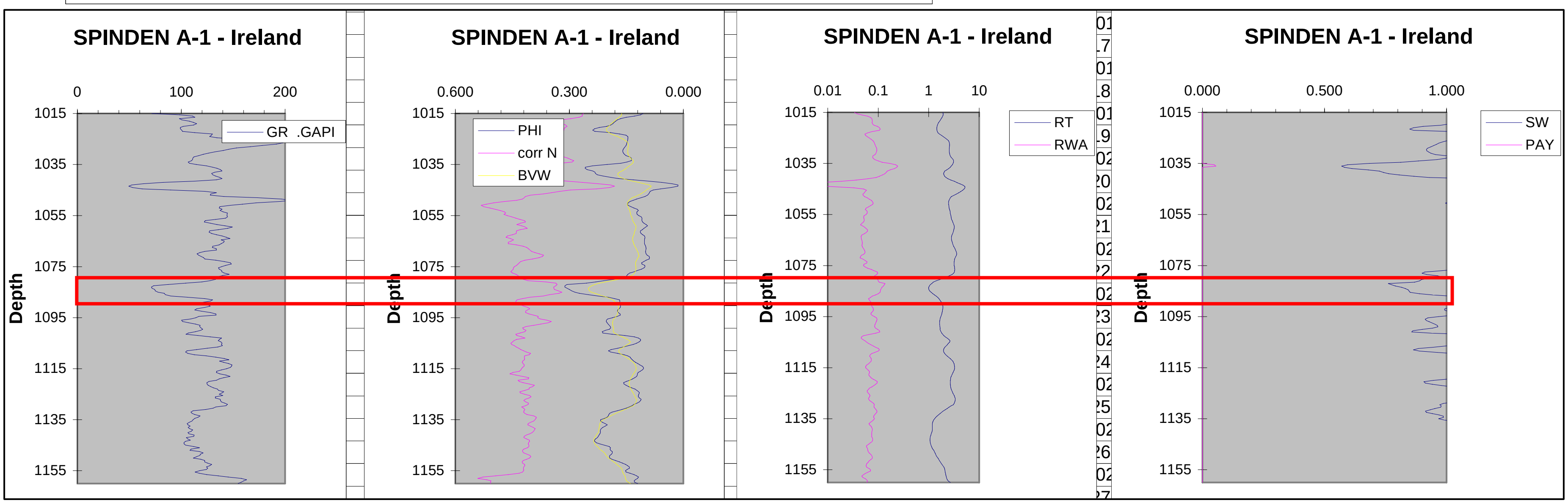
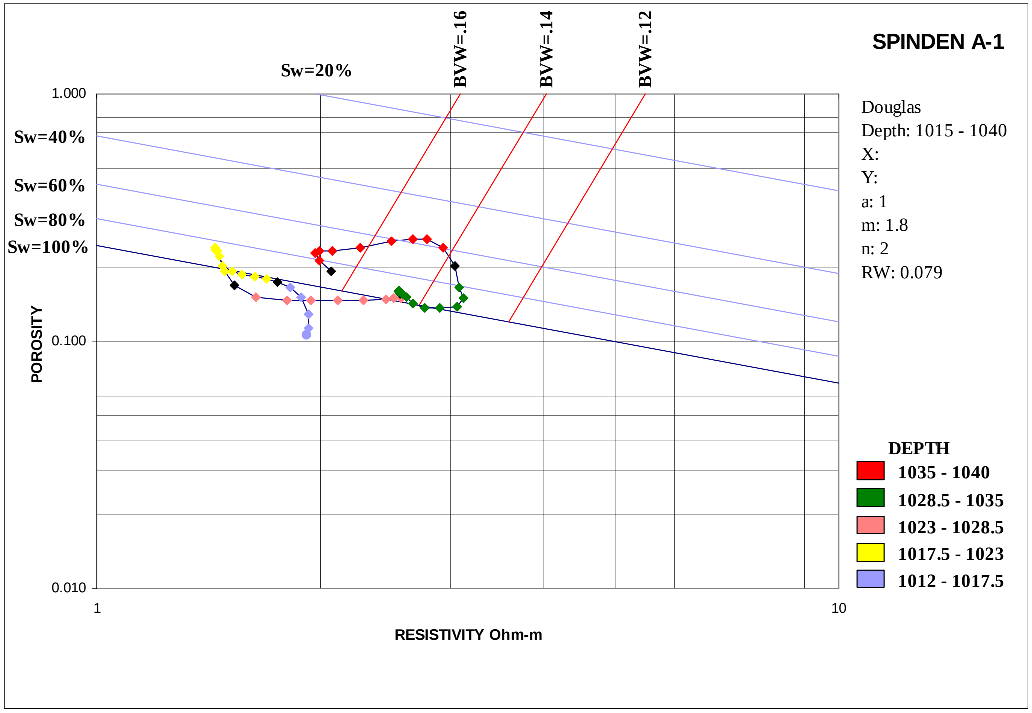


Figure 37: Log analysis of Ireland Sandstone in Spinden A1 well.



Spinden A-1
Douglas (1035-40)

- High GR (> 100 API), separation between desnity porosity and BVW
- Increasing Sw at the base indicate possible transition
- **Probably some gas** where Sw < 60%.
- GR cut-off needs to be tested.

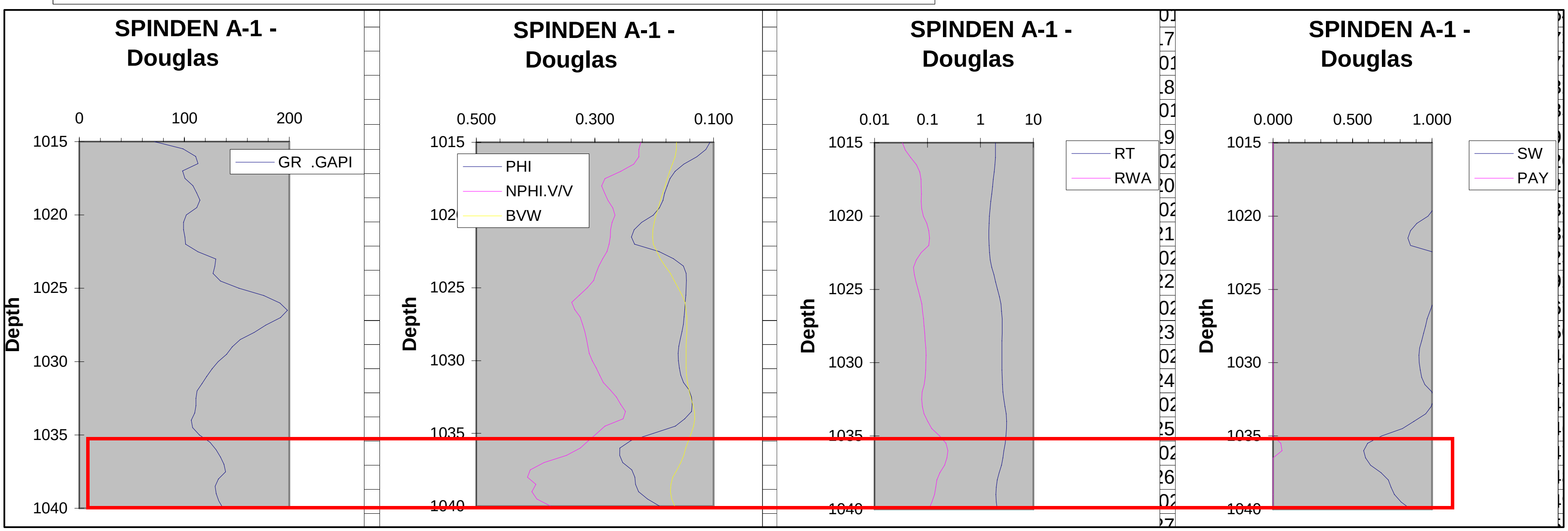
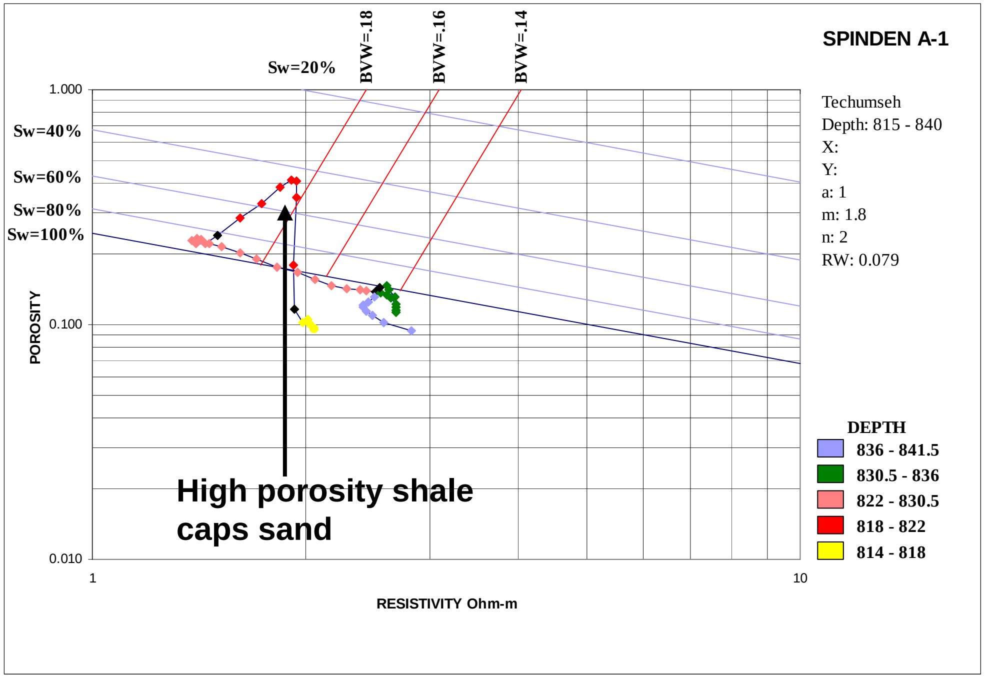


Figure 38: Log analysis of Douglas Sandstone in Spinden A1 well.



Spinden A-1
Tecumseh (822-30 ft)

- Capping shale on top of sand.
- Density porosity and BVW overlap in sand, and high GR (> 100 API)
- **Sand expected to be wet**

Capping shale – not a wash out effect

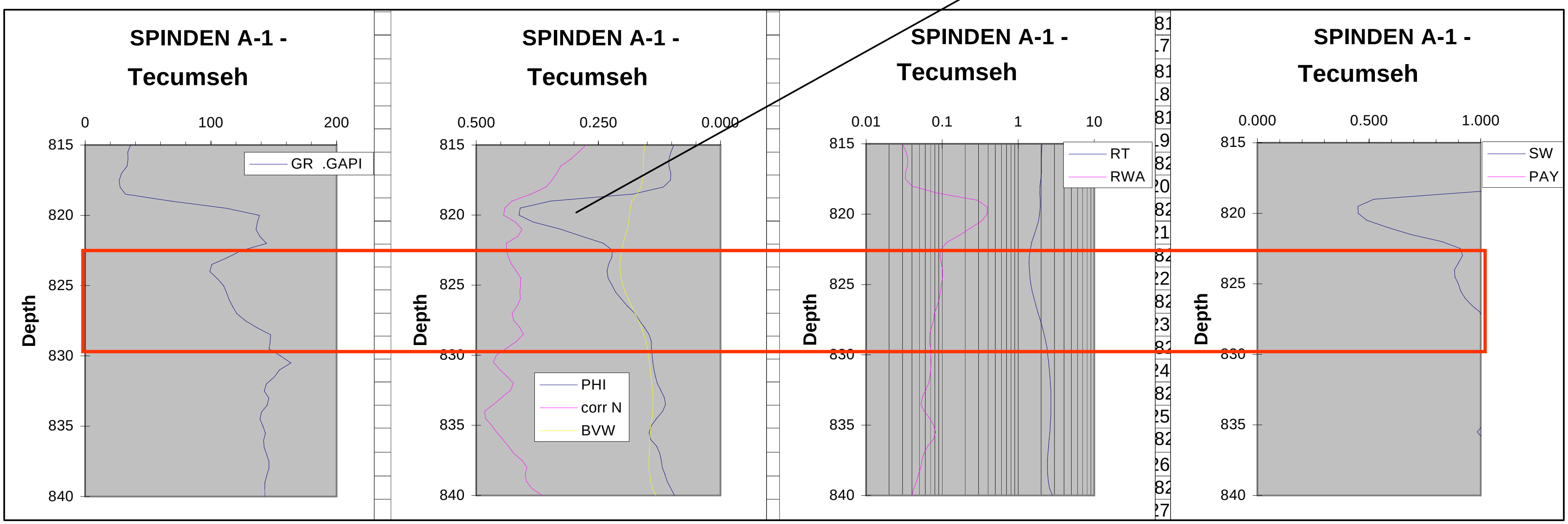


Figure 39: Log analysis of Tecumseh Sandstone in Spinden A1 well.

Spinden A-1

Shale caps Tecumseh sand. The high porosity marking the shale is not due to hole washout

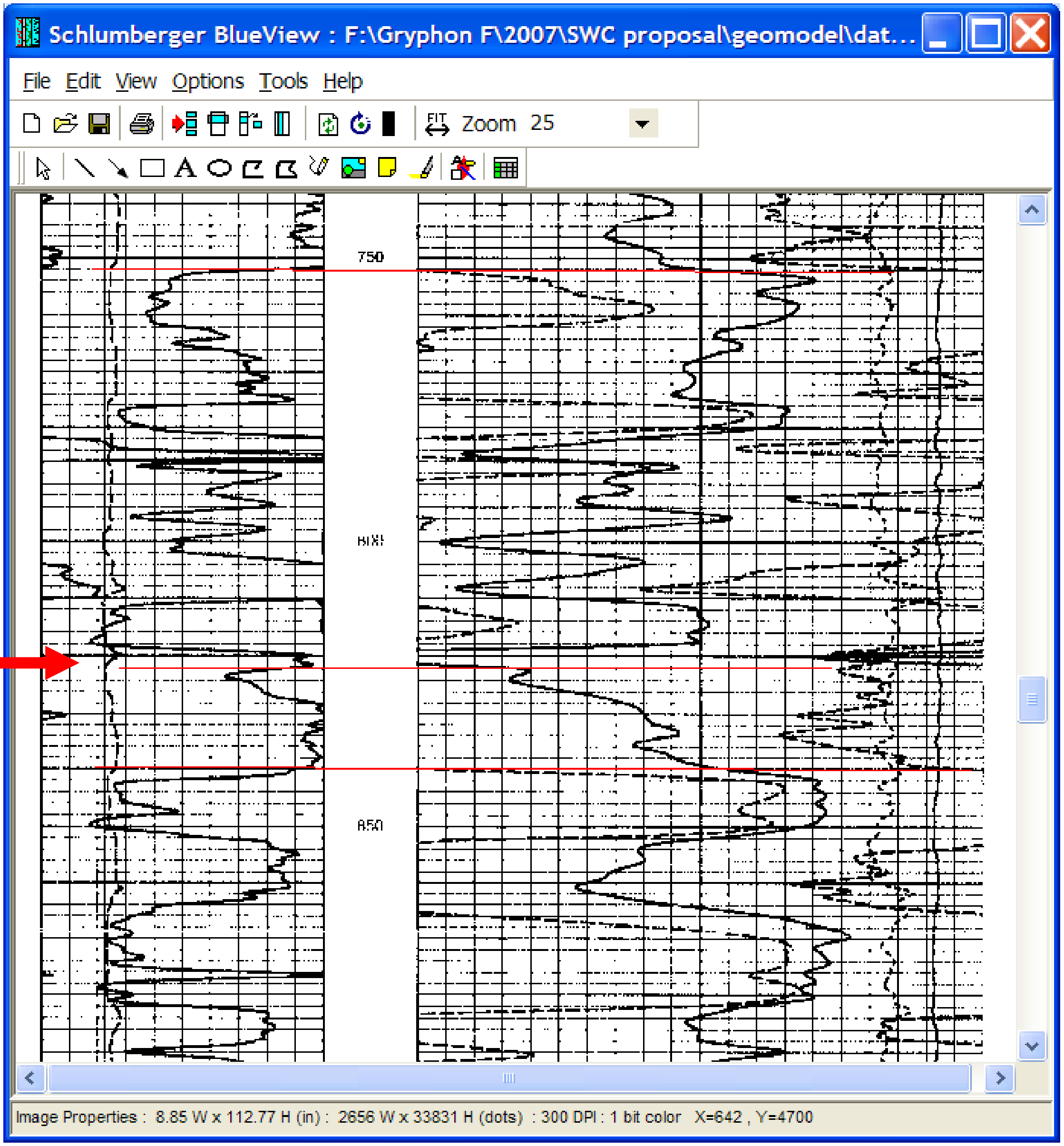
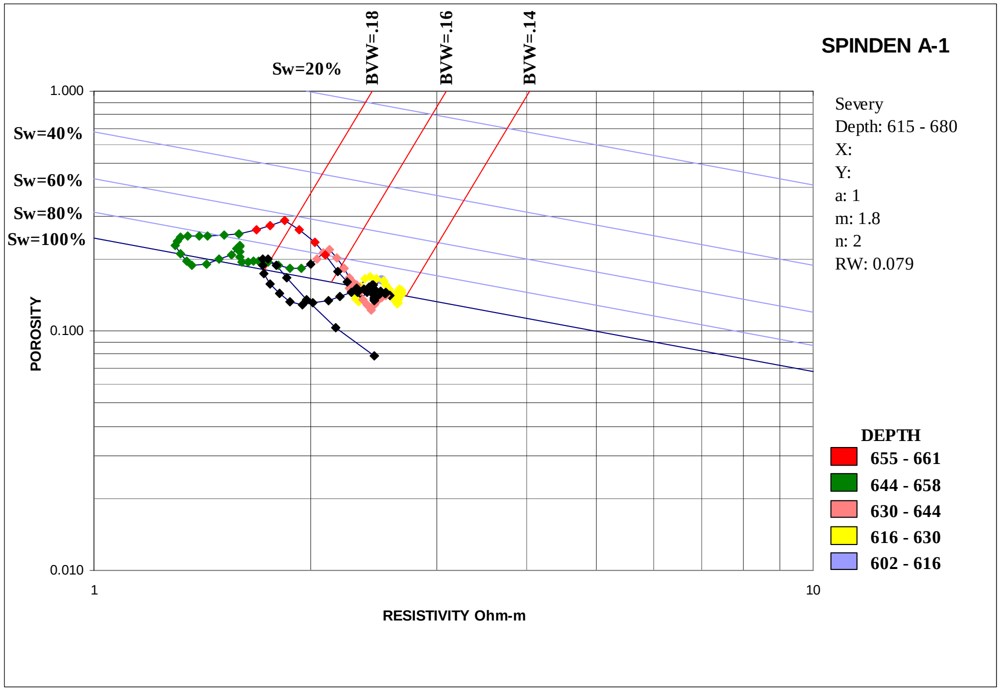


Figure 40: Log showing the location of the shale bed capping the Tecumseh Sandstone in Spinden A1 well.



Spinden A-1
Severy (655-61 ft)

- Cleaner sand (low GR) with high BVW (>0.16) indicating finer pores
- Seperation between density porosity and BVW
- Intermediate Sw (between 60 and 70%) suggests
- **Gas in transition**

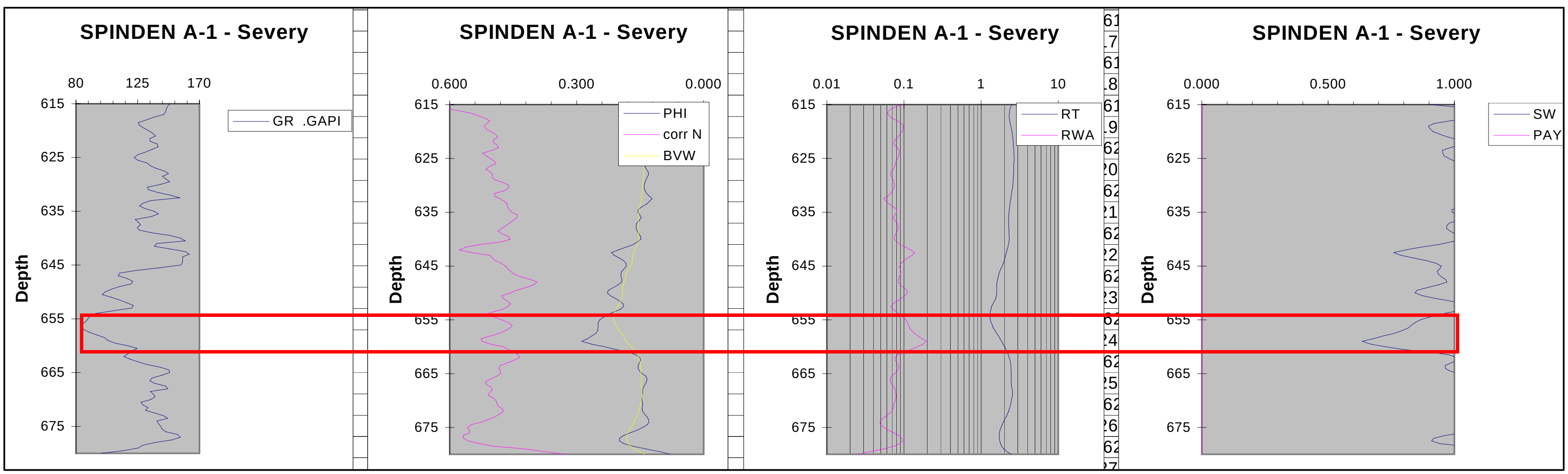
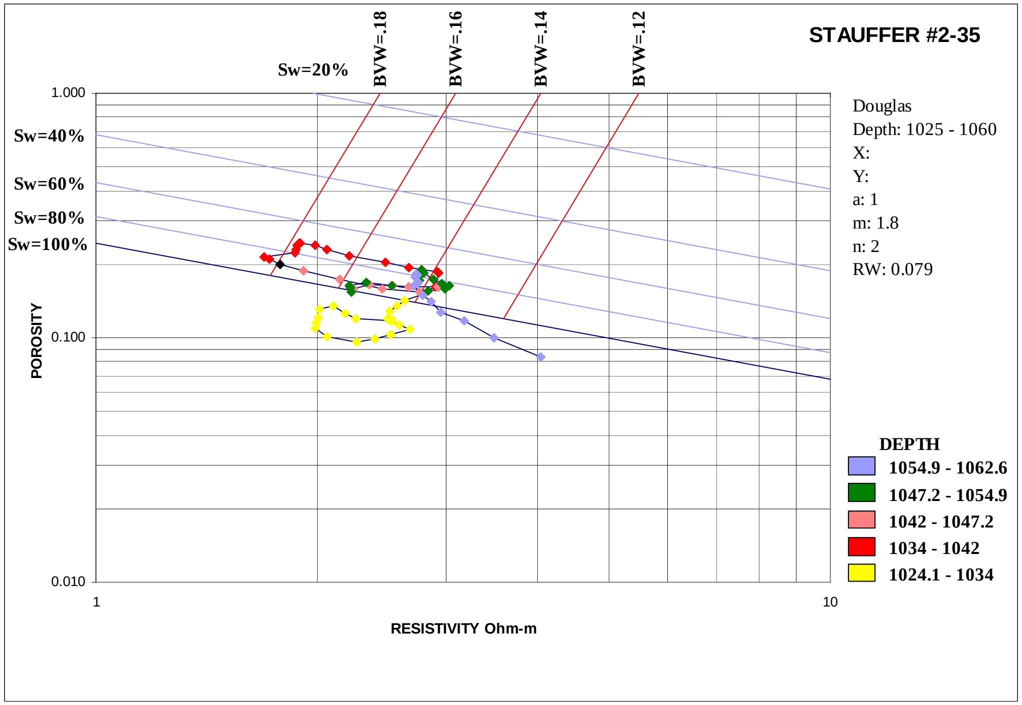


Figure 41: Log analysis of Severy Sandstone in Spinden A1 well.



Stauffer 2-35
Douglas (1034-42 ft)

- Gas confirmed during drilling
- GR < 100 API, seperation between density porosity and BVW
- Sw > 70% and increases with depth
- **Probably some gas in transitional**
- Recommend further testing

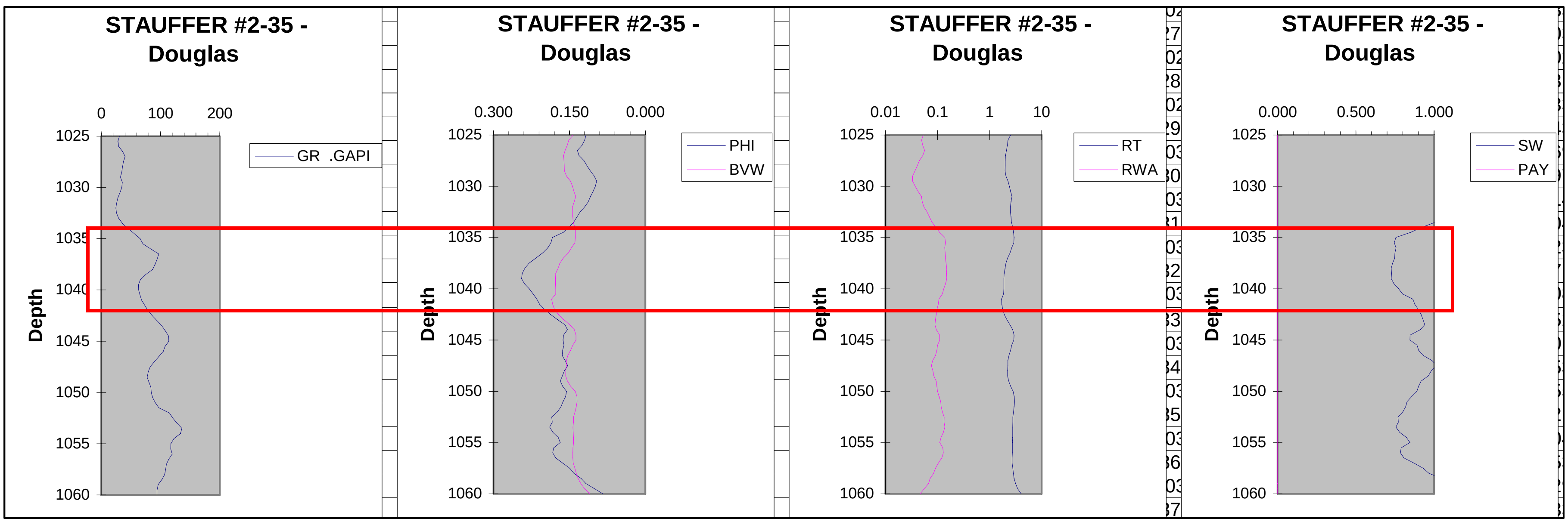
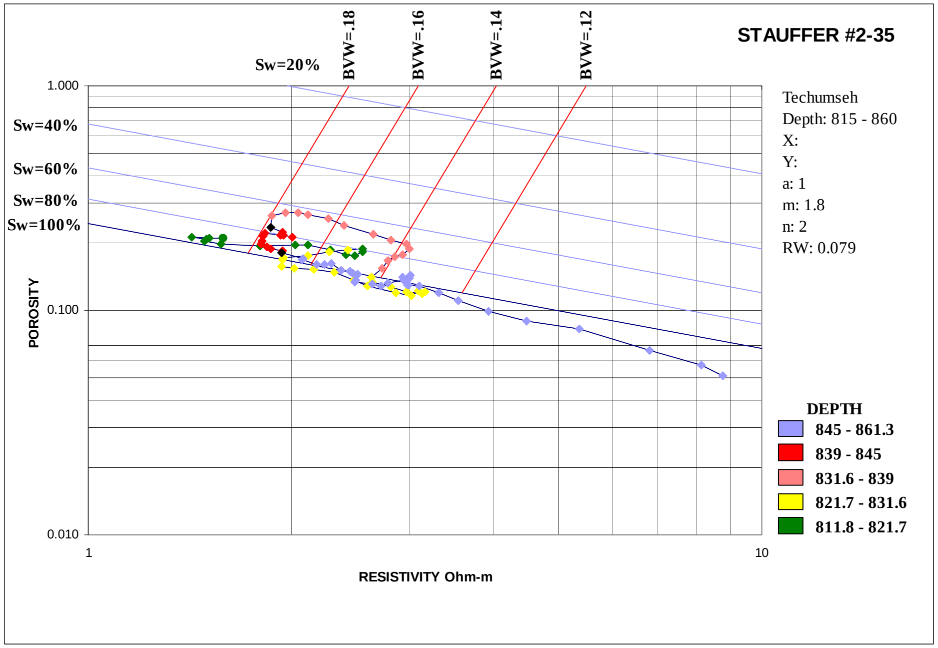


Figure 42: Log analysis of Douglas Sandstone in Stauffer 2-35 well.



Stauffer 2-35

Tecumseh (839-45 ft)

- Little separation between density porosity and BVW
- Sw increases with depth and exceeds 80%
- **Sand expected to be wet**

Shale overlying sand

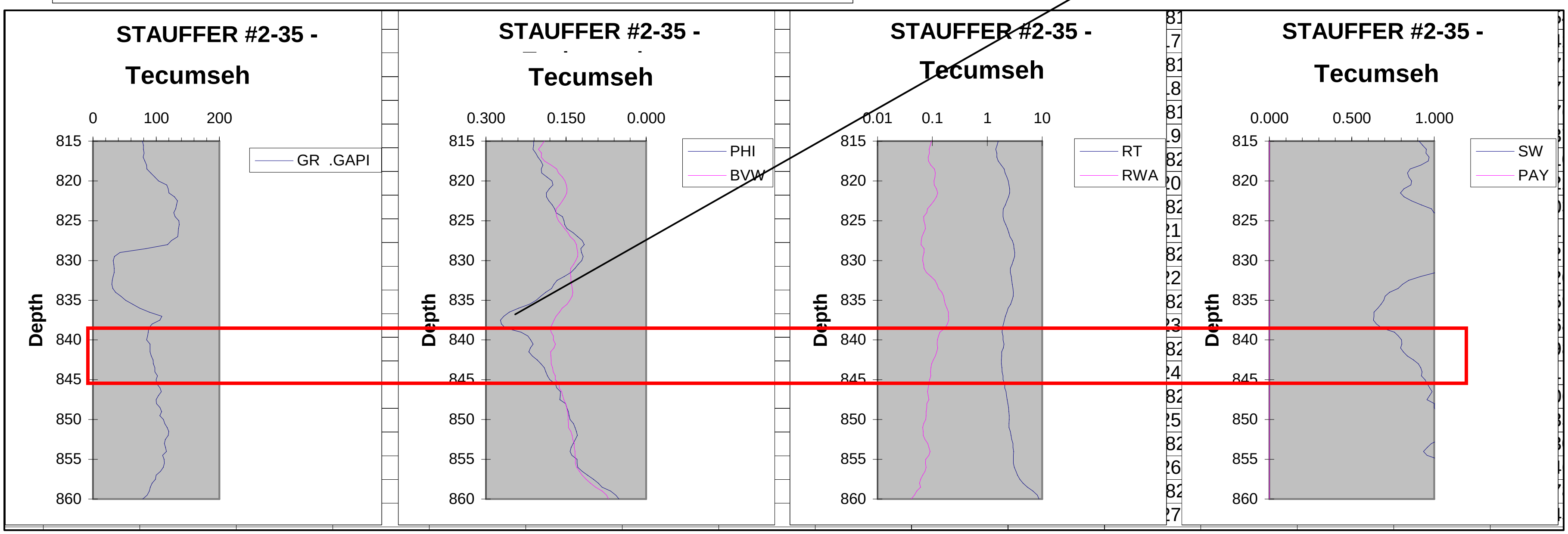


Figure 43: Log analysis of Tecumseh Sandstone in Stauffer 2-35 well.

Stauffer 2-35

Shale bed overlies the Tecumseh sand

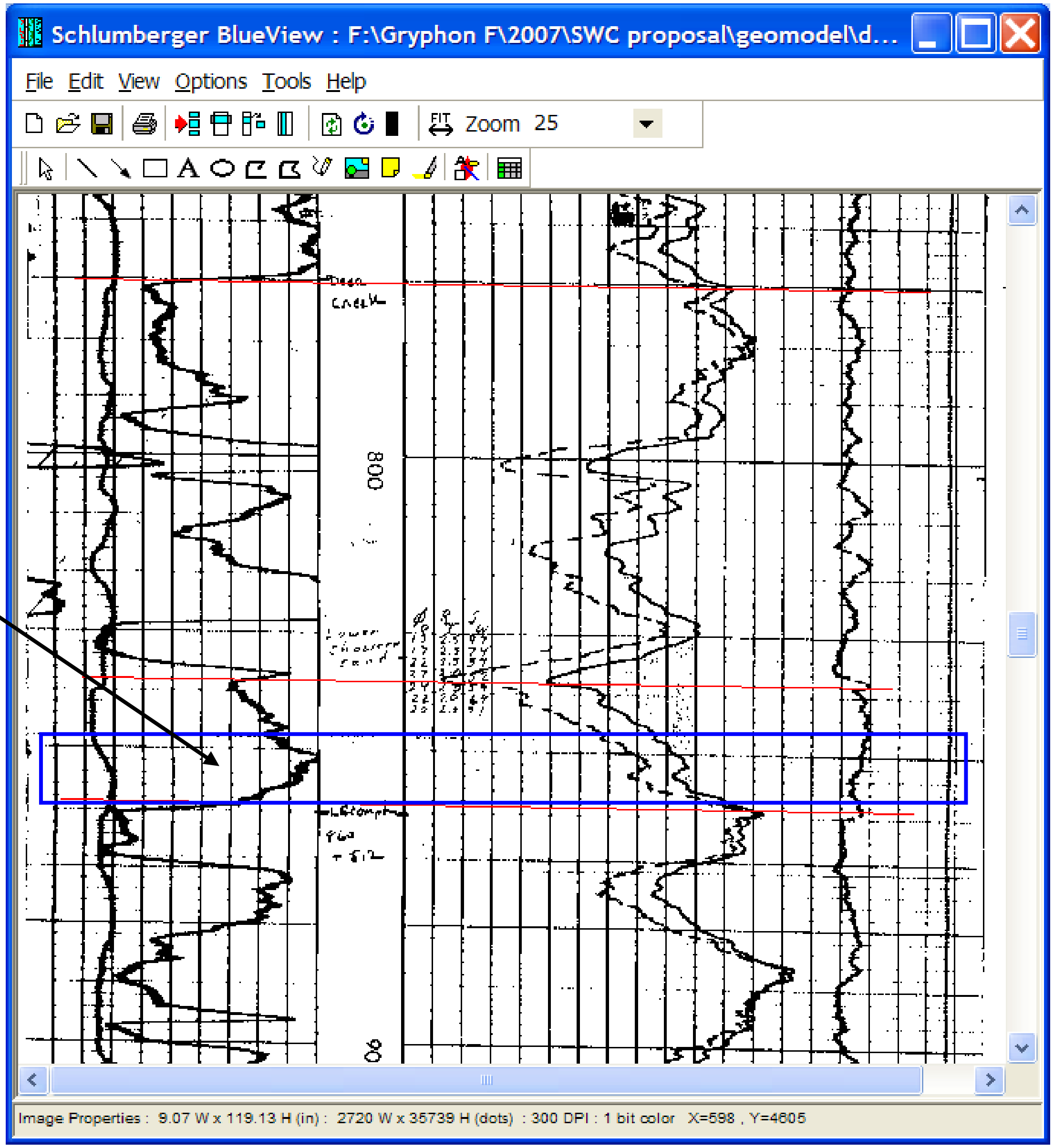
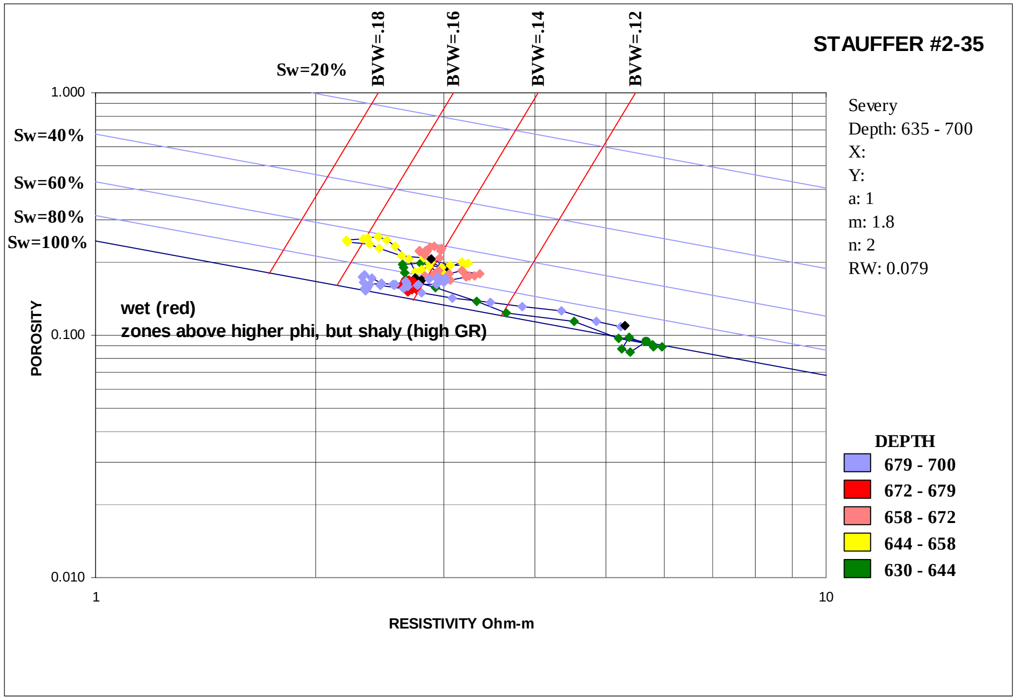


Figure 44: Log showing location of shale bed overlying Tecumseh Sandstone in Stauffer 2-35 well.



Stauffer 2-35
Severy (672-679 ft)

- Overlap of BVW and density porosity
- Sw > 80%)
- Slight cleaning of sand upward
- **Sand expected to be wet**

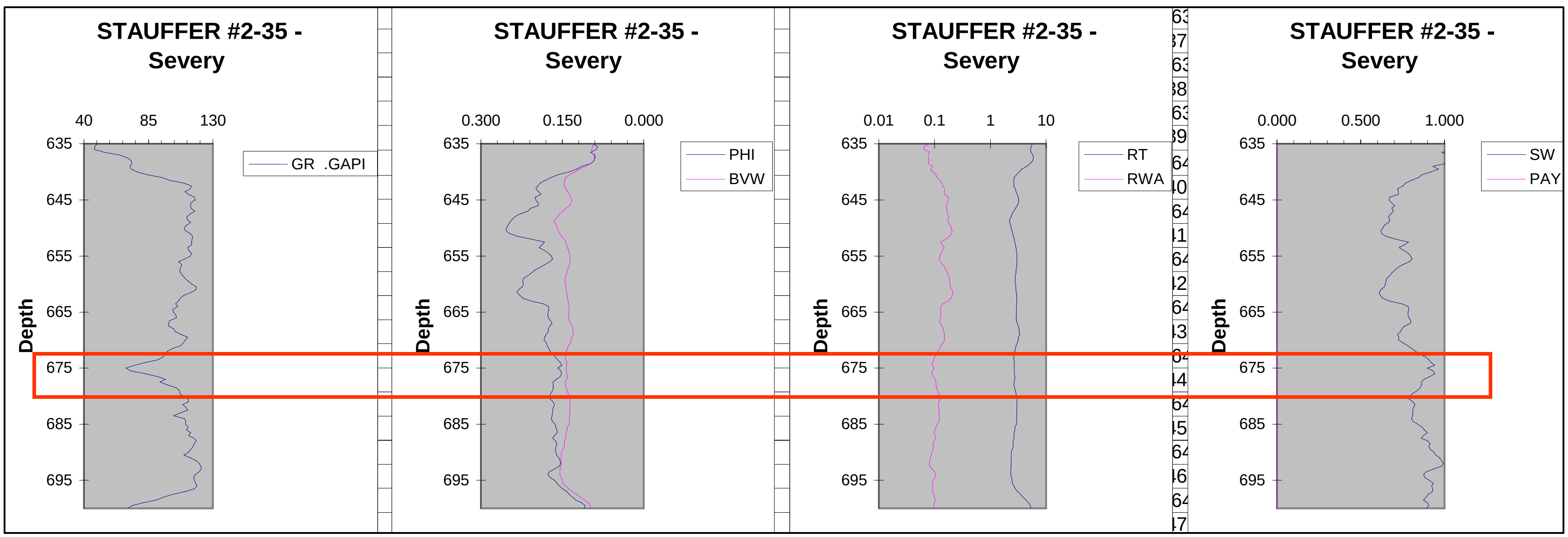
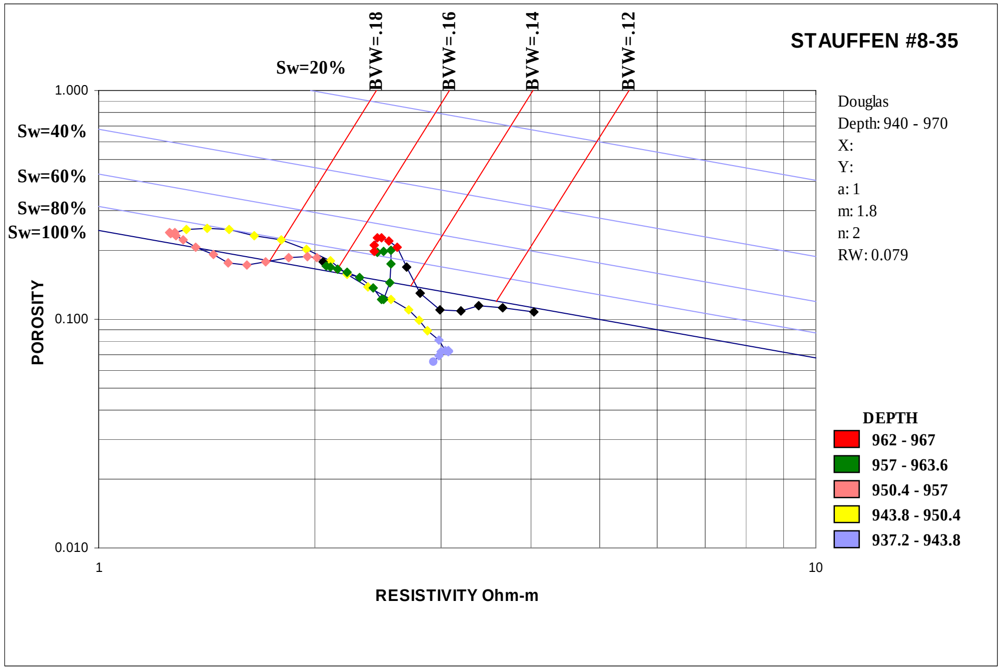


Figure 45: Log analysis of Severy Sandstone in Stauffer 2-35 well.



Stauffer 8-35
Douglas (965-967 ft)

- Shale washout on top of sand (962-964 ft)
- Sand below shale - BVW cluster around 0.15, separation between density porosity and BVW
- Sw < 80%
- **Thin zone with some transitional gas**.
- Zone needs to be tested to see if water is mobile.

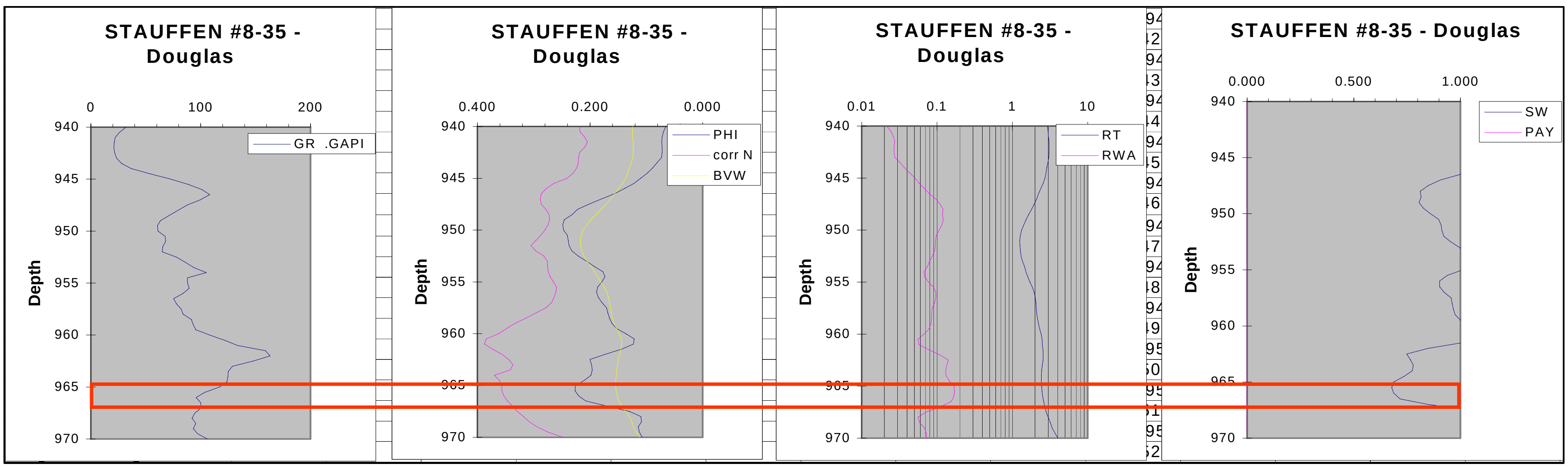


Figure 46: Log analysis of Douglas Sandstone in Stauffer 8-35 well.

Stauffer 8-35 Douglas

- Washout at top in overlying shale

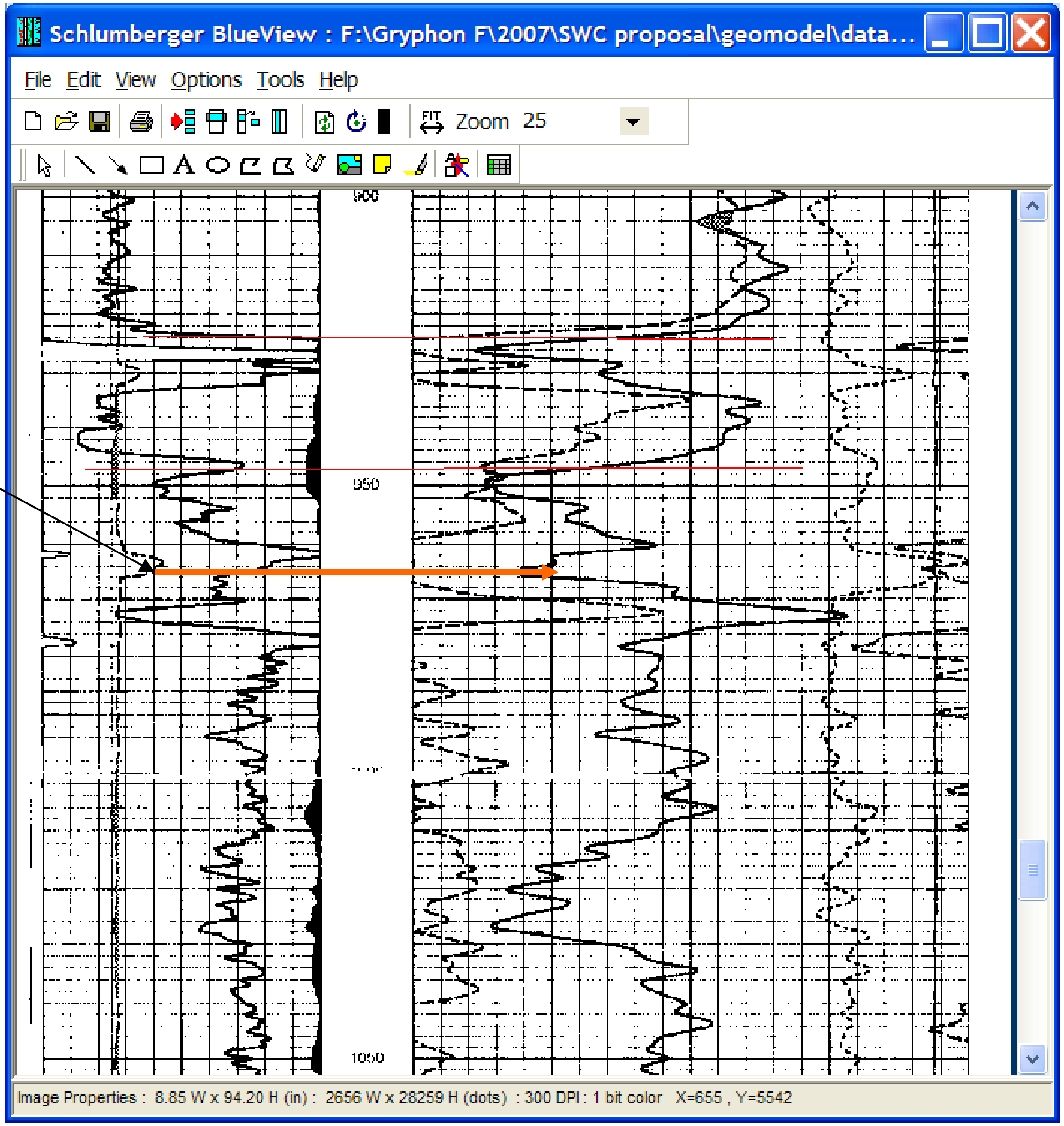
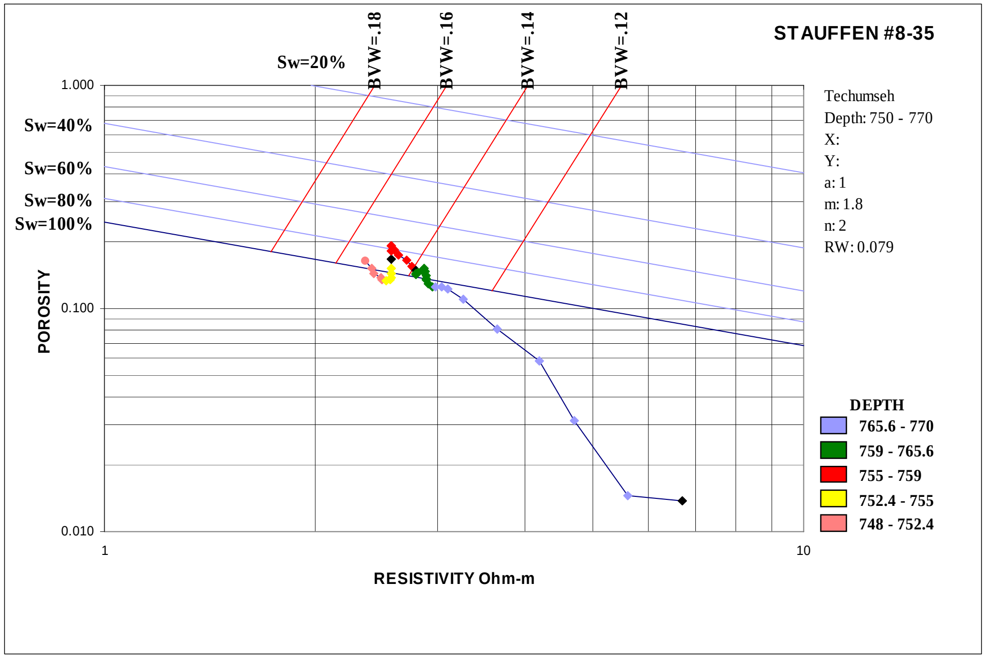


Figure 47: Log showing shale that was washed out. Shale overlies the Severy Sandstone in Stauffer 2-35 well.



Stauffer 8-35
Tecumseh (755-759 ft)

- Small clustering at moderate BVW (0.15) – test to check for mobile water
- Decrease in GR upwards may be indicative of coarsening
- Top of sand - Separation between density porosity and BVW
- Sw > 80%
- Bottom of sand - Sw increases downwards
- **Poor prospect - gas in transition zone**

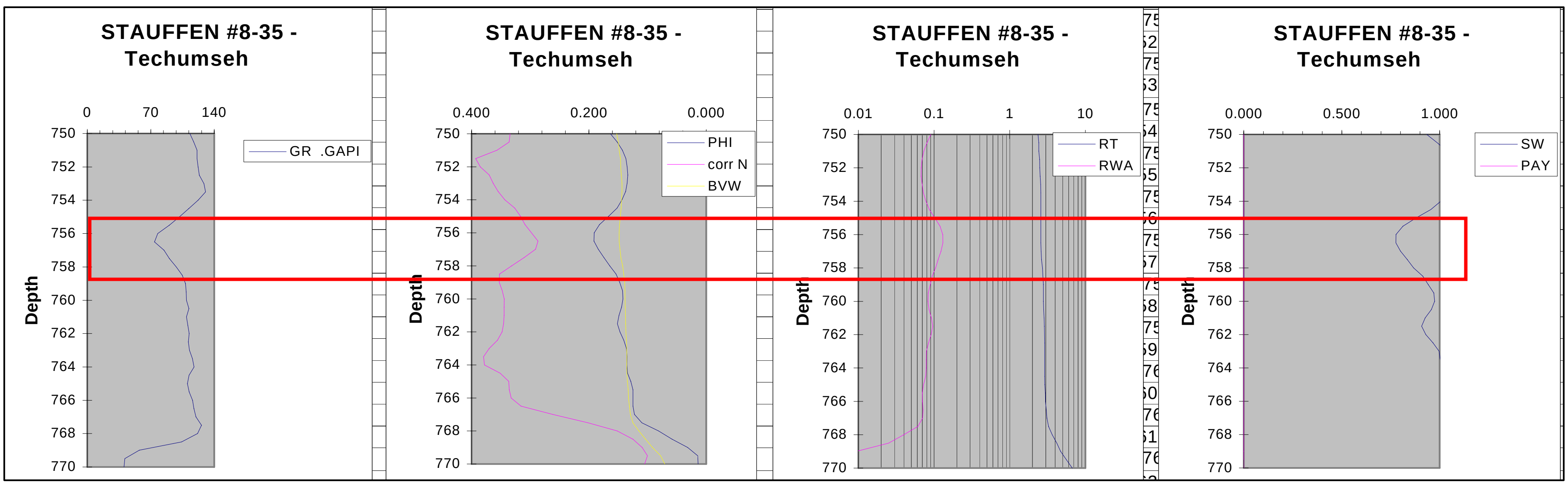
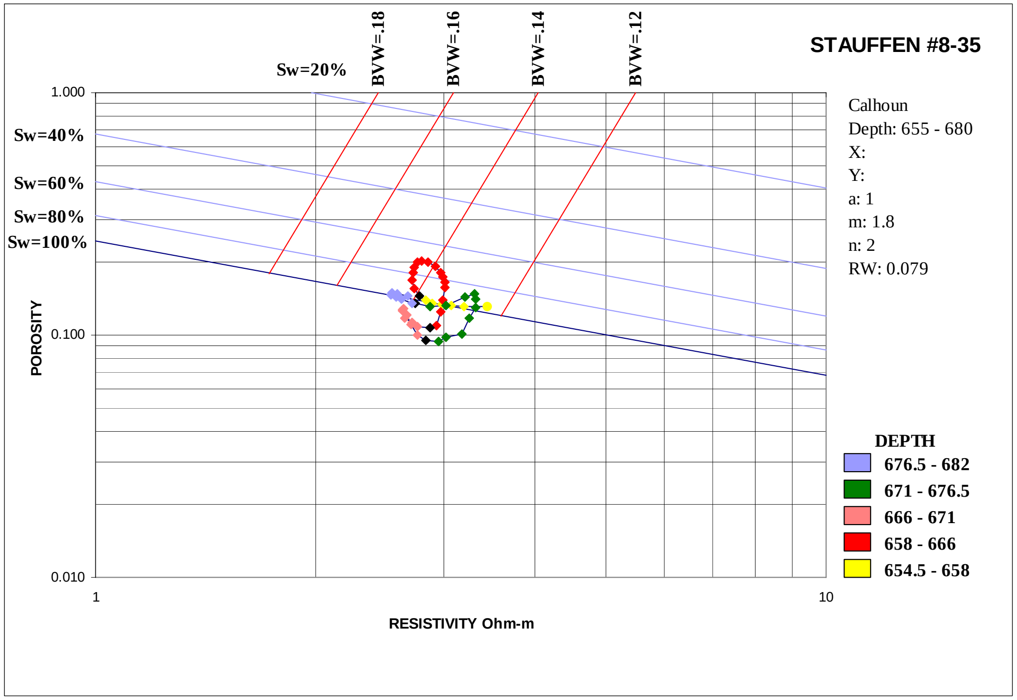


Figure 48: Log analysis of Tecumseh Sandstone in Stauffer 8-35 well.



Stauffer 8-35

Calhoun (658-65 ft)

- Top of sand – low GR and seperation between density porosity and BVW, BVW around 0.14
- Base of sand - Sw increases with depth – indicative of transition
- **Probably gas in transition**

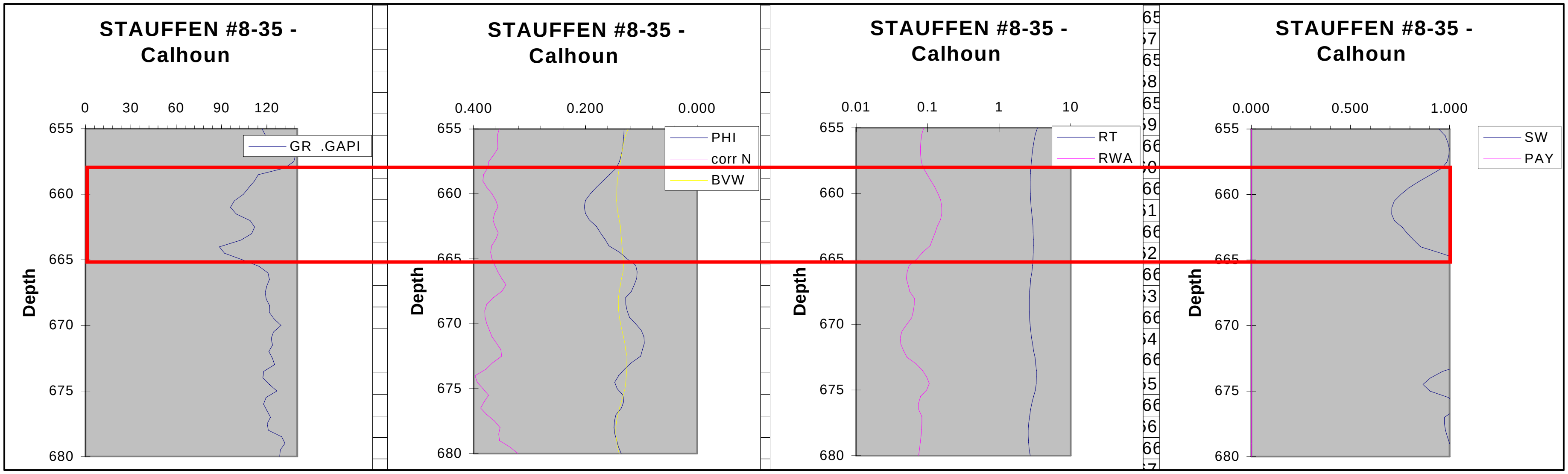
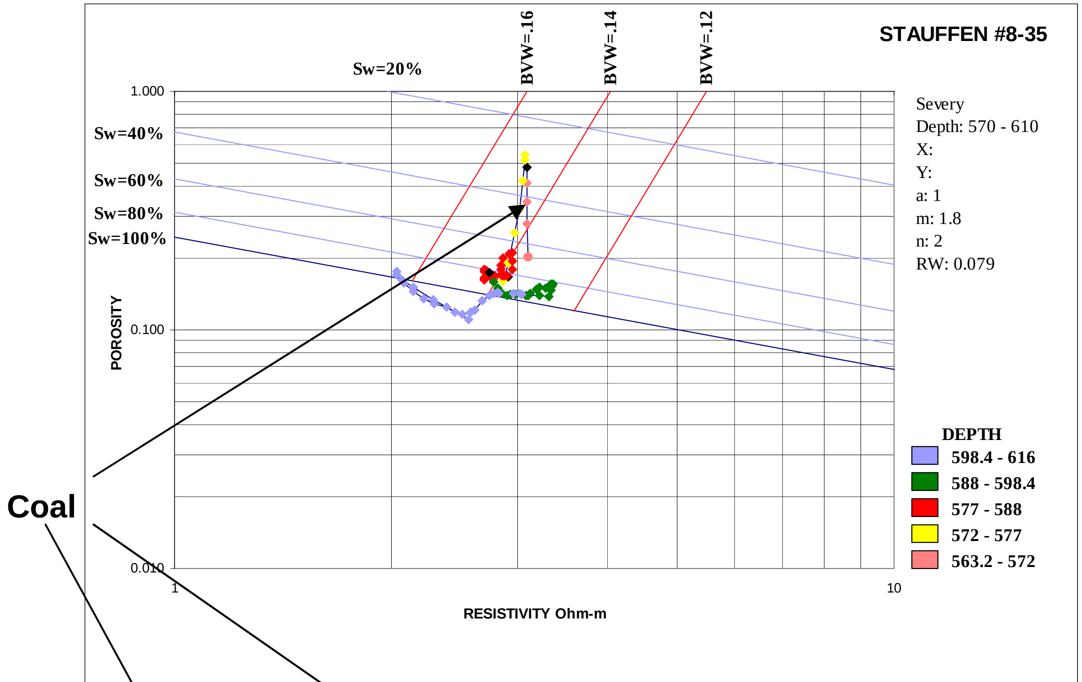


Figure 49: Log analysis of Calhoun Sandstone in Stauffer 8-35 well.



Stauffer 8-35

Severy (577-588 ft)

- Clustered BVW ~0.14
- Coal on top of sand (high porosity, moderate GR)
- GR indicates cleaning upward in sand. No gas effect visible. Porosity low.
- Slight separation between density porosity and BVW, Sw < 80%
- **Probable gas**

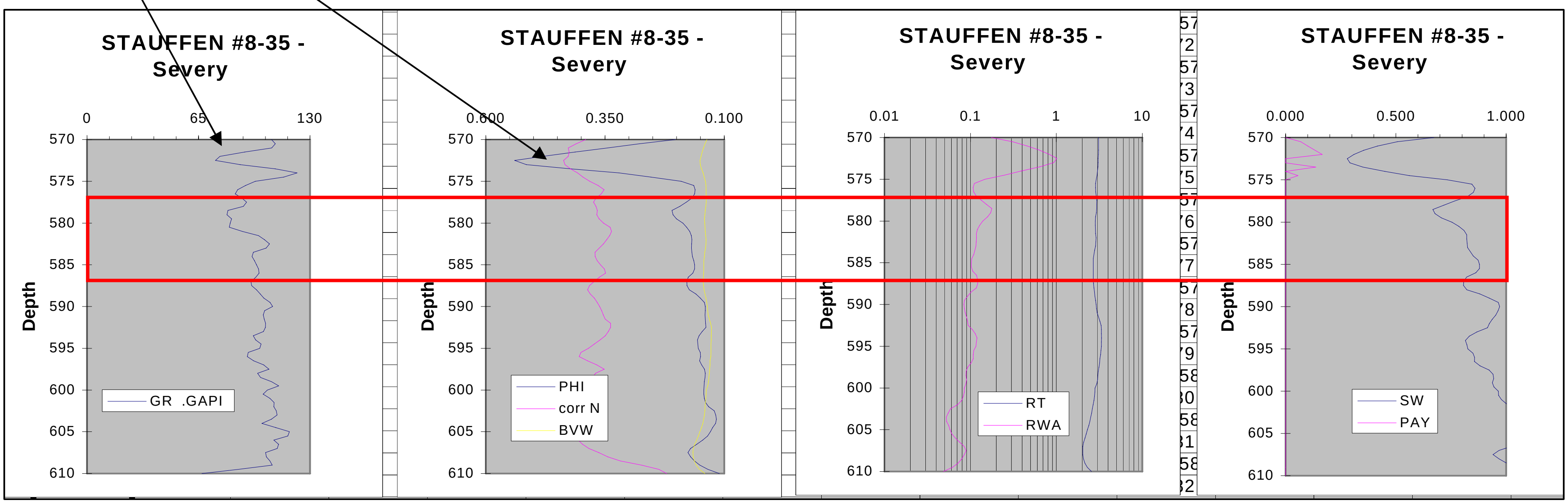
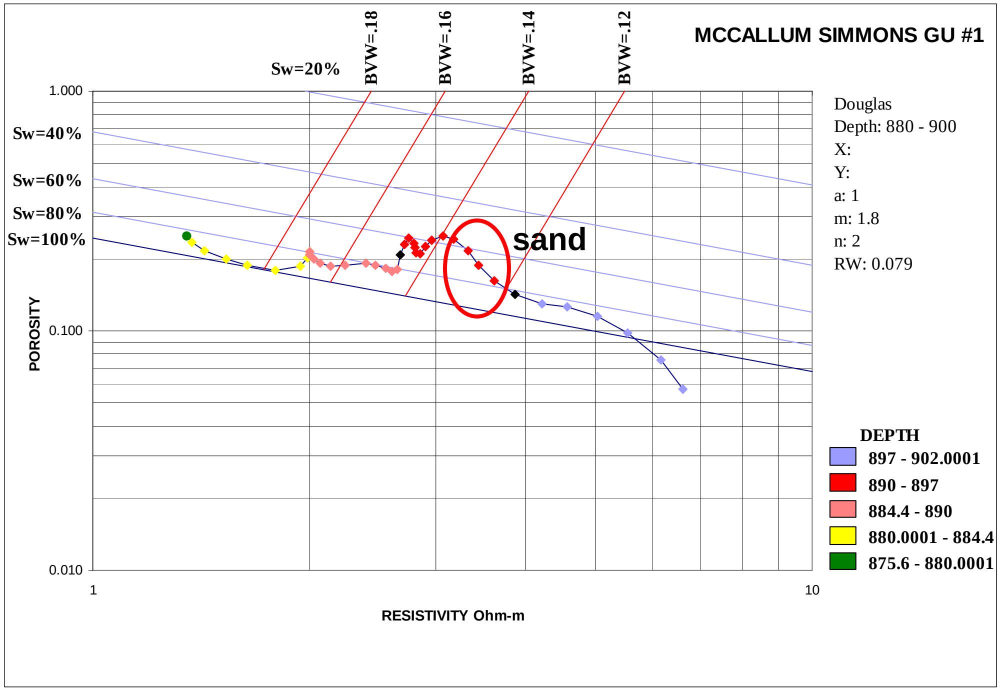


Figure 50: Log analysis of Severy Sandstone in Stauffer 8-35 well.



McCallum Simmons GU #1

Douglas (895-897 ft)

- Washout above sand in shale bed (891-895 ft)
- BVW < 0.14 in sand with separation between density porosity and BVW
- Sw < 80% in sand
- **Probably gas in transition**

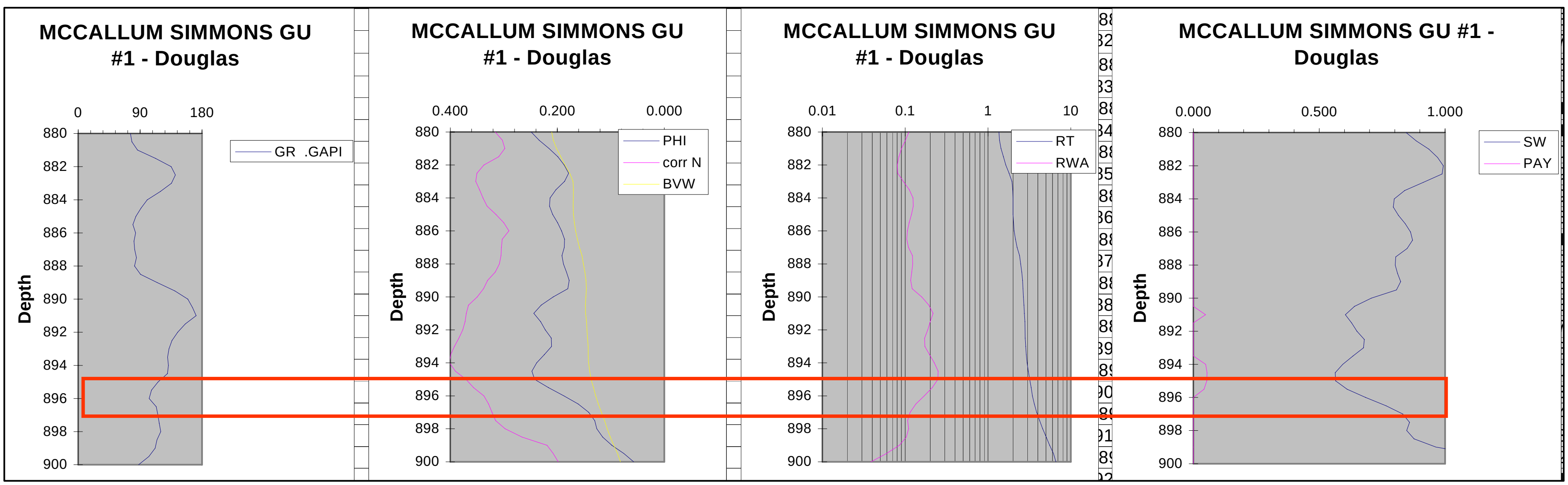
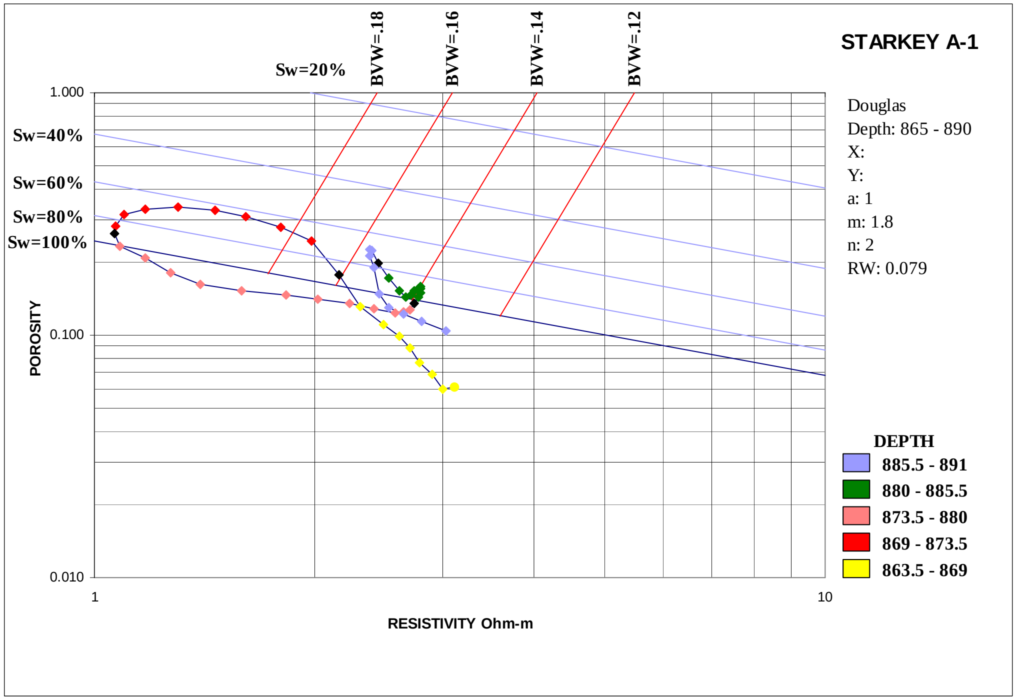


Figure 51: Log analysis of Douglas Sandstone in McCallum Simmons GU 1 well.



Starkey A-1

Douglas (871-874 ft)

- Gas effect on neutron porosity, separation between density porosity and BVW. No washout.
- But high BVW (>0.18) suggesting fine pores and probable lower perm
- Coarsening upward package indicated by decreasing BVW. GR < 100 API.
- **May produce gas.**

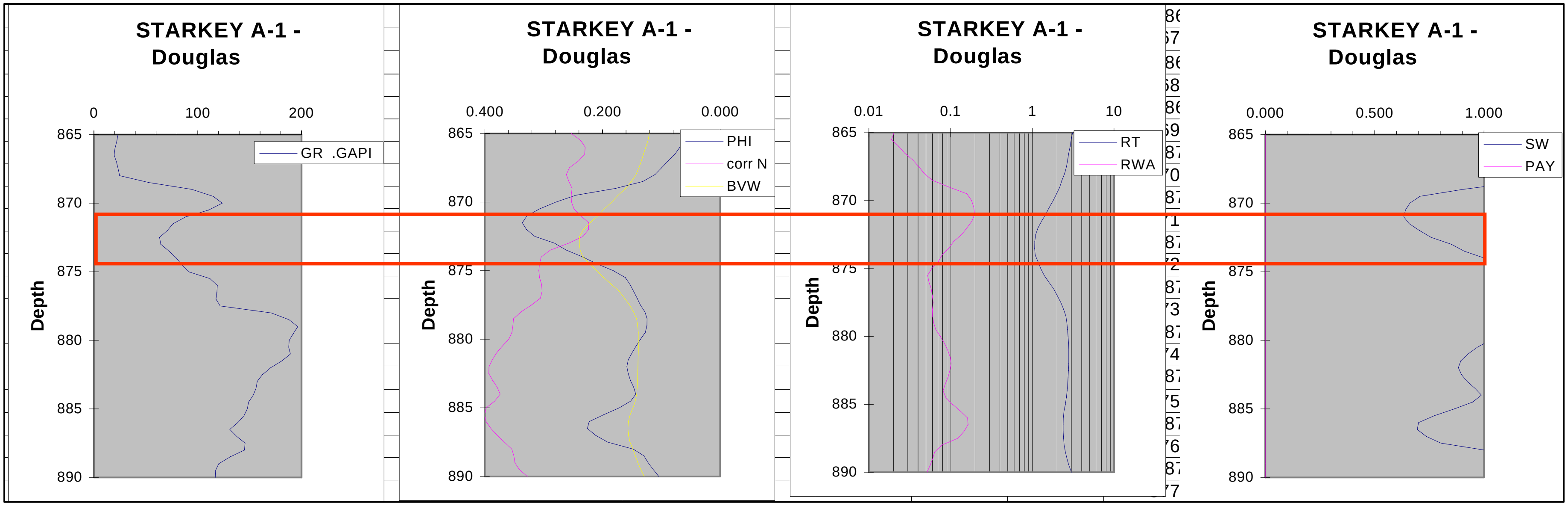
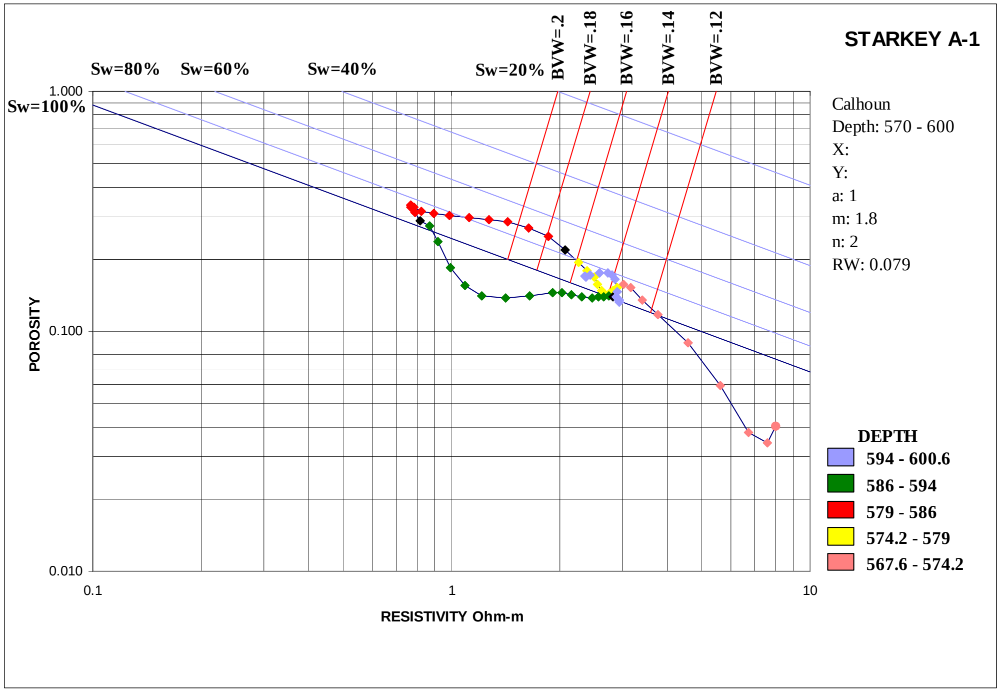


Figure 52: Log analysis of Douglas Sandstone in Starkey A1 well.



Starkey A-1

Calhoun (583-86 ft)

- Slight gas effect on neutron porosity
- high BVW (>0.2) suggest fine pores
- high Sw (+ 80%) suggests transition. Also Sw increases with depth.
- **Gas in transition**

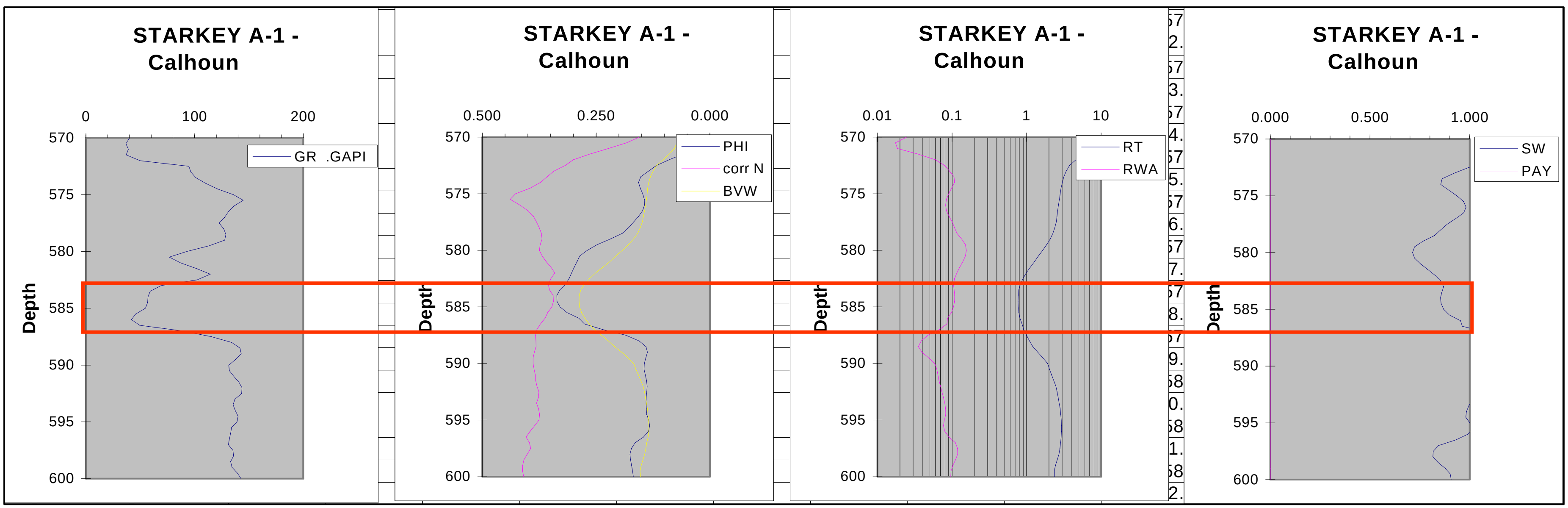
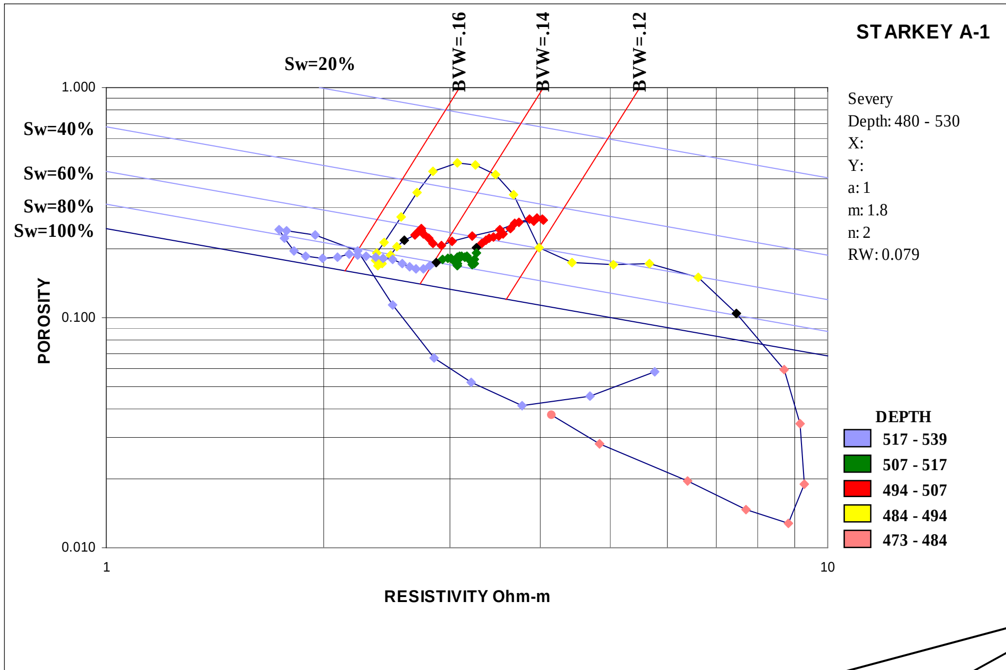


Figure 53: Log analysis of Calhoun Sandstone in Starkey A1 well.



Starkey A-1

Severy (500-506 ft)

- Slight gas effect on neutron porosity
- Low BVW (~0.12) suggest larger pores. Sw increases with depth. Much of sand at Sw < 60%.
- A (3 ft) coal bed is suspected to overly the sand.
- **GAS zone**

Indicative of Coal

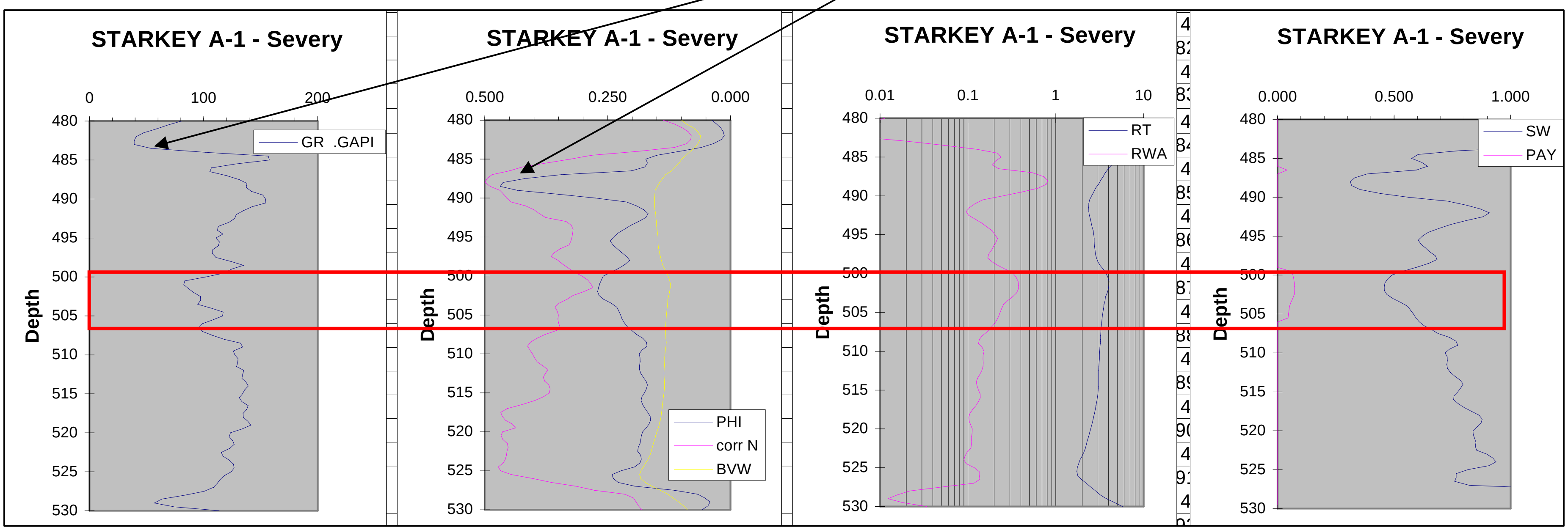
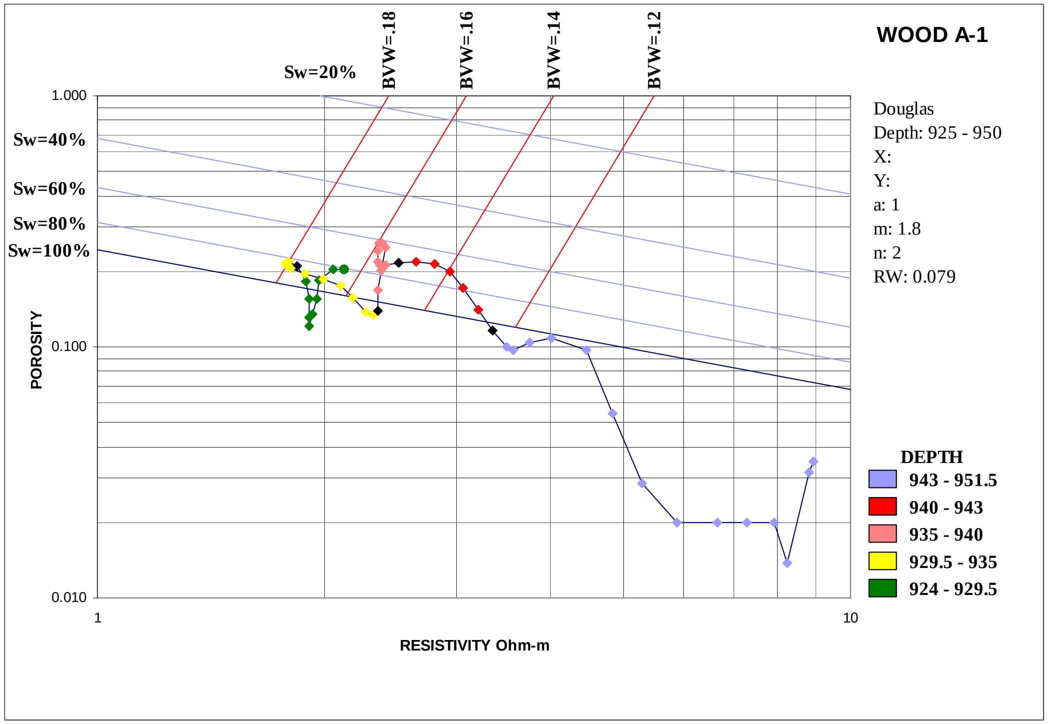


Figure 54: Log analysis of Severy Sandstone in Starkey A1 well.



Wood A-1

Douglas (940-943 ft)

- No gas effect on neutron porosity. Separation between density porosity and BVW.
- Quite shaly (GR> 100 API), but BVW less than 0.155
- Sw < 80% and increases with depth
- **Possible gas in transition**

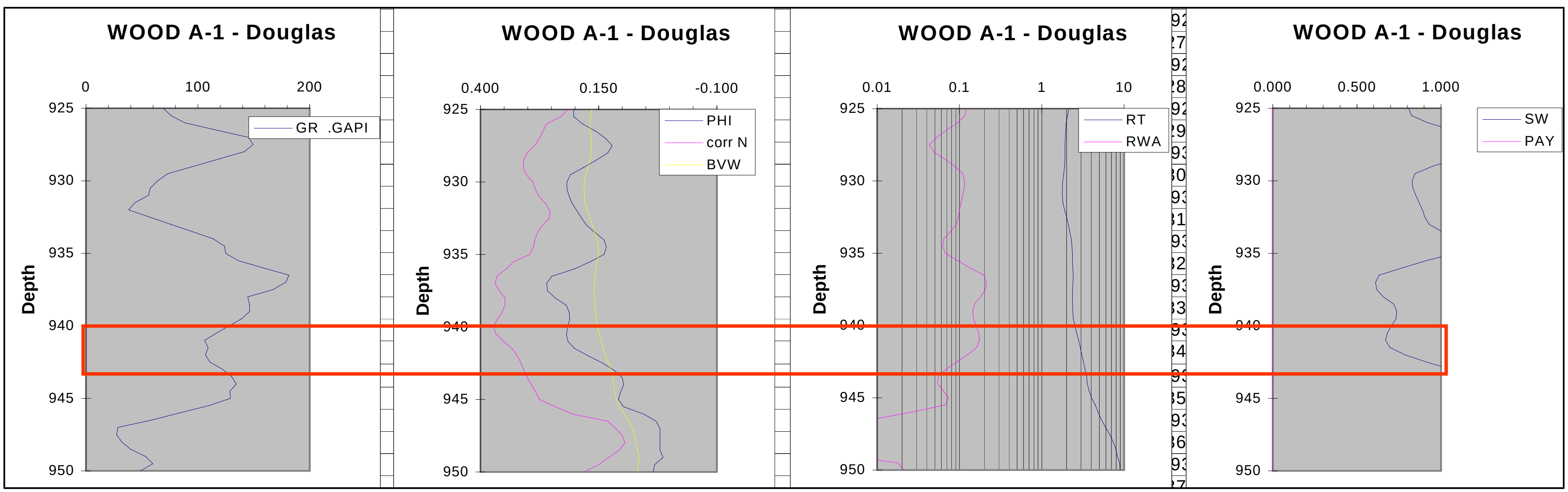
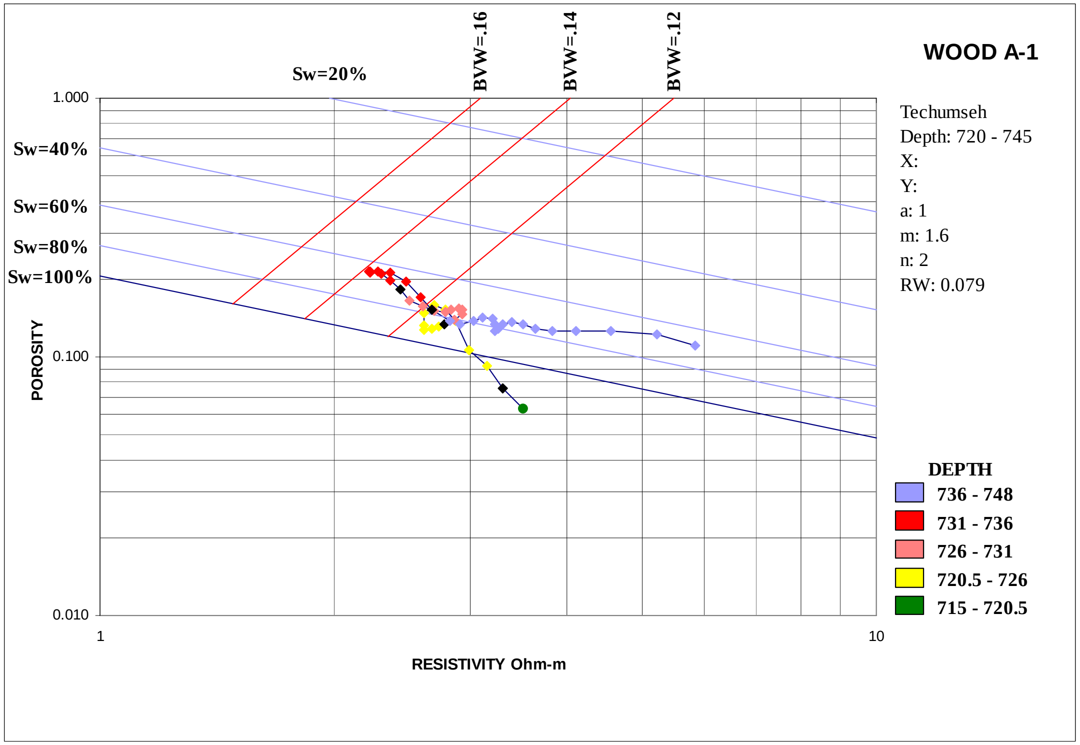


Figure 55: Log analysis of Douglas Sandstone in Wood A1 well.



Wood A-1

Tecumseh (732-736 ft)

- Slight gas effect on neutron log.
- GR < 100 API with moderate porosity and BVW cluster around 0.0135
- Sw < 80%. No transition visible
- **Possibly gas**

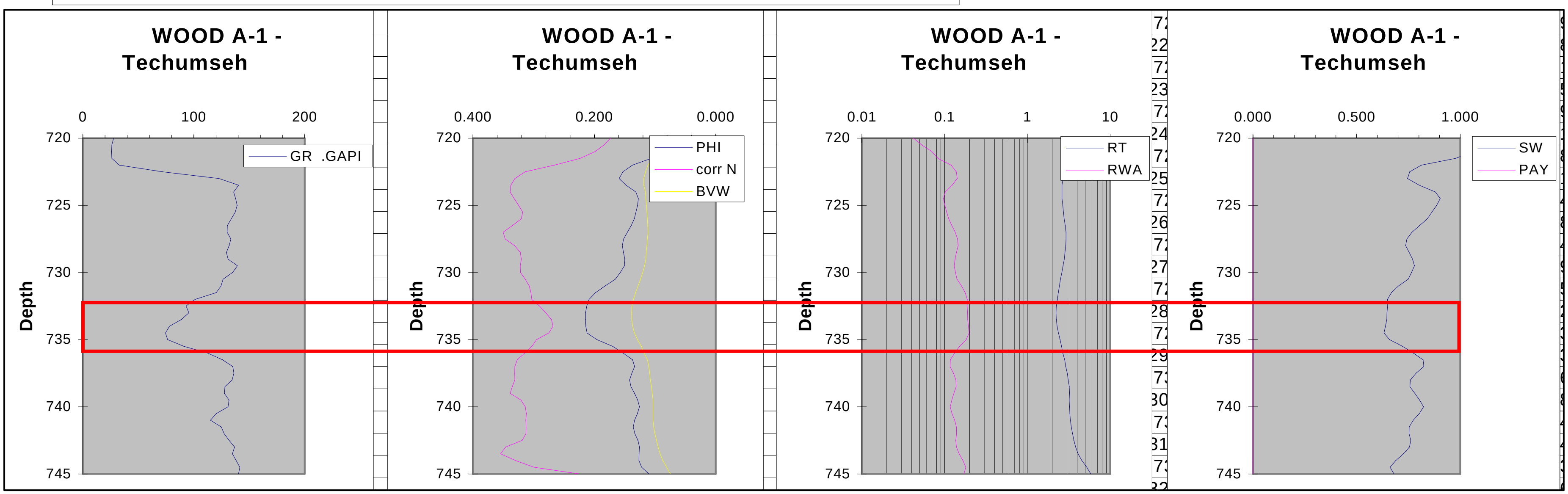
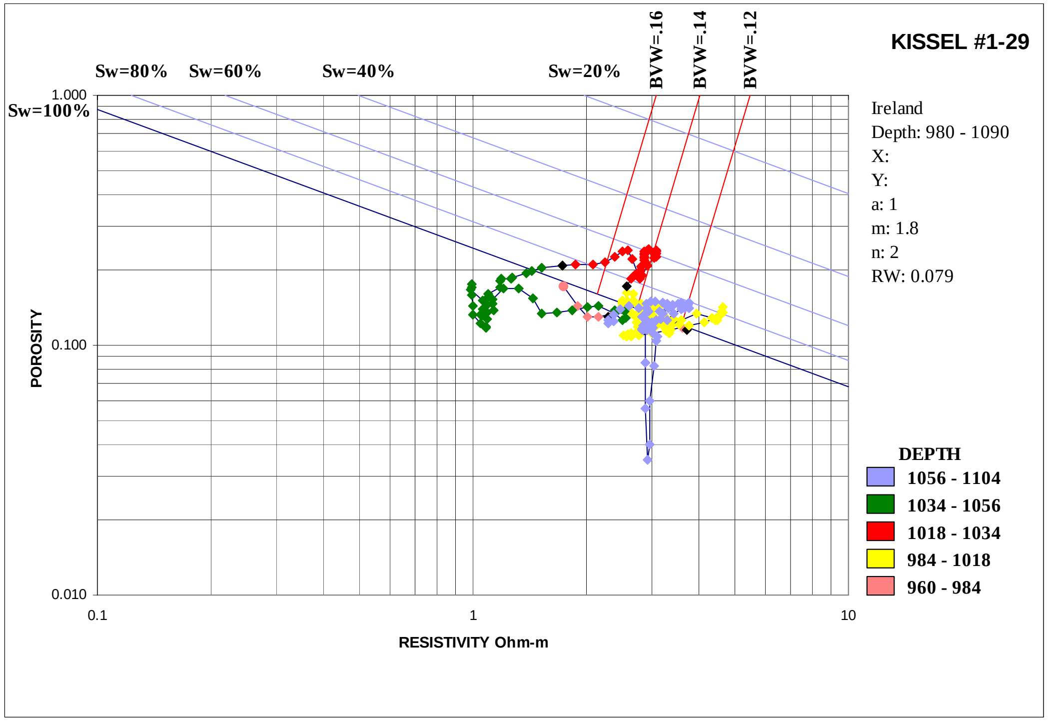


Figure 56: Log analysis of Tecumseh Sandstone in Wood A1 well.



Kissel 1-29

Ireland (1020-1037 ft)

- Gas effect visible on neutron porosity log, separation between density porosity and BVW
- Low GR (< 100 API) and BVW cluster around 0.14
- 60% > Sw > 80%
- **Possibly Gas**

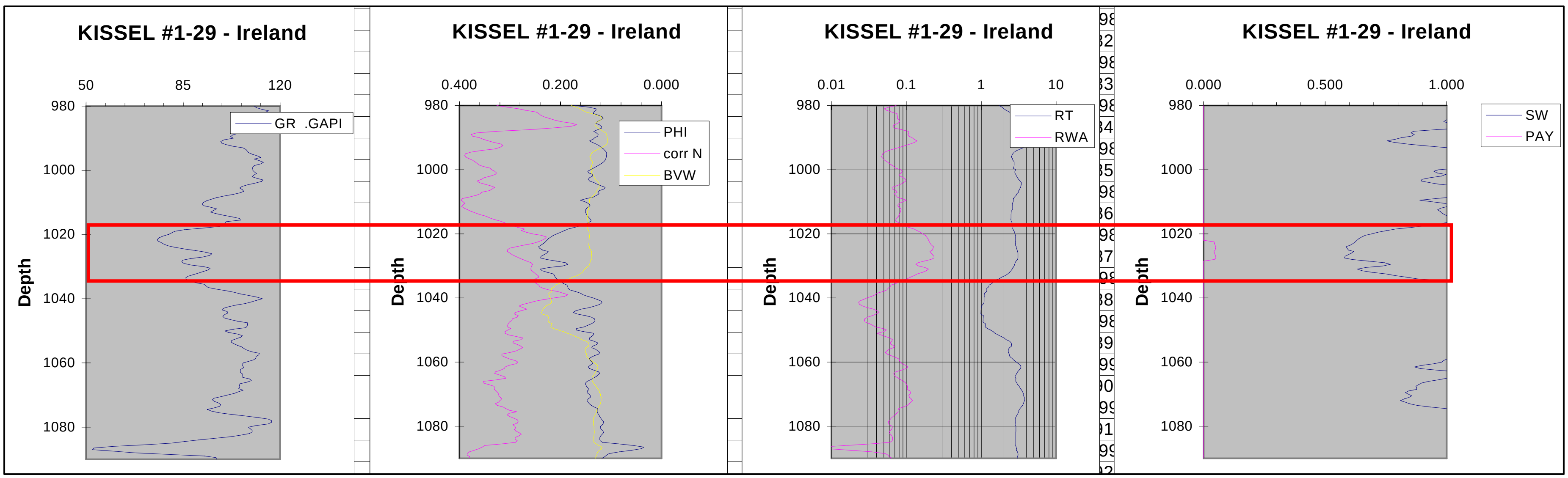
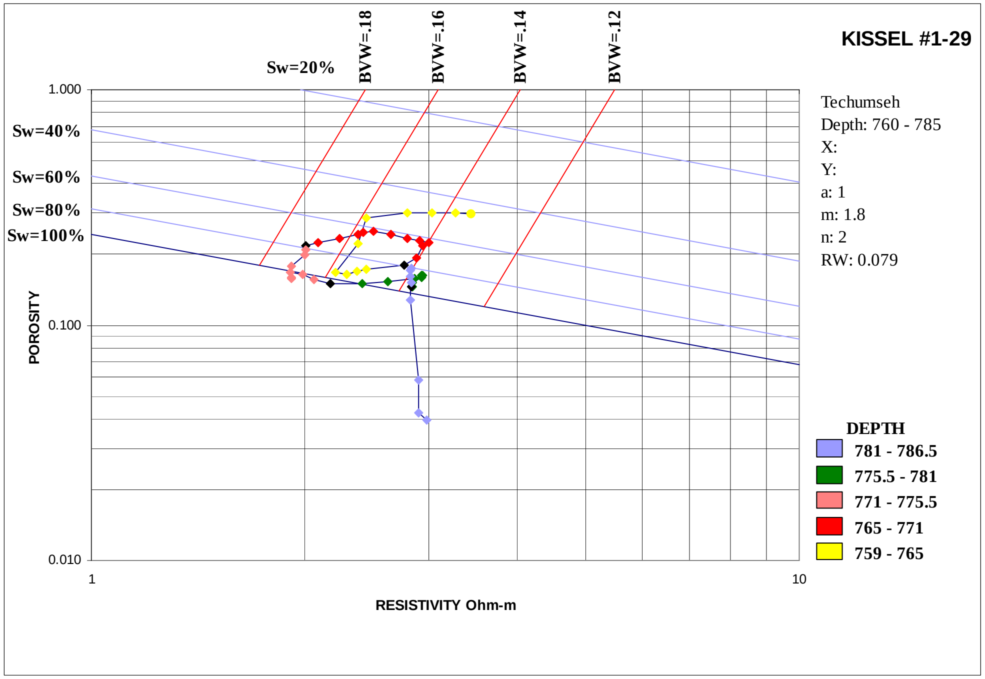


Figure 57: Log analysis of Ireland Sandstone in Kissel 1-29 well.



Kissel 1-29

Tecumseh (766-771 ft)

- Gas effect on neutron porosity, separation between density porosity and BVW
- BVW < 0.16 with some clustering around 0.14. Sw close to 60%
- Possible mudcake build up over this interval indicating higher permeability
- **Possibly gas**

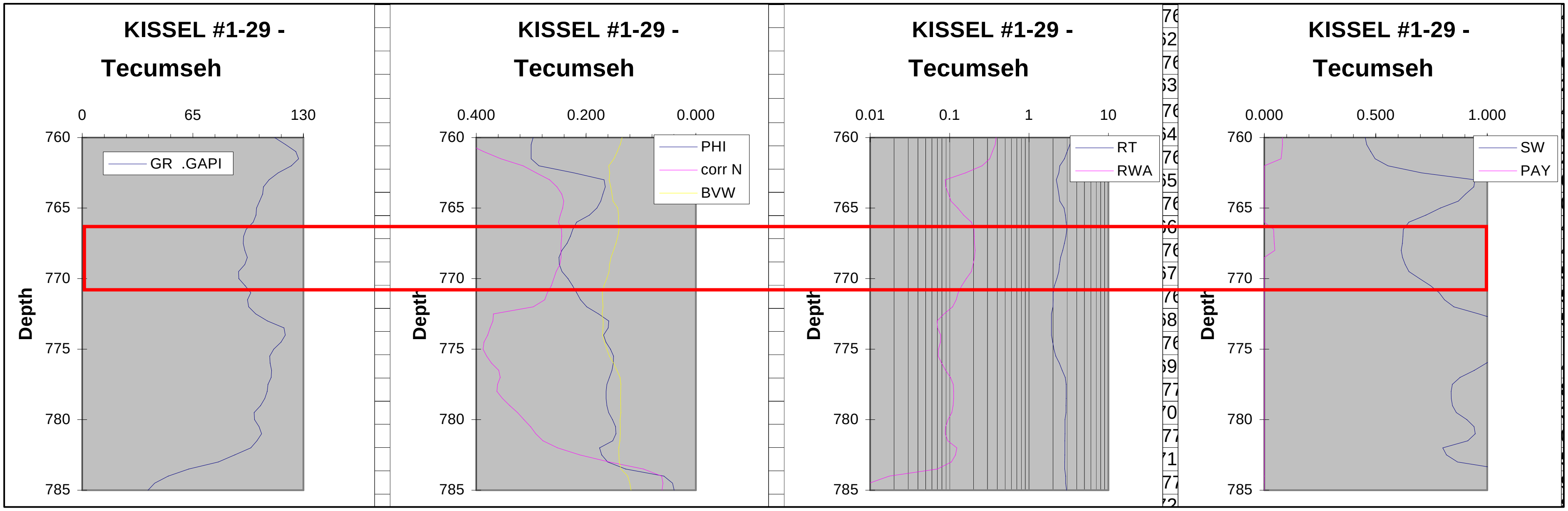


Figure 58: Log analysis of Tecumseh Sandstone in Kissel 1-29 well.

Kissel 1-29

• Mudcake buildup 762-772 ft.

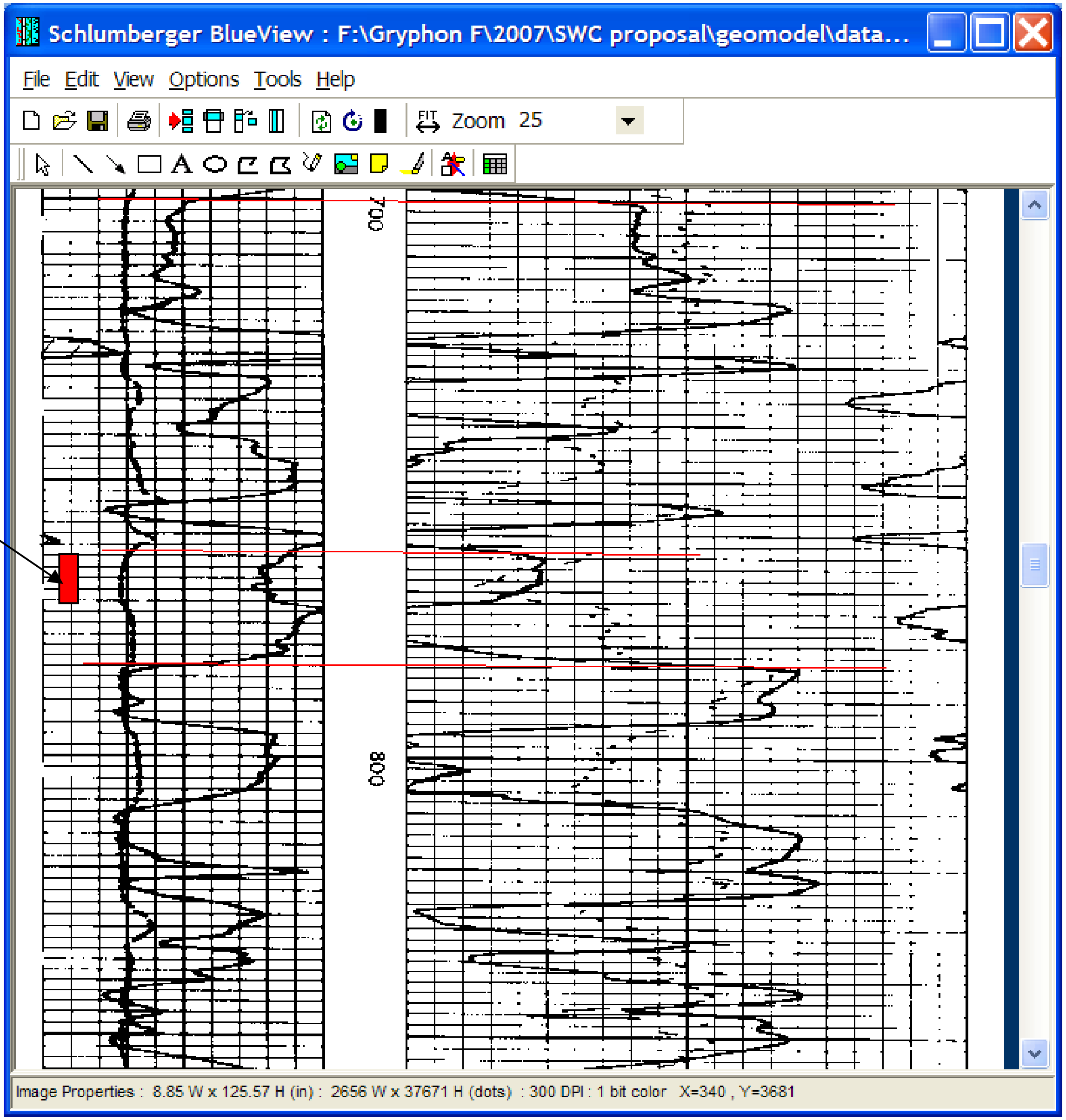
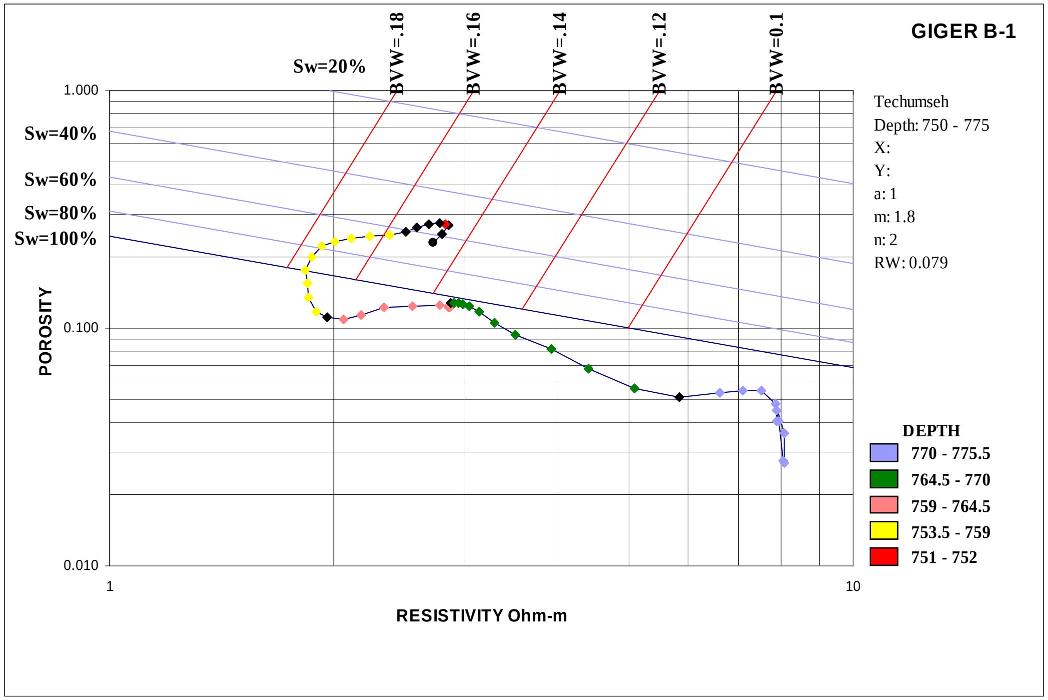


Figure 59: Log showing mud cake buildup over the Tecumseh Sandstone in Kissel 1-29 well.



Giger B-1

Tecumseh (750-755 ft)

- Gas effect on neutron porosity, separation between density porosity and BVW
- BVW clusters around 0.15, moderately high density porosity (28%), Sw ~ 60% or less
- GR high
- **Possibly gas bearing. No show during drilling.**

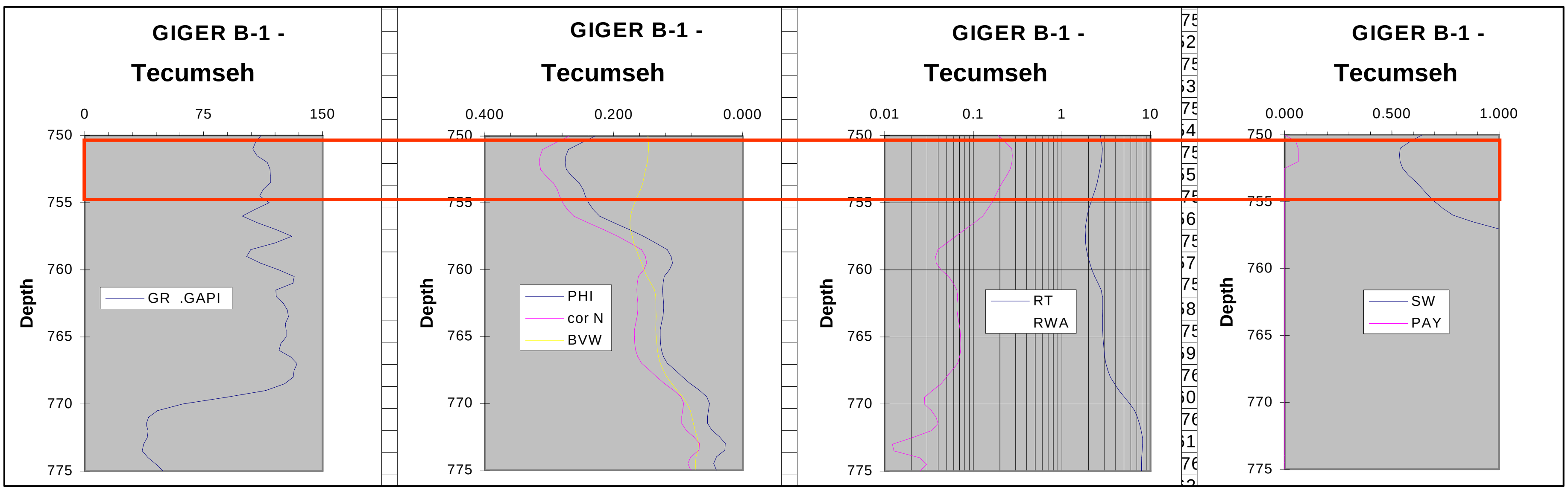
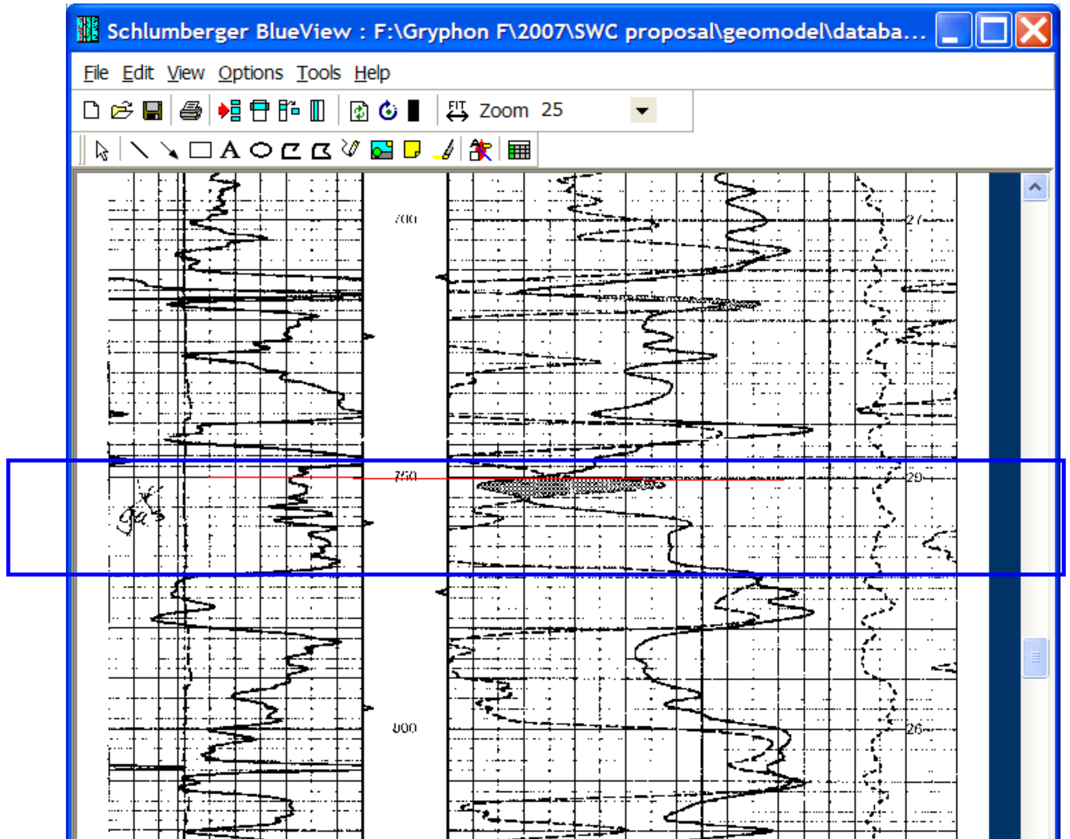


Figure 60: Log analysis of Tecumseh Sandstone in Giger B1 well.

Giger B-1

- Samples indicate fine grain porous sandstone in spite of high gamma ray;
- No gas show during drilling.



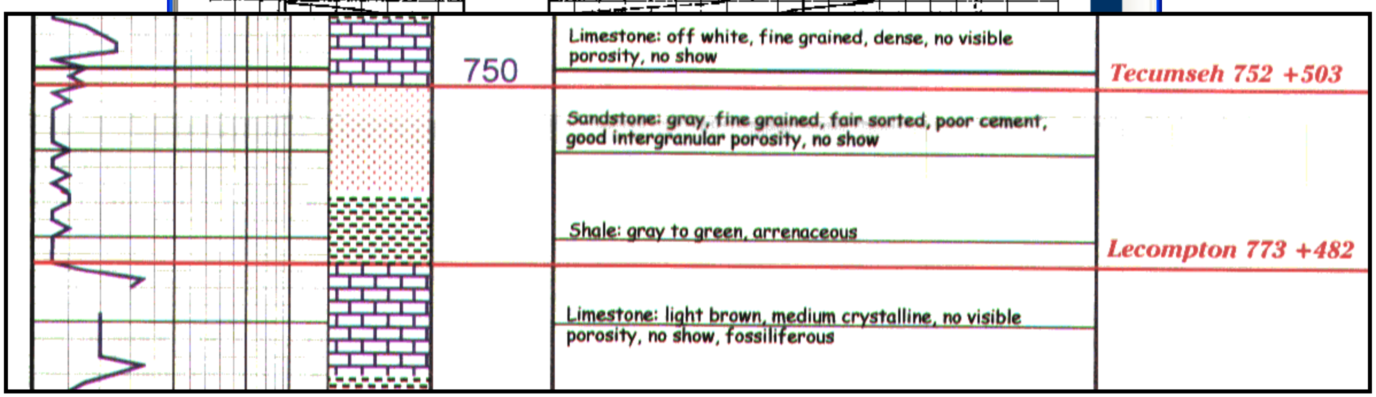
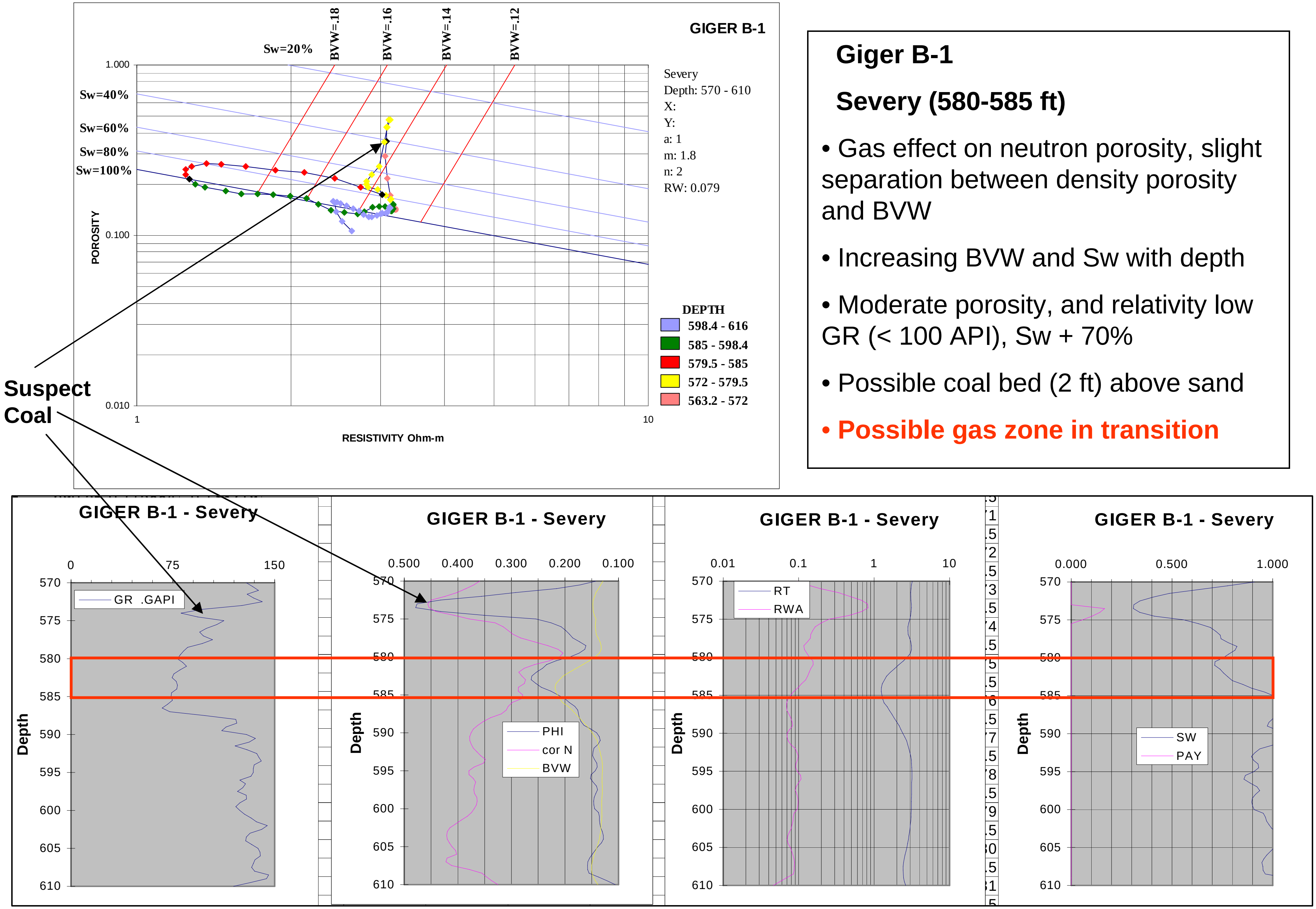


Figure 61: Log showing high GR over sand interval while georeport indicates fine grained sand from the same interval.



Giger B-1

Severy (580-585 ft)

- Gas effect on neutron porosity, slight separation between density porosity and BVW
- Increasing BVW and Sw with depth
- Moderate porosity, and relativity low GR (< 100 API), Sw + 70%
- Possible coal bed (2 ft) above sand
- **Possible gas zone in transition**

Figure 62: Log analysis of Severy Sandstone in Giger B1 well.

Giger B-1, Severy

- **Possible coal bed**

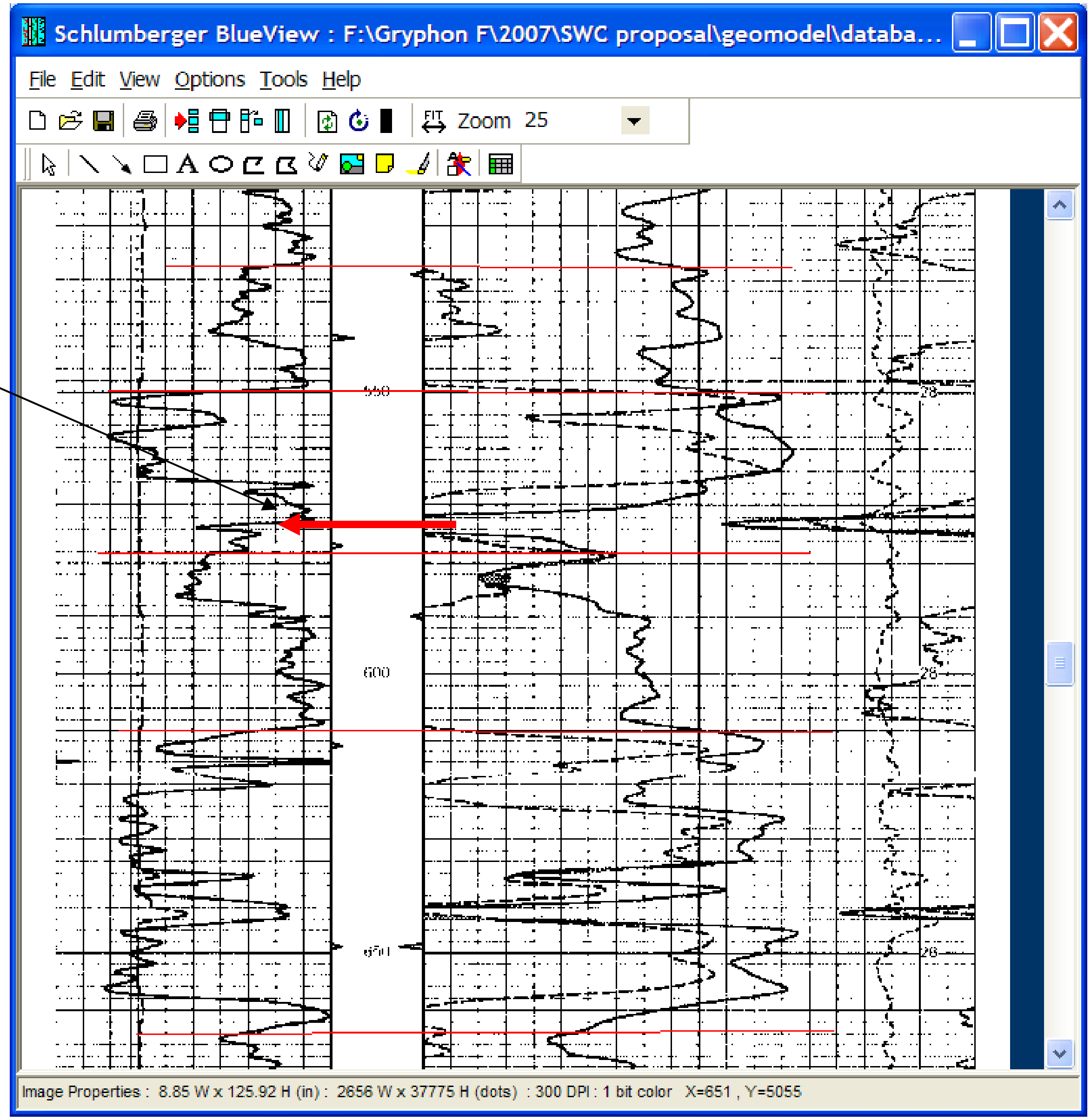
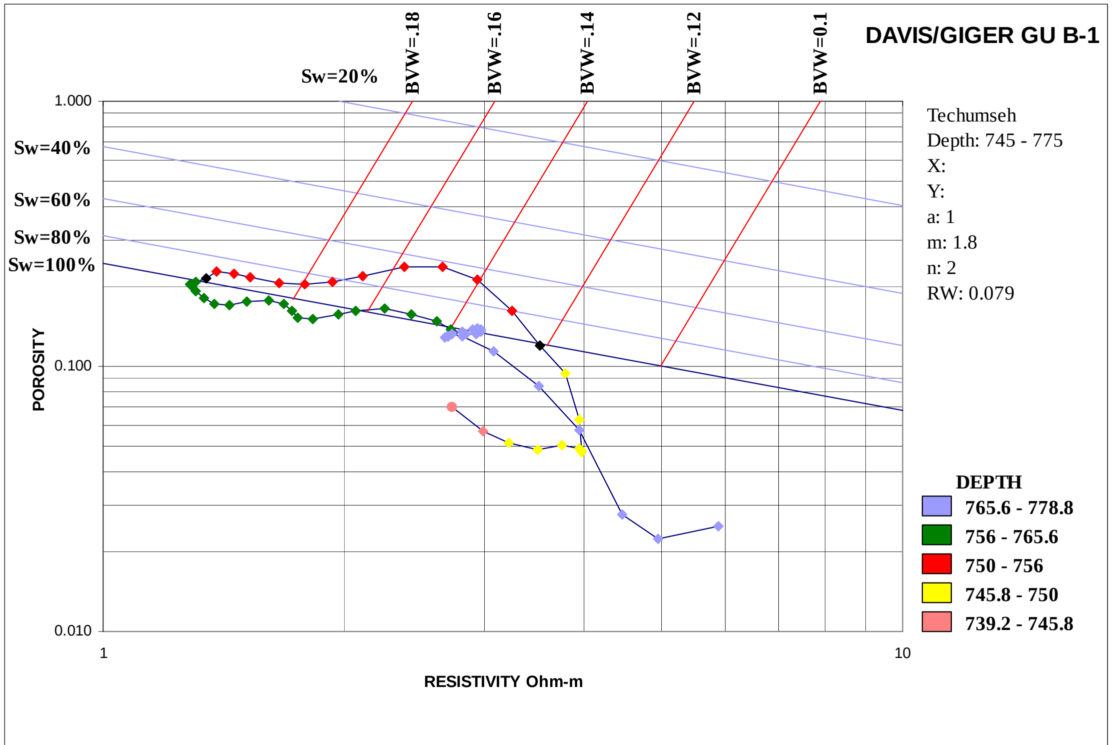


Figure 63: Log showing presence of possible coal bed in Giger B1 well.



Davis/Giger GU B-1

Tecumseh (752-756 ft)

- No gas effect, separation between density porosity and BVW
- Increasing Sw and BVW with depth. Upper sand Sw < 80% and BVW < 0.16.
- **Some chance of gas in transition. No show during drilling.**

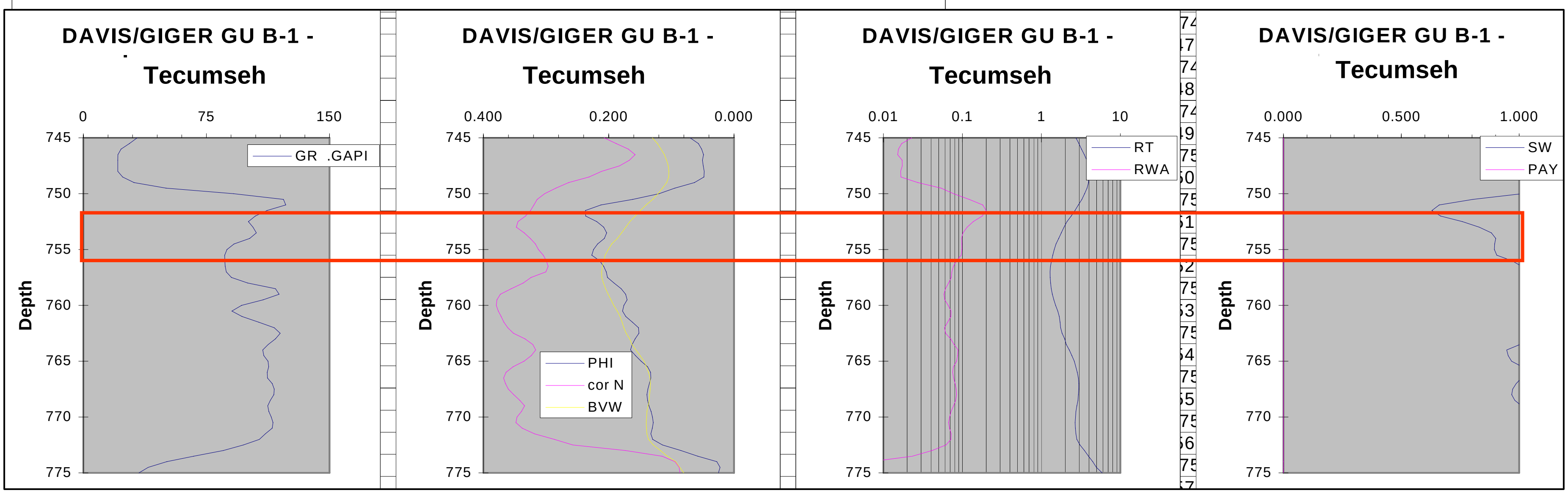
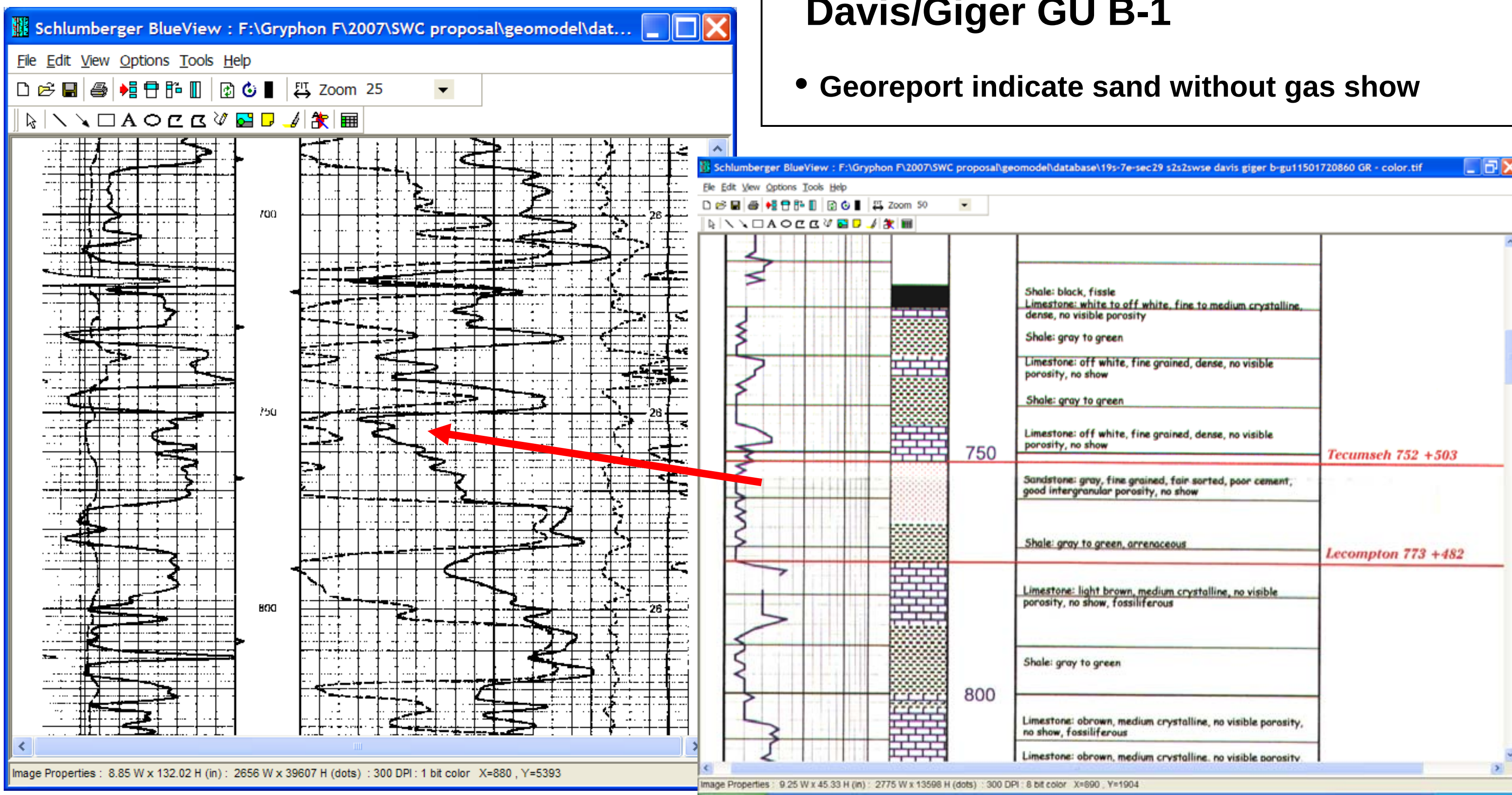


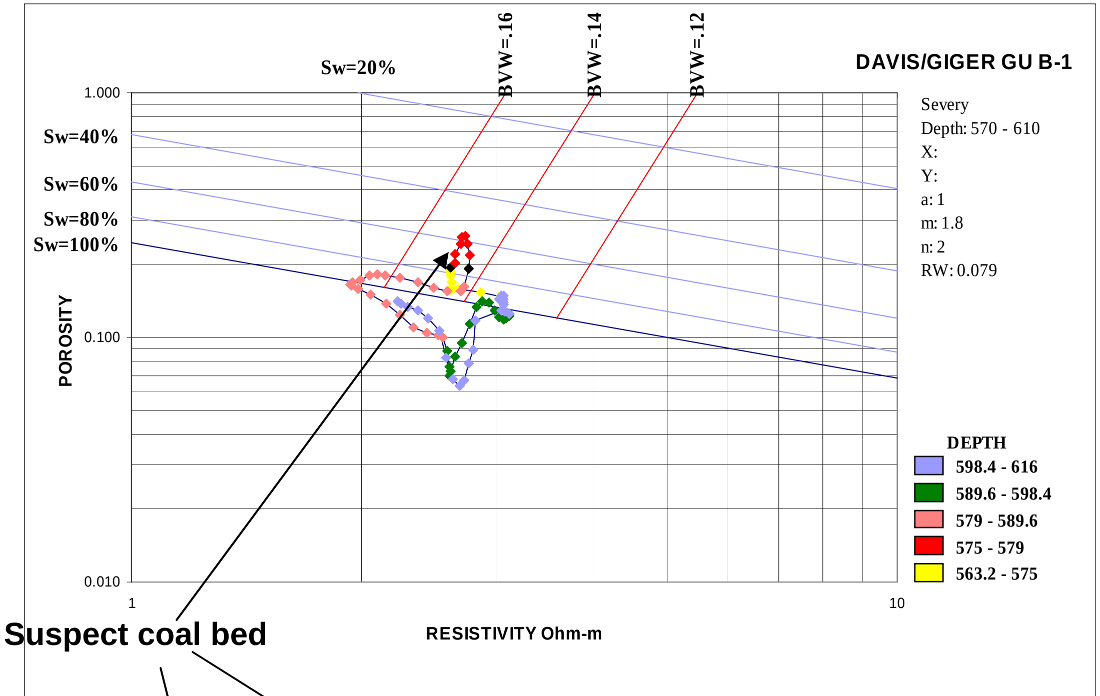
Figure 64: Log analysis of Tecumseh Sandstone in Davis-Giger GU B1 well.



Davis/Giger GU B-1

- **Georeport indicate sand without gas show**

Figure 65: Geo report indicates no gas shows during drilling of Tecumseh Sandstone in Davis/Giger GU B1 well.



Davis/Giger GU B-1

Severy (579-586 ft)

- Suspect coal to overly the sand
- Little separation between density porosity and BVW
- Sw +90%
- **Wet sand**

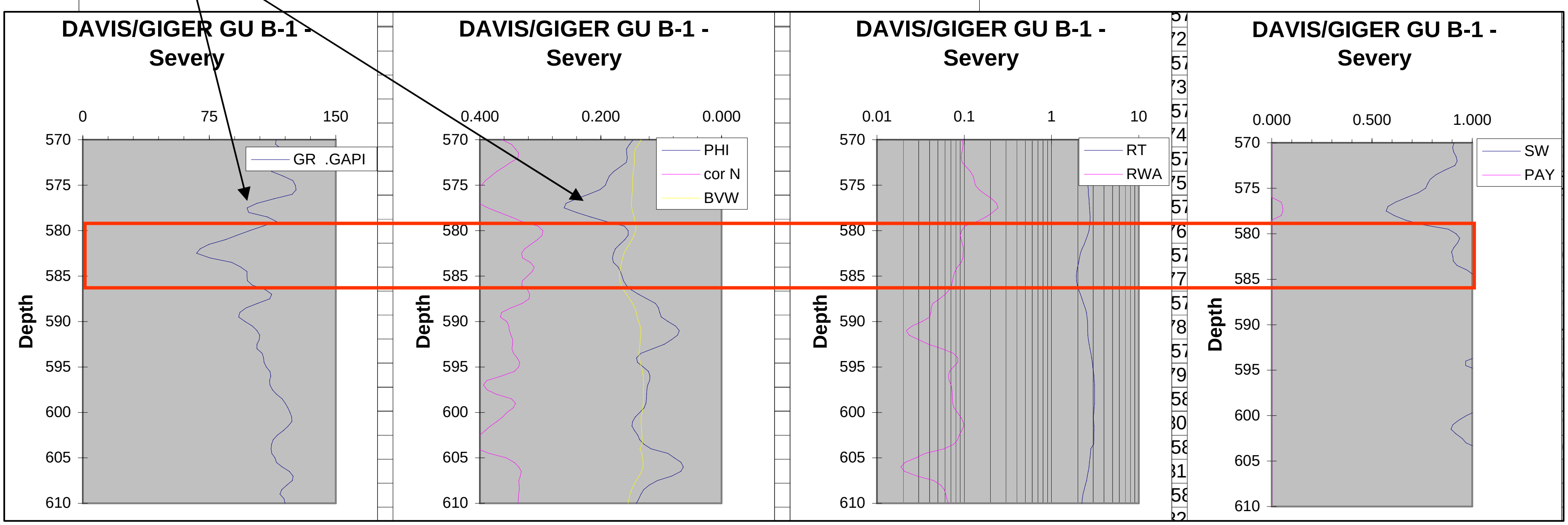
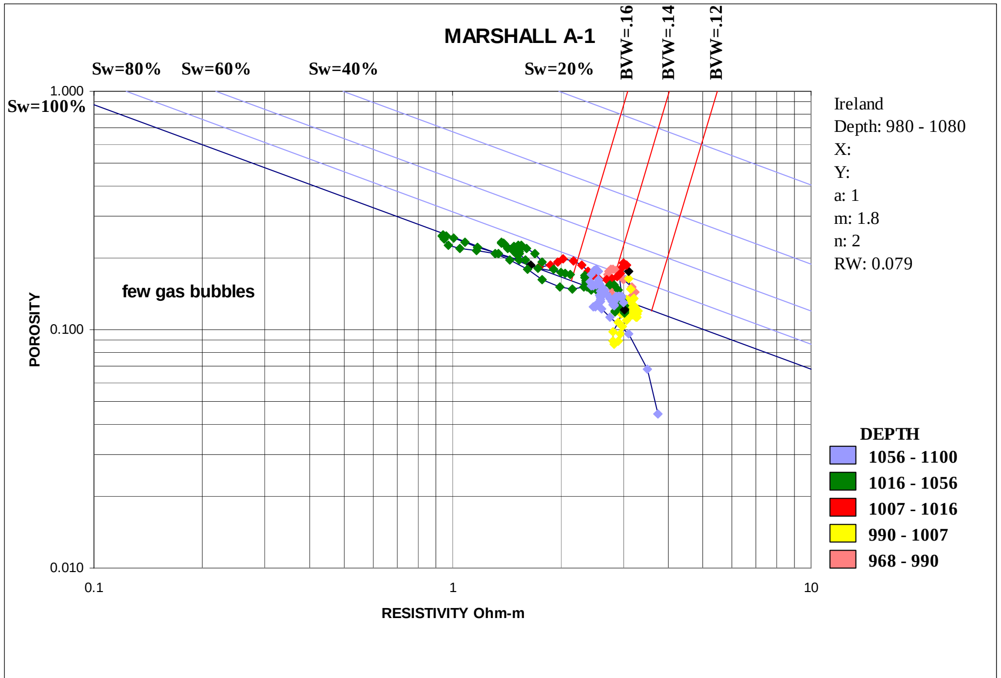


Figure 66: Log analysis of Severy Sandstone in Davis-Giger GU B1 well.



Marshall A1

Ireland (1007-1026 ft)

- Minor separation between density porosity and BVW
- High GR (+100 API) due to micacious sand (georeport)
- Some gas show (bubbles) observed (georeport)
- Sw + 90%
- **Wet Sand**

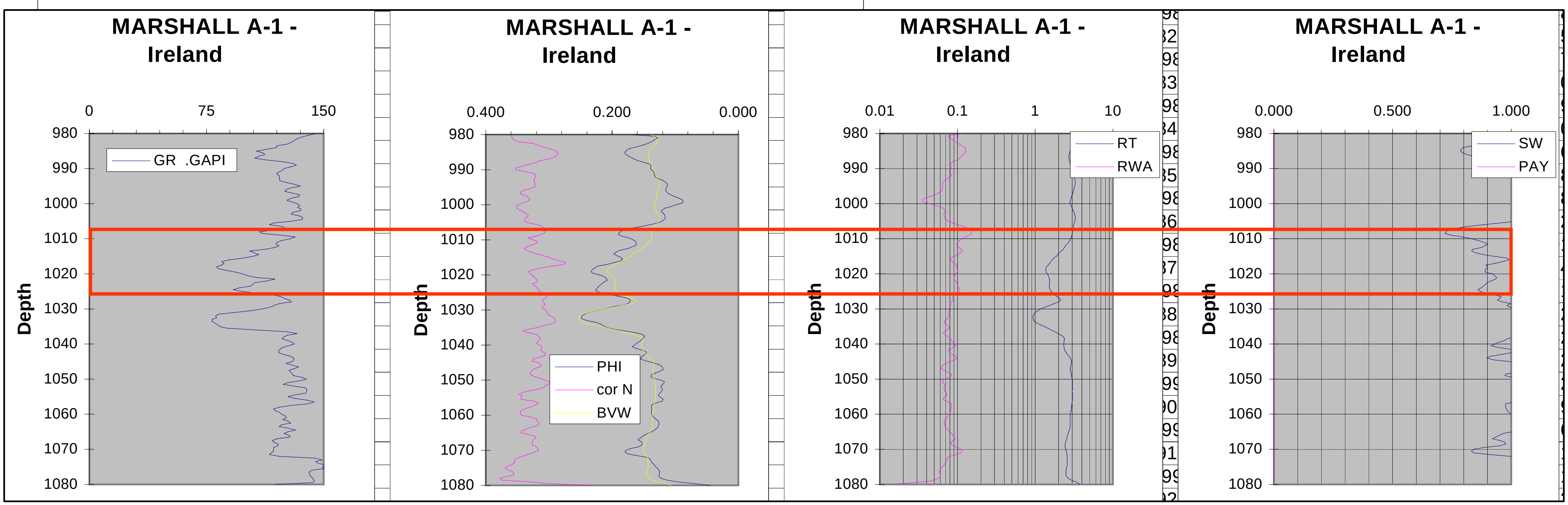


Figure 67: Log analysis of Ireland Sandstone in Marshall A1 well.

Marshall A-1

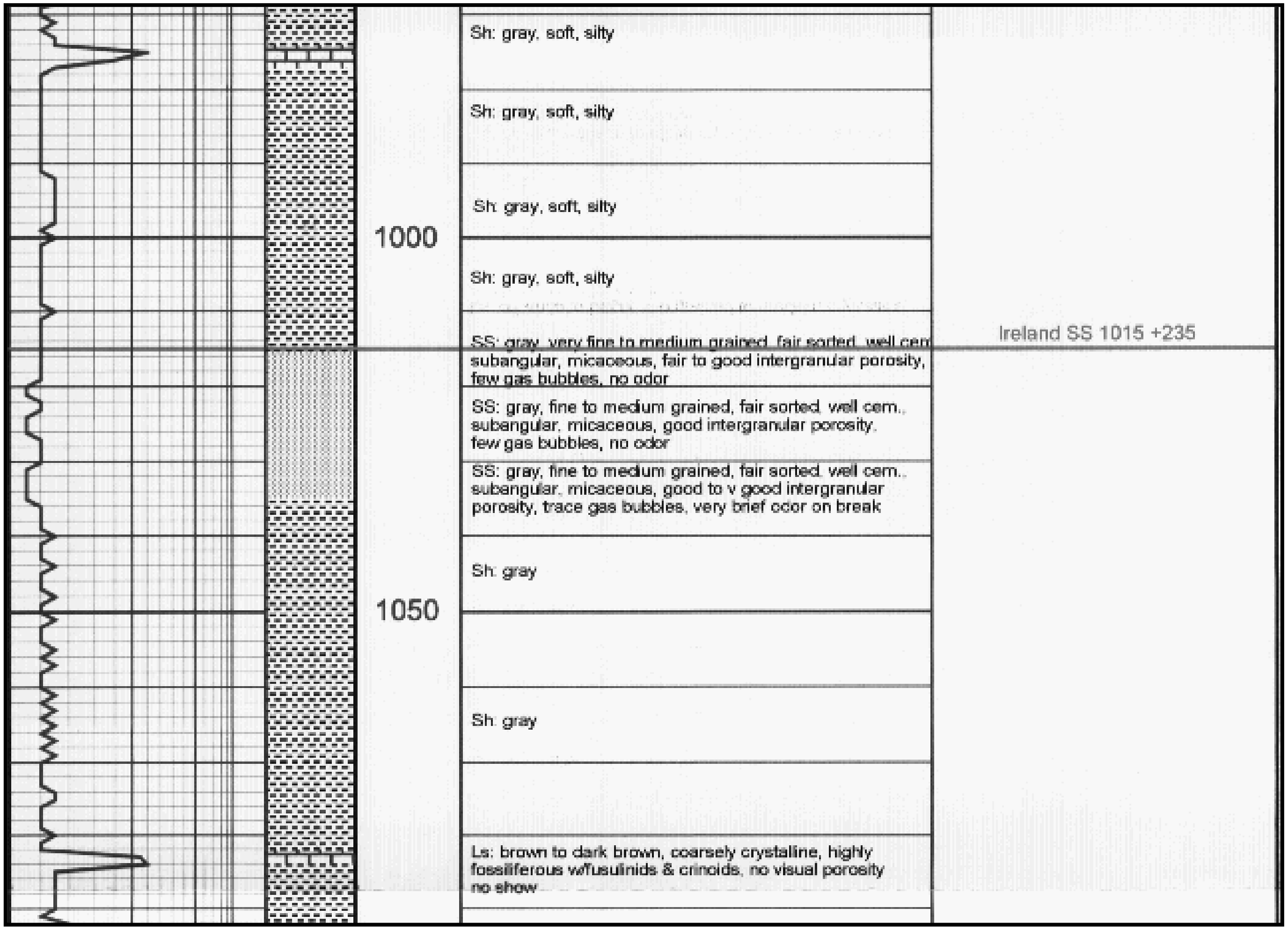
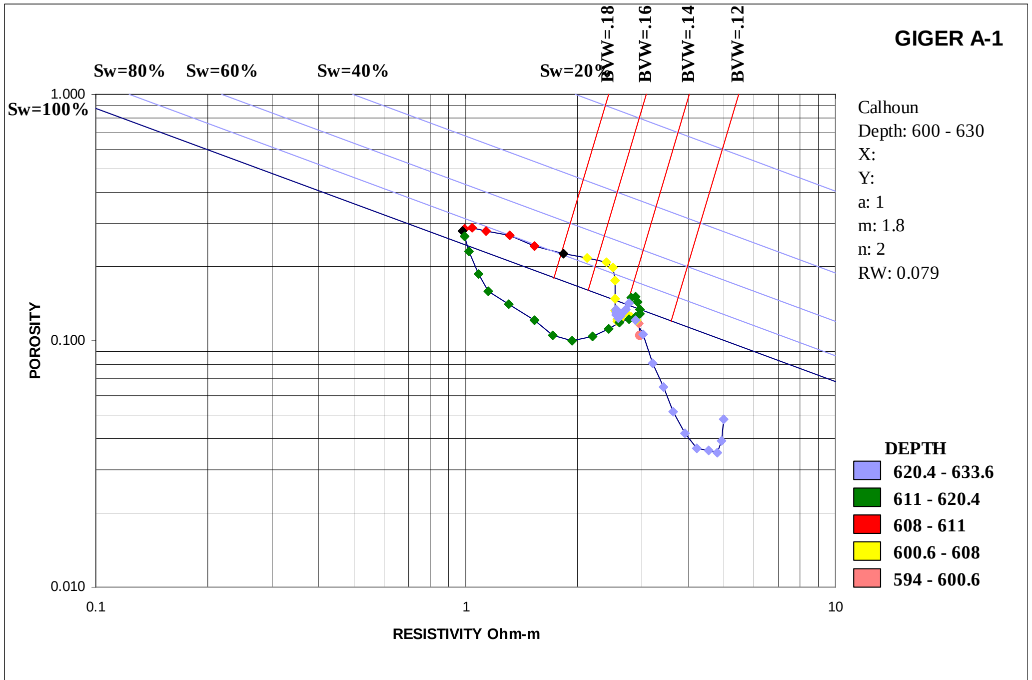


Figure 68: Geo-report showing mention of micacious sand and gas bubbles during drilling of Ireland in Marshall A1 well.



Giger A-1

Calhoun (608-611 ft)

- Gas effect on neutron porosity, separation between density porosity and BVW
- Sw~80% and BVW +0.18
- GR~75 API
- **Probable gas in transition**

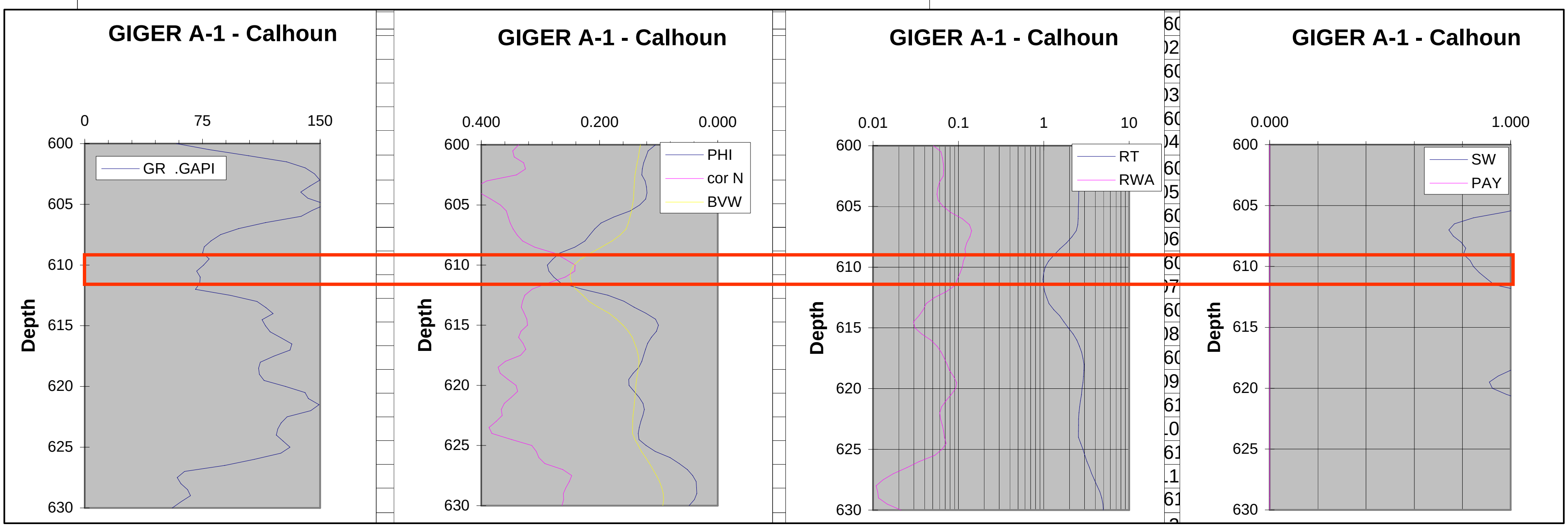
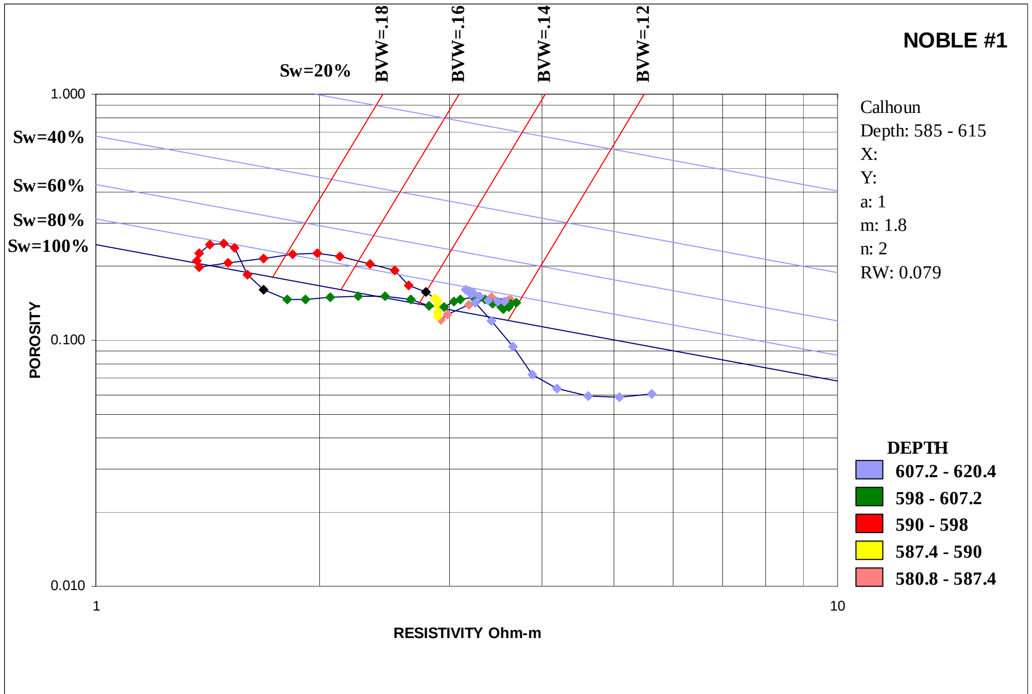


Figure 69: Log analysis of Calhoun Sandstone in Giger A1 well.



Noble #1

Calhoun (593-598 ft)

- Gas effect on neutron porosity, some separation between density porosity and BVW
- High Sw +80% and increasing with depth. BVW +0.14 and increases with depth. Slight gas bubbles on drilling
- **Gas in transition**

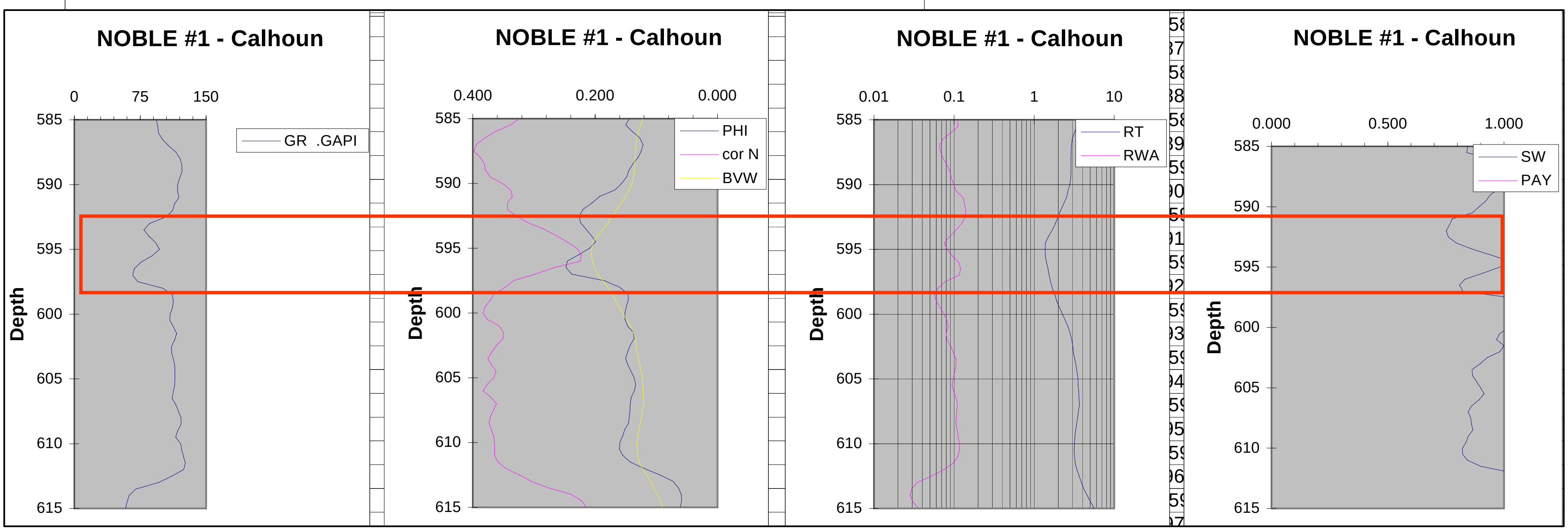


Figure 70: Log analysis of Calhoun Sandstone in Noble 1 well.

Noble #1

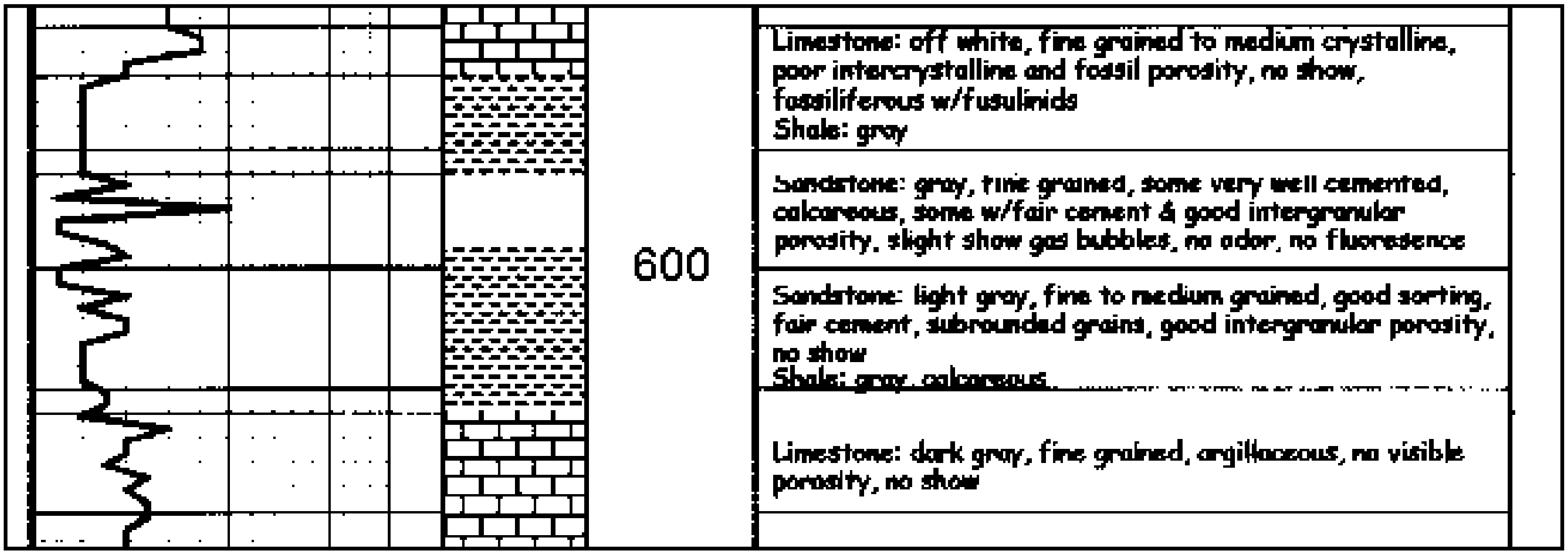
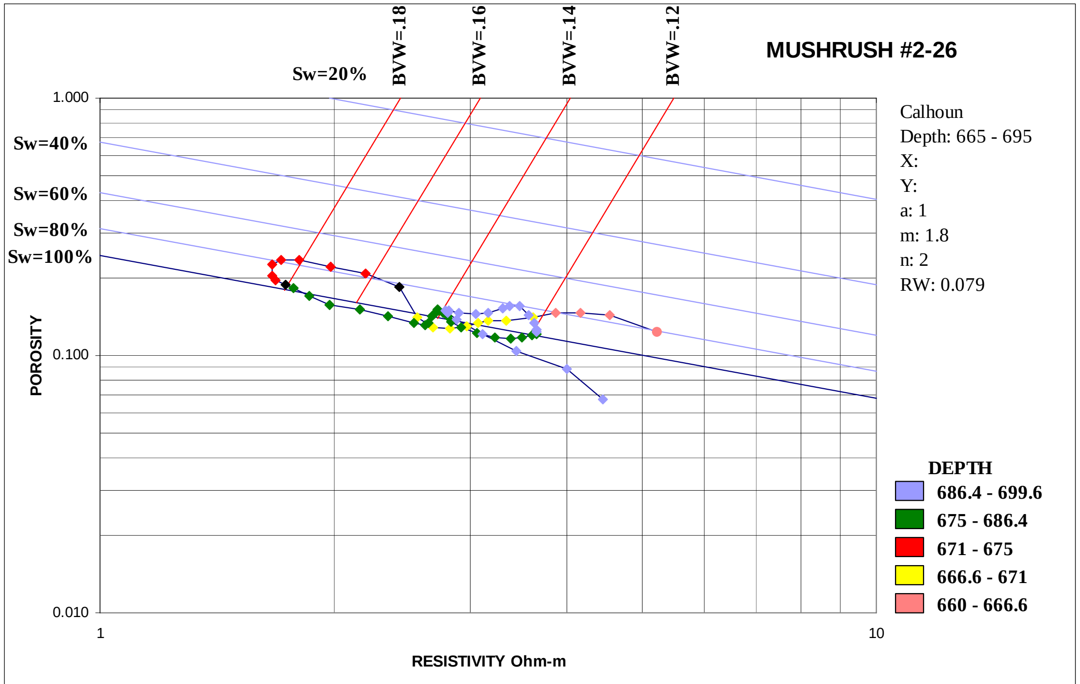


Figure 71: Geo-report showing observation of gas bubbles during drilling of Calhoun Sandstone in Noble 1 well.



Mushrush 2-26

Calhoun (671-675 ft)

- Appearance of gas effect on neutron log, slight separation between density log and BVW
- Sw +80%, BVW >0.16
- **Poor prospect - gas in transition**

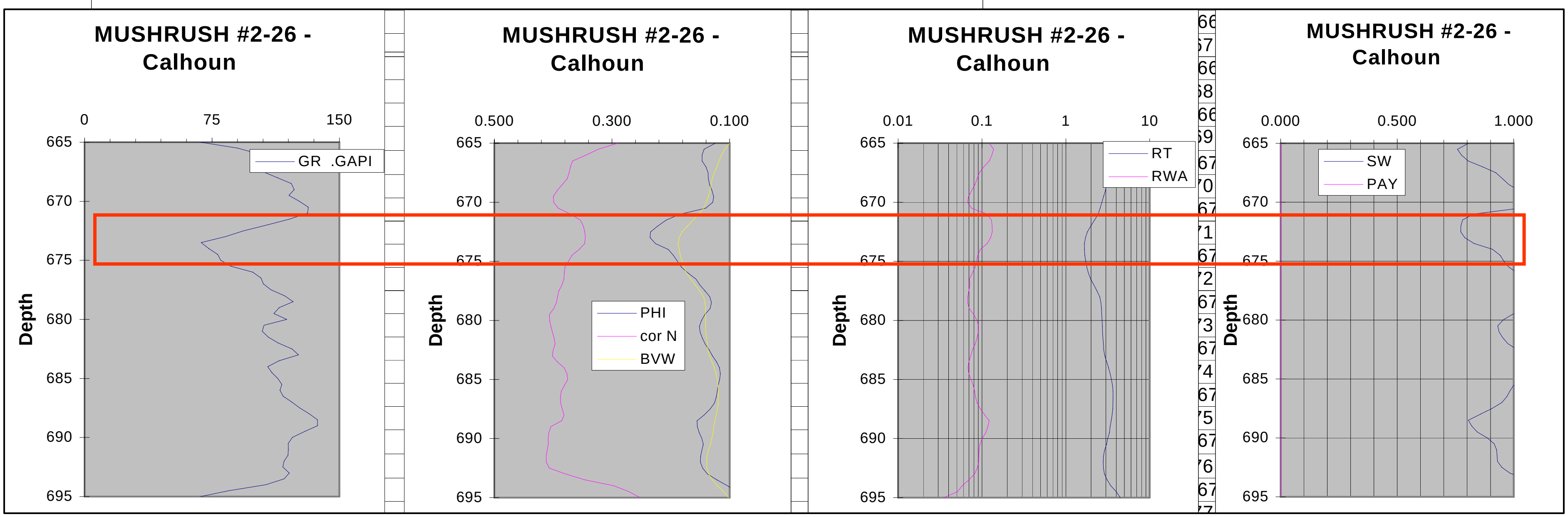
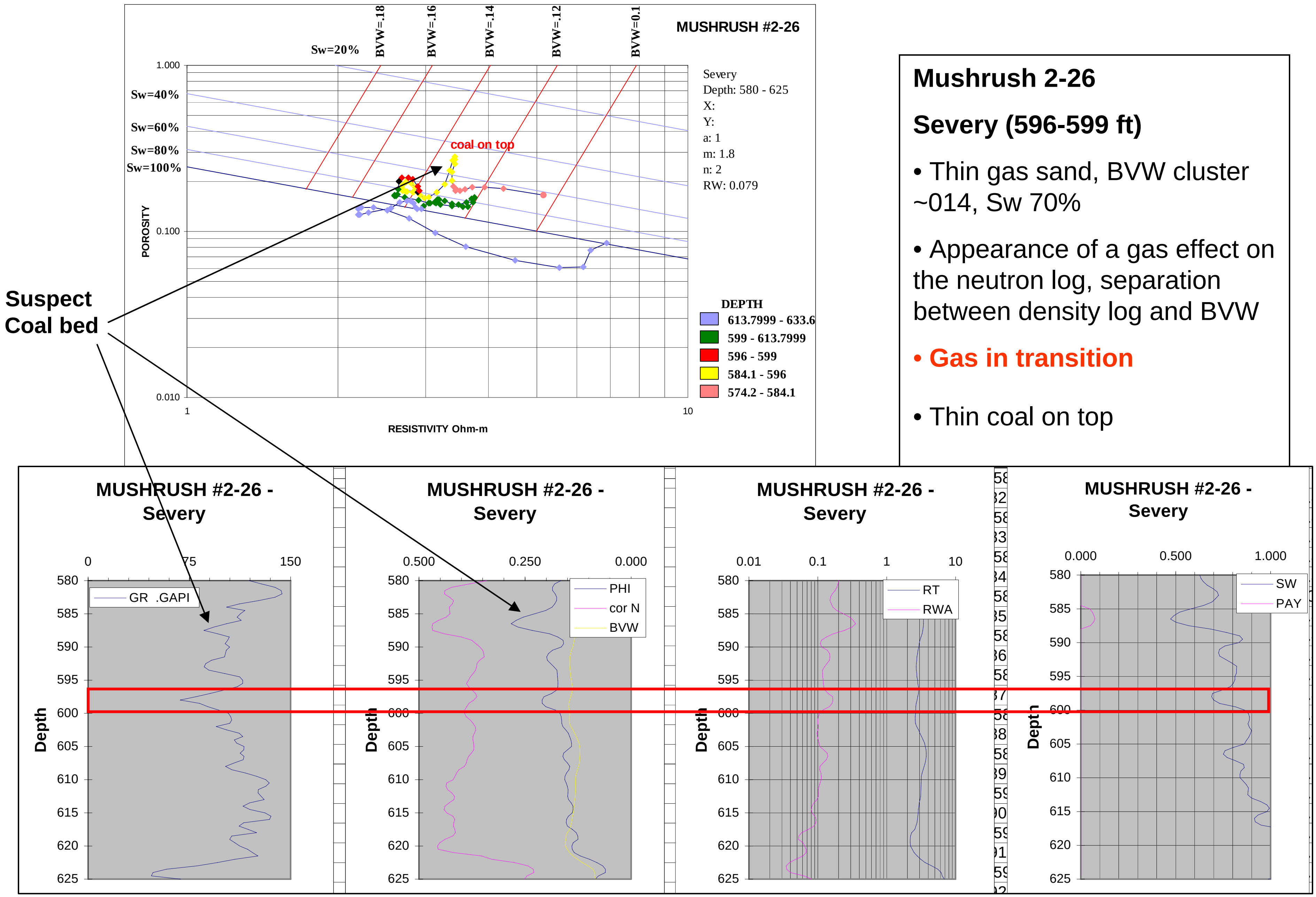


Figure 72: Log analysis of Calhoun Sandstone in Mushrush 2-26 well.

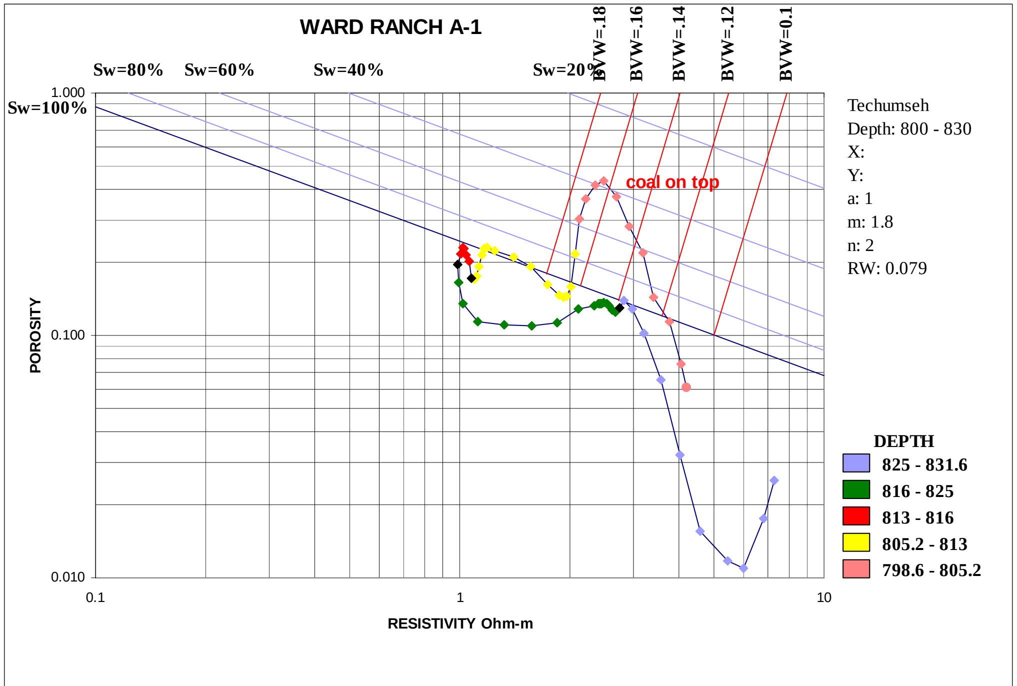


Mushrush 2-26

Severy (596-599 ft)

- Thin gas sand, BVW cluster ~014, Sw 70%
- Appearance of a gas effect on the neutron log, separation between density log and BVW
- **Gas in transition**
- Thin coal on top

Figure 73: Log analysis of Severy Sandstone in Mushrush 2-26 well.



Ward Ranch A-1

Tecumseh (808-816 ft)

- Washout 802-806 ft – so shale (and not coal) overlies the sand
- BVW > density porosity
- **Wet sand**

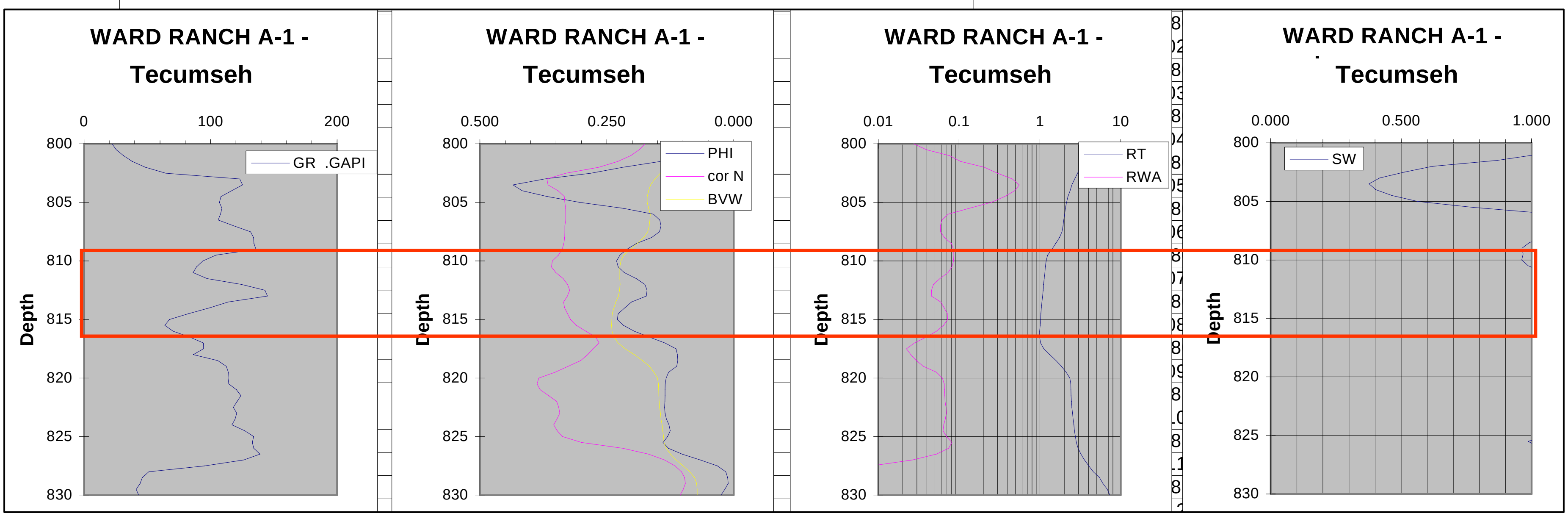


Figure 74: Log analysis of Tecumseh Sandstone in Ward Ranch A1 well.

Ward Ranch A-1

- Wash out coincides with high porosity – suggestive of shale bed rather than coal.

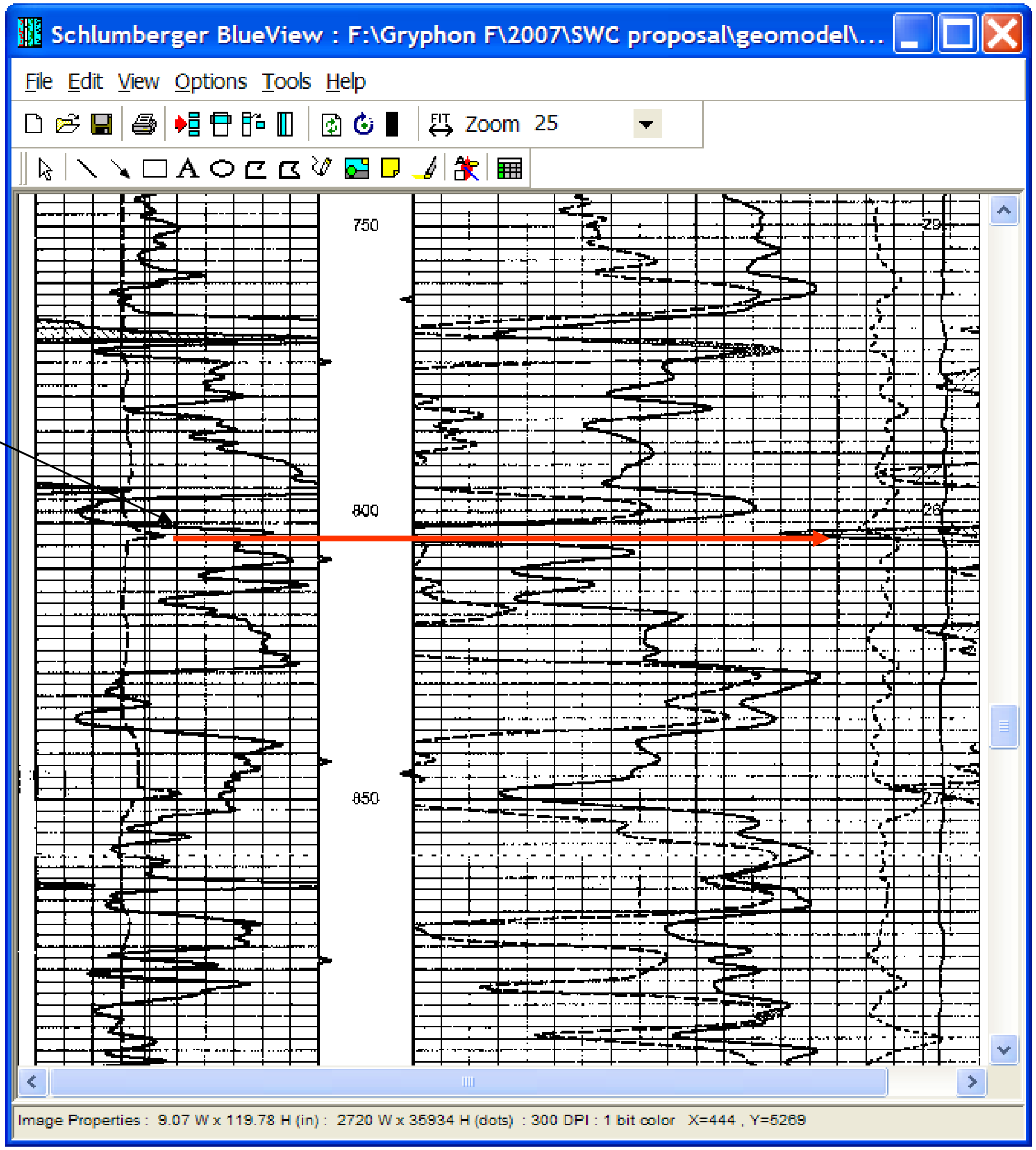
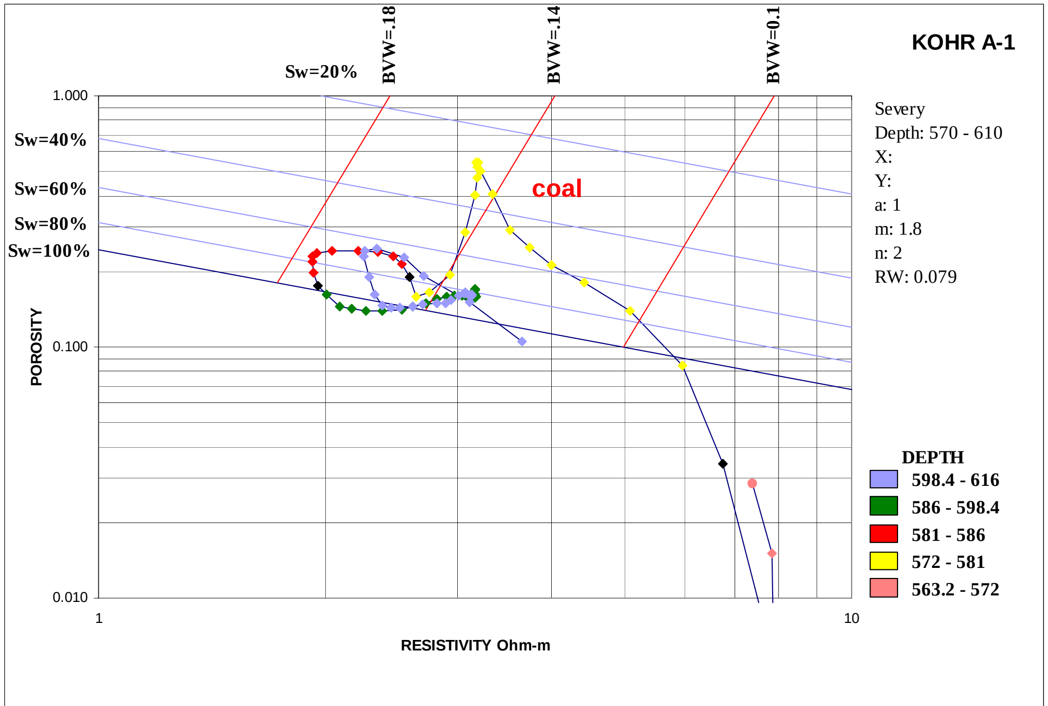


Figure 75: Log showing washout coincident with porosity high implying presence of shale overlying the Tecumseh Sandstone in Ward Ranch A1 well.



Kohr A-1

Severy (582-86 ft)

- Coal overlying sand
- Gas effect on neutron porosity, separation between density porosity and BVW
- Sw < 80% and increases with depth like BVW (> 0.145)
- **Probably gas in transition**

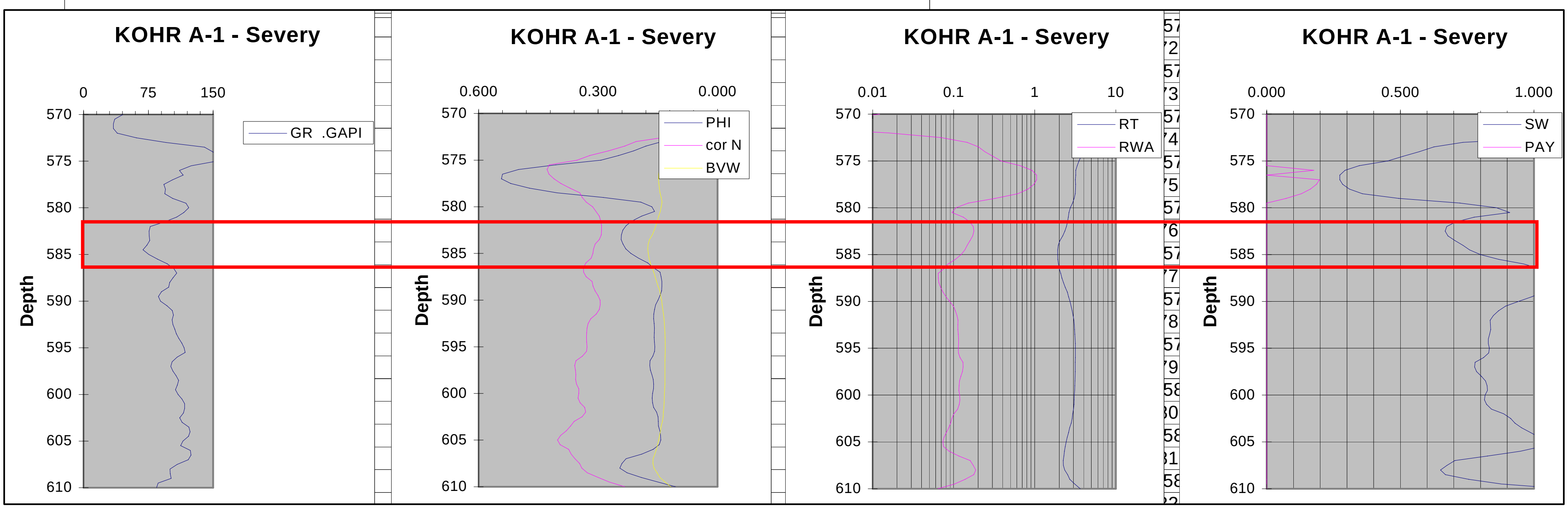
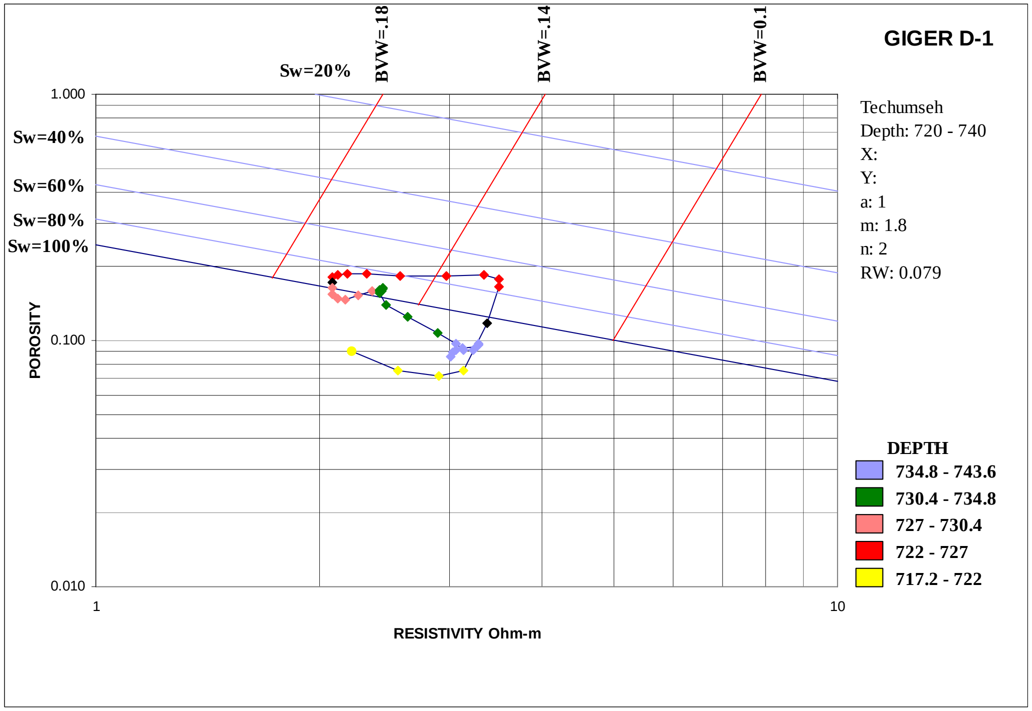


Figure 76: Log analysis of Severy Sandstone in Kohr A1 well.



Giger D-1

Tecumseh (722-727 ft)

- BVW and Sw increase with depth
- Separation between density porosity and BVW
- **Poor prospect - gas in transition**

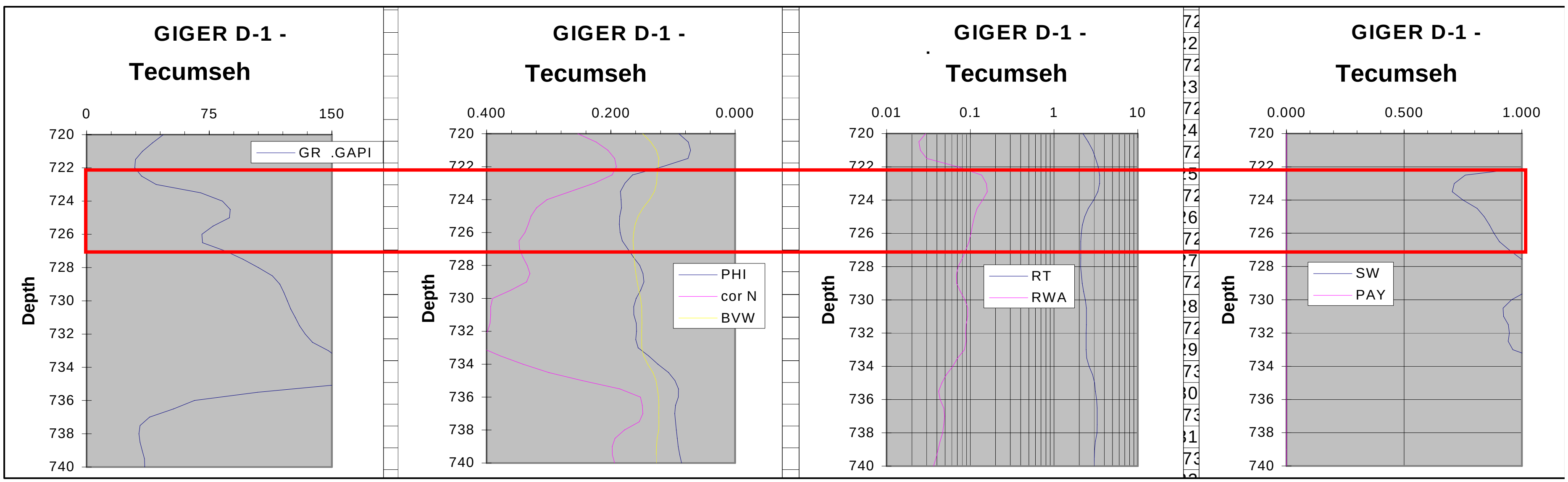
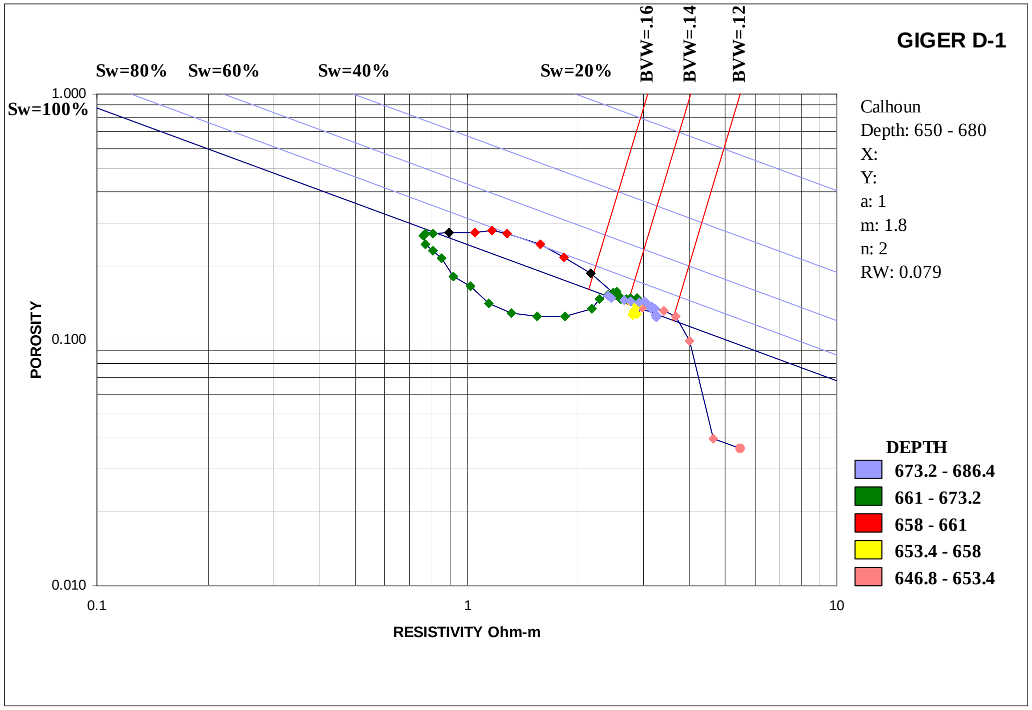


Figure 77: Log analysis of Tecumseh Sandstone in Giger D1 well.



Giger D-1

Calhoun (658-661 ft)

- Gas effect on neutron density, some separation between density porosity and BVW
- Sw > 80% and increases with depth. BVW + 0.16
- **Poor prospect - Gas in transition**,

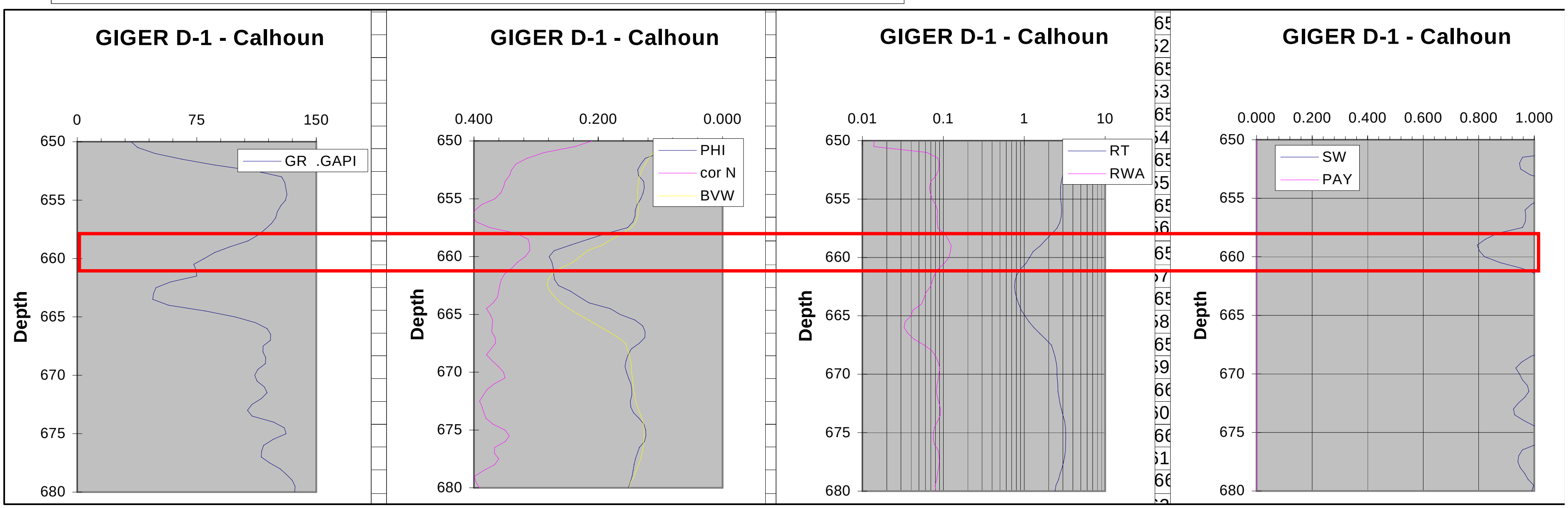


Figure 78: Log analysis of Calhoun Sandstone in Giger D1 well.

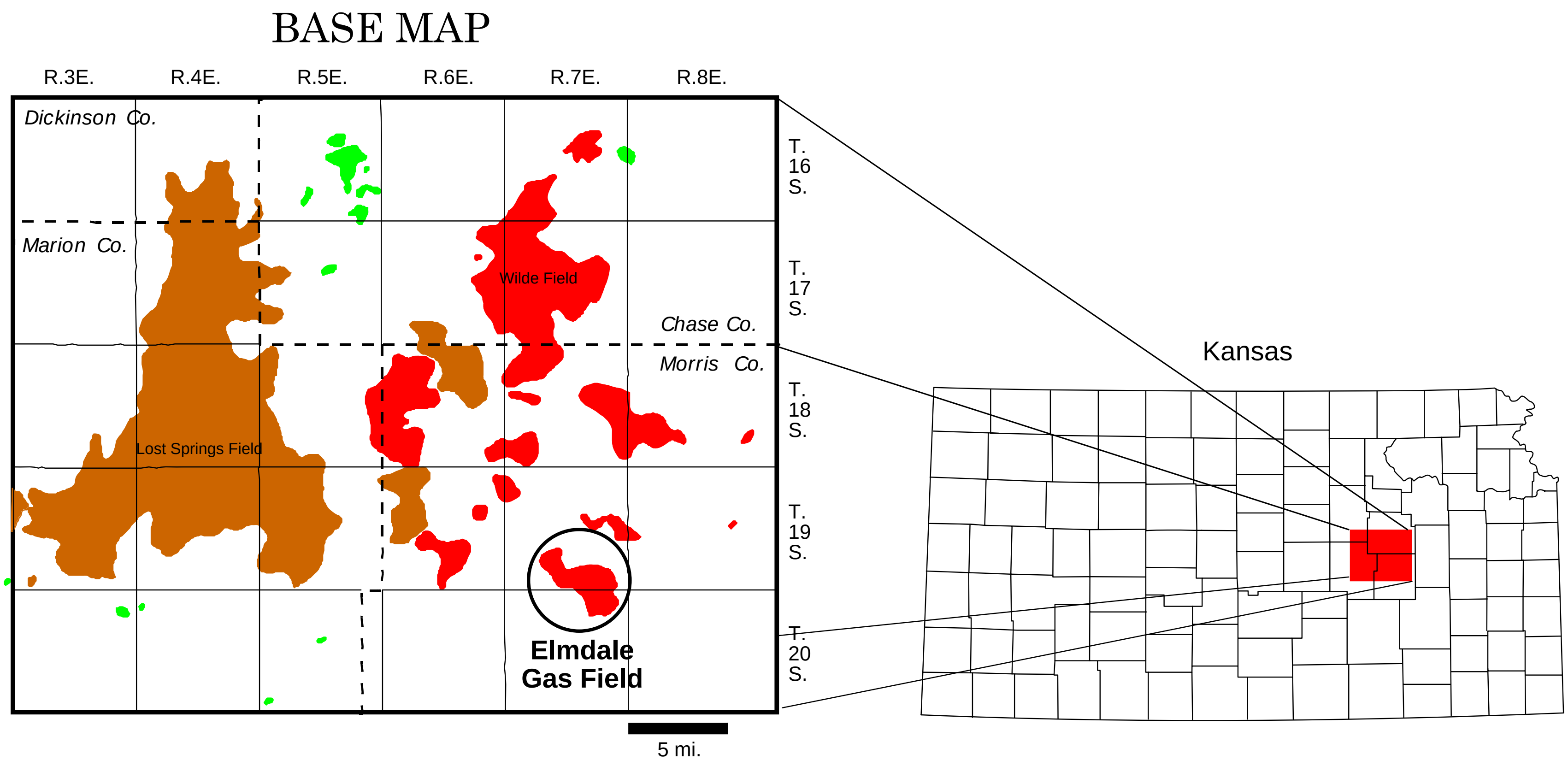


Figure 79: Region around the Elmdale field (Chase County, Kansas) where reported gas samples were collected.

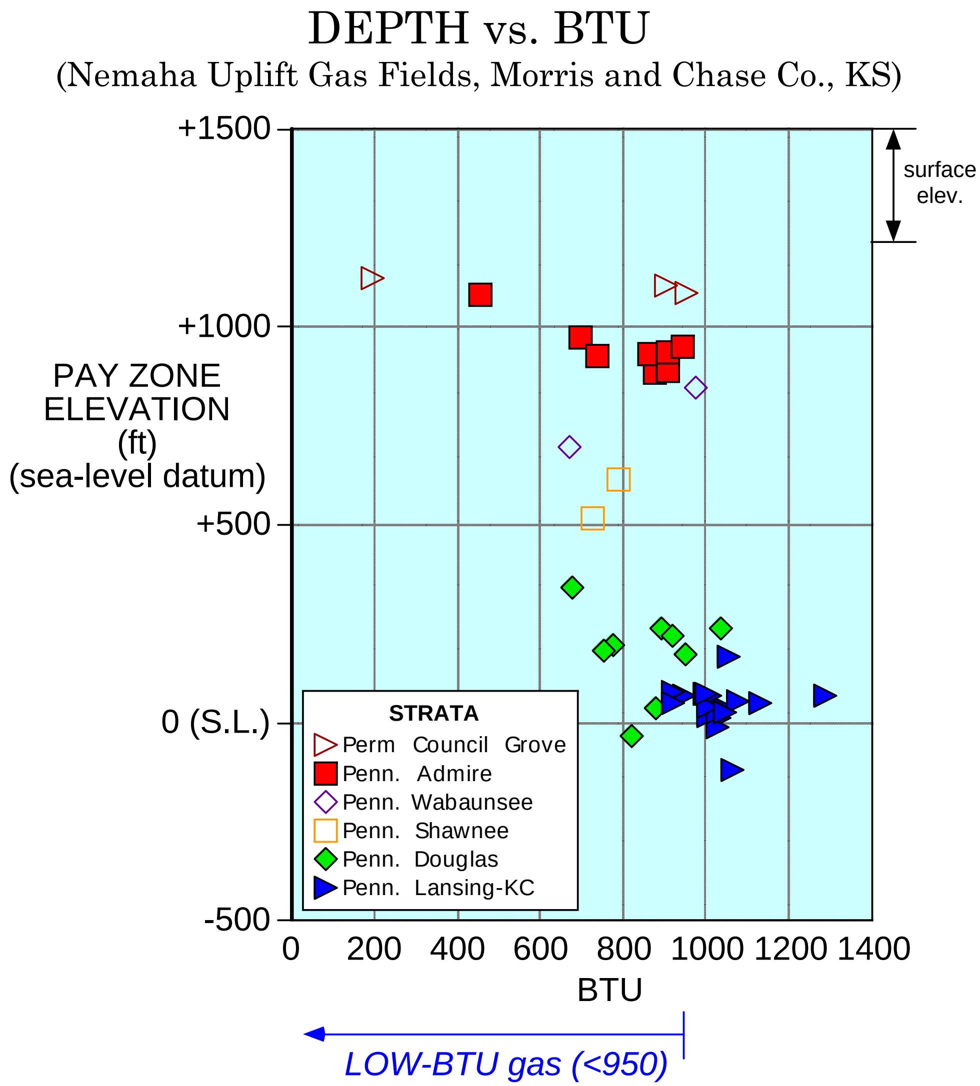


Figure 80: Plot showing occurrence of low-BTU gas in shallower pay zones.

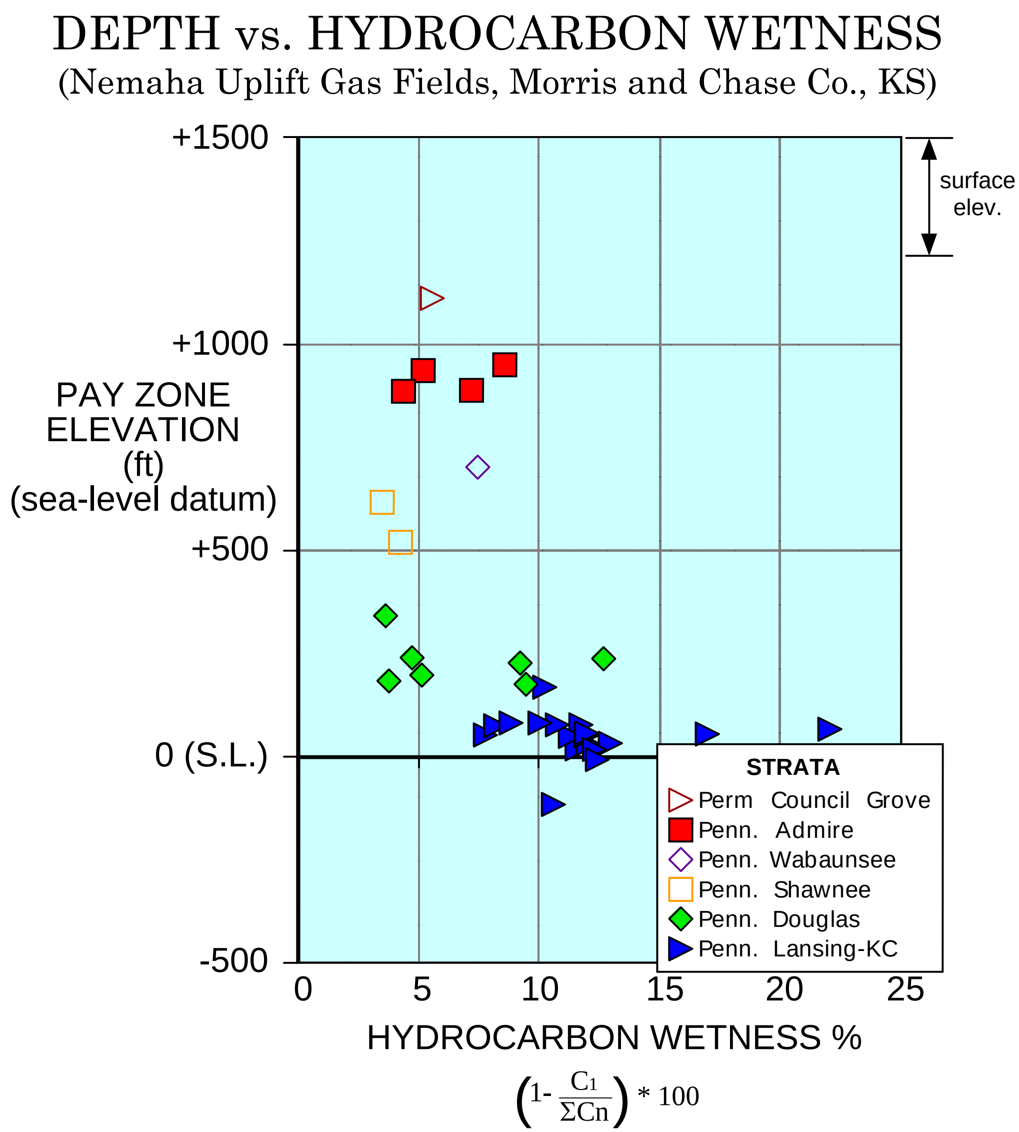


Figure 81: Plot showing the increase of hydrocarbon wetness with increasing age and depth of producing formation.

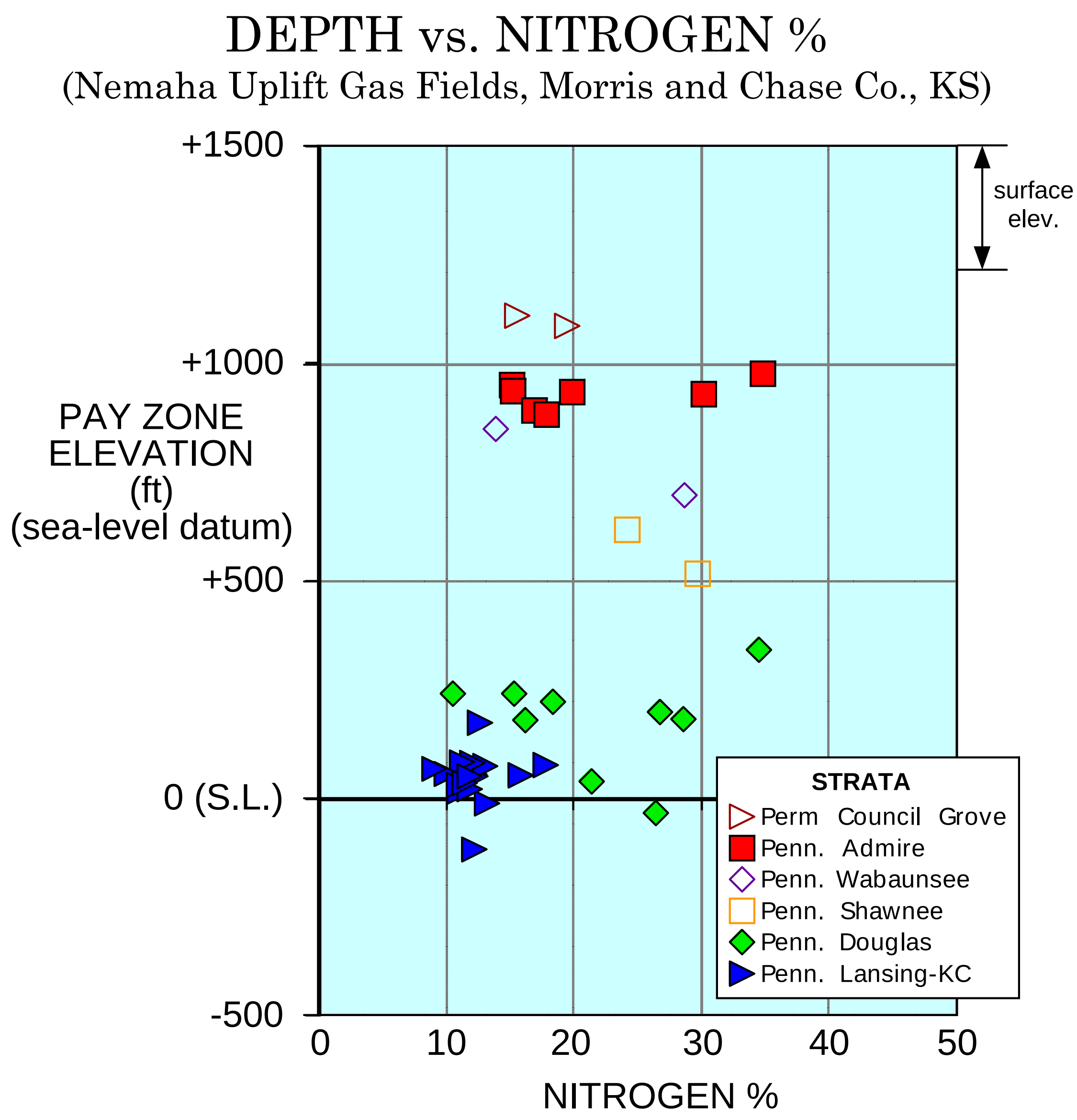


Figure 82: Plot showing relationship of BTU content with depth of producing zones.

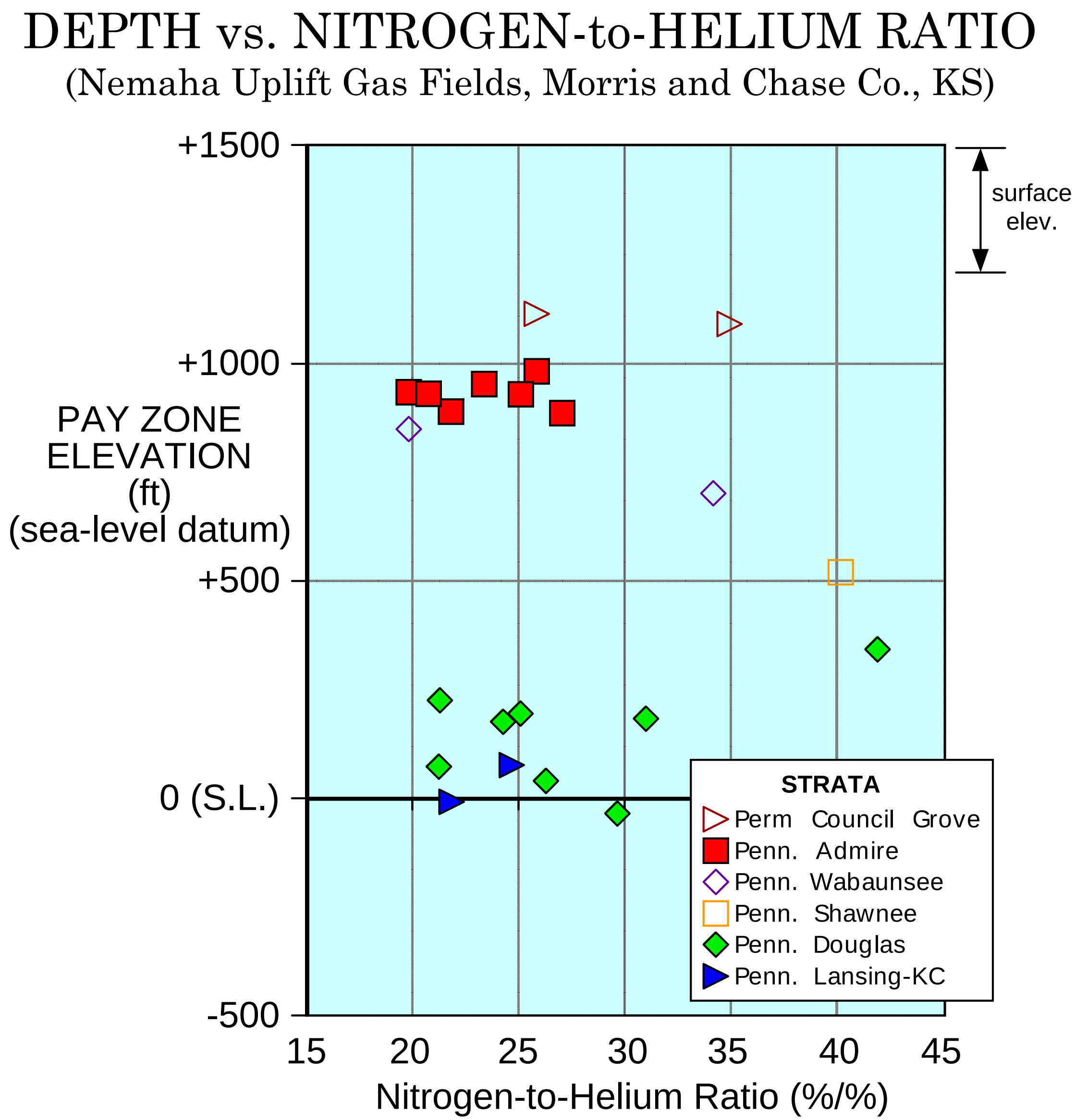


Figure 83: Plot showing lack of correlation between nitrogen-to-helium ratios with age of pay.

PERCENTAGE RANGES in COMPONENT-GAS COMPOSITIONS

Gas fields on Nemaha Uplift
Morris and Chase Counties, KS

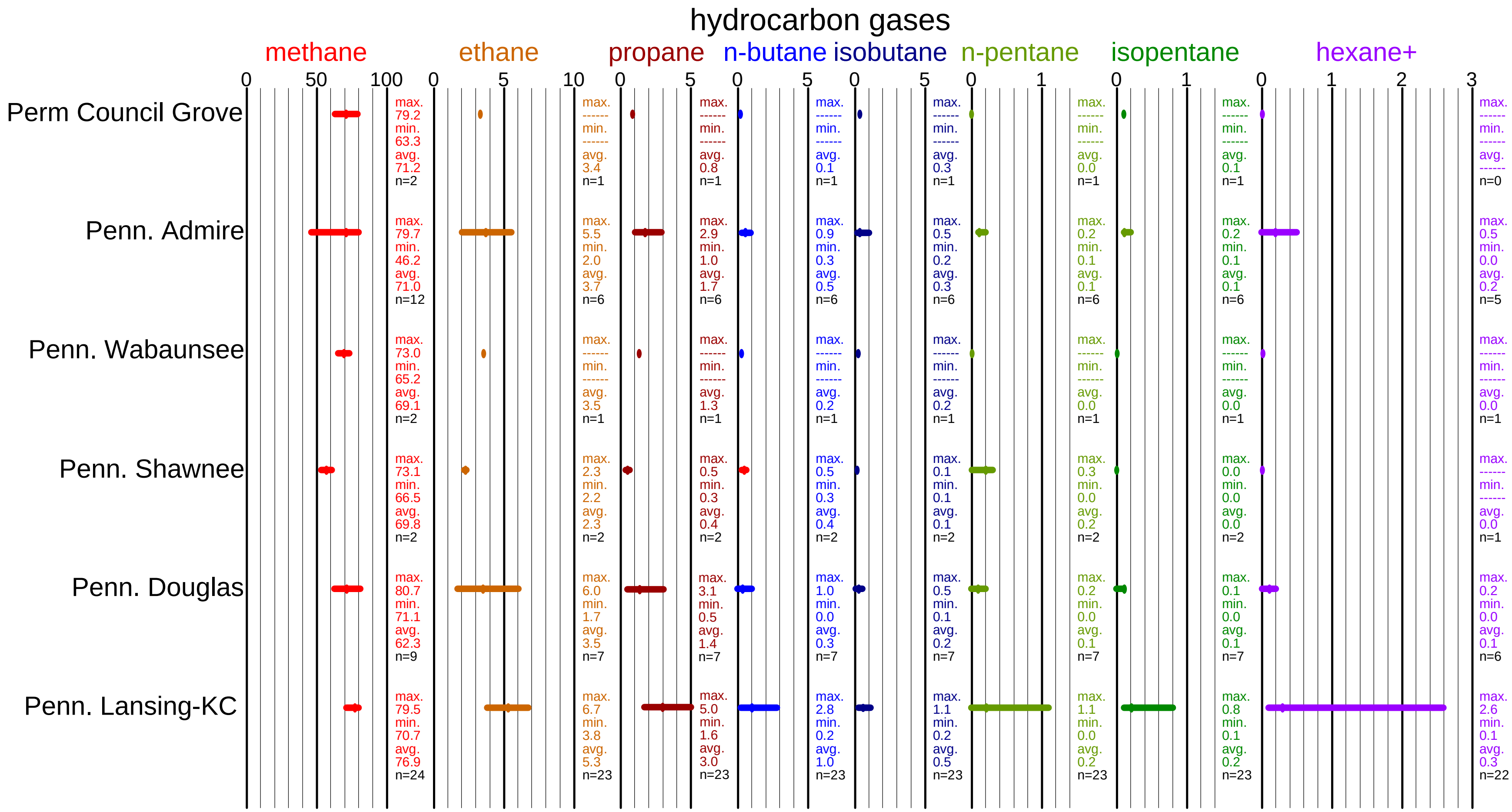


Figure 84A: Compositional ranges of hydrocarbon and nonhydrocarbon gases – Part 1.

PERCENTAGE RANGES in COMPONENT-GAS COMPOSITIONS

Gas fields on Nemaha Uplift

Morris and Chase Counties, KS

nonhydrocarbon gases

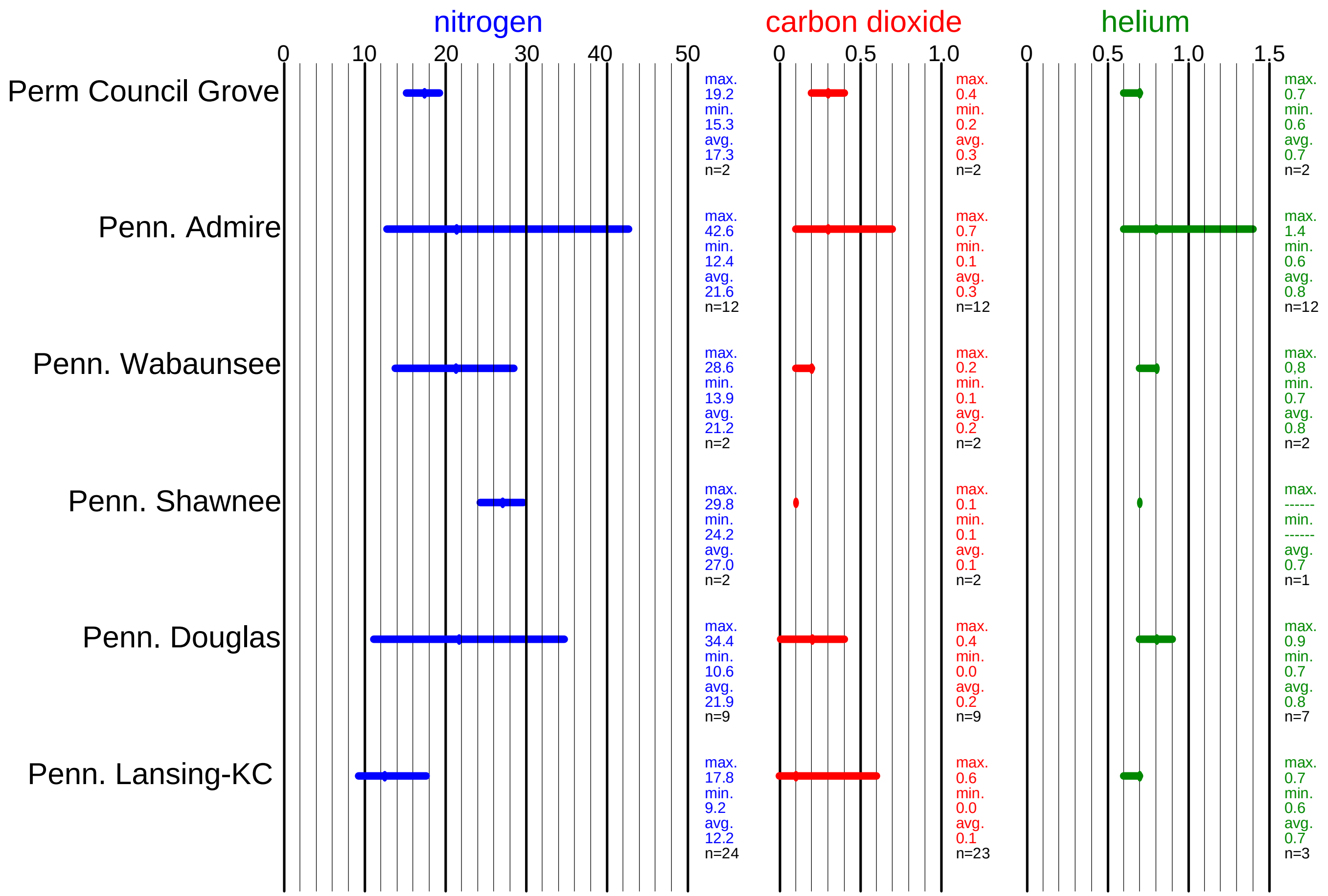


Figure 84B: Compositional ranges of hydrocarbon and nonhydrocarbon gases – Part 2.