Senior Design Project

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Executive Summary:

OSM Energy Inc. has completed an analysis of two prospects for development as natural gas fields in the state of West Virginia. The prospects are located in Kanawha and Doddridge Counties and will be referred to as OSM #1 and OSM #2 respectively.

A geological study of both the prospects was completed with use of the information gathered at the West Virginia Geological and Economic Survey.

The production potential in each prospect is considered to be excellent. A “good” well completed in the Benson Sand produces 400 MMSCF over a 30 -year life, on average. Comparatively, in the Devonian Shale, a good well produces 275 MMSCF with nearly the same life span. Both of the target formations together are predicted to contain reserves in the 3.1 Tcf range. Based on this information, plans for one well to be drilled and completed in each of the prospects were made.

Based on this information, it was concluded that OSM #1 would target the Devonian Shale formation at an approximate depth of 5000 feet and that OSM #2 would target the Benson Sandstone at an approximate depth of 5600 feet.

After completion, reserve estimation was performed on each of the wells based on data gathered from well logs. A volumetric approach was used to interpret the data gathered on OSM #2 while a history matching technique was used to calculate the reserves for OSM #1. It was necessary to take this approach with OSM #1 because gas is produced from shale through a different mechanism than it is from sand. When gas is produced from shale it is desorbed from the rock matrix. Gas production from sandstone on the other hand, is from inter-granular pore spaces.

From well log analysis, OSM estimated the reserves for OSM #1 and OSM #2 to be approximately 2.5 MMCF/Acre and 17 MMCF/acre, respectively. At this point the team at OSM identified the OSM #2 prospect to be the leading contender for development, but decided to go ahead with the project and perform well test analysis, production forecasting, and economical analysis.

OSM engineers determined that each of the prospects could produce for seven years at a constant flow rate. However OSM #2 could produce at almost twice the rate of OSM #1. Again, this confirmed OSM #2 as the leading candidate.

Economical analysis performed on both of the prospects using Monte-Carlo simulation revealed that the OSM #2 prospect had a higher discount cash flow rate of return (DCFROR). Confirming once and for all that OSM #2 is the prospect of choice.

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INTRODUCTION:

The following is the final report of a semester long project. This project is designed to challenge the students to act as petroleum engineers. In this project, two prospects will be compared to determine which of them is the superior selection. This will be done through prospect selection and casing design, well log interpretation and reserve estimation, build-up analysis, production forecasting, and Monte Carlo simulation.

Prospect Selection and Casing Design

This first objective is an important aspect of the large scale project because without the casing, it would be physically impossible to drill the depths necessary to achieve any commercial quantity of hydrocarbon and without the proper completion the production of said hydrocarbon would not meet its economic potential. Another goal of this section is to research the prospects thoroughly so that each conclusion drawn can be supported by data from offset wells. This section also describes the process of selecting a drill prospect, designing a casing string with cement, and the aspects of the completion scenario.

Well Log Interpretation and Reserve Estimation

The objective of this section is to analyze offset well logs to determine the reservoir parameters and estimate the reserves. Reserve estimation is an important part of the project. The reserve estimation, coupled with an economic analysis, will determine whether the project will be completed. The type of information needed to make accurate reserve estimations for a prospect depends on the type of formation in which production will take place. Also, the reserve estimation may be restricted because of the methods that were used to log the well.

This section deals with the process of analyzing the different logs ran in the offsetting wells and the procedures followed to determine the reserves for each well.

Build-Up Analysis

In this section, build-up pressure data is analyzed to determine initial formation pressure, permeability, skin factor, and the flow efficiency. Build-up analysis is a very important tool that is used by the petroleum engineer. It provides an analytical approach to determine important parameters that estimate a well's potential to flow. Being in West Virginia, build-up data is an expensive commodity that is rarely obtained. Therefore, the calculations were done using synthetic data. The synthetic data used in the shale calculation for OSM #1 was further skewed because the build-up pressure data was lower than the reservoir pressure.

Analyzing the data required the conversion of pressure and time data to pseudo-pressure and pseudo-time. A computer program is developed because of the many calculations required in this procedure. This program performs all the necessary calculations involved in this conversion. A copy of this program is attached in the **Appendix XVIII** of this report.

This part of the report details the process of analyzing build-up data to determine the initial formation pressure, permeability, skin factor, and the flow efficiency.

Production Forecasting

The objective of this section was to create a plot of Compressibility versus Pseudo Reduced Pressure for Pseudo Reduced Temperature values of 3.0, 2.4, 2.0, 1.8, 1.6, 1.4, 1.3, 1.2, and 1.1. After this plot was created, it was compared to the Standing and Katz compressibility chart (see **Appendix I**), which can be found in almost any natural gas engineering handbook.

The second objective of this section was to create a plot of viscosity versus pressure for each of the prospects. Also, a polynomial function was fitted to each of these curves. The equations that were fitted to the curves can be found on the viscosity plots included in the **Results** of this report on pages 71 and 72.

The third objective of this section was to determine the maximum flow rate that each reservoir could sustain for seven years. Abandonment pressure of each of the reservoirs is calculated based on assumptions made about the pressure losses in the well-bore, surface equipment, and flow line.

Monte Carlo Simulation

The purpose of this section, the fifth part of a semester long senior design project, was to perform an economical analysis on each of the two prospects that are being considered for development. The economical analysis was performed using a probabilistic approach known as a Monte-Carlo simulation. A Monte-Carlo simulator was developed in MS Visual Basic 6.0 to complete the project.

The program uses a random number generator coupled with the probability distributions of reservoir thickness, porosity, gas saturation, and production schedule to determine the discount cash flow rate of return (DCFROR) representative of all case scenarios for each of the prospects. A probability distribution for the DCFROR of each of the prospects was created and the results were compared.

This method provides the most accurate way of comparing two projects because it allows the engineer to consider all possibilities.

BACKGROUND:

Prospect Selection and Casing Design

There is a lot of background information that is available to the tedious engineer. What is required is the patience to sift through the mounds of information and obtain that which is useful.

The process started at the United States Geological Survey located on Cheat Lake at Mont Chateau. Here, several well files were examined yielding pertinent information into several various reservoirs. This information was collected along with maps, logs and other geologic data and combined into an informative report which will be used to design the two wells. The next phase of the process involved meeting in the Evansdale and Colson libraries, which also contained a vast amount of geologic and other relevant information. Once all of the information was collected, it is sorted and the pertinent data was then used in the process of designing an effective well.

Geology:

The two wells that have been selected for this project are located in the state of West Virginia in the United States of America. The first well is located in Doddridge County on the West Union quadrangle. The site's coordinates are 13,500 feet south of 39 degrees 17 minutes and 30 seconds in the latitude direction. The longitude is 7,400 feet west of 80 degrees 45 minutes and 0 seconds. The other site that has been selected is located in Kanawha County on the Cedar Grove quadrangle. This site's coordinates are 13,075 south of 38 degrees 10 minutes and 0 seconds in latitude and 8,300 west of the longitude line of 81 degrees 25 minutes and 0 seconds.

Doddridge County lies in north central West Virginia (see **Appendix II**). It is located southeast from Pleasants and Tyler and west from Harrison Country. It occupies a central position in the great Appalachian trough and has proven very prolific in both gas and oil through its entire column of oil sand. The site selected has an elevation of 1,283 feet above sea level. The target formation for this site is the Benson Sand.

The Benson sand is a formation in the Upper Devonian Sand that is currently the most important target for production in Doddridge County. The Benson Sand is being produced from 18 fields in Doddridge and Harrison County. Of these 18 fields, the Benson is the major producer of all but three of these fields (Cardwell, 1982). Approximately 100 billion cubic feet of gas remains within the Benson sandstone and siltstone reservoirs. Total production from wells located in the same vicinity as the prospect well are estimated to be between 250 to 300 MMcf, with exceptionally good wells experiencing total production of more than 420 MMcf (Roen and Walker, 1996).

The Benson Sand is an amalgamated unit of sandstone, siltstone, and shale. It can be best defined as gray to grayish brown argillaceous siltstone, with no component coarser then fine sand. The Benson was formed by a Marine slope apron where fine-grained siltstone and sandstone were deposited over time (Cardwell, 1982). Therefore, the depositional environment is said to be of a slope/turbidite nature.

Structurally, Doddridge County consists of a series of anticlines and synclines with trends in the northeast quadrant. The most prominent of these in Doddridge County is the Arches Fork Anticline. The crest of the Arches Fork Anticline passes through the central part of the county, with its' axis trending northeast to southwest. The prospect for Doddridge County is located on the northwesterly dipping leg of this anticline, not far from its' crest (see **Appendix III**). The thickness of the Benson Sand ranges anywhere from 125 feet in the east to about 40 feet in the west. The thickness of the Benson from wells in the same area range between six to fifteen feet (Roen and Walker, 1996). Because of its radioactivity, the gamma-ray logs make the top of the Benson Sand easier to pick out and are sometimes used as a distinct marker for structure analysis in this region (Cardwell, 1982).

The porosity of this formation is always less than 14 percent, with an average between 5 and 10 percent. Narrowing down this porosity range, wells in the same area as the prospect have porosity between six and eight percent (Roen and Walker, 1996). The permeability ranges from less than 0.1 to 2.0 millidarcys.

Kanawha County has the distinction of being the first location in the United States that used Natural Gas for manufacturing purposes. Kanawha County is located in central West Virginia (see **Appendix II**). The site that has been selected has an elevation of 1148 above sea level and its' target formation is the Upper Devonian Shale (see **Appendix IV**). A structural map of this area is located in **Appendix V**.

The Devonian Shale is the interval of Middle and Upper Devonian black organic shales, and medium dark-gray to brownish-gray shale and siltstone. The Devonian Shale occurs between the top of Onondaga Limestone and the base of the Berea Sandstone. The target formations at the bottom of the Upper Devonian portion include units from the Ohio Shale to the Genesee Formation. The thickness of the Upper Devonian Shale is estimated to be 2,200 feet. Ultimate recovery in the same vicinity as the prospect well is about 274 MMcf (Roen and Walker, 1996).

The Upper Devonian Shale represents the westward progradation of terrigenous-derived sediments over organic black muds. The formation began with the accumulation of black organic muds which were then overridden from the east by incoming clays, silts, and sands that built out and prograded westward over the black muds (Caramanica, 1988). Therefore, the depositional environment of the Upper Devonian is a sedimentary marine deposition that had occurred on the Devonian seafloor.

The field that the target formation is located in comprises of 4,480 acres. The Cabin Creek Field was discovered in 1914, and by the 1960's, had produced 11 billion barrels of oil. There is an estimated 21,627 million barrels of oil remaining in this field that are not producible with primary means of recovery (Caramanica, 1988). Gas injection, water injection, and gas completions are now being used to produce from the Cabin Creek Field.

The stratigraphy of the Upper Devonian Shale is characterized by black and dark gray shale units that are inter-stratified with gray and greenish-gray shale and siltstone and in places with very fine-grained sandstone. The dark gray shale, which is rich in organic matter, commonly contains small but significant amounts of uranium (Caramanica, 1988).

The major geological structure of this region is that of the Appalachian basin. The Appalachian basin extends from the crest of the Cincinnati arch on the west to and beneath crystalline rocks of the Blue Ridge thrust sheet on the east. The Devonian gas shales incline eastward from near the crest of the Cincinnati arch at approximately 55 feet per mile. This occurs from a narrow outcrop band that trends almost north-south across central Ohio to downward deep into the basin interior to where they are around a depth of 5,000 feet in western West Virginia (Roen and Walker, 1996).

Well Log Interpretation and Reserve Estimation or Logging Theory

One of the most important aspects of the petroleum industry is well logging. Early wells were not logged. It was not until the properties of hydrocarbons were understood that engineers realized that devices could be lowered into the hole and information gathered that would indicate the location of accumulations of hydrocarbon. These first logs were electric logs that determined the resistivity of the different formations. It was known then that hydrocarbon is very resistive to electricity so the zones bearing the hydrocarbon showed peaks in the resistivity track.

The main purposes behind logging are to determine rock properties, identify zones, and identify hydrocarbon-bearing formations. Logs are also used to quantify the hydrocarbon in the formation. Through the years, it has been found that certain formations are more responsive to certain types of logs. For example, sandstone is very responsive to induction logs (See **Appendix VI**). The induction log measures resistivity. This log is extremely valuable in sandstone for detecting hydrocarbon, but it is useless in a shale formation. In shale, an ultrasonic gas detector log is better at identifying hydrocarbon-bearing zones. The ultrasonic gas detector is an acoustic log that measures the sound in the well bore. It “hears” the hydrocarbon entering the wellbore and records them on the log.

A description of the types of logs commonly used:

The Spontaneous Potential Log (SP Log) is used to detect permeable rock strata, permeable rock strata boundaries, determine formation water resistivity, and to calculate the volume of the shale. The SP log records the difference between the potential of a moveable electrode in the well bore and the potential of a fixed electrode on the surface. This potential comes from the contact of the drilling fluid filling the borehole and the formation. A deflection of the SP curve usually results from the electric current flowing through the mud in the well bore.

The Spontaneous Potential Log is normally recorded on the left side of the log and is generally recorded with either a resistivity, sonic, or porosity log. The log's response to shales usually follows a straight line, which is referred to as the shale base line. This shale line is commonly the minimum reading on a SP log, where the maximum reading refers to clean sand or carbonates. Permeable sandstones cause a deflection of the SP curve to the left of the shale base line. Maximum deflection, or negative SP, occurs to the left of the shale base line and is referred to as the clean sand line.

In sands, deflection of the Spontaneous Potential curve depends on the relative salinities of the formation water and mud filtrate. The SP log can not be run in well bores filled with nonconductive mud because there is no electrical conductivity between the surface and downhole electrodes. Also, when the resistivities of the mud filtrate and formation water are about equal, the SP deflection will be small and featureless.

The caliper log measures the diameter of the tubing or casing. Tubing-profile calipers determine the extent of wear and corrosion that the tubing strings have gone through (see **Appendix VII**). They can also detect holes in the tubing string. The large number of feelers on each size of the caliper insures the detection of even very small irregularities in the tubing wall. Casing-profile calipers perform the same functions as the tubing-profile calipers. They determine the amount of casing wear and they locate holes or areas of corrosion that may require remedial work in producing wells.

Temperature Logs provide continuous measurement of temperature in the well bore. This log consists of a platinum wire exposed to the borehole fluid. The resistivity of this wire, which is measured by a wheatstone bridge, varies with temperature according to a simple well-known relationship. Because of this, the temperature log is useful for numerous things. A couple of them are: finding gas entries to, or exits from, the wellbore, finding channels in poorly cemented sections, finding lost circulation zones in openhole, and finding the cement top in a recently cemented well. Temperature logs may be used to check fluid flow in production or injection wells. They can also detect fluid flow outside the completion string in tubing/casing annulus or casing formation annulus. There are three types of temperature logs: conventional temperature survey, differential temperature survey, and radial differential temperature survey.

Another type of log that was run is the Ultrasonic Gas Detector (UGD). The UGD, **Appendix VIII**, measures the high frequency noise associated with gas entry into the borehole. It is an indictor of gas flow around the pipe, and at perforations. The UGD also detects casing leaks and provides high vertical resolution in complex lithologies. The Ultrasonic Gas Detector makes the evaluation of productive reservoirs more accurate and is useful in selecting the exact perforation intervals. The UGD uses a unique dual detector system, which provides the data on gas entry more accurately.

The Sonic Log is a porosity log that records the travel time of a compressional sound wave through one foot of the formation. The reciprocal of the velocity of the compressional sound wave is called the interval transient time, which is in micro-seconds per foot. The interval transient time is dependent on both lithology and porosity. Modern sonic logs are borehole compensated systems, which reduce the effects of bore-size changes as well as errors due to sonic tilt.

The Gamma Ray tool, **Appendix IX**, measures the amount of natural radioactivity in the formation. It is very useful for lithology determination because shale normally has a higher natural radioactivity than sand due to the amount of clay minerals it contains. The Gamma Ray tool is versatile enough to be used in either open or cased hole. The Gamma Ray curve normally appears on a linear scale in track 1.

The Dual-Induction tool is an electrode resistivity–measuring device that induces a current in the formation using a magnetic field. Receivers higher up on the tool measure the current that is induced in the formation. From the data collected by the tool, the formation resistivity, measured in Ohmmeters, is determined and plotted on the track.

The dual induction tool, that was used to determine the resistivity in the offset wells that OSM analyzed, functions without the presence of a borehole fluid. The tool measures the secondary electromagnetic field that is generated by the current flowing in the producing formation, by the electromagnetic field generated by the tool.

The Density log, **Appendix X**, measures the density of the formation by emitting gamma rays into the formation and measuring the amount of the gamma ray that returns. The computer converts this into measurements of bulk density given in units of grams per cubic centimeter. Because porosity and density are inversely related this log can give accurate interpretations of the porosity of the formation. The more dense a formation, the less porous space it will contain.

The neutron log, **Appendix XI**, is a porosity log that measures the hydrogen ion concentration of a formation. This log measures the liquid filled porosity in clean formations where the porosity is filled with water or oil. The neurtons are electrically neutral atomic particles with a mass almost the same as the mass of a hydrogen atom. The logging tool is continuously emitting high-energy neutrons from a radioactive source. The neutrons collide with the nuclei of the formation material. Each collision causes the neutron to lose some of its energy and the amount of energy loss per collision depends upon the relative mass of the nuclei the neutrons hit. The maximum energy loss occurs when the neutron hits a nucleus of almost equal mass, which is the hydrogen nucleus. Therefor, the greatest amount of energy loss is due to the hydrogen concentration of the formation. After the neutrons collide, they diffuse rapidly until they are captured by the nuclei of other atoms. These nuclei become excited and emit high-energy gamma rays, which are recorded by the detectors on the neutron logging sonde.

Build-Up Analysis

The most commonly used pressure transient test is the pressure build-up test. The main requirement for this test is that the producing well is shut-in and the resulting increase in formation face pressure is measured as a function of time. The basic theory used to analyze pressure build up data has one main assumption, which is that the well is producing at a constant rate for a known time prior to shut-in.

This method of analysis provides the petroleum engineer with several advantages. These are: the problem of rate control is eliminated because the well is shut-in, well-bore storage can be reduced or eliminated with the use of a bottom hole shut-in device, and lastly, the average pressure within the drainage volume of the test well can be determined with a short shut-in period. This test also has several disadvantages which are: loss of production during the test, the well can sand up or experience other mechanical problems during shut-in, it requires a relatively constant rate for a period time prior to shut-in and lastly, well-bore storage can make analysis of some date difficult or impossible is a down-hole shut-in device is not used.

The pressure build-up test is simply a two-rate test. This means that the pressure changes recorded during shut-in are not only influenced by shutting in the well but also by the flow period prior to shut-in. When this well is shut in for a buildup test, the pressure at the formation face will begin to increase and a pressure disturbance will be propagated away from the well-bore at a rate dictated by the formation diffusivity equation and the nature of the flow period preceding shut-in. After some shut-in time, Δt_1, the shut-in transient will have moved to a radius, r_1. Between the formation face at the well-bore and r_1, pressure in the reservoir is increasing. Beyond r_1, the reservoir has not been influenced by the buildup test and pressures are still declining as a result of the flow period prior to shut-in. The buildup test is said to be in transient, or an infinite acting, flow at Δt_1. However, it should be obvious that pressures at the well bore are being influenced by the boundary as a result of the flow period prior to shut-in. The test will remain in transient flow until the shut-in transient reaches the boundary; after this time, pressures throughout the drainage volume to the well begin to equalize and, given enough time, will equalize at the volumetric average reservoir pressure, p_R. Pressure equalization is depicted by the shut-in time Δt_3.

The build-up analysis is performed on wells in order to calculate several different reservoir parameters. The first of these parameters is permeability. Permeability is the ability of the formation to transmit fluid. Permeability is measured in darcies or more commonly the milli-darcy (mD). Good formations exhibit permeability in the range of 1 to 3 darcies and tight formations have permeability in the 0.1 to 10 mD range.

The second parameter commonly determined from a build-up test is known as the skin factor. The skin factor is a measure of damage in the reservoir that causes the flowing hydrocarbon to undergo a pressure drop. Skin factors greater than 0 indicate damage and negative skin factors indicate that the reservoir has been stimulated in some manner.

Also, the flow efficiency can be determined from a build-up test. Flow efficiency is a function of skin and pressure differential across the sandface in the well-bore. Flow efficiency is measured as a percentage, 100% being ideal. Both OSM #1 and OSM #2 well tests indicate flow efficiencies over 100%. This is because the wells were stimulated before they were tested, and are flowing better than they would in their natural state with no damage.

Production Forecasting

To complete the project, the log approximation to the exponential integral solution of the radial diffusivity equation was employed. For this equation to be valid there are four assumptions that have to be made:

1.) The reservoir must behave like it is infinite in size.

2.) The well-bore must be assumed to be of negligible size.

3.) The reservoir must be at a uniform pressure.

4.) The well must be produced at a constant rate.

Because the wells that were analyzed were gas wells the P^2 method was used to perform the calculations. The Pseudo pressure approach was considered but abandoned because the discovery pressures of both of the reservoirs were under 1000 psi. The P^2 approach is considered to be an accurate approximation to pseudo pressure for pressures less than 1500 psi.

The Redlich Kwong equation of state is used to calculate the Z factor as a function of pseudo-reduced pressure and pseudo-reduced temperature. The Newton-Raphson iterative procedure was used to solve the Redlich Kwong equation of state. The Redlich Kwong equation was used because it has the ability to match the curves generated by Standing and Katz through laboratory experiments. An accurate method of calculating the Z factor at all pressures and temperatures is a very useful tool. It would be impossible to accurately use the log approximation to the exponential integral to perform the production forecasting if an accurate method for the calculation of the Z-factor were not available.

Monte-Carlo Simulation

Monte-Carlo simulation was performed on the prospects to determine which one was economically superior to the other. The process is rooted in probability theory and allows the inclusion of uncertainty and randomness into the analysis of the project. The simulator allowed OSM engineers to compare thousands of different scenarios for each project and determine the probability distributions of the discount cash flow rate of return (DCFROR) for each of the prospects.

Economic Constraints	
Drilling Cost	$100,000.00
Casing Cost ($/ft)	$20.00
Gas Price ($/MCF)	$2.00
Op Cost ($/MCF)	$0.25
Working Interest	87.5%
State Tax	5.0%

Production Schedule				
	1	2	3	4
	%Recovery			
1	--	--	--	--
2	--	--	--	--
3	--	--	--	--
4	0.04	0.04	0.03	0.03
5	0.17	0.13	0.12	0.1
6	0.35	0.24	0.22	0.19
7	0.56	0.42	0.35	0.29
8	0.73	0.6	0.5	0.42
9	0.85	0.73	0.62	0.53
10	0.94	0.84	0.73	0.64
11	0.99	0.91	0.82	0.73
12	1	0.96	0.89	0.82
13	--	0.99	0.94	0.87
14	--	1	0.97	0.92
15	--	--	0.99	0.95
16	--	--	1	0.98
17	--	--	--	0.99
18	--	--	--	1

<u>APPROACH</u>:

Prospect Selection and Casing Design

Casing Design Theory:

Choosing the correct size, type, and amount of casing that is used in well construction is of utmost importance to the success of the well. The casing must be of sufficient size and strength to allow the target formations to be reached and produced.

The main functions of the casing in any well are: maintain hole integrity, isolate abnormally pressured zones, protect shallow weak formations from heavier mud weights required in the deeper portions of the hole, and to isolate fresh water, salt and coal seams.

There are four types of casings that are commonly used in well construction. The first, referred to as the conductor, is the largest pipe run into the hole. It is normally set between 40 and 60 feet. The size of conductor used depends on the depth to which the hole is to be drilled. The deeper the hole, the larger the conductor required. This string of pipe is designed to penetrate the fractured, highly weathered rock near the surface and *conduct* the bit to the stable bedrock below.

The second string of pipe run in the hole is the surface casing. Again, size of this string of pipe depends on the planned depth of the well. The main purpose of the surface casing is to isolate fresh-water aquifers from the drilling fluid, any salt-water zones present, and from any hydrocarbon that may be encountered.

The third string of pipe that is run is the drilling casing. This string of pipe, also known as intermediate casing, is necessary to isolate weak zones from the circulating pressure of the drilling fluid. Usually, there is a point encountered in the operation when the weight of the mud required to control the zones at the bottom of the hole is higher than the leak-off pressure of shallow low pressure zones. It is at this point that intermediate casing is run so that the heavier mud can be used to drill ahead.

The fourth and final string of pipe run in the hole is the production casing. The production casing is used to control the hydrocarbon bearing zones that will be produced. This string of pipe adds structural integrity to the well-bore in the producing zones. It is necessary to conduct the hydrocarbons to the surface.

Completion Theory:

The need for completing zones in this region was recognized early because of the low permeability and porosity. While several different scenarios were explored, the method chosen for these two wells was fracturing with nitrogen. The first step in a fracturing with nitrogen is to perforate the casing directly outside the target formation. This opens the well-bore to the formation and allows the hydrocarbon to travel from the reservoir to the well-bore. It also allows the formation to be broken down and fractured.

The second step is to break down the formation. Injecting nitrogen into the well-bore and exceeding the fracture pressure of the target formation breaks down the formation. Once the formation breaks, the third step can begin. This step involves pumping sand out into the fracture to keep it from closing.

The fracture in the formation serves several purposes. The fracture serves to increase the permeability, or ease of flow, of hydrocarbon in the reservoir. It also takes away pressure losses that occur near the well-bore. These pressure losses generally account for the majority of the pressure loss in the reservoir.

Well Log Interpretation and Reserve Estimation

The first step taken in the analysis of the well log for the OSM#1 well was to determine the proper reserve estimation technique needed to make accurate predictions. Because volumetric analysis has been proven inaccurate for analysis of shale formations, it was necessary to use a history matching technique based on research performed by Layne in SPE technical paper # 17069.

Shale

SPE 17069, "An Analysis of Infill Drilling Potential for Increasing Gas Reserves in Devonian Shale," was prepared by A.W. Layne and A.B. Yost II and presented at a SPE Eastern Regional Meeting held in Pittsburgh, Pennsylvania on October 21-23, 1987. This paper encompasses an analysis of infill drilling potential to increase the producible reserves of the Devonian shale formation in Ohio, Kentucky, and West Virginia.

The study utilizes data that has evolved in the Eastern Gas Shales Research Program to compile gas-in-place estimates and to analyze key production mechanisms. The section of this SPE paper that was applicable to this report was that of the case study done in Kanawha County, West Virginia. An infill hypothetical case study was completed in this region with actual field data to verify results of the partition of the study. Results from this study indicate that 50% more gas may be recovered over a 10 year period, if infill wells are located in a more geological favorable area of the field. However, reduced well spacing was found to be unfavorable in Kanawha County and that well siting according to geologic evaluation and stimulation can provide optimum gas recovery for this and other areas where reduced well spacing is not favorable.

The 14 wells that were studied were located in the Clendenin quadrangle in Kanawha County. The wells were drilled down to the Devonian Shale and in some cases deeper. Seven of these wells were hydraulically fractured, 5 of which were stimulated with gelled-water treatments, and 2 fractured with gas assisted water treatments. The other seven wells were explosively stimulated. These wells were completed and stimulated between 3,300 and 5,500 feet in the Middle and Upper Devonian age regions.

An improved history-matching procedure was used in the Kanawha County infill drilling study. Cumulative production and rock pressures measured after ten years of production were matched in the analysis for it to be more accurate, such that less judgement and more factual information would be used to obtain the match. The Kanawha County case study indicated that the variation in flow capacity exists throughout a shale reservoir, and a constant value of permeability or productive thickness is unlikely as well as extreme variation within a given field. Areas of relatively high flow capacity in relation to other portions of a field exist and are the desired sites for infill well site selection. In table 8 of the SPE 17069, various constants that were used in the base case history matching in Kanawha County were listed. Fracture permeability, permeability anisotropy, fracture spacing, matrix porosity and permeability, fracture porosity, and the gas content are listed in there. The gas constant, which was used in this report, was 50 to 80 Mcf/Acre-ft.

Layne estimated an average gas content for the Devonian shale located in Kanawha county to be between 50 and 80 Mcf/Acre-ft (Layne, 1987). In this project a gas constant of 50 Mcf/Acre-ft was chosen. The sonic gas detector track and the gamma ray track (see **Appendix XII**) were then used to determine pay thickness and reserves calculated as shown in table 1 (**Results**, pg. 54).

The first step taken in the analysis of the offset well log data for the OSM #2 well was the same as above, to determine the proper reserve estimation technique needed to make an accurate prediction. OSM decided to perform a volumetric reserve estimation technique for this well.

Second, it was determined from the log which formations had potential for containing hydrocarbon. The next step was to read all the information from the log, (see **Appendix XIII**). This information included: bulk density, resistivity, temperature, neutron porosity, and density porosity logs. After all of the information was obtained, the different layers from each formation was defined by large shale breaks between the lobes with good hydrocarbon bearing indicators, difference in lithology (based on gamma ray), high resistivity, and good porosity. Once the formations were separated into layers, the parameters of possibly communicating layers were averaged together. From this averaged data, the gas saturation and actual formation porosity were determined.

Two approaches were taken in the calculation of the parameters used in the volumetric calculation. Gas saturation and Porosity were the two parameters determined from well log interpretation that were needed to perform the volumetric calculation.

In the first approach, OSM energy used the “SW-11”chart from the Schlumberger chart book circa 1997 (**See Appendix XIV**). This chart uses apparent bulk density, matrix density, and neutron porosity as read from the log, and returns gas saturation and porosity values. However, OSM determined that this method was flawed because of an invalid assumption about the value for the matrix density of the formation. As a result, the conclusions of this interpretation were disregarded. A copy of this chart can be found in the **Results** section of this report on page 54.

The second approach taken by OSM energy used the "CP-5" chart from the Schlumberger chart book circa 1997. This chart, found in **Appendix XV**, uses density porosity and neutron porosity, as read from the well log, and returns a value for the porosity of the formation. The chart also includes a correction for the depth of the formation. Shallow formations are considered to be those at depths<5000'. OSM energy considered the formations encountered in OSM#2 to be shallow for this interpretation.

In the second approach, the gas saturation was calculated from the dual induction log. For this interpretation OSM assumed that only gas and water were present in the formation. This assumption is a valid one as there has been no oil production from the target formations from the offset wells. The results for the reserve estimation performed on OSM#2 can be found in the **Results** on page 55.

Build-Up Analysis

The build-up Pressure analysis performed on OSM #2 was a strict pseudo-pressure analysis. This analysis began by using the synthetic data provided in the syllabus. Once the data was obtained, it was converted to pseudo-pressure and pseudo-time data by using the computer program written by the group. After the data was converted, a log-log plot of change in pseudo-pressure vs change in shut-in time was created (See **Results**, pg. 63). This plot was used to determine the period of time that the well-bore storage effects covered the data, such that the radial flow data could not be seen. These effects were identified by data points, which fall on a unit slope line in the initial phases of build-up.

Well-bore storage represents the period of time just after shut-in where the pressure points that are read are being influenced by the amount of hydrocarbons that are still present in the well-bore. These hydrocarbons have already been produced from the reservoir, but have not made it to the surface. The influence of these hydrocarbons can greatly alter the interpretation of the data, causing the permeability and skin to be analyzed by unrepresentative data. This leads to false interpretations because of the compressibility of hydrocarbons in the well-bore.

After the well-bore storage effects were identified, the data was plotted on a semi-log Horner graph. The end of well-bore storage was estimated and radial flow was observed. A trend line was fitted to the data points that were in the pseudo steady state flow period. The slope of this straight line was used to calculate the permeability and skin factor of the formation.

Analyzing data in the Devonian Shale was more complex since the methods used were relatively new. Simply applying Horner analysis to a Devonian Shale reservoir will not give the correct results. The reason for this is because the production mechanism is much different for gas in shale than gas in sand. A gas in sand is actually in the porous space of the rock. To produce gas from sand, it is necessary to have draw-down pressure. The difference between the pressure and the concentration of the rock causes it to emit the gas it is holding.

Gas in shale is dissolved in the matrix of the formation. The mechanism for production in a shale is that gas on the outer portions of the matrix that are in communication with the small semi-fracture that lead to the well-bore tend to start seeping from the formation slowly. After a while, the gas picks up its rate until the total matrix is experiencing the effect of gas leaving the matrix. Once this point is reached, the maximum pressure has been obtained. Shale wells are not pressure driven, but concentration driven.

Since we were unable to determine the exact process involved in the analyzing of shale data, we were forced to rely on Horner analysis. The process is basically the same with one exception, this being the calculation of apparent permeability and a permeability correction factor as shown below. Also, the fracture half-length can be calculated using an iterative technique, which uses Figure 4-8 and the equation for fracture half-length shown in the **Equations** section, page 40, to determine the F_{cor} value and x_f.

Well Test Data for Build-Up Analysis

OSM #1

Time	Pressure	Time	Pressure	Time	Pressure	Time	Pressure
0	310	0.67	371	12	434	66	492
0.02	312	0.83	374	16	439	72	497
0.03	315	1	378	84	506	78	502
0.05	320	1.25	384	90	510	102	518
0.07	323	1.5	389	96	515	108	522
0.08	328	2	397	20	442	114	525
0.1	330	2.5	404	24	445	120	529
0.13	337	3	408	30	451	126	532
0.17	341	4	414	36	459	132	535
0.25	345	5	417	42	466	138	539
0.33	356	6	420	48	474	144	542
0.42	361	8	425	54	480	150	544
0.5	364	10	429	60	487	156	547
						160.67	549

OSM #2

Time	Pressure	Time	Pressure
0	514	339	822
6.8	605	362	828
26.2	647	391	833
49.9	681	409	835
73.7	710	435	837
98	733	506	844
168	770	557	849
193	782	577	850
221	794	602	851
240	800	673	857
270	806	720	858
		747	859

Production Forecasting

In order to complete the project in an efficient manner, it was divided into three parts. First, a program was written to solve the Redlich-Kwong cubic equation of state and calculate the viscosity of the gas as a function of pressure. Second, team members, who were not involved in working on the first portion of the project, researched the line source solution and determined that the approximation to the exponential integral was the method to use to write the production forecasting portion of the program. Finally, the production forecasting and flow rate optimization portion of the program were written and merged with the first part. The final result was a program that met the three objectives of the project.

As stated above, the first part of the program was developed to solve the Redlich-Kwong equation of state for the Z-Factor. The solution to the Redlich-Kwong equation of state was performed using the Newton Raphson iteration technique. This technique is described in detail in the **Equations** section of this report on page 42. The program requires the user to input the initial reservoir pressure and the specific gravity of the gas.

It is important to have a program that can accurately calculate the Z-factor. The Redlich-Kwong equation of state is the most accurate method that OSM energy has found. Other methods commonly used to calculate the z-factor, (Abou Kassem method, the Gopal method, and Dranchuk, Purvis, and Robinson method) are merely approximations to portions of the Standing and Katz chart. The accuracy of the Z-factor has a large impact on the accuracy of the project.

This part of the program outputs the viscosity vs. pressure relationship to a text file. Once the data was in the text file, it was imported into an Excel spreadsheet where it was graphed and a polynomial was fitted to the curve performed. The polynomial function that was fitted to the viscosity data can be found in the **Results** section on pages 70 and 71.

The second part of the program was designed to determine the maximum flow rate that a well could sustain for seven years. This flow rate was determined by using the log approximation to the exponential integral solution as stated above. The program calculates the properties of the gas, such as Z-factor, viscosity, and compressibility, at every pressure step by calling functions that were written in the first part of the program.

The inputs required by the program include; permeability, porosity, flow rate, line pressure, skin factor, reservoir height, effective drainage radius, reservoir temperature, and depth. These parameters were determined from well log and build up pressure tests that were discussed in earlier portions of this report. The program steps through the calculation incrementing the time until the pressure is no longer adequate to sustain the given flow rate. At this time, a message is printed to the screen telling the user the number of years and the remaining pressure when the calculation was terminated. The calculation is terminated only after the current pressure is less than the predetermined abandonment pressure. If it turns out that the flow rate, that the user has entered, can not be maintained by the reservoir for at least seven years, the user can enter flow rates until the desired results are achieved. The program will calculate pressure as a function of flow rate and time for a maximum of ten years.

Another function of this part of the program is to calculate and graph a pressure profile for the reservoir. This is necessary to determine the pressure away from the well bore and also to determine the amount of energy left in the reservoir after a given time.

This plot is created for times corresponding to the last day of every year by keeping time constant, adjusting the radius and calculating a flowing pressure. (A sample plot can be seen in **Results** on page 69.) To view the program form, please see **Appendix XVII**.

Monte Carlo Simulation

The first step taken in the approach to the solution of this project was to identify the variables to be used in the calculation of the reserves. For OSM #1, volumetrics were used to calculate the reserves. The variables that influence this calculation are porosity, gas saturation, reservoir thickness, and reservoir area. For purposes of the project, the reserves were calculated on a per acre basis, therefore reservoir area did not play an important role in the analysis. Ranges for the porosity, thickness and gas saturation were defined as 5% above and below the values settled upon from the well log analysis.

Probability distribution functions were then assigned to the variables based on the confidence OSM had in the values. OSM was particularly sure about the value for the gas saturation, therefore a triangular distribution was applied to it in the monte carlo simulator.

OSM was not as sure about the values for the porosity and the thickness interpreted from the well log, therefore a uniform distribution was used for each in the simulator.

A different approach was taken in the calculation of the reserves for OSM #2. This was necessary because OSM #2 is completed in a shale formation and volumetrics are not applicable. The reserves for OSM #2 were calculated based on a gas content factor, which was determined for this particular shale by researchers. The gas content factor has units of MMCF/acre-ft. Therefore the reserves for OSM #2 were calculated by multiplying the gas content factor by the thickness of the reservoir. In this case the amount of reserves depends on the thickness of the reservoir and the gas content factor. Therefore, these variables were assigned probability distributions for use in the monte carlo simulator. Uniform distributions were applied to both the gas content factor and the thickness.

The values used in the monte carlo simulation are shown in the tables below:

OSM #1		
ϕ	11.88-13.12	(%)
Sg	46.01-50.85	(%)
h	53.2-55.8	(ft)
A	80	(acre)
Depth	5000	(ft)

OSM #2		
Gas Content Factor	47.5-52.5	(MCF/Acre-ft)
Area	80	(acre)
Depth	5600	(ft)

For each scenario that the program generates, the net present value calculation was used to determine the discount cash flow rate of return for the project (DCFROR).

The DCFROR is defined as the interest rate at which the net present value (NPV) is approximately zero. Because the project is worth millions of dollars, OSM considered the DCFROR to be at the interest rate that made the NPV less than ten dollars. This assumption was made for programming purposes. The iteration that is required to find the DCFROR is very time consuming. The assumption was made to speed the program up.

It is important to note that all of the costs that may be associated with the complete development of the project were not included in the analysis. OSM did not feel that it was necessary to include these costs because they felt that they (the costs) would be virtually identical for both projects. OSM feels that this assumption is a valid one because both of the wells will be drilled in West Virginia. Because of this, labor, electrical, and flowline costs will be nearly identical. The only costs that were considered were those that OSM felt would make a difference in the comparison.

After the program had selected a scenario based on the random number and the probability distribution assigned to each variable, the interest rate was incremented from 0 until the DCFROR was reached. The flow chart and the source code for the program can be found in the **Appendix XXII** and **XXIII**.

Based on this theory, a program was developed to calculate the probability distribution of the DCFROR for each of the prospects.

EQUATIONS:

Prospect Selection and Casing Design

Burst Analysis:

Pressure inside casing at the bottom of the hole(P_{bi}):

$$P_{bi} = (0.052\, psi/ft/ppg) \times (r_{fl}) \times (D_c)$$

Pressure outside casing at bottom (P_{bo}):

$$P_{bo} = (P_{pg}) \times (r_{fl}) \times (D_c)$$

Pressure inside casing at the top (P_{ti}):

$$P_{ti} = (0.052\, psi/ft/ppg) \times (r_{fl}) \times (D_c) - [(Pg_{methane}) \times (D_c)]$$

Pressure outside casing at the top (P_{to}):

$$P_{to} = 0$$

Resultant Pressures:

Top: $P_{tr} = P_{ti} - P_{to}$

Bottom: $P_{br} = P_{bi} - P_{bo}$

Collapse Analysis:

Pressure inside casing at the top (P_{ti}):

$$P_{ti} = 0$$

Pressure outside casing at the top (P_{to}):

$$P_{to} = 0$$

Pressure inside casing at bottom (P_{bi}):

$$P_{bi} = 0$$

Pressure outside casing at bottom (P_{bo}):

$$P_{bo} = (0.052\, psi / ft / ppg) \times (r_{fl}) \times (D_c)$$

Resultant Pressures:

Top: $P_{tr} = P_{to} - P_{ti}$

Bottom: $P_{br} = P_{bo} - P_{bi}$

Tension Analysis:

Cross-section area of steel:

$$A_s = (\frac{p}{4}) \times (d_o^2 - d_i^2)$$

Axial force acting on the casing at the surface:

$$F = (r_{fl}) \times (D_c) - (A_s) \times (P_r)$$

<u>Well Log Interpretation and Reserve Estimation</u>

Chart SW-11 (see **Appendix XIV**)

Chart CP-5 (see **Appendix XV**)

Gas Formation Volume Factor (ft^3/scf):

$$B_g = 0.0282 \times \frac{z \times T}{p}$$

Calculation of Water Saturation (decimal) from Induction Logs:

$$S_W = \sqrt{\frac{R_o}{R_t}}$$

Calculation of Gas Saturation (decimal):

$$S_g = 1 - S_W$$

Volumetric Reserve Calculation (scf):

$$N = \frac{43560 \times A \times h \times f \times (1 - S_{wi})}{B_{gi}}$$

Build-Up Analysis

Equations for MTR of Buildup Test (Pseudo Values):

Permeability:

$$k = \frac{1637 q_{gs} T_r}{mh}$$

where:

k = Permeability (mD)
q_{gs} = Flow rate before shut in (Mscfd)
T_r = Reservoir Temperature (^oR)
m = Slope from the trend line on the Horner Plot
h = Height or thickness of the formation (ft)

Skin:

$$s' = 1.151\left[\frac{\Psi_{ws} - \Psi_{wf}(\Delta t_{ap} = 0)}{m}\right] - LOG\left(\frac{k\Delta t_{ap}}{f r_w^2}\right) + 3.23 + LOG\left(\frac{t_{p,ap} + \Delta t_{ap}}{t_{p,ap}}\right)$$

where:

s' = Skin Factor
Ψ_{ws} = Pseudo static pressure (psia)
Ψ_{wf} = Pseudo flowing pressure (psia)
m = Slope of trend line on Horner plot
k = Permeability (mD)
Δt_{ap} = Pseudo time corresponding to Ψ_{ws}
ϕ = Porosity (%)
r_w^2 = Wellbore radius (ft)
t_{pap} = Pseudo production time

When the skin is known, the flow efficiency can be calculated from:

$$E = \frac{\left(m(P_i) - m(P_{wf})\right) - \left(-0.87(m_{pr})s'\right)}{\left(m(P_i) - m(P_{wf})\right)}$$

where:

E = Flow efficiency (%)
$m(P_i)$ = Initial reservoir pseudo pressure
$m(P_{wf})$ = Flowing pseudo pressure
m_{pr} = Slope from Horner plot
s' = Skin factor

Fracture Half-Length Calculation

$$k = k_a \times F_{cor}$$

where:

k = True Permeability (mD)
k_a = Apparent permeability (mD)
F_{cor} = Permeability correction factor (dimensionless)

$$x_f = \frac{4.064qB}{m_{Lf}h} \times \left[\frac{m}{fc_t F_{cor} k_a}\right]^{1/2}$$

where:

x_f = Fracture half length (ft)
m_{LF} = Slope of square root plot
ϕ = Porosity (%)
m = Viscosity (cp)

<u>Production Forecasting</u>

Flowing Sand Face Pressure Calculation using Equation 4.90 "Natural Gas Reservoir Engineering."

$$P_{wf}^{\ 2} = P_i^2 - \frac{1637qT(mz)_{avg}}{kh}\left[\log\left(\frac{kt}{fmcr_w^{\ 2}}\right) - 3.23 + 0.87 \times s'\right]$$

P_{wf} = Sandface pressure (psia)
P_i = Reservoir pressure (psia)
q = Flow rate (Mscfd)
T = Temperature (^oR)
μ_{av} = Average gas viscosity (cp)
Z_{av} = Average Z factor
k = Permeability (md)
t = Time (days)
h = Reservoir thickness (ft)
ϕ = Porosity (fraction)
c = Total compressibility ($psia^{-1}$)
r_w = Wellbore radius (ft)
s' = Skin factor

Since the pressure is constantly changing as the reservoir is produced, it is impossible to simply calculate in one calculation the pressure after some given time (t). The method that is used is that the first pressure point is calculated after a given time increment Δt. This pressure is then used as the initial pressure to calculate the next time. This process is continued until the appropriate time has been reached.

It is important to keep the time increment small so that error is minimized. If a large Δt is chosen, the pressure calculated will be erroneous. The time increment chosen for this project was one day. In other words, the pressure was calculated at the well bore for the end of each day.

It is important to understand that this is not a summation or integration, it is merely using the previous pressure as the initial pressure and calculating the current flowing pressure.

Newton Raphson Iterative technique on Redlich Kwong E.O.S.

Redlich-Kwong Equation of State.

$$f(x_o) = Z^3 - Z^2 + \frac{P_r}{T_r}\left(\frac{0.42748}{T_r^{1.5}} - 0.08664 - 0.007506\frac{P_r}{T_r}\right)Z - 0.03704\frac{P_r^{\,2}}{T_r^{\,3.5}}$$

$$f'(x_o) = 3Z^2 - 2Z + \frac{P_r}{T_r}\left(\frac{0.42748}{T_r^{1.5}} - 0.08664 - 0.007506\frac{P_r}{T_r}\right)$$

Newton Raphson iteration equation:

$$X_1 = X_0 - \frac{f(X_o)}{f'(X_0)}$$

This iteration equation can be used to solve any cubic function. The way this equation works, is as follows. First an initial value of X_0 is guessed. Then $f(X_0)$ and $f'(X_0)$ is determined. From these two, X_1 can be calculated. If the absolute value of the difference in X_1 and X_0 is less than some epsilon (0.01), then the calculated X_1 is the solution. If the difference is not less than 0.01, then X_0 becomes X_1 and the iteration continues until the difference is less than 0.01.

Viscosity was calculated using the Lee, Gonzalez, and Eakin method. This method does not include corrections for impurities, and values obtained would be correct for pure hydrocarbon gases.

Viscosity Calculation by Lee, Gonzales, and Eakin.

$$m_g = K \times 10^{-4} e^{(X r_g^{\,y})}$$

where:

$$X = 3.5 + \frac{986}{T} + 0.01 M_a$$

$$y = 2.4 - 0.2X$$

$$K = \frac{(9.4 + 0.02 M_a) T^{1.5}}{209 + 19 M_a + T}$$

where:

μ_g = cp
ρ_g = g/cm^3
M_a = molecular weight of gas
T = ^{o}R

Compressibility of the gas:

$$c_g = \frac{c_{pr}}{p_{pc}}$$

An expression for c_{pr} was given by Mattar, Brar, and Aziz as:

$$c_{pr} = \frac{1}{p_{pr}} - \frac{0.27}{z^2 T_{pr}} \left[\frac{\left(\partial z / \partial r_r \right)_{T_{pr}}}{1 + r_r / z \left(\partial z / \partial r_r \right)_{Tpr}} \right]$$

where:

$$\left(\frac{\partial z}{\partial r_r} \right)_{T_{pr}} = \left(A_1 + \frac{A_2}{T_{pr}} + \frac{A_3}{T_{pr}^3} \right) + 2 \left(A_4 + \frac{A_5}{T_{pr}} \right) r_r + 5 A_5 A_6 \; r_r^4 / T_{pr}$$

$$+ \frac{2 A_7 r_r}{T_{pr}^3} \left(1 + A_8 r_r^2 - A_8^2 r_r^4 \right) e^{\left(-A_8 r_r^2 \right)}$$

<u>Monte Carlo Simulation</u>

Three different probability distributions were applied to the variables used in the monte carlo simulator.

The first type of distribution that was applied was the uniform distribution. this type of distribution was used for the reservoir thickness and the porosity. In this type of distribution, there is an equal opportunity that any value between the minimum and maximum value for “x” is possible. OSM decided to use a range of 5% above and 5% below the values settled upon from well log analysis. To determine which of these values will be chosen, it is necessary to use the random number generator to determine a random number between zero and one. Using this number, an equation is set up to relate this random number and the actual value for the variable. This equation is listed below.

Uniform Distribution:

$$X = X_L + R_N \times (X_H - X_L)$$

X_L = Lower Bound

X_H = Upper Bound

X = value

R_n = Random Number ($0< R_n<1$)

A triangular distribution was applied to the gas content factor and the gas saturation. This distribution is characterized by its triangular shape in a plot of frequency versus distribution. The peak is created because there is more confidence placed in one of the values between the minimum and the maximum values. These values are listed in this distribution as the minimum, the maximum and the most probable (likely). Listed below are the equations that govern the relationship between the random number generated and the variable. Also listed is a graph of frequency versus distribution for a triangular distribution.

Triangular Distribution:

$$Rn \leq \left[\frac{(X_m - X_L)}{(X_H - X_L)} \right]$$

$$X = X_L + \sqrt{(X_M - X_L) \times (X_H - X_L) \times R_N}$$

$$Rn \geq \left[\frac{(X_m - X_L)}{(X_H - X_L)} \right]$$

$$X = X_H - \sqrt{(X_H - X_M) \times (X_H - X_L) \times R_N}$$

where:

R_n = Random Number ($0 < R_n < 1$)

X_M = Median value

X_L = Lower Bound

X_H = Upper Bound

X = value

A discrete probability distribution was applied to the production schedule. This distribution is different from the others because it associates a certain probability with each value of the variable. This probability is added from the beginning to the end and a series of inequalities is staged so that the random number can be converted to a value for the variable. These inequalities are listed below. Also listed below is a graph of frequency versus distribution for a discrete distribution function.

Discrete Distribution:

$$0 \leq R_N \leq P_1$$

$$P_1 \leq R_N \leq P_1 + P_2$$

$$P_2 + P_2 \leq R_N \leq P_1 + P_2 + P_3$$

where:

R_n = Random Number ($0 < R_n < 1$)

P_1 = Cumulative Probability of case 1

P_2 = Cumulative Probability of case 2

P_3 = Cumulative Probability of case 3

It is also important to note that the random number generator, generates numbers based on a uniform distribution. It is equally possible to generate a zero, as it is to generate a one. Using this generator enables the program to exploit the uncertainty in the projects. After the uncertainty is determined, the program can determine which of the projects will be more beneficial.

After the program had selected a scenario based on the random number and the probability distribution assigned to each variable, the interest rate was incremented from 0 until the DCFROR was reached.

RESULTS:

Prospect Selection and Casing Design

Kanawha County (Devonian Shale) Casing Program:

13 3/8”	@ 55’	Maintain hole integrity	Grade: H-40, 48 ppf
9 5/8”	@ 1100’	Isolate Fresh Water	Grade: H-40, 32.3 ppf
7”	@ 2350’	Isolate coal/salt formations.	Grade: J-55, 20 ppf
4 ½”	@ 5000’	Production string	Grade: C-75, 11.6 ppf

Doddridge County (Benson Sand) Casing Program:

11 ¾”	@ 55’	Maintain hole integrity	Grade: H-40, 42 ppf
8 5/8”	@1050	Isolate fresh water	Grade: H-40, 28 ppf
4 ½”	@ 5600’	Production String	Grade: C-75, 11.6 ppf

Assumptions:

- Design factor for burst and collapse calculations is 1.1.
- Design factor for tension calculations is 1.5.

- Because the design is not a tapered string, calculations for collapse due to tension were ignored.
- Pressure gradient for fresh water (0.433 psi/ft) was used for burst and collapse calculations.
- Fracture gradient of 8.7 psi was calculated from bulk density information on well logs.
- Worst case scenario for collapse assumed an empty string of pipe with 0 pressure inside on bottom and an annulus full of 16.0 ppg cement.
- Worst case scenario for burst assumed injection at pressure0.3 ppg above fracture gradient of 8.7 ppg (9.0 ppg).

Sample Calculations:

Burst Analysis 4 ½" Production String:

Design Factor is: 1.1

Casing Setting Depth: 5000'

Casing Outside Diameter (Od_c) = 4.5"

Pressure inside casing at the bottom (P_{bi}):

P_{bi} = (0.052psi/ft/ppg)*(9.0ppg)*(5000ft) = 2340psi

Pressure outside casing at bottom (P_{bo}):

P_{bo} = (0.433psi/ft)*(5000ft) = 2165 psig

Pressure inside casing at the top (P_{ti}):

P_{ti} = (0.052psi/ft/ppg)*(9.0)*(5000) – [(0.055psi/ft)*(5000ft)] = 2065 psig

Pressure outside casing at the top:

$P_{to} = 0$

Resultant Pressures:

Top: $P_{tr} = P_{ti} - P_{to} = 2065$ psig

Bottom: $P_{br} = P_{bi} - P_{bo} = 175$ psi

Design Pressure:

Top: $P_{tr} * 1.1 = 2272$ psi

Bottom: $P_{br} * 1.1 = 1194.6$ psi

Based on the above calculations the minimum grade of 4 ½" casing that will meet burst requirements is F-25 9.5 ppf.

Collapse Analysis 4 ½" Production String:

Pressure inside casing at bottom (P_{bi}):

$P_{bi} = 0.0$ psig

Pressure outside casing on bottom (P_{bo}):

$P_{bo} = (0.052\text{psi/ft/ppg})*(16.0\text{ppg})*(5000\text{ft}) = 4160$ psig

Pressure inside casing on top (P_{ti}):

$P_{ti} = 0.0$ psig

Pressure outside casing at top (P_{to}):

$P_{to} = 0.0$ psig

Resultant Pressures:

Top: $P_{tr} = P_{to} - P_{ti} = 0.0$ psig

Bottom: $P_{br} = P_{bo} - P_{bi} = 4160$ psig

Design Pressures:

Top: P_{tr} = 1.1*(0) = 0.0 + 14.7 = 14.7 psia

Bottom: P_{br} = 1.1*(4160) = 4576 +14.7 = 4591 psia

Based on the above design criteria for collapse, the minimum grade of 4 ½" casing that can be used is C-75 11.6 ppf. (Halliburton, 1994)

Tension Analysis 4 ½" Production String:

Cross-section area of steel:

$A_s = (\pi/4)*(4.5^2 - 4^2) = 3.34\ in^2$

Axial force acting on the casing at the surface:

F = (11.6 ppf)*(5000 ft) – (3.34in^2)*(1180 psig)

F = 54,058 lbs.

Design Tension:

F_d = 1.5*(54,058) = 81,088 lb

C-75 buttress thread 4 ½" casing is selected has joint yield strength of 288,000 lb, which is well within design criteria.

All Calculations were done for each string of casing that was used in the hole and the results are in the following set of tables:

Kanawha County OSM #1:

Casing OD (in)	Burst Design Pressure (psia)	Collapse Design Pressure (psia)	Tension Design (lbs)	Grade Selected
13 3/8"	N/A	N/A	N/A	H-40, 48 ppf
9 5/8"	500.00	1,007.00	49,741.00	H-40, 32.3 ppf
7"	1,067.00	2,151.00	65,717.00	J-55,20 ppf
4 1/2"	2,272.00	4,576.00	81,089.00	C-75, 11.6 ppf

Doddridge County OSM #2:

Casing OD (in)	Burst Design Pressure (psia)	Collapse Design Pressure (psia)	Tension Design (lbs)	Grade Selected
11 ¾"	N/A	N/A	N/A	H-40, 42 ppf
8 5/8"	433.00	977.00	41,158.00	H-40, 28 ppf
4 1/2"	2,543.00	5,141.00	90,838.00	C-75, 11.6 ppf

Cement Design/Bit Program:

Class A cement (1.14 ft^3/sx) was used for all cement volumetric calculations. The cement design calculations were based on the following bit program. All strings of casing were cemented to surface except for the production strings. The production strings were cemented 500' above the previous string setting depth.

Bit Program				
Kanawha County Prospect				
Casing OD	13 3/8"	9 5/8"	7"	4 1/2"
Bit	17 1/2"	12 1/4"	8 1/2"	6 1/4"

Bit Program				
Doddridge County Prospect				
Casing OD	11 3/4"	8 5/8"	4 1/2"	
Bit	17 1/2"	11"	6 1/4"	

Cement Program				
Kanawha County Prospect				
Casing OD	13 3/8"	9 5/8"	7"	4 1/2"
SXS	51	450	379	410

Cement Program				
Doddridge County Prospect				
Casing OD	11 3/4"	8 5/8"	4 1/2"	
SXS	84	358	718	

Well Log Interpretation and Reserve Estimation

OSM# 1 History Matching Approach

Formation	Layer	Perforating Depth	Thickness of Pay (ft)	Sonic Gas Detector	Density Porosity (%)
Devonian Shale	**1**	2424' - 2430'	6	Small	7
	2	3154' - 3190'	36	Large	10
	3	4504' - 4512'	8	Medium	2
		Net Pay	50		

OSM# 2 Approach #1 (Unacceptable)

Formation	Layer	Perforating Depth	Thickness of Pay (ft)	Corrected Resistivity ILD to 75 F (ohm-m)	Average RHOB (gm/cc)	Average Density Porosity (%)	Average Neutron Porosity (p.u.)	Porosity (%)	Gas Saturation (%)	Reserves MMCF/Ac
Ball Town	**1**	4110' – 4116'	6	69.76	2.55	8	7	12	40	3.14
	2	4146' – 4148'	10	71.31	2.6	10.3	6.3	10	36	3.92
		4154' - 4158'								
		4174' - 4178'								
	3	4254' – 4264'	10	65.11	2.53	10	5	12	60	7.84
		Net Pay	26							
Riley	**1**	4562' – 4564'	2	54.26	2.65	7	7	10	30	0.65
	2	4572' – 4576'	8	69.76	2.54	9	5.7	13	60	6.80
		4578' - 4580'								
		4588' - 4590'								
		Net Pay	10							
Alex/Benson	**1**	5008' – 5016'	8	82.17	2.43	13	8	17	53	7.85
	2	5288' – 5292'	12	94.18	2.5	11.25	5.5	13.5	60	10.59
		5310' - 5312'								
		5316' - 5318'								
		5320' - 5324'								
		Net Pay	20							40.78

OSM# 2 Approach #2 (Acceptable)

Formation	Layer	Perforating Depth	Thickness of Pay (ft)	Average ILD Resistivity (ohm-m)	Corrected Resistivity ILD to 75 F (ohm-m)	Porosity from CP-5 decimal	Formation Resistivity Factor from Humble eq.	Gas Saturation (%)	Reserves MMCF/Ac
Ball Town	**1**	4110' - 4116'	6	45	69.76	0.075	144.00	30.08	1.47
	2	4146' - 4148'	10	46	71.31	0.09	100.00	30.84	3.02
		4154' - 4158'							
		4174' - 4178'							
	3	4254' - 4264'	10	42	65.11	0.075	144.00	27.62	2.26
		Net Pay	26						
Riley	**1**	4562' - 4564'	2	35	54.26	0.065	191.72	20.71	0.29
	2	4572' - 4576'	8	45	69.76	0.075	144.00	30.08	1.97
		4578' - 4580'							
		4588' - 4590'							
		Net Pay	10						
Alex/Benson	**1**	5008' - 5016'	8	53	82.17	0.12	56.25	35.57	3.72
	2	5288' - 5292'	12	60.75	94.18	0.09	100.00	39.82	4.68
		5310' - 5312'							
		5316' - 5318'							
		5320' - 5324'							
		Net Pay	20					Wellbore	17.41

Build-Up Analysis

OSM # 1: (OUTPUT)

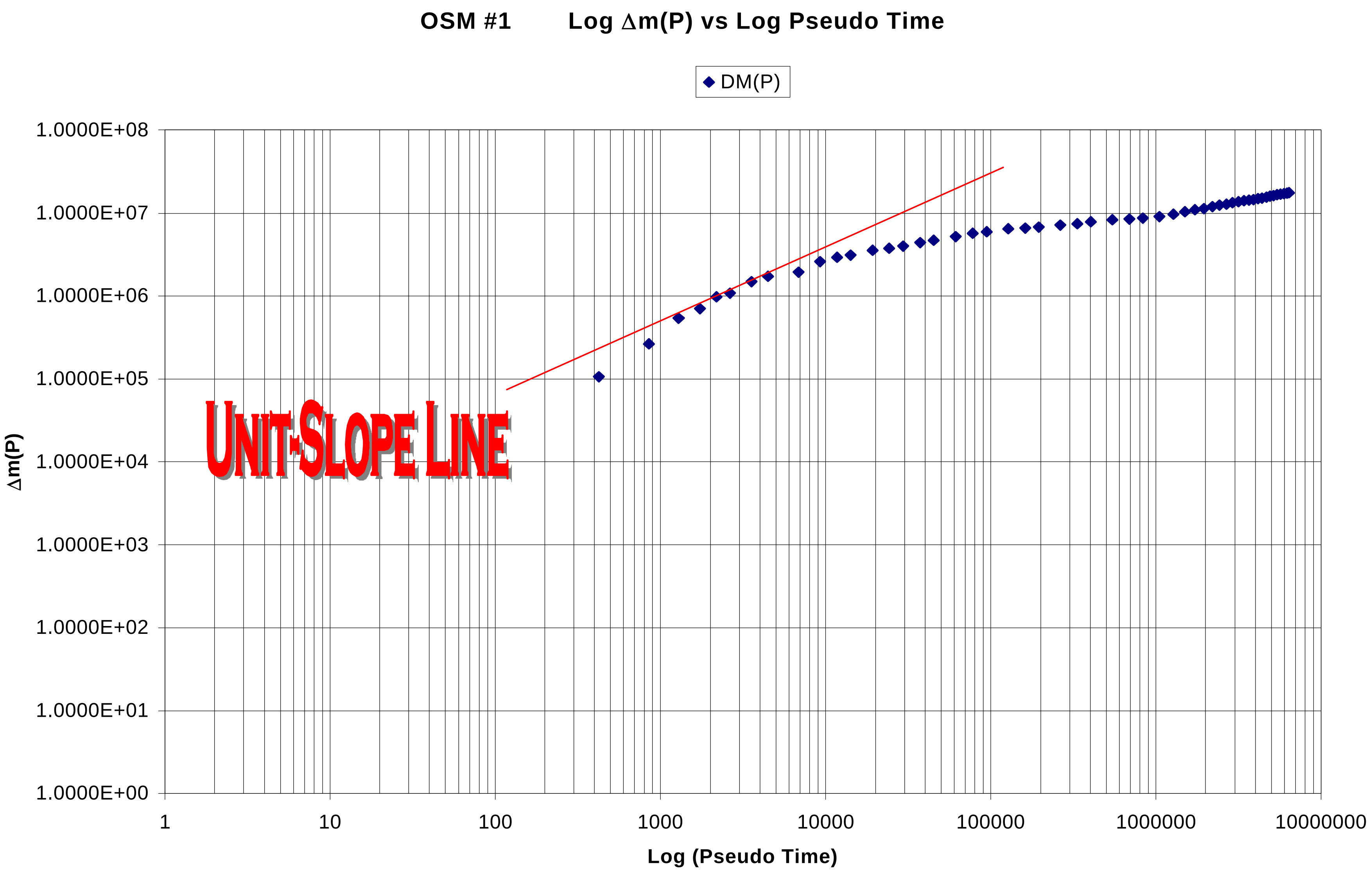
Time	Pressure	Δ P	Viscosity	Z	m(P)	Δ m(P)	Pseudo Time	Adjusted Time	Adjusted Pressure	Δ PA	Horner Time	Pseudo Horner Time	Adjusted Horner Time	Square Root of Time
					2.57E+07									
0.00	310		0.0122	0.97	8.13E+06		0.00	0.00	111.26		0.0			0
0.02	312	2	0.0122	0.97	8.23E+06	1.06E+05	425.36	0.01	112.71	1.45	20341.0	161264.498	122998.7686	0.1414
0.03	315	5	0.0122	0.96	8.39E+06	2.65E+05	854.70	0.02	114.89	3.63	10171.0	80257.279	61499.8843	0.1732
0.05	320	10	0.0122	0.96	8.66E+06	5.35E+05	1290.67	0.04	118.58	7.32	6781.0	53147.847	30750.4421	0.2236
0.07	323	13	0.0122	0.96	8.83E+06	6.99E+05	1730.61	0.05	120.82	9.56	5086.0	39637.337	24600.5537	0.2646
0.08	328	18	0.0122	0.96	9.10E+06	9.75E+05	2177.17	0.06	124.61	13.35	4069.0	31507.516	20500.6281	0.2828
0.10	330	20	0.0122	0.96	9.22E+06	1.09E+06	2626.37	0.08	126.14	14.88	3391.0	26118.813	15375.7211	0.3162
0.13	337	27	0.0122	0.96	9.61E+06	1.48E+06	3543.26	0.10	131.56	20.30	2543.5	19360.302	12300.7769	0.3606
0.17	341	31	0.0122	0.96	9.84E+06	1.71E+06	4470.70	0.13	134.71	23.45	2035.0	15344.244	9462.3668	0.4123
0.25	345	35	0.0122	0.96	1.01E+07	1.95E+06	6815.66	0.20	137.90	26.64	1357.0	10065.329	6150.8884	0.5000
0.33	356	46	0.0123	0.96	1.07E+07	2.60E+06	9232.98	0.27	146.87	35.61	1018.0	7430.350	4556.4729	0.5745
0.42	361	51	0.0123	0.96	1.10E+07	2.91E+06	11683.12	0.34	151.04	39.78	814.6	5872.295	3618.5814	0.6481
0.50	364	54	0.0123	0.96	1.12E+07	3.09E+06	14152.94	0.41	153.56	42.30	679.0	4847.699	3000.9456	0.7071
0.67	371	61	0.0123	0.96	1.17E+07	3.53E+06	19184.31	0.55	159.55	48.29	509.5	3576.580	2237.3231	0.8185
0.83	374	64	0.0123	0.96	1.18E+07	3.72E+06	24254.94	0.70	162.14	50.88	407.8	2829.085	1758.1110	0.9110
1.00	378	68	0.0123	0.96	1.21E+07	3.97E+06	29377.88	0.84	165.64	54.38	340.0	2335.921	1465.2591	1.0000
1.25	384	74	0.0123	0.96	1.25E+07	4.36E+06	37179.83	1.07	170.96	59.70	272.2	1845.953	1150.5119	1.1180
1.50	389	79	0.0123	0.96	1.28E+07	4.69E+06	45079.61	1.29	175.45	64.19	227.0	1522.642	954.4711	1.2247
2.00	397	87	0.0123	0.96	1.34E+07	5.22E+06	61191.72	1.76	182.76	71.50	170.5	1121.986	699.8510	1.4142
2.50	404	94	0.0123	0.96	1.38E+07	5.70E+06	77576.80	2.23	189.28	78.02	136.6	885.221	552.5595	1.5811
3.00	408	98	0.0123	0.96	1.41E+07	5.98E+06	94117.66	2.70	193.06	81.80	114.0	729.822	456.5473	1.7321
4.00	414	104	0.0123	0.96	1.45E+07	6.39E+06	127666.10	3.67	198.79	87.53	85.8	538.300	336.1438	2.0000
5.00	417	107	0.0123	0.95	1.47E+07	6.61E+06	161447.70	4.64	201.69	90.43	68.8	425.875	266.0814	2.2361
6.00	420	110	0.0123	0.95	1.49E+07	6.82E+06	195462.10	5.61	204.61	93.35	57.5	351.938	220.2474	2.4495
8.00	425	115	0.0123	0.95	1.53E+07	7.18E+06	264266.70	7.59	209.52	98.26	43.4	260.567	163.0524	2.8284

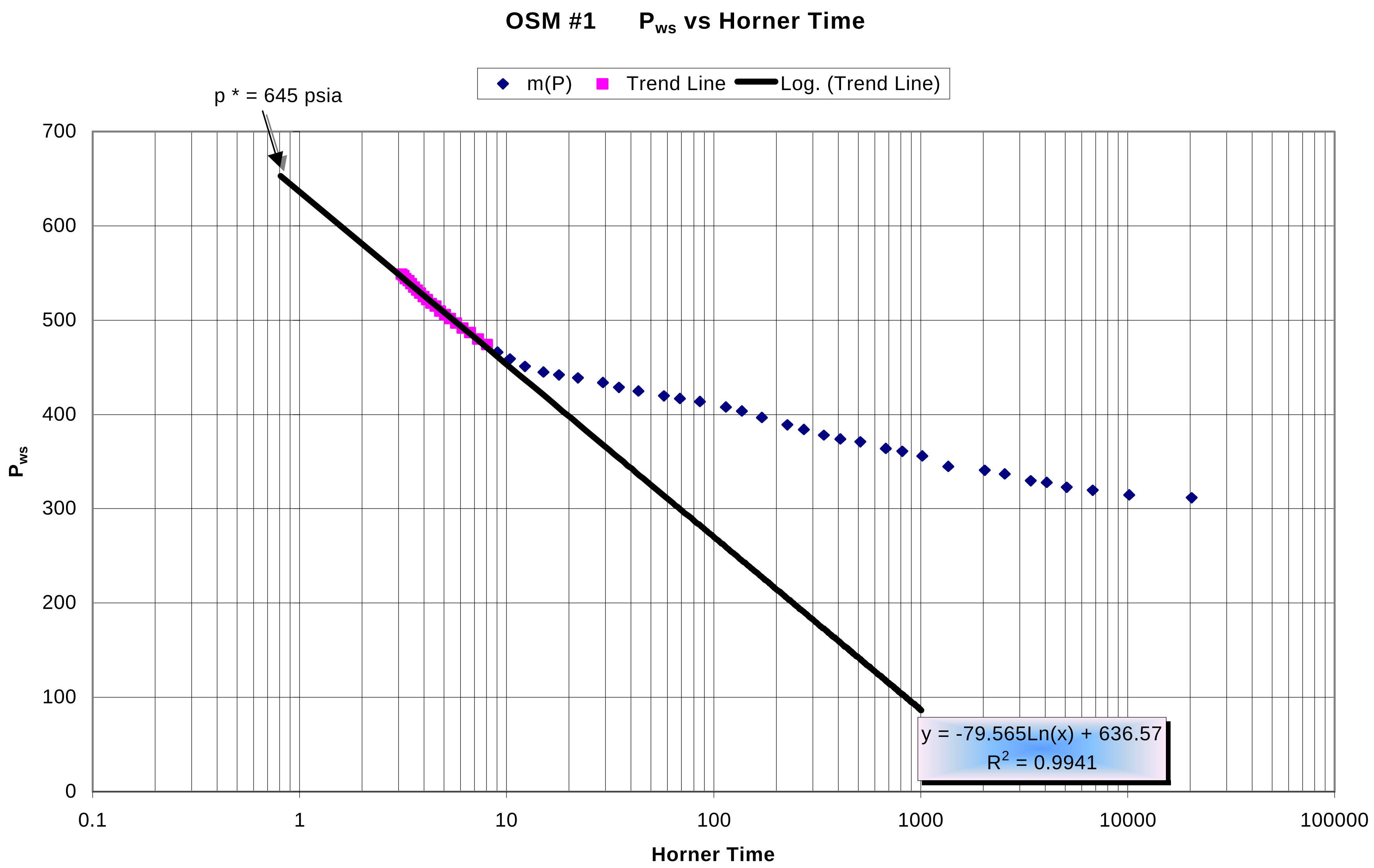
OSM # 1: (cont.)

	Time	Pressure	Δ P	Viscosity	Z	m(P)	Δ m(P)	Pseudo Time	Adjusted Time	Adjusted Pressure	Δ PA	Horner Time	Pseudo Horner Time	Adjusted Horner Time	Square Root of Time
26	10.00	429	119	0.0123	0.95	1.56E+07	7.47E+06	333691.10	9.58	213.50	102.24	34.9	206.564	129.3902	3.1623
27	12.00	434	124	0.0124	0.95	1.60E+07	7.84E+06	403889.40	11.60	218.51	107.25	29.3	170.836	107.0326	3.4641
28	16.00	439	129	0.0124	0.95	1.63E+07	8.21E+06	545831.60	15.67	223.59	112.33	22.2	126.671	79.4925	4.0000
29	20.00	442	132	0.0124	0.95	1.66E+07	8.43E+06	688700.30	19.77	226.66	115.40	18.0	100.601	63.2143	4.4721
30	24.00	445	135	0.0124	0.95	1.68E+07	8.66E+06	832494.70	23.90	229.76	118.50	15.1	83.397	52.4635	4.8990
31	30.00	451	141	0.0124	0.95	1.72E+07	9.11E+06	1050960.00	30.18	236.01	124.75	12.3	66.269	41.7547	5.4772
32	36.00	459	149	0.0124	0.95	1.79E+07	9.73E+06	1273118.00	36.55	244.47	133.21	10.4	54.880	34.6519	6.0000
33	42.00	466	156	0.0124	0.95	1.84E+07	1.03E+07	1498499.00	43.03	252.00	140.74	9.1	46.776	29.5842	6.4807
34	48.00	474	164	0.0124	0.95	1.90E+07	1.09E+07	1727558.00	49.60	260.74	149.48	8.1	40.706	25.7979	6.9282
35	54.00	480	170	0.0124	0.95	1.95E+07	1.14E+07	1959369.00	56.26	267.40	156.14	7.3	36.009	22.8624	7.3485
36	60.00	487	177	0.0124	0.95	2.01E+07	1.20E+07	2194386.00	63.01	275.27	164.01	6.7	32.259	20.5204	7.7460
37	66.00	492	182	0.0124	0.95	2.05E+07	1.24E+07	2431689.00	69.82	280.96	169.70	6.1	29.209	18.6164	8.1240
38	72.00	497	187	0.0124	0.95	2.09E+07	1.28E+07	2671275.00	76.70	286.71	175.45	5.7	26.679	17.0362	8.4853
39	78.00	502	192	0.0124	0.95	2.14E+07	1.32E+07	2913141.00	83.64	292.52	181.26	5.3	24.547	15.7056	8.8318
40	84.00	506	196	0.0124	0.95	2.17E+07	1.36E+07	3156829.00	90.64	297.20	185.94	5.0	22.729	14.5699	9.1652
41	90.00	510	200	0.0125	0.95	2.21E+07	1.39E+07	3402336.00	97.69	301.93	190.67	4.8	21.161	13.5906	9.4868
42	96.00	515	205	0.0125	0.95	2.25E+07	1.44E+07	3650114.00	104.80	307.89	196.63	4.5	19.793	12.7364	9.7980
43	102.00	518	208	0.0125	0.94	2.28E+07	1.46E+07	3899254.00	111.96	311.49	200.23	4.3	18.592	11.9859	10.0995
44	108.00	522	212	0.0125	0.94	2.31E+07	1.50E+07	4150207.00	119.16	316.32	205.06	4.1	17.528	11.3221	10.3923
45	114.00	525	215	0.0125	0.94	2.34E+07	1.52E+07	4402519.00	126.41	319.97	208.71	4.0	16.581	10.7301	10.6771
46	120.00	529	219	0.0125	0.94	2.37E+07	1.56E+07	4656641.00	133.70	324.87	213.61	3.8	15.731	10.1995	10.9545
47	126.00	532	222	0.0125	0.94	2.40E+07	1.59E+07	4912118.00	141.04	328.57	217.31	3.7	14.964	9.7208	11.2250
48	132.00	535	225	0.0125	0.94	2.43E+07	1.61E+07	5168951.00	148.41	332.29	221.03	3.6	14.271	9.2877	11.4891
49	138.00	539	229	0.0125	0.94	2.46E+07	1.65E+07	5427588.00	155.84	337.29	226.03	3.5	13.638	8.8926	11.7473
50	144.00	542	232	0.0125	0.94	2.49E+07	1.68E+07	5687577.00	163.30	341.06	229.80	3.4	13.061	8.5320	12.0000
51	150.00	544	234	0.0125	0.94	2.51E+07	1.70E+07	5948467.00	170.79	343.58	232.32	3.3	12.532	8.2017	12.2474
52	156.00	547	237	0.0125	0.94	2.54E+07	1.73E+07	6210707.00	178.32	347.38	236.12	3.2	12.045	7.8976	12.4900
53	160.67	549	239	0.0125	0.94	2.56E+07	1.74E+07	6415371.00	184.20	349.93	238.67	3.1	11.692	7.6774	12.6756

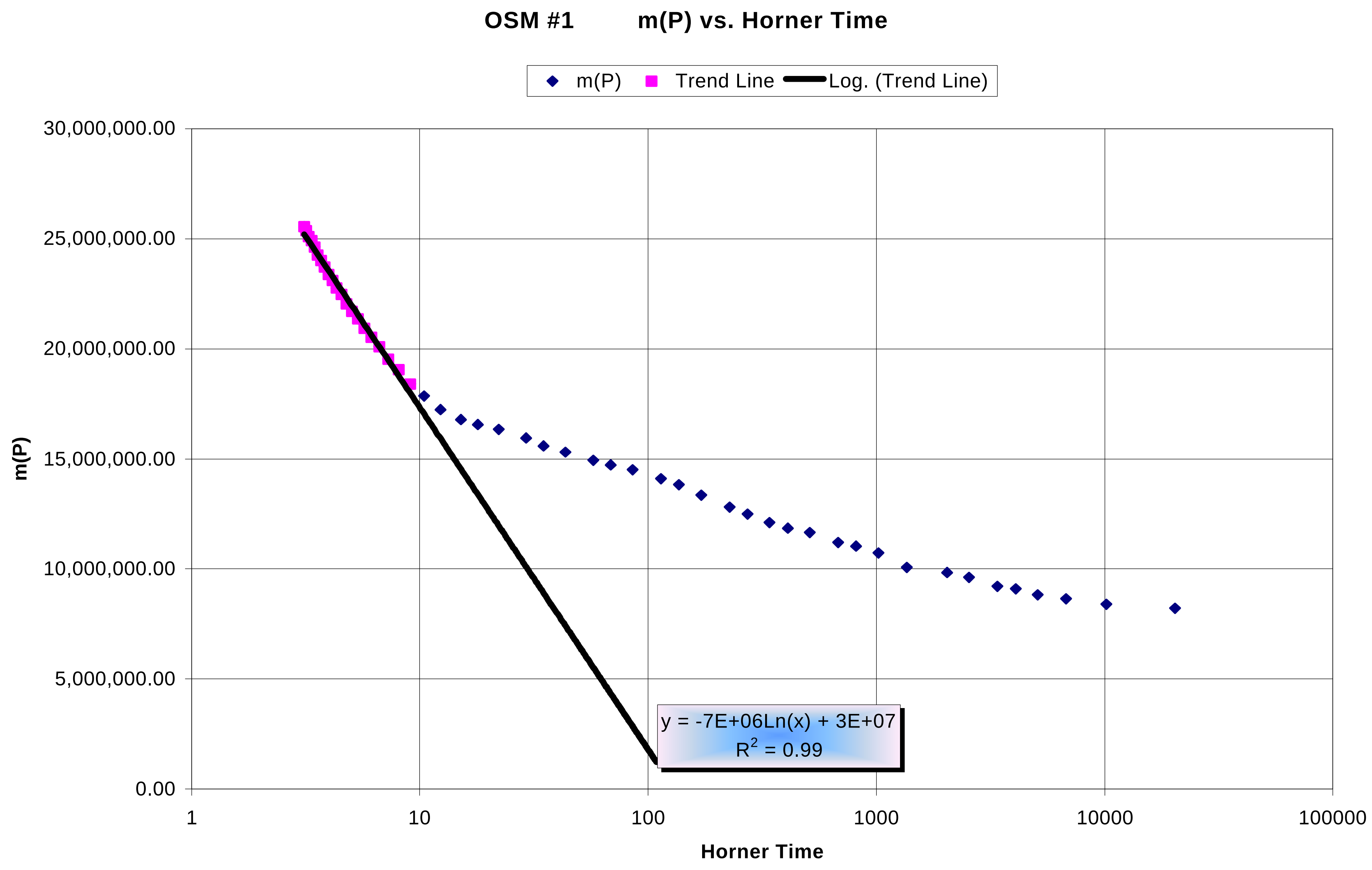
OSM #2: (OUTPUT)

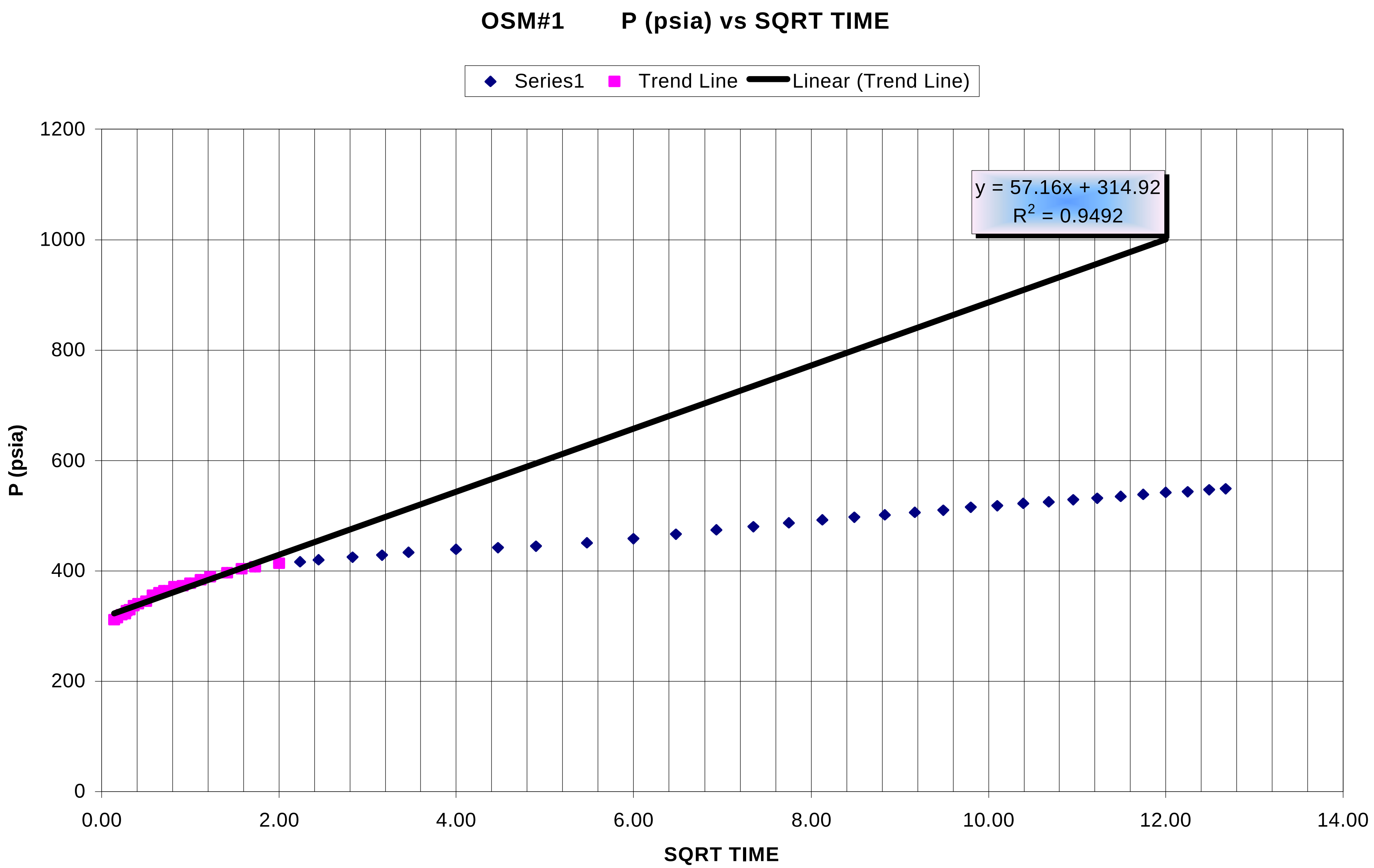
	Time	Pressure	Δ P	Viscosity	Z	m(P)	Δ m(P)	Pseudo Time	Adjusted Time	Adjusted Pressure	Δ PA	Horner Time	Pseudo Horner Time	Adjusted Horner Time
1						7.18E+07								
2	0	514		0.0126	0.95	2.22E+07		0	0.00	183.93		0.000		
3	6.8	605	266	0.0127	0.94	3.08E+07	8.57E+06	323765.6	5.80	254.90	70.97	147.471	212.87	213.07
4	26.2	647	308	0.0128	0.93	3.52E+07	1.30E+07	1306569	23.39	291.51	107.58	39.015	53.50	53.59
5	49.9	681	342	0.0128	0.93	3.90E+07	1.68E+07	2564960	45.92	322.92	138.99	20.960	27.74	27.79
6	73.7	710	371	0.0129	0.93	4.24E+07	2.02E+07	3877608	69.42	350.97	167.04	14.514	18.69	18.72
7	98	733	394	0.0129	0.92	4.52E+07	2.30E+07	5257116	94.12	374.03	190.10	11.163	14.05	14.07
8	168	770	431	0.013	0.92	4.99E+07	2.76E+07	9409876	168.46	412.66	228.73	6.929	8.29	8.30
9	193	782	443	0.013	0.92	5.14E+07	2.92E+07	10913740	195.38	425.62	241.69	6.161	7.29	7.30
10	221	794	455	0.013	0.92	5.30E+07	3.08E+07	12621200	225.95	438.76	254.83	5.507	6.43	6.44
11	240	800	461	0.013	0.92	5.38E+07	3.16E+07	13787650	246.84	445.41	261.48	5.150	5.98	5.98
12	270	806	467	0.013	0.91	5.46E+07	3.24E+07	15641750	280.03	452.10	268.17	4.689	5.39	5.39
13	339	822	483	0.0131	0.91	5.68E+07	3.46E+07	19981470	357.72	470.17	286.24	3.938	4.43	4.44
14	362	828	489	0.0131	0.91	5.76E+07	3.54E+07	21437420	383.79	477.04	293.11	3.751	4.20	4.20
15	391	833	494	0.0131	0.91	5.83E+07	3.61E+07	23283010	416.83	482.79	298.86	3.547	3.95	3.95
16	409	835	496	0.0131	0.91	5.86E+07	3.64E+07	24430990	437.38	485.11	301.18	3.435	3.81	3.81
17	435	837	498	0.0131	0.91	5.89E+07	3.67E+07	26092700	467.13	487.42	303.49	3.290	3.63	3.63
18	506	844	505	0.0131	0.91	5.99E+07	3.76E+07	30664020	548.97	495.57	311.64	2.968	3.24	3.24
19	557	849	510	0.0131	0.91	6.06E+07	3.84E+07	33964840	608.06	501.43	317.50	2.788	3.02	3.02
20	577	850	511	0.0131	0.91	6.07E+07	3.85E+07	35260630	631.26	502.61	318.68	2.726	2.95	2.95
21	602	851	512	0.0131	0.91	6.09E+07	3.86E+07	36882040	660.29	503.78	319.85	2.655	2.86	2.86
22	673	857	518	0.0131	0.91	6.17E+07	3.95E+07	41515500	743.24	510.88	326.95	2.480	2.65	2.65
23	720	858	519	0.0131	0.91	6.19E+07	3.96E+07	44585880	798.20	512.06	328.13	2.383	2.54	2.54
24	747	859	520	0.0131	0.91	6.20E+07	3.98E+07	46351520	829.81	513.25	329.32	2.333	2.48	2.48

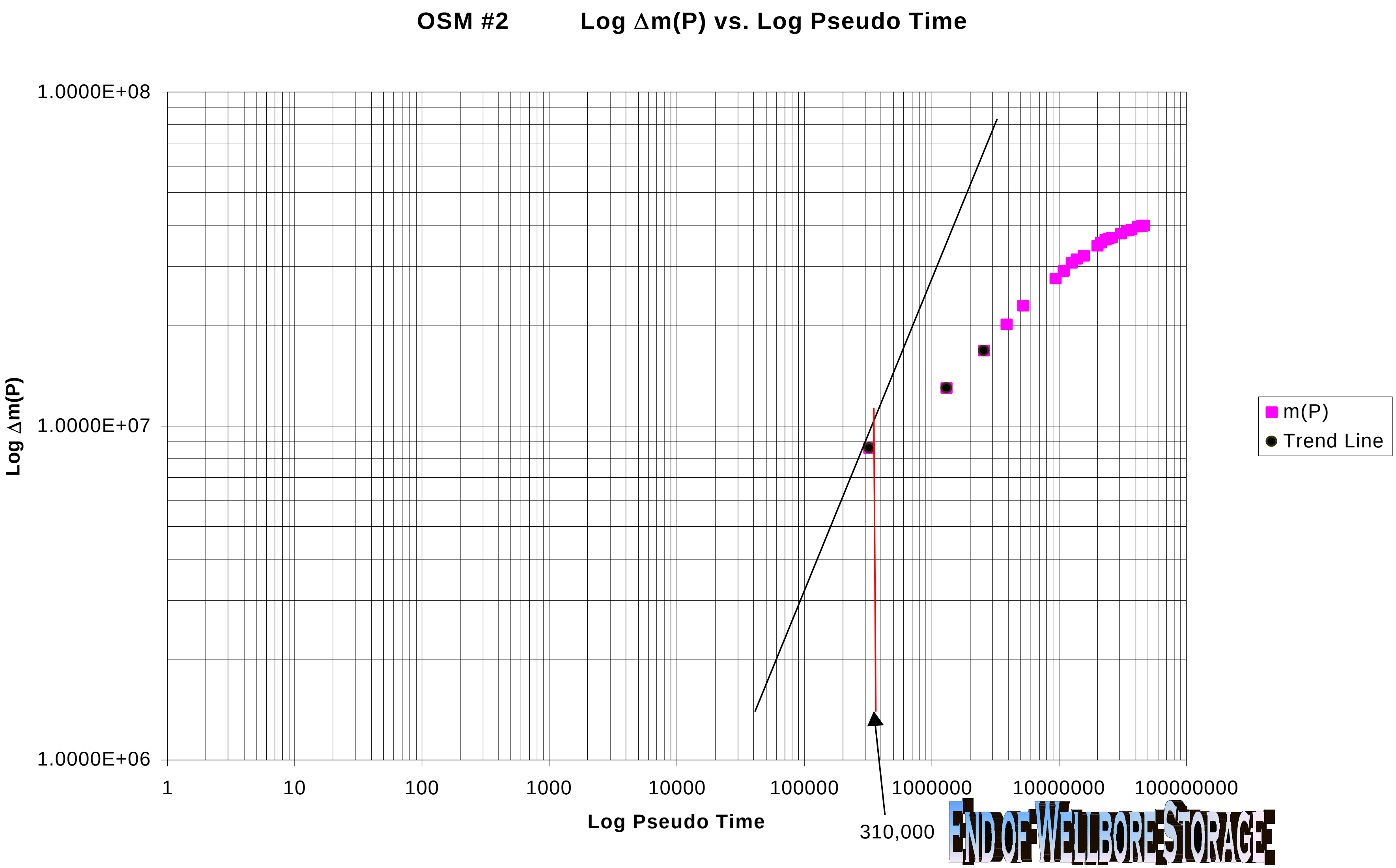

OSM #1 Log ∆m(P) vs Log Pseudo Time
DM(P)
1.0000E+08
1.0000E+07
1.0000E+06
1.0000E+05
1.0000E+04
1.0000E+03
1.0000E+02
1.0000E+01
1.0000E+00
∆m(P)
Unit-Slope Line
1
10
100
1000
10000
100000
1000000
10000000
Log (Pseudo Time)

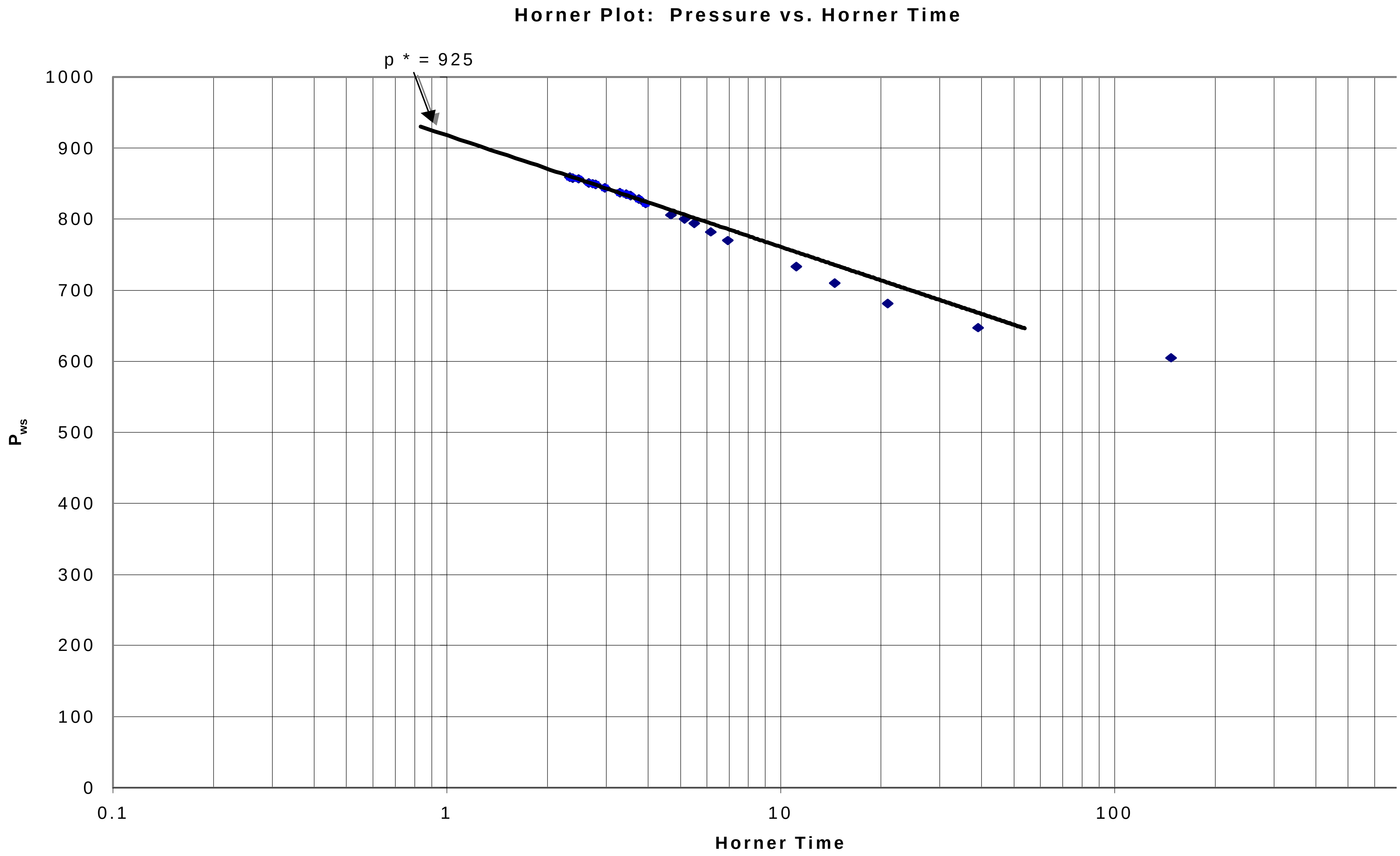


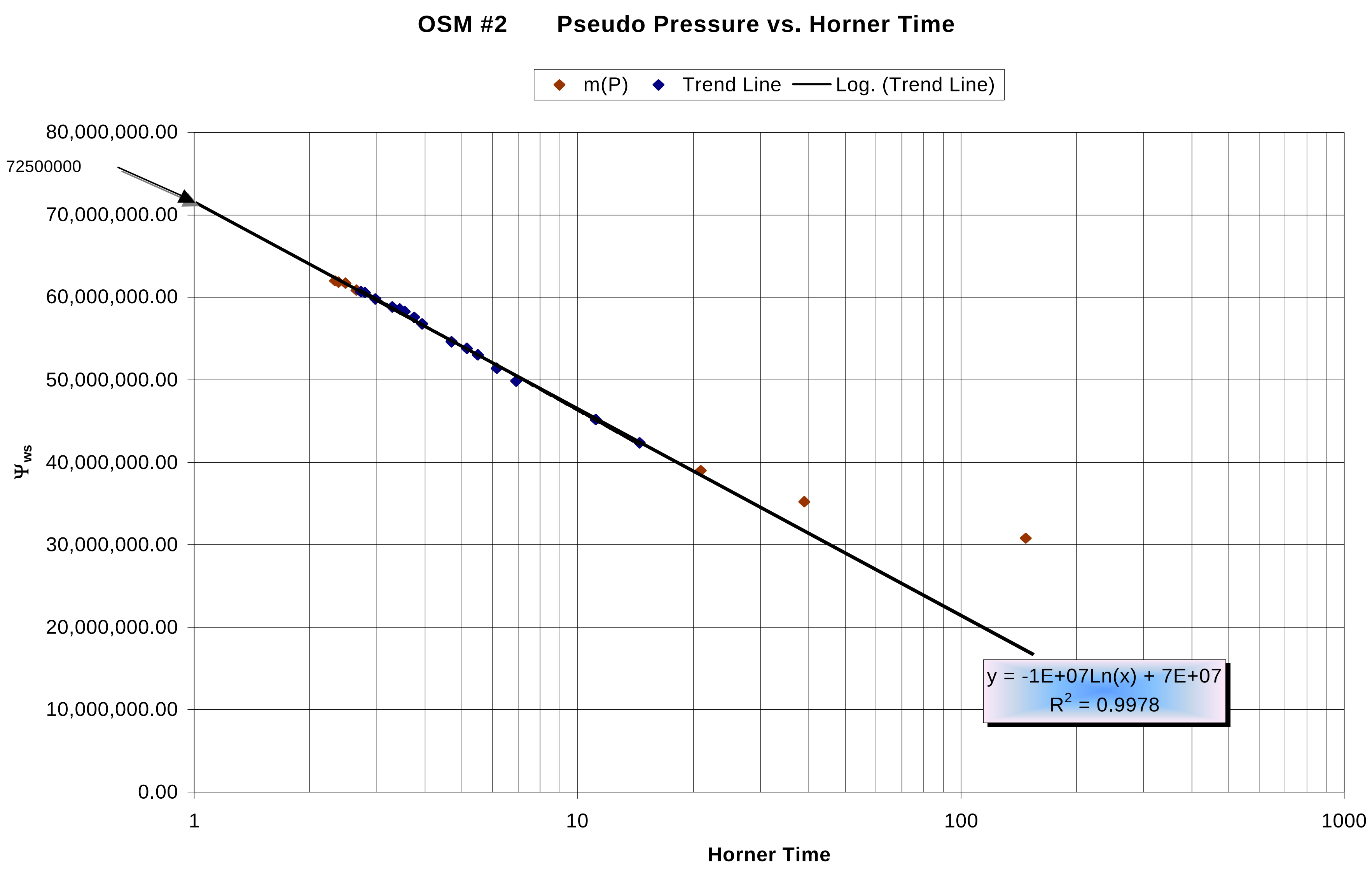
OSM #1 Pws vs Horner Time
m(P)
Trend Line
Log. (Trend Line)
p * = 645 psia
700
600
500
400
300
200
100
0
Pws
0.1
1
10
100
1000
10000
100000
Horner Time
y = -79.565Ln(x) + 636.57
R2 = 0.9941


OSM #1 m(P) vs. Horner Time
m(P)
Trend Line
Log. (Trend Line)
30,000,000.00
25,000,000.00
20,000,000.00
15,000,000.00
10,000,000.00
5,000,000.00
0.00
m(P)
y = -7E+06Ln(x) + 3E+07
R2 = 0.99
1
10
100
1000
10000
100000
Horner Time

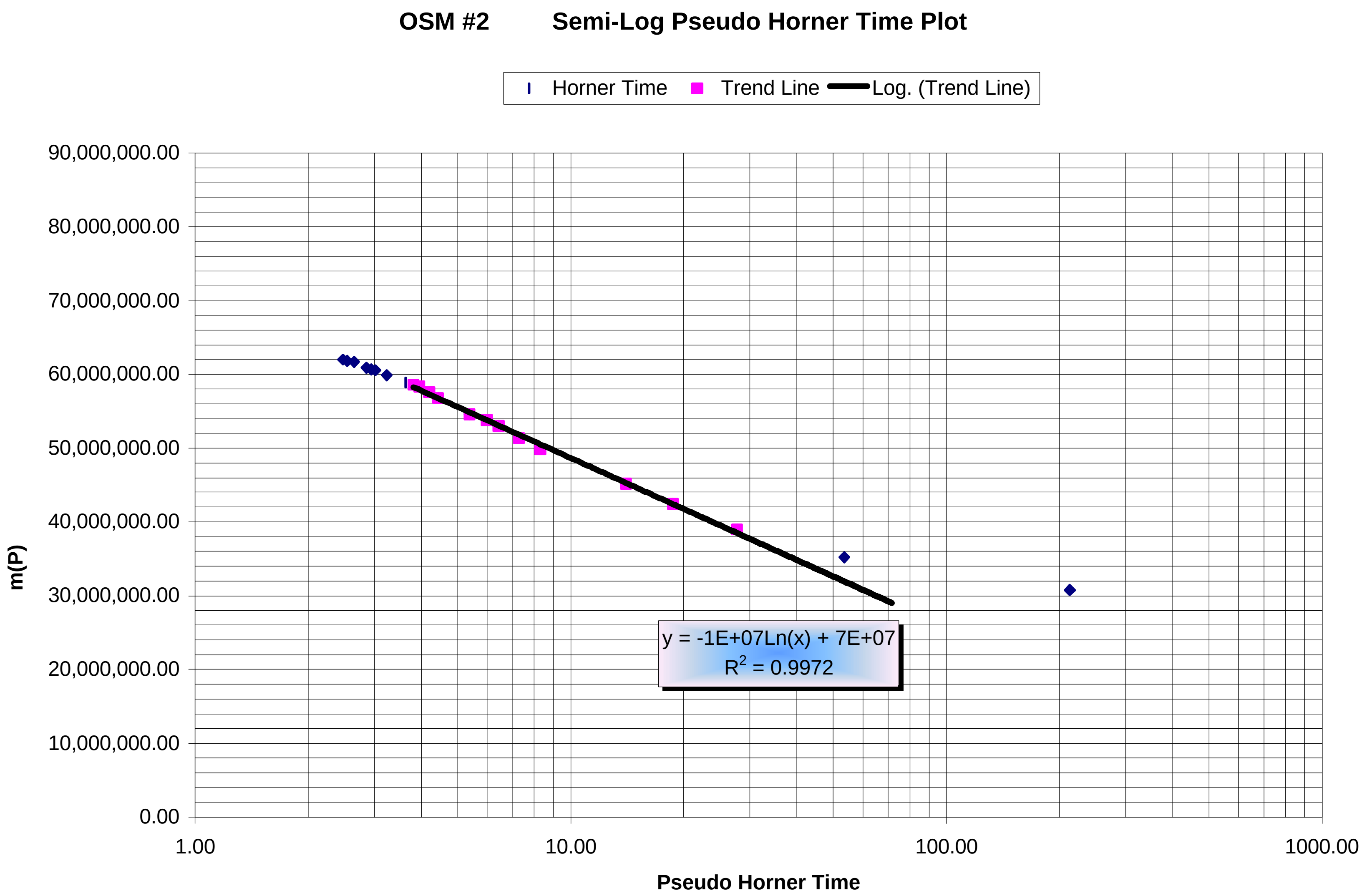

OSM#1 P (psia) vs SQRT TIME
Series1
Trend Line
Linear (Trend Line)
y = 57.16x + 314.92
R2 = 0.9492
P (psia)
SQRT TIME
0
200
400
600
800
1000
1200
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00


OSM #2 Log ∆m(P) vs. Log Pseudo Time
1.0000E+08
1.0000E+07
1.0000E+06
Log ∆m(P)
1
10
100
1000
10000
100000
1000000
10000000
100000000
Log Pseudo Time
m(P)
Trend Line
310,000
END OF WELLBORE STORAGE


Horner Plot: Pressure vs. Horner Time
p* = 925
1000
900
800
700
600
500
400
300
200
100
0
P_{ws}
0.1
1
10
100
Horner Time



OSM #2 Pseudo Pressure vs. Horner Time
m(P)
Trend Line
Log. (Trend Line)
80,000,000.00
72500000
70,000,000.00
60,000,000.00
50,000,000.00
40,000,000.00
30,000,000.00
20,000,000.00
10,000,000.00
0.00
Ψ_{ws}
y = -1E+07Ln(x) + 7E+07
R^2 = 0.9978
1
10
100
1000
Horner Time


OSM #2 Semi-Log Pseudo Horner Time Plot
Horner Time
Trend Line
Log. (Trend Line)
90,000,000.00
80,000,000.00
70,000,000.00
60,000,000.00
50,000,000.00
40,000,000.00
30,000,000.00
20,000,000.00
10,000,000.00
0.00
m(P)
y = -1E+07Ln(x) + 7E+07
R2 = 0.9972
1.00
10.00
100.00
1000.00
Pseudo Horner Time

Build-Up Analysis:(cont)

OSM #1						
Slope of Horner Plot	K_a(mD)	K(mD)	S' Skin Factor	Flow Efficiency	Fracture Half-Length	Initial Formation Pressure (psi)
-7.00E+06	6.19	6.00	-4.50	256.19%	62'	645

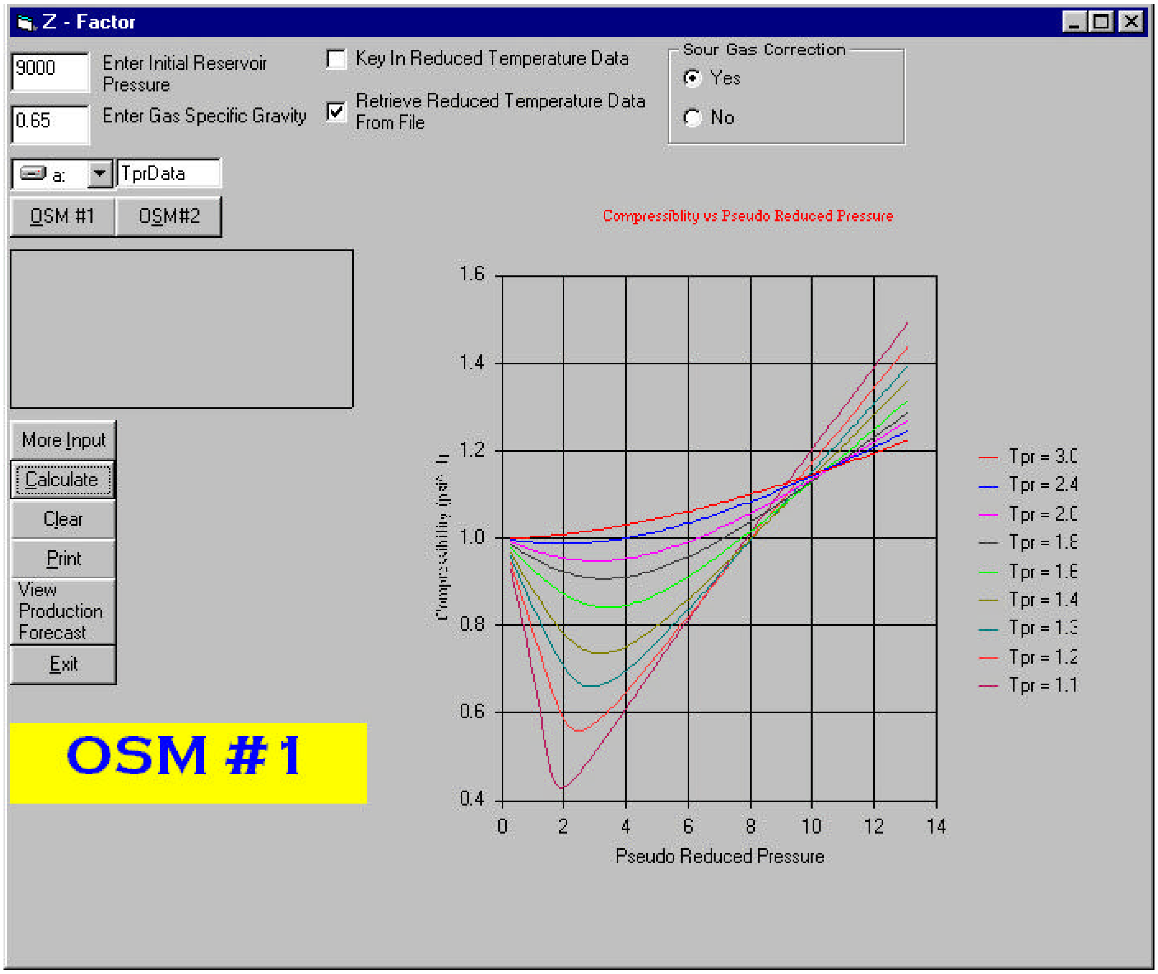
OSM #2				
Slope of Horner Plot	K(mD)	S' Skin Factor	Flow Efficiency	Initial Formation Pressure (psi)
-1.00E+07	4.33	-3.79	166.44%	925

Production Forecasting

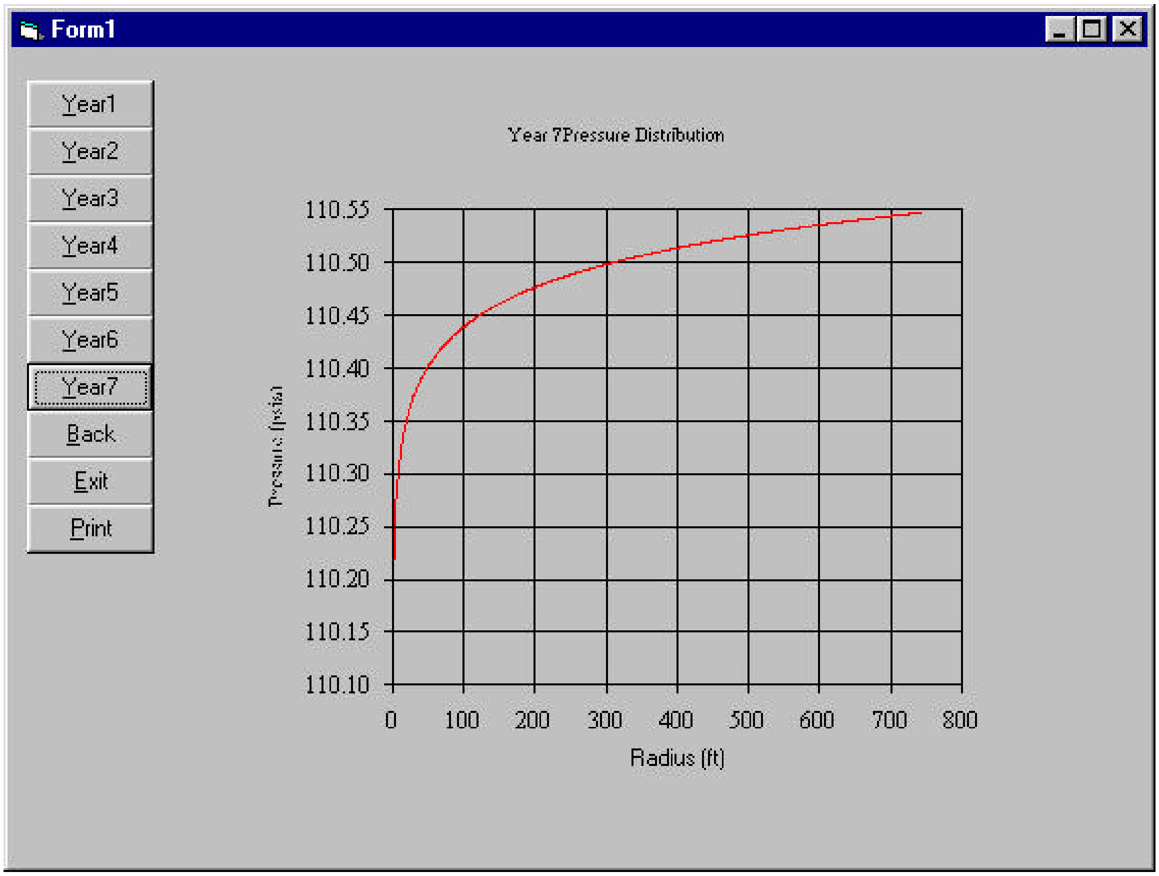
Results:

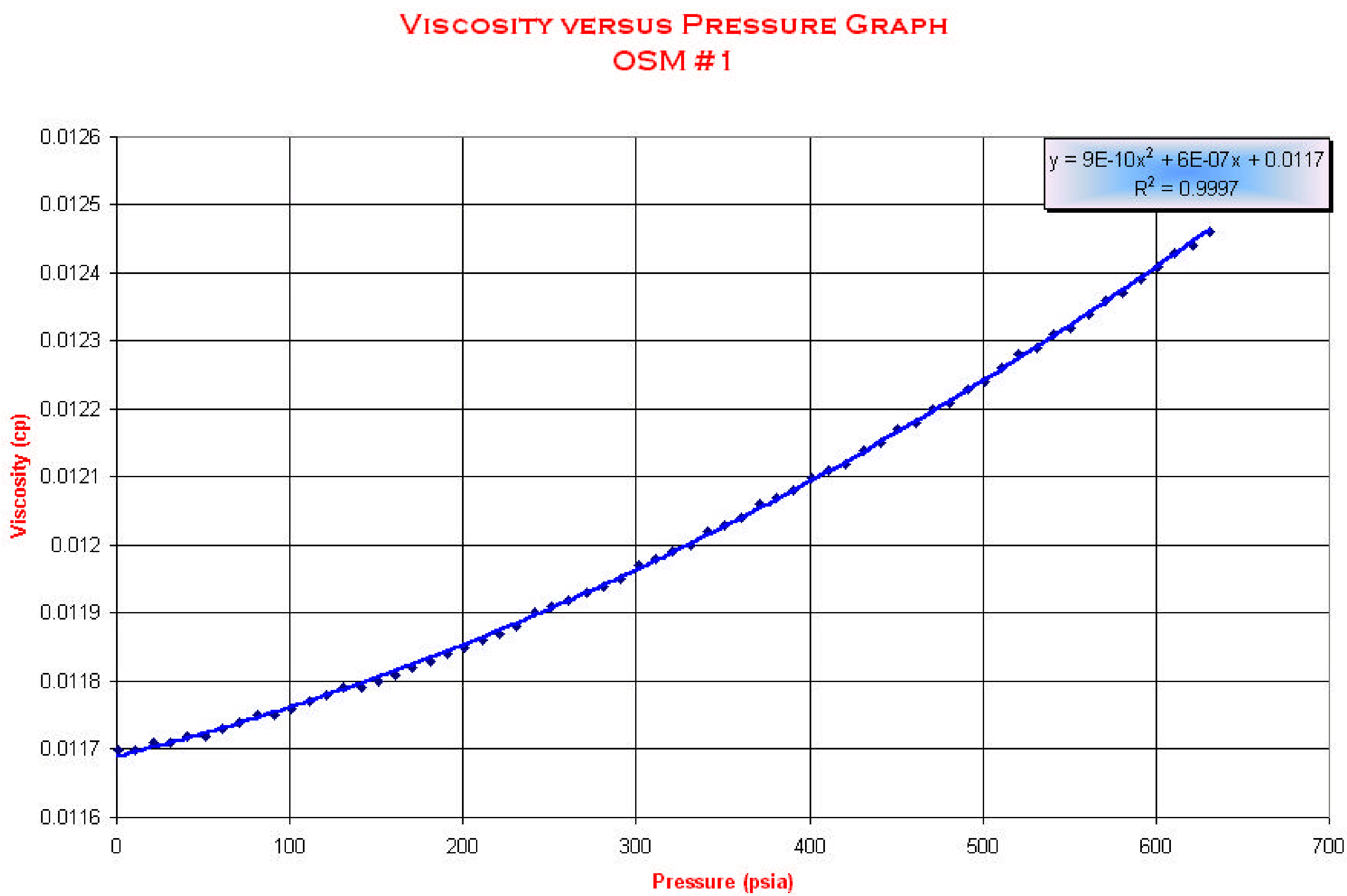
Well Name & Number	Maximum Flowrate (MSCF/D)
OSM # 1	0.165
OSM # 2	0.268

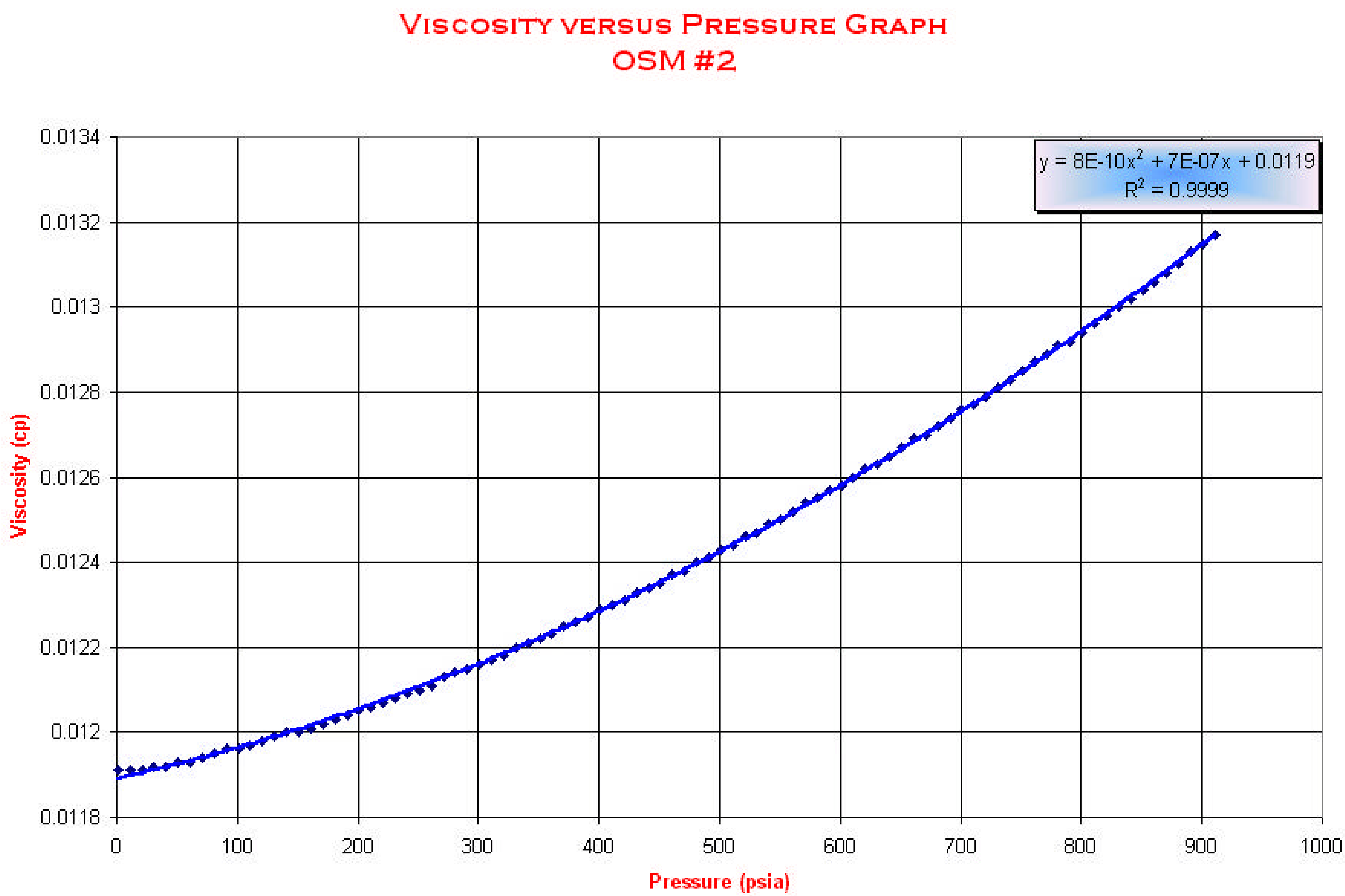
Form #1 in the program, a graph of Compressibility Factor versus Pseudo-Reduced Pressure.



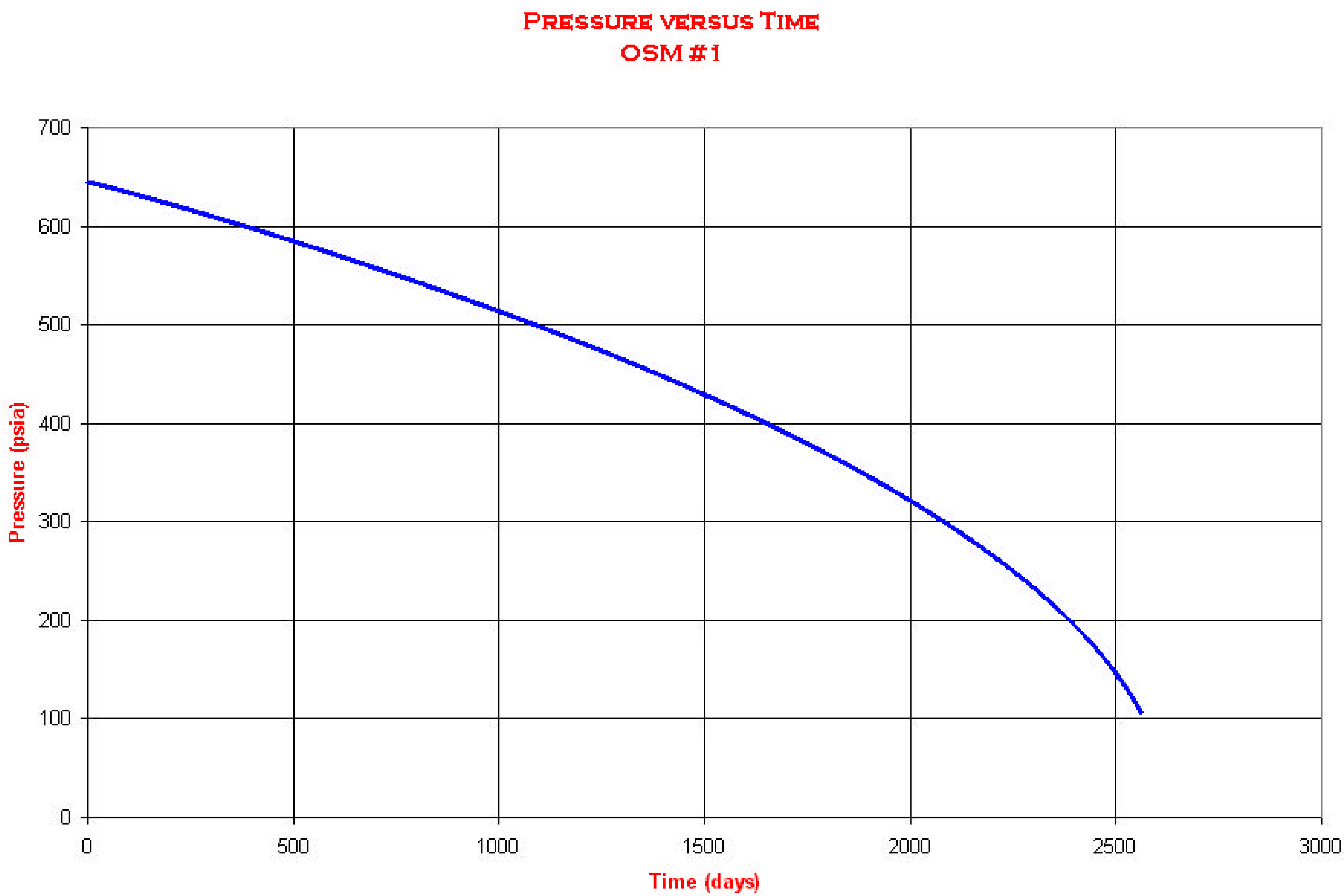
Form #3 in the program, a pressure distribution plot.

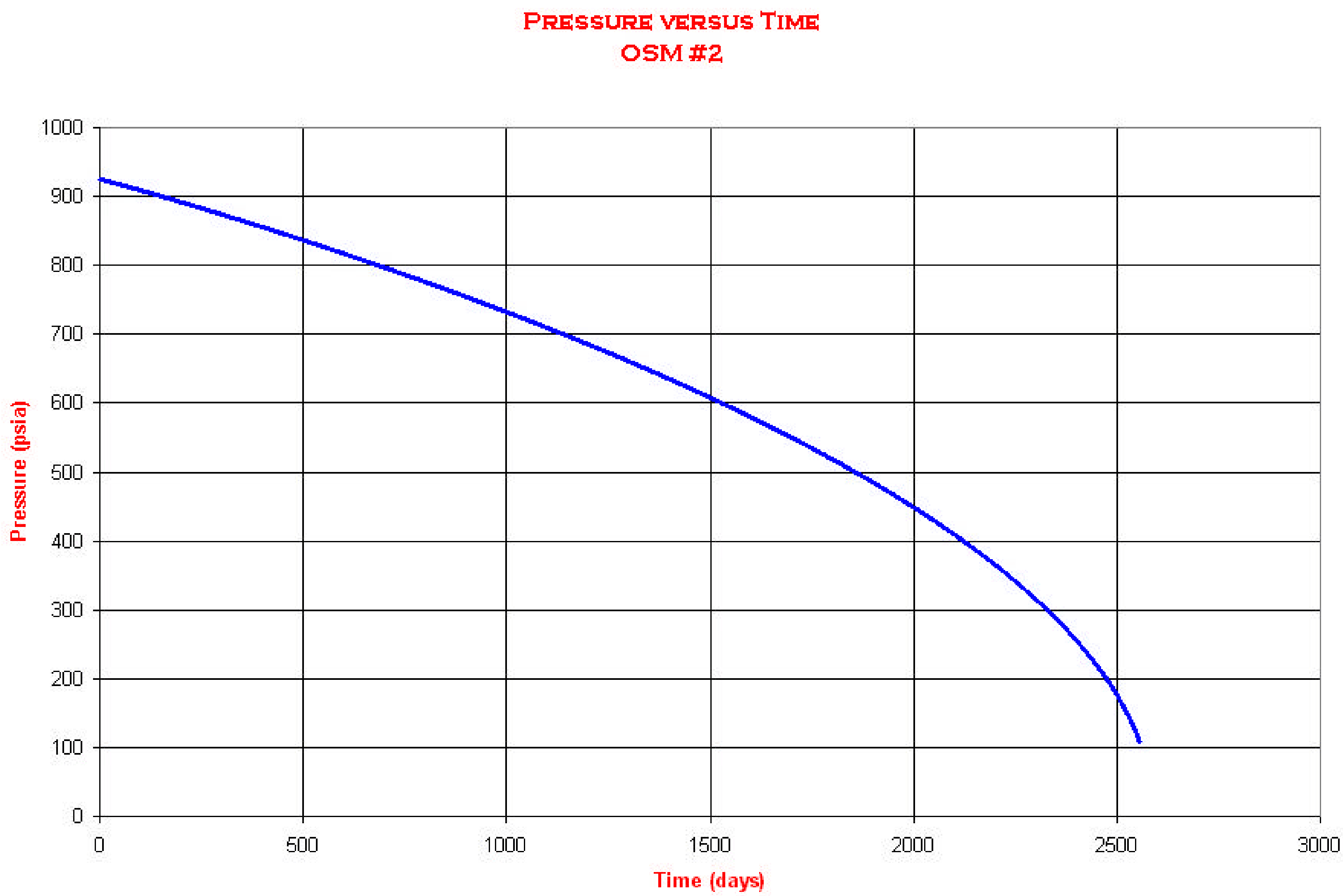



Viscosity versus Pressure Graph
OSM #1
y = 9E-10x2 + 6E-07x + 0.0117
R2 = 0.9997
Viscosity (cp)
Pressure (psia)
0.0126
0.0125
0.0124
0.0123
0.0122
0.0121
0.012
0.0119
0.0118
0.0117
0.0116
0
100
200
300
400
500
600
700



Viscosity versus Pressure Graph
OSM #2
y = 8E-10x^2 + 7E-07x + 0.0119
R^2 = 0.9999
Viscosity (cp)
0.0134
0.0132
0.013
0.0128
0.0126
0.0124
0.0122
0.012
0.0118
0
100
200
300
400
500
600
700
800
900
1000
Pressure (psia)

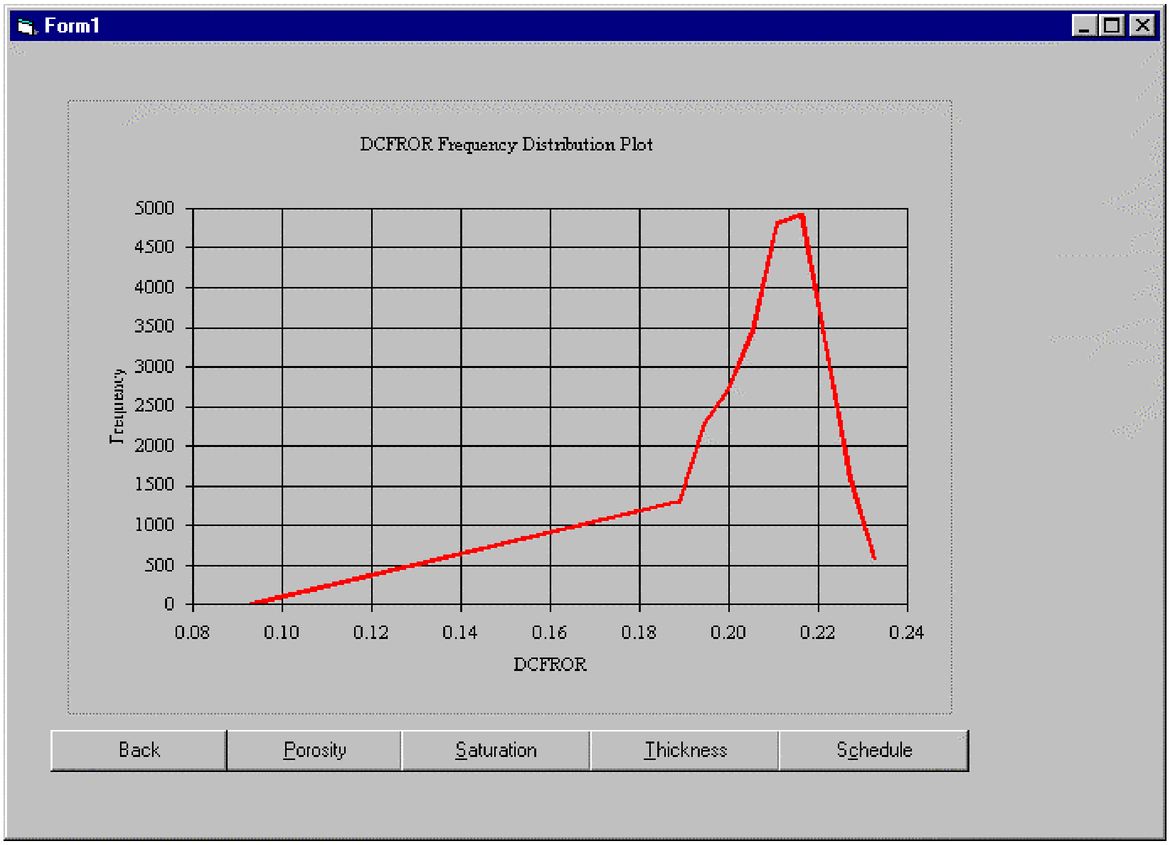

Pressure versus Time
OSM #1
Pressure (psia)
700
600
500
400
300
200
100
0
0
500
1000
1500
2000
2500
3000
Time (days)



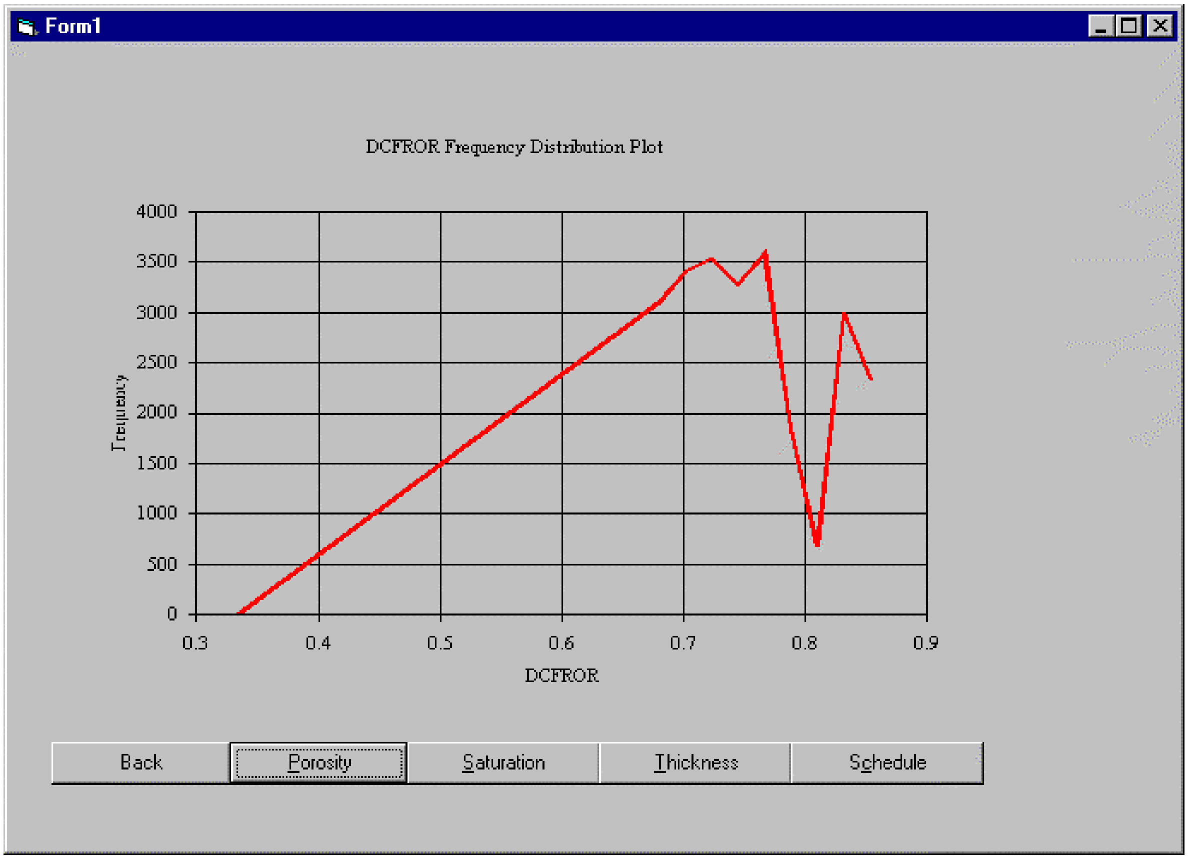
Pressure versus Time
OSM #2
Pressure (psia)
Time (days)
0
100
200
300
400
500
600
700
800
900
1000
0
500
1000
1500
2000
2500
3000

Monte Carlo Simulation

OSM #1

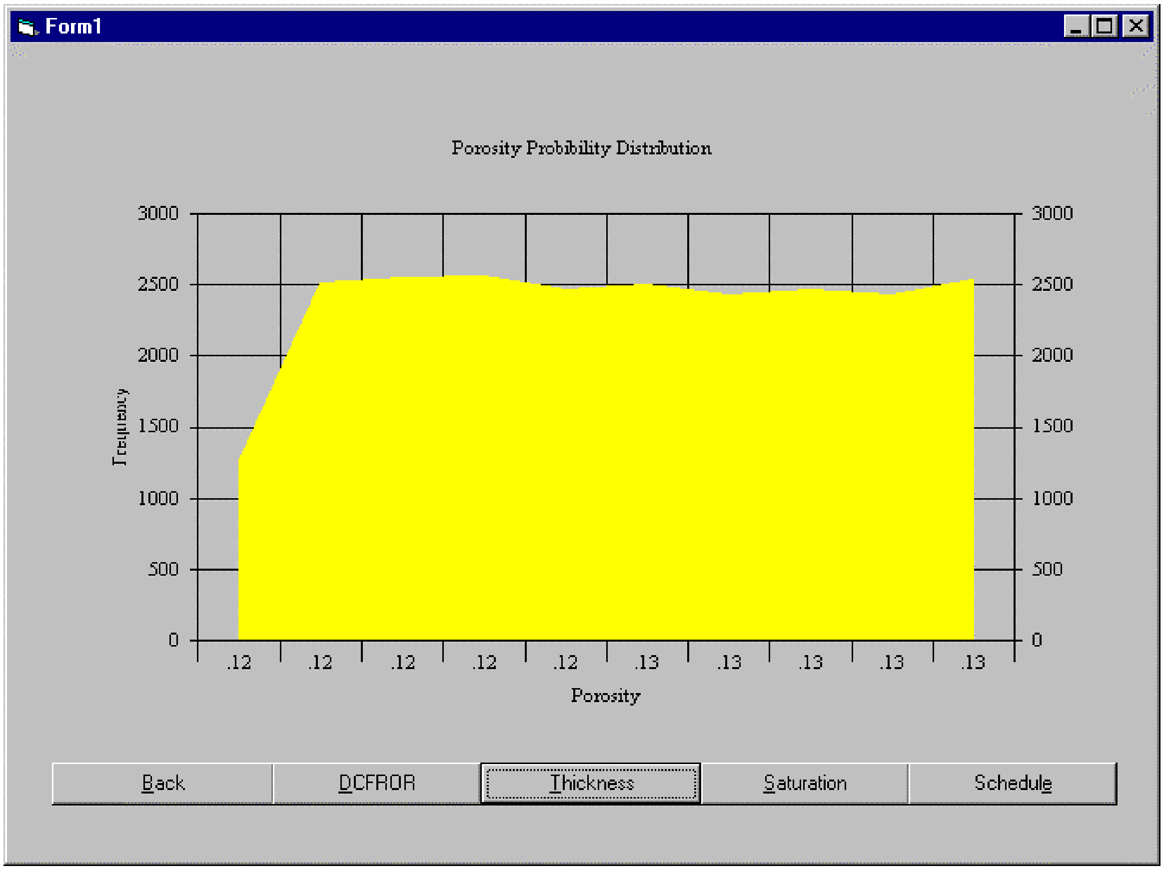


OSM #2

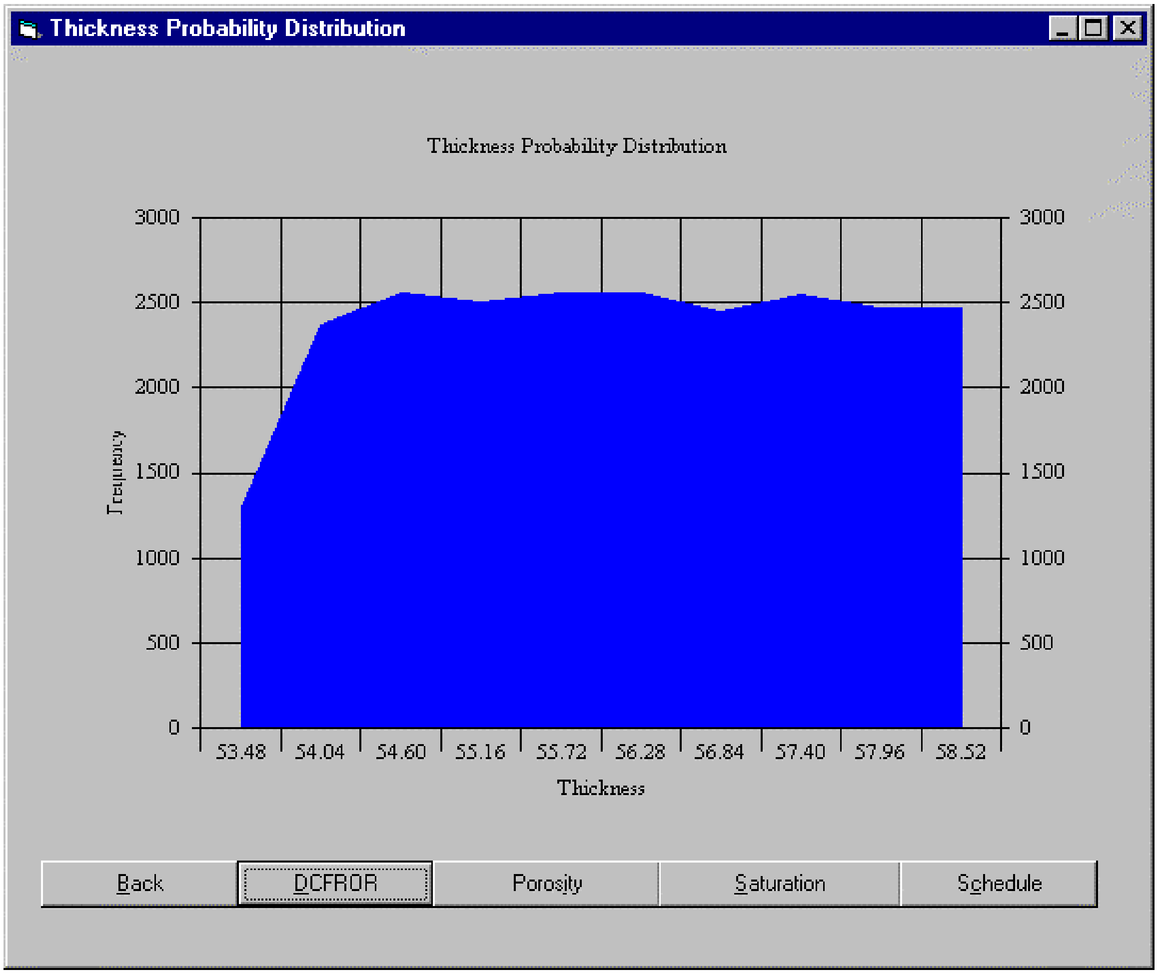


Most Probable DCFROR	
OSM #1	OSM #2
21.5%	76.0%

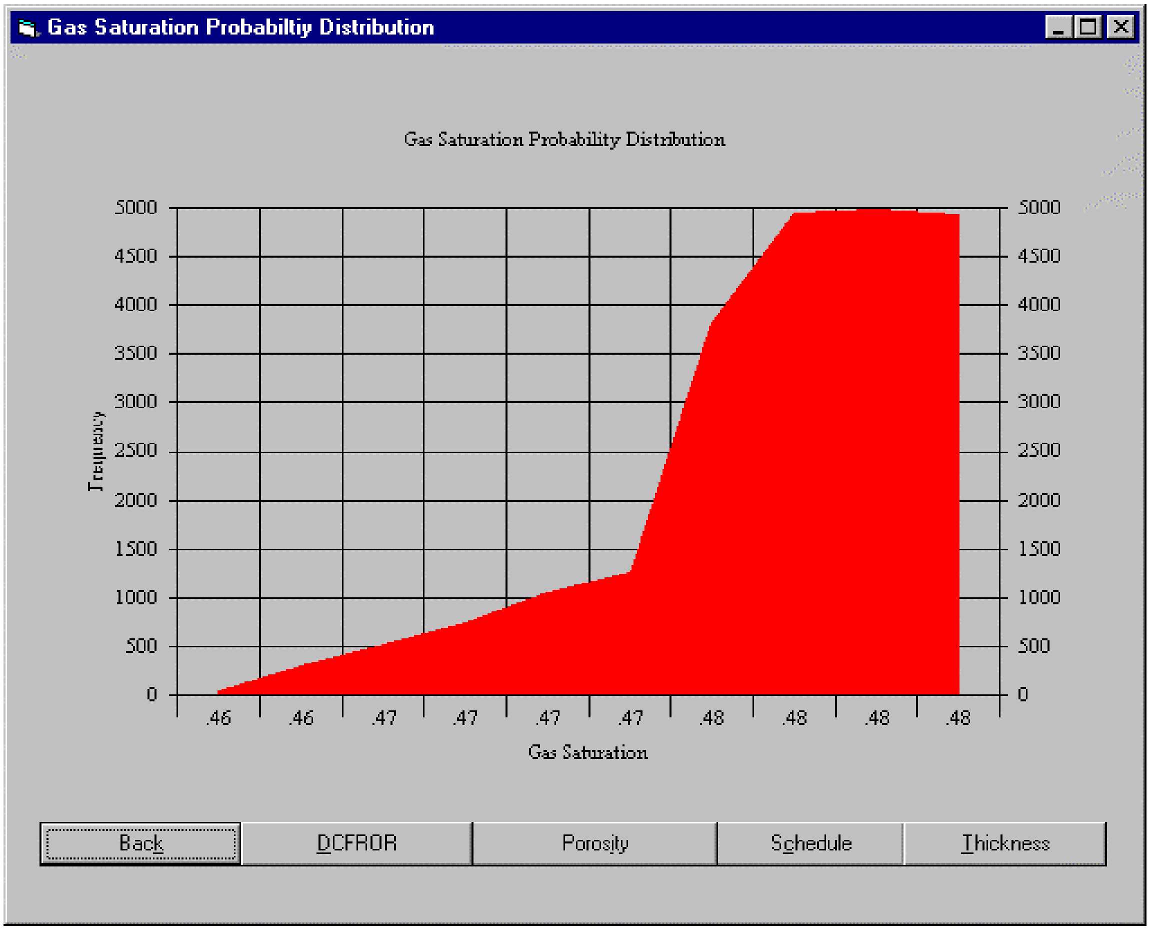
OSM #2


Form1
Porosity Probibility Distribution
3000
2500
2000
1500
1000
500
0
Frequency
.12
.12
.12
.12
.12
.13
.13
.13
.13
.13
Porosity
Back
DCFROR
Thickness
Saturation
Schedule

OSM #2


Thickness Probability Distribution
Thickness Probability Distribution
3000
2500
2000
1500
1000
500
0
Frequency
53.48
54.04
54.60
55.16
55.72
56.28
56.84
57.40
57.96
58.52
Thickness
Back
DCFROR
Porosity
Saturation
Schedule

OSM #2


Gas Saturation Probabiltiy Distribution
Gas Saturation Probability Distribution
Frequency
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
.46
.46
.47
.47
.47
.47
.48
.48
.48
.48
Gas Saturation
Back
DCFROR
Porosity
Schedule
Thickness

DISCUSSION:

Prospect Selection and Casing Design

The casing designs in Doddridge and Kanawha counties were based on and compared to casing designs of offset wells in the respective counties. Because the wells were drilled with air, they were designed with respect to the stratigraphy that was expected to be encountered instead of using the classic graphical technique based on pressure and fracture gradients.

The first of the differences in casing programs were noticed in the choice of conductor string. Since there was a need for two intermediate strings in the Kanawha well, a larger O.D. conductor had to be used. This was not necessary in the Doddridge County well.

The Kanawha County well implemented two different intermediate strings because of the salt and coal formations that were expected to be encountered. The first string in both wells isolates fresh water zones. Both of the wells did utilize a production string of 4 ½” casing.

Well Log Interpretation and Reserve Estimation

The results show that OSM #2 has the potential to contain considerably more reserves than OSM#1. However, the results for OSM #1 may not be truly representative. This was because of the assumption of the pay thickness of the Devonian shale. This calculation was based on data from an offset well. This was a valid assumption for there can be considerably more pay in the well than what is in the offset. Recall that the Devonian shale in this area is approximately 2200’ thick. The offset well that was used in the analysis appears to be cutting the entire section, but only 50' of the shale was contributing to the gas production. Due to the position of the wells in the shale, it is possible for OSM#1 to be connected to more pay zones, thereby dramatically increasing reserves from the 2.55 MMCF/Acre originally calculated.

The first method used in the volumetric calculation for the OSM#2 wells was invalid due to a bad assumption made on the matrix density. A value close to that of limestone was used and this gave us reserves equal to 40 MMCF/Acre. However, the formation encountered was that of sandstone. When the correct matrix density was used on chart SW-11 it is impossible to read gas saturation or porosity.

The second procedure gave reserve estimations equal to 17.4 MMCF/Acre. This was a significant difference and OSM Energy has decided to consider the second procedure to be a valid estimate.

The second procedure utilizes known values of neutron and density porosity to determine the actual porosity. Next, the gas saturation was determined from interpretation of the dual induction log. The true formation resistivity (R_T) was read from the deep induction track and the formation resistivity at 100% water saturation (R_o) was read from the shallow induction track. The water saturation (S_w) was calculated from as the square root of the ratio of R_o/R_T. The gas saturation of the zone was then determined as $1 – S_w$. The calculation of the gas saturation was based on the assumption that only water and gas exist in the reservoir. After these values were determined for each layer, the reserves were calculated.

The first time this second method to the interpretation was performed, an error was made in the calculations, which led to incredibly high values for gas saturation. The value read from the log as R_o was mistaken for formation water resistivity (R_w). As a result, the gas saturation calculated was incorrect (too high). This high saturation led to high values in the reserve estimate. The error was corrected and a new lower estimate was presented in the **Results** section on page 55.

Build-Up Analysis

The results showed that while OSM #2 contained a higher hydrocarbon potential, OSM #1 had the better stimulation. However, these results can not be relied on as accurate because the build-up pressure data was not from the reservoirs in question. The build-up pressure data was obtained from the syllabus that was provided for the class.

The results showed that the permeability in the shale well (OSM #1) was 6 mD. This number does not correlate well considering that the permeability of shale is generally between .1 and 2 mD in this region. For the Benson Sand (OSM#2), the estimated permeability was calculated as 4.33 mD. This was probably a little closer to the actual permeability of true sandstone in this region.

The skin factor for each of the wells was negative indicating that both the wells have had good stimulation jobs. The skin factor in OSM #1 was – 4.50 and the skin factor in OSM #2 was – 3.79. These skin factors tend to give flow efficiencies that are greater than 100%.

Flow efficiency for OSM #1 and OSM #2 were calculated to be 256.19 and 166.44 %, respectively. In other words, OSM #1 can flow 2.56 times greater than the un-stimulated reservoir, where OSM #2 can flow 1.66 times greater. This also gives a good indication about the stimulation that the well has experienced, whether good or bad.

Estimated initial formation pressures for OSM #1 and OSM #2 are 645 and 925 psia, respectively. These pressures were estimated from the extrapolation of the MTR to Δt at one hour from the pressure versus Horner graphs in the **Results**, pages 59 & 60.

Production Forecasting

The results show that OSM #2 is able to produce at a 62% higher rate than OSM #1. This is due to several factors. First, from log analysis, OSM #2 was found to have almost twice the porosity compared to OSM #1. Second, from reserve estimation, OSM #2 was found to have significantly higher reserves on a per acre basis. Third, OSM #2 had a higher discovery pressure. And lastly, OSM #2 was found, from log analysis, to have a slightly greater pay thickness. (For exact values, see **Appendix XVI**)

However, it was found that OSM #2 was inferior in several other categories. These being, OSM #1 had a higher permeability, lower skin factor and a lower abandonment pressure due to the depth of the reservoir. It should be noted that the reservoir parameters for OSM #1 tend to have slightly more error than OSM #2. This is due to the fact that OSM #1 is a shale well and regular build-up analysis may not have been performed accurately. In order to obtain correct results, it is necessary to use a technique, which is modified specifically for shale reservoirs.

In the presentation, it was reported that the maximum flow rate in OSM #2 was 0.095 MSCF/D. Upon closer inspection, a grievous error was discovered. It seems that the net pay for OSM #2 was initially reported as 20 ft. The flow rate of 0.095 MSCF/D was initially calculated using this thickness. At a later time, it was discovered that the actual pay thickness should have been 56 ft., which gives a much higher flow rate of 0.268 MSCF/D.

In the second part of the project, the teams were asked to create viscosity versus pressure plots for each of the wells on their respective agendas. OSM respectfully complied and the graphs are shown above in the **Results** section of this report pages 70 and 71. To examine the behavior, a polynomial function was fit to the data using a regression technique available in Microsoft Excel 97. It can also be noted that the regression coefficient (R^2) was 0.9997 for OSM #1 and 0.9999 for OSM #2. This indicates that the polynomial fit was nearly perfect for both cases. This allows the engineer to determine what the viscosity would be at any pressure by using the equation obtained from regression analysis.

Also, the teams were required to develop compressibility factor versus pseudo-reduced pressure plots for the various values of pseudo-reduced temperature. This proved to be the most difficult portion of the project. Prior to determining the correct equation and iteration technique, OSM Energy tried several other ineffective methods. Some of which were, the Dranchuk, Pervis and Robinson Method and the Gopal method. After these techniques failed, the professor provided the teams with the Redlich-Kwong equation of state and the Newton-Raphson iterative technique. (See **Equations**, pg 42) This technique, though somewhat flawed in the beginning, proved to be the best choice and was used to construct the Z-factor chart.

This part of the project also required that the constructed chart be compared to the Z-factor correlation of Standing and Katz. As can be seen between the graphs on page 68 and **Appendix I**, OSM's chart resembles the correlation of Standing and Katz. This indicates that in using the Redlich-Kwong equation, OSM was able to construct an accurate plot.

Monte Carlo Simulation

OSM was able to accurately analyze the economic potential of the two prospects up for consideration (OSM #1 and OSM #2). OSM was able to do this by applying the laws of probability and creating a monte carlo simulator program. The program enabled the engineers to develop probability distributions for the DCFROR for each of the prospects. These DCFROR distributions were compared and it was determined that OSM #2 should be the prospect developed by the company. OSM #2 was chosen because it had the highest probability of obtaining the highest DCFROR. The high DCFROR value for the project will benefit the company because the project can make money over a broader spectrum of interest rates than OSM #1 is capable of.

OSM feels that the program allows the engineers to accurately predict the economic performance of the projects.

CONCLUSION:

In conclusion, OSM Energy Inc. has thoroughly researched the possibility of developing prospects located in Kanawha County (OSM #1) and Doddridge County (OSM #2) West Virginia. The team began by researching the geology of the two prospects, using the West Virginia Geological and Economic Survey as it's primary source of geological information. OSM was also able to obtain offset well logs and well files from this same department.

OSM analyzed the well logs and calculated the reserves for each of the prospects. At this time in the project the engineers at OSM felt that the prospect assigned OSM #2 had a clear advantage over its counterpart, OSM #1. From the well log analysis, OSM predicted the reserves in OSM #2 to be approximately 17.4 MMCF/Ac and the reserves in OSM #1 to be approximately 2.5 MMCF/Ac. Despite the clear advantage that OSM #2 had at this time, the engineers at OSM decided to continue the project so that the prospects could be compared using an economic yardstick.

Pressure build-up tests from both wells, were then analyzed by OSM to determine initial formation pressure, permeability, skin factor, and flow efficiency. However, OSM engineers did not feel that the test data was very accurate and did not consider the well test analysis essential to the evaluation of the prospects.

Next, a production forecast was performed for each of the prospects. OSM desired to determine whether or not the wells would be able to produce for a seven year period, and if they could, the maximum rate which the wells could maintain for that period. Making use of the lines source solution and a computer program developed by

OSM for this purpose, OSM determined that the maximum rates that could be maintained by OSM #1 and OSM #2 were 0.165 MSCF/D and 0.268 MSCF/D, respectively.

Finally, OSM engineers performed an economical analysis of both of the prospects using a monte carlo simulator developed in-house specifically for this purpose. Using the simulator, OSM was able to plot the probability distribution of the DCFROR for each of the prospects. From the probability distributions, OSM determined that the most probable DCFROR for OSM #1 was 21.5% and that for OSM #2 was 76%.

These results only confirmed what OSM engineers had hypothesized at the conclusion of the well log analysis. OSM Energy strongly recommends the development of the OSM #2 prospect over the OSM #1 prospect. However, if it is possible to develop both of the prospects it is strongly encouraged.

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Caramanica, Frank P. Oil and Gas Report and Map of Kanawha and Boone Counties, West Virginia. West Virginia Geological and Economic Survey Bulletin B-19A. 1988.

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Struble, Richard A. Evaluation of the Devonian Shale Prospects in the Eastern United States. Morgantown Energy Technology Center. Ohio. 1983.

<u>Appendix I</u>:

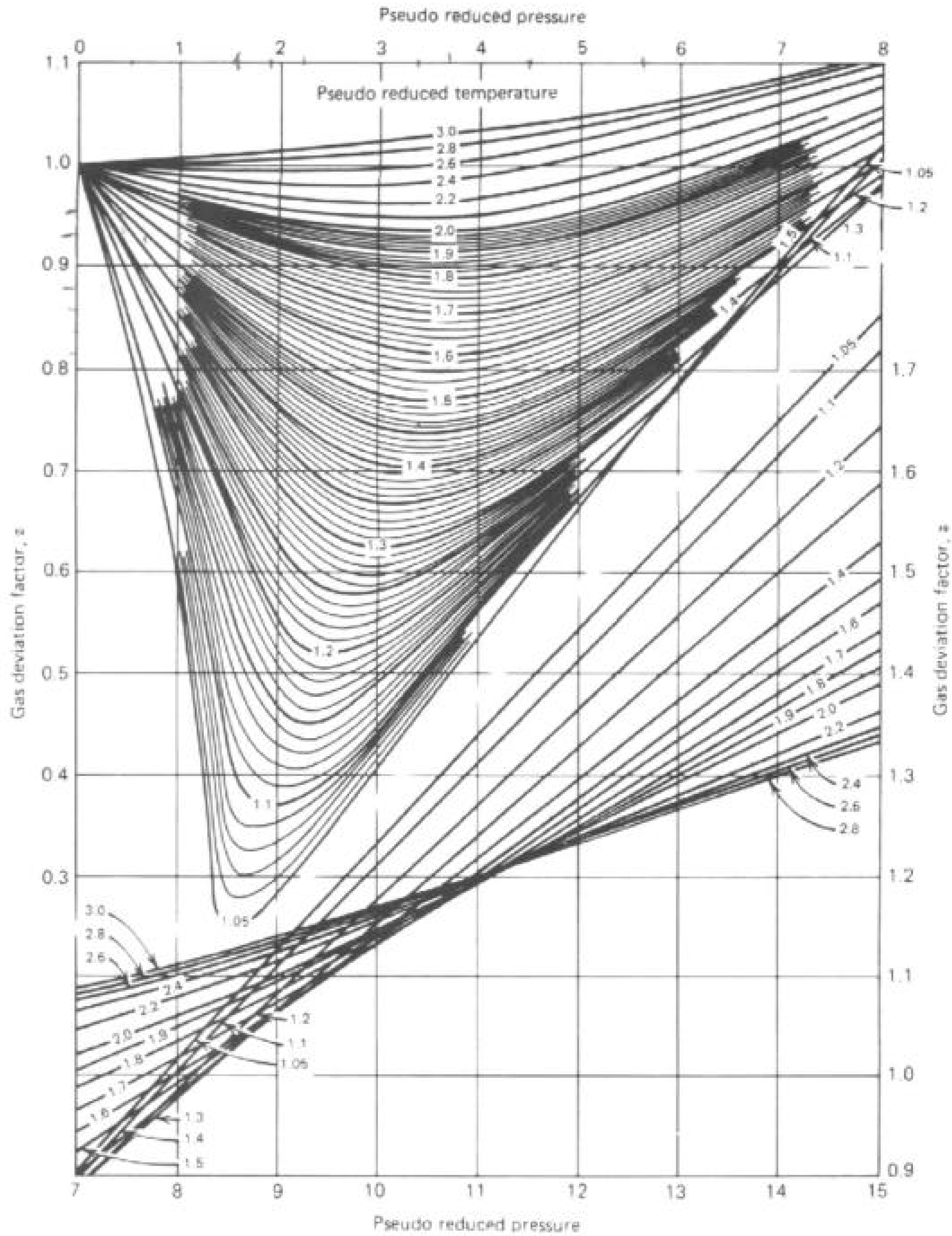
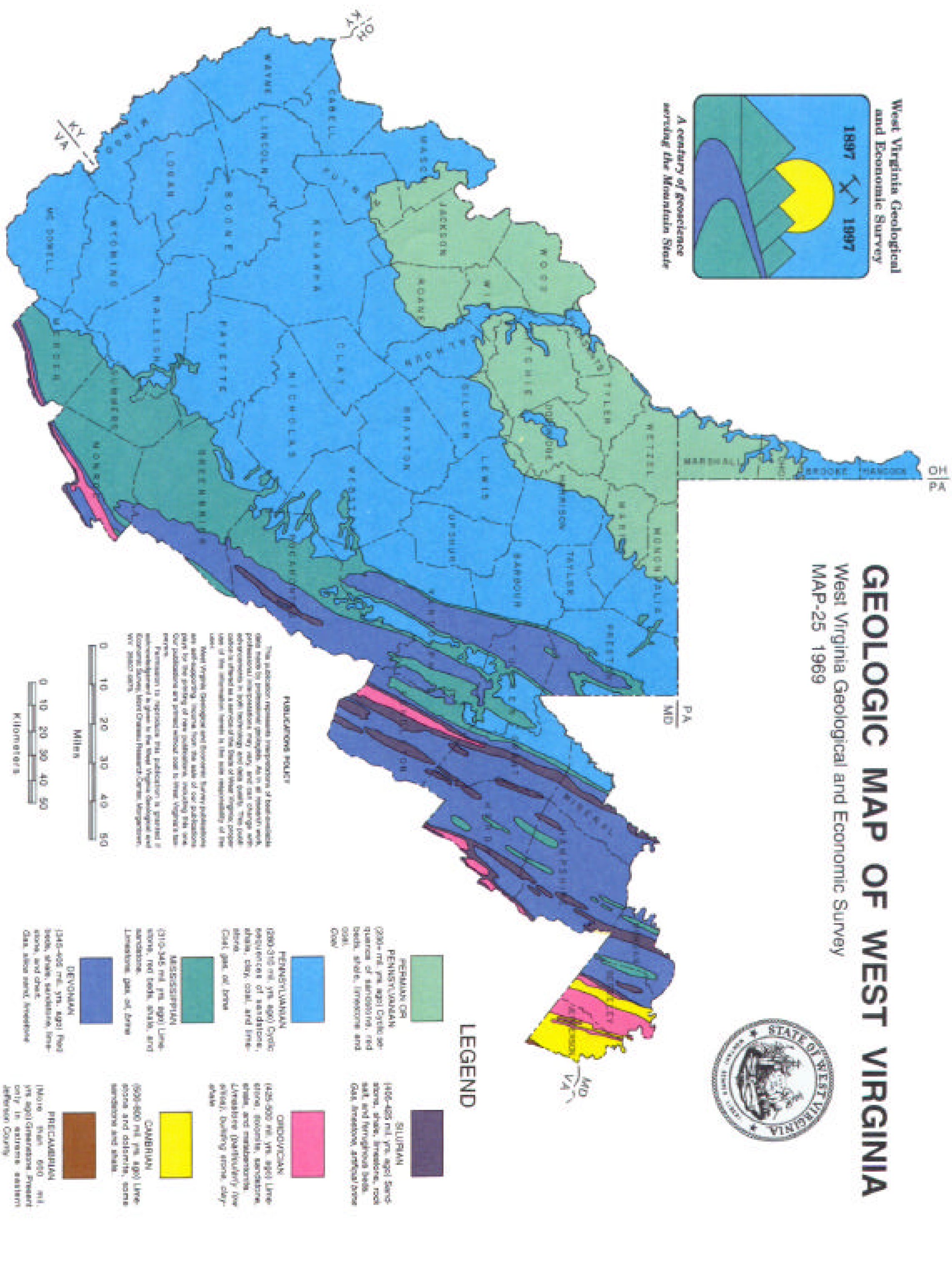
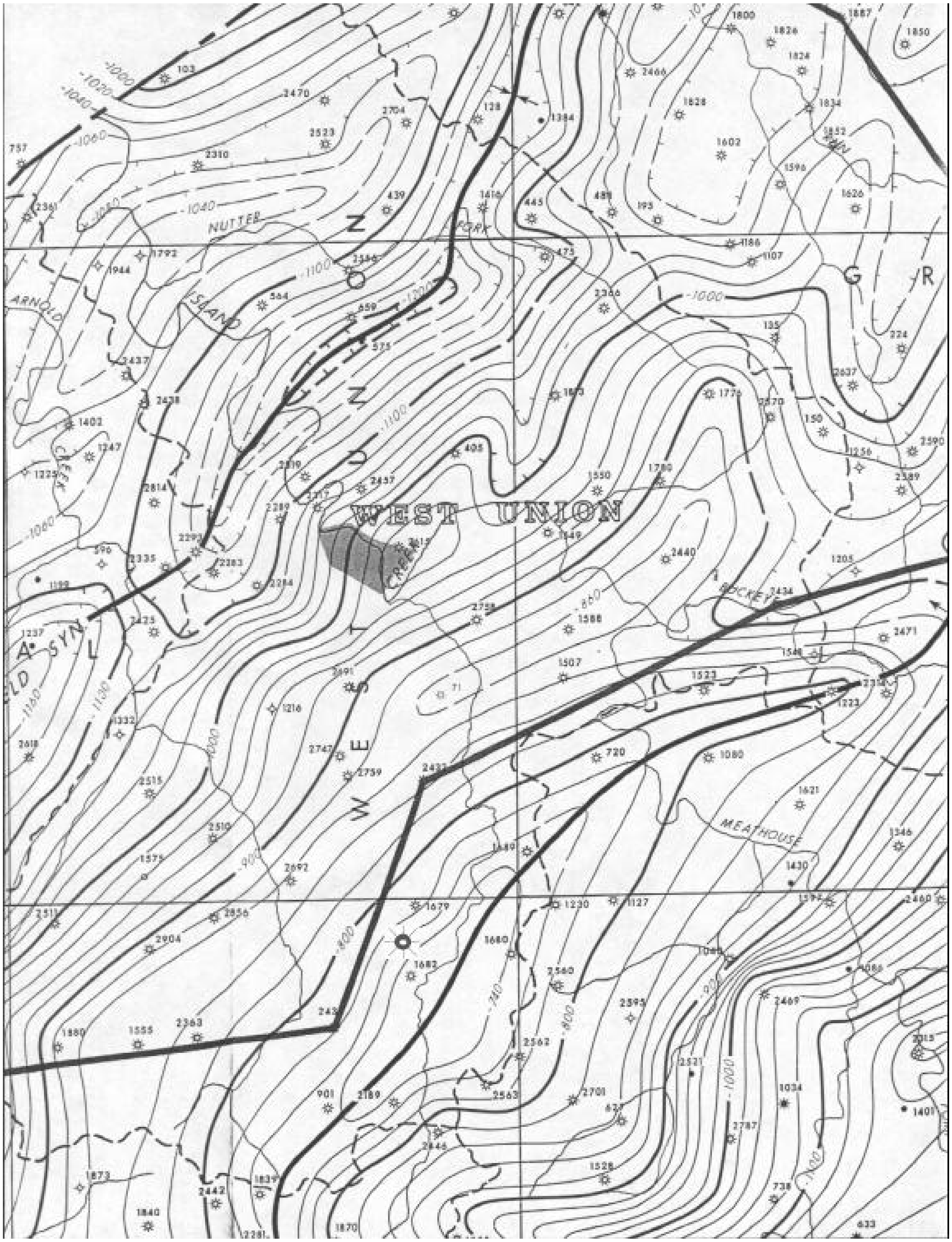


Fig. 2.4 Gas deviation factor for natural gases. (After Standing and Katz.)

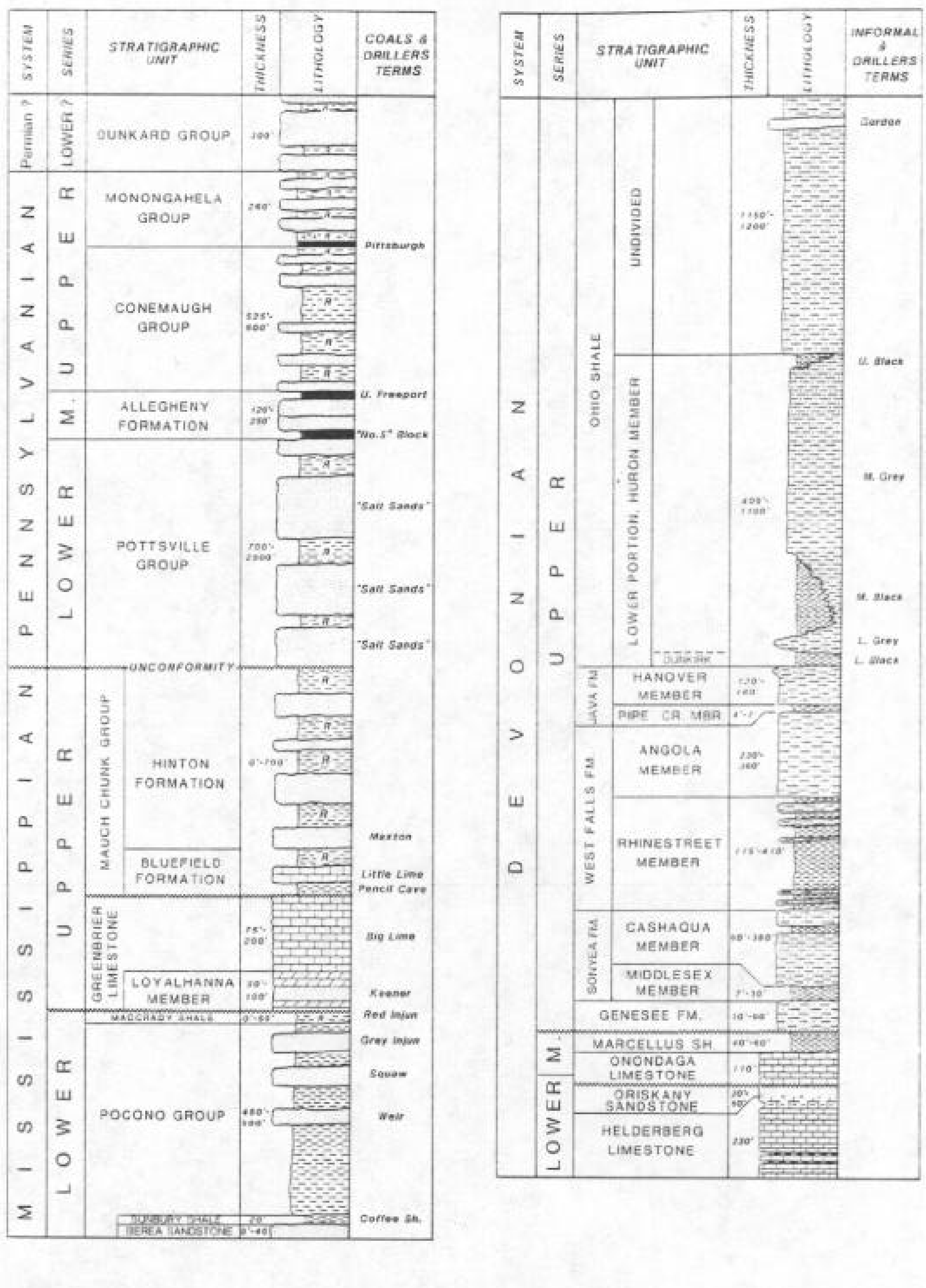
<u>Appendix II</u>:



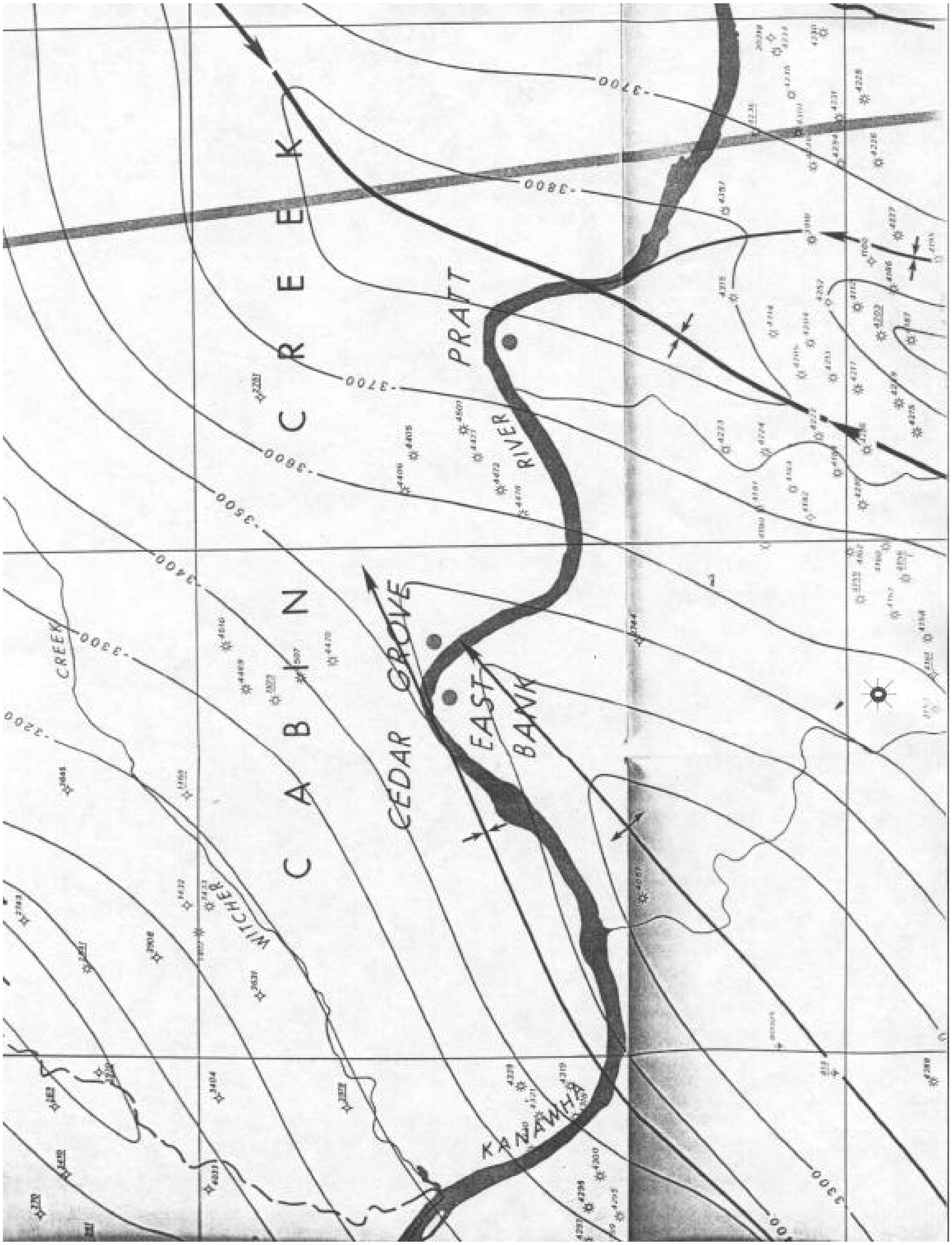
<u>Appendix III:</u> Structure Map of Doddridge County.



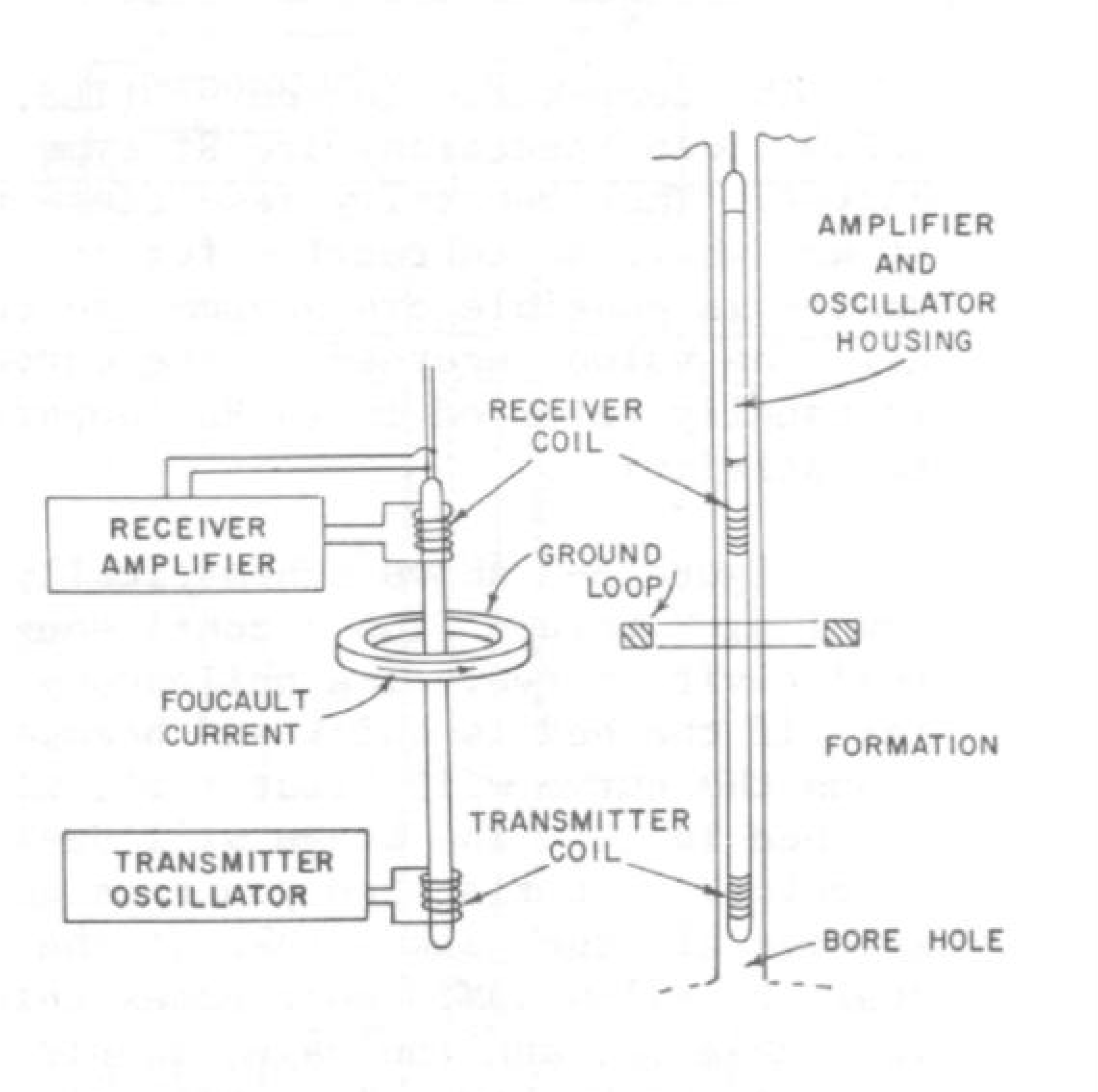
Appendix IV: Stratigraphic Cross Section of Kanawha County



Appendix V: Structural Map of Kanawha County



Appendix VI: Dual Induction Tool



<u>Appendix VII</u>: Casing and Tubing Calipers

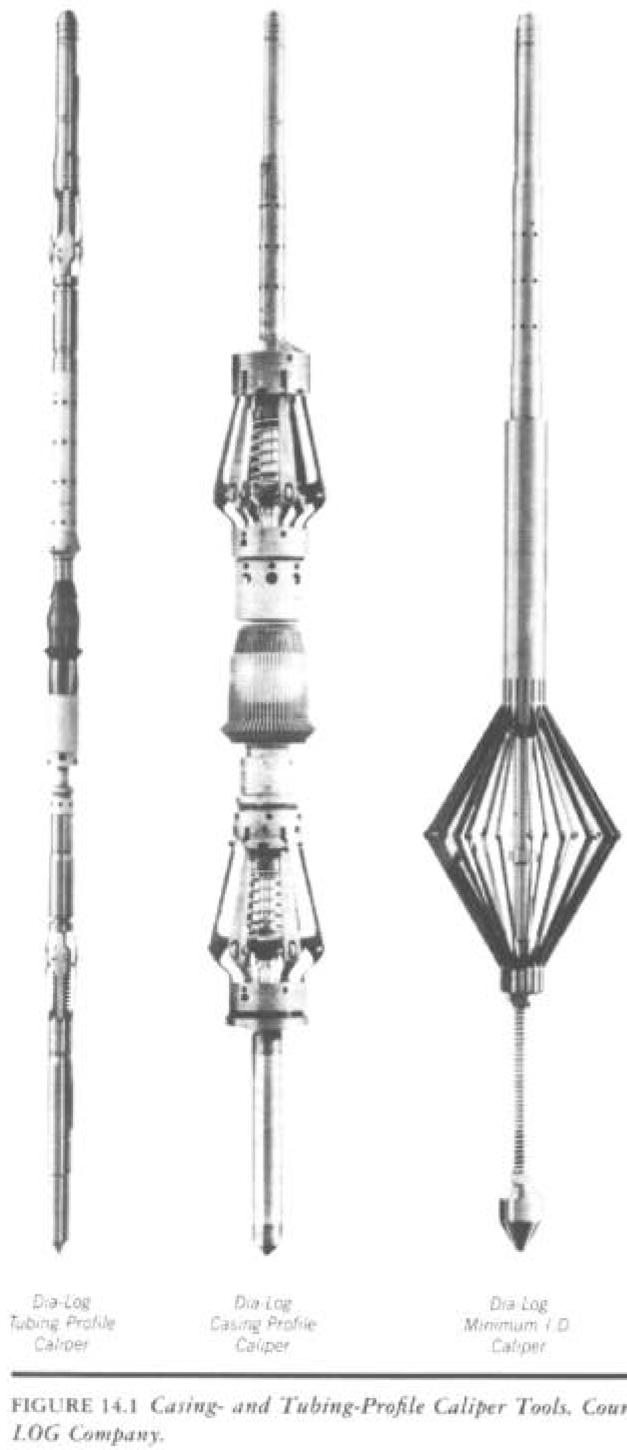


FIGURE 14.1 *Casing- and Tubing-Profile Caliper Tools. Courtesy the DIA-LOG Company.*

Appendix VIII: UltraSonic Gas Detector

<u>Appendix IX</u>: Gamma Ray Tool

The BPB Dual Laterolog delivers exceptional performance over a very wide range of formation resistivities, even under the most demanding conditions of high Rt/Rm contrast.

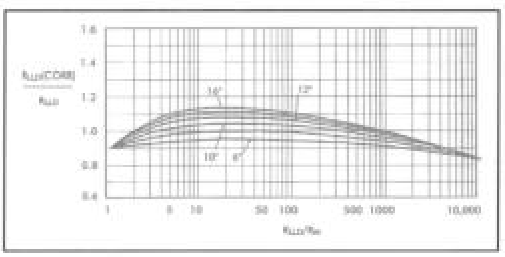
Good quality formation resistivity data is essential for the computation of accurate water saturations, and Laterologs are the primary source of this data in open holes drilled with salt water based muds.

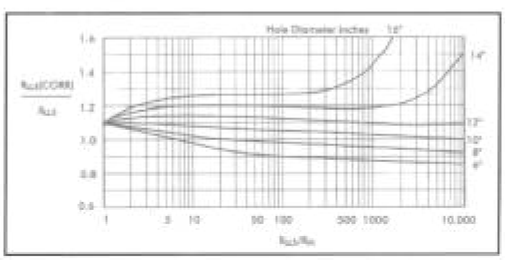
DUAL LATEROLOG SONDE (DLS)

The BPB **Dual Laterolog** is a dual penetration resistivity tool with integral Gamma Ray and SP.

Primary curves are the **Laterolog Deep** and **Laterolog Shallow.** In non-invaded zones these overlay and measure Rt, the true formation resistivity. In permeable or damaged zones the curves separate. Rt and depth of invasion are then computed using the invaded zone resistivity Rxo, normally measured by **Microlaterolog** or **Microlog** tools run in combination.

The challenge is to provide accurate results in the presence of potentially extreme resistivity contrasts between formation and drilling mud. The BPB Dual Laterolog meets this challenge with a radical design, avoiding the problems associated with traditional dual frequency operation. The result is a tool with excellent accuracy, stability and dynamic range.





Deep (top) and Shallow(bottom) borehole corrections

- special drivers eliminate electrode polarisation effects
- a special pattern of low frequency square waves eliminates phase shift and interference effects to give a cleaner log
- electrode geometry is optimised to provide good vertical resolution, well balanced radial penetration and reduced sensitivity to borehole effects
- Groningen effects (as the tool approaches a non-conductive bed) are detected by special circuitry, reducing the danger of mis-interpreting the effect as a transition zone

Appendix X: Density Tool

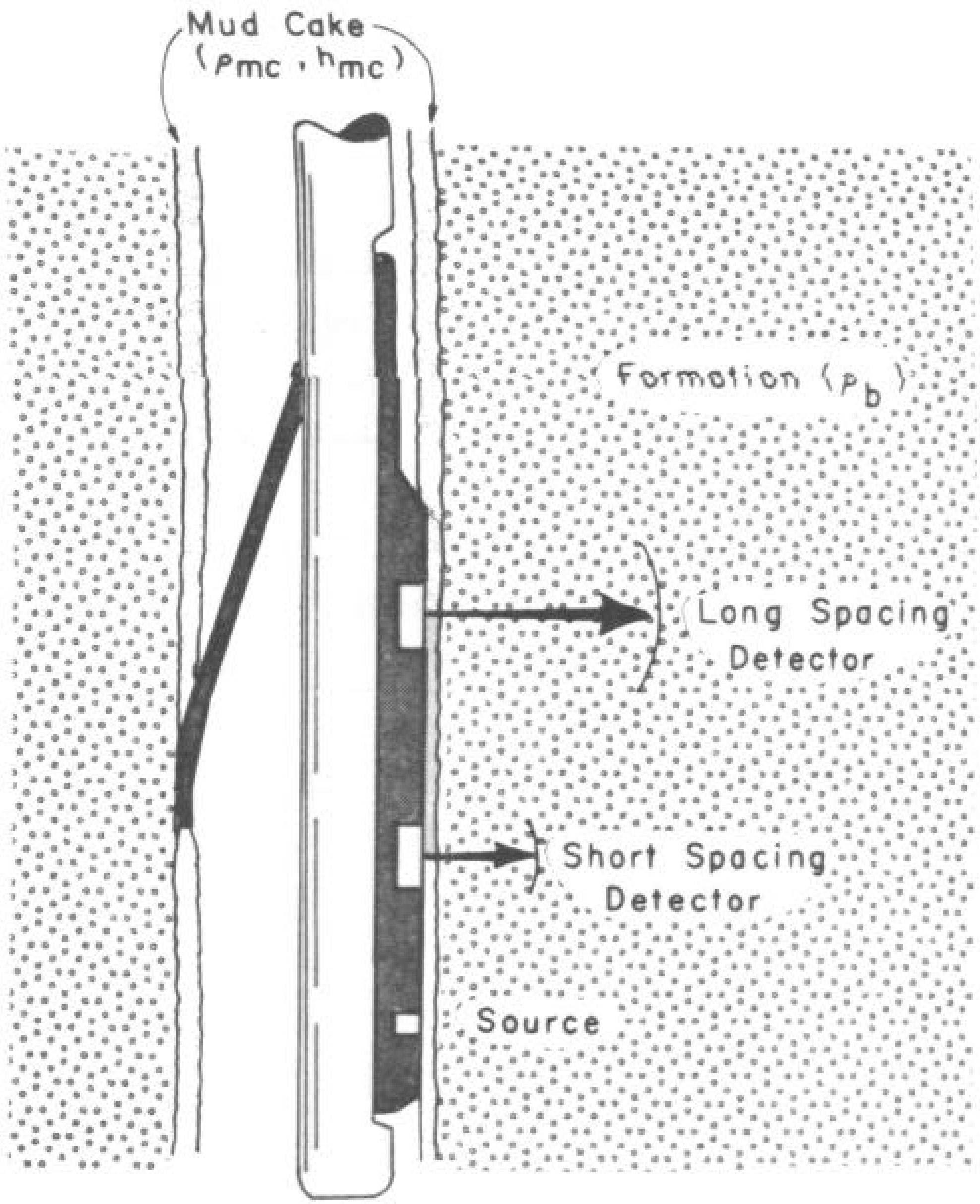


Figure 8-2 Schematic of density log tool
(courtesy Schlumberger)

<u>Appendix XI</u>: Neutron Tool

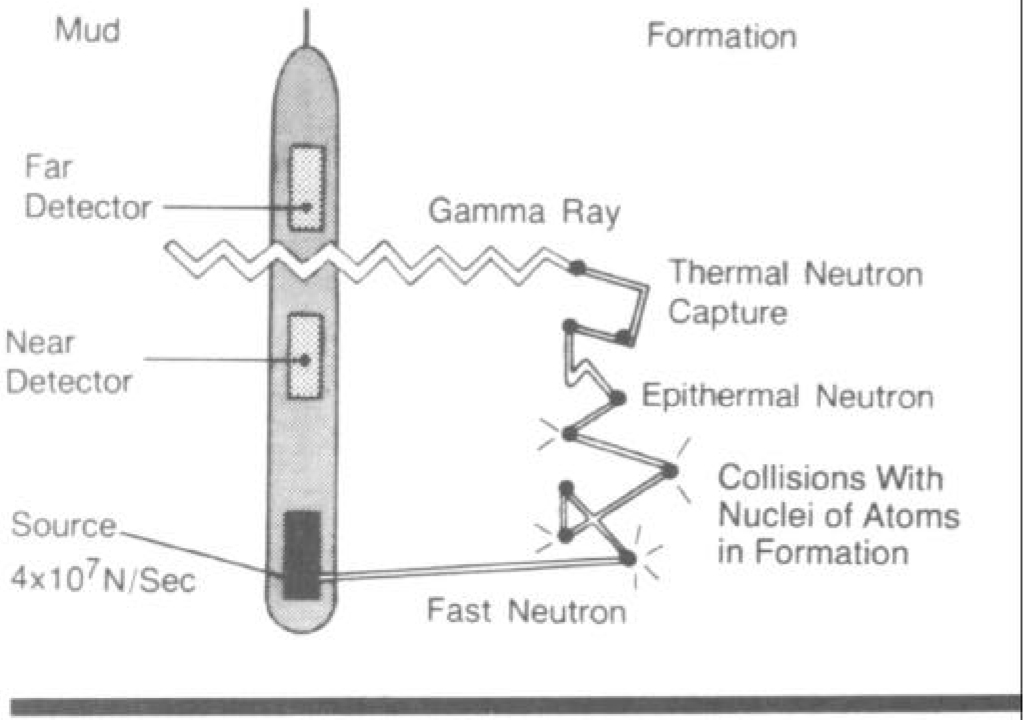
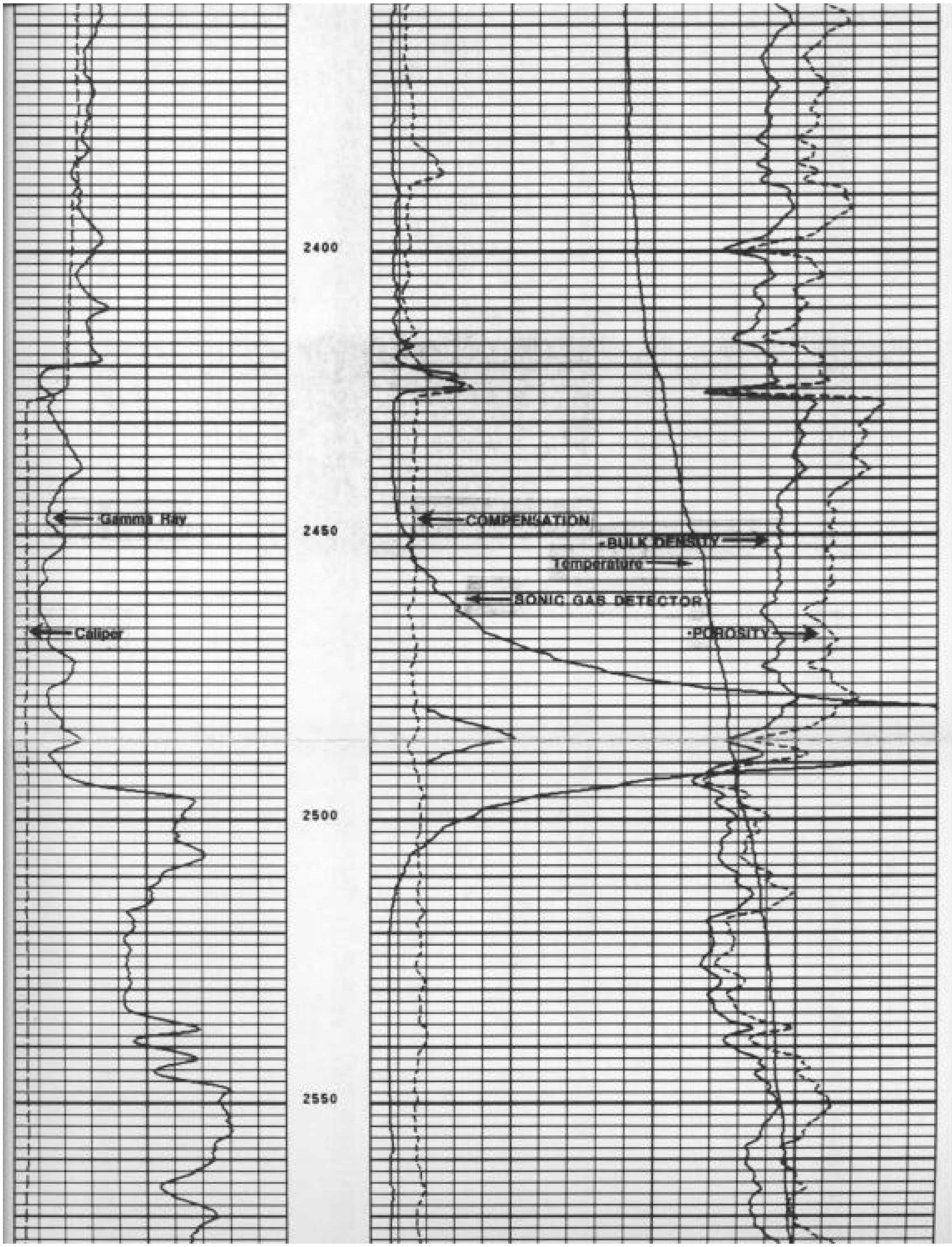
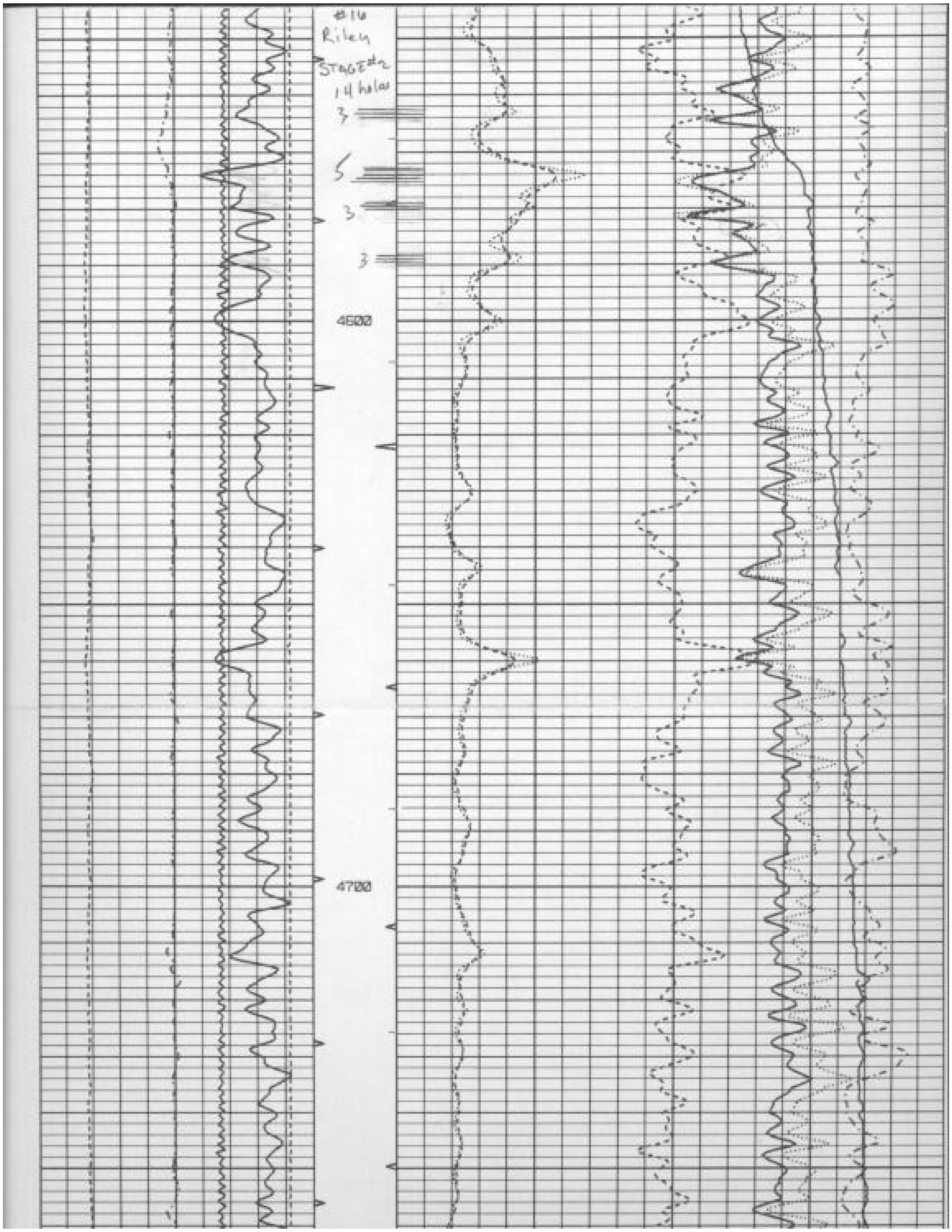


FIGURE 4.24 *Generalized Neutron Tool.*

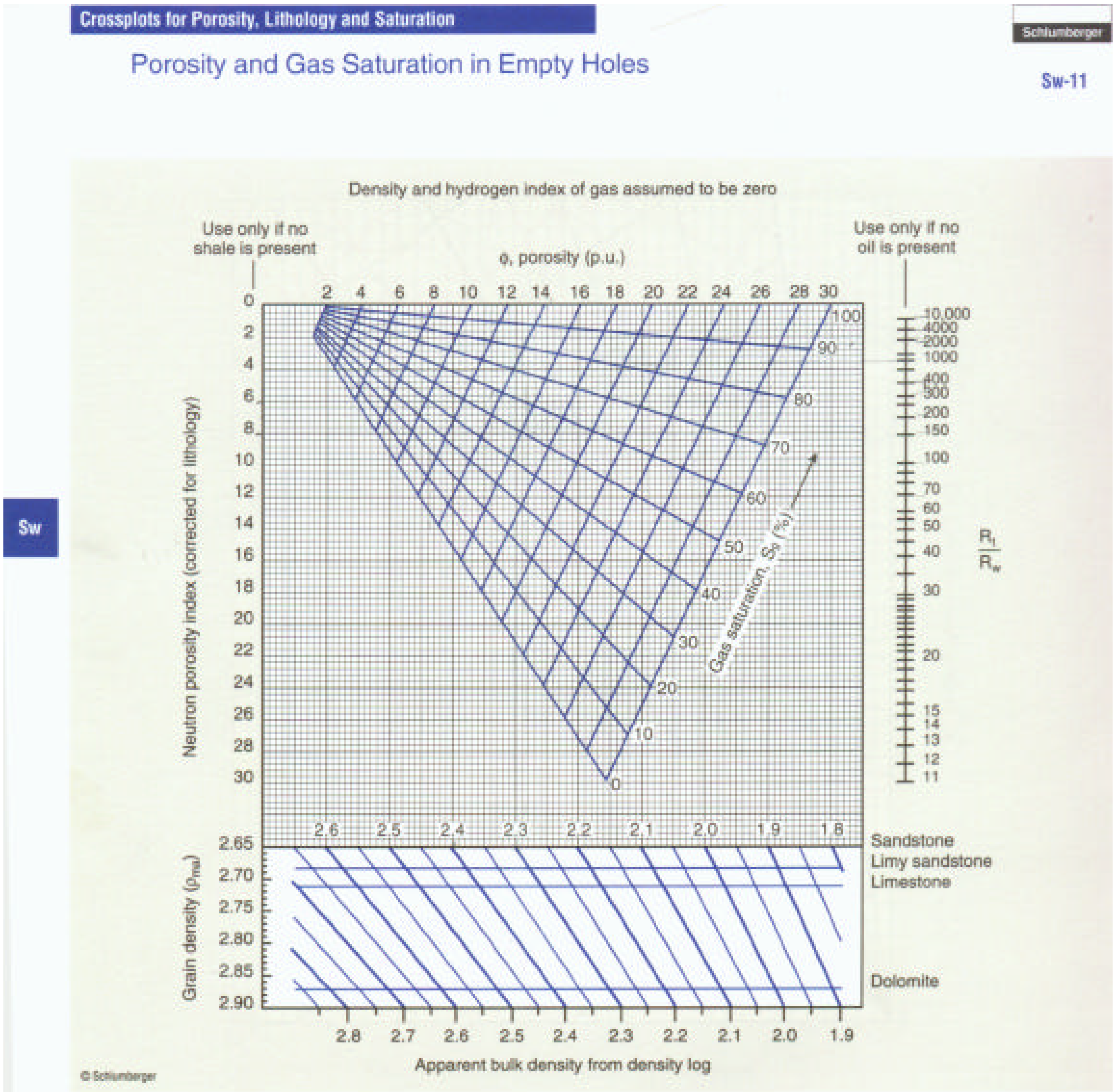
Appendix XII: Logs for OSM #1



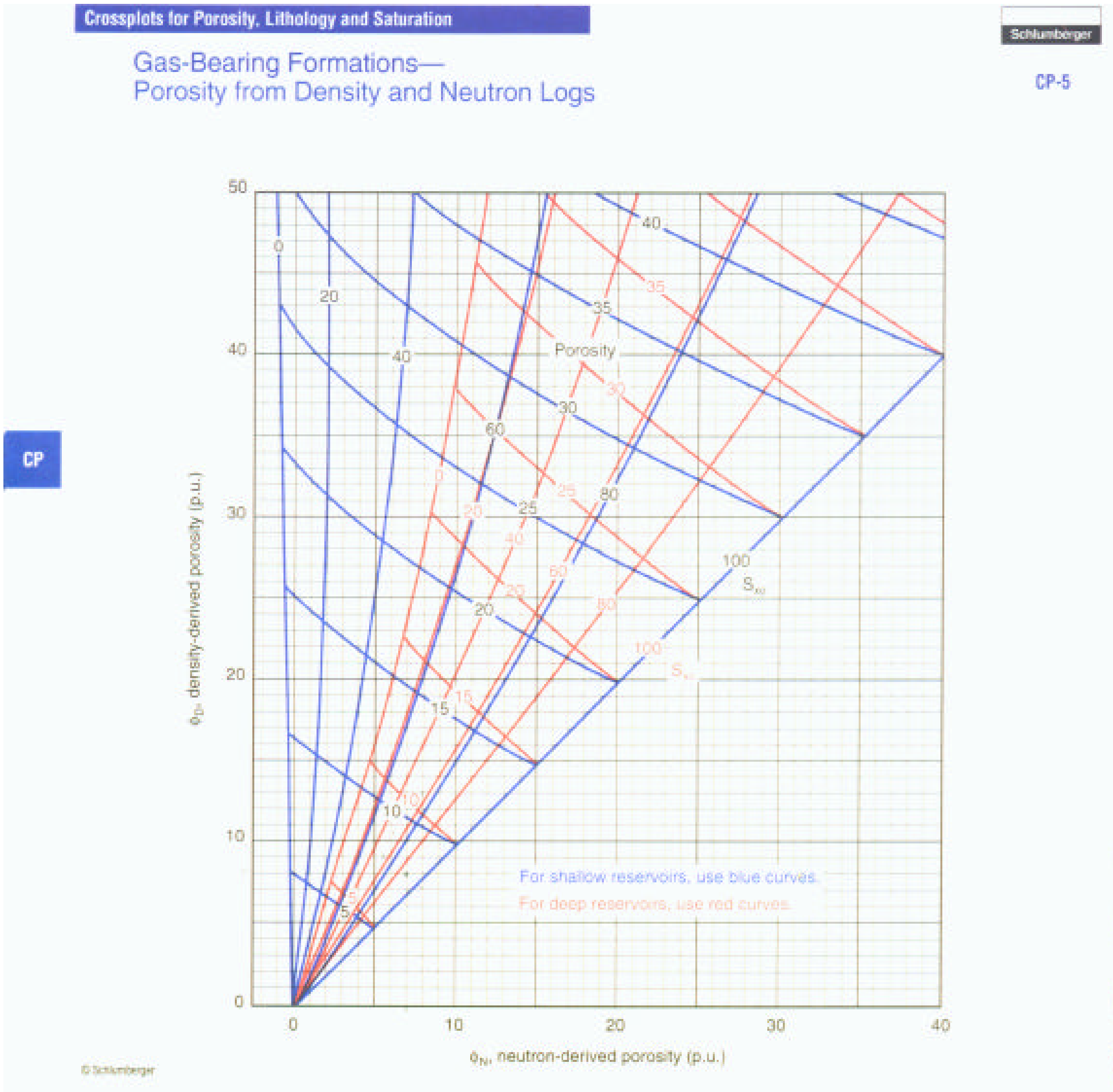
<u>Appendix XIII:</u> Logs for OSM #2



Appendix XIV: Chart Sw-11



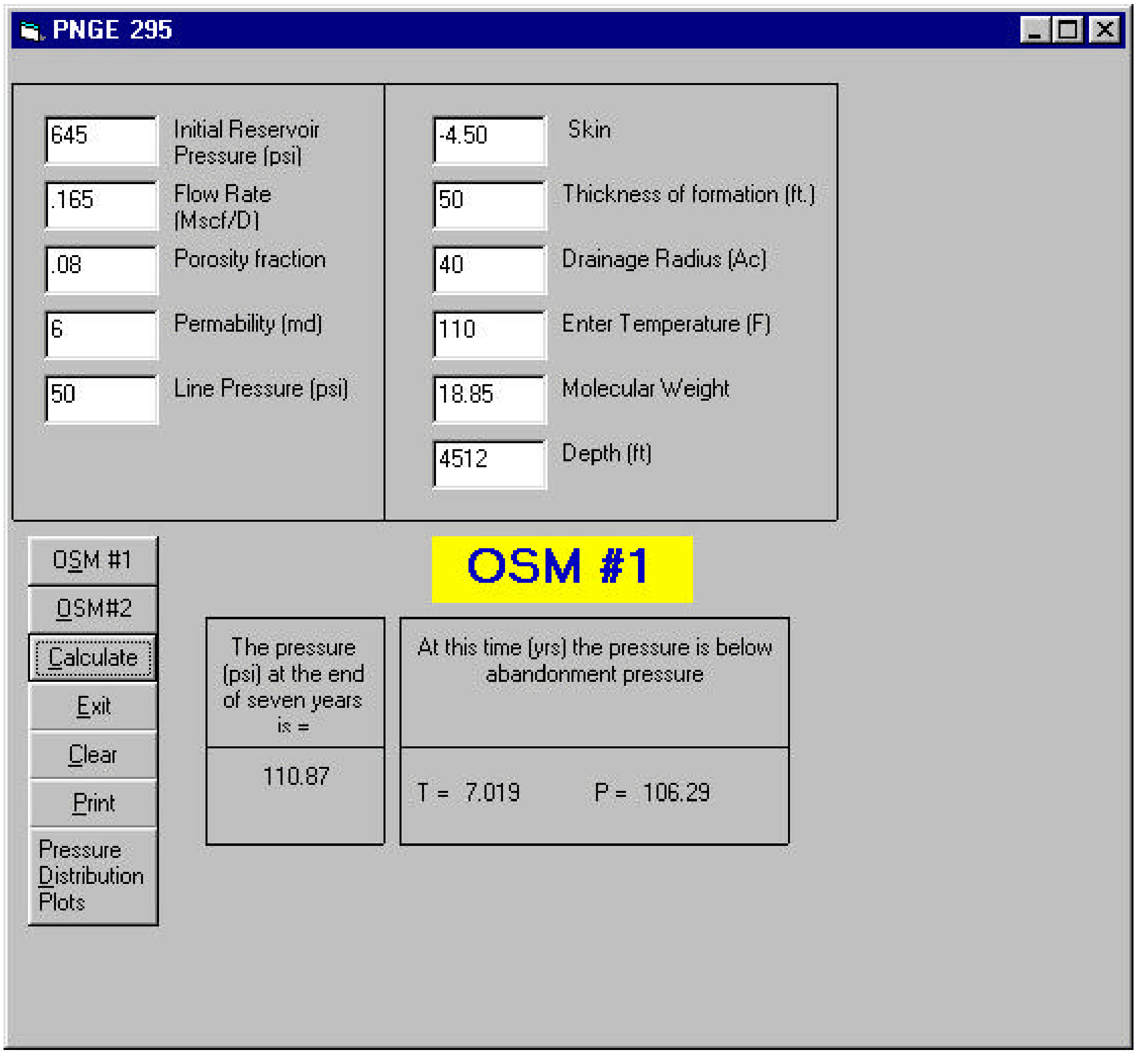
Appendix XV: Chart Cp-5



Appendix XVI:

Well Name & Number	Skin Factor	Porosity (fraction)	Permeability (md)	Pay Thickness (ft)	Reserve Estimation (MMCF/Ac)	Flow Rate (7years) MSCF/D
OSM #1	-4.5	0.08	6	50	2.55	0.165
OSM #2	-3.79	0.14	4.33	56	17.4	0.268

Appendix XVII: Main Program Form for Production Forecasting.



Appendix XVIII:

Program Source Code for Conversion To Pseudo Values

```
Private Sub Check1_Click()
If Check1.Value = 1 Then
   Check2.Value = 0
   Text2.Visible = True
   Text1(0).Visible = False
   Text1(1).Visible = False
   Text1(2).Visible = False
   Text1(3).Visible = False
   Text1(4).Visible = False
   Text1(5).Visible = False
   Text1(6).Visible = False
   Text1(7).Visible = False
   Text1(8).Visible = False
   Text1(9).Visible = False
   Text1(10).Visible = False
   Text1(11).Visible = False
   Text1(12).Visible = False
End If

End Sub

Private Sub Check2_Click()
If Check2.Value = 1 Then
   Check1.Value = 0
   Text2.Visible = False
   Text1(0).Visible = True
   Text1(1).Visible = True
   Text1(2).Visible = True
   Text1(3).Visible = True
   Text1(4).Visible = True
   Text1(5).Visible = True
   Text1(6).Visible = True
   Text1(7).Visible = True
   Text1(8).Visible = True
   Text1(9).Visible = True
   Text1(10).Visible = True
   Text1(11).Visible = True
   Text1(12).Visible = True


End If
End Sub

Private Sub Check3_Click()
If Check3.Value = 1 Then
   Check4.Value = 0
   skin = -2
   Text24.Text = "50,000"
End If

End Sub
```

```
Private Sub Check4_Click()
If Check4.Value = 1 Then
   Check3.Value = 0
   skin = -4
   Text24.Text = "100,000"
End If

End Sub

Private Sub cmdCalculate_Click()

ReDim zA(1 To sRow, 1 To sCol) As Single
ReDim NA(1 To sRow, 1 To sCol) As Single
ReDim DPA(1 To sRow, 1 To sCol) As Single
ReDim AVDUMA(1 To sRow, 1 To sCol) As Single
ReDim DUMA(1 To sRow, 1 To sCol) As Single
ReDim PseudoPa(1 To sRow, 1 To sCol) As Single
ReDim DPSEUDOPA(1 To sRow, 1 To sCol) As Single
ReDim PSTIME(1 To sRow, 1 To sCol) As Single
ReDim APPC(60) As Single
ReDim AMOL(60) As Single
ReDim ATPC(60) As Single
ReDim PC(60) As Single
ReDim C(60) As Single
ReDim MOL(60) As Single
ReDim TC(60) As Single
ReDim PSTIME(60) As Single
ReDim Pmin(sCol) As Single
Dim CT As Single
ReDim PAV(sCol) As Single
ReDim ZAV(sCol) As Single
ReDim NAV(sCol) As Single
ReDim CTAV(sCol) As Single
ReDim rho(sCol) As Single
ReDim Pq1(sRow) As Single
ReDim Pq2(sRow) As Single
ReDim Pq3(sRow) As Single
ReDim Pq4(sRow) As Single
Dim Aj, Ai, Bi, Ci, CT2 As Single
Dim rhoa, rho2, rho3, rho4 As Single

'Assign project data to the appropriate variables

Temp = Text15.Text + 460
Pi = Text4.Text
WELL_RADIUS = Text8.Text
AREA = Text3.Text
depth = Text16.Text
SHEIGHT = Text17.Text
poros = Text5.Text
Q_max = Text6.Text
Q_min = Text7.Text
Gas_Price = Text18.Text
Delvr_Pres = Text19.Text
```

```
Dp_Gather = Text25.Text
Dp_Procs = Text26.Text
GLDIA = Text27.Text
GL_Length = Text28.Text
Min_Spacing = Text29.Text
No_Wells_Max = AREA / Min_Spacing

TDIA = Text30.Text

u = sRow
w = sCol

'Calculate specific gravity, Ppc, Tpc, and Molecular Weight'
If Check1.Value = 1 Then
   GAMMA = Text2.Text
   Ppc = 709.604 - 58.718 * GAMMA
   Tpc = 170.491 + 307.344 * GAMMA
   MW = GAMMA * 29
End If

'Read Data Files for properties of gas mixture'
If Check2.Value = 1 Then

   filenum = FreeFile
   FileName = App.Path
   FileName = FileName & "\Press.TXT"


   Open FileName For Input As #filenum
   For i = 0 To 12
     Input #filenum, PC(i)
   Next i
   Close #filenum

   filenum = FreeFile
   FileName = App.Path
   FileName = FileName & "\Temprt.TXT"

   Open FileName For Input As #filenum
   For i = 0 To 12
      Input #filenum, TC(i)
   Next i
   Close #filenum

   filenum = FreeFile
   FileName = App.Path
   FileName = FileName & "\Molefr.TXT"

   Open FileName For Input As #filenum
   For i = 0 To 12
      Input #filenum, MOL(i)
   Next i
   Close #filenum

'Read Composition of Gas Mixture'
```

```
    For i = 0 To 12
      C(i) = Text1(i).Text
    Next i
End If

'Calculate Apparent Molecular Weight PPC and TPC'
If Check2.Value = 1 Then

    SUMP = 0
    SUMT = 0
    SUMM = 0

    For i = 0 To 12
        APPC(i) = C(i) * PC(i)
        AMOL(i) = C(i) * MOL(i)
        ATPC(i) = C(i) * TC(i)
        SUMP = SUMP + APPC(i)
        SUMT = SUMT + ATPC(i)
        SUMM = SUMM + AMOL(i)
    Next i
    Ppc = SUMP
    Tpc = SUMT
    MW = SUMM
    GAMMA = MW / 29

End If

'Sour Gas Correction'

a = 0.2:    B = C(9)

If Option1.Value = True Then
    G = 120 * ((a ^ 0.9) - (a ^ 1.6)) + 15 * ((B ^ 0.5) - (B ^ 4))
    CTPC = Tpc - G
    CPPC = Ppc * CTPC / (Tpc + B * (1 - B) * G)
    Tpc = CTPC
    Ppc = CPPC
End If

'Store minimum pressure from each isochronal
'test into array Pmin()
k = 1
For i = 1 To sCol - 1
    For j = 1 To sRow
        If PRESSURE(j, i) = 0 Then
            Pmin(k) = PRESSURE(j - 1, i)
            k = k + 1
            GoTo 3
        End If
    Next j
3:
Next i

'Find minimum pressure value for the
'isochronal test
Psmall = 100000
```

```
For i = 1 To sCol - 1
   For j = 1 To sCol - 1

      If Pmin(i) <= Pmin(j) Then
         newPmin = Pmin(i)
      End If
      If newPmin < Psmall Then
         Psmall = newPmin
      End If
   Next j
Next i

'Average pressure, average Zfactor, average Viscosity, average Compressibility'
For k = 1 To sCol - 1

   PAV(k) = (Pi + Pmin(k)) / 2
   ZAV(k) = RedlichKwong(PAV(k), Temp, Ppc, Tpc)
   rho(k) = DENSITY(PAV(k), GAMMA, ZAV(k), Temp)
   NAV(k) = VISCOSITY(MW, Temp, rho(k))
   CTAV(k) = Compress(Temp, PAV(1), Tpc, Ppc)

AVG_VIS = NAV(1)
AVG_Z = ZAV(1)
AVG_CT = CTAV(1)

Text9.Text = Format(Val(NAV(1)), "0.0000")
Text10.Text = Format(Val(ZAV(1)), "0.00")
Text11.Text = Format(Val(CTAV(1)), "0.00000")
Next k

'Start of Pseudo Pressure calculation'
'Initialize counters and start loop'

j = 1
mpi = 0
TIMESUM = 0
TIME(0) = 0
For i = 1 To Pi

'Calculate Zfactor based on current pressure'
   PRES = i
   ZCURRENT = RedlichKwong(PRES, Temp, Ppc, Tpc)

   rho2 = DENSITY(PRES, GAMMA, ZCURRENT, Temp)
   Vis1 = VISCOSITY(MW, Temp, rho2)
   DUM = (2 * PRES) / (Vis1 * ZCURRENT)
   CT = Compress(Temp, PRES, Tpc, Ppc)

   Ai = 1 / (Vis1 * CT)

   If i = Pi - 1 Then
      initial_Vis = Vis1
      Initial_ct = CT
      Text13.Text = Format(Val(CT), "0.0000")
      Text14.Text = Format(Val(Vis1), "0.0000")
   End If
```

```
   If i > 1 Then
'Calculate previous pressure and Zfactor for previous pressure'

       NEXTP = i - 1

       ZPREVIOUS = RedlichKwong(NEXTP, Temp, Ppc, Tpc)
       rho2 = DENSITY(NEXTP, GAMMA, ZPREVIOUS, Temp)
       Vis2 = VISCOSITY(MW, Temp, rho2)
       CT2 = Compress(Temp, NEXTP, Tpc, Ppc)

'PSEUDO PRESSURE DUMMY VARIABLES

       DDUM = (2 * NEXTP) / (Vis2 * ZPREVIOUS)
       AVDUM = (DDUM + DUM) / 2
       PSEUDOP = AVDUM
'RUNNING SUM OF PSEUDO PRESSURE
       mpi = PSEUDOP + mpi
       If i >= Psmall Then

          For k = 1 To sCol - 1
              For n = 1 To sRow

                 If PRESSURE(n, k) = i Then
'Snatch test values out of run time calculation and store them to arrays'
                    If PRESSURE(n, k) = 0 Then
                       GoTo 10
                    End If

                    zA(n, k) = ZCURRENT
                    NA(n, k) = Vis1
                    DPA(n, k) = Abs(i - Pi)
                    AVDUMA(n, k) = AVDUM
                    DUMA(n, k) = DUM
                    PseudoPa(n, k) = mpi

                 End If
              Next n
           Next k
       End If

10:
 End If
Next i

Text12.Text = Format(Val(mpi), "0.00")

'SUB TO CALCULATE PSEUDO PRESSURE FOR EACH PRESSURE
'INCREMENT BETWEEN 1 AND Pi AND STORE THESE VALUES IN
'A ONE DIMENSIONAL ARRAY TO BE USED TO CONVERT REAL
'PRESSURE TO PSEUDO PRESSURE THROUGH INTERPOLATION
'IN THE PRODUCTION FORCASTING PORTION OF THE PROGRAM

 Call PSEUDO(Pi, Temp, Ppc, Tpc, GAMMA)
```

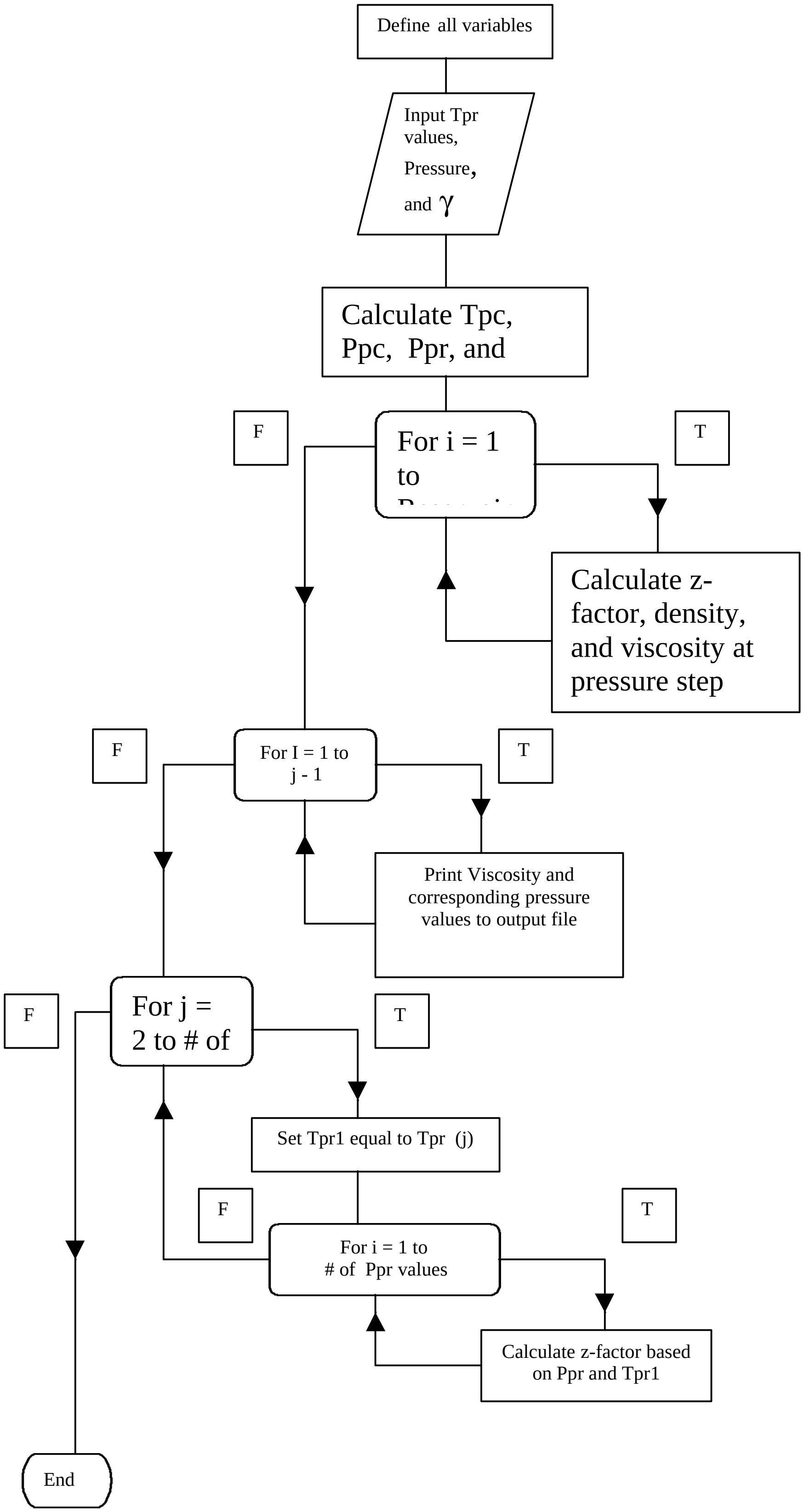
```
'Dimension flex grid and dump data to data file'
With frmMs_Chart.MSFlexGrid1
        .FixedRows = 1:     .FixedCols = 0
        'Clear the grid
        .Clear
        .Cols = sCol           'Number of columns
        .Rows = sRow + 1 '      '# of Rows        '
    End With

'Fill Titles
With frmMs_Chart.MSFlexGrid1
        .Clear
        For j = 0 To .Cols - 1
            .ColWidth(j) = 1200
            .ColAlignment(j) = flexAlignCenterCenter:
            'If j = 0 Then
                '.TextMatrix(0, j) = "No."
            'Else
                .TextMatrix(0, j) = Titles(j)
            'End If
        Next j
End With

With frmMs_Chart.MSFlexGrid1

For i = 1 To sRow
    .Col = 0
    .Row = i
    .Text = Format(Val(TIME(i)), "0.0")
    .ColWidth(1) = 1000
Next i

'Selected_Data() array is used in flexgrid1 form and frmMs_chart form

For k = 1 To sCol - 1
    For i = 1 To sRow
        .Col = k '+ 1
        .Row = i
        .Text = Format(Val(PseudoPa(i, k)), "0.00")
        .ColWidth(k) = 1700
        .CellAlignment = 3
    Next i
Next k
End With
 Z_initial = RedlichKwong(Pi, Temp, Ppc, Tpc)
 B_gi = 0.0283 * Z_initial * Temp / Pi

 'B_gi = 0.00502 * Z_initial * Temp / Pi
 Gi = SHEIGHT * 640 * 43560 * 0.15 / B_gi
 Label37.Caption = Format(Gi / 10 ^ 9, "scientific")
 G1 = Gi
 Vi = SHEIGHT * 640 * 43560 * 0.15
 Command3.Visible = True
 'frmFlexgrid1.Show

End Sub
```

```
'@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@@
Private Sub cmdClear_Click()
For i = 0 To 12
   Text1(i).Text = ""
Next i

Text15.Text = ""

Label24.Caption = ""
End Sub
'@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@@@@
Private Sub cmdexit_Click()
End
End Sub

'@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@@@@
Private Sub cmdPrint_Click()
frmZfactor.PrintForm
End Sub
'@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@@@@
Private Sub Command1_Click()

Text2.Text = "0.7" 'Gas Gravity (GAMMA)
Text3.Text = "640" 'Area of Reservoir (area)
Text4.Text = "3150" 'Initial Pressure (Pi)
Text5.Text = "0.15" 'Porosity[1-Sw] (poros)
Text6.Text = "5" 'Maximum contracted flow rate (Q_max)
Text7.Text = "4" 'Minimum contracted flow rate (Q_min)
Text8.Text = "0.33" 'wellbore radius (wlbrad)
Text15.Text = "195" ' temperature (Temp)
Text16.Text = "6200" 'Depth (depth)
Text17.Text = "25" 'sheight (sheight)
Text18.Text = "2" 'Gas Price (Gas_Price)
Text19.Text = "500" 'Minimum delivery pressure (Delvr_Pres)
Text25.Text = "20" ' Pressure drop in the Gathering System (Dp_Gather)
Text26.Text = "35" ' Pressure drop in Processing Facilities (Dp_Procs)
Text27.Text = "6" 'Flowline Diameter (GLDIA)
Text28.Text = "5" 'Flowline Length (GL_Length)
Text29.Text = "80" 'Minimum Well Spacing (Min_Spacing)
Text30.Text = "3" 'Tubing Diameter (TDIA)

End Sub

'@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
Private Sub Command3_Click()
   frmZfactor.Hide
   'frmFlexgrid1.Show
   frmMs_Chart.Show

End Sub

Private Sub Command4_Click()
```

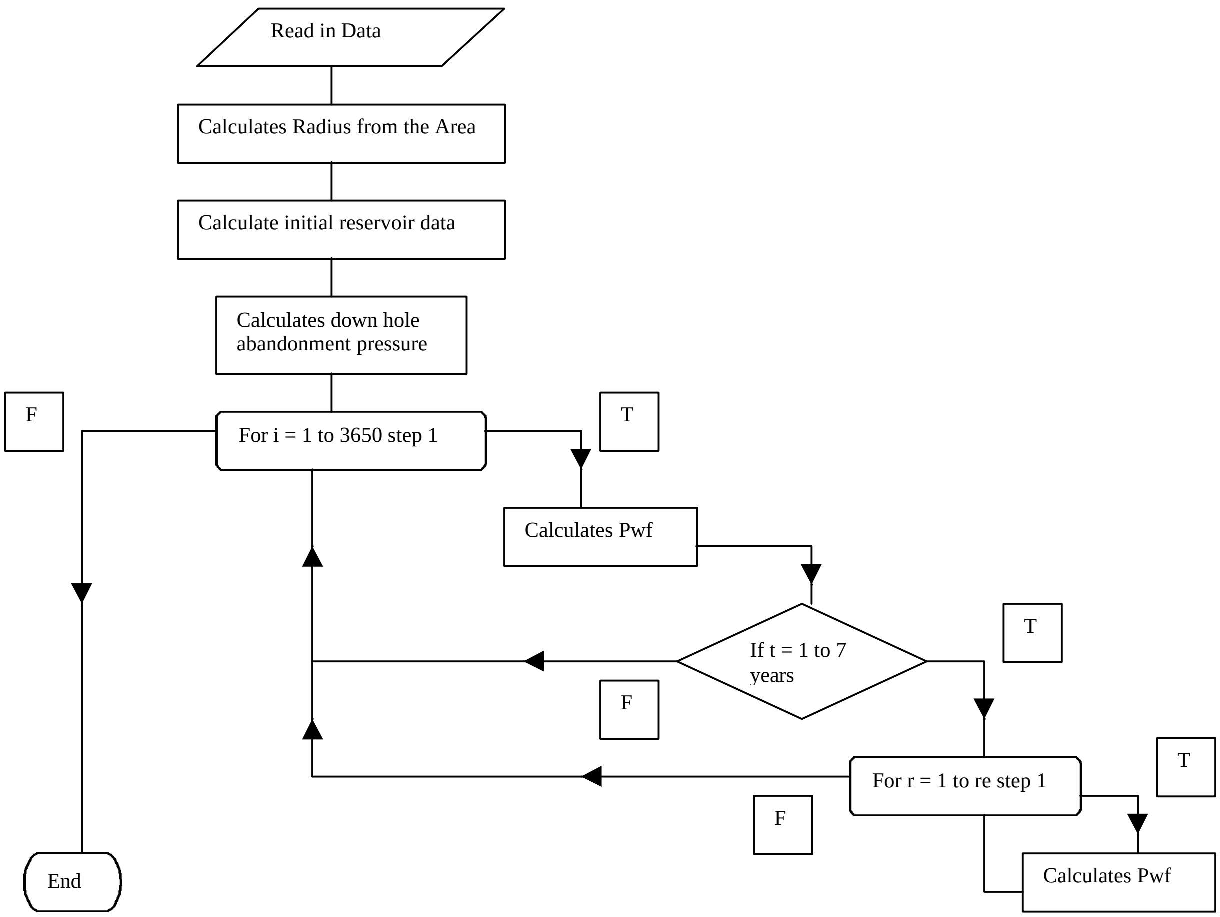
```
    Text15.Text = "195" ' temperature (Temp)
    Temp = Text15.Text
    Text8.Text = "0.33" 'wellbore radius (wlbrad)
    wlbrad = Text8.Text
    Text3.Text = "640" 'Area of Reservoir (area)
    AREA = Text3.Text

    Text16.Text = "6200" 'Depth (depth)
    Text17.Text = "25" 'sheight (sheight)
    Text4.Text = "3150" 'Initial Pressure (Pi)
    Text5.Text = "0.15" 'Porosity[1-Sw] (poros)
    Text2.Text = "0.7" 'Gas Gravity (gamma)

    Text6.Text = "5" 'Maximum contracted flow rate (Q_max)
    Text7.Text = "4" 'Minimum contracted flow rate (Q_min)
    Text18.Text = "2" 'Gas Price (Gas_Price)
    Text19.Text = "500" 'Minimum delivery pressure (Delvr_Pres)

End Sub

'@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
Private Sub Form_Load()
Option1.Value = True
Check1.Value = 1
Check2.Value = 0
End Sub
'@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@
Sub PSEUDO(Pi, Temp, Ppc, Tpc, GAMMA)
'THIS SUBROUTINE CALCULATES THE PSEUDO PRESSURE FOR EACH
'PRESSURE STEP BETWEEN 1 AND Pi AND STORES THESE VALUES
'TO A ONE DIMENSIONAL ARRAY PSEUDO_ARRAY THAT IS USED
'TO CONVERT REAL PRESSURE TO PSEUDO PRESSURE THROUGH INTERPOLATION
'IN OTHER PORTIONS OF THE PROGRAM
ReDim PSEUDO_ARRAY(Val(Pi)) As Single
j = 1
Sum = 0
TIMESUM = 0
TIME(0) = 0
For i = 1 To Pi

'Calculate GAS PROPERTIES based on current pressure'
    PRES = i
    ZCURRENT = RedlichKwong(PRES, Temp, Ppc, Tpc)

    rho2 = DENSITY(PRES, GAMMA, ZCURRENT, Temp)
    Vis1 = VISCOSITY(MW, Temp, rho2)
    DUM = (2 * PRES) / (Vis1 * ZCURRENT)
    CT = Compress(Temp, PRES, Tpc, Ppc)

    If i > 1 Then
'Calculate previous pressure and THE GAS PROPERTIES for
'previous pressure

        NEXTP = i - 1
```

```
        ZPREVIOUS = RedlichKwong(NEXTP, Temp, Ppc, Tpc)
        rho2 = DENSITY(NEXTP, GAMMA, ZPREVIOUS, Temp)
        Vis2 = VISCOSITY(MW, Temp, rho2)
        CT2 = Compress(Temp, NEXTP, Tpc, Ppc)

'DUMMY VARIABLES USED TO CALCULATE PSEUDO PRESSURE

        DDUM = (2 * NEXTP) / (Vis2 * ZPREVIOUS)
        AVDUM = (DDUM + DUM) / 2
        PSEUDOP = AVDUM
        Bi = (Ai + Aj) / 2

        Sum = PSEUDOP + Sum
        PSEUDO_ARRAY(i) = Sum
    End If

Next i
End Sub
```

<u>Appendix XIX</u>: Program Flow Chart for Production Forecasting, Part 1.



<u>Appendix XX</u>: Flow Chart for Production Forecasting, Part 2.



Appendix XXI:

Program Source Code for Production Forecasting (7 year flow rate).

```
Private Sub Check3_Click()
If Check3.Value = 1 Then
    Check4.Value = 0
    Drive1.Visible = False
    Text3.Visible = False
    Text6.Visible = True
    Text7.Visible = True
    Label18.Visible = True
    Label20.Visible = True
    Label21.Visible = True
    Command2.Visible = True
    Command1.Visible = False
    Command5.Visible = False
End If
End Sub

Private Sub Check4_Click()
If Check4.Value = 1 Then
    Check3.Value = 0
    Drive1.Visible = True
    Text3.Visible = True
    Text6.Visible = False
    Text7.Visible = False
    Label18.Visible = False
    Label20.Visible = False
    Label21.Visible = False
    Command2.Visible = False
    Command1.Visible = True
    Command5.Visible = True
End If
End Sub

Private Sub cmdCalculate_Click()

'All variables must be declared
Dim Tpr1 As Single
Dim Sum As Single
Dim Ppr As Single
Dim d_im As Single
Dim Z_G As Single
Dim G_density As Single
Dim GRAPH1A(1 To 100, 1 To 10) As Double
Dim Press(10000) As Single
Dim Tpr(20) As Single
Dim Vis1(10000) As Single

Pmax = Text4.Text

If Check4.Value = 1 Then
```

```
'Read in Data file'
    pathnameProjectData = Drive1.Drive
    nameProjectData = pathnameProjectData + "\" + Text3 + ".txt"
    Open nameProjectData For Input As #1
        j = 2
    Do While Not EOF(1)
        Input #1, Tpr(j)
        j = j + 1
    Loop
    Close #1
    Cuont1 = j - 2
End If

'Calculate  Ppc and Molecular Weight'
GAMMA = Text2.Text
Ppc = 709.604 - 58.718 * GAMMA
Tpc = 170.491 + 307.344 * GAMMA
MW = GAMMA * 29

'This loop calculates the Viscosity of the gas as a function of Pressure
d_im = Pmax / 10
j = 1
For i = 1 To Pmax Step 10
    Ppr = i / Ppc
    Tpr1 = Temp / Tpc
    Z_G = RedlichKwong(Ppr, Tpr1)
    G_density = DENSITY(i, GAMMA, Z_G, Temp)
    Vis1(j) = VISCOSITY(MW, Temp, rho)
    Press(j) = i
    j = j + 1
Next i

Open "a:Viscosity.txt" For Output As #2
Print #2, "Pressure", "    Viscosity"
For i = 1 To j - 1 Step 1
    Print #2, Format(Val(Press(i)), "0.0"), Format(Val(Vis1(i)), "0.00000")
Next i
Close #2

'This loop stores the values of Ppr into the first clumn of the two dimension
'GRAPH1A array
Sum = 0
sum2 = 1
Ppr = Pmax / Ppc
For i = 1 To 100
    Ppr1 = Ppr / 100
    Sum = Sum + Ppr1
    If Sum >= 0.2 Then
        GRAPH1A(sum2, 1) = Sum
        sum2 = sum2 + 1
    End If
Next i

'Calculate Z_factor for Ppr and Tpr values and store them into the two
'dimensional array GRAPH1A for graphing
```

```
'This loop also calculates the viscosity as a function of pressure
Sum = 0
For j = 2 To 10
   Tpr1 = Tpr(j)
   Debug.Print Tpr1
   For i = 1 To sum2 - 3
      Ppr = GRAPH1A(i, 1)
      Z_factor = RedlichKwong(Ppr, Tpr1)
      GRAPH1A(i, j) = Z_factor
      Next i
   Next j

'Graph the Z_factor as a function of Ppr
NO_COLUMNS = 0
MSChart1.chartType = VtChChartType2dXY
With MSChart1
   .ColumnCount = 18
   .RowCount = sum2 - 3
For k1 = 2 To 10

   For k = 1 To 2
      NO_COLUMNS = NO_COLUMNS + 1

      For i = 1 To sum2 - 3 Step 1
         .Column = NO_COLUMNS
         .Row = i
         If k = 1 Then
            .Data = GRAPH1A(i, 1)
         Else
            .Data = GRAPH1A(i, k1)
         End If

      Next
   Next
Next
End With
   MSChart1.Plot.UniformAxis = False

Command3.Visible = True
End Sub

Private Sub cmdClear_Click()
Text4.Text = ""
Text2.Text = ""
Text3.Text = ""
Text7.Text = ""
Text6.Text = ""
jump = 0
End Sub

Private Sub cmdexit_Click()
   End
End Sub

Private Sub cmdPrint_Click()
   frmZfactor.PrintForm
```

```
End Sub

Private Sub Command1_Click()
   Label1.Caption = "OSM #1"
   Text4.Text = "645"
   Text3.Text = "TprData"
   Text2.Text = "0.65"
   Drive1.Drive = "a:"
   Temp = 110 + 460
End Sub

Private Sub Command2_Click()
If Text7.Text > 0 Then
   Cuont = Text7.Text
   If jump < Cuont Then
      ReDim Tpr(Cuont + 2) As Single
      Tpr(jump) = Text6.Text
      jump = jump + 1
      Text6.Text = ""
   End If
End If

If jump - 2 >= Cuont Then
   Text7.Visible = False
   Text5.Visible = False
   Text6.Visible = False
End If
Text7.Text = Cuont - 1
End Sub

Private Sub Command3_Click()
   Form2.Show
   frmZfactor.Hide
End Sub

Private Sub Command4_Click()
   Form2.Show
   frmZfactor.Hide
End Sub

Private Sub Command5_Click()
   Label1.Caption = "OSM #2"
   Text4.Text = "925"
   Text3.Text = "TprData"
   Text2.Text = "0.65"
   Drive1.Drive = "a:"
   Temp = 120 + 460
End Sub

Private Sub Form_Load()
   Option1.Value = True
   Check4.Value = 1
   Check3.Value = 0
   Dim jump As Single
   jump = 2
End Sub
```

```
Private Sub Command1_Click()
' Read in the data and initialize
Skin = Val(Text6.Text)
Por = Val(Text3.Text)
q = Val(Text2.Text)
Pinit = Val(Text1.Text)
perm = Val(Text4.Text)
P(0, 0) = Pinit
thick = Val(Text7.Text)
Temp2 = Val(Text9.Text) + 460#
Mole = Val(Text10.Text)
Depth = Val(Text11.Text)
Radius = ((Val(Text8.Text) * 43560) / 3.14)

If Radius <= 0 Then

' Ending for negative in the Radius calculation
   Label9.Caption = "The area is negative please try another value"
   GoTo 50
Else
   GoTo 3
End If

3:
Radius = (Radius) ^ 0.5

'Average pressure and compressibility
Ppr = Pinit / Ppc
Tpr = Temp2 / Tpc
zfact = RedlichKwong(Ppr, Tpr)
Paba = Val(Text5.Text)
Paba = Paba + Paba * (Exp((Mole * Depth) / (1544 * Temp2 * zfact)))
Paverage = (Pinit + Paba) / 2
PRES = Paverage
Ppr = PRES / Ppc
Tpr = Temp2 / Tpc
z = RedlichKwong(Ppr, Tpr)
c = Compress(PRES, Tpr, Ppr, z)
c = c / Ppc

'to export pressure time data to text file
Open "a:Pressure.txt" For Output As #2
Print #2, "Pressure", "    Time"

For t = 1 To 3650 Step 1

'we are interested only in well-bore pressure
   r = 0.25

   If t = 1 Then
      PRES = P(0, 0)
   Else
      PRES = P(t - 1, 0)
   End If
```

```
    Ppr = PRES / Ppc
    Tpr = Temp2 / Tpc
    z = RedlichKwong(Ppr, Tpr)
    rho2 = DENSITY(PRES, GAMMA, z, Temp2)
    mhu = VISCOSITY(MW, Temp2, rho2)
' Equation 4.90 270 notes
    da = Log((perm * t * 24) / (Por * mhu * c * (r ^ 2))) - 3.23
    ea = 0.87 * Skin
    fa = da + ea
    Ga = (1637 * q * Temp2 * mhu * z) / (perm * thick)
    ha = fa * Ga
    ja = (P(t - 1, 0) ^ 2) - ha
' Test to see if the value is negative
    If ja <= (Paba ^ 2) Then
' ending for negative in the Pressure calculation

        Label9.Caption = "At this time (yrs) the pressure is below abandonment pressure "
        Label10.Caption = Format(Val(t / 365), "0.000")
        Label14.Caption = Format(Val(P(t - 1, r)), "0.00")
        GoTo 50
    Else: GoTo 2
    End If

2:
' Calculate Current Pwf
   P(t, 0) = (ja) ^ 0.5
   Print #2, Format(Val(P(t, 0)), "0.0"), Format(Val(t), "0.0")

    If t = 2555 Then
        Label12.Caption = "The pressure (psi) at the end of seven years is = "
        Label13.Caption = Format(Val(P(t, 0)), "0.00")
    End If


    If t = 3650 Then
        Label9.Caption = "The pressure (psi) at the end of ten years is = "
        Label14.Caption = Format(Val(P(t, 0)), "0.00")
        Label10.Caption = "10"
    End If


    If t = 365 Or t = 730 Or t = 1095 Or t = 1460 Or t = 1825 Or t = 2190 Or t = 2555 Then
        Sum = 0
        For r = 0.25 To Radius Step 1
            Sum = Sum + 1
            P(0, Sum) = r
        Next r
        For i = 1 To Sum
            r = P(0, i)
            da = Log((perm * t * 24) / (Por * mhu * c * (r ^ 2))) - 3.23
            ea = 0.87 * Skin
            fa = da + ea
            Ga = (1637 * q * Temp2 * mhu * z) / (perm * thick)
            ha = fa * Ga
            ja = (P(t, 0) ^ 2) - ha
```

```
' Test to see if the value is negative
        If ja <= 0 Then
' ending for negative in radius moves to the next time value
' so that only a negative differential at well-bore will end the program
          GoTo 10

        Else: GoTo 15
        End If

15:
' Calculate Current Pwf
        P(t, i) = (ja) ^ 0.5
      Next i
   End If

10:
Next t

50:
Close #2
End Sub

Private Sub Command2_Click()
   End
End Sub

Private Sub Command3_Click()
Text1.Text = Pmax
Text2.Text = "0.2683"
Text3.Text = ".14"
Text4.Text = "4.33"
Text5.Text = "50"
Text6.Text = "-3.79"
Text7.Text = "56"
Text8.Text = "40"
Text9.Text = "120"
Text10.Text = MW
Text11.Text = "5324"
Label19.Caption = "OSM #2"
End Sub

'functions
Private Sub Command4_Click()
Text1.Text = ""
Text2.Text = ""
Text3.Text = ""
Text4.Text = ""
Text5.Text = ""
Text6.Text = ""
Text7.Text = ""
Text8.Text = ""
Text9.Text = ""
'Clear the labels if immediate runs are necessary
   Label9.Caption = ""
   Label10.Caption = ""
   Label12.Caption = ""
```

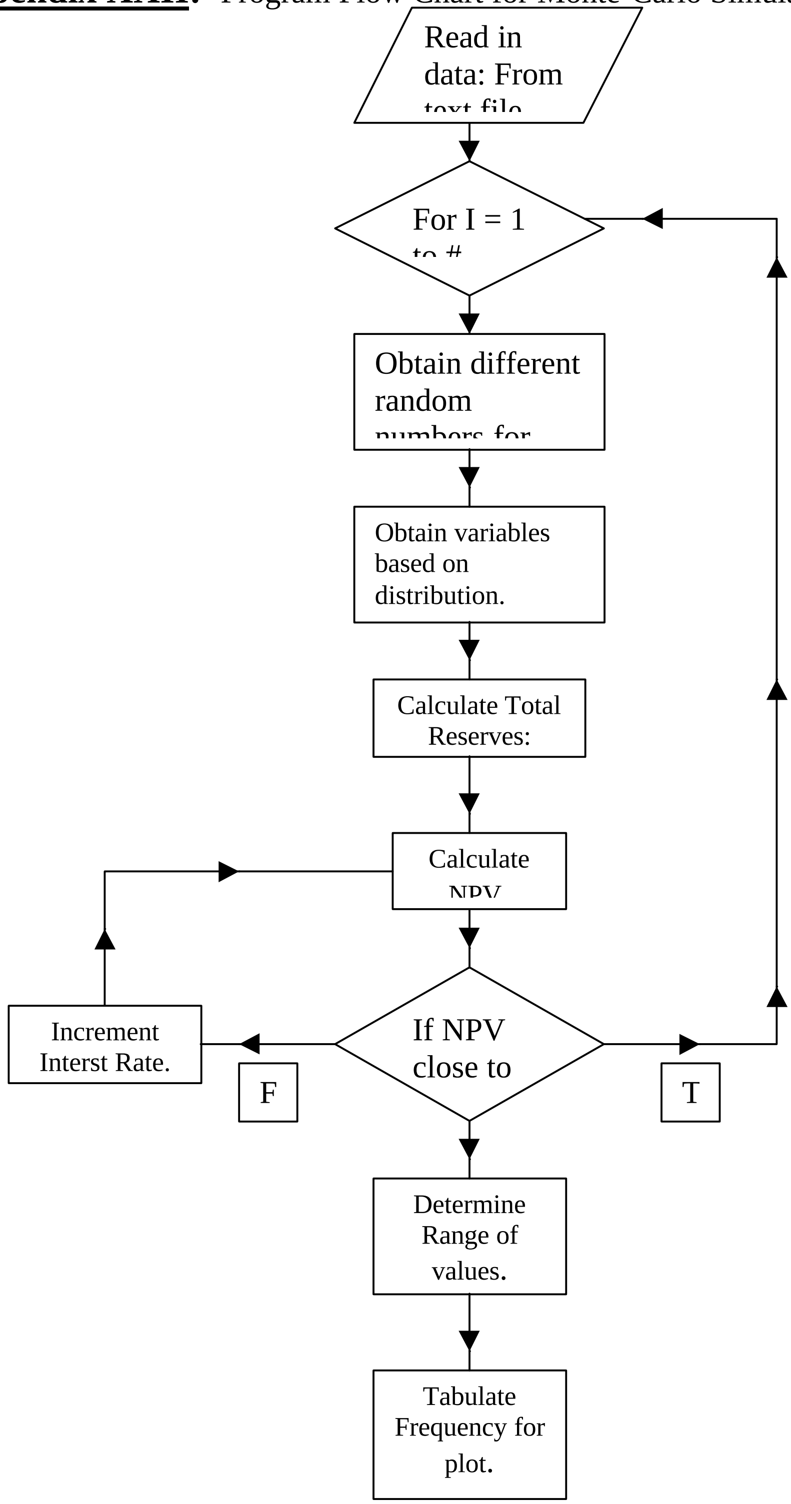
```
   Label13.Caption = ""
End Sub

Private Sub Command5_Click()
   Form2.PrintForm
End Sub

Private Sub Command6_Click()
   Form1.Show
   Form2.Hide
End Sub

Private Sub Command7_Click()
Text1.Text = Pmax
Text2.Text = "0.1655"
Text3.Text = ".08"
Text4.Text = "6"
Text5.Text = "50"
Text6.Text = "-4.50"
Text7.Text = "50"
Text8.Text = "40"
Text9.Text = "110"
Text10.Text = MW
Text11.Text = "4512"
Label19.Caption = "OSM #1"
End Sub

Private Sub Command10_Click()
   Print Form1
End Sub

Private Sub Command2_Click()
NO_COLUMNS = 0
MSChart1.chartType = VtChChartType2dXY
With MSChart1
   .ColumnCount = 2
   .RowCount = Sum
   .TitleText = "Year 2 Pressure Distribution"

For k = 1 To 2
   NO_COLUMNS = NO_COLUMNS + 1

   For i = 1 To Sum Step 1
      .Column = NO_COLUMNS
      .Row = i
      If k = 1 Then
         .Data = P(0, i)
      Else
         .Data = P(730, i)
      End If

    Next
Next
End With
   MSChart1.Plot.UniformAxis = False
End Sub
```

```
Private Sub Command1_Click()
NO_COLUMNS = 0
MSChart1.chartType = VtChChartType2dXY
With MSChart1
   .ColumnCount = 2
   .RowCount = Sum
   .TitleText = "Year 1 Pressure Distribution"
For k = 1 To 2
   NO_COLUMNS = NO_COLUMNS + 1

   For i = 1 To Sum Step 1
      .Column = NO_COLUMNS
      .Row = i
      If k = 1 Then
         .Data = P(0, i)
      Else
         .Data = P(365, i)
      End If

    Next
Next
End With
   MSChart1.Plot.UniformAxis = False
End Sub

Private Sub Command3_Click()
NO_COLUMNS = 0
MSChart1.chartType = VtChChartType2dXY
With MSChart1
   .ColumnCount = 2
   .RowCount = Sum
   .TitleText = "Year 3 Pressure Distribution"
For k = 1 To 2
   NO_COLUMNS = NO_COLUMNS + 1

   For i = 1 To Sum Step 1
      .Column = NO_COLUMNS
      .Row = i
      If k = 1 Then
         .Data = P(0, i)
      Else
         .Data = P(1095, i)
      End If

    Next
Next
End With
   MSChart1.Plot.UniformAxis = False
End Sub

Private Sub Command4_Click()
NO_COLUMNS = 0
MSChart1.chartType = VtChChartType2dXY
With MSChart1
   .ColumnCount = 2
```

```
    .RowCount = Sum
    .TitleText = "Year 4 Pressure Distribution"
For k = 1 To 2
    NO_COLUMNS = NO_COLUMNS + 1

    For i = 1 To Sum Step 1
        .Column = NO_COLUMNS
        .Row = i
        If k = 1 Then
            .Data = P(0, i)
        Else
            .Data = P(1460, i)
        End If

    Next
Next
End With
    MSChart1.Plot.UniformAxis = False
End Sub

Private Sub Command5_Click()
NO_COLUMNS = 0
MSChart1.chartType = VtChChartType2dXY
With MSChart1
    .ColumnCount = 2
    .RowCount = Sum
    .TitleText = "Year 5 Pressure Distribution"
For k = 1 To 2
    NO_COLUMNS = NO_COLUMNS + 1

    For i = 1 To Sum Step 1
        .Column = NO_COLUMNS
        .Row = i
        If k = 1 Then
            .Data = P(0, i)
        Else
            .Data = P(1825, i)
        End If

    Next
Next
End With
    MSChart1.Plot.UniformAxis = False
End Sub

Private Sub Command6_Click()
NO_COLUMNS = 0
MSChart1.chartType = VtChChartType2dXY
With MSChart1
    .ColumnCount = 2
    .RowCount = Sum
    .TitleText = "Year 6 Pressure Distribution"
For k = 1 To 2
    NO_COLUMNS = NO_COLUMNS + 1

    For i = 1 To Sum Step 1
```

```
        .Column = NO_COLUMNS
        .Row = i
        If k = 1 Then
            .Data = P(0, i)
        Else
            .Data = P(2190, i)
        End If

     Next
Next
End With
    MSChart1.Plot.UniformAxis = False
End Sub

Private Sub Command7_Click()
NO_COLUMNS = 0
MSChart1.chartType = VtChChartType2dXY
With MSChart1
    .ColumnCount = 2
    .RowCount = Sum
    .TitleText = "Year 7Pressure Distribution"
For k = 1 To 2
    NO_COLUMNS = NO_COLUMNS + 1

    For i = 1 To Sum Step 1
        .Column = NO_COLUMNS
        .Row = i
        If k = 1 Then
            .Data = P(0, i)
        Else
            .Data = P(2555, i)
        End If

    Next
Next
End With
    MSChart1.Plot.UniformAxis = False
End Sub

Private Sub Command8_Click()
    Form2.Show
    Form1.Hide
End Sub

Private Sub Command9_Click()
    End
End Sub
```

Appendix XXII: Program Flow Chart for Monte-Carlo Simulation.



Appendix XXIII:

Program Source Code for Monte-Carlo Simulation.

```
Private Sub Command1_Click()

ReDim Schedule_1(100) As Single
ReDim Schedule_2(100) As Single
ReDim Schedule_3(100) As Single
ReDim Schedule_4(100) As Single
ReDim Schedule(Val(Text10.Text)) As Single
ReDim Active_Schedule(Val(Text10.Text)) As Single


ReDim Time(100) As Single

Dim pathnameProjectData As Variant
Dim nameProjectdata As Variant



Drive1.Drive = "a:"
Text9.Text = "Schedule"

pathnameProjectData = Drive1.Drive
   nameProjectdata = pathnameProjectData + "\" + Text9 + ".txt"
   Open nameProjectdata For Input As #1
      j = 1
   Do While Not EOF(1)
   Input #1, Time(j), Schedule_1(j), Schedule_2(j), Schedule_3(j), Schedule_4(j)
      j = j + 1
      If j > 18 Then
         GoTo 2
      End If

   Loop
2:

   Close #1

   Count1 = j



With MSFlexGrid1
   .Cols = 5
   .Rows = 19

   .Row = 0

   .TextMatrix(0, 0) = "TIME(hrs)"
   .TextMatrix(0, 1) = "Schedule 1"
   .TextMatrix(0, 2) = "Schedule 2"
```

```
    .TextMatrix(0, 3) = "Schedule 3"
    .TextMatrix(0, 4) = "Schedule 4"



    For j = 1 To 18
        .Row = j
        .Col = 0
        .TextMatrix(j, 0) = Time(j)

        .Col = 1
        .TextMatrix(j, 1) = Schedule_1(j)

        .Col = 2
        .TextMatrix(j, 2) = Schedule_2(j)

        .Col = 3
        .TextMatrix(j, 3) = Schedule_3(j)

        .Col = 4
        .TextMatrix(j, 4) = Schedule_4(j)

    Next j


End With

End Sub

Private Sub Command10_Click()
frmGraph5.Show
frmRanges.Hide

End Sub

Private Sub Command2_Click()
ProgressBar1.Min = 1: ProgressBar1.Max = Val(Text10.Text)

 Dim Poros_Min As Single
 Dim Poros_Max As Single
 Dim Thick_Min As Single
 Dim Thick_Max As Single
 Dim Saturation_Min As Single
 Dim Saturation_Med As Single
 Dim Saturation_Max As Single
 'Dim Schedule As Single
 ReDim Poros(Val(Text10.Text)) As Single
 ReDim Thick(Val(Text10.Text)) As Single
 ReDim Saturation(Val(Text10.Text)) As Single
 Dim Total_Reserves As Single
 Dim area As Single
 Dim BGI As Single
 Dim GasCost As Single
 ReDim Range_Array(100) As Single
 Dim Interest As Single
```

```
 ReDim Dcfror(Val(Text10.Text)) As Single
 ReDim Active_Schedule(100) As Single
 ReDim Frequency(21) As Single
 Dim GasProduced As Single
 Dim WellDepth As Single
 Dim OperCost As Single
 Dim Tax As Single
 Dim Working_Interest As Single
Dim DCFROR_RANGE As Single
Dim DCFROR_MAX As Single
Dim DCFROR_MIN As Single
Dim Increment As Single
Dim Frequency_Min As Single
Dim Frequency_Max As Single
Dim Frequency_Min1 As Single
Dim Frequency_Max1 As Single
Dim DrillCost As Single
Dim Poros_Min1 As Single
Dim Poros_Max1 As Single
ReDim Poros_Range(10) As Single
ReDim Poros_Frequency(10) As Single
Dim Poros_Frequency_Max1 As Single
Dim Poros_Frequency_Max As Single

Dim Poros_Frequency_Min As Single
ReDim Thick_range(10) As Single
Dim Thick_Frequency_Min1 As Single
Dim Thick_Frequency_Max1 As Single
ReDim Thick_Frequency(10) As Single
Dim Thick_Frequency_Min As Single
Dim Thick_Frequency_Max As Single

Dim Saturation_MIN1 As Single
Dim Saturation_MAX1 As Single
ReDim Saturation_RANGE(10) As Single
ReDim Saturation_Frequency(10) As Single
Dim Saturation_Frequency_Min As Single
Dim Dcfror_Range_Array(10) As Single
ReDim Schedule_6(Val(Text10.Text)) As Single
Dim SCHEDULE_6Frequency_Min1 As Single
Dim SCHEDULE_6Frequency_Max1 As Single
Dim SCHEDULE_6Frequency_Max As Single
ReDim SCHEDULE_6RANGE(Val(Text10.Text)) As Single
ReDim SCHEDULE_6FREQUENCY(Val(Text10.Text)) As Single
Dim Factor As Single
Dim Factor_Min As Single
Dim Factor_Max As Single
Dim xxx5 As Single
```

```
 Poros_Min = Val(Text1.Text)
 Poros_Max = Val(Text2.Text)
 Thick_Min = Val(Text3.Text)
 Thick_Max = Val(Text4.Text)
 Saturation_Min = Val(Text6.Text) / 100
 Saturation_Med = Val(Text11.Text) / 100
 Saturation_Max = Val(Text5.Text) / 100
 BGI = Val(Text8.Text)
 area = Val(Text7.Text)
 GasCost = Val(Text12.Text)
 OperCost = Val(Text14.Text)
 Tax = Val(Text16.Text) / 100
 Working_Interest = Val(Text15.Text) / 100
 Well_Depth = Val(Text13.Text)
 Interest = Val(Text17.Text) / 100
 DrillCost = Val(Text18.Text)
 Factor_Min = Val(Text19.Text) * 1000
 Factor_Max = Val(Text20.Text) * 1000

'START LOOP THAT GENERATES RANDOM NUMBERS TO BE USED IN MONTE CARLO
SIMULATION
For i = 1 To Val(Text10.Text)

xxx = Rnd()
xxx2 = Rnd()
xxx3 = Rnd()
xxx4 = Rnd()
ProgressBar1.Value = i

' UNIFORM DISTRIBUTION FOR POROSITY AND THICKNESS

 Poros(i) = (Poros_Min + xxx * (Poros_Max - Poros_Min)) / 100
 Thick(i) = Thick_Min + xxx2 * (Thick_Max - Thick_Min)



 'TRIANGULAR DISTRIBUTION SATURATION
If xxx3 <= ((Saturation_Med - Saturation_Min) / (Saturation_Max - Saturation_Min)) Then

    Saturation(i) = Saturation_Min + Sqr((Saturation_Med - Saturation_Min) * (Saturation_Max -
Saturation_Min) * xxx3)

ElseIf xxx3 >= ((Saturation_Med - Saturation_Min) / (Saturation_Max - Saturation_Min)) Then
    Saturation(i) = Saturation_Max - Sqr((Saturation_Max - Saturation_Med) * (Saturation_Max -
Saturation_Min) * xxx3)

End If
'Next i

'For i = 1 To Val(Text10.Text)
'CALCULATION OF TOTAL RESERVES  BASED ON VARIABLES FROM THE RANDOM
NUMBER GENERATOR
```

```
If Check1.Value = 0 Then
   Total_Reserves = Poros(i) * Saturation(i) * 43560 * area * Thick(i) / BGI
End If


If Check1.Value = 1 Then
   xxx5 = Rnd()
   Factor = Factor_Min + xxx5 * (Factor_Max - Factor_Min)
   Total_Reserves = (Factor * Thick(i) * area)
End If



'SELECTION OF PRODUCTION SCHEDULE BASED ON THE RANDOME NUMBER XXX4
If xxx4 < 0.25 Then
    yyy = 12
   For k = 1 To 12
      Active_Schedule(k) = Schedule_1(k)
      Schedule_6(i) = 1
   Next k
ElseIf xxx4 >= 0.25 And xxx4 < 0.5 Then
    For k = 1 To 14
      Active_Schedule(k) = Schedule_2(k)
      Schedule_6(i) = 2
   Next k
   yyy = 14
ElseIf xxx4 >= 0.5 And xxx4 < 0.75 Then
    For k = 1 To 16
      Active_Schedule(k) = Schedule_3(k)
      Schedule_6(i) = 3
   Next k
   yyy = 16
ElseIf xxx4 >= 0.75 And xxx4 < 1# Then
    For k = 1 To 18
      Active_Schedule(k) = Schedule_4(k)
      Schedule_6(i) = 4
   Next k
   yyy = 18
End If

 'ITERATIVE PROCEDURE TO FIND THE DCFROR

Interest = 0#
3:
 GasProduced = 0#
   NPVSum = 0#




   For z = 0 To yyy Step 1
      GasProduced = Total_Reserves * Active_Schedule(z + 1) - GasProduced
      If z = 0 Then
         NCF = -20 * Well_Depth - DrillCost
      End If
```

```
        If z > 0 Then
            NCF = ((GasProduced / 1000 * GasCost) * (1 - Tax)) * Working_Interest - GasProduced / 1000 *
OperCost
        End If

        NPV1 = NCF / (1 + Interest) ^ z
        NPVSum = NPVSum + NPV1
    Next z

    'If Abs(NPVSum) > 0.1 Then
     If NPVSum > 0 Then
        If NPVSum < 300000 And NPVSum > 50000 Then
            Interest = Interest + 0.01
            GoTo 3

        ElseIf NPVSum < 50000 And NPVSum > 10000 Then
            Interest = Interest + 0.0005
            GoTo 3
        ElseIf NPVSum < 10000 And NPVSum > 1000 Then
            Interest = Interest + 0.00005
            GoTo 3
        ElseIf NPVSum < 1000 And NPVSum > 100 Then
            Interest = Interest + 0.00001
            GoTo 3
        ElseIf NPVSum < 100 And NPVSum > 50 Then
            Interest = Interest + 0.000001
            GoTo 3
        ElseIf NPVSum < 50 And NPVSum > 1 Then
            Interest = Interest + 0.0000001
            GoTo 3
        ElseIf NPVSum < 10 Then
            Dcfror(i) = Interest
            GoTo 4
        Else
            Interest = Interest + 0.05
            GoTo 3
        End If
     End If
 If NPVSum < 0 Then
:
 End If

4

' END OF BIG LOOP
If i > 147 Then
:
End If
Next i


'DETERMINE THE PROBABILITY DISTRIBUTION OF THE POROSITY
Poros_Min = 1
Poros_Max = 0
```

```
For i = 1 To Val(Text10.Text)
   Poros_Min1 = Poros(i)
   Poros_Max1 = Poros_Min1

   If Poros_Min1 < Poros_Min Then
      Poros_Min = Poros_Min1
   End If

   If Poros_Max1 > Poros_Max Then
      Poros_Max = Poros_Max1
   End If

Next i

Poros_RANGE1 = Poros_Max - Poros_Min

Increment = Poros_RANGE1 / 10
Range_Array(0) = Poros_Min
For i = 1 To 10
   Range_Array(i) = Poros_Min + Increment * i
Next i

For i = 1 To 10
 Poros_Range(i) = (Range_Array(i - 1) + Range_Array(i)) / 2
Next i


For i = 1 To 10
   Poros_Frequency(i) = 0
   For j = 1 To Val(Text10.Text)
      If Poros(j) < Poros_Range(i) And Poros(j) >= Poros_Range(i - 1) Then
         Poros_Frequency(i) = Poros_Frequency(i) + 1
      End If
   Next j
Next i

For i = 1 To 10
   Poros_Frequency_Min1 = Poros_Frequency(i)
   Poros_Frequency_Max1 = Poros_Frequency_Min1

   If Poros_Frequency_Min1 < Poros_Frequency_Min Then
      Poros_Frequency_Min = Poros_Frequency_Min1
   End If

   If Poros_Frequency_Max1 > Poros_Frequency_Max Then
      Poros_Frequency_Max = Poros_Frequency_Max1
   End If

Next i



'DETRMINE THE PROBABILITY DISTRIBUTION OF THE THICKNESS
'Thick_Min = 1000000000
Thick_Max = 0
```

```
For i = 1 To Val(Text10.Text)
   Thick_MIN1 = Thick(i)
   Thick_MAX1 = Thick_MIN1

   If Thick_MIN1 < Thick_Min Then
      Thick_Min = Thick_MIN1
   End If

   If Thick_MAX1 > Thick_Max Then
      Thick_Max = Thick_MAX1
   End If

Next i
Thick_Range1 = Thick_Max - Thick_Min
Increment = Thick_Range1 / 10
Range_Array(0) = Thick_Min
For i = 1 To 10
  Range_Array(i) = Thick_Min + Increment * i
Next i


For i = 1 To 10
 Thick_range(i) = (Range_Array(i - 1) + Range_Array(i)) / 2
Next i


For i = 1 To 10
   Thick_Frequency(i) = 0
   For j = 1 To Val(Text10.Text)
      If Thick(j) < Thick_range(i) And Thick(j) >= Thick_range(i - 1) Then
         Thick_Frequency(i) = Thick_Frequency(i) + 1
      End If
   Next j
Next i



For i = 1 To 10
   Thick_Frequency_Min1 = Thick_Frequency(i)
   Thick_Frequency_Max1 = Thick_Frequency_Min1

   If Thick_Frequency_Min1 < Thick_Frequency_Min Then
      Thick_Frequency_Min = Thick_Frequency_Min1
   End If

   If Thick_Frequency_Max1 > Thick_Frequency_Max Then
      Thick_Frequency_Max = Thick_Frequency_Max1
   End If

Next i

'DETERMINE THE PROBABILITY DISTRIBUTION FOR THE SCHEDULE

SCHEDULE_6Min = 1
SCHEDULE_6Max = 4
```

```
'For I = 1 To Val(Text10.Text)
   'SCHEDULE_6MIN1 = Schedule_6(I)
   'SCHEDULE_6MAX1 = SCHEDULE_6MIN1

   'If SCHEDULE_6MIN1 < SCHEDULE_6Min Then
      'SCHEDULE_6Min = SCHEDULE_6MIN1
   'End If

   'If SCHEDULE_6MAX1 > SCHEDULE_6Max Then
      'SCHEDULE_6Max = SCHEDULE_6MAX1
   'End If

'Next I


SCHEDULE_6Range1 = SCHEDULE_6Max - SCHEDULE_6Min
'Increment = SCHEDULE_6Range1 / 4
Range_Array(0) = SCHEDULE_6Min
For i = 1 To 4
   If i = 1 Then
      Range_Array(i) = SCHEDULE_6Min
   End If
    Range_Array(i) = SCHEDULE_6Min + 1
Next i
SCHEDULE_6RANGE(0) = 0

For i = 1 To 4
SCHEDULE_6RANGE(i) = Range_Array(i)
Next i

For i = 1 To 4
   SCHEDULE_6FREQUENCY(i) = 0
   For j = 1 To Val(Text10.Text)
      If Schedule_6(j) < SCHEDULE_6RANGE(i) And Schedule_6(j) >= SCHEDULE_6RANGE(i - 1)
Then
         SCHEDULE_6FREQUENCY(i) = SCHEDULE_6FREQUENCY(i) + 1
      End If
   Next j
Next i




For i = 1 To 10
   SCHEDULE_6Frequency_Min1 = SCHEDULE_6FREQUENCY(i)
   SCHEDULE_6Frequency_Max1 = SCHEDULE_6Frequency_Min1

   If SCHEDULE_6Frequency_Min1 < SCHEDULE_6Frequency_Min Then
      SCHEDULE_6Frequency_Min = SCHEDULE_6Frequency_Min1
   End If

   If SCHEDULE_6Frequency_Max1 > SCHEDULE_6Frequency_Max Then
      SCHEDULE_6Frequency_Max = SCHEDULE_6Frequency_Max1
```

```
    End If

Next i


Saturation_Min = 1
Saturation_Max = 0




For i = 1 To Val(Text10.Text)
    Saturation_MIN1 = Saturation(i)
    Saturation_MAX1 = Saturation_MIN1

    If Saturation_MIN1 < Saturation_Min Then
        Saturation_Min = Saturation_MIN1
    End If

    If Saturation_MAX1 > Saturation_Max Then
        Saturation_Max = Saturation_MAX1
    End If

Next i


Saturation_Range1 = Saturation_Max - Saturation_Min
Increment = Saturation_Range1 / 10
Range_Array(0) = Saturation_Min
For i = 1 To 10
    Range_Array(i) = Saturation_Min + Increment * i
Next i


For i = 1 To 10
Saturation_RANGE(i) = (Range_Array(i - 1) + Range_Array(i)) / 2
Next i

For i = 1 To 10
    Saturation_Frequency(i) = 0
    For j = 1 To Val(Text10.Text)
        If Saturation(j) < Saturation_RANGE(i) And Saturation(j) >= Saturation_RANGE(i - 1) Then
            Saturation_Frequency(i) = Saturation_Frequency(i) + 1
        End If
    Next j
Next i

 Dim Saturation_Frequency_Min1 As Single
 Dim Saturation_Frequency_Max1 As Single
 Dim Saturation_Frequency_Max As Single



For i = 1 To 10
    Saturation_Frequency_Min1 = Saturation_Frequency(i)
    Saturation_Frequency_Max1 = Saturation_Frequency_Min1
```

```
    If Saturation_Frequency_Min1 < Saturation_Frequency_Min Then
        Saturation_Frequency_Min = Saturation_Frequency_Min1
    End If

    If Saturation_Frequency_Max1 > Saturation_Frequency_Max Then
        Saturation_Frequency_Max = Saturation_Frequency_Max1
    End If

Next i


'DETERMINE THE PROBABILITY DISTRIBUTION OF THE DCFROR

DCFROR_MIN = 1
DCFROR_MAX = 0

For i = 1 To Val(Text10.Text)
    DCFROR_MIN1 = Dcfror(i)
    DCFROR_MAX1 = DCFROR_MIN1

    If DCFROR_MIN1 < DCFROR_MIN Then
        DCFROR_MIN = DCFROR_MIN1
    End If

    If DCFROR_MAX1 > DCFROR_MAX Then
        DCFROR_MAX = DCFROR_MAX1
    End If

Next i






DCFROR_RANGE = DCFROR_MAX - DCFROR_MIN

Increment = DCFROR_RANGE / 10
Dcfror_Range_Array(0) = DCFROR_MIN
Range_Array(0) = 0
For i = 1 To 10
    Range_Array(i) = DCFROR_MIN + Increment * i

Next i


For i = 1 To 10
    Dcfror_Range_Array(i) = (Range_Array(i - 1) + Range_Array(i)) / 2

Next i


For i = 1 To 10
```

```
    Frequency(i) = 0
    For j = 1 To Val(Text10.Text)
        If Dcfror(j) < Dcfror_Range_Array(i) And Dcfror(j) >= Dcfror_Range_Array(i - 1) Then
            Frequency(i) = Frequency(i) + 1
        End If
    Next j
Next i

For i = 1 To 10
    Frequency_Min1 = Frequency(i)
    Frequency_Max1 = Frequency_Min1

    If Frequency_Min1 < Frequency_Min Then
        Frequency_Min = Frequency_Min1
    End If

    If Frequency_Max1 > Frequency_Max Then
        Frequency_Max = Frequency_Max1
    End If

Next i

'GRAPH THE DCFROR

Dim Graph1a(11, 11) As Single



With frmGraph.MSChart1
    .ColumnCount = 2
    .RowCount = 10

    For j = 1 To 2
        For i = 1 To 10
            If j = 1 Then
                Graph1a(i, j) = Dcfror_Range_Array(i)
            ElseIf j > 1 Then
                Graph1a(i, j) = Frequency(i)
            End If

        Next i
    Next j






NO_Columns = 0
For k = 1 To 2
    NO_Columns = NO_Columns + 1
    For i = 1 To 10 Step 1
        .Column = NO_Columns
        .Row = i
        If k = 1 Then
            .Data = Graph1a(i, 1)
```

```
        Else
            .Data = Graph1a(i, 2)
        End If

    Next i
Next k

End With
    frmGraph.MSChart1.Plot.UniformAxis = False


'GRAPH THE PROBABILITY DISTRIBUTION FOR POROSITY
'Dim Graph1a(11, 11) As Single



With frmGraph2.MSChart1
    .ColumnCount = 2
    .RowCount = 10

    For j = 1 To 2
        For i = 1 To 10
            If j = 1 Then
                Graph1a(i, j) = Poros_Range(i)
            ElseIf j > 1 Then
                Graph1a(i, j) = Poros_Frequency(i)
            End If

        Next i
    Next j






NO_Columns = 0
For k = 1 To 2
    NO_Columns = NO_Columns + 1
    For i = 1 To 10 Step 1
        .Column = NO_Columns
        .Row = i
        If k = 1 Then
            .Data = Graph1a(i, 1)
            .RowLabel = Format(Val(Graph1a(i, 1)), "#.00")

        Else
            .Data = Graph1a(i, 2)
        End If

    Next i
Next k

End With
    frmGraph2.MSChart1.Plot.UniformAxis = False
```

```
'GRAPH THE PROBABILITY DISTRIBUTION FOR SATURATION
'Dim Graph1a(11, 11) As Single



With frmGraph3.MSChart1
    .ColumnCount = 2
    .RowCount = 10

    For j = 1 To 2
        For i = 1 To 10
            If j = 1 Then
                Graph1a(i, j) = Saturation_RANGE(i)
            ElseIf j > 1 Then
                Graph1a(i, j) = Saturation_Frequency(i)
            End If

        Next i
    Next j





NO_Columns = 0
For k = 1 To 2
    NO_Columns = NO_Columns + 1
    For i = 1 To 10 Step 1
        .Column = NO_Columns
        .Row = i
        If k = 1 Then
            .Data = Graph1a(i, 1)
            .RowLabel = Format(Val(Graph1a(i, 1)), "#.00")
        Else
            .Data = Graph1a(i, 2)
        End If

    Next i
Next k

End With
    frmGraph3.MSChart1.Plot.UniformAxis = False


'GRAPH THE PROBABILITY DISTRIBUTION FOR THICKNESS
'Dim Graph1a(11, 11) As Single



With frmGraph4.MSChart1
    .ColumnCount = 2
    .RowCount = 10
```

```
    For j = 1 To 2
        For i = 1 To 10
            If j = 1 Then
                Graph1a(i, j) = Thick_range(i)


            ElseIf j > 1 Then
                Graph1a(i, j) = Thick_Frequency(i)
            End If

        Next i
    Next j





NO_Columns = 0
For k = 1 To 2
    NO_Columns = NO_Columns + 1
    For i = 1 To 10 Step 1
        .Column = NO_Columns
        .Row = i
        If k = 1 Then
            .Data = Graph1a(i, 1)
            .RowLabel = Format(Val(Graph1a(i, 1)), "0.00")
        Else
            .Data = Graph1a(i, 2)
        End If

    Next i
Next k

End With
    frmGraph4.MSChart1.Plot.UniformAxis = False

With frmGraph5.MSChart1
    .ColumnCount = 2
    .RowCount = 4

    For j = 1 To 2
        For i = 1 To 4
            If j = 1 Then
                Graph1a(i, j) = SCHEDULE_6RANGE(i)


            ElseIf j > 1 Then
                Graph1a(i, j) = SCHEDULE_6FREQUENCY(i)
            End If

        Next i
    Next j
```

```
NO_Columns = 0
For k = 1 To 2
   NO_Columns = NO_Columns + 1
   For i = 1 To 4 Step 1
      .Column = NO_Columns
      .Row = i
      If k = 1 Then
         .Data = Graph1a(i, 1)
         .RowLabel = Format(Val(Graph1a(i, 1)), "0.00")
      Else
         .Data = Graph1a(i, 2)
      End If

   Next i
Next k

End With
   frmGraph5.MSChart1.Plot.UniformAxis = False

Beep



End Sub

Private Sub Command3_Click()
End
End Sub

Private Sub Command4_Click()
Check1.Value = 1

Text1.Text = "6.01"
Text2.Text = "6.65"
Text3.Text = "47.5"
Text4.Text = "52.5"
Text5.Text = "47.5"
Text11.Text = "50"
Text6.Text = "52.5"
Text7.Text = "80"
Text8.Text = "0.004"
Text12.Text = "2"
Text13.Text = "5000"
Text14.Text = ".25"
Text15.Text = "87.5"
Text16.Text = "5"
Text10.Text = "25000"
Text17.Text = "100"
Text18.Text = "100000"
Text19.Text = "47.5"
Text20.Text = "52.5"
```

```
End Sub

Private Sub Command5_Click()
Check1.Value = 0


Text1.Text = "11.88"
Text2.Text = "13.125"
Text3.Text = "53.2"
Text4.Text = "58.8"
Text5.Text = "50.85"
Text11.Text = "48.43"
Text6.Text = "46.01"
Text7.Text = "80"
Text8.Text = "0.004"
Text12.Text = "2"
Text13.Text = "5600"
Text14.Text = ".25"
Text15.Text = "87.5"
Text16.Text = "5"
Text10.Text = "25000"
Text17.Text = "100"

End Sub

Private Sub Command6_Click()
frmGraph.Show
frmRanges.Hide

End Sub
Private Sub Command7_Click()
frmRanges.Hide
frmGraph2.Show

End Sub

Private Sub Command8_Click()
frmRanges.Hide
frmGraph3.Show
End Sub

Private Sub Command9_Click()
frmGraph4.Show
frmRanges.Hide
End Sub
```