Interference Testing Applied to Proved Undeveloped Well Locations

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Summary

- A reservoir is a creature of capillary forces.
- Capillary forces must be broken down one pore throat at a time.
- This process is performed by a wave that restricts the areas and volumes being drained as surely as sealing boundaries until it reaches the sealing boundaries.
- The wave propagates as a function of hydraulic diffusivity and the time of initiation. It is predictable.
- The passage of this wave is distinct and easily recognizable but it does not look like the picture in the textbook.
- The capillary wave can be used to make money in spite of the SEC but could best be used to reduce uncertainty in reservoir continuity thereby increasing the accuracy of reserve reports.

Introduction

Reservoir continuity is one of the most critical aspects of property evaluation that Evaluation Engineers encounter. Interference testing is a simple procedure to establish reservoir continuity. Traditionally this has been underutilized because the application of the technique and test results have been inconclusive. The difficulty in the application of interference testing has to do with knowing ***what to look for*** in pressure data and ***when to look for it.***

Capillary Forces

There are physical reasons that account for historical frustrations with the method. First, the evaluator is seeking information about the propagation of pressure depletion in a reservoir that is composed of billions and trillions of pores that represent physical containers of the fluids that are produced. These fluids are locked in place by formidable electronic forces that manifest themselves as true physical barriers to fluid movement. These are generally refered to as capillary forces. This is the same mechanism that produces wetting of surfaces by water and oil or produces the strength of thin films such as soap bubbles. These are associated with phase changes because the affects of electronic forces at the interface surfaces can be seen. ***Whether their influences can be seen or not, these forces exist.***

The act of initiating production is to apply enough pressure differential to serially break down the structural barrier imposed at each pore throat. The flow of oil or gas is produced by breaking the electronic barrier at each pore throat and maintaining the opening with continuous flow from pore to pore. The process is one of serial opening followed by production from pore to pore until reaching the wellbore. At each pore throat, the entry pressure must be broken and enough depletion of that pore passed out of the pore to open the next pore throat. This is a slow and tortuous process that requires substantial time.

Cone of Influence

The cone of influence is a pressure depletion region around each well that is surrounded by an advancing wall of static capillary forces. As the pores open serially to allow flow to the wellbore, the volume of the cone of influence slowly begins to expand the volume of the reservoir being drained. Think of these as small magnetic doors to each pore. This is manifested to a pressure gauge as the passage of a step drop in capillary pressure. It will appear in time sequence to a remote pressure gauge as a step drop in pressure followed a rapid decay of pressure. **Figure 1** is such a pressure step viewed by a gauge in an offset well to the only producing well in a new reservoir that was at initial pressure. Note that the pressure is stable at initial pressure before the wave arrival. The bounding capillary shockwave is represented by the apparent gap in the data as pointed out by the red arrow in **Figure 1.**

It should be noted that had the recording of pressure been stopped at 24 hours, the test would have indicated no communication. This would have been the case if the system had been modeled by a traditional potential flow diffusion simulator. Most interference tests are terminated before the capillary interference wave has had time to reach the static offset well. This capillary wave represents the pressure boundary of the cone of influence. The blue arrows point to higher order capillary waves that were produced earlier by the primary wave reaching boundaries. In other words, this is the transient history of the offset producing well from a remote location. For the purposes of this technical note, focus on the bounding wave alone.

Figure 2 shows a simple image of the radial flow system with an element that represents the breakdown of capillary entry pressure and the bundle of capillary elements that connect it to the wellbore. Think of the element as **PacMan®** literally eating his way through the formation. This is his first nephew **PoreBoy™**. **PoreBoy™** exists between the initial capillary pressure and the cone of influence. He must reduce the pressure at his front face sufficiently to rupture the static pore entry shear stresses, then pass enough fluid through his body length of ΔX before he can advance to the next collection of pore throats.

At this juncture, to make this a technical note one must produce a derivation. **Figure 3** shows an element on which an energy balance needs to be performed and related to the stream of capillaries reaching back to the wellbore of the producing well.

The model involves balancing Darcy flow through the element with the pressure depletion of the element then performing an energy balance between the trailing capillary stream bundle and the element to calculate the velocity of the element.

- **Constant Pressure on Leading Edge Face of Element**
- **Darcy Flow From Element**
- **Energy Balance Between Shockwave Element, and its Capillary Stream Tube Volume**
- **Addition of Expanding Fluid Mass and Its Elastic Energy to the Cone of Influence**

Fluid Growth of Cone

The next step is to create an equation and work to eliminate the $\Delta P/\Delta X$ term from the energy balance and rearrange to calculate the speed of the element as U_{wf}. Wave velocity is reduced with time, it is not constant. The location of the element, or simply stated, the length of the capillary trail from the well, is what is of interest. The last step is to integrate the velocity over time to achieve the effective length of the trail of capillaries. These equations are shown in **Table 1.**

HOLD IT. ATTENTION! Note that the equation in Table 1 is the classic radius of investigation equation or drainage radius. The radius of investigation is the location of a diffusion wave that is passing through the reservoir and acting as a means for connecting the reservoir pore by pore to the well. This equation also indicates how long one must wait to see interference. This wave moves at a very slow pace. If one does not wait long enough, interference will not be detected in an offset well. Note also that the distance is solely a function of hydraulic diffusivity and time from initiation. Flowing a well at a higher rate will not speed up the process. The capillary shockwave is the physical phenomenon that exists at the radius of investigation. One cannot detect any boundaries that exist beyond the radius of investigation.

In few cases is there an undisturbed reservoir to begin the test. What does one look for?

Note the changing scales until the tell-tale peak is exposed. During the buildup, fluid is flowing toward the well that is building up. Then there is a stable period where static capillary forces re-establish. Then the interfering well cone of influence begins to pass through the observation well breaking the static pressure, and initiating flow in the opposite direction. These are completely separate events! This is the signature of interference. Note that it takes a quality pressure gauge to see all of the detail. The difference between the stair-steps of points is the resolution of the pressure gauge. This was a dual quartz gauge capable of 0.01 psi resolution. The preceding example is a Permian basin well with an offset well 1440 feet away. The following example was off the Coast of Africa and proved interference from a well 8500 feet away. The third example represents two other wells sequentially interfering with the well being tested.

All of the well tests in **Figures 4 and 5** received bearing the same question **"What in the #%@* is this?"** When two wells are interfering and one is shut in, the producing well's cone of influence begins approximately half way in between. The time required for interference to appear in the shut-in well will be approximately 3/4$^{\text{ths}}$ of the wave transit time because of the "head start." This rule applies to a homogeneous reservoir, but changes in thickness and permeability can be handled as well.

It should be noted that if the first test is questioned, one could do this process again and again and expect to see the same detail in the results.

Two Well Testing

If two wells begin producing at the same time, the shockwave fronts will meet at the same time. This method requires only 1/4$^{\text{th}}$ the time. That is an advantage if you have control of both wells and do not have to see the wave passage. The response in both wells would be a doubling of natural log pressure derivative at the same point in time. It is my opinion that the wave passage is a more compelling case when presenting evidence to outside parties.

The beauty of interference testing is that you can calculate the permeability and hence hydraulic diffusivity at each well during the early part of the flow, then measure the effective or mean hydraulic diffusivity by the time of the wave passage from the well of generation to the well of observation. Rate changes are not going to affect the arrival time but will be seen in the pressure profile behind the wave. ***The wave moves as a function of the properties at the wave front.*** All that this testing requires is a recording pressure gauge with an accurate clock. Please note that the hydraulic diffusivity is the coefficient of the diffusivity equation used in all reservoir modeling. This is a critical piece of information that can be developed directly from the test with a simple calculation.

The method of execution can go something like this: Gauges are placed in each of two suspected interfering wells. Each well is opened on a fixed choke to create a short drawdown and buildup. Next one well is turned on. The other well is observed for arrival of the capillary shockwave front. While waiting, the short tests are analyzed for permeability and the hydraulic diffusivity for each well is computed. The average of these values is used to estimate the transit time of the wave. If the wave arrives on schedule or within a reasonable tolerance of say + or – 10%, it is reasonable to assume that the wave passed through the reservoir unabated. Hence there appears to be a clear path between wells. At issue is how many locations are located on that clear path.

Drill and perform interference tests with two more wells. How many PUD locations are added using the same logic?

It would appear that these PUD locations have many other undeveloped locations completely surrounded. Each of the interference tests will produce a transient from the perspective of each of the wells. That information can be turned into a single well transient analysis of the reservoir limits from four points of perspective, but stay with the current case.

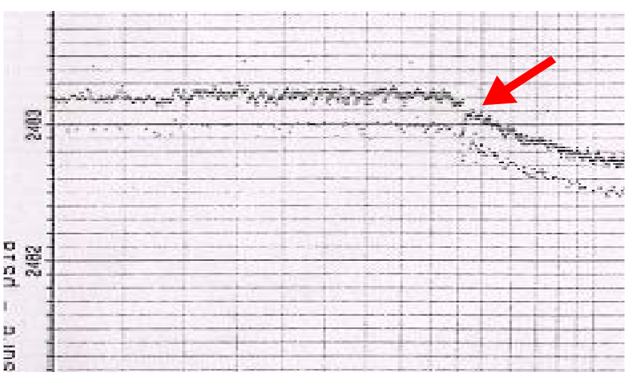
Could one make a more compelling case for proving undeveloped locations?

When there is a predictable and singularly observable wave why not use it?

Future Steps

It would appear that a sound approach to get this accepted by the SEC would be to present a case to them that involves an actual test with ample prior warning as to the intentions of the operator and the physics of the technique to be used. Develop a case for interference PUDs by testing; then prove it by drilling an interior location. This could reduce the number of drilled holes to produce PUD locations in the future. **Acceptance generally derives from use. Use involves the willing participation of all parties.** Acceptance is also based upon consistently making money with the technique by avoiding unnecessary or dry holes.

This is a necessary first step in the rehabilitation of interference testing as a means for evaluating reservoirs. The next and intermediate step is recognition of the clear radius method for dealing with water down-dip. Only then can the SEC be approached on the more sophisticated method of single well energy mapping to confirm seismic images.



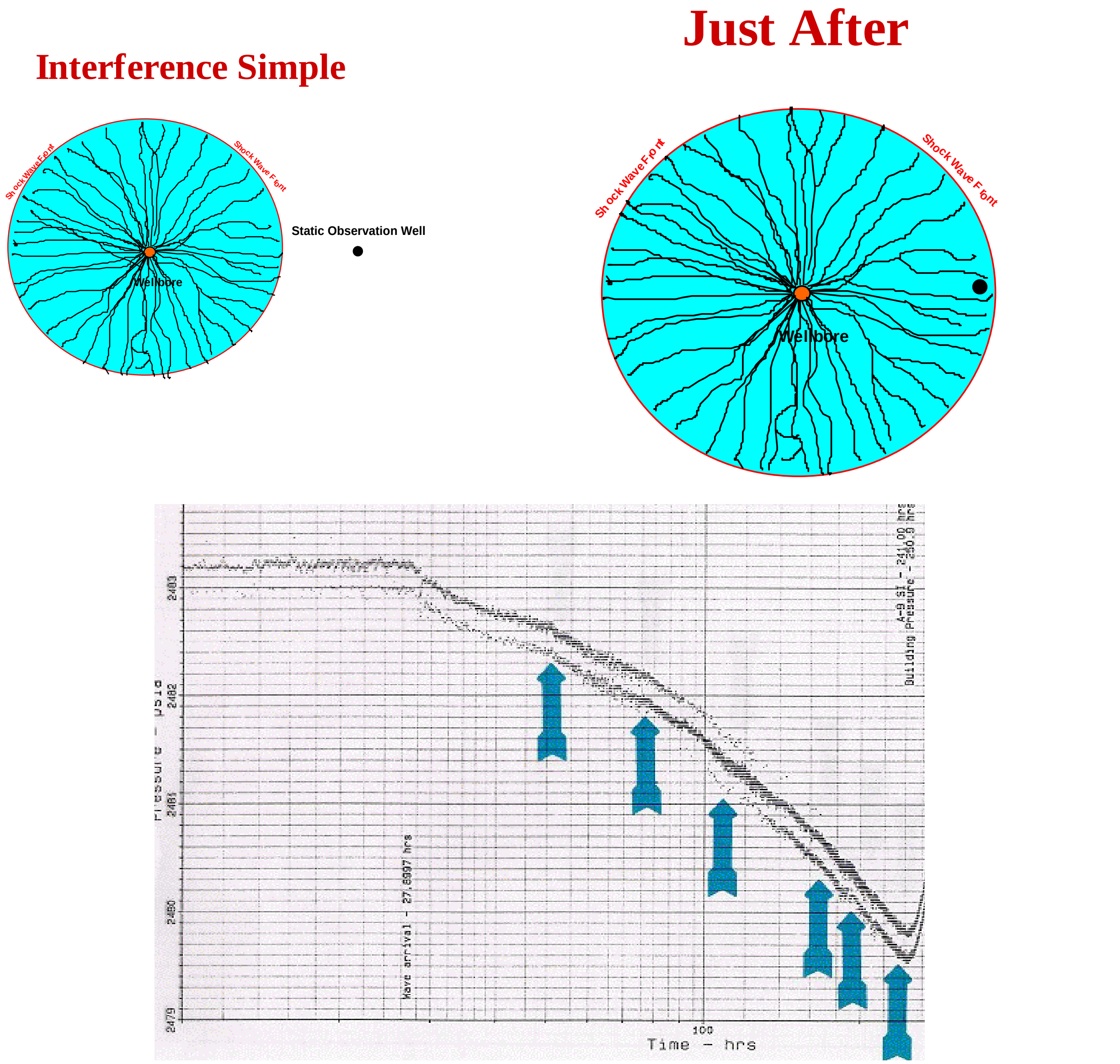


Fig. 1 - Capillary Shockwave Passing the Static Observation Well Initiated by Opening a Well 2000 Feet Away 27 Hours Earlier.

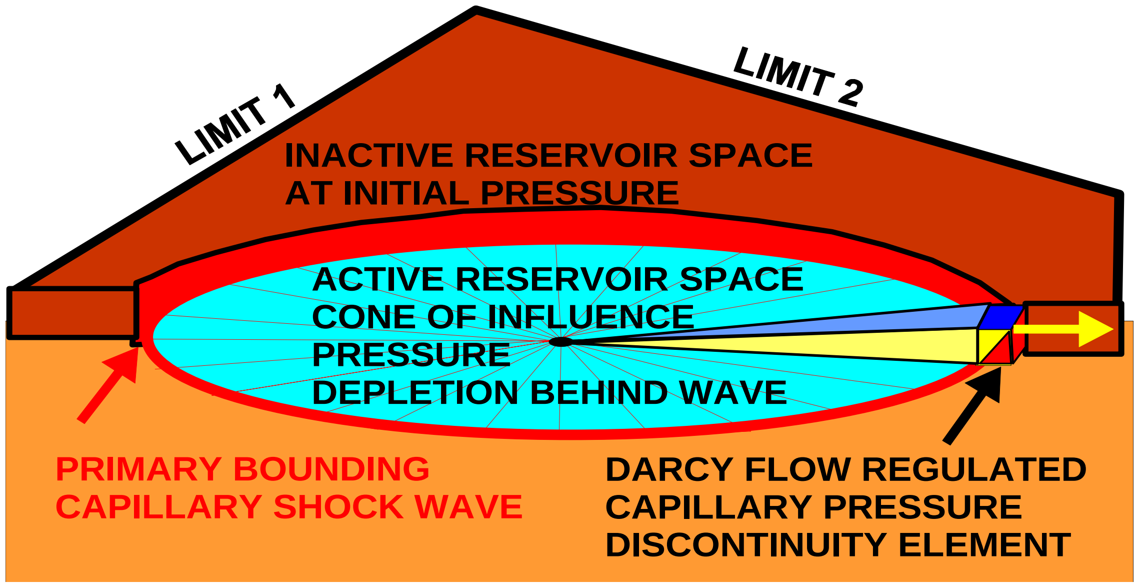


Fig. 2 - The Radial Capillary Structure of the Cone of Influence and the Bounding Capillary Shockwave Element.

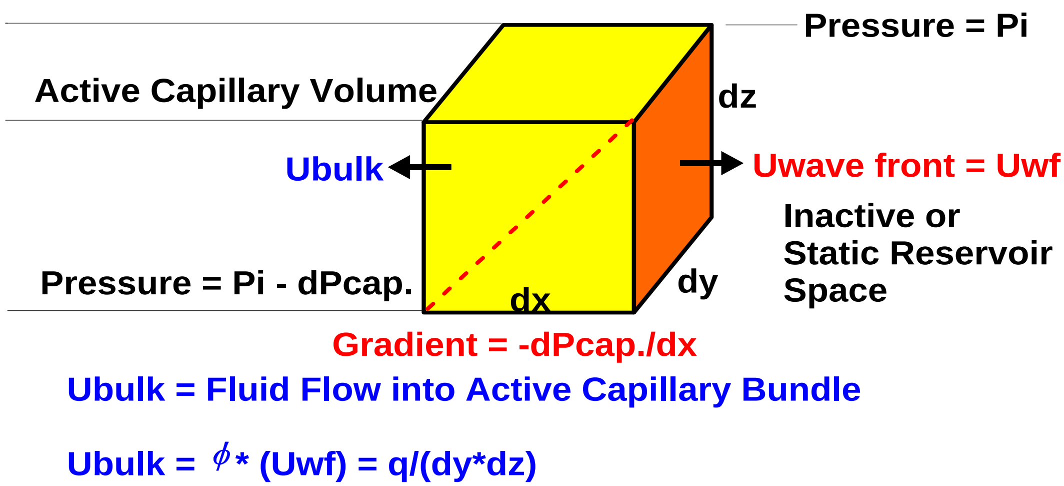


Fig. 3 - The Bounding Capillary Shockwave Element.

$$q \,/\, \text{Tube Area} = U_{Bulk} = \phi * U_{Wave\ Front}$$

Fluid Continuity… Darcy's Law………Energy Equation

$$\phi * Uwf = -(k/\mu) * dPc/dx = -(k/\mu) * (-1/(t * Ct * Uwf)$$

$$Uwf = \sqrt{k/(\phi * \mu * t * Ct)} = \sqrt{\eta / t}$$

$$L = \int_0^t Uwf\, dt = \int_0^t \sqrt{\eta / t}\, dt = 2\sqrt{\eta t}$$

Table 1 - Equating Fluid Growth of Cone in Terms of Bulk Fluid Velocity.

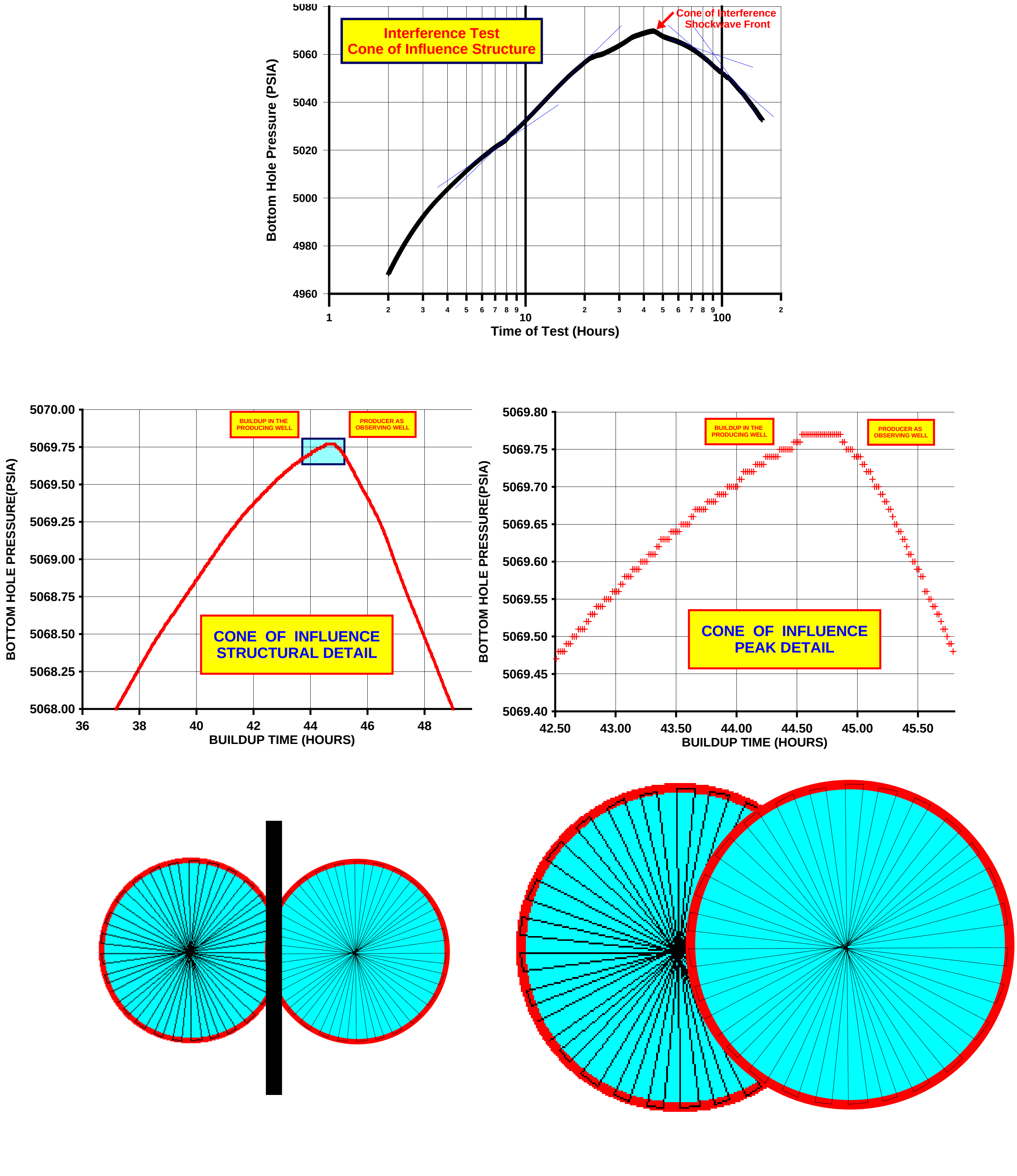


Fig. 4 - Sequential Zoom and Magnification of the Data at the Peak

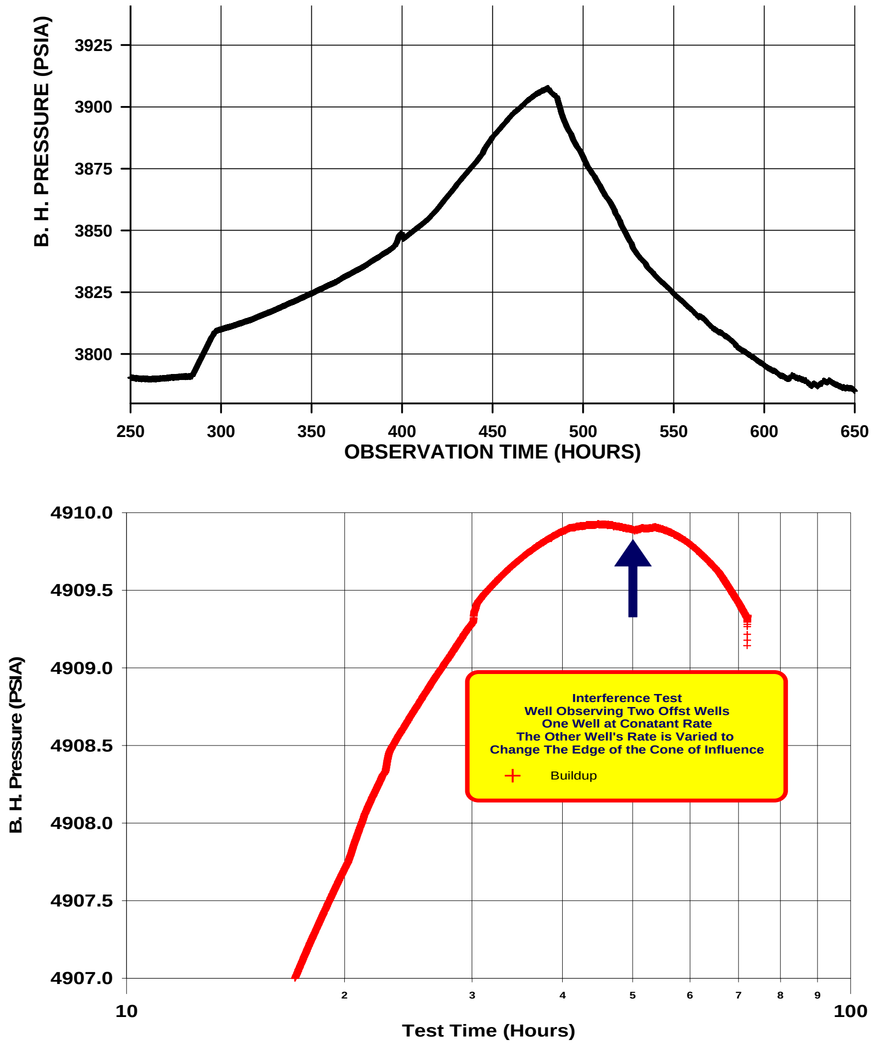


Fig. 5 - Second Buildup with Interference Above and a Buildup with Two Interfering Wells in Sequence

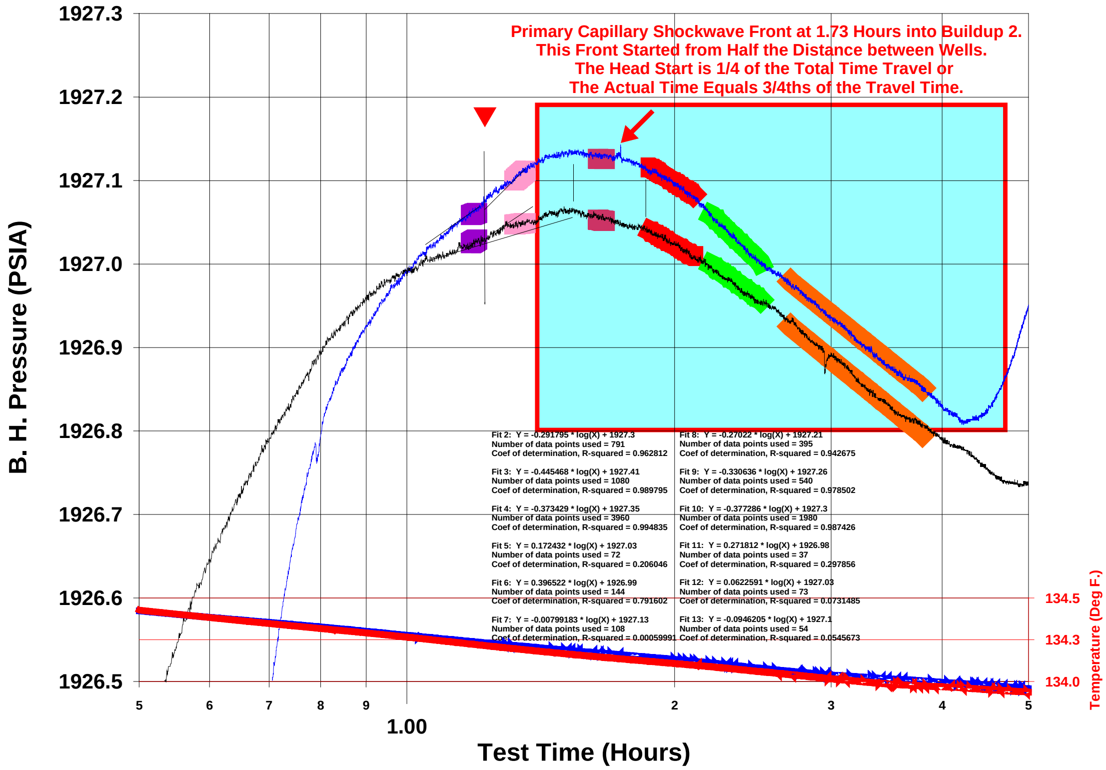


Fig. 6 - Repeated Tests Bear the Same Fingerprints to a Surprising Level of Detail.

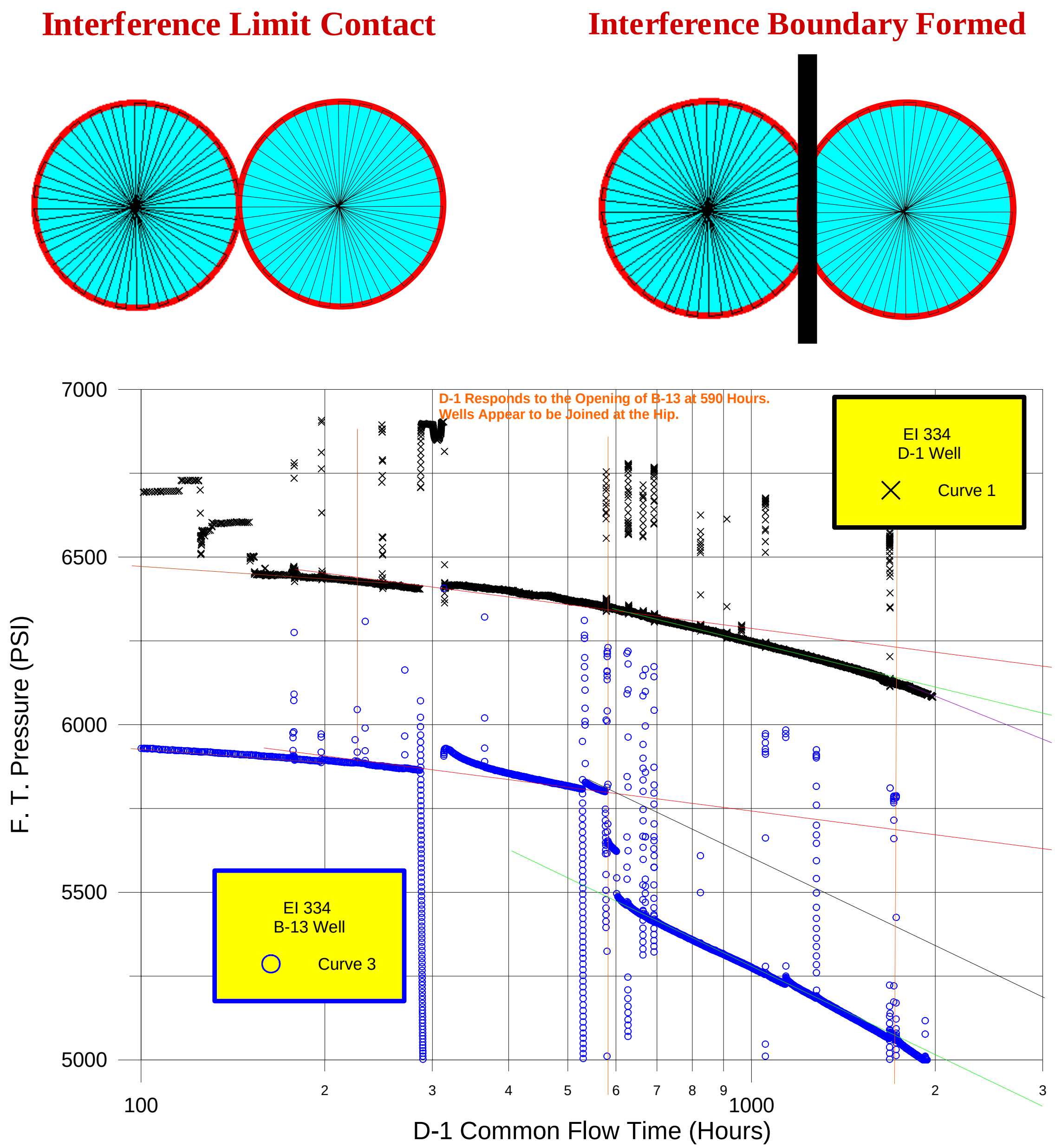


Fig. 7 - Two Well Test Configuration Requires Two Gauges

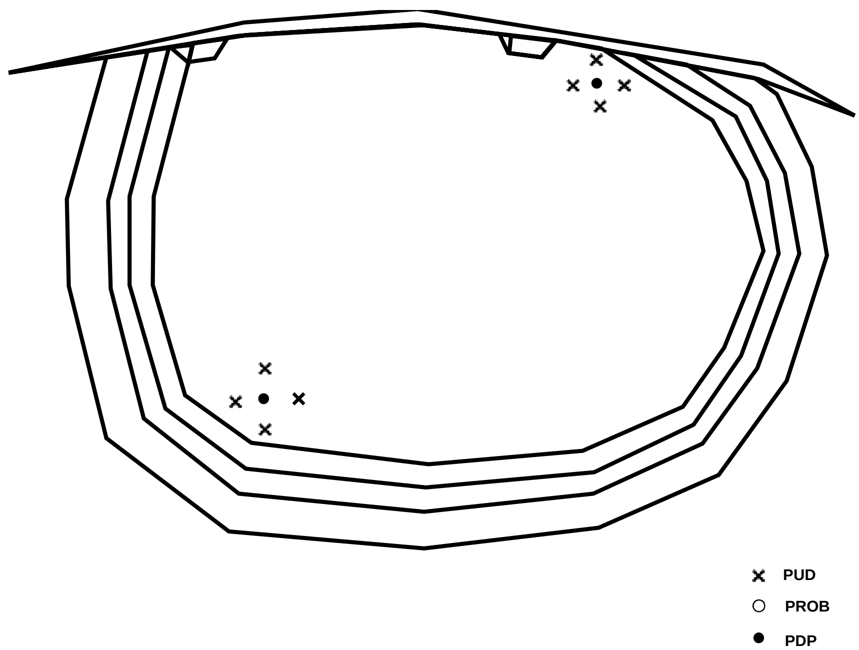


Fig. 8 - SEC PUD Locations Newly Discovered Reservoir Two Delineation Wells

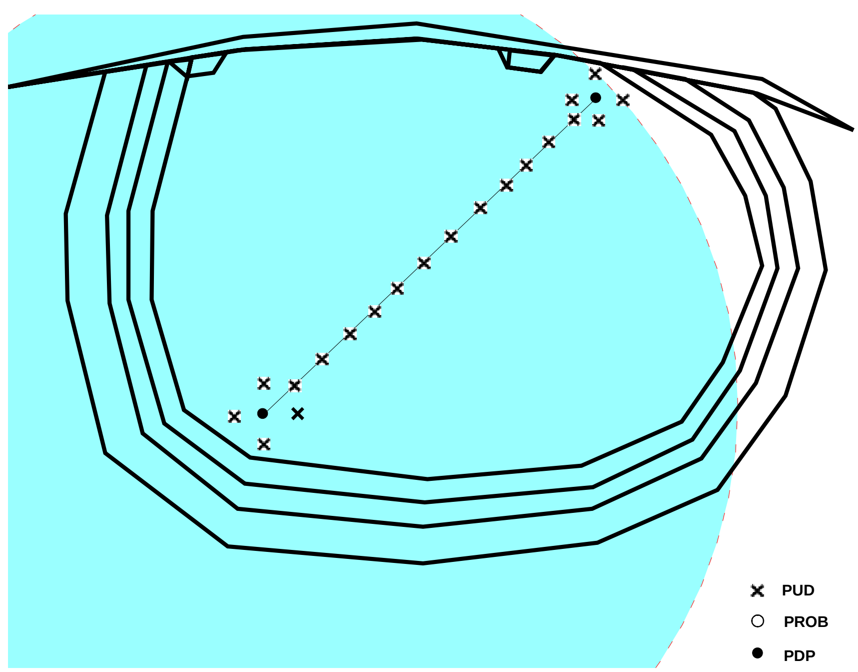


Fig. 9 - Proposed PUD Locations Based Upon Direct Passage of Capillary Shockwave Between Wells.

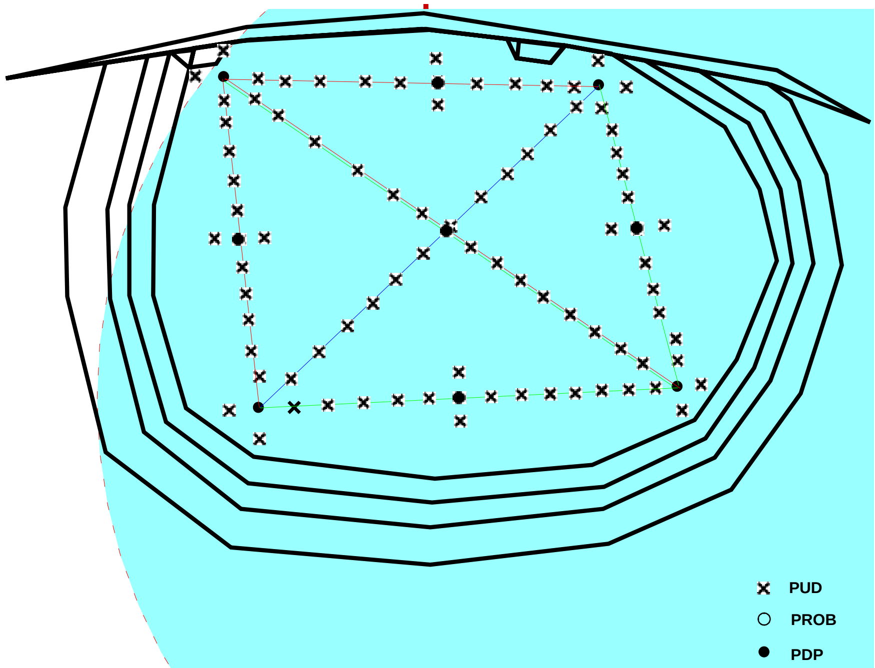


Fig. 10 - Proposed PUD Locations Based Upon Direct Passage of Capillary Shockwave Passed From Two More Delineation Wells.