Dewatering 101

Contents

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I. Dewatering Chronology

Historical Description

Dewatering is routinely performed to produce hydrocarbons in conventional fields. It is simply the practice of producing water along with oil and gas as long as the economics of disposing of the water is favorable. Specifically, if disposing of the water costs less than the revenues produced from operating the well, you continue to operate and produce the well. When the economic relationship “flips,” the well is simply “shut in” and abandoned.

Transition (Chronological) Description

However, since the 1990’s, dewatering has taken on a dramatic new role in the production of oil and natural gas. Operators, especially in Oklahoma, began a process of producing bypassed oil and gas from the “transition zone.” Transition zones are areas that typically surround conventional oil and gas fields where the petroleum-bearing rock contains an increased concentration of water and a proportionally decreased concentration of oil and gas. In addition, operators found that soft carbonate formations such as limestones and dolomites that have very good porosity and permeability (such as the Hunton limestone), exhibit an extremely good response to dewatering.

Current Description

Through these observations, the “dewatering concept” began to evolve. Operators found that a tremendous amount of oil and gas was trapped within the pores of these porous formations. The oil and gas was trapped by pressure exerted on those pores by the formation water. They found that by removing the water from the structure (dewatering), the source of the pressure trapping the hydrocarbons in the pore spaces were removed. The decreased pressure caused the hydrocarbons to move out of the pores and then flow through the well bore. This concept is now used throughout the Mid-Continent to produce large quantities of oil and gas through dewatering.

II. Dewatering Geology

Vertical Problems

Early dewatering was done with vertical wells that were completed with standard fracing methods. However, through the development of many fields, it became apparent that formations like the Hunton were not uniform or continuous. Within the formation, pressure, heat, faulting, and other geological processes had in effect “compartmentalized” the formation. Compartmentalization can be understood by visualizing a table with a number of glasses of water on it; some touching, some not, some large, some small, some wide, some narrow, some full, some with some water, and some with none at all (the compartments). Put a sheet of paper (the Earth’s surface) over the whole assemblage and then start poking holes down through the paper with a pencil (the drill bit). Sometimes the pencil will hit water (a good well); sometimes it will hit the table (dry hole). Sometimes it will hit the edge of a glass (fault) and get kicked into the glass (compartment) and hit water (another good well, although lucky!). Sometimes it will hit the rim and get kicked out to the side of the glass (another dry hole). As this illustrates, a field could be drilled with a lot of wells, but there was always a large element of luck when drilling these compartmentalized formations.

Horizontal Solutions

As the operators began to understand the compartmentalization of their target formations, they began to explore the possibility of beginning with a vertical well and then at the formation, drilling horizontally through it (Fig. 1). Once the operators developed this technique of drilling horizontal “laterals” through the formations, the results were fantastic. With an old-style vertical well, when drilling to a target formation that was 75 feet thick, the most exposure to the formation through the well bore was 75 feet (the thickness of the formation). But with the onset of horizontal drilling, one borehole could be extended laterally through the formation resulting in exposure to the reservoir for thousands of feet through the formation. The problem experienced by compartmentalization of the formation was now erased; as these laterals were drilled through one compartment after another, after another in the same borehole.

Horizontal Problems

However, with horizontal wells came a new problem - the fault. Faults are breaks on the earth’s crust where blocks of rocks move against each other. The faults that tend to occur in these environments are “dip-slip” or “normal” faults (Fig. 1). Along a dip-slip fault the rock is broken. On one side of the fault the rock moves up, while on the other side of the fault the rock moves down. Sometimes the rock moves tens of feet, sometimes the rock moves hundreds of feet. Without knowing where the faults exist, the operators could begin a lateral well in the target formation and then suddenly find themselves in a different formation with no oil or gas because they had drilled across a fault and, on the other side of that fault, the target formation had been up-thrown (moved up). If the fault was penetrated 5 feet after entering the target formation, then one has, in essence, drilled something akin to a dry hole, as they would only be able to produce from a very small section of the target formation.

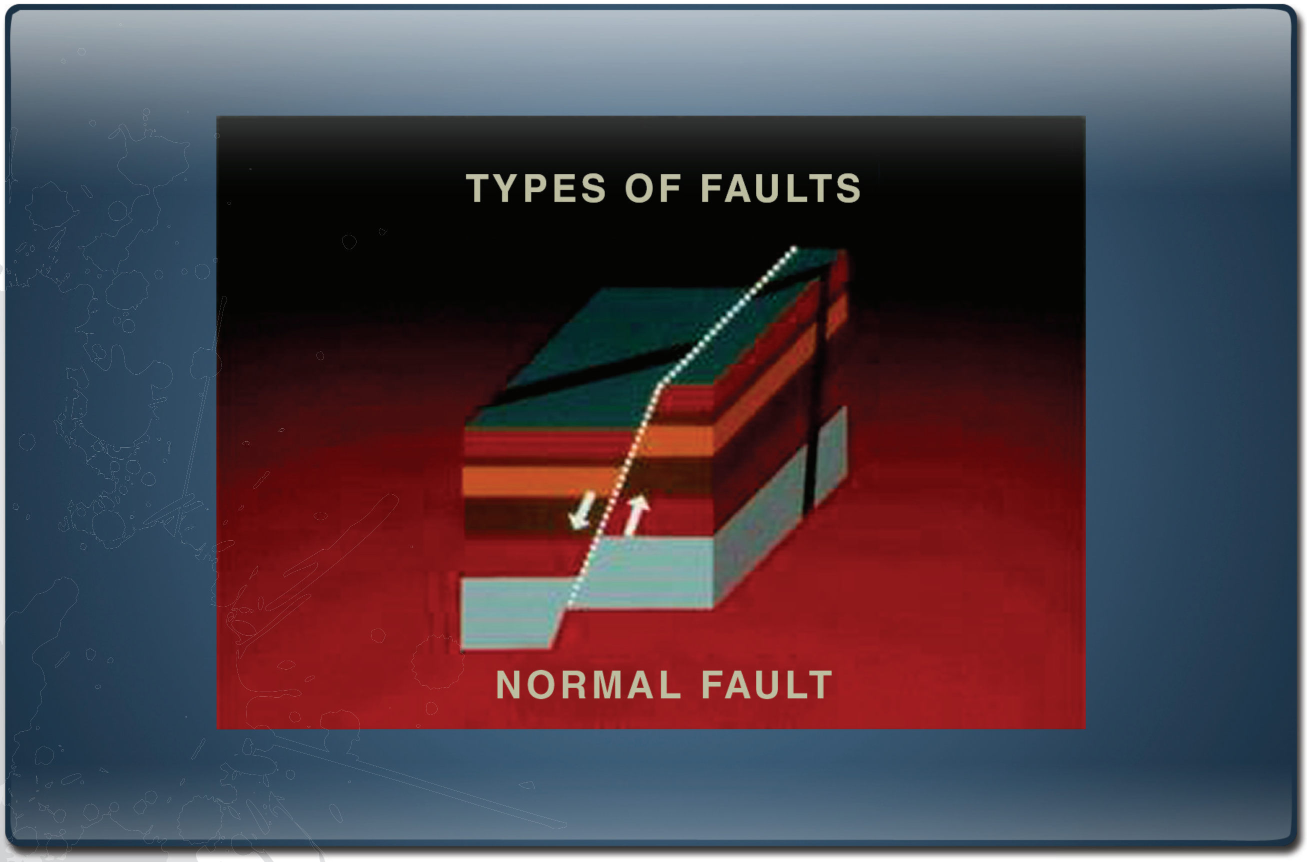

Fig. 1

Science Solutions

Historically, most operators relied on what limited data was available from previously drilled wells in the area (rock cores, well logs, etc.) to "guess" where these faults are located. Even with considerable "well control" (data from previously drilled wells) in the area, these mostly vertical faults were very difficult to accurately map. Tools widely used in drilling conventional wells were seldom, if ever, applied to the transitional/dewatering projects. A prime example of "unused, yet valuable" technology is the use of 2-D seismic surveys. In brief, a 2-D seismic survey is a process whereby an acoustic source is used to generate an impulse. The impulse travels down through the ground and then parts of that impulse are reflected back to the surface, or refracted downward through the subsurface, and then reflected back when they encounter another structure from which the waves will be reflected. The reflections are recorded on a seismograph and then decoded to form a picture of the subsurface. This is done continuously across an area of any given size. The 2-D seismic presents an excellent map of the subsurface and is very accurate at showing precisely where faults are located. In addition, the 2-D seismic can show water tables, clay lenses, confining layers, and other subsurface features that might act as oil or gas "traps" that would otherwise go undetected.

III. Dewatering Plays

Conventional Fields

A "conventional field" begins with the drilling of a single producing well. Most of the oil and gas fields in the U.S. were developed decades ago before 3-dimensional (3-D) or even 2-D seismic (images of the subsurface created using various energy waves) were used to "map" areas of interest. As stated above, mapping was done by geologists using data collected from the well or a group of wells drilled in the area. The geologists could tell from the well data the depth, thickness, and other essential data of the producing formation. Obviously, with data from only one well, or even a few, one cannot make very accurate estimates about the size or geographic boundaries of the field, the consistency of the reservoir rock, the thickness of the formation, or other quantifications of the field. Given success in a well, drillers would drill another well at some nearby location with a higher elevation (using the rationale that high points on the surface meant high points in the formation, which is usually the best way to avoid water). As they drilled additional wells and collected data, the geologists could then "map" the features of the formation. Of course, at some point, they would drill a well that produced a lot of water, and when most of the fields were drilled 20, 30, 40 or more years ago, that usually meant they would plug and abandon the well. Years ago, there was no market for natural gas and oil prices were very low, so the expense of disposing of water made it uneconomical to continue to produce the well. If you drilled a well and found water, you abandoned the well and moved on.

Transitional Fields

Surrounding the conventionally produced field is a transition zone (Fig. 2). This transition zone might be three or four times the areal extent of the primary field (some have been 20 times as large as the primary field) and contain vast amounts of unproduced oil and gas. Beyond the transition zone, the hydrocarbon-containing formation stops or contains only water. One example is the Mount Vernon Field in Lincoln County in central Oklahoma (Fig. 3). From 1979 to 1997, the field was produced conventionally and yielded approximately 158,000 barrels of oil and 200 MMcf (million cubic feet) of gas. From 1979 to 2001, "dewatering" was implemented in the transition zone. The field then produced another 1.26 million barrels of oil and 18.5 Tcf (trillion cubic feet) of gas (with nearly 1.8 million barrels of natural gas liquids) (Fig. 4). Conventional production was only 10% of the total production of both oil and natural gas from this field. Without dewatering, the remaining 90% would have been left behind.

Dewatering Field Development

Until recently, virtually every operator managed a dewatering project the same way. Operators would drill a saltwater disposal well, drill some producing wells until the water was too much for the saltwater well to handle the water, drill another disposal well and repeat. By connecting all of the wells together with a pipeline infrastructure, you could move water from the producing wells to the disposal wells (Fig. 5). Operators laid out their plan so that they could drill a well or two in every section in which they had leases and then further develop the field by drilling as many more wells as the formation and leases could sustain. It has worked. While the results from operators has varied due to reservoir differences, for the most part, if an operator was willing to produce water long enough, the operator would eventually produce oil and gas in economic quantities.

IV. Waveland Dewatering

Today, in conjunction with our operating and investing partners in new dewatering plays, Waveland is applying considerably more science to the projects. Experts from all disciplines are involved in the projects at every stage, including industry veterans who have experience in dewatering the Hunton, geologists, drilling engineers, petrophysicists, and drilling contractors. Everyone on the team has been involved in one dewatering project or another and brings their collective expertise to the table. For example, in our Sneaky Pete Project, which is operated by Pathfinder Exploration in Norman, Oklahoma, in addition to its highly experienced internal staff, a collection of unique technologies and resources are being applied. A very special component unique to this project is the active involvement of individuals from the Sarkey Energy Center at the University of Oklahoma. The university's energy department conducts cutting-edge research for major E&P companies such as Devon Energy and BP/Amoco and through the relationships established by Pathfinder's principals, these resources are being applied to the Sneaky Pete Project.

The Geosciences Coordinator for Pathfinder is Dr. James Forgotson. In addition to his teaching responsibilities at the university, Dr. Forgotson was a past director of the School of Geology and Geophysics and currently holds the Kerr-McGee Chair in geology. The university's Mewbourne College of Earth and Energy is involved in the petrophysical analysis of formations, providing insights into the behavior of rock under pressures, which allows for new design capabilities in fracture simulation of the reservoir. The same level of expertise applied to studying the samples from Devon or BP/Amoco is now being applied to wells drilled in our projects. This type of high-level technical resource is rarely available outside the realm of major oil companies' research departments.

Tools widely used in drilling conventional wells are seldom, if ever, applied to the transitional zone/dewatering projects. A prime example of "unused yet valuable" technology is the use of 2-D seismic surveys discussed above. In the Pathfinder project, a 2-D line is shot as close to the path of each lateral as possible. This shows the precise location of almost every fault (Fig. 6). Drilling a well with a 3,000-foot lateral can cost over $2 million and crossing a fault can render the wellbore essentially useless. Contrast with the cost of shooting a mile or so of seismic (you need overlap at both ends) at a cost of perhaps $30,000, 50 or more laterals could be shot for the cost of one bad well.

Another consideration in shooting seismic in central Oklahoma is the possibility of discerning the existence of very small structures that have been overlooked in the "pincushion" approach to conventional drilling in the past. As an example, a small Wilcox formation "bump" might only cover 20 acres or less, and therefore could easily have been missed in a typical exploration program. Drilling a

Example: Mt. Vernon Field Dewatering Project

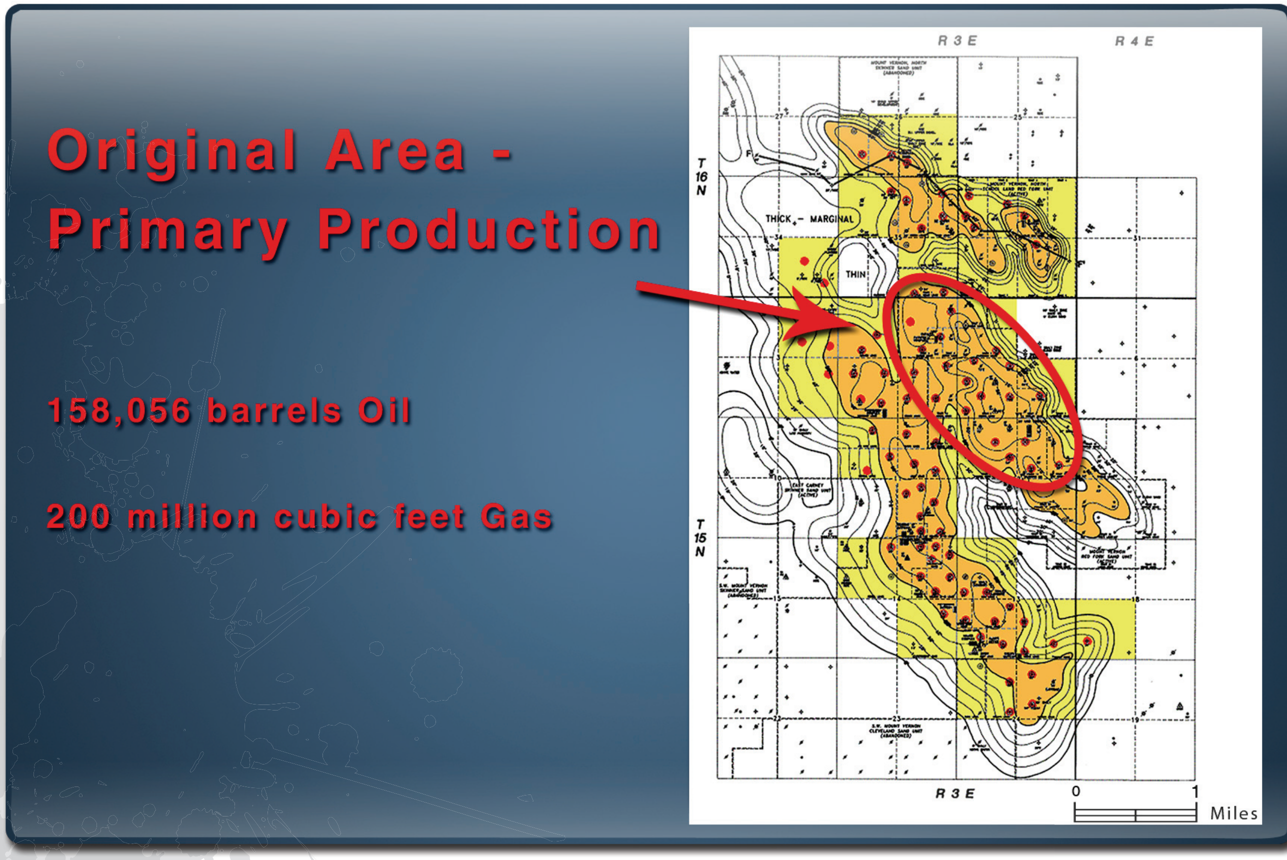

Fig. 2

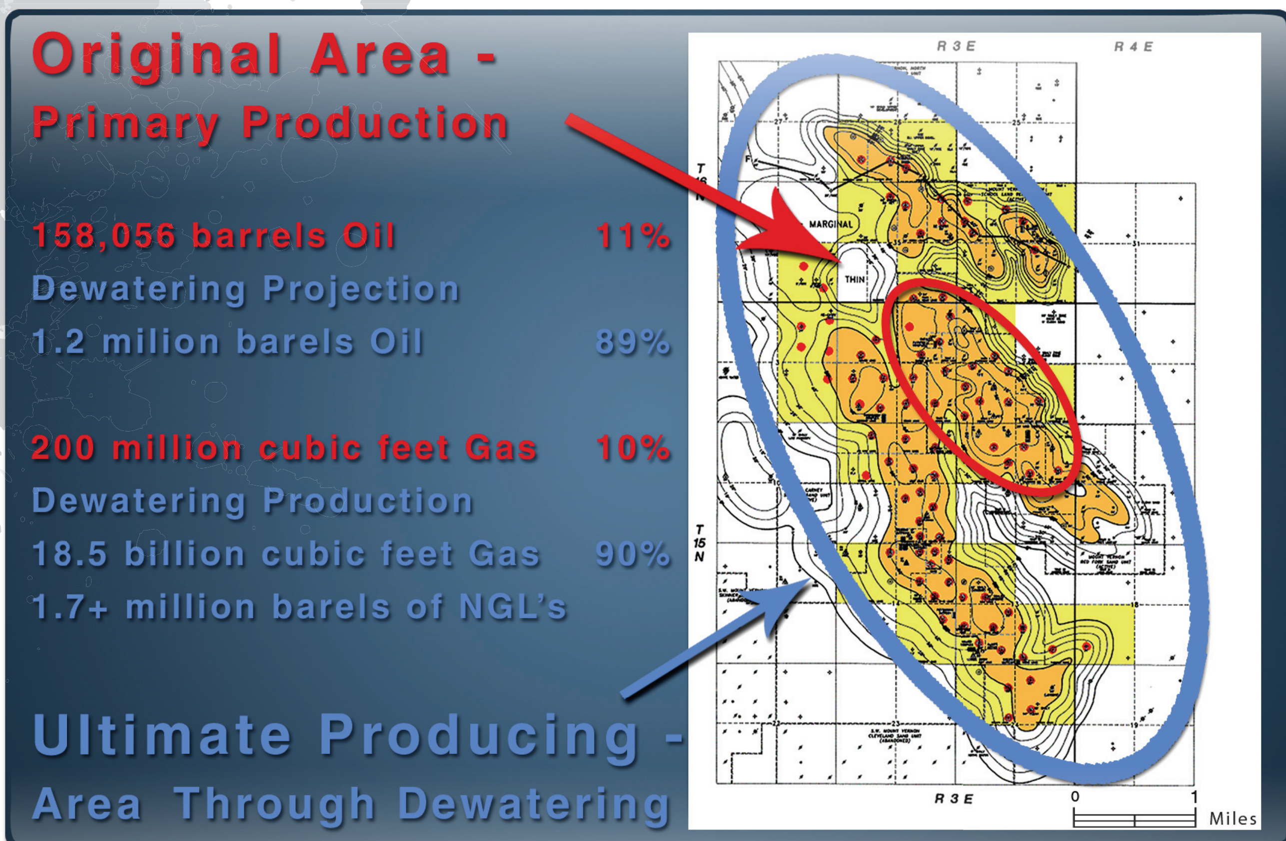

Fig. 3

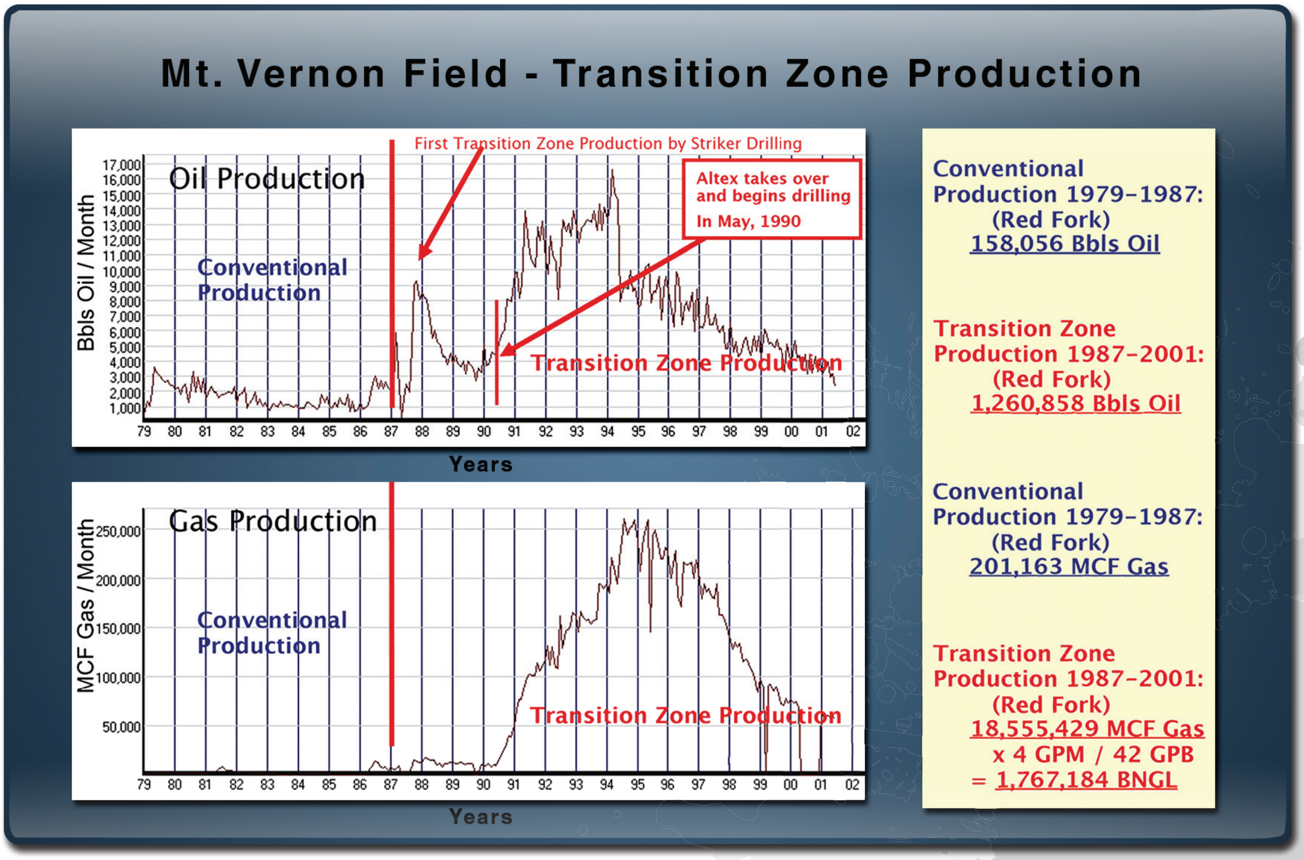

Fig. 4

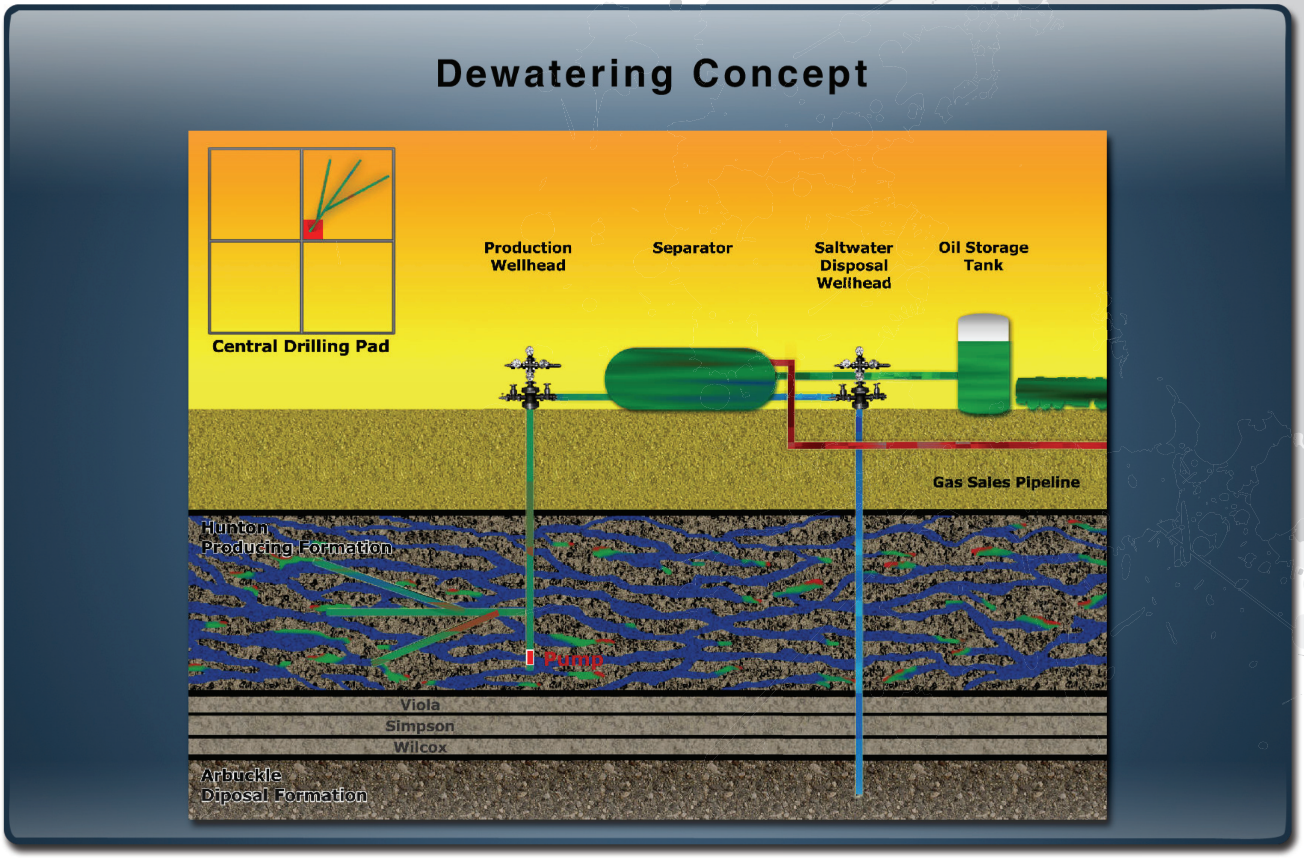

Fig. 5

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vertical well to that overlooked structure could result in the production of hundreds of thousands of barrels of oil. There are many of these undiscovered small bumps, and seismic can be of great value in recognizing them.

Waveland has been directly involved in drilling horizontal Hunton wells since 2002, and our other industry partners have been drilling for much longer. To our and our partners' knowledge, the use of an FMI (formation micro-imaging) log had never been used in these wells (Fig. 7). This tool provides an electrical borehole image generated by micro-resistivity measurements and is an essential source of data to help one understand the reservoir structure, sedimentary features, and reservoir fractures. Fractures are a KEY in stimulation and production techniques. Employing this technology on the wells in our projects has given the geological and geophysical team an extraordinary amount of data. State-of-the-art MWD (measurement while drilling) equipment provides real-time measurements, allowing the operator to make the necessary corrections in real time to maintain the wellbore in an optimum orientation, as well as assisting in the continuous monitoring of hydrocarbon shows.

Technology, experience, and opportunity are hallmarks to Waveland's Mid-Continent dewatering success. Dewatering continues to open doors for efficient, profitable production of hydrocarbons, even during periods of low commodity prices. The type of Mid-Continent dewatering currently being deployed by Waveland and our industry partners places us in a unique niche, remaining ahead of industry and creating outstanding opportunities for our investors.

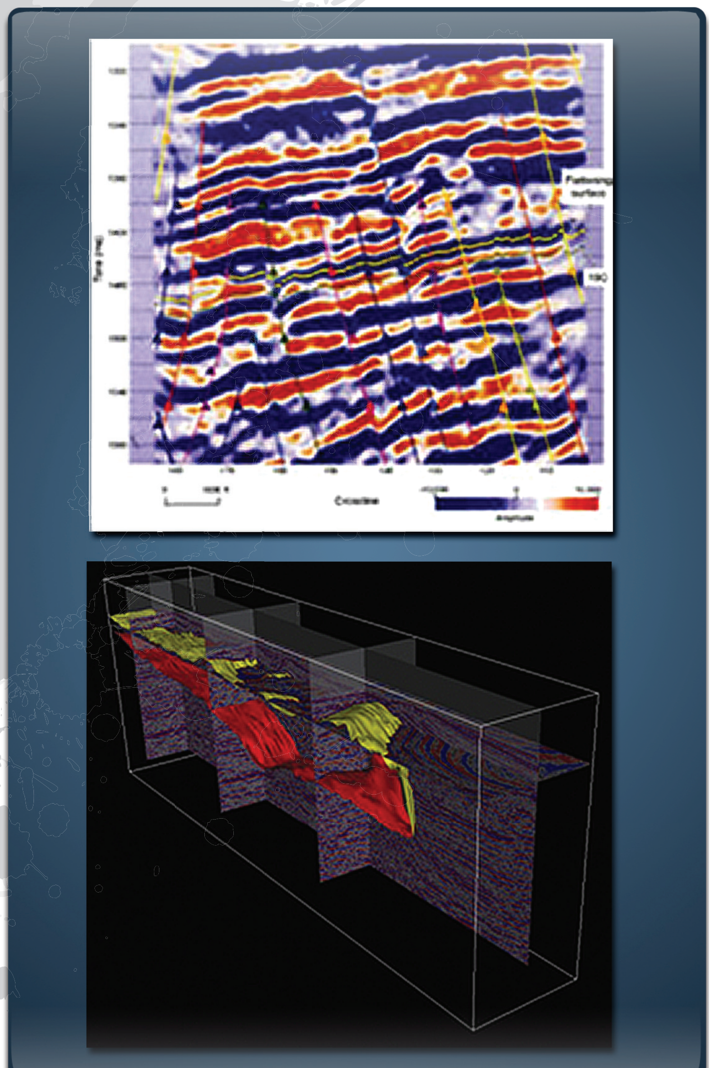

Fig. 6

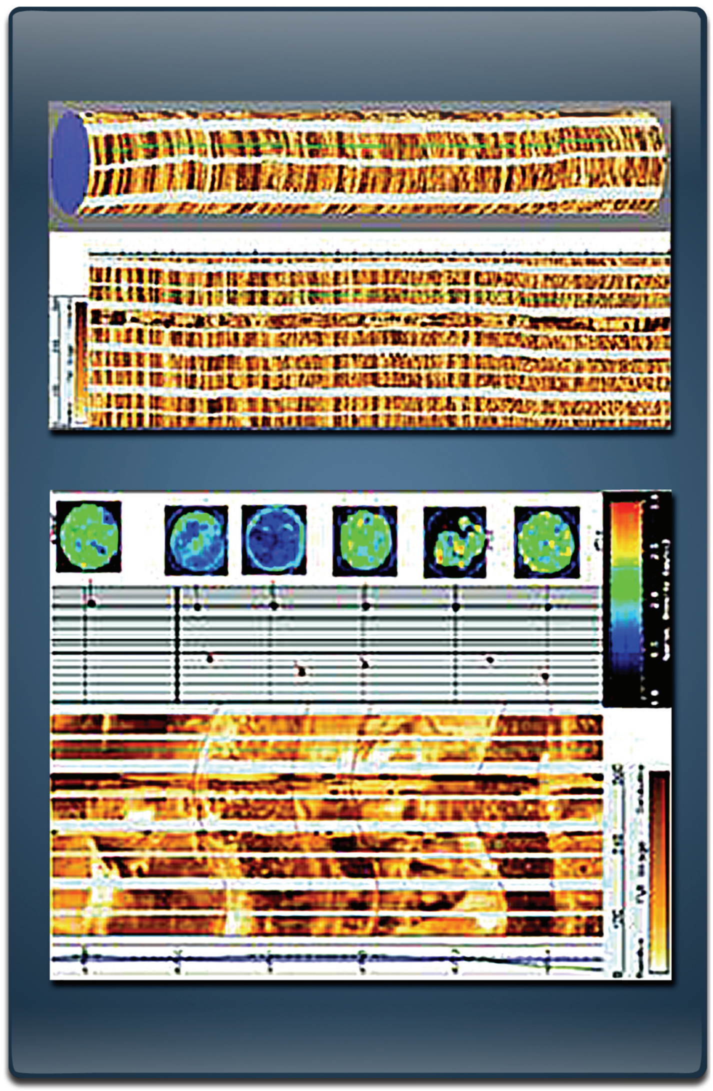

Fig. 7

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