ENERGY IMAGING

Pressure analysis explains seismic

A new capillary shock-wave model enhances the accuracy of 3-D seismic interpretation.

AUTHOR

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A year ago, a new wave mechanics approach to pressure-transient analysis called WaveX was introduced.[1] This pressure analysis method generated reservoir dimensions, limit shapes and images from a family of capillary shock-wave fronts as they passed through the reservoir at slow diffusive speeds. A new case study illustrates the economic effectiveness of combining traditional material balance reservoir engineering with geophysics and WaveX pressure-transient imaging.

The problem

A new well has been successfully drilled and completed on the basis of a prospect generated with 3-D seismic data and traditional material balance calculations on offset wells. The target was a higher amplitude seismic event associated with gas sands that apparently never were drained by offset wells. The hydrocarbon-bearing sands and seismic amplitudes are discontinuous, making the generation of net pay maps from 3-D seismic data extremely difficult. The initial performance of the well suggested that although it is "a keeper," it may not be as large as initially mapped. Many questions were associated with a geologic nonconformity that would impact reserves from the current well and a future development well. In fact, the economic viability of the second development well was in question.

The solution approach

Why did the property team elect to conduct a pressure analysis test? Producing this well while monitoring flowing tubing pressure at a constant rate controlled by a fixed choke would give the exploration team tangible results while generating cash flow to the project. They expected to learn:

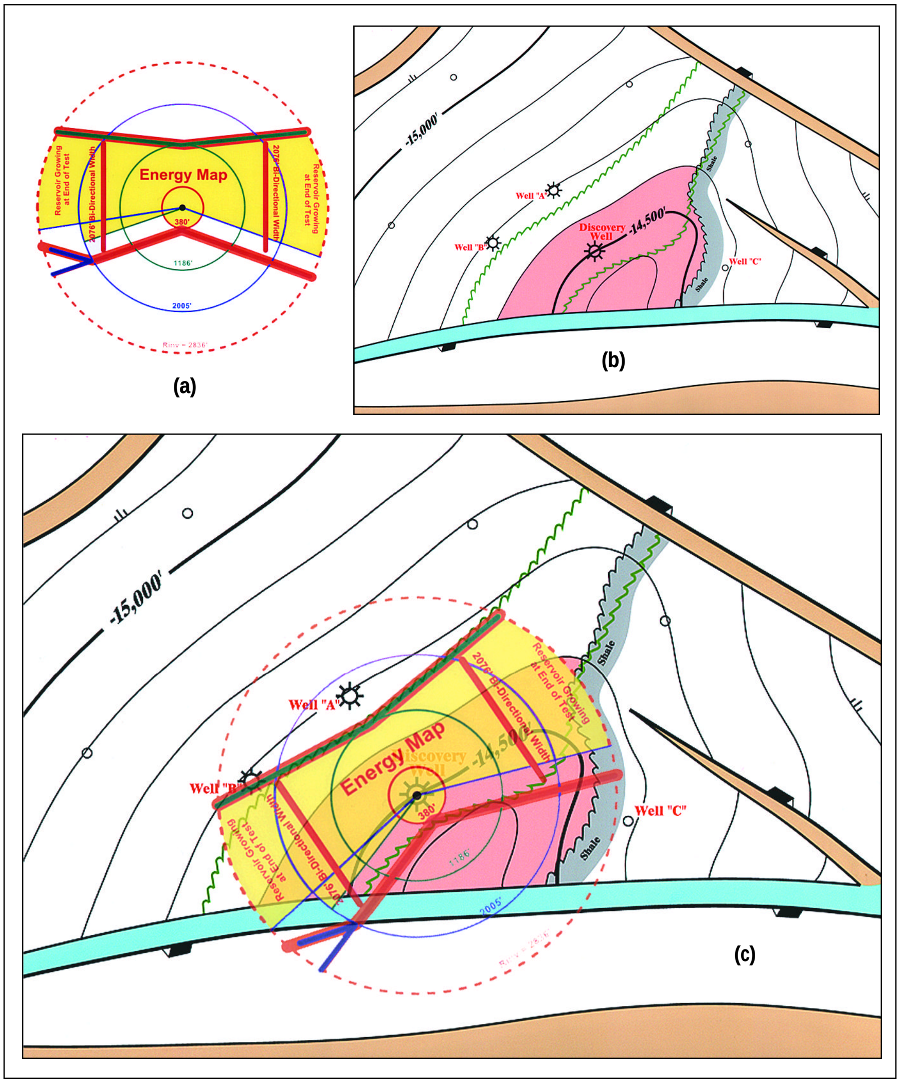

Figura 1.The energy map of pressure-transient boundaries (a) was compared to the structural map (b),and the overlay (c) showed that the field was smaller than the original interpretation.A second development well was not drilled.

- distances from the well to the permeability limits;
- amount of gas explored by the test; and
- type of drive mechanism.

The operator had used shock-wave front pressure-transient analysis in the past to confirm geologic maps. Producing this well to sales while monitoring the flowing tubing pressure with a SPIDR has proven successful in generating independent reservoir dimensioning for gas reservoirs with fluid production less than 300 bbl/MMcf. The results of the analysis developed specific information on the distance from the well to the nearest reservoir boundary contacts. It also produced information as to the shape of each contact relative to a straight line. Because the transient model is based upon discrete finite capillary rays, it can provide information as to relative disposition of individual limits. It is possible to detect corners for intersecting faults and learn if any of the limits are nearly parallel to each other. Finally, the shock-wave model produces running integrals of the volume of gas in place as well as dimensional information for direct comparison with 3-

D seismic data.

The individual boundary contacts and angle of intersection computations then are assembled into an energy-equivalent image of the reservoir using the volume information to orient the boundaries with respect to each other – without making reference to a seismic map. This boundary contact drawing then can be overlaid onto a seismic image as an independent reference for interpretation.

Pressure testing and analysis

Data gathering is simple and cost-effective. The new well is placed on production on a fixed choke and pressures recorded as the gas is sold. The principal goal is to maintain a 2.5-1 pressure ratio across the choke.

This gas well was tested using a SPIDR surface-mounted pressure gauge and the associated downhole data conversion process. The best time to capture transient data is during the initial production period. No prior stabilizing buildup is required for the drawdown, hence there are no production delays or losses. The analysis was performed "blind," with no prior geologic information for the analyst. The shock-wave front model builds the image from a sequence of abrupt energy shifts visible in the traditional semi-log plot. These events are caused by the growing capillary array from the well interacting with a permeability change. A traditional simulator model cannot replicate these singularity events. That is why historically it has been a common practice to "smooth out" test data numerically for the traditional iterative history-matching analysis process.

In contrast, the shock-wave front model sees limits as discrete events. A sealing limit is manifested as a sharp or singular shift in the derivative value on the semi-log pressure plot. Each boundary contact is described by the distance to the point of tangency and by the characteristic shape at the point of contact. A limit may be straight, concave to the well or convex. In Figure 1a, the red limit is the first contact, the green limit is the second contact, and the blue chevron represents a probable change in the direction of one of the limits. It has an insufficient energy shift to be a separate discrete limit. The area described in yellow is the energy integral for the test. Finally, from the linearity plot an equivalent bidirectional width for the parallel limits system can be calculated. This is depicted as two red bars an appropriate distance from the well. This squares nicely with the projections for limits 1 and 2 up and down the reservoir. An energy map that maintains all balances and dimensions is referred to as a "snap fit." This means one

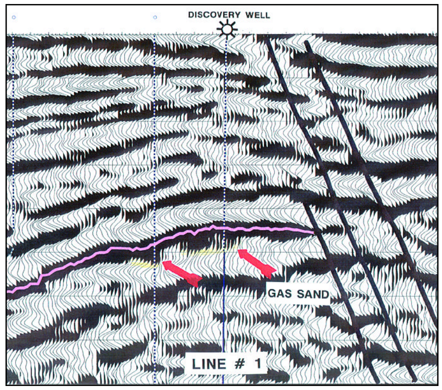

Figure 2.Higher amplitude events from the seismic were plotted on Figure 1b as green, squiggly lines, confirming the boundary. (Courtesy of Seitel Data)

representation is seen on a transparency. Of course, the transparency can be flipped over for the mirror-image case that in all instances is as legitimate as the first. It should be noted that the method does not imply direction but does recognize relative boundary placements. The pressure-transient analysis is complete. At this point it is taken to a meeting in the operator's offices to compare with an as-yet-unseen geologic map.

Geology and geophysics

The prospect is a three-way, high-side closure on a large, regional down-to-the-south basin fault. The objective sands are within the Frio stratigraphic sequence. Existing well control demonstrates a sand pinch-out over the structure. An initial 3-D seismic-based structure map was constructed to drill this prospect (Figure 1b). In addition, a velocity anomaly was evident from the 3-D seismic data over the structure. Nearby well control allowed for the Frio sands to be directly tied to the 3-D seismic data via synthetic seismograms. No apparent gas-water contacts were evident from the initial interpretation of the 3-D seismic data. However, higher amplitude events were associated with the gas sands (Figure 2).

The initial discovery well found hydrocarbons within the objective sands. Correlation of the new sands to offset wells demonstrated that the new well encountered sands that were not present in offset wells. Obviously, the predrill sand maps needed to be corrected. Pressure-testing and analysis were completed and applied to the new interpretation. It was determined that we could demonstrate several sand lobes within the higher amplitude event on the 3-D seismic data.

A working meeting

The comparison of an independently generated energy image and a seismic image always has an element of suspense. But the key to successful exploration (exploration that involves making money) is based upon bringing as much data from as many independent sources and disciplines as possible together in order to reconcile differences. The business of exploration is to prioritize information and make unemotional judgments as to relative value. Profitable exploration is the assembly of information in order to reduce decision-making risk.

By placing the WaveX map over the structure map (Figure 1c), Boundary 2 seems to fit the distance and shape described in the geologic map. The blue fault appears to coincide with the distance of the blue anomaly or boundary shift. However, Limit 1 appears to cut across the middle of the reservoir. Initial well performance using traditional production plots and static material balances seemed to support a smaller picture from the standpoint of energy decline. A proposed offset well was discussed. A reduction in reservoir volume would be critical to the drilling decision for the second well. The nonconformity to the east was the principal uncertainty in the analysis.

The western reservoir boundary had been defined by a higher amplitude seismic event. A second higher amplitude event on the eastern side of the well had been noted but could not be structurally correlated with a boundary. The original western amplitude event had been ascribed to a gas-water contact. The transient test matched the boundary shape, casting doubt upon the gas-water contact interpretation. A quick traverse of the reservoir was made to plot the locus of both higher amplitude events. The amplitude reversals are shown in Figure 2, and the locus boundary is plotted over the map in Figure 1b as green lines. The next step was to again match the WaveX overlay to the geologic map in Figure 1c, which confirmed the geologic interpretation of a sand channel.

Increased certainty in defining a reservoir improves economics. Production performance, seismic and pressure-transient images enhance and complement each other. Team play and communication among the reservoir engineer, the pressure-test analyst and the geophysicist were essential in accurately defining this prospect. More importantly, a noncommercial well was not drilled. The money was applied to other ventures. E&P

References

1. Goldsberry, F.: "Shockwave model reduces risk," Hart's E&P, pp. 43-45, September 2000.