Gulf of Mexico reservoir management--2: Method described for using 4D seismic to track reservoir fluid movement

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ABSTRACT (ABSTRACT)

The use of time-lapse 3D seismic data (4D) to analyze changes in reservoir status during production of giant Eugene Island Block 330 field in the Gulf of Mexico is described. The technique utilizes seismic imaging, feature extraction and pattern recognition coupled with seismic forward and inverse modeling.

FULL TEXT

This is the second part of an article about the use of time-lapse 3D seismic data (4D) to analyze changes in reservoir status during production of giant Eugene Island Block 330 field in the Gulf of Mexico off Louisiana. Because of the 4D effects being observed by the partners in the LF sand reservoir, the Global Basins Research Network (GBRN) began an independent but collaborative analysis of the differences observed between the two 3D seismic datasets in this area. We utilized a 4D seismic analysis technique consisting of seismic imaging, feature extraction, and pattern recognition functions, coupled iteratively with high resolution, seismic forward and inverse modeling.(8) Pattern recognition, rather than interpolation and recomputation, is used to examine similarities and differences among the seismic amplitudes of the datasets. This technique minimizes the difficulties in matching acquisition parameters, variable geometries, and technology improvements that have accompanied the development of 3D seismic methodologies over the years.

The 1985 and 1988 3D seismic surveys were first converted into a common coordinate grid by interpolating the surrounding bins of the 1988 survey to produce bins that correspond to the coordinate grid of the 1985 survey. The preparation into a 4D dataset ready for inter-comparison then requires extraction of similar power spectra from the two datasets. The intercomparisons are accomplished in attribute-derivative space, since we have found that only the lowest frequency amplitude spectra preserve the best commonality among the differently acquired acoustic datasets. Specifically, the waveform envelope of the reflection strength (or "second" reflection strength) is calculated and compared.(9) The normalization technique cannot correct for differences in reflection strength caused by orientation changes between the surveys relative to rock geometry in the subsurface, so the match is never perfect.

"Zapped" horizon differences

We then auto-tracked ("zapped") the major reflector of the double reflection strength that corresponds to the LF reservoir along the structural contour of the top of the LF in each of the surveys, and extracted the variation in amplitude for each survey.

Because the double reflection strength datasets have been normalized, we then computed the differences between the two zapped, LF horizons. This 2D amplitude difference surface clearly shows "dim-outs" that are approximately parallel to structural contours and that migrate somewhat up dip from the north and east in the eastern A5 and A8ST fault block (Fig. 7).(Fig. 7 omitted) To the west, the area of high reflection a strengths decreases with time in the All fault block, as might be expected for a reservoir with depleting fluid pressures and oil saturations.

A clear boundary between amplitude changes in the A5 and All compartments within the LF reservoir (Fig. 7).

Within the A5 well compartment, amplitudes remained strong in the south and west of the fault block, suggesting that there is considerable bypassed pay for the A8ST well to drain.

A velocity inversion computed by Texaco supports the increase in velocity predicted by the dim-out in the east.(10) Logs from the Texaco No. 4 well through the far eastern segment of the reservoir at the four corners indicate that the LF sand is shaling out to the east, but the change in amplitudes from 1985 to 1988 also indicates either significant compressibility changes or migration up dip of an oil/water contact is also occurring in the reservoir. However, no significant water has been produced from the LF reservoir, and the drive appears to be depletion.

High amplitude regions

The data fields were then segmented into volumes of similar high amplitude regions (HARs), and data from outside these HARs excluded from future analyses (Fig. 8).(Fig. 8 omitted) It is important to note that HARs are not bounded by isosurfaces connecting equal seismic amplitudes. Instead, non-linear, region-growing operators are applied to each dataset to isolate HARs, beginning from initial "seed points." Rough-cut connectivity between HARs within each dataset can be obtained at this stage by properly choosing the "manifolding" operators such as low-pass spatial filtering, dilation, and erosion, which "grow" the connections between segmented HAR seed points. The HARs of the LF and surrounding reservoirs were then computed (the 1985 survey in green, Fig. 8A, and the 1988 survey in red, Fig. 8B).

Similarities, differences

The robust method for HAR growing, and the short time step between surveys insures similar registrations and shapes of the corresponding HARs between surveys. Thus, differences might indicate fluid dynamics within an HAR.

The similarities and differences in the LF region from 1985 to 1988 were visualized and the locations indicated where seismic amplitudes have decreased-blue, increased-red or remained similar-green and yellow (Fig. 8C). 5

A good test of the normalization technique used in the 4D analysis is provided by the IC sand, imaged in detail in the insert in Fig. 8C. There was no production from this sand until the Pennzoil C11ST well was completed in 1991. The green and yellow areas with similar amplitudes cover 90% of the volume of the reservoir; whereas red and blue indicating increases and decreases, respectively, are found around the edges, indicating that there are edge effects present in our analysis technique.

Analysis of drainage

We then examined the volumetric variations in the similarities and differences between the HARs of the LF reservoir observed between the 1985 and 1988 seismic datasets. Changes in amplitude over time estimate the drainage of hydrocarbons from 1985 to 1988 and identify zones of possible bypassed hydrocarbons for future drilling. Near zero seismic differences indicate locations where there was minimal change within the HARs of the surveys, which we interpret to be possible by-passed pay (green in Fig. 9, top).(Fig. 9 omitted) Decreases in amplitude could be caused by water encroachment or pressure depletion between the times of the two surveys (blue in Fig. 9, top) and increases in amplitude could be from GOR increases and secondary gas dissolution (red in Fig. 9, top).

In the eastern fault block, 105,000 bbl of oil were produced from the A5 well over the 3 years between the two seismic surveys. The 4-D seismic mapping indicated that significant dim-out occurred over about 220 acre-ft of the reservoir, from the east and north (blue). Production efficiencies of 480 bbl/acre-ft would be required to produce this volume from this acreage, and some clean sand within EI 330 field have exceeded 800 bbl/acre-ft. sup 2 Further calibration of drainage volumes versus seismic amplitude changes will require study of more extensively drained (1 reservoirs. An analysis of the larger and thicker (up to 120 ft) LF reservoir to the west is underway at Lamont and Penn State using the 1992 3D seismic survey as well.

The 4D seismic differencing analysis produces a detailed, volumetric representation of the predicted drainage infrastructure within the bypassed pay interval, as well (yellow in Fig. 9, bottom). In fact, the 3D pattern of bypassed hydrocarbons has surprising connectivity and logic to it. The amplitude pattern is lineated at 30deg to the major bounding faults. Perhaps these apparent lineations are small shear faults caused by a component of shear to the west accompanying extension to the south in the vicinity of the LF reservoir (thus the 30deg rotation). This fault pattern which might affect reservoir permeability cannot be recognized in either of the primary 3D seismic surveys, but becomes a recognizable amplitude signal in the differenced, 4D a dataset.

Seismic model

Quantification of the observed reservoir drainage effects at near tuning thickness was then accomplished using a 2D finite element forward model. By calibrating the modeling results with the observations (pressures and GORs from the A5 and All wells, Fig. 3), it was possible to compute the expected seismic amplitude changes even at tuning thicknesses.(Fig. 3 omitted) First, we modeled the fluid content of a 35 ft thick LF reservoir as 60% oil--Sw of 40% (Fig. 10, top), then we inserted a small gas cap (100% gas) in the center and drained the oil-Sw of 80%, oil saturation of 20%-to the west, replacing it with lower pressured water, but left the eastern portion of the reservoir with bypassed oil-same Sw of 40% (Fig. 10, center).(Fig. 10 omitted) Drainage and replacement of pressured oil with lower pressured water produced a pronounced dim-out in the predicted seismic amplitudes (blue over red, from tuning) in the seismic differences plot even in at tuning thickness is (Fig. 10, bottom). The formation of a gas cap, even at low pressure, produced a large amplitude increase (red over blue, then another red from a tuning) in the difference plot (Fig. 10). Bypassed oil d remained at similar amplitudes (yellow over light blue) in the difference plot (Fig. 4 inset).(Fig. 4 omitted) The edge effects in the difference model are caused by the mismatches caused by the changes in velocity of the fluids filling the reservoir over time.

Summary

In the future, the GBRN feels that sparsely-distributed well information will be used to calibrate seismic changes observed during acoustic monitoring of entire fields, leading to reservoir characterization that can predict pressure distributions, interface changes such as O/W contact movements, porosity anomalies, permeability boundaries, GOR changes, and in particular, bypassed hydrocarbons-all in true 3D and near real-time. However, the prediction of changes in reservoir physical parameters such as pressure and fluid content from the 4D analysis of changes in seismic amplitudes over time is ultimately an ill-posed, inverse problem. Therefore, in the future, refinements to the 4D solution might be strongly coupled to the results of forward models of the different physical species (reservoir fluids, elastic, and acoustic). Such complex intercomparisons of data and model results would require a visualization "nexus" similar to NASA's Mission Control, operated by teams of production scientists and engineers, in near real-time. A CD-ROM containing detailed accounts of this and related field studies of the Eugene Island 330 field GBRN project is available for $10 shipping and handling from David Roach, GBRN, Lamont-Doherty Earth Observatory, Palisades, N.Y. 10964. Phone (914) 365-8330, fax (914) 359-1631. Internet address is roach(at)ldeo.columbia.edu.

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DETAILS

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