TITLE: ECONOMIC RECOVERY OF OIL TRAPPED AT FAN MARGINS USING HIGH ANGLE WELLS AND MULTIPLE HYDRAULIC FRACTURES

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Objective

The objective of this project is to utilize advanced technologies to demonstrate economic recovery of oil from the fan-margin portion of a slope-basin clastic reservoir. A high-angle well will be drilled in the fan margin and will be completed with multiple hydraulic-fracture treatments. Connectivity of thin reservoir layers will be established along the well path by the fracture planes. Geologic modeling, reservoir characterization, and fine-grid reservoir simulation will be used to select the location and orientation of the well. Design parameters for the hydraulic-fracture treatments will be determined by hydraulically fracturing an existing well. Fracture azimuths will be predicted (in part) by the microseismic logging of an offset well during the hydraulic-fracture treatment of the existing well.

Summary of Technical Progress

Design work began for a hydraulic-fracture treatment of an existing well in the Yowlumne Field, Kern Co., Calif. Localized geologic and reservoir description work was completed in the area of the well. Estimates of formation mechanical properties and stress profile were made using full-wave sonic log data and treating-pressure data from a hydraulically-fractured well in the field. Fracture azimuth was predicted using field borehole breakouts identified from four-arm dual-caliper dipmeter logs.

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Yowlumne Unit B 84-32 is a vertical producing well located in the NW fan-margin area of the field (Fig. 1). During the planned hydraulic-fracture treatment of well No. 84-32, an offset well (water injection well No. 86-32) will be logged with acoustic detection devices. Data collected from the fracture treatment and microseismic logs will be used to predict fracture azimuths and design parameters for the hydraulic-fracture treatments of a new well to be drilled in the NE fan-margin.

Structure and Stratigraphy

The Yowlumne sand is approximately 200 ft thick at the location of well No. 84-32. It is bounded by siliceous shales and is internally subdivided into six flow units (Fig. 2). Correlation of flow units is difficult in the fan margin, as sand packages break up and become interbedded.

Figure 1 also shows the trace of a reverse fault between well Nos. 84-32 and 86-32. The presence of the fault is indicated by a three-dimensional (3-D) seismic survey, cross-sections, and pressure data. Vertical separation of the fault is less than 50 ft. Historical production and injection rates indicate the two wells are in hydraulic communication.

Rock Properties

Openhole logs were used to determine interval thicknesses and rock properties, such as shale volume (V_{sh}), porosity (ϕ), water saturation (S_w), and permeability (k). These parameters are shown in Table 1. Net sand and net pay were based on the following cutoffs:

1. Net sand: $V_{sh} < 0.30$, $\phi > 0.11$, $k > 0.1$ md
2. Net pay: $V_{sh} < 0.30$, $\phi > 0.11$, $k > 0.1$ md, $S_w < 0.40$

Permeability values were estimated using porosity-permeability relationships from core and log data in the field.

Mechanical Properties

Full-wave sonic log data and hydraulic-fracture treating pressures from other wells in the field were used to estimate regional mechanical properties for the Yowlumne sand and bounding shales. These data were also used to predict a stress profile for well No. 84-32.

Relationships were established for the ratio of shear to compressional wave travel times with shale volume (calculated from gamma-ray logs) for the Yowlumne sand and bounding shales. These relationships were used to calculate Poisson's ratio (ν), shear modulus (G), and Young's modulus (E). Minimum horizontal shear stresses (σ_x) were then calculated for the Yowlumne sand and bounding shales using pressure data obtained from

repeat formation testers (RFT). Minimum horizontal shear stress values were then calibrated to treating-pressure data from a hydraulically-fractured well in the field¹.

Mechanical properties and stress profiles were then predicted in the area of well No. 84-32 based upon the following assumptions for pore pressure:

1. No pore pressure variation by layer.
2. Permeability-thickness (kh) weighted-average variation of pore pressures for each layer.

The second assumption is the most likely representation of pore pressure. Nevertheless, either assumption indicates that vertical growth of the fracture should be confined to the Yowlumne sand between the overlying and underlying shales (Table 2).

Although this technique of estimating the stress profile is often used for tectonically relaxed environments, it is theoretically inappropriate for strike-slip regimes with strong compressional forces¹, such as in the Yowlumne Field. However, it is still useful for observing the relative impact of pore pressures on fracture height.

Fracture Azimuth

Borehole breakouts identified from four-arm dual-caliper dipmeter logs were used to estimate regional stress orientation. Borehole deformations were assumed to be the result of differential horizontal stresses. The azimuth of the shorter axis measured by the dual caliper was assumed to coincide with the direction of maximum horizontal stress (S_{Hmax}). Borehole elongations due to washouts, keyseats, sloughing shales, etc. were omitted².

Within the Yowlumne sand, breakouts trend in a general north-south S_{Hmax} orientation. As shown in Fig. 3, of the 12 wells with breakouts identified in the reservoir interval, eight indicate S_{Hmax} is oriented N 20° E. All other breakout data indicate S_{Hmax} is oriented approximately east-west.

Regional breakout data from surrounding fields suggest the S_{Hmax} is oriented north-south³, which is consistent with local fold axes and reverse faulting (including the reverse fault between 84-32 and 86-32 shown on Fig. 1). Therefore the hydraulic fracture in 84-32 is expected to propagate NNE-SSW, perpendicular to the reverse fault.

References

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3. Castillo, D.A., and Zoback, M.D., Systematic Variations in Stress State in the Southern San Joaquin Valley: Inferences Based on Well-Bore Data and Contemporary Seismicity, *AAPG Bull.*, 78, 1268-1269, 1994.

TABLE 1

Rock Properties						
Zone	Gross Thickness, ft	Net Thickness, ft	Net Pay Thickness, ft	Vsh, fraction	ϕ^* , %	k*, md
Upper Shale	58	0	0	0.69	N/A	N/A
Sand A	84	9	9	0.26	12.30	0.76
Sand B	44	27	26.5	0.14	15.21	8.27
Sand C	23	4	4	0.10	12.87	1.19
Sand D	30	15	15	0.12	12.36	0.62
Sand E	35	22	17	0.07	13.41	1.45
W Sand	13	0	0	0.41	N/A	N/A
Lower Shale	18	0	0	0.53	N/A	N/A

* average properties consider pay only

TABLE 2

Mechanical Properties					
Zone	Gross Thickness, ft	Pressure**, psi	Fracture Gradient**, psi/ft	Pressure***, psi	Fracture Gradient***, psi/ft
Shale	58	5979	1.142	5979	1.142
Sand A	84	4500	0.956	5060	0.985
Sand B	44	4500	0.947	5060	0.977
Sand C	23	4500	0.946	4500	0.946
Sand D	30	4500	0.943	3560	0.893
Sand E	35	4500	0.939	3560	0.889
W Sand	13	6089	0.980	6089	0.980
Shale	18	5906	0.981	6096	0.981

** assumes uniform pore pressure distribution across sands A-E

*** assumes kh-weighted pore pressure distribution across sands A-E

Fig. 1 Structure map of Yowlumne Field, Kern Co., Calif.

Fig. 2 Yowlumne Unit B 84-32 Zonation.

Fig. 3 Yowlumne Sand S_{Hmax} azimuths from borehole breakouts

Fig. 2 Yowlumne Unit B 84-32 zonation.

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Fig. 3 Yowlumne Sand Shmax azimuths from borehole breakouts.

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