SBGf07999

Application of RMS Amplitude Anomaly Mapping in Inferring Controls on Fluid Saturation and Fault-Bound Reservoir Compartments in the C4 Member (Lower Misoa Formation), Phase III Area, Bloque I Area, Lake Maracaibo, Venezuela

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Abstract

Three-dimensional seismic data are increasingly being used in reservoir characterization studies as an aid in detecting and delineating structural and lithologic features as well as changes in fluid distribution that may not be resolvable with log data at wide well spacings. Amplitude maps, in addition to displaying distribution of lithology, can also be effective in inferring subtle faults associated with changes in reservoir fluid content.

In a 12-month reservoir characterization study of tide-dominated deltaic and shelf reservoirs of the Lower Eocene Misoa Formation in a 4-mi² (10.4-km²) rectangular area (Phase III Area) in the Bloque I Area, 3-D seismic data were used in conjunction with logs from approximately 50 wells to detect and delineate faults and to infer interwell sand-body distribution. The goal of this reservoir analysis was to construct an improved geological model of oil- and gas-productive reservoirs in the Lower Eocene to better understand controls on reservoir compartmentalization and to identify areas of unswept hydrocarbons. This paper provides examples from the C4 Member and demonstrates how 3-D seismic data were used to infer the presence of faults not previously detected in earlier studies of these reservoirs with conventional log data and to illustrate their control on fluid distribution.

GEOLOGIC SETTING AND PRODUCTION HISTORY

Lower Eocene strata in the Phase III Area in the Bloque I Area (Figure 1) occur in a fault-bounded monocline, dip approximately 15° eastward, and are sealed updip (westward) by the Eocene Unconformity, a major angular unconformity in the Maracaibo Basin (Figure 2). The Eocene unconformity is an erosional surface overlain by 10- to 30-ft-thick (3- to 9-m) fluvial sandstones. Northwest-trending faults in the central part of the field break the Lower Eocene into several separate fault blocks (Figure 2).

Different structural trends in the Bloque I Area were generated in the Maracaibo Basin by multiple tectonic events spanning the Paleocene to the Pliocene because of the effects of oblique collision between the Caribbean and South American plates (Pindell, 1993). The study area is bounded westward by the Icotea Fault, a major, north-trending, left-lateral strike-slip fault associated with multiple episodes of transpression in the Eocene to Miocene (Lugo, 1991; Lugo and Mann, 1995). A set of northwest-trending normal faults in the interior of the field displace upper Eocene strata by as much as 150 ft (45.7 m) and are truncated by the major Eocene-Miocene unconformity (Ambrose and others, 1997). These northwest-trending faults are interpreted to have originally been right-lateral shear features related to oblique collision between the Caribbean and South American plates (Pindell, 1993). A southwest-northeast-oriented seismic line in the Phase III Area depicts these faults (Figure 2). Many of these right-lateral shears were subsequently reactivated into normal faults during a post-Eocene phase of left-lateral transpression. These faults are inferred to a have a strike-slip component difficult to detect and quantify on log cross sections.

Oil production in the Lower Eocene Misoa Formation in the Bloque I Area began in 1955. The original reservoir pressure of approximately 3,200 psi quickly declined to less than 1,000 psi throughout much of the reservoir. The reservoir pressure declined within 15 years below the bubble point (approximately 2,250 psi for the C4 Member), and a secondary gas cap developed in the structurally highest, western part of the field. This secondary gas cap is abruptly bounded by the westward limit of the C4 Member where this stratigraphic unit is eroded by the Eocene Unconformity. It is also broken into multiple, fault-bounded segments (Figure 3). Wells with neutron-density logs, particularly those in the western, structurally high part of the field, and the distribution of wells shut in with high GOR (gas-oil ratio) values in excess of 3,000, where they coincide with 3-D seismic anomalies, were used to infer that areas of higher gas saturation are primarily related to faults and secondarily to areas where gas injection has occurred since 1962 (Figure 3).

The current fluid distribution has subsequently been modified by both water and gas injection. Water injection in zones that had early high water-cut values commenced in 1969. These zones of high water cut commonly occur in high-permeability tidal-channel deposits, whereas relatively muddier tidal-bar deposits have been incompletely swept by waterflood (Ambrose and others, 1997).

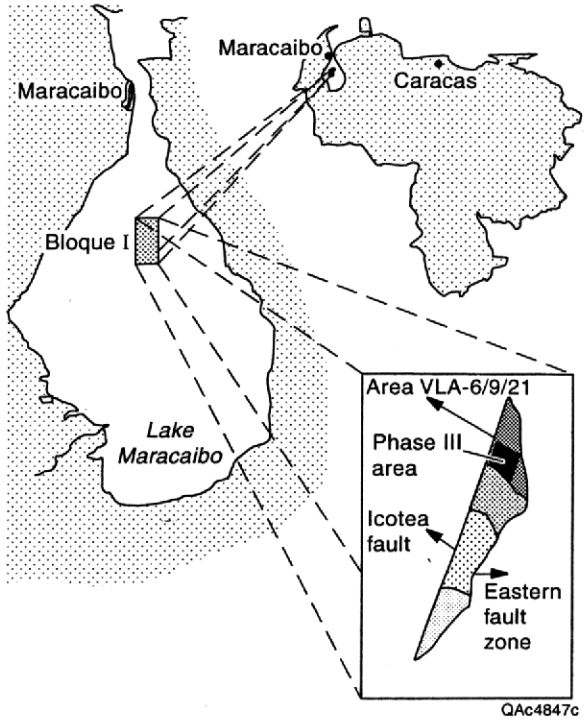

Figure 1. Location of the Phase III and Bloque I Areas in Lake Maracaibo, Venezuela.

SEISMIC AMPLITUDE ANOMALIES

Amplitude reversals are observed in gas-bearing strata in the C4 Member in the Bloque I Area (Figure 4). Impedance values in the C4 Member were assigned by layers honoring log-defined correlations of stratigraphic subunits and seismic trends in the study area. A 20-Hz, 90° phase Ricker wavelet was used to generate respective synthetic sections. Comparison between these two synthetic sections suggests that gas caps in reservoirs may significantly alter the seismic image by introducing bright/flat spots and ambiguous events that mimic shale reflections.

On the basis of impedance trends from fluid modeling, the three sandstones are designated as having layers of high, low, and low/high impedance, respectively. A synthetic log from the 90° phase Ricker wavelet exhibits a high impedance and a normal polarity reflection (peak) for the wet/oil sandstone, a low impedance and a reversed polarity reflection (trough) for the gas sandstone, and a trough-then-peak package for the gas-oil contact, characterized as a "flat spot" in the set of seismic reflections (Figure 4).

In map view, striking patterns of amplitude anomalies (reversals) are noted in an RMS amplitude map of C4 Member (Figure 5). These amplitude reversals exhibit northwestward trends and are most prominent (1) in the western part of the field in the region of the C4 gas cap, especially along the truncation line of the Eocene Unconformity, where hydrocarbon-bearing sandstones in the C4 Member are vertically juxtaposed against Miocene sandstones and shales, and (2) on the downthrown (northeast) side of the two northwest-trending faults in the north-central part of the study area (Figure 5). Amplitude reversals in the area are also bounded abruptly in the north-central and northeastern part of the study area by the 90-percent water-cut contour line, where water-cut values exceed 90 percent in the downdip, eastern part of the area.

The spatial relationship between these amplitude reversals and faults implies fault-sealed traps in the area. Negative amplitudes occur as gas-reversed anomalies that are trapped either by faults or updip by the Eocene Unconformity. Many of the wells that penetrate gas anomalies have one or more C4 sandstones associated with polarity reversals (Figure 5). In contrast, water injection wells show no sign of polarity reversal. Between water injection wells and the gas anomalies, 90-percent water-cut contours can be drawn.

CONCLUSIONS AND IMPLICATIONS FOR RESERVOIR DEVELOPMENT

Effective reservoir characterization and a complete understanding and identification of controls on production commonly are obtainable only through a comprehensive integration of all available field data. This paper provides an example of how RMS amplitude mapping and analysis of Ricker wavelet polarity, validated with production data, can be used to enhance the structural interpretation previously made from log data and to document more effectively controls on reservoir compartmentalization. Collectively, these data enable identification of areas of trapped hydrocarbons. Moreover, these data can be employed to predict areas of poor sweep efficiency in areas where faults, identified from 3-D seismic transects and RMS amplitude maps responding to variability in fluid distribution, are inferred to exert a profound control on poorly swept areas. Complete documentation of these fault-bound reservoir compartments will result in an improved reservoir model, where more reliable predictions can be made about future pathways of injected water, gas, and other fluids in secondary and advanced tertiary recovery programs.

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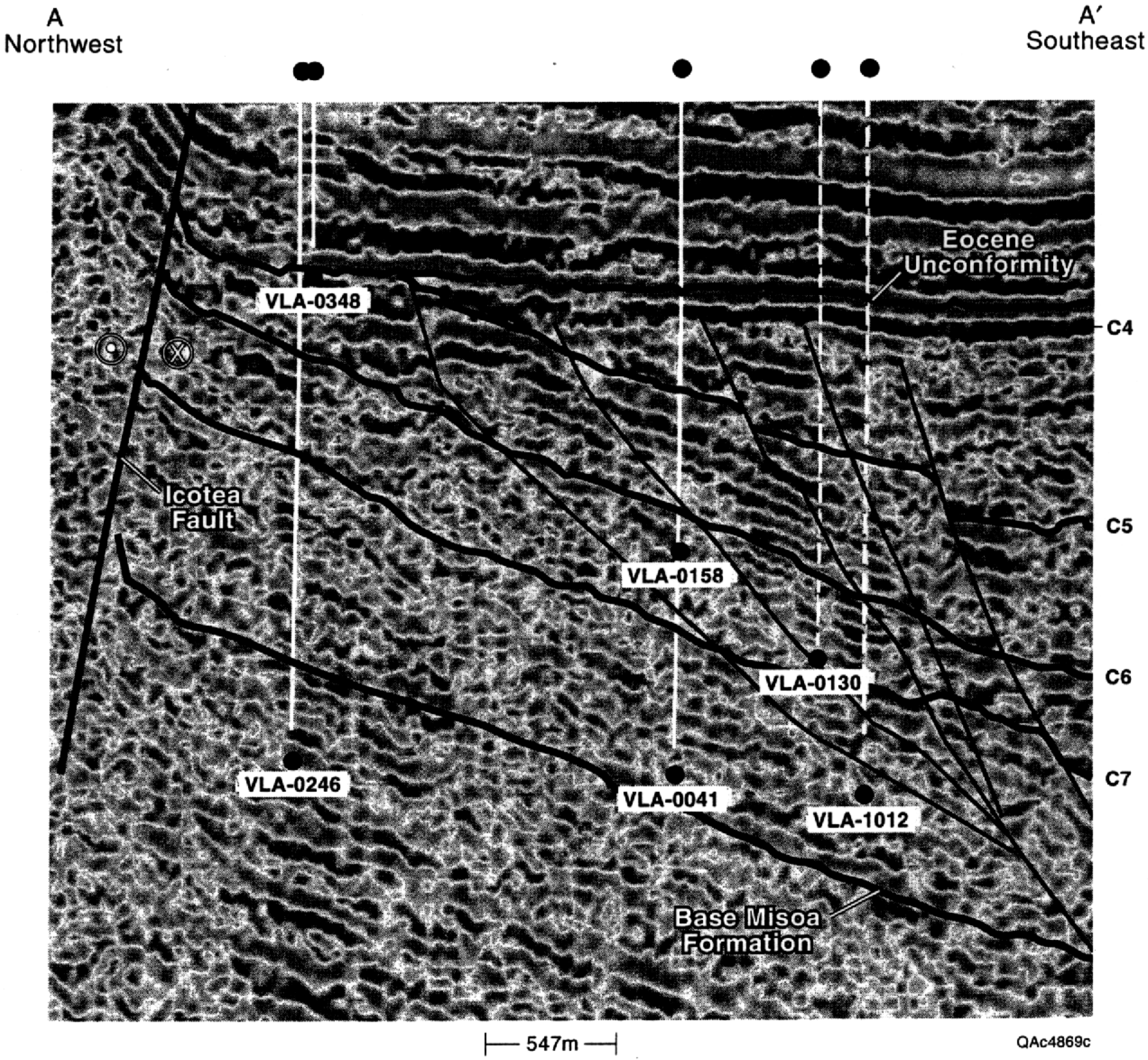

Figure 2. Seismic transect A–A′, located in figures 3 and 5.

ACKNOWLEDGMENTS

The authors would like to thank PDVSA Exploración y Producción for permission to publish this work. Word processing was performed by Susan Lloyd. Joel L. Lardon and David M. Stephens drafted the figures. Publication authorized by the Director, Bureau of Economic Geology, The University of Texas at Austin.

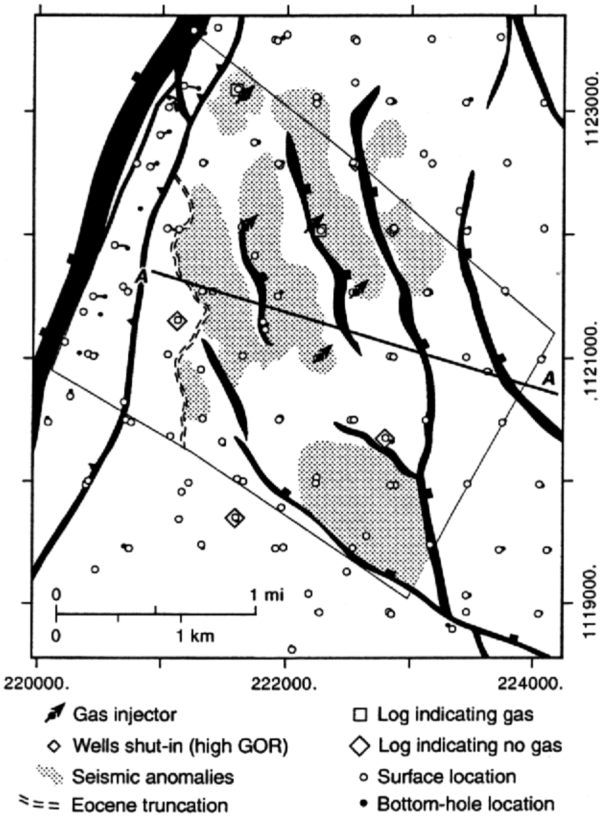

Figure 3. Areas of RMS amplitude anomalies, faults, gas production, and gas injection in the Phase III Area. Seismic transect A–A′ shown in figure 2.

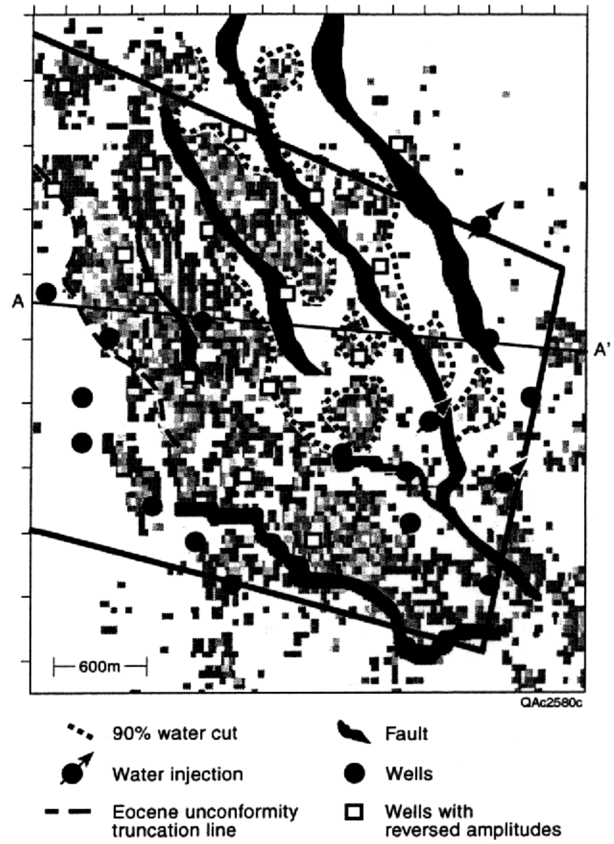

Figure 5. Distribution of amplitude anomalies, faults, water injection, and areas of more than 90 percent water cut in the Phase III Area. Seismic transect A–A′ shown in figure 2.

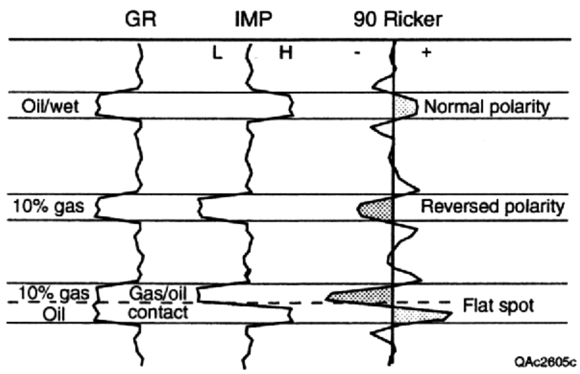

Figure 4. Amplitude reversals in oil-water, gas, and gas-oil sandstones in the C4 Member in the Phase III Area.