Sedimentological and Stratigraphic Analysis for High-Resolution Reservoir Characterization of the Oficina Formation (Sincor Field, Orinoco Heavy Oil Belt, Venezuela)*

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General Setting

The Eastern Venezuelan Basin holds large reserves of extra heavy crude oil found in the Orinoco Heavy Oil Belt (Figure 1) (approximately 460 km long and between 40 km and 80 km wide) along the northern side of the Orinoco River. Reservoir rocks are the highly permeable and unconsolidated fluvial and deltaic sands of the Oficina Formation, one of the most important extra heavy oil reservoirs in the world (Isea, 1987).

Sincor, an operator in the Junin Block, one of the four segments of the Orinoco Heavy Oil Belt, adopted a multi-disciplinary approach to drill a large number of horizontal cold production wells (Svanes et al., 2004). Data from vertical observation wells and deviated stratigraphic wells were used to analyze the depositional environment in a sequence stratigraphic framework and to characterize reservoir architecture. In addition, geological information from the horizontal wells and three-dimensional seismic data, including seismic inverted into acoustic impedance, were used to construct structure maps as well as sand and shale probability maps. All data is integrated in fit-for-purpose geomodels which are used to evaluate well pattern development plans, calculate full-field production percentile profiles, and evaluate uncertainties in water production, well production potential, and cluster performance.

The Eastern Venezuelan foreland basin developed during the Neogene and Quaternary on the Late Mesozoic passive margin of the South American craton as a result of the oblique collision between the Caribbean plate with the South American plate. Paleotopographic depressions, formed by the 'Base Tertiary' unconformity, were filled with lower to middle Miocene fluvial and fluvial-deltaic deposits of the Oficina Formation. The formation is overlain by the Freites Formation of Pliocene age. Since the early Miocene, more than 8 km of sediments are deposited in the basin center and NE part, indicating that sediment delivery could keep pace with the high rate of accommodation space generation. The main source area was formed by the Precambrian Guayana shield located southeast of the Sincor field.

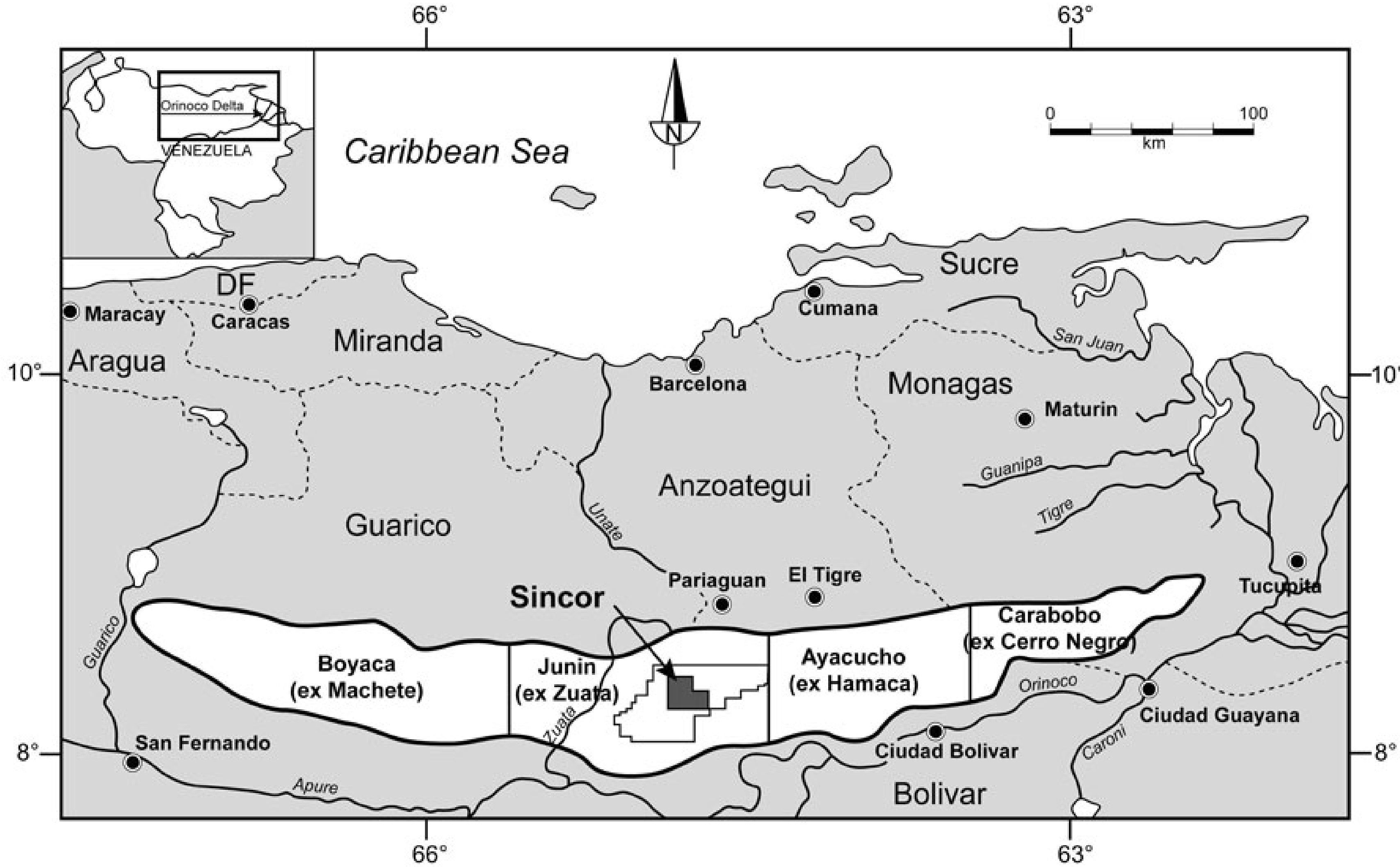

Figure 1: Location map of the Sincor Field in the Orinoco Heavy Oil Belt.

Depositional Facies

Six main facies associations are recognized. Coarse-grained braided channel-belt sandstone bodies dominate the lower part of the succession. These sandstone bodies reach a maximum thickness of up to 40 m, are poorly sorted and commonly contain thick kaolinitic intervals with paleosoils.

Meandering channel-belt sandstones dominate the upper part of the succession and are found in the upper part of stratigraphic intervals otherwise dominated by braided channel-belt deposits. These are most commonly formed by sharp-based, low-angle cross-stratified medium-grained, moderately to poorly sorted sandstone, frequently upward fining into fine-grained sandstone.

Mouth-bar deposits occur infrequently and are limited to the middle part of the succession. They are formed by a dark colored basal mudstone that contains some shallow-marine faunal indicators. The mudstone is overlain by a heterolithic interval composed of a regular alternation of mudstone or siltstone and very fine-grained sandstone layers.

Crevasse splay sandstones occur throughout the Lower Oficina section. They are particularly well preserved in the non-channelized areas where they occur frequently. They are ripple-laminated and generally fine- to very fine-grained and may show a gradual or rapid upward fining grain-size trend. Crevasse splay sandstone bodies are often underlain or overlain by an in situ coal layer that may have associated rootlets preserved in the sandstone beneath it.

Thick and narrow sandy bodies, interpreted as incised valley fills, are present within the middle part of the succession, normally showing a blocky to fining-upward log trend.

The interdistributary fines of the lower part of the succession are rich in kaolinite and contain abundant root traces. Often, an in situ thin coal layer is found overlying the mudstone. Interdistributary fines of the upper part of the succession are formed by a silt to very fine-grained sandstone and heterolithic mudstone and very fine- to fine-grained sandstone (with laminae between 0.5-1 cm thick) or mudstone-sandstone interbeds.

Commonly occurring foraminifera belong to the *Miliammina-Eggerella* benthic foraminifera assemblage in which *Trochammina* is present (Keij and Nijssen, 1986). This faunal composition suggests brackish water conditions (5-10‰ salinity) in (high) marsh zones, sandy mud flats and shallow bay environments around mean high-water level (Scott et al., 1996; Hayward et al., 1999, Shennan et al., 1999). In addition, paleosol profiles, in situ coals, and the occurrence of abundant mangrove sporomorphs suggest that a mangrove vegetation belt was present (Keij and Nijssen, 1986; Gonzalez-Guzman, 2000, 2001).

Sequence Stratigraphic Approach

The sequence stratigraphic framework that has been established was based on the recognition of sedimentary facies and key stratigraphic surfaces that are correlatable over the entire Sincor area and mapped on 3-D seismic. Our aim is 1) to construct a sequence stratigraphic framework for the temporal development of alluvial architecture and 2) to be able to apply the A/S regime approach to the spatially restricted Sincor subsurface dataset that covers a time span of approximately 9 million years.

The starting point for our approach is the principle of separating the fluvial sedimentary succession into units that contain an aggradational part and a degradational part based on facies analysis. The close link to sediment supply and water discharge changes will change the location of the degradation and aggradation turn-around points in the fluvial system. Aggradation and degradation occur in response to changes in stratigraphic base level. The mechanism, or mechanisms, controlling the aggradational/degradational behavior of the fluvial depositional system is analyzed and interpreted by applying the concept of accommodation to sediment supply ratio (A/S) based on the regime theory of Swift and Thorne (1991) and Thorne and Swift (1991a,b).

The effect of a change in A/S ratio has a sedimentary process response component (for example, change in channel platform style, geometry and depositional environment) as well as a stratigraphic component. For the situation where alluvial sediments are preserved (A/S > 0) only two types of effective A/S ratio response exist:

A. Positive and increasing A/S equivalent to increasing rate of aggradation (alluvial base level can be picked at subsequently larger incremental steps from each other upward in the stratigraphy), and
B. Positive but decreasing A/S equivalent to decreasing rate of aggradation (alluvial base level can be picked at subsequently smaller incremental steps from each other upward in the stratigraphy).

The application of the A/S approach enables the definition of three base-case alluvial stratigraphic base-level inflection points. We define:

1. The maximum aggradation turn-around from increasing rate of aggradation to decreasing rate of aggradation;
2. The minimum aggradation turn-around from decreasing rate of aggradation to increasing rate of aggradation (no degradation is reached), and
3. The subaerial unconformity which marks the turn-around from aggradation to degradation to aggradation (no deposition and degradation during a time period at the studied locality).

This methodology has been applied to the lower fluvial part of the Oficina Formation in the Sincor Field, resulting in 3 stratigraphic units F to D.

The upper deltaic part contains marine-flooding surfaces which are used to subdivide the succession into 3 stratigraphic units C to A. These units are further divided in two or three stratigraphic subunits.

Stratigraphic Development of Depositional Environments

Units F, E, and D are interpreted to have been formed in wide, sand-dominated, and relatively straight rivers typified by erosive bases and a braided thalweg pattern around irregularly offsetting repetitive bar forms. Rivers with a sinuous channel pattern are present near the top of subunits D2 and D1. Between these rivers, fine-grained flood plains were present. A relatively low A/S caused frequent channel switching and the formation of broad-channel sand belts, but each unit is typified by a gradual increase in A/S ratio. The presence of two forms of *Beaconites* ichnofabrics indicate purely freshwater conditions (Buatois et al., 2005), and the abundantly encountered palynomorphs are dominated by marsh forests and riverine swamp environments (Gonzalez-Guzman, 2000, 2001).

Subunit C2 is interpreted as having formed in delta top distributaries and prograding lobate mouth bars that were related to flow expansion with a probable tidal influence toward the top of the unit. Marsh forests fringed the distributary channels and coastline. Subunit C1 is interpreted as an upper estuarine environment and contains *Palaeophycus* and *Planolites* ichnofabrics (Buatois et al., 2005). This subunit shows thick and narrow sandy bodies difficult to correlate because the well spacing; it is interpreted as an incised valley, placing a sequence boundary between C1 and the overlying unit B2.

Units B and A are interpreted as having formed on an upper to lower delta plain that was typified by relatively wide meandering channel belts and adjacent flood plains, including brackish-water mangrove swamps, tropical lowland plain, and marshes. Sand was deposited mainly as large, composite point bars in wide (1 to 4 km) alluvial valleys. Abundantly occurring palynomorphs indicate the presence of extensive mangrove forests, but the eastern side of the field contains more abundant phytoplankton.

In general, the palynoflora encountered indicates a tropical or subtropical climate during deposition. The stratigraphic evolution indicates a long-term A/S increase-to-decrease cycle that spans the entire lower Oficina Formation with the maximum flooding surface on top of subunit C1 and a sequence boundary separating C1 from B and A successions. This low frequency cycle encompasses two levels of higher frequency base level cycles at stratigraphic unit (at 100-ky scale) and subunit scale.

Reservoir Characterization

All well data, from vertical stratigraphic wells, slanted observation wells, and horizontal production wells, has been used to construct detailed shale thickness distribution maps for each stratigraphic subunit in the fluvial lower part of the Oficina Formation. The maps are used to better understand and evaluate the areal extent of shale layers and their effect on fluid flow. Within most fluvial subunits, the N/G decreases toward the top in response to an increasing A/S ratio equivalent to an increasing rate of aggradation. A laterally continuous “low N/G layer” (~500 km^2) occurs at the top of the D3 stratigraphic unit across which pressure shifts are recorded in many of the observation wells. Similarly, detailed facies maps and sand thickness distribution maps for each stratigraphic subunit in the deltaic upper part of the Oficina Formation were constructed. These maps are employed to assess uncertainties related to 3D connectivity, well placement, and hydrocarbon volume calculations. All maps are coupled to an analysis of the distribution of facies associations and depositional environments. The data has also allowed for an assessment of sandstone body dimensions and shape. Trends in petrophysical properties are analyzed and employed for facies recognition in non-cored wells and a Kv/Kh estimation of the different sedimentary facies.

References

Buatois, L.A., M.K. Gingras, J. MacEachern, M.G. Mangano, J.P. Zonneveld, S.G. Pemberton, R.G. Netto, and A. Martin, 2005, Colonization of brackish-water systems through time: evidence from the trace-fossil record: Palaios, v. 20, p. 321–347.

Gonzalez-Guzman, E., 2000, 2001, personal communication to Svanes et al., 2004.

Hayward, B.W., H.R. Grenfell, and D.B. Scott, 1999, Tidal range of marsh foraminifera for determining former sea-level heights in New Zealand: New Zealand Journal of Geology and Geophysics, v. 42, p. 395-413.
Isea, A., 1987, Geological synthesis of the Orinoco Oil Belt, Eastern Venezuela: Journal of Petroleum Geology, Vol.10, No.2, pp. 135-148, 1987
Keij, A.J., and L. Nijssen, 1986, personal communication to Svanes et al., 2004.
Scott, D.B., E.S. Collins, J. Duggan, A. Asioli, and T. Saito, 1996, Pacific rim marsh foraminiferal distributions: Implications for sea-level studies: Journal of coastal research, v. 12, p. 850-861.
Shennan, I.A., D.B. Scott, M. Rutherford, M., and Y. Zong, 1999, Microfossil analysis of sediments representing the 1964 earthquake, exposed at Girdwood Flats, Alaska, USA: Quaternary International, v. 60, p. 55-74.
Svanes, T., A.W. Martinius, J. Hegre, J.-P. Maret, R. Mjøs, and J.C.U. Molina, 2004, Integration of subsurface applications to develop a dynamic stochastic modeling workflow: AAPG Bulletin, v. 88, p. 1369-1390.
Swift, D.J.P., and J.A. Thorne, 1991, Sedimentation on continental margins,I: A general model for shelf sedimentation, in D.J.P. Swift, G.F. Oertel, R.W. Tillman, and J.A. Thorne, eds., Shelf Sand and Sandstone Bodies: International Association of Sedimentologists, Special Publication 14, p. 3-31.
Thorne, J.A., and Swift, D.J.P., 1991a, Sedimentation on continental margins, II: application of the regime concept, *in* D.J.P. Swift, G.F. Oertel, R.W. Tillman, and J.A. Thorne, eds., Shelf Sand and Sandstone Bodies: International Association of Sedimentologists, Special Publication 14, p. 33–58.
Thorne, J.A., and Swift, D.J.P., 1991b, Sedimentation on continental margins, VI: a regime model for depositional sequences, their component systems tracts, and bounding surfaces, *in* Swift, D.J.P., Oertel, G.F., Tillman, R.W., and Thorne, J.A., eds., Shelf Sand and Sandstone Bodies: International Association of Sedimentologists, Special Publication 14, p. 189–255.
Tibert, N., and D.B. Scott, 1999, Ostracodes and agglutinated foraminifera as indicators of paleoenvironmental change in an Early Carboniferous brackish bay, Atlantic Canada: Palaois, v. 14, p. 246-260.