Regional Distribution and Controls of Heavy Oil and Oil Sand in the Eastern Venezuelan and Trinidad Basins*

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Introduction

Hydrocarbon occurrences range from the Cretaceous to Pleistocene in the Eastern Venezuelan and Trinidad basins. Distribution and occurrences of heavy oil and oil sands form an apparently random stratigraphic pattern within the Tertiary succession in the Trinidad basins. Regional controls on the distribution of heavy oil and oil sand include the age and stratigraphy of the deposit, history of uplift and faulting, and lithofacies variability keyed to depositional environments. Heavy oil and oil sand reservoirs within the same stratigraphic interval exhibit a variety of API values.

Tectonic regional controls produce thermal events that affect source rock maturation. Faults control migration, provide trapping mechanisms, and can compartmentalize reservoirs. Depositional controls impact source rock quality, reservoir distribution, and reservoir quality. Biodegradation and water washing of deposits can occur within separate reservoir compartments in the same stratigraphic reservoir interval.

This article examines the distribution of heavy oil and oil sand reservoirs, summarizes the potential controls on the distribution of lower API gravity reservoirs, and provides examples from the Trinidadian basins. We will define heavy oil as having API gravity below 22.3° and oil sand with less than 10°API.

Regional Setting

Trinidad lies in the eastern reaches of the eastern Venezuelan Basin (Figure 1) and is subjected to compressive stresses from the NNW that produced transpressional faults and NE-SW trending folds and thrust faults, dividing Trinidad into three discrete basins - a Northern, Southern and Southwestern. Most hydrocarbon occurrences are found in the Southern Basin associated with Late Tertiary structures.

At least three tectonic phases account for the deformation across the Southern Basin (Kennan and Pindell, 2007): 1) southeast-directed thrusting during the Miocene; 2) Pliocene strike-slip along the NE-SW faults and growth faulting; and 3) Pliocene-Recent strike-slip faulting and normal faulting. These phases account for the major tectonic elements in and around the Southern Basin and their associated oil accumulations in predominantly Miocene and Pliocene reservoirs.

Source Rock

Oils found onshore and offshore Trinidad are attributed to the same geochemical family, with differences in geochemical composition due to variations in maturity, source type facies, and alteration (Talukdar et al., 1988, 1990). Oil is sourced primarily from the Gautier and Naparima Hill formations and possibly the Cuche. Fractionation of these marine source rocks produced excellent oils that accumulated in the Tertiary reservoirs.

Geochemical work by Rodrigues and Deokie (1995) indicates that oil produced from the Naparima Hill Formation is paraffinic, generated from mixed terrestrial and marine kerogens. The oblique collision of the Caribbean and South American plates resulted in the Naparima and Gautier formations entering the hydrocarbon-generating window. Hydrocarbon migration likely occurred in the overthrusting phase that followed, forming the fold belt which extends from the Southern Range to the El Pilar fault in the north.

Structure and Tectonic Controls

Structural controls on heavy-oil-sand distribution are evident by varying oil-water contacts between and within oil fields and can be directly observed at outcrop (Wach and Vincent, 2008). API gravity and oil-water contacts can vary between fault blocks within the same hydrocarbon reservoir. For example, in the intermediate Herrera Sands, faults and associated anticlinal structures provided the traps for oil accumulation (Hosein, 1990). Thrust faults and (NW-SE trending) normal faults act as flow barriers, forming separate hydrocarbon accumulations with different formation pressures and oil-water contacts. Similar differences occur between stratigraphic intervals and are influenced by the structural controls.

Stratigraphic Distribution

In Trinidad the heavy-oil and oil-sand distribution is generally constrained within the Miocene and Pliocene reservoirs of the Southern Basin (Figure 2), with oil sands apparently restricted to the Pliocene reservoirs. Producing reservoirs occur from 300 feet to 12,000 feet drilled depth and are from shallowest to deepest: Morne L'Enfer, Forest, Cruse, Karamat, and Herrera (Russell, 1988). Porosity decreases with depth from 30-33%, for the shallow Morne L'Enfer reservoirs, to 18 to 30% for Cruse reservoirs.

Permeabilities vary from 10 to 1495 md, depending on reservoir shale content. Shallow formations exhibit high permeabilities of 0.5 to 1.5 darcies, of which unconsolidated reservoirs are typical. Permeability generally decreases with depth, and at the Cruse level it averages 50 md. Hydrocarbon gravities vary from <10° API oil sand (tar/bitumen) to medium gravity crude oils of l4-28°API. Crude oil recoveries range from <l% for the shallow heavy oil to 15 to 25% for the medium gravity crude oils (Russell, 1988).

Reservoir Lithology and Depositional Environment

The sandstones forming the uppermost Miocene through Plio-Pleistocene reservoirs are immature litharenites, with evidence of sediment recycling; grains are dominantly fine- to lower medium-grained and subrounded. Overall the sands were deposited within a deltaic setting.

API Oil Variability

Table 1 illustrates the variability in the API of oils within fields, in this case the Guapo block of the Pliocene Morne L'Enfer Formation exposed in the Stollmeyer Quarry (Wach and Vincent, 2008). Shallower reservoir intervals have excellent porosity and permeability, but API gravity is poor (low) in the younger Cruse interval.

Hydrocarbon Alteration

Several studies have attempted to evaluate the controls of gravity variations among crude oils in Trinidad. These studies conclude that oil gravity distribution is highly variable and appears independent of depth, age, temperature, and geographic location of reservoirs (Rodrigues and Deokie, 1995).

Common to all studies is that the complex distribution may be a function of multiple alteration processes (Heppard et al., 1990; Talukdar et al., 1988, 1990; Rodrigues and Deokie 1995). These include biodegradation, water washing, gas-condensate mixing, gas stripping, evaporative fractionation, thermal alteration, and alteration imposed by secondary migration. If alteration processes are the major controls on API gravity distribution, accurate API gravity prediction will entail an understanding of geochemical changes, migration pathways and history, source kitchens, and subsurface temperature variations which should be reflected in reservoir crude qualities.

Reservoir Depth

Rambarran (1987) showed the significance of gravity segregation of heavy oil distribution in the Parrylands Forest "A" reservoir. Samaan also shows some gravity segregation and API variation with depth. Shallow reservoir intervals can have heavy oil in the Penal area, and the deep Herrera can be either heavy or gas/condensate (Higgins, 1955; Requejo et al., 1994).

In Table 1 it can be argued that the shallower reservoir interval, the Cruse, may have been subjected to biodegradation of the oils leading to the lower API gravity. However, previous work by Vincent and Wach (2007) suggested there is not necessarily a direct correlation to depth and higher API values.

Conclusions

Table 2 is a summary of the geological controls that are apparent in the distribution of heavy oil and oil sand within the reservoirs in the Trinidad basins. Heavy oil and oil sand distribution in the Pliocene and Pleistocene reservoirs of the Eastern Venezuelan and Trinidad basins appears to be controlled by several factors that have contributed to biodegradation of the lighter ends, leaving accumulations of lower API heavy oil and oil sand deposits. Biodegradation is enhanced by the Plio-Pleistocene reactivation of pre-existing fault structures. This fault control is evident within fields such as Guapo with uplifted blocks comprising oil sand.

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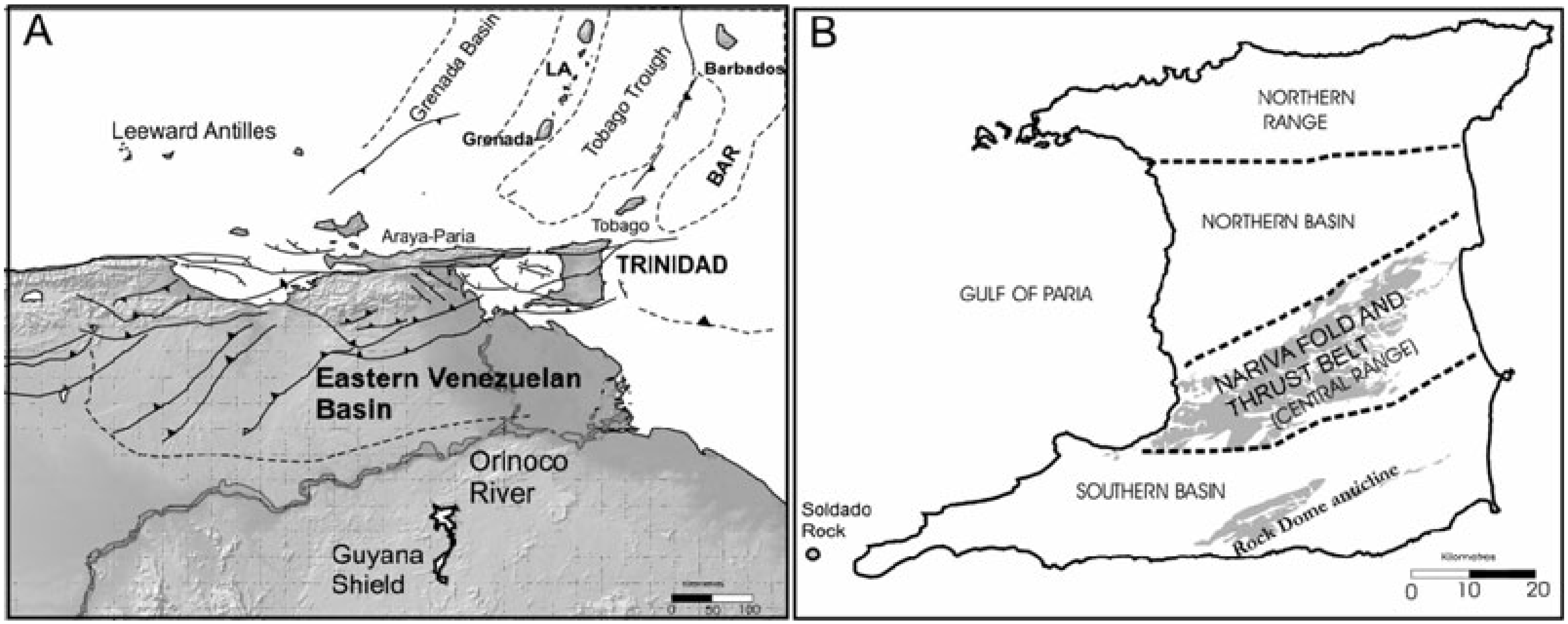

Figure 1. Structural features of the eastern Venezuelan and Trinidad basins. A) Location of Trinidad relative to northeastern South America (BAR: Barbados accretionary prism, LA: Lesser Antilles island arc). B). Geological provinces of Trinidad.

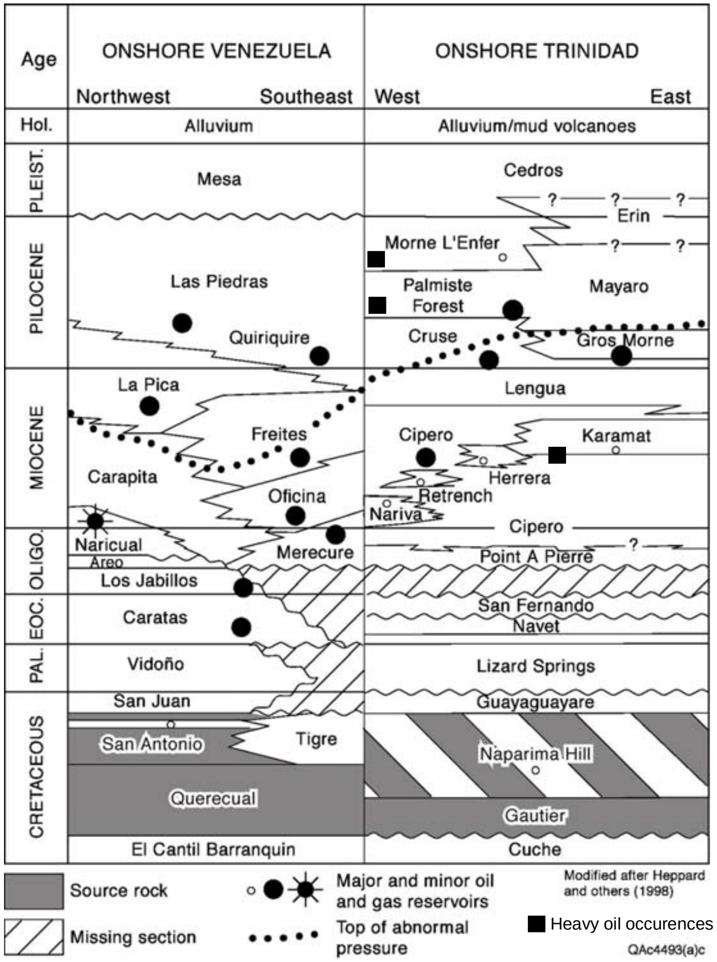

Figure 2. Generalized stratigraphic column of eastern. Venezuela - Trinidad stratigraphy with heavy oil - oil sand occurrences marked with solid squares (modified from Heppard et al., 1998).

Formation	Depth (ft)	Net Pay (ft)	Porosity (%)	Permeability (md)	Oil Gravity (API)
Morne L'Enfer	0-1000	75-100	30-33	up to 1500.	8-10 est.
Cruse	1300-4000	300	18-33	50-450	14
Nariva	3500-4300	100	20	400	27

Table 1. Guapo field reservoir properties (Beard 1985; Russell, 1988; Wach et al., 2004).

Control	Type	Effect	Result
Tectonic/Structure	Oblique compression	Folding and faulting	Trap formation, variable oil/water contacts and formation pressures
	Faulting	Migration	Baffles and barriers
	Folding/faulting	Uplift	Thermal maturation
	Reactivation	Renewed uplift	Thermal maturation, breached traps, biodegradation, re-migration
Source Rock	Terrestrial, marine and mixed terrestrial kerogens	Oil, gas and condensate	Sulphur and heavy metals
Stratigraphy		Timing	Hydrocarbon maturation
		Burial	Hydrocarbon maturation
		Stratigraphic interval	Baffles and barriers, variable oil/water contacts and formation pressures
Reservoir Depth	Burial	Thermal maturation	? inconclusive
Reservoir Lithology and Depositional Environments	Grain size and lithology	Reservoir quality	Reservoir porosity
	Vertical and lateral lithofacies variation	Baffles and barriers to flow	Reservoir permeability
	Depositional environment	Baffles and barriers to flow	Reservoir permeability
	Sedimentation rate	Burial rates and depth	Thermal maturation
Hydrocarbon Alteration	Biodegradation	Loss of light ends	Heavy oil
	Water washing	Loss of light ends	Heavy oil
	Gas washing/stripping	Loss of light ends	Heavy oil
	Secondary migration	Loss of light ends	Heavy oil

Table 2. Controls on heavy oil and oil sand occurrences.