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ENERGY STUDY:
LATIN AMERICA

THE ORINOCO HEAVY OIL BELT IN VENEZUELA
(OR HEAVY OIL TO THE RESCUE?)

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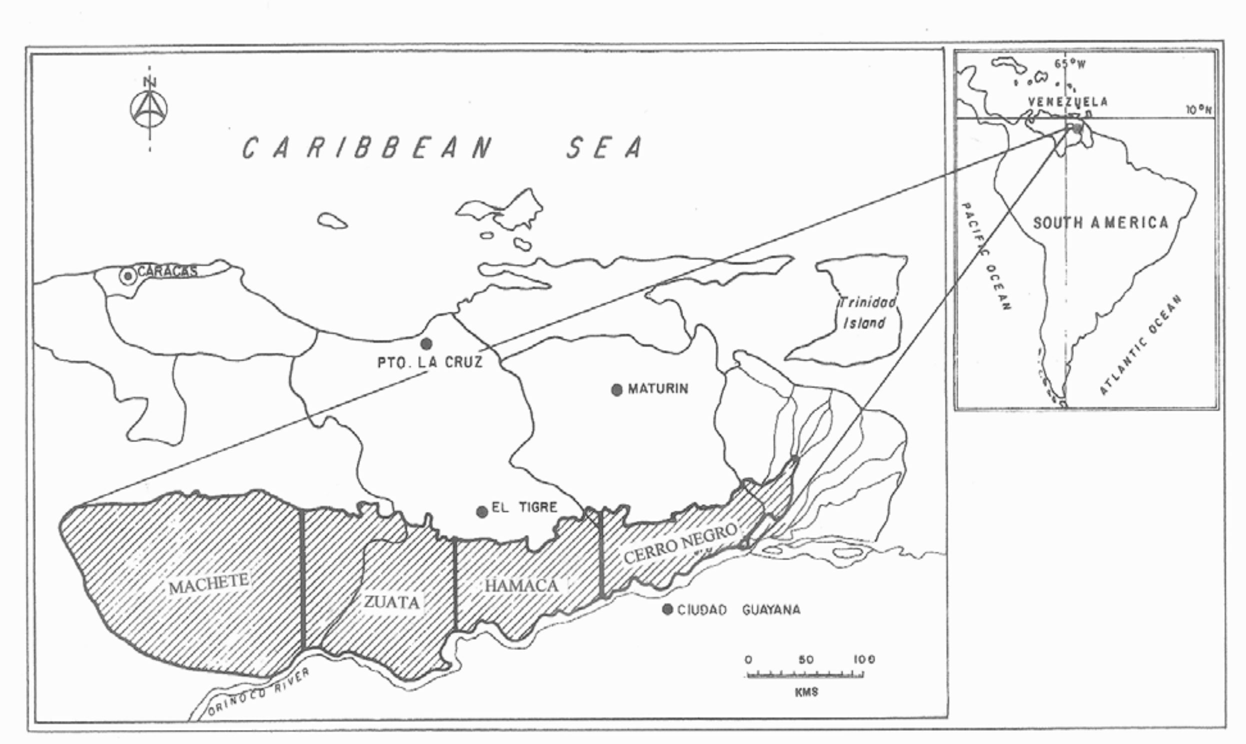
Summary

North of the Orinoco River in Venezuela, in an area of the size of Massachusetts lie the largest oil deposits in the world, estimated at 1.3 trillion barrels of oil "in place" (some estimates are considerably higher). The Heavy Oil Belt in Venezuela, "Faja Petrolifera del Orinoco" (Figure 1) contains an estimated 270 billion barrels of recoverable oil, which matches the oil reserves of Saudi Arabia. Improved technology and/or higher oil prices could increase the size of the reserves even further.

Figure 1: Location Map of the Orinoco Heavy Oil Belt



On the other hand, current projects instituted in the Heavy Oil Belt within the last five years with an investment of more than $12 billion, will, at their peak to be reached at the end of this decade, produce only 660,000 barrels/day. Over the 35 year life time of the current projects, only about 8 billion barrels of oil will have been produced, which is less than 3% of the total oil reserves. The reason for these low production figures is, of course, that heavy oil is very expensive to produce and to refine (because of high sulfur and metal content). The unanswered question is whether it would be in the U.S. national interest to make further investments in new technology and changes in tax policy that would increase the total reserves and the production rates. These practical moves would decrease U.S. dependence on Middle East oil.

From the geological and petroleum systems point of view, the Heavy Oil Belt has many unique features. Many of these features including the deposition of source beds, the "cooking" of the oil and the timing of migration of the oil to the reservoirs are all related to plate tectonic events. When North America parted from Gondwanaland during the Late Triassic to Early Jurassic times (~ 200 million years ago), the northern passive margin of South America was created. This margin subsided as sediments were deposited on it. Some of the sediments were very rich in organic materials most notably in Middle Cretaceous (~150 million years ago). These include the La Luna Formation in the Maracaibo region and the equivalent Quarequal and San Antonio Formations in the Eastern Venezuelan Basin. These formations contain the vast majority of the organic matter that produced the oil and gas in Venezuela.

The next Plate Tectonic event started with the "oblique collision" and the eastward motion of the Caribbean Plate with respect to the South American Plate. The collision started in Eocene times (~50 million years ago), was most intense in Miocene times (~25 to 10 million years ago), and is continuing to the present. The collision led to the formation of thrust belts, which were uplifted and then eroded. South of the thrust belt lay the fore deeps, which received enormous amounts of sediments and created the deep sediment filled Eastern Venezuelan Basin. Further south flexural and isostatic uplift led to the elevation and subsequent erosion of the ancient Guyana shield. Eroded sediments were transported by north flowing rivers into the Eastern Venezuelan Basin. The sandstone deposits thus formed are of Early Tertiary age (~50 to 25 million years ago) and are represented principally by the Mercure and Oficina Formations and their equivalents. These formations contain the bulk of the oil in the Heavy Oil Belt.

The orogenic activity and the loading of sediments in the Eastern Venezuelan Basin helped raise the temperatures and gave rise to a complex process of " cooking" of the organic rich sediments (known as source rocks). The cooking proceeded from north to south in the basin, and the oil that resulted from the cooking, migrated up dip a few hundred kilometers to the southern margin of the basin. It now resides in reservoirs there and forms the Heavy Oil Belt. It is interesting to note that the original organic matter in these reservoirs is immature and that there is no oil left in the source rocks where it originated, but the migrated oil has found a home in these reservoirs far from the source beds. These reservoirs can then be exploited for the vast quantities of oil in them. During the migration, other changes took place in the oil. The lighter fractions in the oils evaporated - that together with microbial activity (which was aided by meteoric waters that carried oxygen to support the aerobic bacteria) turned the light oil into heavy oil.

While the presence of oil in the Heavy Oil Belt has been known since the 1930’s, the first rigorous evaluation of the resources was made in the 1980’s and led to the division of the belt into four areas: Machete, Zuata, Hamaca, and Cerro Negro. The oil in place was estimated at 1,3 trillion barrels, and the recoverable reserves at 267 billion barrels. The “Apertura” in 1995 led to the opening of this belt (in addition to other areas in Venezuela) to the participation of foreign oil companies. These companies have joined with PdVSA to start 35-year projects, which will enable a peak production of 660,000 barrels/day. At the end of the 35-year period, however, less than 3% of the Heavy Belt Reserves will have been recovered.

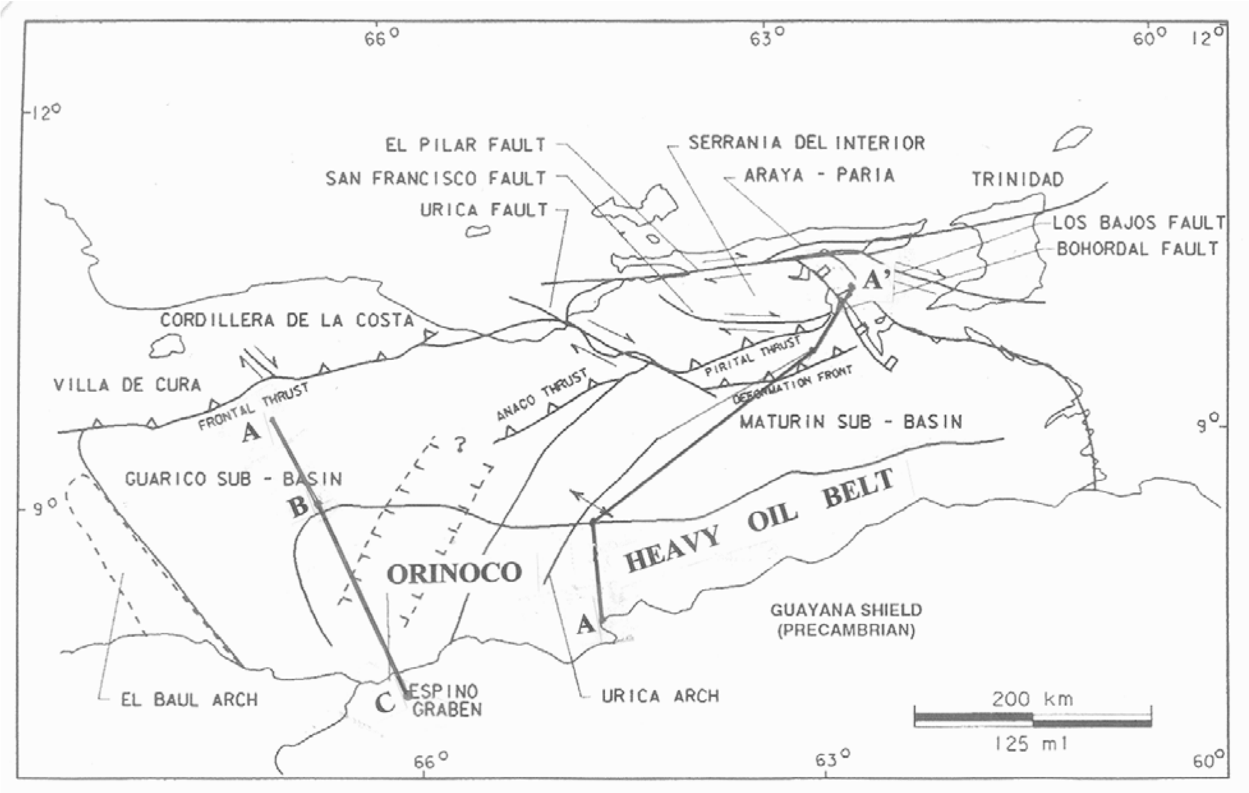
New technology including 3D seismics, horizontal wells and, specifically to these projects, the dissolving of the heavy oil by diluents which enable the heavy oil to be transported to upgrading facilities on the Venezuelan coast, has made these projects viable. (The upgrading facilities upgrade the heavy oil to medium grade oil). Clearly, further investments and further development of technology may be the keys, which would make the Heavy Oil Belt the most important oil producing area in the world.

Introduction

In this study, we consider various aspects of the origin, location, and production of heavy oils in Venezuela. These include the regional geology in terms of the geodynamic evaluation of the area, the stratigraphic model and depositional systems as well as the geologic structure and tectonics. The study of regional geology helps us locate the source beds, the petroleum reservoirs, and the seals, which are essential to the understanding of the petroleum systems. We then turn to questions regarding the estimates of the total quantity of oil in place, the quality of the crudes, the role of bacteria in degrading the oil, and in problems relating to the production of heavy oil. Finally, we turn to the current heavy oil projects.

We note that even though the Heavy Oil Belt lies at the southern edge of the Eastern Venezuelan Basin, it is essential to study the entire basin because the entire basin is involved in the genesis of the Heavy Oil Belt. We also note that the Eastern Venezuelan Basin consists of the Guarico and Maturin subbasins (Figure 2).

Figure 2: Major structural features of the Eastern Venezuelan basin (from Erlich and Barrett, 1992). Geologic sections along A B C and A A' are shown in Figures 6 and 7).



We have relied extensively on and extracted information from the following published papers: Roadifer (1987), Fiorillo (1987), Hollerbach (1987), Erlich and Barrett (1992), de Audemard et al (1987), Taheri and Audemard (1987), and Parnaud et al. (1995). We have obtained information about the current heavy oil projects from the Web sites of the operating companies and government entities.

Geodynamic Evolution and Tectonic History

The geodynamic evolution and tectonic history of the Eastern Venezuela has been described by a number of authors including Parnaud et al (1995) and Erlich and Barrett (1992). We follow the latter authors in the description below.

The Paleozoic and later history of the Eastern Venezuelan basin can be divided into four main phases:

1. A Paleozoic prerift phase.
2. A rift and drift phase during Jurassic and earliest Cretaceous time.
3. A passive margin period ranging from the late Jurassic and Earliest Cretaceous time to the Eocene time.
4. An oblique collision phase resulting in strike slip and compression/transpression. This diachronous phase extended from the Early-Middle Eocene (in the west) to Late Oligocene-Middle Miocene (in the east) and is continuing to the present day.

Paleozoic Prerift Phase

Paleozoic deposits have been mainly identified on the basis of seismic records. In the Guarico subbasin, the Hato Viejo and the Carrizal Formation have been recognized near its southern margin where the total sedimentary cover is very thin. Limited drilling results indicate that these formations consist of fine to coarse-grained sandstones, which are slightly calcareous and intercalated with conglomerates and green shales. They are believed to have been deposited in coastal to neritic marine environments. The Carrizal Formation has been dated as Late Devonian to Early Carboniferous. The Paleozoic sequence reached a thickness of about 1.5 to 2.0 seconds (twt), which is about 3000-5000m. These Paleozoic rocks play no role as source rocks or reservoir rocks in the Eastern Venezuelan Basin.

Rift Phase

When North America separated from Gondwanaland, a part of the opening involved formation of the northern margin of South America. This opening separated Yucatan from northern South America and took place during Late Triassic to Early Jurassic. In the Eastern Venezuelan basin, this phase is represented by Late Jurassic basalts and red beds deposited in the Espino graben (Figure 1). Intense faulting in the northeastern part of the belt, presently known as the Altamira fault zone took place. Apparently, the rifting was not associated with major crustal stretching or major subsidence, which suggests that strike slip or transform faulting, was the major tectonic activity during separation rather than extension. Synrift sediments deposited during this phase are also not important for the generation or accumulation of oil and gas.

Passive Margin Phase

This phase is characterized by the passive subsidence of the northern margin of South America from the Late Jurassic or Earliest Cretaceous to the Eocene. During this time, 3 or 4 km of marine clastic rocks - including several thick Early Cretaceous carbonate units - were deposited. This phase is also notable for the deposition of the organic risk Querecual and San Antonio units, which are the source rocks for the heavy oil.

Strike-Slip and Compression/Transpression

The oblique collision of the Caribbean plate with the South American plate with strike-slip and compression/transpression tectonics led to the development of a foreland basin. The foreland basin deposits overlie the passive margin deposits. The oblique and hence time transgressive collision started in the Early Middle Eocene in the west and was most prominent during the Oligocene-Middle Miocene in the east. Overthrusting resulting from the collision gave rise to uplift and erosion.

South of the thrust belt lay the foredeep and further south, flexural and isostatic upwarping occurred. This pattern progressed from west to east. This is illustrated by the collision and overthrusting of the Coridillera de la Costa/Villa de Cura on to the passive margin of South America in the Eocene with the development of the western and northern Maturin subbasin to the south but with flexural upwarping further south (immediately to the north of the Guyana

Shield). See Figure 2. This is further illustrated by the Early Miocene compression/transpression between the Caribbean and South American plates which caused overthrusting and uplift of the Serrania del Interior, down warping of the Central Maturin subbasin and flexural or isostatic uplift of parts of the Guarico subbasin. The southward thrusting of the Serrania del Interior continued into the Miocene. The tectonics and depositional history of the foreland basin played a critical role in the heavy oil systems. Reservoirs in the Merecure, Oficina and Freites formation range in age from Oligocene to Middle Miocene and in the Las Piedras they are of Plio-Pleistocene age. These reservoirs as well as the seals by the thick shales of the Carapita formation were deposited during this phase. The traps that are associated with faulting were also formed during this phase.

Stratigraphic Model and Depositional Systems

Paleozoic Pre Rift phase and Mesozoic Rift Phase

Rocks deposited during the Paleozoic prerift phase and the Mesozoic rift phase have little significance with respect to the Heavy oil Belt and we discuss these only very briefly. Well data show that Cambrian sandstones of the Hato Viejo formation are at least 90 m thick and the Cambro-Ordovician sandstones and shales of the Carrizal formation are at least 640 m (both the Hato Viejo and the Carrizal Formations were found in wells at the southern margin of the Guarico subbasin). Also, according to Erlich and Barrett (1992), rocks of Pre Cretaceous age may have been originally more widespread prior to initial rifting and erosion in the Middle to Late Jurassic. At any rate, the rift stage rocks do not occur South of El Pilar fault. Rift-related Jurassic igneous rocks do occur in Eastern Venezuelan basin in grabens. Basalts in the Espino graben are especially notable.

Passive Margin Phase

The Passive margin deposition is characterized by three principal transgressive phases. The first phase commenced with the deposition of the basin sandstone of the Barranquin formation in the Barremian (Figure 3). As the transgression progressed, platform limestones were deposited. These constitute the Albian El Cantil formation and the Albian to Turonian Querecual and San Antonio formations. The main source rocks were deposited during the transgressive phrase.

These organic rich marine mudstones were deposited between the El Pilar fault and the deformation front (Figure 2) and are coeval with the deposition of platform carbonates to the south. The maximum transgressive advance to the south took place in the Turonian and is characterized by the deposition of the Tigre Formation, which forms the top of the Temblador group. This group is mainly non-marine but grades up to the upper Canoa and Tigre Formations.

The second transgression took place during the Maastrictian-Eocene and is characterized by the massive sandstone of the San Juan formation and the overlying black shales of the Vidono formation. At the end of this trangression, epeirogenic uplift of the Heavy Oil Belt and the Guyana shield took place, and the area was subsequently eroded to a peneplain. The eroded late Paleocene - Early Eocene section is the first stratigraphic evidence of the collision and overthrusting of the Cordillera de la Costa/ Villa de Cura allochthon (Figure 2) onto the passive margin of South America.

The first transgression following the oblique collision took place in the Oligocene and commences with deposition of the basal sandstone of the Roblecito Formation (Mercure group equivalent). It consists of alternating fine to coarse-grained sandstones and shales. These sediments are derived from the Guyana shield to the south; the deposition environment was continental to the south grading to an inner shelf environment to the north.

The Roblecito formation marks the maximum point of transgression and is overlain by the regressive sandstones of the Chaguaramas Formation. These two (Roblecito and Chaguaramas) Formations are the equivalent of the Mercure group (Figure 4). They are present only in the western part of the Heavy Oil Belt (Machete and Western Zuata areas) and form reservoirs for heavy oil.

Early Miocene compression/transpression between the Caribbean and South American plates caused overthrusting and uplift in the Serrania del Interior, down warping of the Central Maturin subbasin and flexural or isostatic uplift of the Guarico subbasin east to the Urica arch.

During the Miocene cycle, the most important reservoirs in the belt, the Oficina and the Freitas (Figures 3 and 4) were deposited conformably overlying the Mercure formations. The thick shale sequence of the Carapita formation was deposited in the foredeep to the north and generally forms the main seal of the Oligocene - Miocene Mercure, Oficina, and Freitas reservoirs.

Figure 3: Generalized stratigraphy of the study area showing source rocks and reservoirs. (The lightly stippled rock types are not producing reservoirs). After Parnaud et al. 1995.

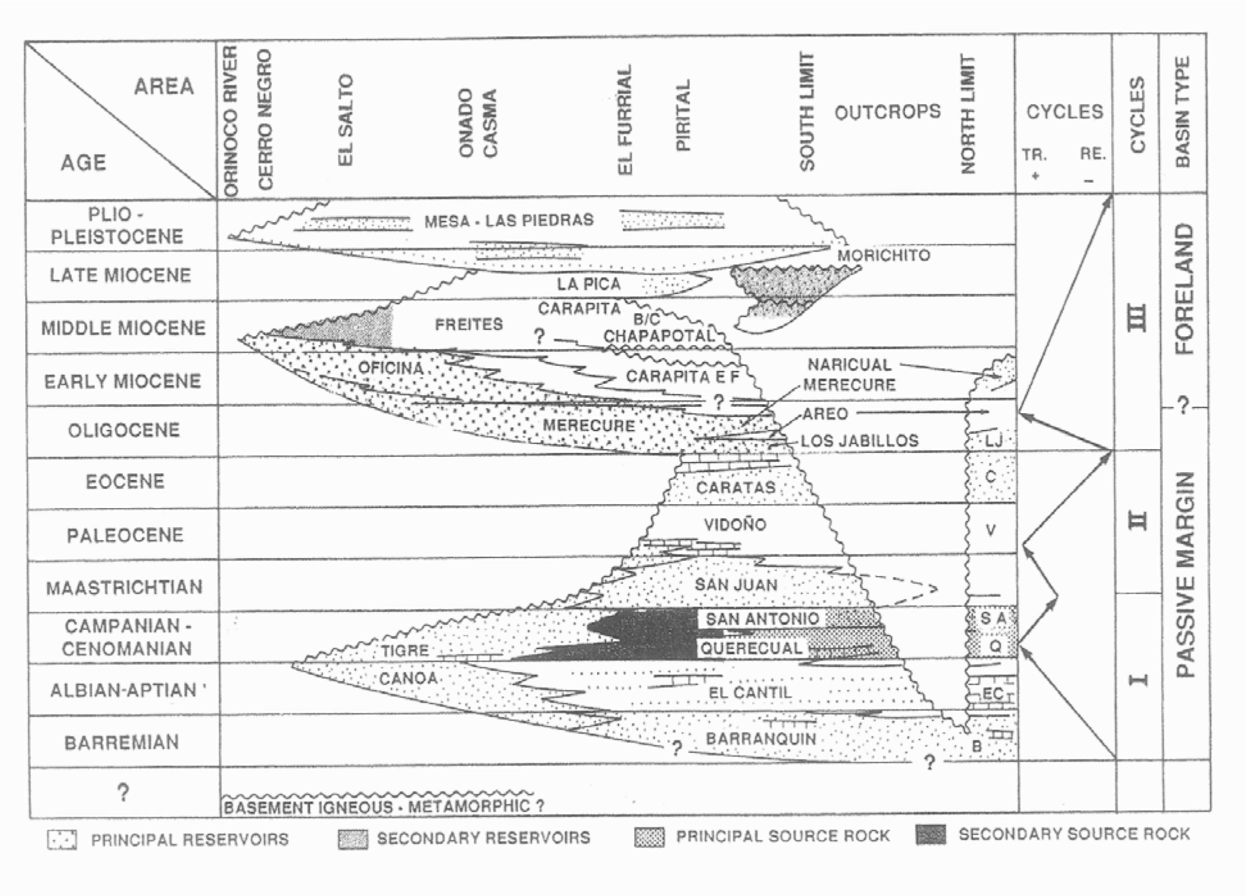
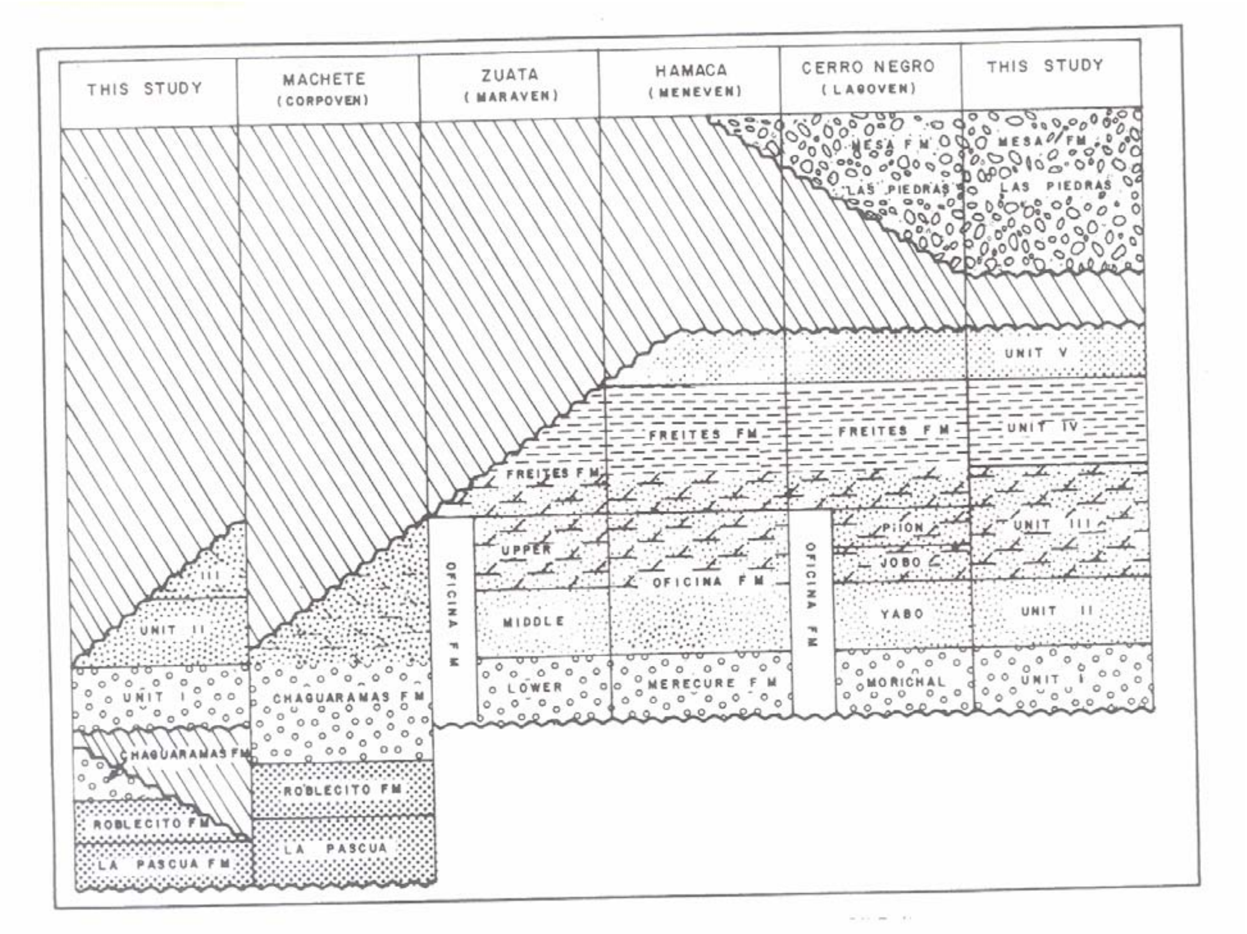
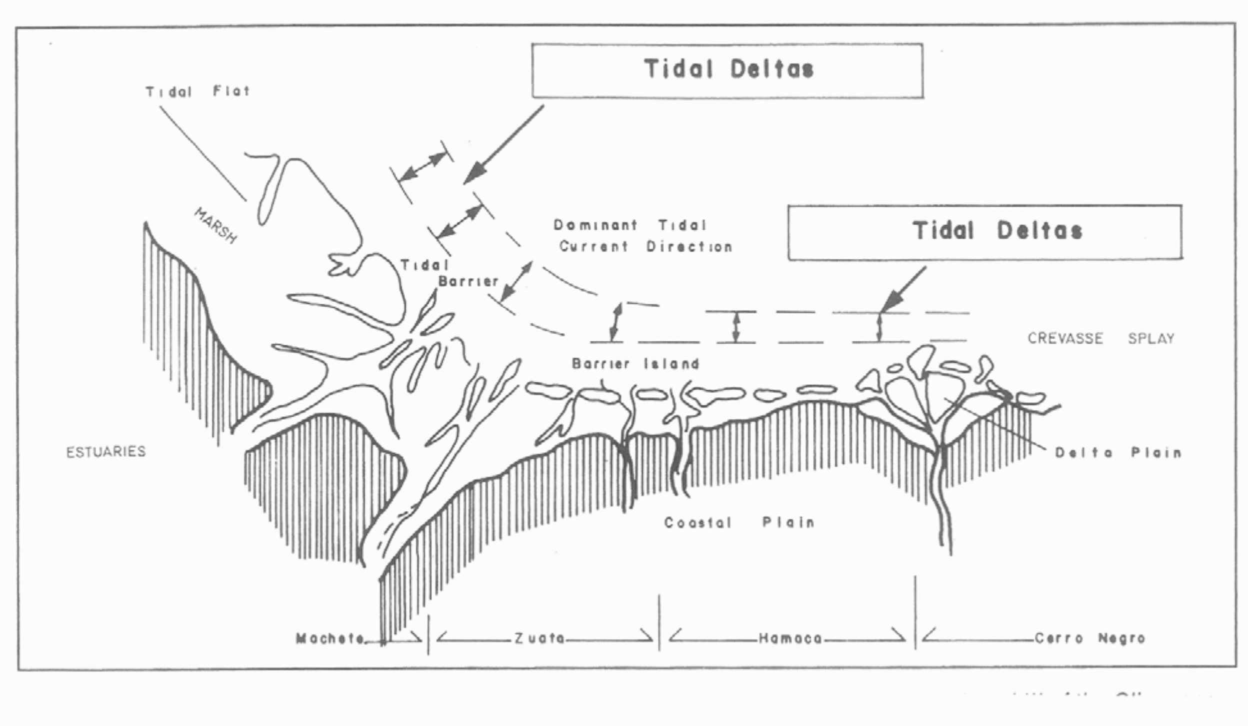


Figure 4: Stratigraphic correlation chart of Tertiary formations in the Orinoco Heavy Oil Belt. The Merecure and Freites Formations are the main reservoirs. (From Fiorillo, 1987)



The general direction of sedimentation of the basal Oligocene to Miocene sandstones that form the most important reservoirs was from south to north corresponding to various deltas nurtured by rivers flowing from the south (Figure 5). The lower part of the basal units constitutes the fill of the paleo topography and is very variable in thickness. Transgressive shore and bar type sandstones form the upper part of the basal units. The marine influence is greater to the east and results in the successive increase of mud areas in the delta plain from Hamaca through Zuata to Machete towards the west. The fluvial late-Miocene-Pliocene Las Piedras Formation conformably overlies older rocks and forms the youngest reservoir in the area. Figures 6 and 7 show geologic cross sections in Guarico and Maturin subbasins respectively.

Figure 5: Sketch of the paleogeographic elements that controlled the sedimentation of units I, II, and III in Figure 4, (From Fiorillo, 1987)



Structure and Tectonics

The Hato Viejo fault system (Figure 8) divides the Heavy Oil Belt into two structural provinces. West of the fault system, in a large section of the Machete and Zuata areas, the Tertiary lies unconformably on thick sequences of Cretaceous and Paleozoic sediments, which were deposited, in a deep structural depression. East of the fault system the tertiary lies over the Precambrian igneous-metamorphic basement of the Guyana shield.

The Heavy Oil Belt is terminated on the west by the structural Machete high (not shown in the maps in this paper) which is oriented in the northeast-southwest direction. The Heavy oil belt consists of a number of rigid blocks separated by faulting. There is no evidence of folds within the belt. In the Eastern Province the faults which are of the normal-tensional type have three preferential directions: (1) An east-west orientation corresponding to the strike of a hinge line north of Hamaco and Cerro Negro, (2) N 60^0 - 70^0 E, a trend parallel to the predominant direction of the oldest rocks in the Guyana shield and (3) N 30^0-45^0W, a prominent orientation reflecting the Pre-Tertiary topographic trends. In the Western province the predominant directions of faulting are east west and northeast southwest. The average vertical displacement of the faults is about 60 m regardless of orientation. The traps can be stratigraphic pinchouts or structural truncations. Sands associated with meanders of the north flowing rivers from the Guyana platform often serve as reservoirs, the traps being provided by the intersecting faults with the Carapita shales (Figure 2) often providing the seals.

SOURCE ROCKS, OIL KITCHENS AND MIGRATION PATHS

Oil in the Heavy Belt found in Tertiary reservoirs originated most likely in the upper Cretaceous Querecual and San Anatonio formations deposited a few hundred kilometers to the north in the Pirital slab and the Serrania del Interior region. The hydrocarbon yield of the Querecual and San Antonio varies and largely the varying depositional environment may govern the variation. These formations consist largely of black cherts and limestones, which were deposited, in a pelagic marine environment. The average TOC content varies between 2 to 6% of the weight with a petroleum potential higher then 5 mg HC/g rock. Less important source rocks also are present in the Carapita (which is mainly gas prone) and Oficina formations.

The oil in the Cerro Negro area and presumably in other areas of the Heavy Oil belt has a marine signature and is believed to be derived from the Cretaceous Querecual and San Antonio formations. Talukdar (1991) concluded that the Cretaceous rocks of the Eastern Venezuelan Basin passed through the oil window progressively from north to south. This progression is shown in Figure 9. It is notable that in the rocks of the Heavy Oil Belt the oil is immature. Therefore the heavy oil came from elsewhere. Migration of oil proceeded from north to south. Long distance migration of up to a few hundred kilometers probably took place in the Late Middle Miocene and this oil is now preserved in the reservoirs of the Heavy Oil Belt. Faulting after this time, which cut off the supply to the Heavy Oil Belt, disrupted these long and laterally continuous pathways.

CHARACTERIZATION OF QUALITY OF THE CRUDE

Taheri and Audemard (1987) applied multivariate statistics to characterize the quality of the crude in the Heavy Oil Belt. They considered 14 crude characteristics but were able to establish that five crude properties (API gravity, viscosity at $210^{0\ F}$, Vanadium, Sulfur and asphaltine content) are sufficient to characterize the crude, which they divided into four categories, A, B, C, and D. As one proceeds from A to D the following changes take place successively: The API gravity decreases and the viscosity, sulfur and vanadium content increase. These characteristics are shown in Table 1. Obviously A category oils are the most desirable and D the least.

The following description of the locations of the oils in the four categories is extracted from Taheri and Audemard (1987).

Group A oils are located predominantly in the northeastern part of Zuata and the northwestern part of Hamaca.

Group B oils are also found in a belt located in the northern part of Zuata and Hamaca, which extends from the eastern Machete boundary in a narrow band that widens in eastern Zuata to the western part of Hamaca.

Group C crudes are located in an area that extends from Central Zuata to Cerro Negro. In Hamaca and Cerro Negro they occur in sub parallel and elongated zones separated by other zones with lower quality crudes.

Group D extra-heavy crudes occur generally along the southern part of the belt extending from Machete to Cerro Negro.

Audemard et al (1987) discuss the crude quality by area rather than by category. The following is extracted from their publication:

Machete area. Crudes generally have low API gravity (5^0 - 11^0), high viscosity (400 or - 1000 cst at 210^0 F), high V (600 - 1100 ppm), high S (3.5-5.4%0, and high asphaltine (13-22%). In terms of regional distribution, the crudes tend towards Group D towards the south. There seems to be no correlation of category with depth, probably because the crude is located in reservoirs of different ages.

Zuata area. Crudes in this area are almost totally degraded. Also in these crudes there is a directly proportional relationship between API gravity and depth. Groups A and B crudes reside in the northern part of the area and group C in the central part.

Hamaca area. 90% of the crudes in this area are totally degraded. Group B crudes reside in the northern part of the area and in an NW-SE lobe in the central part. Lower API gravity crudes reside in the SW and SE parts of the area. No relationship seems to exist between API gravity and depth.

Cerro Negro area. Almost all the crudes are totally degraded. Group A oils exist in the northeastern part of the area and heavier crudes in the southwestern part. API gravity does not appear to correlate with reservoir depth.

Figure 10 is a generalized map showing the API gravity values in the Heavy Oil Belt.

EVALUATION OF TOTAL OIL IN PLACE

In the Machete area CORPOVEN used the shaly sand technique and the Simondoux equation to interpret the logs of 66 wells. In the Zuata area MARAVEN applied the Waxman Smits shaly sand techniques in 154 wells. In the Hamaca area MENEVEN also applied the Waxman Smits shaly sand technique in 150 wells. In the Cerro Negro area LAGOVEN used the shaly sand technique and the Simondoux equation in 45 wells. In order to make an estimate of the Net Oil Sand thickness (NOS) cut off values for various petrophysical parameters such as porosity, water saturation, oil saturation, shaliness index, and pay thickness have to be established. Table 2 gives the cut off values of parameters of Net Oil Sands (NOS) in the four areas. Table 3 lists the ranges and average values of reservoirs in all four areas. The map in Figure 11 gives the NOS thickness in the Heavy Oil Belt as well as an estimate of the total oil in place. Table 4 gives a range of average values of the fluid properties of the crude oils.

Thus we see from Figure 11 that the Heavy Oil Belt contains an estimated amount of nearly 1.2 trillion barrels of heavy oil of napthenic base containing large amounts of vanadium, nickel, and sulfur. The oil is heavily degraded. The estimates of recoverable oil are shown in Table 5.

MICROBIAL DEGRADATION

Heavy oil is heavy (low API gravity) due to escape of volatiles during migration, but more importantly due to microbial action. Microbial action is also responsible for the high sulfur content of heavy oils. Some conditions must be met to carry out sub-surface biodegradation. Meteoric waters, which contain oxygen and bring bacteria to the oil to aid biodegradation are important. (In the Zuata area degradation is less where meteoric water circulation is limited by shale seals). Waters that induce degradation must contain dissolved oxygen at least at 8 ppm in order to maintain aerobic bacteria. The waters must contain nutrients and the reservoir temperature must not exceed 80 degrees C in order for the bacteria to survive. Hydrogen sulphide, which kills them, should not be present.

It appears that heavy oil with high sulfur content is produced through a complex process involving aerobic bacteria, which degrade the petroleum, and anaerobic bacteria, which synthesize hydrogen sulfide, which, in turn, limits the growth of aerobic bacteria. If this growth were not limited, the bacteria would degrade the oils, which would end in their transformation to solid bitumens and asphalts and even further to carbon dioxide and water. Thus heavy oil with high sulfur content results from a synergistic process in which the aerobic bacteria degrade the oil by reducing the light hydrocarbons, and the anaerobic bacteria synthesize hydrogen sulfide, which not only thus increases the sulfur content but also inhibits any further activity of the aerobic bacteria. Figure 12 sketches this process.

PROBLEMS RELATING TO PRODUCTION OF HEAVY OIL

Heavy oil is difficult to produce because of its high viscosity and it is expensive to refine because of its high sulfur and metal content. We deal here only with difficulties related to production. Two kinds of methods have been used for producing the oil in the Heavy Oil Belt-methods that employ steam and those that employ diluents.

Steam can be used in the Steam Stimulation ("Huff and Puff') methods or by Steam Flooding. In the Steam Stimulation method, steam is injected into the reservoir for a period of several weeks. The well is then allowed to flow back and then pumped. Several cycles of Steam Stimulation are carried out until the volume of oil that is recovered relative to the volume of steam that is injected is not cost effective. This method enables rapid recovery of oil at the outset but generally limits the oil recovered to 15%, and therefore, is not a very good method for total recovery of oil from a field, but it has been widely used in the past in Venezuela.

In Steam Flooding, steam is injected continuously into injection wells and produced continuously at production wells some distance away. Steam Flooding is generally carried out in "patterns"; a typical pattern consists of a central injection well and eight surrounding wells located at the corners and the middle of the sides of a square surrounding the injection well. The dimensions of the square vary with the depth of the reservoir; the deeper the reservoir, the bigger the square. This method has been used with much success in the heavy oil fields of California and Indonesia. Examples are Texaco's Kern River field in California and the Duri field in

Indonesia. This method works well when there is more or less uniform permeability in the reservoir. Where the permeability is different in different directions from the injection well, much wastage of steam can occur. Temperature monitoring wells within the pattern can help to monitor the advance of steam in different directions and on the basis of temperature information gathered; additional producing wells can be located. Recently a remote sensing technique- time-lapse gravity gradiometry has been suggested by Talwani et al. This technique utilizes measurements of gravity gradient on the surface of the field at time intervals, generally of several months to monitor changes in the gravity field due to replacement of oil by steam. This procedure serves to monitor the location of the steam oil interface. A variation of the steam flooding technique is the SAGD (Steam Assisted Gravity Drainage) method in which steam is injected through horizontal wells. Parallel producing wells are placed below the injection wells. Both kinds of wells are placed near the bottom ob the reservoir. Steam raises from the injection wells, making the oil above it more mobile. Gravity assists in draining the oil and condensate through the production wells.

The current projects in the Heavy Oil Belt use a different method for producing oil. They make use of the fact that even though the oil is heavy, it is still mobile in the reservoir because of the existing temperatures there. Oil is produced by employing down hole pumps to pump the oil to the surface where it is diluted with a very light oil and then piped to an upgrader located on the Venezuelan coast. At the upgrader the heavy oil is upgraded to lighter oil and the diluent is returned to the wellhead and recycled. The upgraded oil known as “syncrude” has higher API gravity and is generally classified as Medium Grade oil, and is easier to transport and refine.

HISTORY OF OIL EXPLORATION IN THE EASTERN VENEZUELAN BASIN

The Heavy Oil Belt lies in the southern part of the Eastern Venezuelan Basin and since the exploration histories of the different parts of the entire basin are closely linked, we will, in the following, discuss the history of exploration of the entire basin, The progress of the exploration was governed by several factors including the development of new technology, licensing arrangements, political developments, and international oil prices. The technology developments fall into two classes: those that were applicable to all oil and gas exploration (not confined to heavy oil) and those that are specific to heavy oil production.

The first discovery of oil was (as has been the case of first discoveries in all parts of the world) through an oil seep, the Guanaco seep in 1890. (The Guanaco field as well as other fields in the Eastern Venezuelan Basin is indicated in Figure 13). Actually even earlier, in 1539, a barrel of oil from an oil seep was transferred to Spain aboard the Santa Cruz for medicinal use by the king. Serious exploration in the Eastern Venezuelan Basin began in 1909 when the Governor General of Venezuela granted exploration leases to the Venezuelan Development Company. The Bermudez company drilled the first successful exploratory well in 1912-1913 in the Guanaco heavy oil field; however the first major discovery in the Eastern Venezuelan Basin did not come until June 1928, when Stanolind (Amoco) and Standard Oil of Venezuela drilled the wildcat Moneb-1 well to discover the giant Quiriquire field in the Maturin sub-basin. This was followed by Gulf Oil's discovery of the Oficina field in 1934. Standard Oil made the first discovery in the Heavy Oil Belt in 1935 when the La Canada-1 well tested at 40 barrels/day of 7 deg API gravity oil. In 1936 the Temblador field was discovered. Note that the Oficina and Temblador fields lie just to the north of the Heavy Oil Belt.

In the 1930's nationalist sentiment began to grow which led to the suspension of oil concessions in 1938 and to a more favorable (from the Venezuelan point of view) level of royalties and the sharing of profits. In 1943 royalties were fixed at a uniform 16.67%, and from 1946, the state obtained 50% of all company profits. In spite of these somewhat draconian measures a vigorous expansion of oil activities took place in Venezuela during the period 1943 to 1958. This expansion was in part due to the application of the common depth point seismic technique, which aided in the discovery of new fields and in the expansion of older fields. Thus the Quiriquere and the Temblador fields were greatly extended. In 1956-57 with the drilling of new wells the production of heavy oil reached a level of 20,000 barrels/day and it was then that the name "Faja Petrolifera del Orinoco" (Orinoco petroleum belt) was given to the area. In 1960 the decision of the Venezuelan government not to grant new concessions and the lowering of world oil prices caused a slump in exploration activities in Venezuela. Between 1960 and1975 only six marginal to medium sized fields were discovered. During this time, in 1967, Galavis and Velarde presented the first formal study of the Heavy Oil Belt. They concluded that 693 billion barrels of oil existed in this area. In 1975 the oil industry was nationalized and in 1978 the Venezuelan government asked Petroleos de Venezuela (PdVSA) to make an evaluation of the petroleum potential of the Heavy Oil Belt. The PdVSA study was completed in 1983. During the course of this study extensive geophysical work was carried out and more than 600 wells were drilled. In addition petrophysical studies as well as studies of the physical and chemical character of the heavy crude oil were carried out. The results of this study have been reported elsewhere in this paper. For the study and to carry out further exploration PdVSA assigned separate areas in the belt to its four national affiliates: Machete area (Corpoven), Zuata area (Maraven), Hamaca area (Meneven), and Cerro Negro area (Lagoven). In July 1995 the government of Rafael Caldera initiated the so-called “La Apertura”. This provided the opening of Venezuela’s first profit sharing and development licensing rounds. Under this process 10 exploration areas were opened for private tender. It is estimated that the Venezuelan government obtained $2 billion in bonuses alone. (It is also believed that some companies, notably Shell, refused to participate in this arrangement). The “Apertura” resulted in a number of companies joining with PdVSA in carrying out exploration and production in the Heavy Oil Belt. It appears that the current president, Chavez, and the current energy minister are not in favor of the opening, although the present government has agreed to let the existing contracts proceed with continuing large amount of ongoing activity. It should also be recognized that recently the regional companies, Lagoven, Corpoven, Maraven, and Meneven have been reorganized. Instead of regional companies, a single company now exists and its various divisions are based on functions rather than regions.

ONGOING PROJECTS IN THE HEAVY OIL BELT

The Orinoco Heavy Oil Belt located in eastern Venezuela north of the Orinoco river covers an area of 54,000 square km, that is, about twice the size of the state of Massachusetts. The belt is about 600 km in length and about 90 km in width. Although the basin associated with this belt is not very large, it contains the largest deposits of extra heavy crudes (<10 API gravity) in the world. The belt has been divided into four areas, Machete, Zuata, Hamaca, and Cerro Negro (Figure 1); All of these areas currently have ongoing exploration and production projects. The Zuata area contains the Sincor and Petrozuata projects, the Hamaca area the Hamaca project, and the Cerro Negro area the Cerro Negro project.

Petrozuata is a joint venture between Conoco (50.1%) and PdVSA (49,9%). It is a 35-year contract that began in 1997 making this the oldest of the current heavy oil projects in Venezuela.

The $2.4 billion project is located in a 55,000-acre area of the Zuata region of the Heavy Oil Belt.

The total recoverable oil in the area of this project is 1.6 billion barrels. Conoco has already exploited its anticipated 680 million barrels with the drilling of over 320 wells. They are currently producing 120,000 barrels per day. When this project is at its peak, Conoco expects that a total of 750 wells will have been drilled which will produce 150,000 barrels per day. The wells in this project use multilateral holes that have five or six horizontal sidetracks. The current drilling record (January 2001) is a 6000 feet (1829 meters) horizontally drilled sidetrack.
The heavy oil is blended with lighter oil for transport to the project's processing facility in San Jose on the Venezuelan coast. The blend is piped along a pair of pipes 200 km long, whose capacity is currently about 200,000 barrels/day. It is expected that this capacity will be expanded to 500,000 barrels/day to accommodate peak production. Petrozuata and Sincor are in discussions to share the pipelines. At the billion dollar upgrading plant, the team will upgrade the heavy oil to light crude oil (8-10 API gravity to 19-25 API gravity). The upgrader plant uses Conoco's specialized delayed coking technology. The production capacity is 104,000 barrels/day of syncrude transformed from the original 120,000 barrels/day of crude oil delivery. **Sincor** is a joint venture project between Totalfinaelf, PdVSA, and Statoil, which have respectively 47%, 38%, and 15% stakes. The cost for this 35-year project is estimated at $4 billion.

The project is slated to exploit the oil resources on a 500 square km area within the Zuata region. The participating companies estimate the total field size to be approximately 48 billion barrels, of which 2.6 billion barrels are to be recovered. The first well of this project was tested in December 1999. Drilling horizontal wells- often with a single vertical section having six to eighteen horizontal sections emanating from it carries out exploitation of this field. Currently there are 80 double-stacked horizontal wells. A vertical to horizontal drilling record has been made on the project with a length of 5,122 meters by a 12.25 inch drill bit. There will be an estimated total of 1500 wells drilled on this project. The initial phase will allow for production to rapidly reach 40,000 barrels/day of extra-heavy crude oil (8.5 API gravity), which will be blended with 25,000 barrels of light crude oil (30 API gravity) to obtain a blend of 16 API gravity oil to be marketed internationally. Output can be increased to 80,000 barrels/day or more of extra-heavy crude depending on market conditions. It is estimated that at its peak, the Sincor project will yield 200,000 Barrels/day of heavy oils.

The heavy oil will be piped to an upgrading plant in San Jose, on the Venezuelan coast, There the peak light oil production is expected to be 170,000-180,000 barrels/day. The drilling project is approximately 71% complete. Full production capacity is expected to be reached by the end of 2002.

Hamaca. The "Hamaca Heavy Oil Project" a joint venture company Petrolera Ameriven (PA) that is jointly owned by Phillips (40%), Texaco (30%), and PdVSA (30%) runs a $4 billion project. The project began in 1996, but drilling for this project, which will run for 35 years, began in the summer of 2000. The goals of this project are to recover and upgrade 2.1 billion barrels of heavy oil from a 30 billion barrel field. PA intends to recover the 8-10 API gravity oil by drilling long horizontal wells and employing down hole pumps. Peak production of 190,000 barrels/day is expected to be reached in 2004. This method of cold production will replace thermal alternative methods of recovery such as steam flooding. The vertical sections of the wells will be 610 to 915 meters, and the horizontal sections will be unto 1.6 km long.

The heavy oil will then be mixed with 47 API gravity naptha blend diluent in order to transport it. The diluent piped to the wellhead through 40 cm pipes is mixed with the heavy oil. And then the mixture is piped 224 km to San Jose through a newly constructed 107 cm PA pipeline and an existing 76 cm PdVSA pipeline. In San Jose PA is building a $1 billion upgrading facility that will extract the diluent and convert the heavy oil into 26 API gravity syncrude. The upgrader facility is expected to come on line in 2004. While this upgrader is in the construction phase, production of 36,000 barrels/day of crude will be blended with 20,000 barrels/day of lighter 30 API gravity oil, and sold on the open market.

Cerro Negro is the second oldest major heavy oil project in the Faja Orinoco. It represents a $2 billion investment (ExxonMobil 41.67%, PdVSA 41.67%, and Veba Oil and gas 16.66%).

The goal of the project is to recover 1.5 billion barrels of heavy oil from the Cerro Negro region. The project began with 3D seismic data in 1997, and followed with drilling development and facilities construction. The oil is recovered from the ground at a temperature of 130 degrees F;

Each well has horizontal sections off a main vertical hole and produces about 2,000 barrels/day of heavy oil. The heavy oil recovered is diluted with light oil and piped 350 km to an upgrading facility in San Jose. Peak production was anticipated for March 2001 at 120,000 barrels/day of syncrude.

SUMMARY OF ONGOING PROJECTS

Table 6 summarizes information about the projects in the Heavy Oil Belt since the "Apertura". (No information is available for projects in the Machete area). A number of foreign oil companies (Conoco, TotalFinaElf, Statoil, Phillips, Texaco, ExxonMobil, and Veba) together with PdVSA have invested a total of $12.4 billion in heavy oil projects, which have been licensed for 35-year periods. Several thousand wells will be drilled during this period. The general pattern of drilling consists of a single vertical well with five to eighteen horizontal wells emanating from each vertical well.

The peak production at the end of the present decade is estimated at 660,000 barrels/day, which over the 35-year life of these projects will amount to slightly less than 8 billion barrels, a quantity less than 3% of the total recoverable oil in the Heavy Oil Belt. Thus even with the investment of more than $12 billion, only a small fraction of the total recoverable oil is going to be recovered over the length of these projects, It is of interest to note that the peak production rates could only fulfill about 6% of the daily oil import requirements of 1.1 million barrels/day by the U.S. Clearly a much larger rate of investment is needed if a larger part of the import needs of the U.S. are to be met from Venezuelan Heavy Oil.

APPENDIX

Figure 6:
East- west structure cross-section and composite structural map drawn on the upper surface of basement (From Fiorillo, 1987).

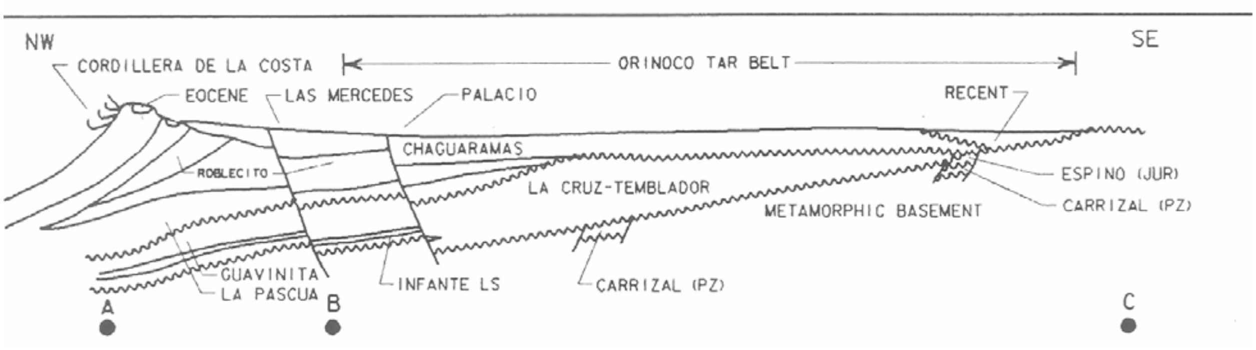


Figure 7:

Geologic cross section through the Guarico subbasin. Location of section is shown in Figure 2. (From Erlich and Barrett, 1992).

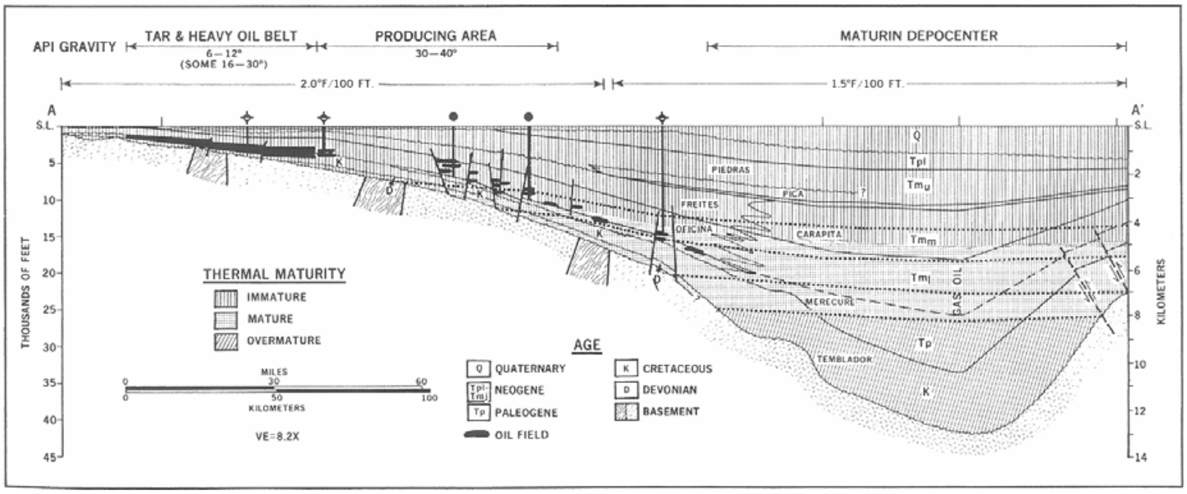


Figure 8:

Geologic cross section through the Maturin subbasin. Location of section is shown in Figure 2. (From Roadifer, 1987).

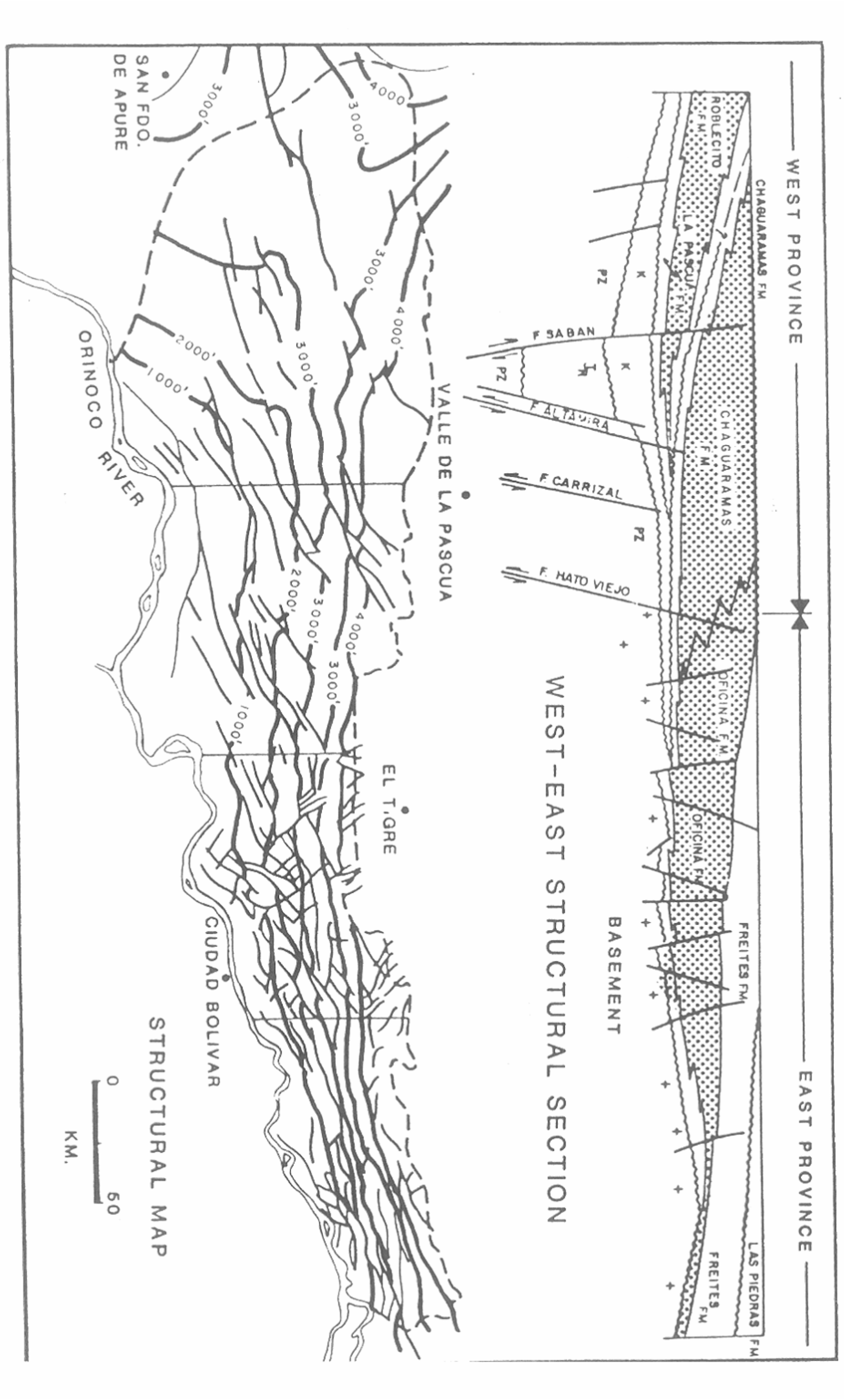


Figure 9:
Oil “kitchens” of the Guarico and Maturin subbasins. Time indicated represents the interval during which the Cretaceous and Early Tertiary source rocks were within the oil window (rocks within the Orinoco Heavy Oil Belt are immature; very early stage of maturity at present). Arrows show dominant hydrocarbon migration direction. (From Erlich and Barrett, 1992 who adapted it from Talukdar (1988) and Talukdar (1991)

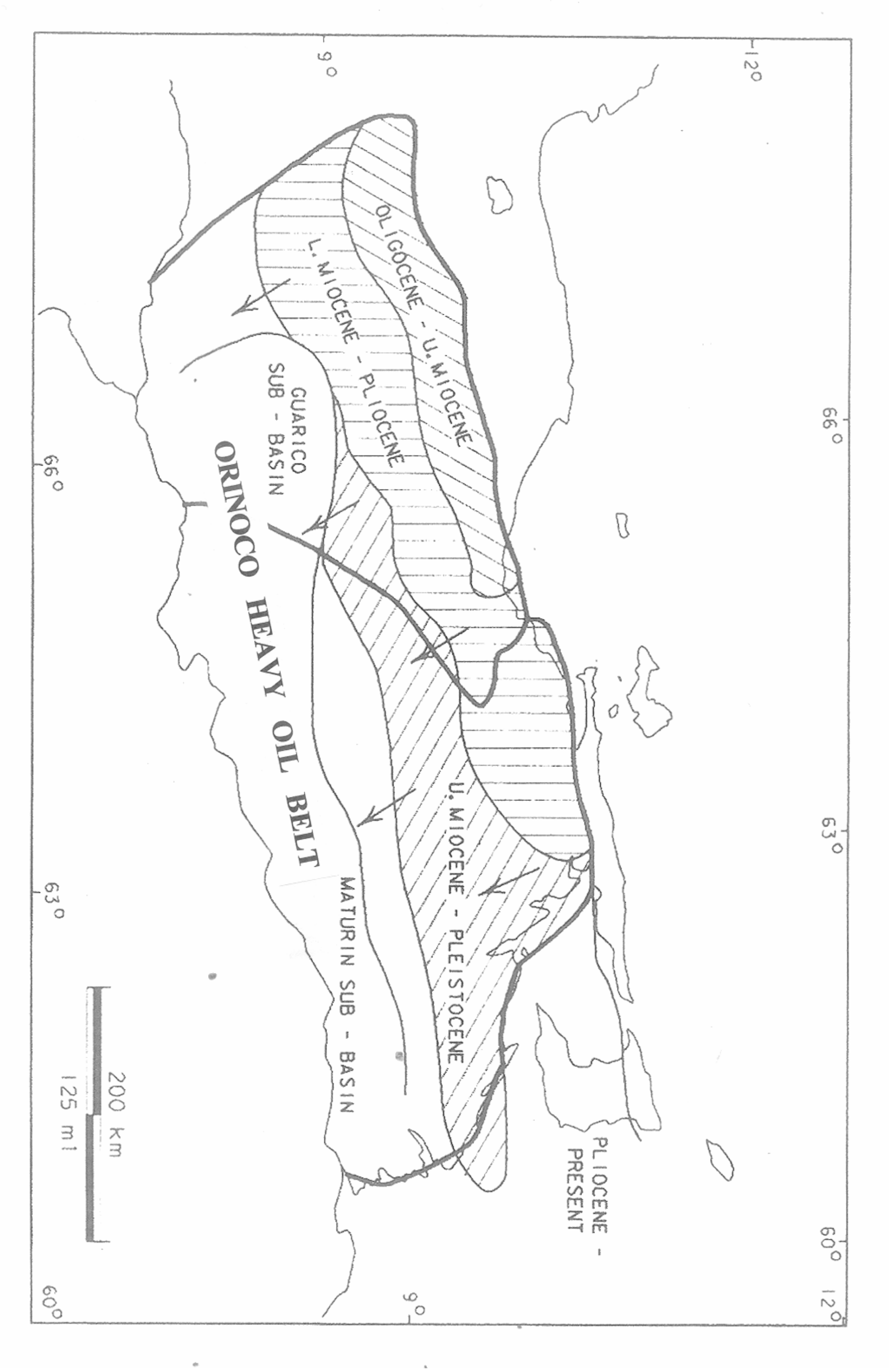


Figure 10:
Map showing API gravity values of heavy oil in the Orinoco Heavy Oil Belt. (From Fiorillo, 1987)

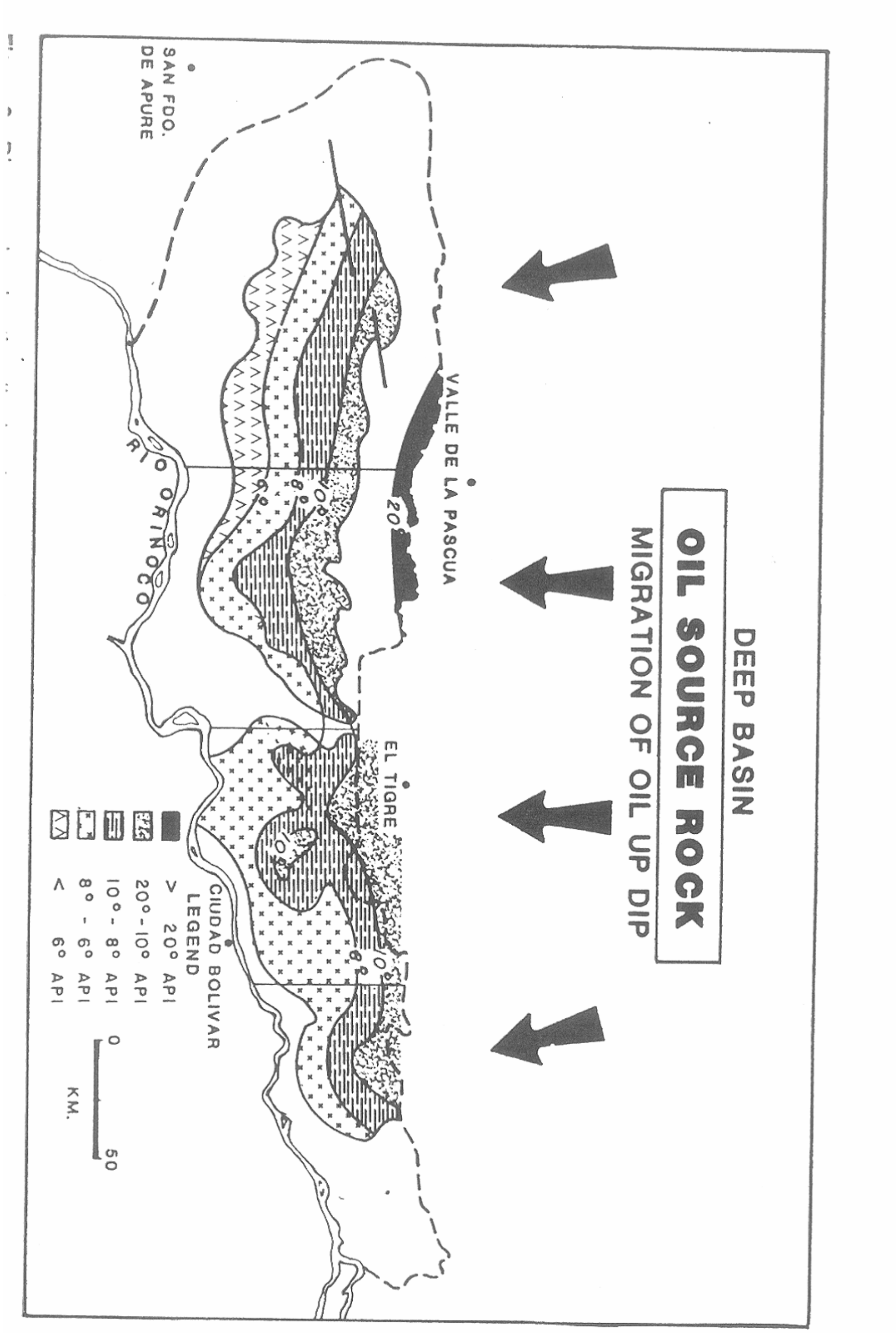


Figure 11:
Map of major oil accumulations (millions of oil in place) and net oil sand thickness (NOS) in the Orinoco Heavy Oil Belt.

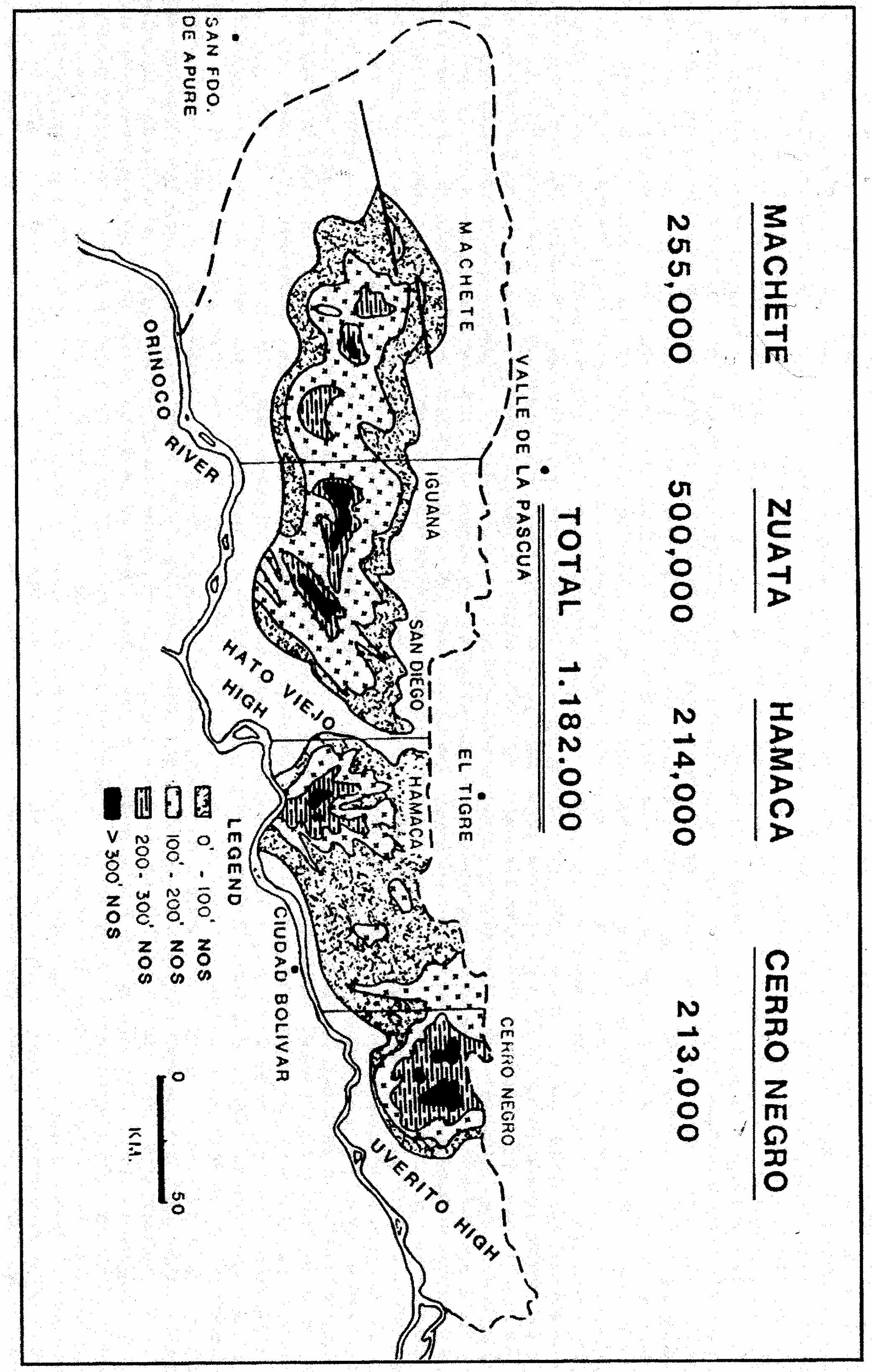


Figure 12:
Sketch of Biodegradation of petroleum. (From Hollerbach, 1987)

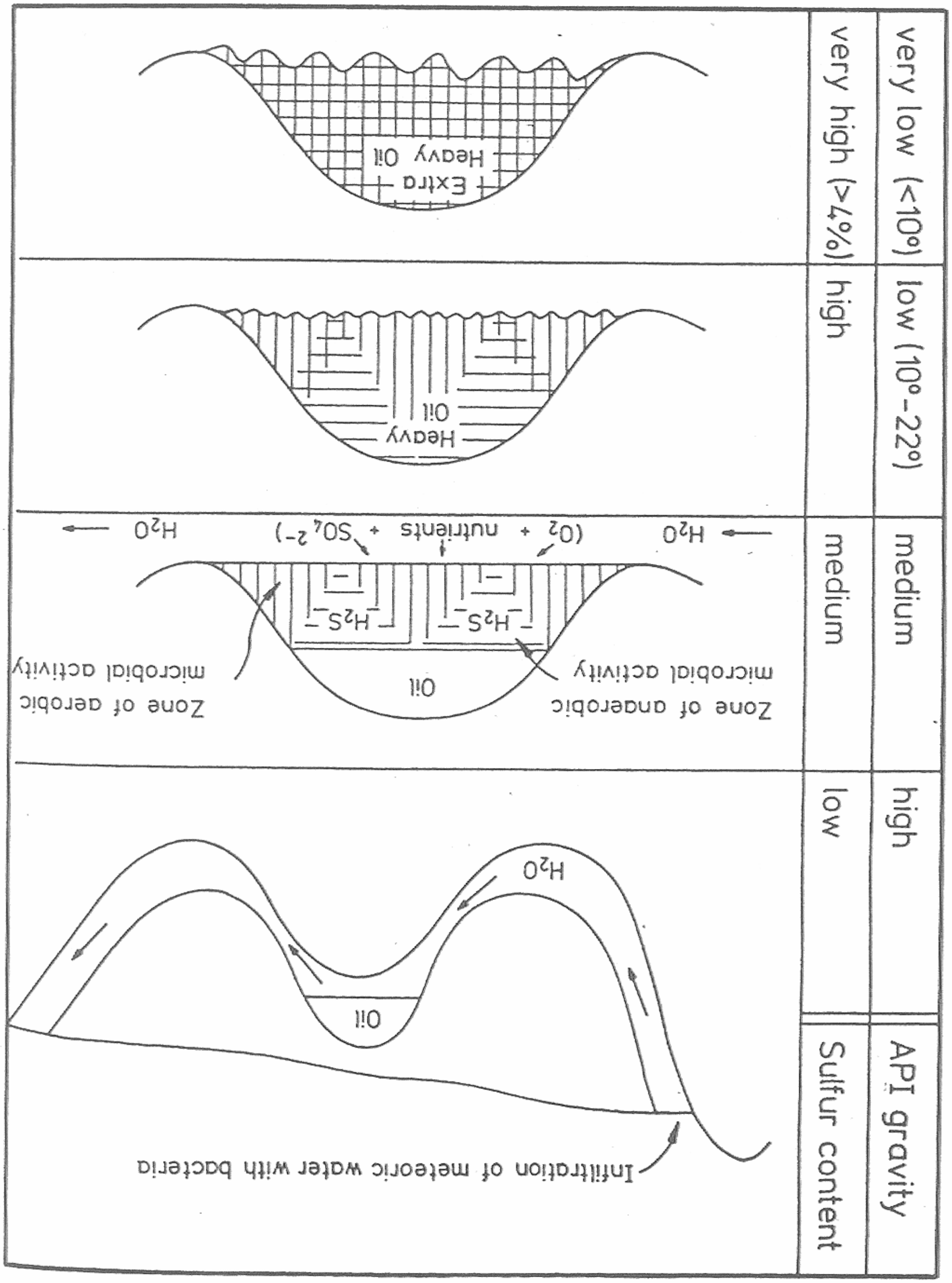


Figure 13:
Major hydrocarbon provinces of Eastern Venezuelan Basin. Numbered dots in the Maturin subbasin show the locations of recent important ells: 1=Boqueron-3, 2=El Furrial-1, 3=Amarillis-1, 4=El Carito-1X, 5=Bosque/El Tejero-2E.

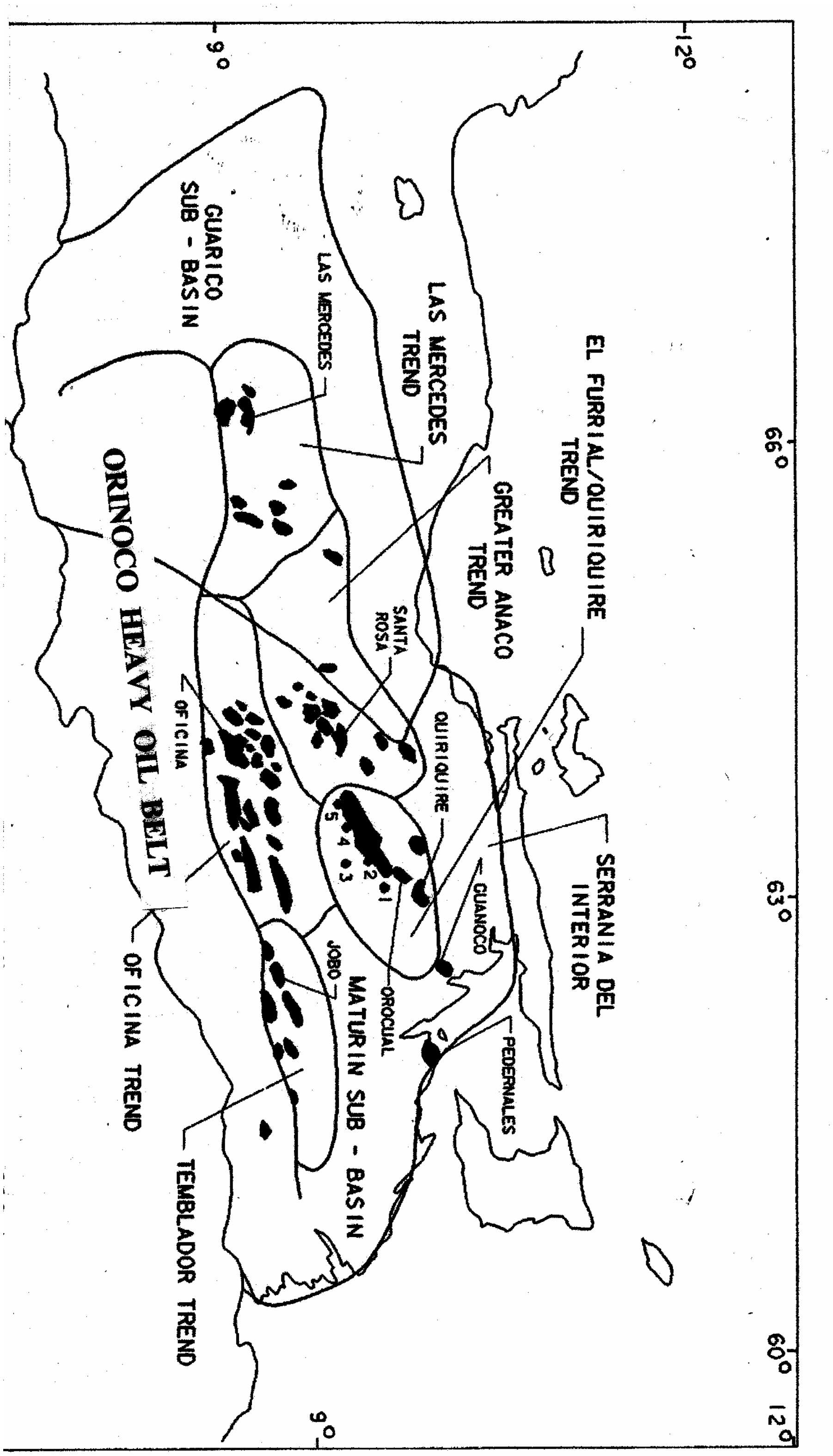
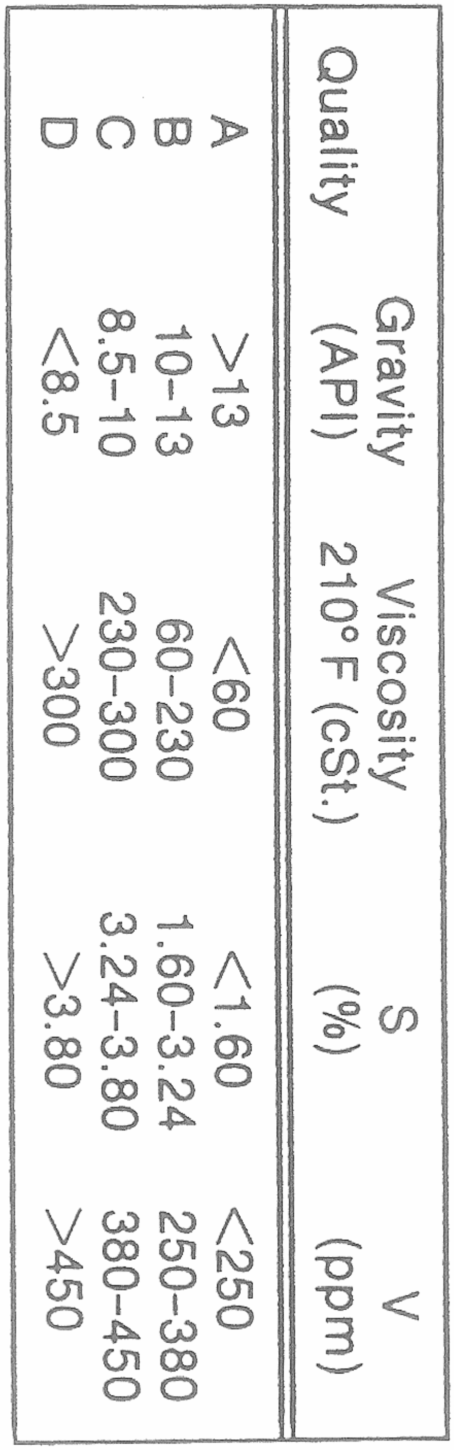
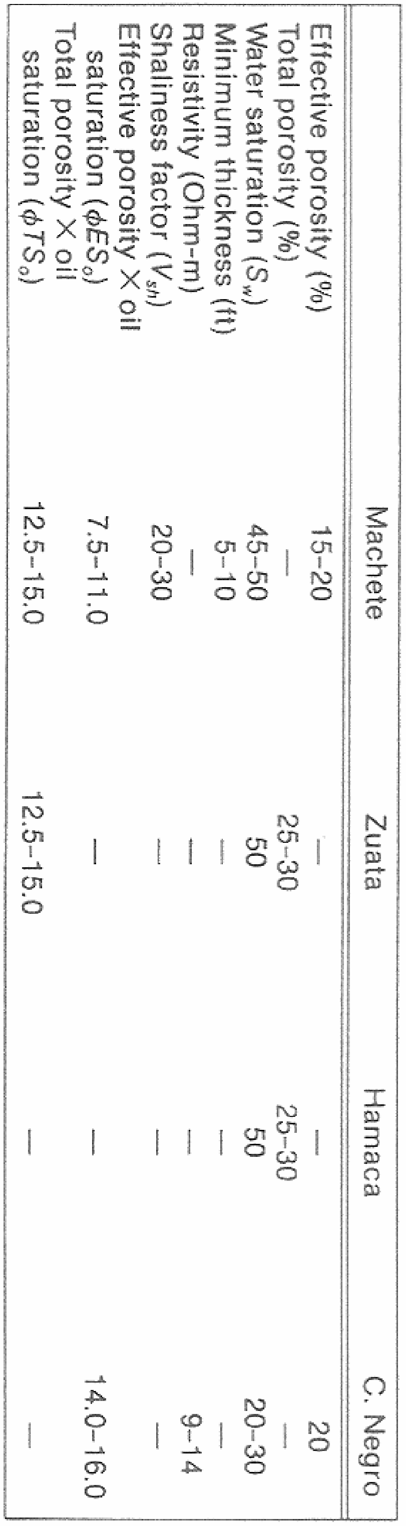


**Table 1:
Range of variation of the crude properties in the Orinoco Heavy Oil Belt.
(From Fiorillo, 1987).**



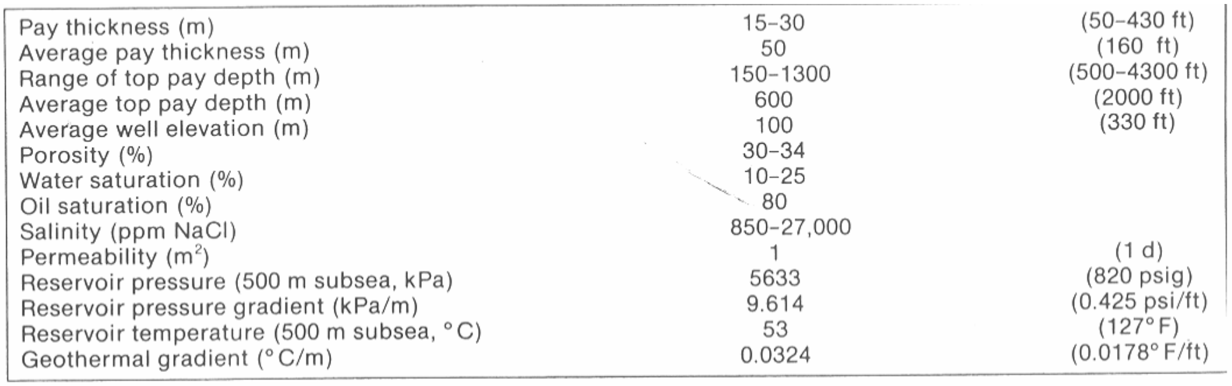
Quality	Gravity (API)	Viscosity 210° F (cSt.)	S (%)	V (ppm)
A	>13	<60	<1.60	<250
B	10–13	60–230	1.60–3.24	250–380
C	8.5–10	230–300	3.24–3.80	380–450
D	<8.5	>300	>3.80	>450

Table 2:
Cut off values of parameters for the calculation of net oil sand (NOS) in Orinoco Heavy Oil Belt. (From Fiorillo, 1987).



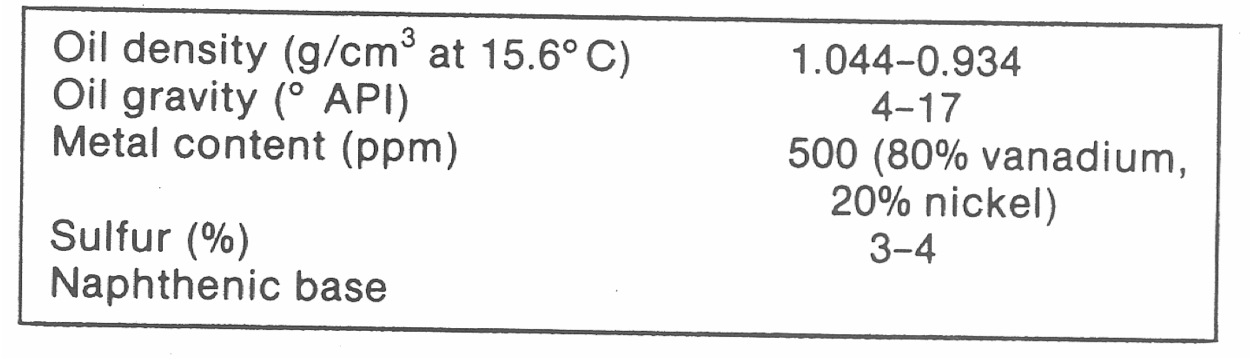
	Machete	Zuata	Hamaca	C. Negro
Effective porosity (%)	15–20	—	—	20
Total porosity (%)	—	25–30	25–30	—
Water saturation (S_w)	45–50	50	50	20–30
Minimum thickness (ft)	5–10	—	—	—
Resistivity (Ohm-m)	—	—	—	9–14
Shaliness factor (V_{sh})	20–30	—	—	—
Effective porosity × oil saturation (ϕES_o)	7.5–11.0	—	—	14.0–16.0
Total porosity × oil saturation (ϕTS_o)	12.5–15.0	12.5–15.0	—	—

Table 3:
Ranges and average values of reservoir data in the Orinoco Heavy Oil Belt. (From Fiorillo, 1987).



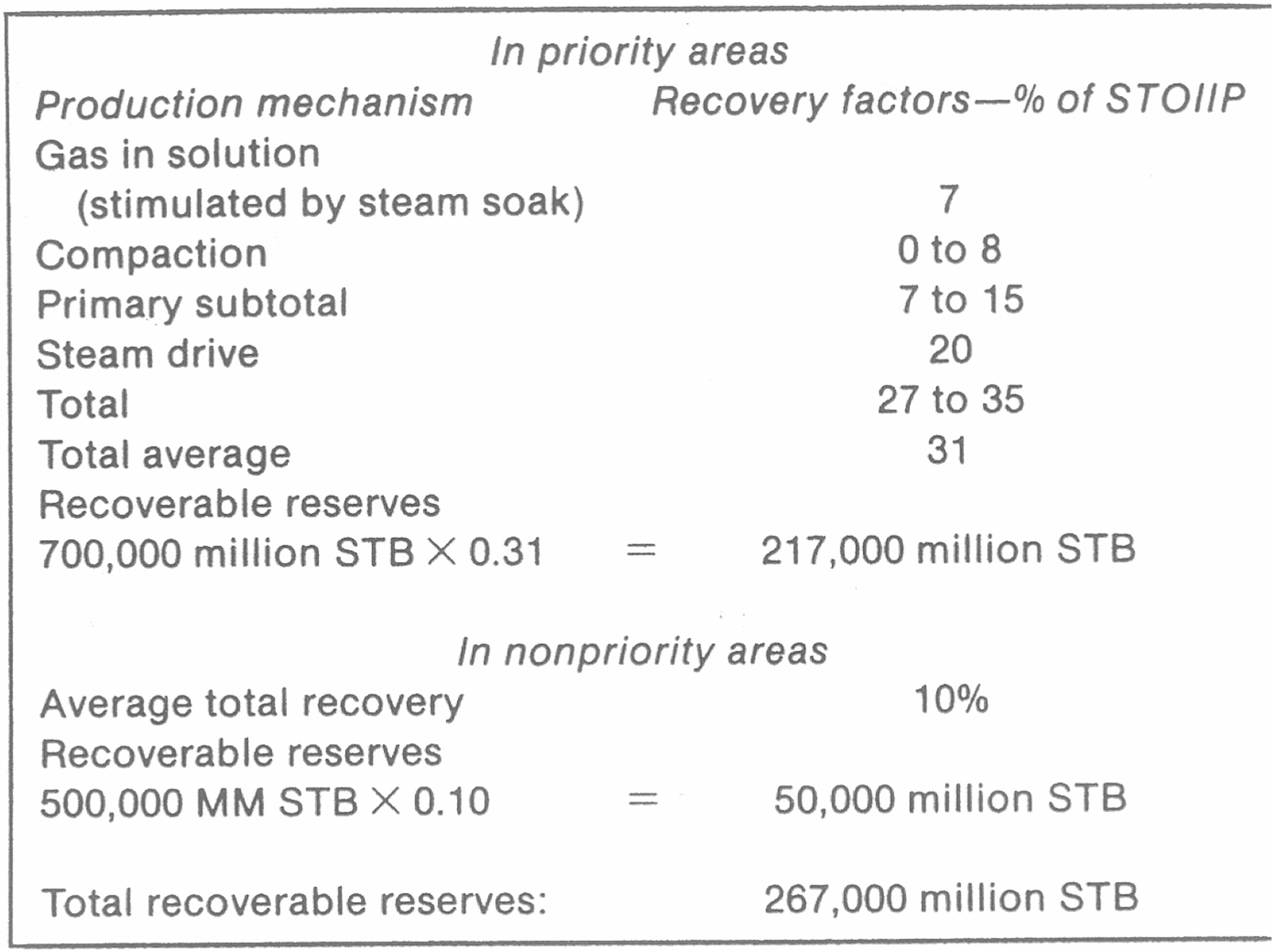
Pay thickness (m)	15–30	(50–430 ft)
Average pay thickness (m)	50	(160 ft)
Range of top pay depth (m)	150–1300	(500–4300 ft)
Average top pay depth (m)	600	(2000 ft)
Average well elevation (m)	100	(330 ft)
Porosity (%)	30–34	
Water saturation (%)	10–25	
Oil saturation (%)	80	
Salinity (ppm NaCl)	850–27,000	
Permeability (m^2)	1	(1 d)
Reservoir pressure (500 m subsea, kPa)	5633	(820 psig)
Reservoir pressure gradient (kPa/m)	9.614	(0.425 psi/ft)
Reservoir temperature (500 m subsea, °C)	53	(127°F)
Geothermal gradient (°C/m)	0.0324	(0.0178°F/ft)

Table 4:
Fluid properties of heavy oils in the Orinoco Heavy Oil Belt. (From Fiorillo, 1987).



Oil density (g/cm^3 at 15.6°C)	1.044–0.934
Oil gravity (° API)	4–17
Metal content (ppm)	500 (80% vanadium, 20% nickel)
Sulfur (%)	3–4
Naphthenic base	

Table 5:
Estimates of recovery factors and recoverable oil in stock tank barrels (STB) in the Orinoco Heavy Oil Belt. (From Fiorillo, 1987).



	In priority areas	
Production mechanism		*Recovery factors—% of STOIIP*
Gas in solution (stimulated by steam soak)		7
Compaction		0 to 8
Primary subtotal		7 to 15
Steam drive		20
Total		27 to 35
Total average		31
Recoverable reserves		
700,000 million STB × 0.31	=	217,000 million STB
	In nonpriority areas	
Average total recovery		10%
Recoverable reserves		
500,000 MM STB × 0.10	=	50,000 million STB
Total recoverable reserves:		267,000 million STB

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