A REVIEW OF THE GEOLOGY OF PETROLEUM IN VENEZUELA

By

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CONTENTS

ILLUSTRATIONS

Page

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INTRODUCTION

Oil fields of Venezuela (figs. 1-9) produced an average of 2,327,992 barrels per day in the first six months of 1979 and had produced a total of 35,594,384,239 barrels to July 1 of that year; estimated proved reserves were 17,870 million barrels (Oil and Gas Journal, Dec. 31, 1979). In addition, four fields[1] produce gas alone, which is piped to Caracas and Valencia for industrial and domestic uses. Of the gas (38 billion cubic meters in 1977) that is produced in association with the oil, 56 percent was being returned to the producing formations, 36 percent was being used in field operations and for domestic consumption, and 8 percent was being flared.

Surface seeps of oil and asphalt, on the waters and the shores of Lake Maracaibo in the west, and at Guanoco in the far east of northern Venezuela, were known and used by the natives, the conquistadores, and Caribbean pirates—for water-proofing baskets, for medicinal and lighting purposes, and for caulking ships. The seep at Guanoco was being mined by the New York and Bermudez Asphalt Company for paving material for export prior to development in 1914 of Mene Grande, the first commercial subsurface oil-producing field, by Shell Oil Company.

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[1]Locations of only two gas fields are shown in figure 1; locations of the other two are not known to the writer.

Venezuela has 37 giant oil fields (100 million barrels or greater), distributed widely over the northern region of the country (fig. 2). Production is from sedimentary rocks of Cretaceous to Pliocene age and from basement rocks that are overlain by Cretaceous formations (figs. 3-9). The major proportion of the sedimentary rock section is made up of shales and sandstones although there are widespread and important limestones in the Cretaceous. The thickness of the sedimentary section is more than 24,000 feet in eastern Venezuela and is more than 30,000 feet in western Venezuela. Producing formations are principally sandstone but also include limestone and sandy limestone-especially in the Cretaceous. The basement rocks are deeply weathered, fractured granites and gneisses.

Oil entrapment in Venezuelan oilfields is attributable to stratigraphic conditions, including both shale-sandstone facies changes and pinch-outs at unconformities, and to structural conditions, including closed folds and flexures in which faulting contributes to the closure of reservoir beds. Cretaceous fields are predominantly controlled by structure, Eocene fields by combined structural and stratigraphic conditions, and Miocene fields predominantly by stratigraphic conditions.

Sources of the oils produced are shales and limestones in contact with the reservoirs; migration has probably been minimal. The oils produced from basement rocks have their source in the overlying Cretaceous formations; those in the freshwater Oligocene-Miocene sandstones of the Maracaibo

Basin are derived from the subjacent Eocene formations, and oil produced from freshwater Pliocene sandstone of the giant Quiriquire Field of eastern Venezuela had its source in the tilted and faulted Cretaceous and Miocene beds over which the sandstone was deposited.

Evidence for the indigenous origin of the oils is in the wide range of their gravities from formation to formation (Table 1) and from place to place within formations of the same age.

Table 1. <u>Age of reservoir rocks and gravities of oils produced</u>

Age of reservoirs	A.P.I. gravities
Pliocene	11° - 28°
Miocene	10° - 65°
Oligocene	11.5° - 39°
Eocene	10.3° - 40°
Paleocene	12.9° - 34°
Cretaceous	13° - 43.5°

The oils are generally asphaltic and sulfurous, but the characters of their bases also vary widely, and some are paraffinic. Oils of the Cretaceous generally have the highest gravities and are most likely to be paraffinic. In general, gravities decrease from oldest and deepest to youngest and shallowest beds.

Acknowledgments

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BASIN EVOLUTION

Sedimentary rocks (fig. 10) occur in northern and western Venezuela beyond the Orinoco River, south of which lie the Guyana Highlands of crystalline gneisses and granites. On the basis of present-day configurations, Venezuela is divided into six or more basins (fig. 1). The Maracaibo Basin is bounded on the south and the east by the eastern arm of the Andes and on the west by the Sierra de Perija. On the north, it is separated from the Gulf of Venezuela Basin by a fault trending west to east across the northern end of the strait that joins Lake Maracaibo to the gulf.

The Falcon Basin trends northeastward from the eastern boundary of the Maracaibo Basin into the Caribbean. It is not well marked physiographically, but is defined on the basis of surface and near-surface Eocene formations in the Andes and between it and the Maracaibo Basin. Eastward from the northeastern arm of the Andes, southward from the ranges of the northern coast, northward from the Guyana Highlands at the east and the Colombian border at the west, northeastern Venezuela is divided by the El Baul uplift into the Maturin Basin at the east and the Barinas-Apure Basin at the west.

The Cariaco Basin is bounded by the eastern arms of the Cordillera de la Costa, the Isla de Tortuga, and islands of the Nueva Esparta group.

The Bonaire Basin appears to be an extension of the Falcon Basin.

Martinez (1966, 1972 and 1976b) has estimated that in all of Venezuela there are 1,381,000 cubic kilometers of sediments that contain (discovered?) reserves of 69,200 million barrels of oil and undiscovered reserves of 23,757 million barrels of oil (Table 2).

Table 2

Venezuela's sedimentary basins

Name	Area (est) sq. km.	Volume of sediments cu. km.	Est reserves (millions of bbls) [1]	Percent explored	Percent proven	reserves (millions of bbls) [3]
Maturin	181500	474000 [2]	15100	96	44	4736
Barinas-Apure	78650	333000	2400	97	22	768
Maracaibo	60500	297000 [2]	51200	95	25	18202
Falcon	30250	161000 [2]	400	96	19	154
Falcon-Bonaire	39325	?	?			
Gulf of Venezuela	24200	95000 [1]	?			
Cariaco	18150	21000 [3]	100	60	0.3	77
		1381000	69200			23757

[1] Martinez, 1966
[2] Martinez, 1977b
[3] Martinez, 1972

Case (1974) has reported that seismic surveys in the Bonaire Basin indicate thicknesses of 2 to 4 kilometers or more and the presence of folds, faults, and angular unconformities. Sea depths are 200 to 2000 meters.

The basin configurations (fig. 1) are the results of the forces that closed the entire marine depositional history over what is now Venezuela's landmass and are not representative of earlier conditions. It is more appropriate to consider the sedimentary history of two regions of the country: an eastern one containing the Maturin, the Barinas, and the Cariaco Basins, and a western one containing the Maracaibo, the Falcon, and the Gulf of Venezuela Basins. Sedimentary rocks of Paleozoic age are known from outcrops in the Sierra de Perija on the northwestern Colombia-Venezuela border, the Andes, and at El Baul in Cojedes State; but the sedimentary basin development that led to the oil and gas fields of Venezuela commenced in the Cretaceous and continued through the Tertiary. Strata that accumulated throughout all that time bear high degrees of lithologic similarity and yet are greatly varied in respect to age and locality. Overall, clastic deposits predominate and grade without sharp breaks from one period and place to another except at the boundary between the Eocene and the Miocene in the eastern Maracaibo Basin. There, both late Eocene folding and a hiatus in deposition are evident. Sand, silt, clay and only occasional limestone beds accumulated in low-lying coastal and continental-shelf environments during long-continuing, but always gentle, episodes of transgression and regression of the sea.

An Early Cretaceous sea, advancing from the north across northern and western Venezuela and Trinidad, accumulated crossbedded, coarse sandstone and sandy carbonaceous shale, reef limestone, and more shale, giving rise to the Cogollo Group of western Venezuela and the similar Sucre Group of eastern Venezuela. Continuing expansion of the marine condition led in Late Cretaceous time to widespread deposition (fig. 11) in western Venezuela, of the La Luna Formation, and in eastern Venezuela, of the Querecual Formation. These deposits are predominantly limestones; the La Luna is as much as 315 m thick, and the Querecual is much as 740 m thick. The La Luna was succeeded by the massive dark-gray to black pyritic shale of the Colon, and the Colon was succeeded by the black to greenish gray shale of the Mito Juan, which is sandier and siltier and is locally interbedded with sandstone and impure limestone (fig. 12). The Querecual is overlain by similar limestones and shales of the Santa Anita Group. Late Cretaceous eugeosynclinal conditions in a relatively narrow belt of northern coastal Venezuela from the northern part of Portugesa State eastward, even across extreme northern Trinidad, led to inclusion there of bedded cherts in the limestone, to the deposition of graywacke and conglomerate to agglomerate, and to intrusions of basaltic and andesitic flows of the Arrayannes Group.

The Cretaceous sea withdrew from the region of central northern Venezuela and from the south and west region of Tachira and Merida States; but in most of western and eastern Venezuela and Trinidad, epicontinental marine conditions continued from Late Cretaceous into the Paleocene.

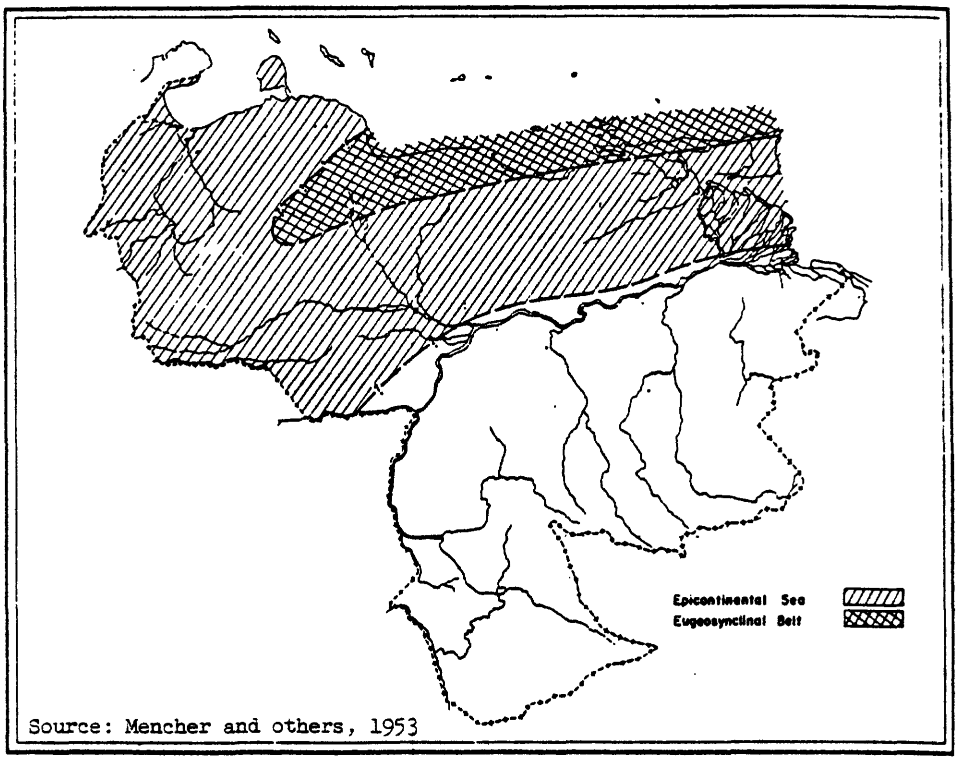


Figure 11. Map showing extent of Cretaceous sedimentary environment in Venezuela.

Paleocene sedimentation followed Cretaceous sedimentation in a shallowing, constricting sea in western Venezuela from Falcon to the Colombia border. There, Guasare glauconitic and sandy limestone beds were interlayered with sandstones and calcareous shales. In the northern Lake Maracaibo area, in the region of La Concepcion, Mene Grande, and the Bolivar Coastal Fields, the Guasare sand and shale beds attained thicknesses of more than 3000 m, and as much as 6000 m. Southward, in Tachira and Merida States, these interfingered with fresh to brackish-water coal-bearing deposits of the Angostura Formation that reached thicknesses of 1000 m (fig. 13). In north-central Venezuela, in a narrow belt between San Carlos and Rio Chico, deeper marine to geosynclinal conditions led to the accumulation of the Guarico Formation of reef limestones, soft olive shales and sandstones containing fragments of igneous rocks, and of volcanic tuffs, agglomerates, and flows on older geosynclinal deposits already intensely folded. In northern and northeastern Anzoategui State in northeastern Venezuela, the contemporaneous Caratas Formation of the Santa Anita Group is composed of glauconitic, calcareous, or dolomitic, fine-to-medium grained sandstone, gray and brownish-gray shale, and siltstone.

The restricted coverage of the Paleocene sea in Venezuela carried over into the early Eocene (fig. 14). In eastern Venezuela, the early to middle Eocene formations are transgressive limestone and sandstone of the lower Merecure Group of northern Monagas and Anzoategui States. In northern Guarico, similar deposits make up the Tememure Formation. Early Eocene formations are present also on the Isla Margarita, in Sucre

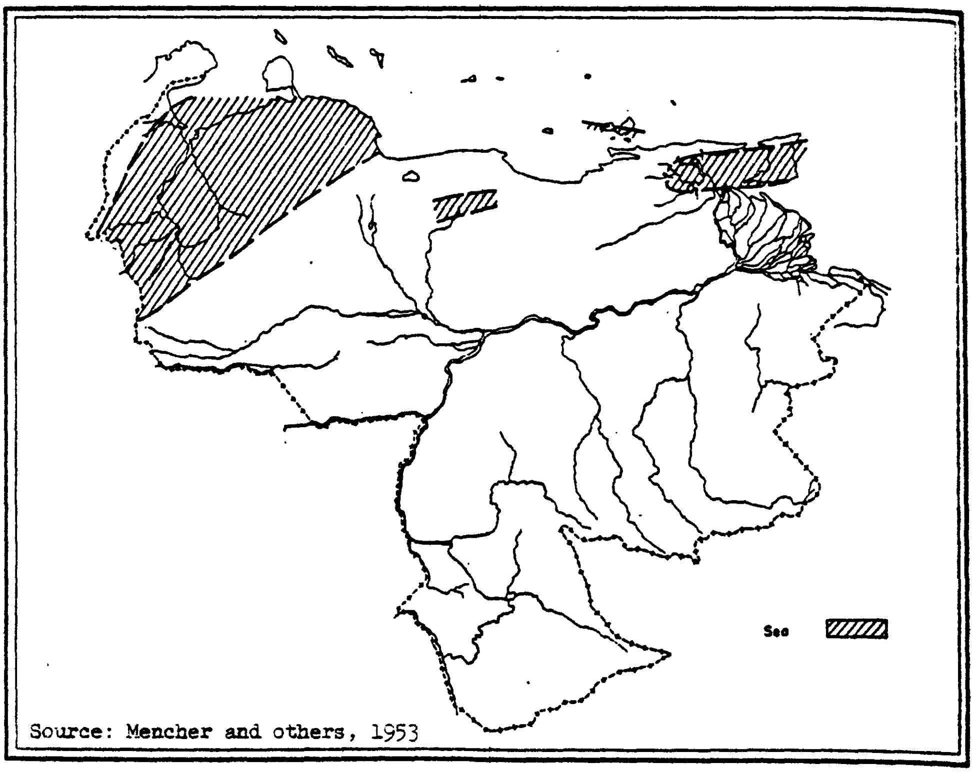
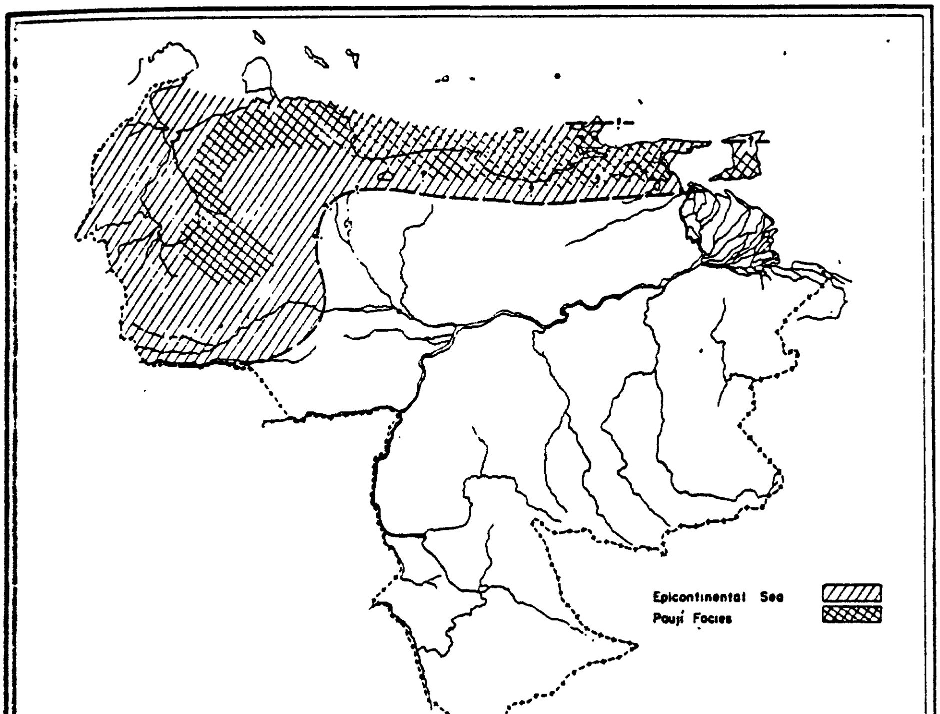


Figure 14. Map showing extent of early Eocene deposition in Venezuela.

State in far northeastern Venezuela, and in central and southern Trinidad. In western and southern parts of the Maracaibo Basin, early Eocene brackish to freshwater deposits of interbedded light gray sandstone and dark gray carbonaceous and micaceous shale, and interbeds of subbituminous to bituminous coal attain a maximum thickness of 1000 m. Northward across La Concepcion, the Bolivar Coastal Fields, and Mene Grande, 3000 m to more than 6000 m of Trujillo or lower Misoa beds of black micaceous and carbonaceous sandy shale accumulated, with thin coal layers in the lower part and micaceous sandstone beds throughout. In the region of the Isla Margarita, coarse conglomerates, lenticular algal and orbitoidal limestones, gray sandstones interbedded with calcareous gray and olive shales, organic limestones, and calcareous sandstones were deposited in a narrow trough between the Cordillera de la Costa and some northern landmass.

In western Venezuela, the early Eocene shaly Trujillo (lower Misoa) beds were succeeded by hard, quartzitic, light-gray to brownish-gray medium to coarse-grained, thick-bedded to massive sandstone beds. Locally, these are conglomeratic and, in other areas, the lower parts contain subordinate amounts of fine to medium, gray and dark-gray micaceous, carbonaceous laminae and are in places flaggy and ripplemarked. These upper Misoa beds attain a thickness of 1725 m at Cerro Misoa, near the Mene Grande oilfield, and interfinger eastward with marine formations in Falcon State.

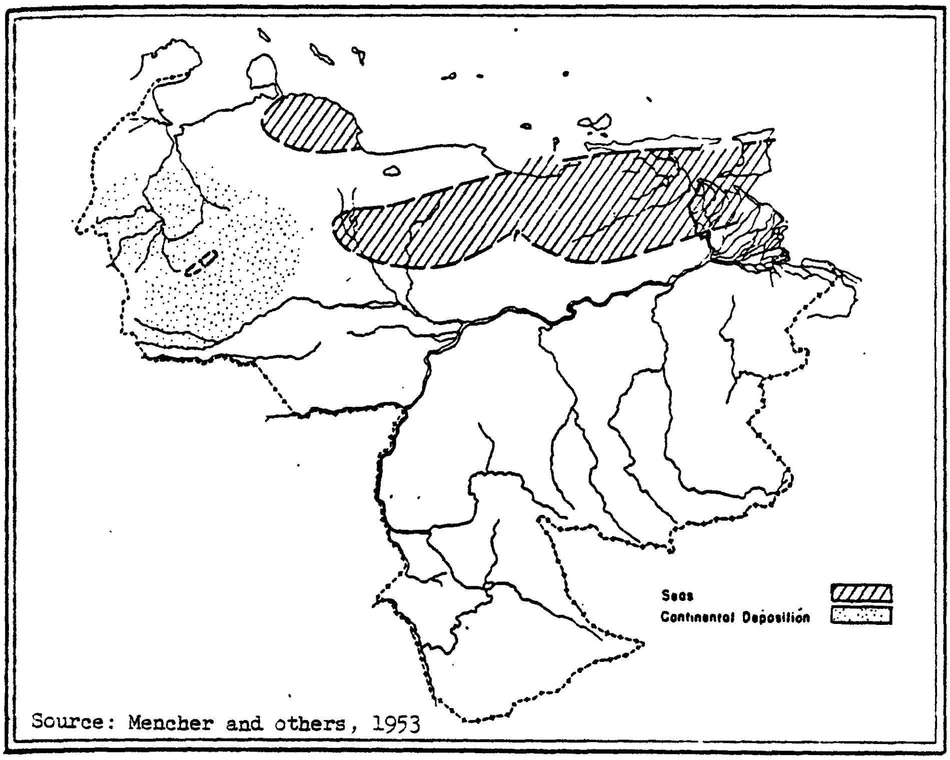
Middle and late Eocene sediments were spread widely and thickly over western Venezuela, including the region now occupied by the Andes, across the northern region now occupied by the Cordillera de la Costa, and across Trinidad, but did not reach farther south. The deepening middle to late Eocene sea in which the Trujillo and Misoa beds accumulated continued to receive clastic deposits that now make up the Pauji Formation, principally dark olive-brown to black fossiliferous shale containing interbedded black shale and light-gray sandstone in its lower part, and containing reef limestone and glauconitic sandstone locally near the base. Thickness at Mene Grande is 1800 m. Westward and southwestward from the Bolivar Coastal Fields, the Pauji beds grade into shallow-water interbedded shales, limestones, and sandstones which, in turn, interfinger with coals and sandy swamp deposits toward the Colombian border. Northwestward, the Pauji Formation continues into Falcon State where it has been named the Cerro Mission Shale. The late Eocene sea appears also to have extended in a narrow zone across northern Venezuela and across Trinidad (fig. 15) until rapid uplift in Falcon state and the Cordillera de la Costa stopped Pauji deposition and led to erosion of Pauji shales previously laid down in west-central Falcon and the Bolivar Coastal Fields. This uplift did not mark the end of the Eocene, however, even in this region; for the erosional period was followed by later Eocene deposition of the Aguanegra clastic units, varying from conglomerates to shales, and including some shallow-water limestone. The late Eocene unconformity has not been noted elsewhere; but shallowing of the late Eocene sea is evidenced by ripple marked and crossbedded deposits, carbonaceous sandstone, oyster reefs, and orbitoidal limestone of the Andean region.



Source: Mencher and others, 1953

Figure 15. Map showing extent of late Eocene deposition in Venezuela.

Although sedimentary basin configurations and depths varied widely and intricately over all of Venezuela from the Cretaceous to the late Eocene, it is evident that, in general, the changes were gradual and gentle--even where unconformities are present. The late Eocene and post-Eocene movement, however, was widespread and violent and resulted in extensive folding, faulting, uplift, and erosion. Structural folding, uplift, and erosion in western Venezuela at the close of Eocene time culminated in continental conditions over all that region, except in eastern Falcon. Furthermore, late Eocene-early Oligocene uplifting appears to have given rise, for the first time, to a distinctive eastern Venezuela basin that was bounded on the north by the Cordillera de la Costa and that extended from Cojedes State at the west, eastward through the region of the present Orinoco Delta and Trinidad (fig. 16). Freshwater swamps and brackishwater environments in the area of Barcelona accumulated the early Naricual beds of carbonaceous shale, sandy shale, and sandstone, and the later interbedded coals, sandstone, and shales. Southeastward, in Monagas State, these clastic deposits interfinger with marine calcareous and glauconitic beds. Coals were deposited also in the western reaches in northwestern Guarico and in Cojedes States, while brackish-water and marine La Pascua, sandstones and shales accumulated in what were to become Las Mercedes oilfields in Guarico. Naricual coal-bearing measures were deposited in a northern coastal region from Barcelona eastward, succeeding previously deposited early Oligocene carbonaceous shale, sandy shale, and sandstone, and attaining a thickness of more than 1000 m. The coal-bearing deposits were, in turn, overlain by hard tight sandstones and gray shales.



Source: Mencher and others, 1953

Figure 16. Map showing extent of early Oligocene deposition in Venezuela.

Southeastward, into Monagas State these interfinger with shaly marine calcareous and glauconitic beds. Southwestward, at this time, beds of sandstone--including the "U" sands of the Oficina Formation--gray shale, siltstone and black carbonaceous shale were deposited in the Oficina area; and brackish-water to marine sandstones and dark shales with lignites, all of La Pascua Formation, were accumulating in Las Mercedes area. The accumulation of similar clastic deposits in various fresh to brackish to marine environments continued, resulting in the oil-bearing La Pascua, the Roblecito, the Chaguaramas, the Carapita, and the Oficina oil-producing formations of central Venezuela. In large part, deposition continued without apparent significant lapse into the early Miocene.

From late Eocene to late Oligocene time, most of western Venezuela was above sea level and subjected to both folding and erosion. There, in that time, Oligocene continental clastic deposits--Icotea sandstones and claystones--accumulated in depressions and synclinal lows on the Eocene surface. From the Bolivar Coastal Fields and the west side of Lake Maracaibo, these grade westward into mottled claystones and siltstones of El Fausto Group in the Sierra de Perija. The only marine beds of late Eocene-early Oligocene age in western Venezuela are those in eastern Falcon State; however, from late Oligocene into the Miocene, a shallow marine basin (fig. 17) received fine to coarse clastic materials that make up the sand and shale beds of the La Rosa and Lagunillas Formations of the Bolivar Coastal Fields, the youngest marine beds recognized there (fig. 18).

The eastern Venezuela sedimentary basin persisted from early Oligocene into the Pliocene. It contained a shallow sea in which conditions of sedimentation varied in response to widely shifting conditions of depth and shoreline

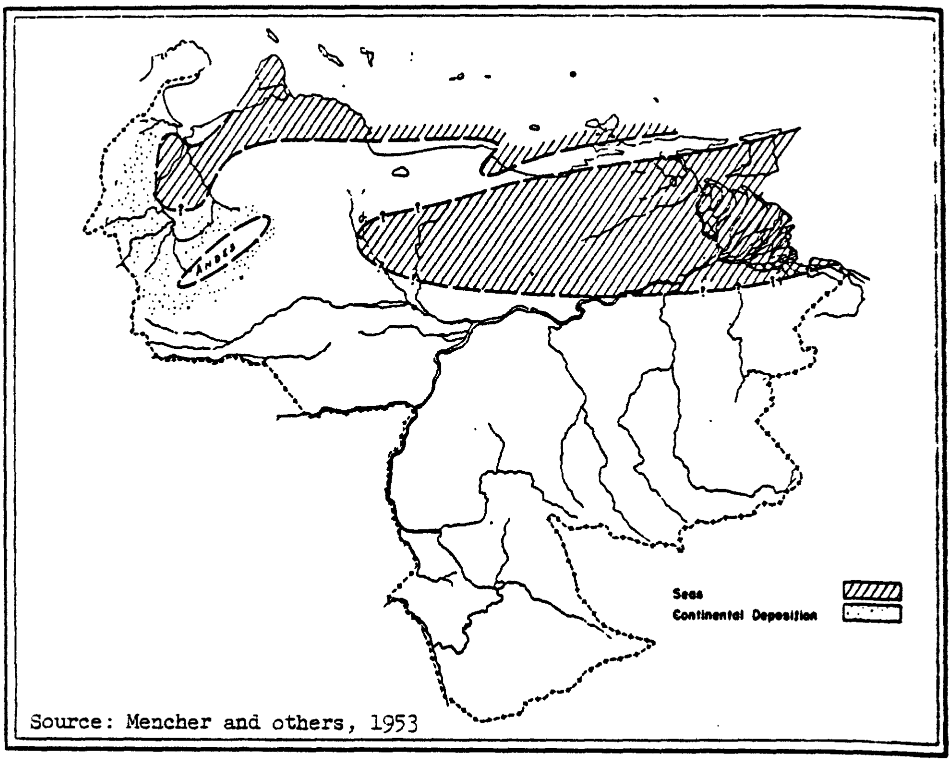


Figure 17. Map showing extent of Oligocene-Miocene deposition in Venezuela.

relationships. Subsidence was slow but long continuing, leading to the accumulation of as much as 6000 m of Tertiary sediments. At the same time, continuing uplift in the region of the Cordillera de la Costa was accompanied by southward migration of the axis of deposition; and gray, dark-gray, and brownish-gray shales, sandstones, siltstones, lignites, lignitic sandstones, and minor limestones were deposited southward to the vicinity of the present course of the Orinoco River and westward to the region of Las Mercedes oilfields. In the eastern Venezuela basin, freshwater coarse sand and gravel, and clays of the Pliocene Sacacual Formation were deposited over the upturned edges of Cretaceous and Tertiary beds and became the reservoir of the Quiriquire oilfield.

It was the regional uplifting movements that began in the Miocene and closed marine deposition in western Venezuela that culminated in the configuration of the major physiographic features now recognized.

REGIONAL STRUCTURE AND PETROLEUM TRAPS

Although the Sierra de Perija on the Colombian border in the extreme northwest, the Andes, and the Cordillera de la Costa of Venezuela (fig. 1) are the consequences of great orogenic events, the predominant condition throughout most of the country's post-Paleozoic history was one of widespread but gentle, low-amplitude movement. Great thicknesses of sediments attest to long periods of subsidence. A predominance of clastic units, from conglomerate to shale, and of high-frequency interfingering of freshwater, brackish-water, and marine sediments that in many places pass without perceptible breaks from age to age testify to a persistent general downwarping and gentle oscillation of floors of deposition.

Relatively little is known about Paleozoic stratigraphy or structure. Formations that are undisputedly Paleozoic crop out only in the Andes and the Sierra de Perija. Cretaceous geosynclinal forces contorted and metamorphosed rocks of that age in the extreme north of eastern Venezuela, and effects of Late Cretaceous orogenic movements in the extreme north are evident in spatial patterns and physical characters of sediments exposed there. Late Eocene structural movements, however, had important influences on the distribution of oil and gas fields in the Maracaibo and the Falcon Basins. There, uplift and folding and faulting that commenced in late Eocene and continued to mid-Oligocene created structural traps and exposed Eocene rocks that were subsequently overlain by both continental and marine Oligocene and Miocene deposits that consequently became reservoirs of Eocene oil. These uplifting movements culminated in the closing of the Maracaibo Basin to marine waters and gave rise to the accumulation there of Miocene continental beds. Movements during this time also involved rejuvenation of the Cordillera de la Costa which, with the general uplift of the Maracaibo-Western Venezuela region, gave rise, for the first time, to a discrete eastern Venezuela Basin. The uplift in the Cordillera de la Costa continued into the Pliocene, moving the axis of deposition southward. In the meantime, middle to late Miocene movement in western Venezuela gave first rise to the Andean mountains. All movements culminated in the Pliocene with folding, faulting, and thrusting in the Serrania del Interior and the foothills of central Venezuela and the creation of the oil-producing structures of the Maturin Basin. These last movements were believed by Mencher et al. (1953) to have given rise to the major physiographic features of the country and to have had major influence on the oil structures of all of Venezuela. De Juana and Rodriguez (1951) related oil fields in the Cretaceous formations to structure, those in the Eocene to structure and stratigraphy, and those in the Miocene to stratigraphy.

RESERVOIR ROCKS

The principal reservoirs of the giant fields of La Paz, Mára, and La Concepcion are fractured Cretaceous limestone strata, but, overall, the most important reservoir rocks of the oil fields of Venezuela are shallow marine to nonmarine clastic deposits of Miocene, Oligocene, and Eocene ages. Water and solution gas drives are reported. In the La Paz, Mara, and Totumo fields in northwestern Venezuela, basement rocks of granodiorite, schist, quartzite, and La Quinta (Jurassic?) sandstone are also oil reservoirs. Porosity, of 0 to 4 percent, and permeability are the results of fracturing to depths as great as 264 feet (80 m). Fractured gneiss also is reported to be productive at the Miranda field, offshore of La Vela, Falcon State.

In addition to that from the Cretaceous limestone reservoirs at La Paz, Mara, and La Concepcion, production from Cretaceous carbonate units has been found in 16 other Maracaibo Basin fields, 8 of which have been productive only from the Cretaceous (fig. 1). Porosity and permeability are the results of fracturing of the hard, massive, dark-gray to black bituminous limestones of several stages of deposition. The Cretaceous formations include also lesser amounts of dark shale and sandstone. At Alturitas and El Rosario fields, both fractured limestone and fractured standstone are reported to have been productive. Total thicknesses of

Cretaceous section over all the western Maracaibo region are 500 (152 m) to 2,000 feet (680 m). Porosities average 2 to 10 percent and permeabilities range from 0.1 to 3,000 millidarcies.

In the Barinas fields, Cretaceous production is from a predominantly sandstone section 50 feet (15 m) thick near the middle of a 600-foot (180-m) -thick series that is made up, for the most part, of interbedded sandstones and shales, but which also includes limestone beds at its base and above the oil-bearing section. Porosity of 14 to 18 percent and permeability of 1 to 5,640 millidaries are reported.

Cretaceous oil-producing formations in eastern Venezuela in Guarico, in northeastern Anzoategui, northern Monagas, and southern Sucre States and in the Temblador fields region in southern Monagas and Delta Amacuro States are predominantly shallow-marine and nonmarine sandstones. However, a Cretaceous limestone reservoir in Manresa field and both limestone and sandstone reservoirs in the Mercedes field have been reported. The pays are in a section that includes an upper 312-foot (95-m) -thick marine sequence of glauconitic, fine-grained sandstone and siltstone, friable, gritty sandstone, dark carbonaceous phosphatic shale, whitish sandstone and siltstone, and thin beds of hard, gray, massive, glauconitic and, in places, fossiliferous dolomite that rests upon a lower 304-foot (93-m) -thick nonmarine member made up of coarse grits, sandstone, siltstone, and claystone mottled dull gray, green, yellow, brown, red, and purple. Porosity of both the sandstone and the limestone is reported to be fracture related and, in the Manresa field, it is related also to weathering. Gross thicknesses at the Mercedes field are 60 feet (18 m) of the limestone and 425 feet (130 m) of the sandstone.

Reservoirs of Paleocene age are present only on the western side of the Maracaibo Basin. In the West Tarra and Tres Bocas fields, 4 to 50 feet (1 m to 15 m) of net pay are in a section of dark-gray carbonaceous shale and claystone that include interbeds of fine to very fine sandstone 1 1/2 to 30 feet (1 m to 9 m) thick, some lignite, and thin lenses of brown clay-ironstone. At La Paz and Mara, the pays are in fine-grained, medium-bedded, smooth, buff, slightly argillaceous sandstone that grades upward into light-brown, fine- to medium-grained calcareous sandstone, to thinly bedded, shaly, micaceous gray sandstone that in turn are, interbedded with gray carbonaceous shale, fossiliferous, sandy limestone, and some glauconitic shale. A total of 1,300 feet (400 m) of Paleocene has been reported at Mara, with 230 feet (7 m) of gross pay, porosity of 22 percent and permeability of 500 millidarcies. Formations of Paleocene age are present but are not productive in western Falcon State, the foothills of north-central Venezuela, and Anzoategui State.

Eocene reservoirs are more numerous and richer than those in the older formations, but are confined to the Maracaibo and the Barinas producing fields. All are in sandstones. Those of fields on the western side of the Basin, from Las Cruces field at the south to La Concepcion field on the north, are in lower and middle Eocene lagoonal or swamp deposits made up of clay shale, with lignite beds, and with sandstone lenses interspersed throughout. Total thicknesses in the southwest are 200 to 1,000 feet (68 m to 350 m). At La Concepcion, there are 2,000 feet (700 m) of lower and middle Eocene dark-gray shale and gray, micaceous, sandy shale, containing irregular lenses of sandstone as thick as 3 1/2 feet (1 m) and lignite beds. Eastward, in the Bolivar Coastal Fields and the Mene Grande field, the lignites are absent and thicknesses of section increase. At the former, the lower Eocene Trujillo Formation is made up of thin-bedded, dark shale and shaly sandstone interbedded with gray and pink quartzitic sandstone, dark blue-gray, to dark-gray to black, locally micaceous and carbonaceous shale, and subordinate gray and brown sandstone. It is overlain by the middle Eocene Misoa Formation, which is sandier overall, being made up of alternating beds of hard, coarse, white to dark-brown sandstone and brown to black, hard, platy shale, quartzitic light-gray to brownish-gray, medium- to coarse-grained, and locally conglomeratic, thick-bedded to massive sandstone, limestone, and calcareous sandstone. Gross pay thickness of 2,000 feet (700 m), net pay thickness of 600 feet (183 m), porosities of 2 to 32 percent, and permeabilities of 1 to 7,500 millidarcies have been reported for the Eocene of the Bolivar Coastal Fields.

Middle Eocene lenticular, glauconitic and limonitic sands in the lower part of a sandy sideritic shale section are productive in Barinas fields. Gross pay thicknesses are 50 to 80 feet (15 m to 24 m), porosities are 16 to 20 percent, and permeabilities are 1 to 4,000 millidarcies.

Lower to middle Oligocene reservoirs also are in lenses, channels, and laminae in claystone, shale, and siltstone series in oil fields of the Lake Maracaibo area and of Falcon, Guarico, and Anzoategui States. Gross pay thicknesses of 2 to 600 feet (2/3 m to 183 m), porosity of 32 percent, and permeabilities of 2 to 2,750 millidarcies have been reported.

The entire Oligocene section is reported to be 900 feet (274 m) thick in Falcon, with sandstone beds as much as 30 feet (9 m) thick.

In the Mercedes Field area of Guarico State, 2,900 (880 m) feet of upper Oligocene beds that also include lignites, freshwater clays, and clay-pebble conglomerate overlie 300 feet (100 m) or more of interbedded marine sandstone and dark shales that also include a few lignite beds. Eight Oligocene pay sands having gross thickness of 300 feet (100 m) have been reported there.

The Chimire Field in southern Anzoategui is reported to have at least two Oligocene pay sands with porosity of 15 to 27 percent and permeability of 50 to 5,000 millidarcies. In the La Vieja Field, among the northernmost of Anzoategui, 5 Oligocene sands, each with gross thicknesses of 50 to 100 feet (15 m to 34 m) , have been reported to have 11-14 percent porosity, horizontal permeability of 20 to 1315 millidarcies, and vertical permeability of 18 to 785 millidarcies.

Sandstone pays of Miocene age are the most widely distributed and, in gross, probably the richest in Venezuela. Their character and depositional history are like those of the earlier Eocene and Oligocene formations and, in the Temblador Fields, like those of the underlying Cretaceous. The recognition of formational boundaries has been difficult, particularly in eastern Venezuela; and the Oficina Formation, considered by Mencher and others (Figure 10, this report) to be principally Oligocene, now is most commonly designated as Miocene or Oligocene-Miocene.

In Bolivar Coastal Fields of the Maracaibo Basin, lower and middle Miocene La Rosa and Lagunillas Formations are 9,900 (3200 m) feet or more thick and contain as much as 1,800 feet (550 m) of gross, and 300 feet (100 m) of net sandstone pay, with porosity of 10 to 38 percent and permeability of 1-2120 millidarcies. The Lagunillas Formation is the sandier, being made up of light-gray, light-green, and whitish sandstone, siltstone, and shale and containing mottled claystone in upper parts and lignite and glauconite in the lower parts. The La Rosa consists of green shale and clay-shale with a lesser amount of sandstone interlaminated. It thins westward from 600 feet to 850 feet (183 m to 260 m) in the Bolivar Coastal Fields to 0 to 400 feet (0 m to 136 m) on the west side of the Lake, where it contains a tar sand zone, a lignitic series, and aggregated sand thicknesses of 60 feet (18 m) or more.

Eastward, only a short distance from the Bolivar Coastal Field, at Mene Grande, the Middle Miocene Isnotu Formation produces from sandstone beds that are 6 to 10 feet (2 m to 3 m) thick, white to light gray, fine grained to finely conglomeratic, locally micaceous, and ripple marked, occurring in some 3,000 feet (1020 m) of interbedded clay and sandstone, and lesser clay-shale, lignite, and conglomerate.

Lower and middle Miocene oil-producing formations, the Mosquito and the Caujarao, in Falcon State, made up of soft fine-grained sandstone containing plant remains, a hard, dense, calcareous cap, and a very hard massive, fossiliferous sandstone, are reported to have porosities of 3 to 39 percent and permeabilities of 1 to 2,300 millidarcies. The total thickness of the Miocene is on the order of 3,000 feet (1020 m).

The giant oil fields of Anzoategui and Monagas States produce principally from the Oligocene-Miocene Oficina Formation (fig. 19) or others that appear to be equivalents. As many as 36 pay sands have been reported in the Oficina at the Chimire field in central Anzoategui. Net pay of 700 feet (213 m) in a gross pay zone of 4,000 feet (1360 m) is reported to have porosity of 15 to 27 percent and permeability of 50 to 5,000 millidarcies. At El Roble, among the northern fields of this central Anzoategui producing area, 250 feet (76 m) of gross pay and 10 to 20 percent porosities have been reported. Six hundred feet (183 m) of Miocene have been reported in the Temblador area where it is distinguishable from underlying Cretaceous formations only by comparison of heavy-mineral suites.

The Oficina Formation is 2,000 to 4,000 feet (610 m to 1220 m) thick in the Oficina Field area and 7,500 to 10,000 feet (2290 m to 3400 m) thick in the Santa Ana to Santa Rosa Fields area. It consists of gray-brown to gray shale, light-gray, fine to coarse sandstone and siltstone and contains as many as 50 thin lignite beds, lignitic shale, green to light-gray claystone, sideritic and glauconitic sandstone, and thin cone-in-cone limestone.

The Oligocene-Miocene Carapita Formation of northern Monagas State is 9,000 feet (2740 m) thick. The lower 2,000 feet (610 m) is composed of sandstone and silty shale. The upper 7,000 feet (2300 m) consists of dark-brown to brown-gray fissile shale, with thin seams of clay ironstone, and a few thin beds of fine-grained sandstone pay having porosity of 30 percent and less, and permeability of 600 millidarcies. The middle Miocene La Pica Formation is also a reservoir in this area. As many as 25 pay sands with porosity of 24 percent but "low" permeability have been reported. The section ranges in thickness from 200 to 4,500 feet (61 m to 1370 m) and is made up of brackish-water to marine gray shale and silty shale, locally derived fine-grained clayey sandstone, and soft to moderately hard, dark-gray to gray-black, silty, micaceous, lignitic shale with interlaminated fine sandstone and siltstone.

The youngest producing formation is the Pliocene Las Piedras of the Quiriquire oil field of northern Monagas State. It is part of the Sacacual Group which contains brackish-water deposits of light-gray to green-gray, interlaminated, fine-grained, carbonaceous sandstones, clay-shales, light-gray fine-grained friable sandstone, lignites and unsorted alluvial fan deposits of sand grains to boulders. A maximum of 702 feet (214 m) of net pay and an average of 233 feet (71 m) net pay having an average porosity of 20 percent and permeability of 100 to 11,000 millidarcies are reported.

PETROLEUM SOURCE ROCKS

For the most part, the oils of Venezuela's fields appear to be indigenous to the predominantly dark shale and to the limestone of the formations in which they are found. Exceptions are producing formations of clearly continental origin such as the Icotea sandstone of the Bolivar Coastal Fields and the Isnotu of Mene Grande, which derived their oil from underlying Eocene reservoir sands, and the Pliocene Quiriquire Formation of Quiriquire which trapped oil from underlying Cretaceous and Oligocene beds. The oil in the basement rocks of La Paz, Mara, and Totumo came from the surrounding Cretaceous beds; and, apparently, the marine Oligocene-Miocene reservoirs of the Bolivar Coastal Fields were supplied with Eocene oil from beds folded and truncated below the Eocene-Oligocene-Miocene boundary.

PROPERTIES OF CRUDES

The oils tend to be heavy and high in sulfur. In general, those in older, deeper formations and those in areas that had been subjected to higher intensities of structural activity are higher in gravity than the oils in the youngest, least disturbed beds; however, their characters vary widely from formation to formation and from place to place within the same or equivalent formations. In the Maracaibo Basin, gravity of Cretaceous oil ranges from 13° API to 43.5° API; in Falcon, the range is 30°-35° API, and in the Maturin Basin, 37°-40°. Paleocene oils of Maracaibo fields are reported to have gravities of 12.9° to 34°. Miocene oils of the Bolivar Coastal fields are rated at 14°-17.9°, and those of the Lamar

Field at 33.8°-37°. In the Falcon Basin, gravities of Miocene oils are 25°-50.5° API and in the Maturin Basin, 10°-65° API.

In the Mene Grande field in the Maracaibo Basin, API gravity is 24°-31° in the Eocene; 16.7° in the Isnotu and 17.5° in the Main pay zones, of Miocene age; and is 10° in the Pliocene. In fields of the Maturin Basin, the Miocene Oficina Formation produces oil of gravities of 10°-16°, 22°-44°, and 38°-65°. Miocene La Pica sands produce oils of gravities between 16° and 37° in different fields and between 16° and 36° in the same field.

DISCUSSION OF SELECTED OIL FIELDS

Western Venezuela

The La Paz field of western Venezuela was discovered in 1922 on the basis of oil seeps and structure mappable at the surface. Oil production from Eocene Concepcion sandstone, Paleocene Guasare sandstone and limestone, Cretaceous limestone, and metamorphic, crystalline basement rocks had totalled 810,005,771 barrels by July 1, 1979 (Auldridge, 1979). Production to 1944 was from the Tertiary formations and was modest. Oil in the Cretaceous, discovered in 1944, and oil in the basement, discovered in 1953, have made La Paz the giant that it is.

The Concepcion sandstone produces from a total of 200 feet (68 m) of aggregate thickness of sands near the middle of a 1500- to 1700-foot (460- to 520-m) -thick section of sandy shale, sand, and coal. Porosity has been reported to be 26 percent and permeability 500 millidarcies (Staff, Caribbean Oil Co., 1948). The Paleocene Guasare sandstone is reported to aggregate

150 feet (46 m) in thickness, to have an average porosity of 22 percent and permeability of 2 to 500 millidarcies. Porosity of the Cretaceous is reported to vary between 0 and 4 percent, and permeability between 1 and 40 millidarcies (Petroconsultants, 1977). The prolific production from this apparently dense limestone is attributed to the great thickness of section, the vuggy and fractured nature of it, and the great size of the folded structure that La Paz shares with the Mara oil field. The structure, which may have as much as 4000 feet (1360 m) of closure, is a faulted anticline that trends northeast is asymmetric with the northwest flank the steeper, and is complexly faulted. Reservoir pressures were such as might be expected with an active water drive (4900-5000 p.s.i. at 11,000 ft.), and initially recoverable reserves are estimated to have been 950,000,000 barrels (Petroconsultants, 1977). The developed area is 30,665 acres in which some 190 wells have been drilled.

The Mene Grande field, discovered in 1914 by the Caribbean Petroleum Company, a subsidiary of Shell, was the first commercial field discovery of Venezuela. By July 1, 1979, it had produced 603,198,336 barrels of oil (Auldridge, 1979) from a developed area of 11,000 acres and 774 wells. The discovery was based upon surface geologic investigation and the presence of a great oil seep. Production is from sandstones of the Miocene Isnotu, the upper Eocene Pauji, and the middle Eocene Misoa Formations. The structure is that of a faulted southward-plunging anticlinal nose. A west block, with quite uniform surface, dips steeply westward, and an eastern block, which is itself complexly faulted, bears the form of the broad gentle nose. At least two periods of folding and faulting--late Eocene and post-Oligocene Miocene--are clearly evident in a greater complexity of faulting and higher structural relief in the Eocene beds and in the unconformable relationship between the Eocene and Miocene formations (fig. 20).

Outcropping updip parts of Sanalejos and Isnotu sandstones contain seeps of oil of 10° API gravity that is not producible through the drilled wells but has formed a barrier to further migration of the oil from the Miocene reservoirs downdip. Oils in the Miocene "K", "H", and "G" sands--the "Upper Heavy Oil Series"--have an average gravity of 16.7° API and are present principally in the south-central and western parts of the field. Average gravity of the oils of the Miocene "Main Oil Zone" is 17.5°; and that of the oils in the Eocene Pauji formation is 23.3° API. Gravities of oils in the oldest, deepest, producing formation at at Mene Grande, the Eocene Misoa, range between 24° and 31° API in two lower zones, and average 25.7° in the uppermost of the three. The gross thickness of the Miocene pay zones is 1000 to 2000 feet (340 m to 680 m). Net pay thicknesses are 300 to 500 feet (1020 m to 170 m). Porosities are approximately 27 percent in the "Heavy Oil Zone" and 31 percent in the "Main Oil Zone." Gross thicknesses of the Eocene pay zones are 1480 to 1600 feet (450 m to 490 m), and net thicknesses are as much as 570 feet (179 m). Porosities of Eocene pay formations average 12 percent in the Pauji and 10 percent in the Misoa. It has been reported that a water drive is

A.

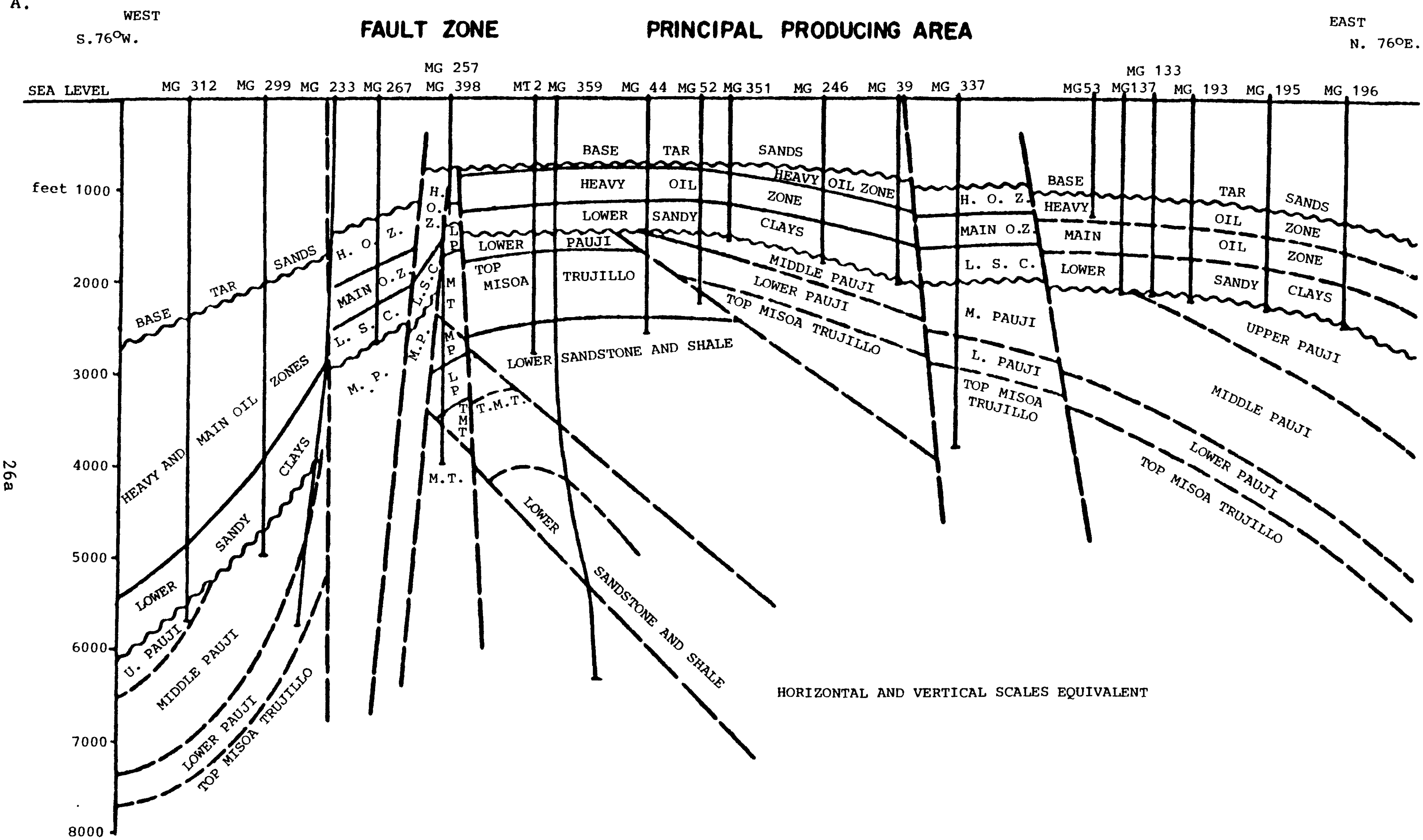


Figure 20A.--Cross section depicting structural and stratigraphic conditions of the Mene Grande oil field, Venezuela (modified from Mencher and others, 1953).

B.

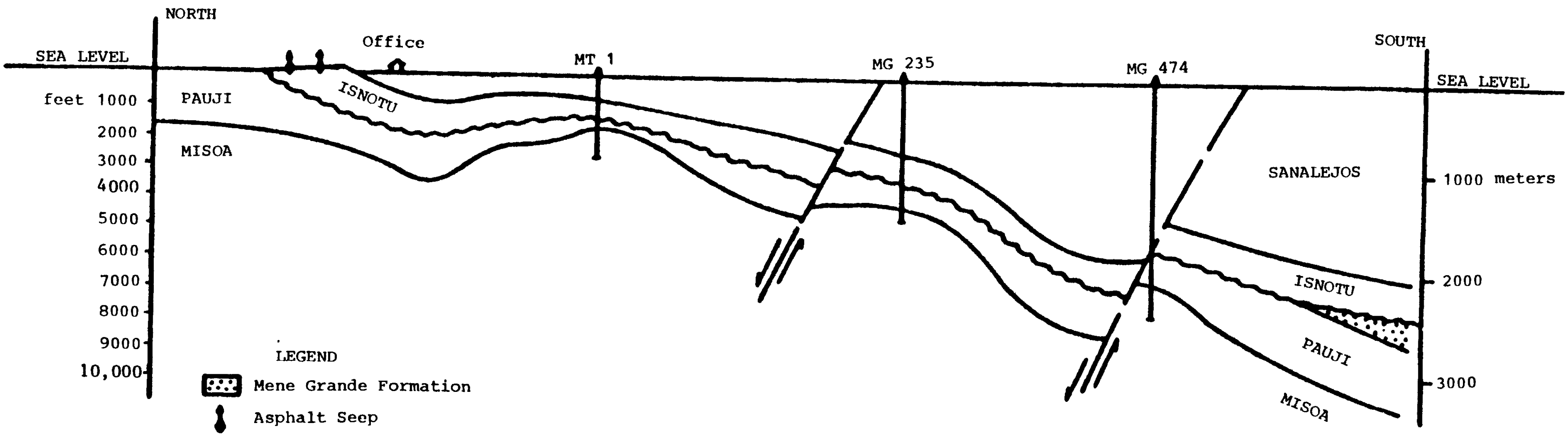


Figure 20B.--Cross section depicting structural and stratigraphic conditions of the Mene Grande oil field, Venezuela (modified from Mencher and others, 1953).

active in Miocene pay formations of the west fault block but is not active in the east block (Staff, Caribbean Oil Co., 1948).

The oils at Mene Grande appear to have originated in the Eocene formations and to have migrated in part across the Eocene-Miocene unconformity into the productive Miocene formations that are not marine and are low in organic content.

Eastern Venezuela

In eastern Venezuela, fields of the Anaco Group are controlled both by structural and by stratigraphic conditions. Santa Ana, the first found of the seven fields, was discovered in 1937. Production from all fields of the group--Toco, San Joaquin, Guario, Santa Rosa, El Roble, San Roque and Santa Ana--totaled more than 399,100,000 barrels as of July 1, 1979 (Auldridge, 1979). More than 500 wells have been drilled in this area, which is 66 km long and 14 km wide.

The major proportion of the oil produced in the Anaco fields is from sandy zones of the Miocene Oficina Formation, which ranges in thickness between 6,900 and 10,000 feet (2150 m and 3,400 m). Production has been obtained also from sandstone in the lower Periquito Formation (also called Merecure),which is 1,800 to 1,900 feet (550 m to 580 m) thick. Before 1953, only one hole had been drilled through the Miocene formations. That one, in the Toco field, found the Cretaceous Temblador unconformably overlain by the Periquito. The Periquito consists of light-gray to dark-gray, massive to poorly bedded, hard, fine- to-coarse grained sandstone and grit interlaminated and thinly interbedded with carbonaceous shale, gray claystone, and siltstone. The

Periquito is overlain without apparent break by the thick sequence of Oficina gray shale, interlaminated shale and sandstone, and light-gray, fine-grained sandstone. Lignite, thin limestone, and green claystone appear in minor proportions but are widespread. The Oficina is overlain unconformably, and variably, by younger Miocene-Pliocene beds of the Freites formation, which are marine gray and green shale, greenish-gray sandstone, pebble beds and fossiliferous grit, brackish-water deposits, black chert conglomerate, and sandy limestone, by Miocene-Pliocene, Sacacual, fresh- to brackish-water sandstone, and by Pleistocene, Mesa sandstone, gravel, and claystone. Thickness of the Mesa Formation is as much as 1,600 feet (490 m), and that of the Freites Formation is as much as 1,500 feet (460 m).

The fields, except for El Roble and San Roque, are controlled by structural closures that occur as a series of elongate domes trending northeastward. Closures are 500 to 1,500 feet (152 m to 460 m); steep dips and a zone of thrust faults bound the southeast side of the entire structural trend. Among the structural highs, only the Santa Rosa is reported to have a complex system of strike-slip faults. El Roble and San Roque fields lie down-dip on the regional structure and are controlled by faulting and by pinchout of the productive sands of the Oficina Formation.

Eighteen pay zones were found in the Oficina section and two in the Periquito section in the San Joaquin field. Sixteen Oficina pays and one Periquito pay were reported at Santa Rosa (Preconsultants, 1977). Contrary to the condition noted in several Maracaibo Basin fields, gravities of the oils in the Anaco Group are higher (40.5° to 47° API) in the younger Oficina than in the Periquito (33° API-34.6° API). The oils are paraffinic;

gas caps were present, at least in part; and reserves include a large proportion of 47°-60° API gravity condensate. Edgewater was reported at El Toco, but it is assumed that gas has provided the drive in most of the fields.

Finally, mention must be made of the Orinoco petroliferous belt, which has been variously reported to have reserves of 700 billion (Gutierrez, 1976), 1050 billion (Demaison, 1978), and as much as 3 trillion barrels (Volkenborn, 1979). The belt has been described as a banana-shaped region in the Maturin Basin roughly 25 to 75 km wide and extending some 600 km west-east between Calabozo in Guarico State and the vicinity of Tucupita in the Delta Amacuro Territory (fig. 21). In this belt, heavy oil in Cretaceous and Tertiary deltaic sandstones is considered to have been derived from the same or equivalent sources as the oil of the Maturin Basin fields bounding the belt at the north. Generally decreasing API gravity values in the direction away from the producing fields and toward the southern edge of the basin have been considered to be the results of deterioration on exposure and to inspissation and bacterial action accompanying migration.

Four extensive highs--Gorin-Machete, Altamire-Sualta-Iguana, Hamaca-Santa Clara, and Cerro Negro are deemed to hold the largest reserves.

Accumulations of oil have been influenced both by folded structure and faulting in this region where regional dip is to the north at 2° to 4°. Depths to the oil-bearing sands are 1,100 to 3,100 feet (330 m to 940 m). Gross sand thicknesses are 280 to 450 feet (85 m to 132 m) and net thick-

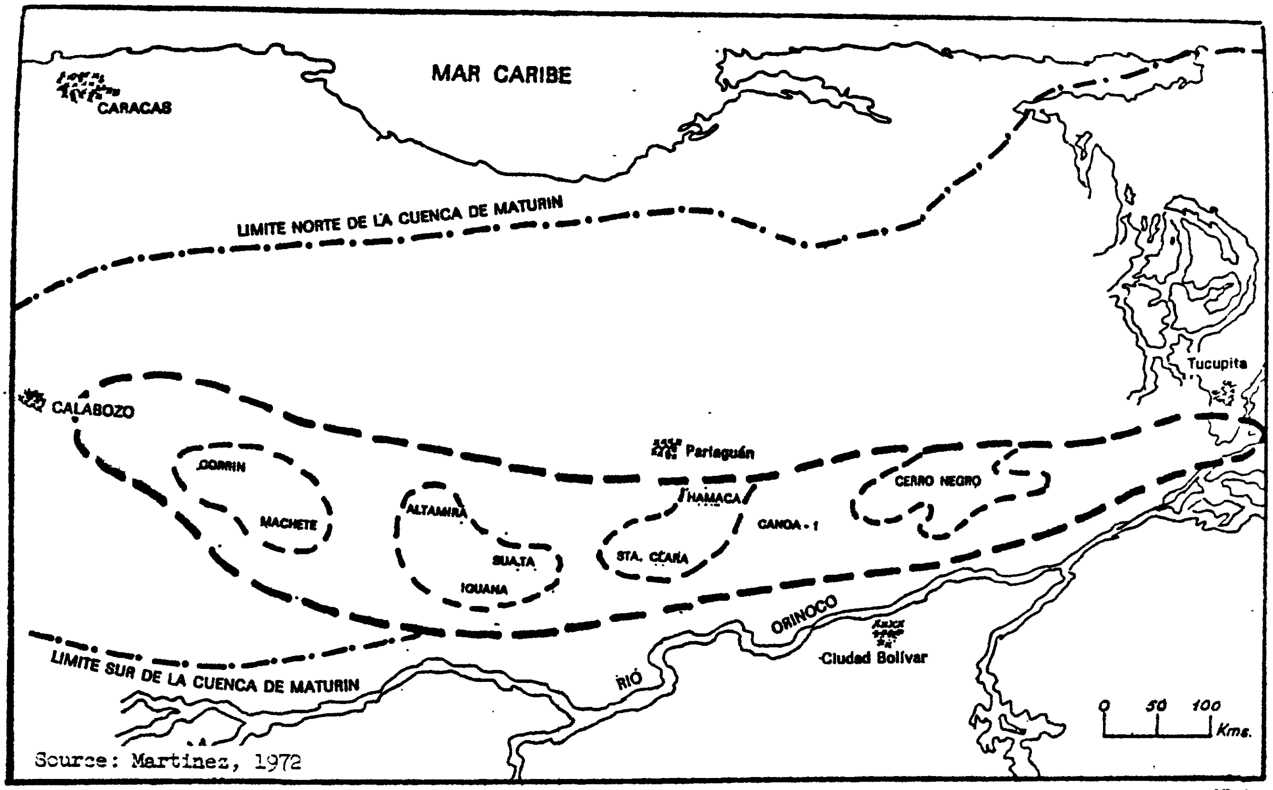


Figure 21. Map showing location of Orinoco heavy oil belt.

nesses are 140 to 200 feet (40 m to 60 m). Oil gravities range between 8° and 14° API. The oil, in some cases, flows to well bores, but rates are so low (tens of barrels or less per day), volumes of gasoline and diesel fuels yielded are so small, and sulfur, vanadium, and nickel contents are so high that development of production facilities would not be economic, even now.

A Belt Office in the Venezuelan Ministry of Mines and Hydrocarbons has been established, however, to conduct intensive studies of the geology of the region and the chemistry of the oils to provide information needed to plan production and processing of the heavy oil when that becomes desirable. As a result of studies begun in 1969 by the Belt Office, estimated locations of geographic boundaries are being extended to the south, west, and east: to the Orinoco River, across Apure State as far as the Colombia border, and eastward across the Amacuro delta to beyond the coast. Estimates of average thickness of petroliferous sand in the belt have been increased to 100 m, from prior estimates of 40 to 60 m. A Belt Office test well produced 80 barrels per day, naturally, and some gas. The crudes of the belt are very low in gasoline and diesel fuel content, contain 2 to 5 percent sulfur, and 200 to more than 500 ppm vanadium and nickel. Nevertheless, plans to determine the extent of occurrence and the volumes contained in the Orinoco heavy oil belt and to attain production of 1 million barrels per day by the year 2,000 were announced in 1979 by Petroleos de Venezuela (Borregales, 1979).

GEOLOGICAL OBSERVATIONS AND CONCLUSIONS

Four geologic conditions guide considerations of ultimate reserves and the prospects for finding new areas productive of oil in Venezuela. These are: 1) the highly variable nature, both vertically and horizontally, of the sedimentary facies; 2) the widespread presence of great volumes of oil; 3) the great thicknesses of sediments; and 4) the complicated late Eocene to middle Oligocene folding and faulting that resulted in both stratigraphic and structural unconformity between Eocene and Oligocene to Pliocene formations and, consequently, in a complexity of structural conditions of Eocene and older rocks that is not revealed in the younger, shallower ones. All these conditions are highly encouraging of a belief that more oil remains to be found, both in the old producing areas and in some not-yet-tested ones.

New prospects for oil fields and pools exist in the presently producing basins in the form of stratigraphic accumulations not yet detected at normal depths, and in structurally and stratigraphically controlled accumulations at depths that heretofore have been beyond the limits of economic exploitation. The best among these are in the Cretaceous formations beneath Lake Maracaibo where depth of burial has retarded probing but where a few deep tests have produced good shows of oil and in the Falcon basin. The Cretaceous is prospective also in the Barinas Basin where Cretaceous production has been established in fault traps. A late start at commercial development of the basin and generally small sizes of accumulations appear to have retarded exploration; therefore, much is still to be done. In addition, an estimate of 140,000,000 barrels of initially recoverable oil in the Eocene and Cretaceous in the Silvestre field of the Barinas Basin (Petroconsultants, 1977) should stimulate interest in looking further. Elsewhere in the presently producing areas, the Cretaceous is well enough known to discourage prediction of major new discoveries.

New Eocene oil-producing areas may remain to be found in stratigraphic and structural traps in the eastern and northern region of Lake Maracaibo, in the Falcon basin where depths to the Eocene also have been discouraging to early prospecting, and in the late-developing Barinas Basin. Optimism is spurred by recent events, including a flow of 4445 barrels per day from lower Eocene sands at 16,000 feet in the Ceuta Field under Lake Maracaibo. Reserves are estimated at 90 to 500 million barrels by Meneven's president (Journal of Commerce, Nov. 27, 1979). Otherwise, the course of prospecting in the presently producing basins will be marked by increasingly intensive exploration of increasingly smaller areas for increasingly smaller pools. Structural and stratigraphic traps in Miocene and younger rocks are likely to be small because these formations, being the shallowest, are already the best explored.

Overall, the best prospects for new large oil fields are areas that are wholly or largely under waters in the Gulf of Venezuela, and the Gulf de la Vela, the Bonaire and the Cariaco Basins, and in the Orinoco Delta onshore and offshore. These areas were covered by the same seas in which the presently producing formations were deposited, and they have remained for the most part untested simply because of the availability of oil in areas that were less expensive to explore and to develop. Discoveries in 1979 of oil in the Gulf de la Vela and of gas 25 miles north of the Peninsula de Paria are very encouraging.

The well in the Gulf de la Vela had an initial flow of 2,000 barrels per day from the deepest of three zones at a depth of 7,900 feet (2,400 m) (U.S. Embassy, Caracas, unpub. data, 29 May 1979). Caution in predicting ultimate productivity here is imposed by the fact that other, older tests have been drilled in this region of complex structural conditions. In those, oil was reported in both Miocene and Cretaceous formations.

The gas discovery in the Gulf of Paria comprises four structural areas, which were reported (U.S. Embassy, Caracas, unpub. data, 9 May 1979) to have a combined total potential to produce 90 million cubic feet per day. Reported total depth is 13,600 feet (4,120 m).

SELECTED REFERENCES

Alayeto E., M. B., and Louder, L. W., 1974, The geology and exploration potential of the heavy oil sands of Venezuela (the Orinoco petroleum belt) in Hills, L.V., ed., Oil sands--fuel of the future: Canadian Society of Petroleum Geologists Memoir. 3, p. 1-18.

Arnold, Ralph, Macready, G. A., and Barrington, T. W., 1960, The first big oil hunt: New York, Vantage Press, 353 p.

Auldridge, L., 1979, Worldwide reserves, holding up despite record production; Worldwide Report: Oil and Gas Journal, v. 77, no. 53, December 31, 1979, p. 67-122.

Borregales, C. J., 1979, Evaluation and development of the Orinoco oil belt, Venezuela: United Nations Institute for Training and Research, Conference on long-term energy resources, Montreal, November 26 - December 6, 1979, preprint.

Case, J. E., 1974, Major basins along the continental margin of northern South America, in Burk C. A. and Drake C. L., eds, The geology of continental margins: New York, Springer-Verlag, p. 733-741.

DeJuana, C. G., and Rodriguez, L. P., 1951, Fundamental geological characteristics of the Venezuelan oil basins: World Petroleum Congress, Third, The Hague, 1951, Proc., Sec. I, Geology and Geophysics, p. 41-55.

Demaison, G. J., 1978, Tar sands and supergiant oil fields: Oil and Gas Journal, v. 76, no. 17, April 24, 1978, p. 198-206.

Edgar, N. T., Kaneps, A. G., and Herring, J. R., 1973, Initial reports of the Deep Sea Drilling Project, V. XV: Washington, D.C., U.S. Government Printing Office.

Galavis S., J. A., and Velarde, H. M., 1967, Geological study and preliminary evaluation of potential resources of heavy oil of the Orinoco far belt eastern Venezuelan Basin: in VII World Petroleum Congress, 1967, Proc., v. 3, p. 234.

Guariguata P., R. C., and Richardson, J. A., 1960, Produccion petrolifera del basamento en el oeste del Lago de Maracaibo, in Memoria Tercer Congreso Geologico Venezolano, v. 3: Venezuela Direccion de Geologia Publicacion Especial No. 3, p. 985-1008.

Gutierrez, F. H., 1976, The Orinoco oil belt. Report to April 1976: Venezuela Ministry of Mines and Hydrocarbons: Official Pub. No. 1.078524, Al Alquitrana, 41 p.

Hedberg, H. D., 1931, Cretaceous limestone as petroleum source rock in northwestern Venezuela: American Association of Petroleum Geologists Bull. v. 15, no. 3, p. 229-244.

Hedberg, H. D., and Sass, L. C., 1937, Synopsis of the geologic formations of the western part of the Maracaibo Basin, Venezuela: Boletin Geologico y Mineral (Venezuela), v. 1, no. 2-4, p. 73-112. (English ed.)

Hedberg, H. D., Sass, L. C., and Funkhouser, H. J., 1947, Oil fields of Greater Oficina area, central Anzoategui, Venezuela: American Association of Petroleum Geologists Bull., v. 31, no. 12, p. 2089-2169.

Liddle, R. A., 1932, Outlines of Venezuelan stratigraphy: Pan-American Geologist, v. 57, p. 161-185.

Liddle, R. A., 1946, The geology of Venezuela and Trinidad, 2d ed: Ithaca, N.Y., Paleontologic Research Institute, 890 p.

Mackensie, A. N., 1937, The geologic section of the Barinas region, Districts of Barinas, Bolivar and Obispos, State of Barinas Venezuela: Boletin Geologico y Mineral (Venezuela), v. 1, no. 2-4, p. 253366 (English ed.)

Martinez, Anibal R., 1966, Our gift, our oil: Vienna, 199 p.

Martinez, A. R., 1972, Recursos de hidrocarburos de Venezuela: Caracas, Edreca Editores, 151 p.

Martinez, R., 1970, Giant fields of Venezuela, in Geology of giant petroleum fields: American Association of Petroleum Geologists Mem. 14, p. 326-336.

Martinez, R., 1977a, El progresso de la exploracion en las cuencas tradicionales, in Memoria Cuarto Congreso Geologico Venezolano, v. 4, Venezuela Direccion de Geologia Publicacion Especial No. 5, p. 1.333-1.348.

Martinez, R., 1977b, Los recursos de hidrocarburos en las areas nuevas: in Memoria Cuarto Congreso Geologico Venezolano, v. 4, Venezuela Direccion de Geologia Publicacion Especial No. 5, p. 1.349-1.358.

Mencher, E., Fichter, H. J., Renz, H. H., Wallis, W. E., Patterson, J. M., and Robie, R. H., 1953, Geology of Venezuela and its oil fields: American Association of Petroleum Geologists Bull., v. 37, no. 4, p. 690-7777.

Merwin, W., 1978, The mineral industry of Venezuela: U.S. Bureau of Mines Minerals Yearbook, Vol. 111, Area Reports, International, Preprint, 15 p.

Miller, J. B., 1958, Habitat of oil in the Maracaibo Basin, Venezuela, in Habitat of oil, A symposium: Tulsa, Okla., American Association of Petroleum Geologists, p. 601-640.

Murany, E. E., 1972, Tectonic basis for Anaco Fault, eastern Venezuela: American Association of Petroleum Geologists Bull., v. 56, no. 5, p. 860-87.

Noran, D., 1978, Growth marks enhanced oil recovery: Oil and Gas Journal, March 27, 1978, v. 76, no. 13, p. 113-140.

Notestein, F. B., Hubman, C. W., and Bowler, J. W., 1944, Geology of the Barco Concession, Republic of Colombia, South America: Geological Society of America Bull., v. 55, no. 10, p. 1165-1216.

Owen, E. W., 1975, Trek of the oil finders: A history of exploration for petroleum: American Association of Petroleum Geologists Mem. 6, 1647 p.

Patterson, J. M., and Wilson, J. G., 1953, Oil fields of Mercedes region, Venezuela: American Association of Petroleum Geologists Bull., v. 37, no. 12, p. 2705-2733.

Payne, A. L., 1951, Cumarebo Oil Field, Falcon, Venezuela: American Association of Petroleum Geologists Bull., v. 35, no. 8, p. 1850-1878.

Petroconsultants, 1977, International oil and gas field records: Geneva.

Ravard, Rafael, 1977, Venezuela: Oil and Gas Journal, v. 75, no, 35, August 1977, p. 492.

Regan, J. H., 1938, Notes on the Quiriquire oil field, District of Piar, State of Monagas: Boletin Geologico y Mineral (Venezuela), v. 2, no. 2-4, p. 197-200 (English ed.)

Renz, H. H., 1942, Stratigraphy of northern South America, Trinidad and Barbados: American Science Congress, 8th, U.S.A., 1940, Proc., v. 4, p. 513-571.

Rubio, F. E., 1960, Condiciones de las acumulaciones de petroleo en los campos costaneros del Distrito Bolivar, Lago de Maracaibo; in Memoria Tercer Congreso Geologico Venezolano v. 3, Venezuela Direccion de Geologia Publicacion Especial No. 3, p. 1.009-1.024.

Schaub, H. P., 1948, Outline of sedimentation in Maracaibo basin, Venezuela: American Association of Petroleum Geologists Bull., v. 32, no. 2, p. 215-227.

Smith, J. E., 1951, The Cretaceous limestone-producing areas of the Mara and Maracaibo Districts, Venezuela: World Petroleum Congress, 3d, The Hague, 1951, proc., Sec. I, Geology and Geophysics, p. 56-71.

Staff, Caribbean Oil Co., 1948, Oil fields of the Royal Dutch Shell Group in Western Venezuela: American Association of Petroleum Geologists Bull., v. 32, no. 4, p. 517-628.

Stephenson, M., 1951, The Cretaceous limestone producing areas of the Mara and Maracaibo Districts, Venezuela: World Petroleum Congress, 3d, The Hague, 1951, Proc., Sec. II, p. 665.

Sutton, F. A., 1946, Geology of Maracaibo basin, Venezuela: American Association of Petroleum Geologists Bull., v. 30, no. 10, p. 1621-1741.

Theofilos, Nicholas, 1978, The mineral industry of Venezuela: U.S. Bureau of Mines Minerals Yearbook; 1976, preprint, 14 p.

Tiratsoo, E. N., 1976, Oilfields of the World, Second Edition: Beaconsfield, England, Scientific Press Ltd., 384 p.

Venezuela Direccion de Geologia, 1956, stratigraphical lexicon of Venezuela (English edition): Venezuela Direccion de Geologia Publicacion Especial No. 1, 664 p.

Venezuela Ministerio de Minas e Hidrocarburos, 1955, Annuario petroleo y minero de Venezuela, dates de 1954-1955--Venezuela petroleum and minerals yearbook: 405 p.

Volkenborn, A., 1979, Venezuela's heavy oil development prospects and plans: United Nations Institute for Training and Research Conference on Long-term Energy Resources, Montreal, Nov. 26-Dec. 6, 1979, Preprint, 6 p.

Zambrano, Elias, Vasquez, Enrique, Duval, Bernard, Latreille, Michel, and Coffinieres, Bernard, 1977, Sintesis paleogeografica y petrolera del occidente de Venezuela, in Memoria Cuarto Congreso Geologico Venezolano, v. 1: Venezuela Direccion de Geologia Publicacion Especial No. 5, p. 482-552.