Cretaceous Fine-Grained Mudstones of the Maracaibo Basin, Venezuela

Goddard, Donald A.[1] and Talukdar, Suhas C.[2]

[1]Louisiana State University, Baton Rouge, Louisiana

[2]Consultant, The Woodlands, Texas

Abstract

The Maracaibo Basin of western Venezuela is considered one of the most prolific petroleum producing regions in the world. The Cretaceous interval consists mainly of fine-grained clastic and carbonate sediments deposited during a period of passive margin development. Stratigraphically, the early Cretaceous Apon Formation of Aptian age contains interbedded rich organic dolomitic and calcareous shale and black bituminous limestone (Mercedes, Tibu, Guaimaros and Machiques Members). These represent maximum flooding surfaces and constitute important source and reservoir rocks in the southwest region of the Maracaibo Basin. To the north, the Apon along with the Lisure and Maraca Formations of the Aptian-Albian Cogollo Group, represent a shallow to middle shelf environment transgressive systems tract consisting mostly of limestone and fine-grained sandstone.

In the south, the Cretaceous Capacho, consisting of black shale and the La Luna Formation comprised of interbedded calcareous shale and black cherty limestone, were deposited during a period of relative sea level rise. The La Luna Formation is the primary source rock in the basin as well as a reservoir in places where microfractures produce the necessary permeability for hydrocarbon flow. Numerous geochemical studies performed in the Maracaibo Basin provide evidence for the existence of multiple stratigraphic intervals containing hydrocarbon generating organic-rich shale and calcareous mudstone within the Cretaceous. Integrated reservoir studies and production data indicate that some of the same intervals are excellent oil and gas producers where fracture systems exist.

Introduction

Petroleum exploration in western Venezuela began around 1911 when geologists entered the region working their way through Falcon State from areas in the Eastern Venezuela Basin (Arnold et al., 1960). The initial investigation of oil seeps in the Maracaibo Basin (Fig. 1) between 1911 and 1915 encountered numerous oil seeps flowing from both Tertiary and Cretaceous outcrops. Therefore, from the outset the hydrocarbon potential of the Cretaceous rocks had been observed, although not clearly understood until many years later. However, it was the initial work of these early explorers that later led to the discovery of several giant fields, most notable among these being La Paz, La Concepcion, and Mara in the northwest part the basin, and Tarra, Bonito, Las Cruces, and Los Manueles in the southwest.

In the early 1920's production from the fields in the southeast Maracaibo Basin was predominantly from shallow Tertiary clastic reservoirs, with minor production from shallow Cretaceous fractured carbonates in the southwest near Rio de Oro in the Perija Mountain Range. It was not until 1946, with the improvement in drilling technology that the first Cretaceous wells in the north were drilled and produced in the La Paz Field. Based on the prolific production from the Cretaceous fractured carbonate and basement reservoir in La Paz, exploration continued along strike in a northwesterly direction. This resulted in the discovery of Mara Field in 1951 (Carmona et al., 1997).

Technological advances in geophysics, geochemistry, petrophysics, and drilling were responsible for deeper Cretaceous discoveries onshore and offshore in Lake Maracaibo. Armed with these technologies, oil companies continued exploration and field development (1955-2000), including fieldwork and abundant coring while drilling the wells. This activity provided the petroleum professionals with the necessary data for understanding the Cretaceous stratigraphy of the region (Fig. 2) and details about the hydrocarbon habitat. Their studies focused on the geological, geochemical, and structural aspects of the Cretaceous reservoirs and have resulted in numerous publications (Bartok et al., 1981; Talukdar et al., 1988; Talukdar and Marcano, 1994; Lugo and Mann, 1995; Parnaud et al., 1995; Llerena and Marcano, 1997; Erlick, 1997; Yurewicz et al., 1998; Alberdi-Genolet and Tocco; 1999). Using these publications as the principal source of information, this paper will concentrate on the fine-grained rocks within the Cretaceous in view of their importance as source rocks, reservoirs, and seals.

Stratigraphic Aspects

Differences Between North and South

From geological studies in the Venezuelan Andes and the Perija Range, and examination of cores taken from wells drilled in the Maracaibo Basin (Renz, 1959; Salvador, 1961; Trump and Salvador, 1964; Bartok et al., 1984; Alberdi-Genolet and Tocco, 1999), it became evident that stratigraphic characteristics differed somewhat from north to south (Fig. 2). In the Cretaceous, the most important difference occurs in the Albian with deposition of the lime-rich facies of the predominantly calcareous Cogollo Group in the north and the more sandy facies of the Aguardiente Formation in the south. The only other major difference of any significance is the presence of the thick Capacho shale deposited on top of the Maraca Formation in the southern regions of the basin (Fig 3). These differences can be observed on the wireline logs from the Mara Field in the north and the Tarra Field in the south (Figs. 4a and b).

The Cogollo Group

In the southern region of the Maracaibo Basin, the Apon Formation consists of hard, nodular limestone and numerous interbeds of black, calcareous shale. The thickest of these shale layers, the Guaimaros Member, is approximately 100 feet (33 m) thick (Fig. 4b) and is considered an important source rock and an excellent producer of oil and gas after fracture stimulation (Llerena and Marcano, 1997; Yurewicz et al., 1998). In the northwestern onshore oil fields (La Paz, Mara, La Concepción) and the fields in Lake Maracaibo, the reservoirs in the Cogollo Group (Apon, Lisure, Maraca) produce where the wells intersect natural fractures and faults (Bartok et al., 1984; Carmona et al., 1997). The unit consists predominantly of micrite-rich carbonates with interbedded mudstone, wackestone, and shale. On modern resistivity and porosity logs through this unit, the porosity highs (9-12 %) tend to be erratic from top to bottom (Fig. 4a). It is suggested that the high porosity zones are attributed not only to matrix porosity in the carbonates but also to the fracture-dominated mudstone and shale intervals (Carmona et al., 1997). Therefore, optimum productivity of the Cogollo reservoirs occurs where both fractures and matrix porosity are present, and is independent of lithology.

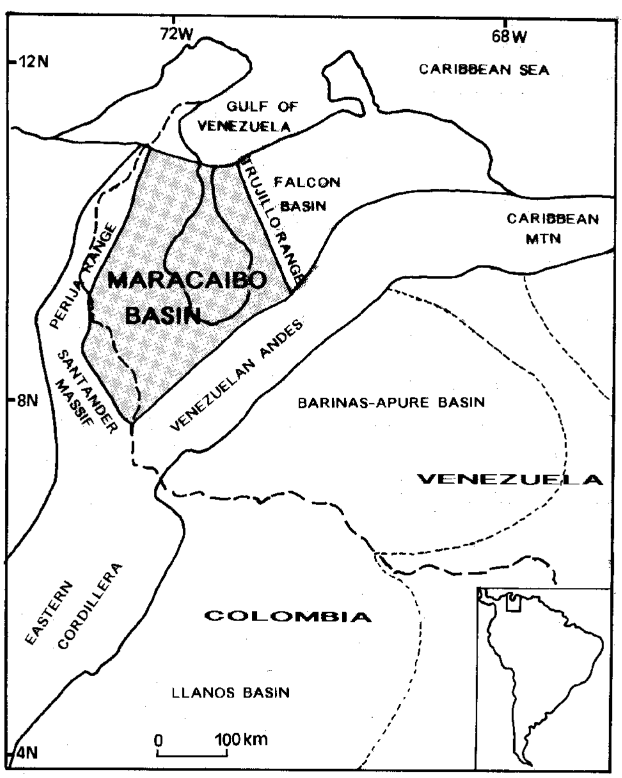

Figure 1. Location map of the Maracaibo Basin.

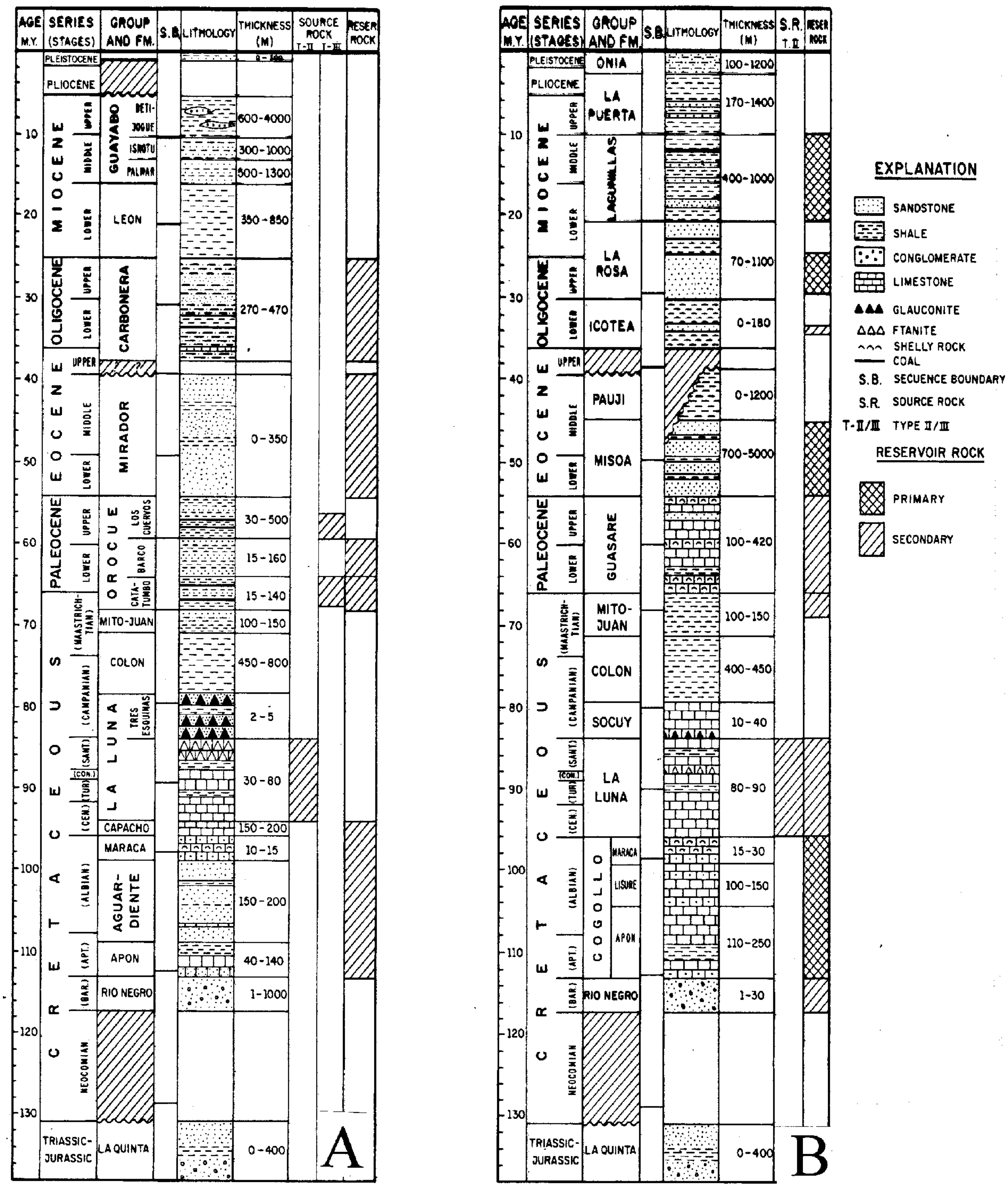

Figure 2. Stratigraphic columns for the Maracaibo Basin with lithologies, thicknesses and Formation names. (A) Details for the southern sector. (B) Details for the northern sector (After Talukdar and Marcano, 1994).

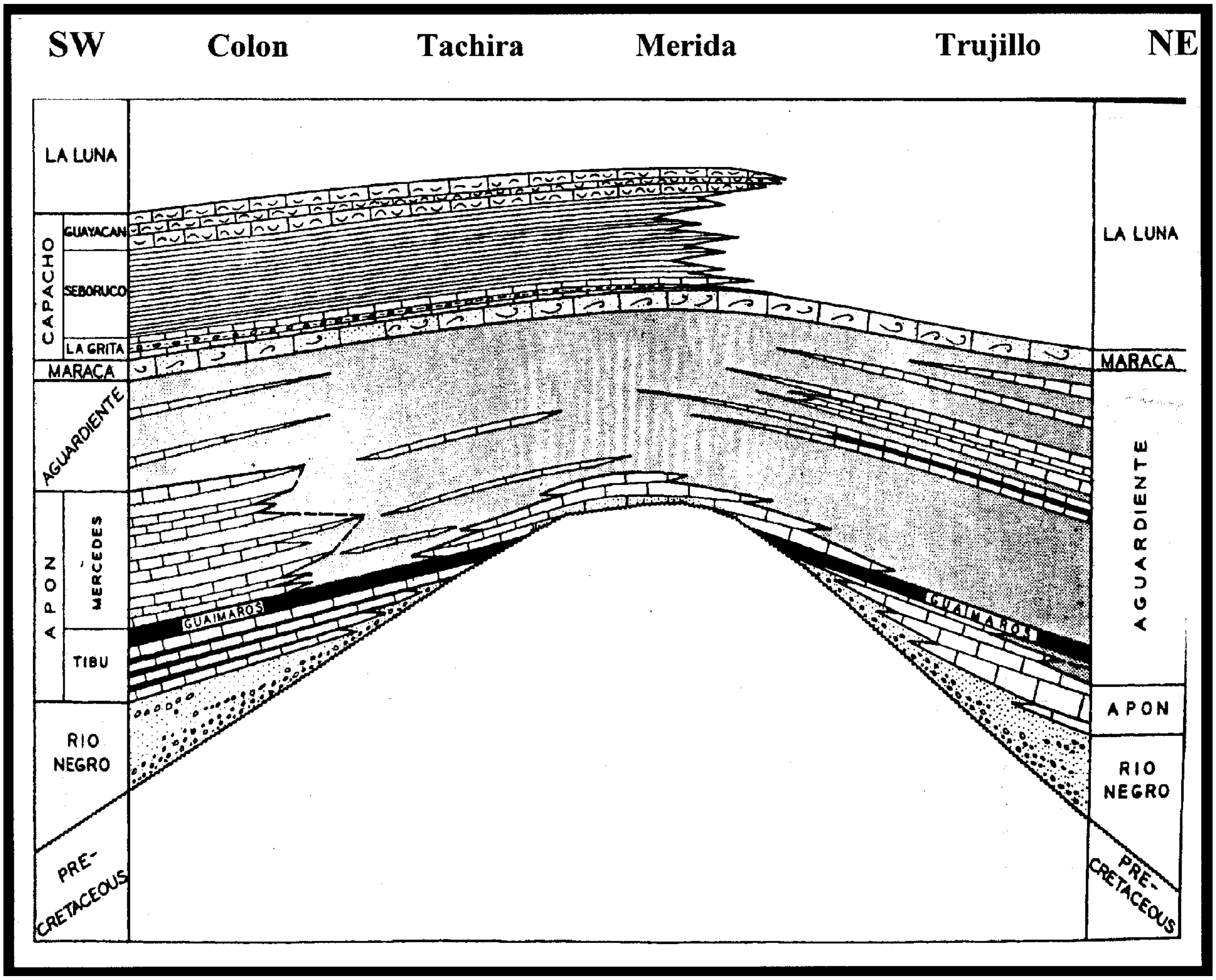

Figure 3. Schematic cross section from northeast to southwest across the Maracaibo Basin showing the lithologic variations and stratigraphic nomenclature differences (Modified from Salvador, 1961).

Capacho/La Luna

La Luna Formation's importance as a reservoir, as well as its excellent sourcing characteristics and the Capacho Formation's hydrocarbon generation potential in the south, have made them the subject of numerous geological and geochemical studies (Talukdar et al., 1988; Talukdar and Marcano, 1994; Yurewicz et al., 1998; Alberdi-Genolet and Tocco, 1999). Since they also outcrop extensively in the mountains bordering the Maracaibo basin (Fig. 1) their lithologies have been well described (Renz, 1959; Salvador, 1961; Trump and Salvador, 1964). The Capacho Formation (Fig. 2) is over 500 feet (170 m) thick, and consists predominantly of black limestone (basal La Grita Member) and overlying thick, black micaceous argillaceous shale (Seboruco Member). Its uppermost unit (Guayacan Member) is a crystalline limestone interbedded with black shale. The overlying La Luna Formation also consists of black calcareous shale interbedded with cryptocrystalline limestone and calcareous cherts. Under the microscope, thin alternating bands of carbonate and shale can be observed mimicking the thicker layers. These rocks give off a strong petroliferous odor on a fresh break. In certain outcropping areas of the Venezuelan Andes, phosphatic interbeds occur within siliceous limestone intervals. In the north, the La Luna Formation attains a thickness of 400 feet (140 m) and thins gradually to the south to a thickness of 100 feet (34 m) in the Andean region where its source potential has diminished.

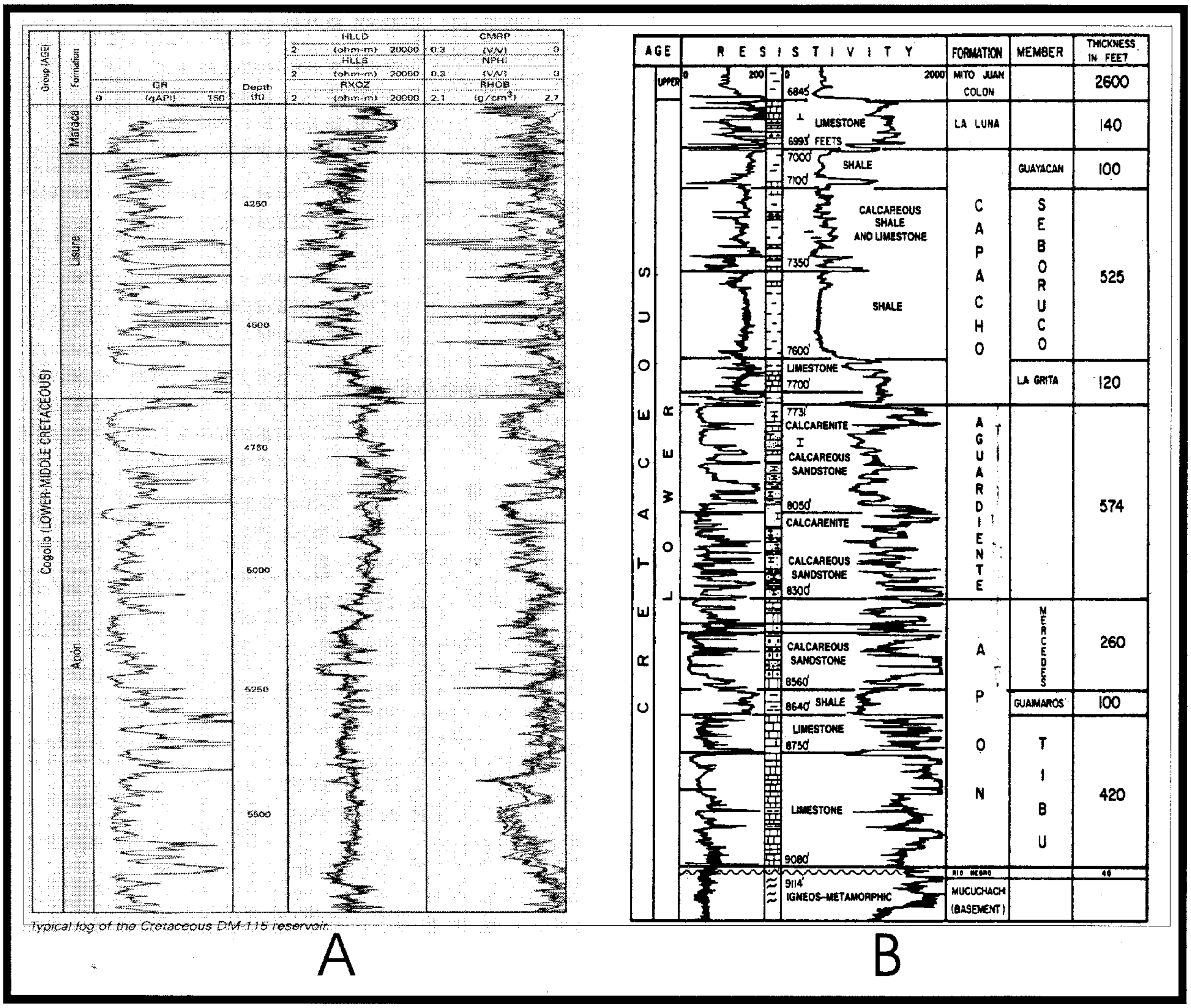

Figure 4. Wireline logs from wells in the northern and southern regions of the Maracaibo Basin. (A) Log from Mara Field in the north showing the Cogollo Group's Apon, Lisure, and Maraca Members. (B) Log from the Tarra Field in the south showing the thick Capacho Formation shale below the La Luna Formation (Modified from Schlumberger, 1997).

Mito Juan/Colon

The thick (2600 feet/850 m) Mito Juan/Colon shales (combined as a single unit because of difficulties in separating) form a regional seal to Cretaceous reservoirs over the entire Maracaibo Basin. Because of their marine (type III) organic matter and typically low hydrogen indices, they are considered poor quality gas sources. However, they may be generating some oil in the deeper intervals in the southwestern regions of the basin (Llerena and Marcano, 1997; Yurewicz et al., 1998). Where they out crop, they are described as consisting of massive dark gray fissile, colloidal shale and mudstones containing abundant microfauna allowing biostratigraphers to precisely determine their Santonian-Maastrichtian age (Trump and Salvador, 1964). In the southwest region of the basin, the Mito Juan/Colon Formation contains fine-grained calcareous sandstone, siltstone, and lenticular limestone in its upper section (Rio de Oro Member). These thin beds have produced minor quantities of oil and gas in a few wells. Data from the Mito Juan/Colon Formation show that it has the ability to source, produce and seal.

Environments of Deposition and Sediment Source

The environments of deposition within the Cogollo Group (Aptian-Albian) are quite diverse within the Maracaibo Basin's formations. The variations in their lithofacies and depositional characteristics have been observed in cores from Lake Maracaibo wells and in outcrops (Bartok et al., 1984). Parnaud et al., (1995) described in detail and mapped the paleogeographic distribution of this Group (Fig. 5). The carbonate facies of mudstones and wackestones in the central and northern areas (Fig. 5a, b) are associated with supratidal and intratidal environments. Shallow and open marine environments are reported for the wackestones, mudstones, and terrigenous shales deposited in the northwestern part of the basin. In the south, the carbonates and interbedded shales (Guaimaros Member) of the Apon Formation are shallow marine and lagoonal deposits. The siliciclastic sediments reaching the basin during Aptian-Albian time were provided by the Guyana Shield located to the southeast and from positive areas to the west and southwest (Fig. 5a).

The Capacho Formation is interpreted as a transgressive deposit associated with a slow deposition rate. Fossil fish remains and planktonic foraminifera found in the limestone of the lowermost La Grita Member of the Capacho Formation in the south (Fig. 5c) indicate these sediments were deposited in a shallow marine environment. The thick shales of the middle Seboruco Member contain abundant forams that are believed to be associated with a deep marine environment. As with the lowermost member, the bioclastic limestones, interbedded siltstones and shales of the uppermost Guayacan Member are also considered shallow marine deposits (Trump and Salvador, 1964).

The anoxic-euxinic conditions under which the La Luna Formation was deposited and its association with a period of maximum transgression in the region of the Maracaibo Basin have been well documented in the literature (Talukdar et al., 1988, Talukdar and Marcano, 1994; Yurewicz et al., 1998). Deposition of the cherts and occurrence of phosphatic limestone intervals within the La Luna have been attributed to a combination of upwelling and anoxic events that took place during Cenomanian-Campanian time (Erlich, 1997). Recently, trace metal analyses on La Luna samples from the Perija Range performed by Alberdi-Genolet and Tocco (1999) again showed the deep-water restricted circulation environment responsible for the preservation of marine organic matter in these sediments. Similarly, the underlying organic rich Capacho shales in the south also are considered restricted deepwater deposits.

The widespread Mito Juan/Colon shales were deposited in moderately deep-water. They contain abundant benthonic foraminifera and the uppermost intervals give evidence of turbidite deposition. The sources of the fine-grained clastics to the basin are the Guyana Shield to the southeast and the highs to the southwest, and northwest of the basin (Fig. 5d).

Petroleum Systems

Cretaceous, La Luna Formation lime mudstones, fractured Cogollo Group carbonates and La Luna Formation mudstones, and Colon shales are important elements of the La Luna-Misoa Petroleum System. Approximately 98% of the total recoverable oil reserves of 52.2 billion bbl and gas reserves of 51.97 tcf in multiple reservoirs in the Maracaibo Basin (Talukdar and Marcano, 1994) can be attributed to the system (Fig. 6).

The La Luna Formation (and also equivalent Capacho Formation) lime mudstones and calcareous shales are the most prolific oil source rocks in the basin. They are organic rich (TOC 1.5-9.6%), contain marine, highly oil prone type II kerogen, and are mature to overmature over the entire basin. The richness and high kerogen quality, organic matter distribution in fine laminations, along with very low porosity and permeability of the La Luna lime mudstones at the depths of oil generation, were responsible for the very high oil expulsion efficiency of about 75% (Talukdar et al., 1988).

The La Luna Formation sourced oil migrated into basement rocks, Cretaceous fractured Cogollo Group carbonates and La Luna Formation mudstones, and Paleocene, Oligocene, Eocene and Miocene sandstones. Cretaceous Cogollo and La Luna Formation reservoirs are secondary. The Eocene and Miocene are the most important reservoirs of the petroleum system (contain 50% and 44% of total recoverable reserve, respectively).

The thick interval of Colon shales overlying the La Luna is the most important regional seal that controlled the migration of La Luna oil initially into Cretaceous structures, from which the oil then moved upward into the Tertiary reservoirs through faults.

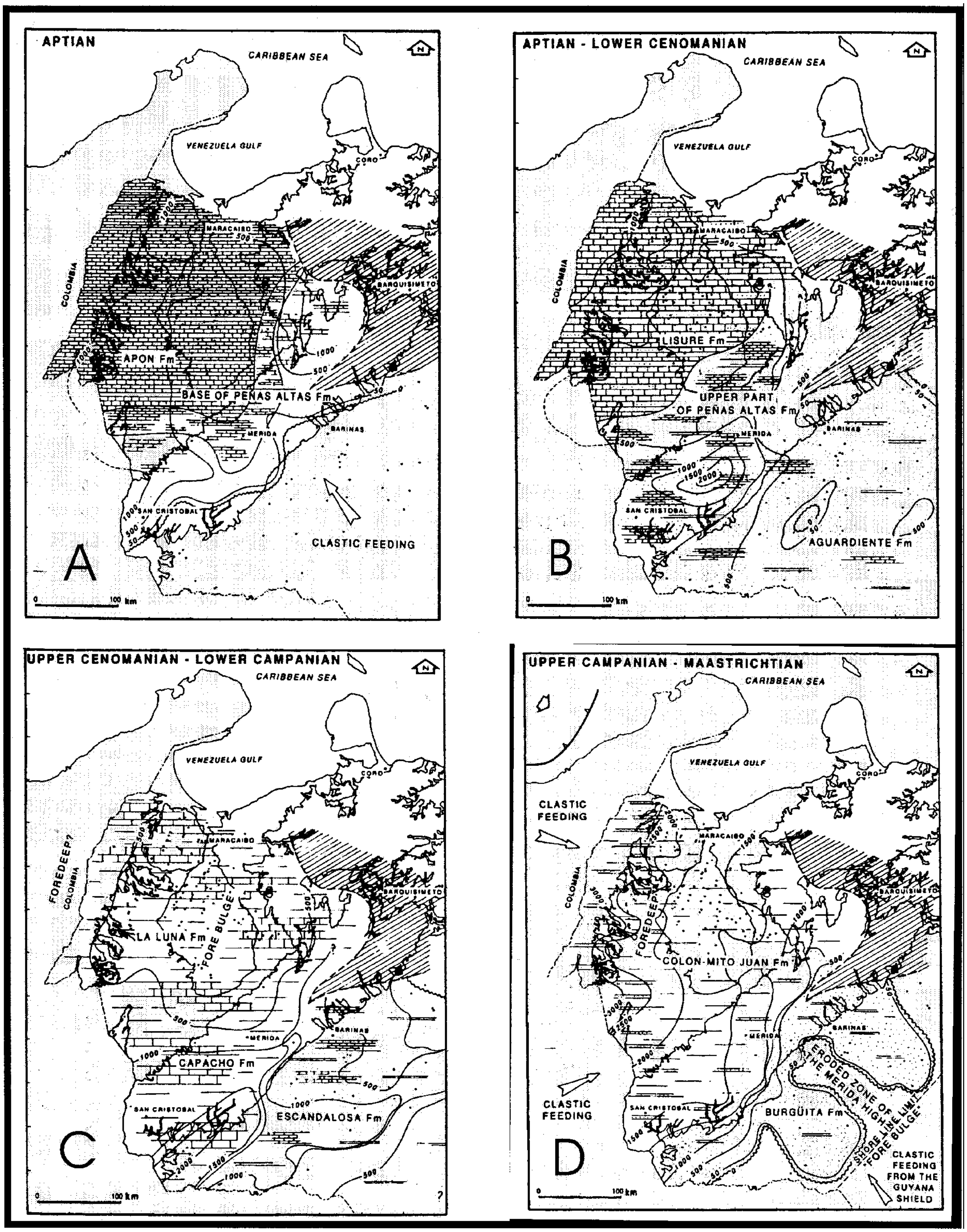

Figure 5. Paleogeographic distribution of the Cretaceous sediments in the Maracaibo Basin. (A) Distribution of the Apon Formation carbonates during Aptian time and source of clastics. (B) Distribution of the Lisure Formation of the Cogollo Group during Aptian-Lower Cenomanian time. (C) Distribution of Capacho and La Luna Formations. (D) Distribution of Mito Juan/Colon shales and showing the source of the clastics (Modified from Parnaud et. al., 1995).

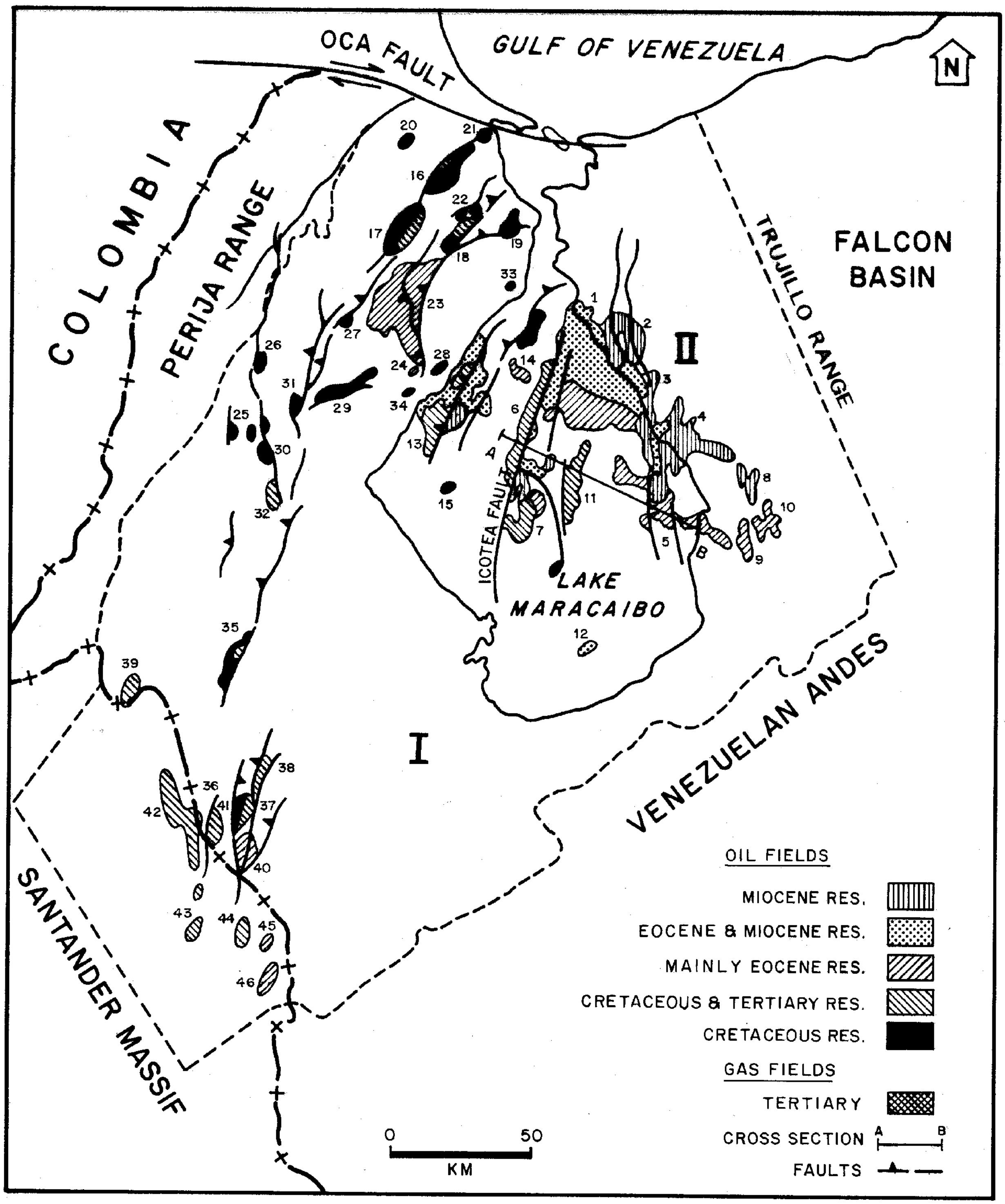

Figure 6. Location of oil and gas fields in the Maracaibo Basin (After Talukdar and Marcano, 1994).

A secondary petroleum system Machiques-Piche is also present in the southwestern Maracaibo Basin that contributed oil to the fractured Apon carbonates (Llerena and Marcano, 1997). The lime mudstones of the middle Cretaceous Machiques member of the Apon Formation are the source rocks. The Machiques source rocks are organic rich (1-5.5% TOC), and are comparable in lithology and type II kerogen quality to the La Luna Formation source rocks (Alberdi-Genolet and Tocco, 1999). The Machiques Member sourced oils are similar to the La Luna Formation sourced oils in oil quality. The two oil families can only be distinguished from each other by certain biomarker characteristics that support more restricted marine conditions for the Machiques Member. Therefore, the contribution of the system was included in the La Luna-Misoa Petroleum system.

Conclusions

Several conclusions can be reached from the information provided in this paper and from the literature. These conclusions can be summarized as follows:

9. After over ninety years of petroleum related activity in the Maracaibo Basin, details regarding its petroleum system and the characteristics related to its source rocks, reservoirs and seals have been well documented and are fairly well understood.
10. Early geological work in the foothills of the surrounding Andes and Perija Mountain Ranges, where numerous seeps were encountered, geophysical surveys and geochemical investigation of drilled cores taken in the basin proper have been performed. The integration of this data has resulted in the discovery and eventual production of enormous quantities of oil and gas from a variety of lithologies including fine-grained rocks.
11. The important fine-grained Cretaceous source rocks, reservoirs and seals can be found within the Cogollo Group and in the Capacho, La Luna, and Mito Juan/Colon Formations. Not only do the fine-grained rocks in these intervals behave as important source rocks, but also produce hydrocarbons where fracture systems exist. The shales and mudstone possess excellent intra-formational, as well as regional sealing characteristics.
12. The Cretaceous fine-grained mudstones and shales related to the petroleum system of the Maracaibo Basin were deposited mostly in marine environments and sourced locally, and from geographic highs bordering the basin.
13. The Cretaceous source rocks pertaining to this petroleum system are responsible for the bulk of the hydrocarbon reserves in the Maracaibo Basin.

References

Alberdi-Genolet, M. and R. Tocco, 1999, Trace metals and organic geochemistry of the Machiques Member (Albian-Aptian) and La Luna Formation (Cenomanian-Campanian), Venezuela: Chemical Geology, v. 160, p. 19-38.

Arnold, R., G. A. MacReady, and T. W. Barrington, 1960, The first big oil hunt, Venezuela 1911-1916: Vantage Press, New York, Washington, Hollywood, 353 pp.

Bartok, P., T. J. A. Riejers, and I. Juhasz, 1981, Lower Cretaceous Cogollo Group, Maracaibo basin, Venezuela: Sedimentology, diagenesis and petrophysics: AAPG Bulletin, v p.1110-1134.

Carmona, R., J. Graterol, N. Pina, O. Suarez, E.. Frost, G. Gomez and T. Quinn, 1997, Revitalization of Mara Field: SPE Annual Technical Conference and Exhibition, San Antonio, Texas, paper 38665, p.241-256.

Erlich, R. N., 1997, Origin and depositional environments of Turonian-Maastrichtian organic rich and phosphatic sediments of western Venezuela: VI Simposio Bolivariano, Exploracion en las Cuencas Subandinas, Cartagena, Colombia, Memoria I, p. 478-524.

Llerena, J., and F. Marcano, 1997, El sistema petrolifero en la subcuenca de Catatumbo, Cuenca de Maracaibo, Venezuela: VI Simposio Bolivariano, Exploracion en las Cuencas Subandinas, Cartagena, Colombia, Memoria I, p. 540-551.

Lugo, J. and P. Mann, 1995, Jurassic-Eocene tectonic evolution of Maracaibo basin, Venezuela: in A.J. Tankard, R. Suarez, and H. J. Welsink, Petroleum basins of South America: AAPG Memoir 62, p.699-725.

Parnaud, F., Y. Gou, J.C. Pascual, M. A. Capello, I. Truskowski, and H. Passalacqua, 1995, Stratigraphic synthesis of western Venezuela: in A.J. Tankard, R. Suarez, and H. J. Welsink, Petroleum basins of South America: AAPG memoir 62, p. 681-698.

Renz, O., 1959, Estratigrafia del Cretaceo en Venezuela Occidental, Boletin de Geologia (Venezuela), vol. V, p.3-48.

Salvador, A., 1961, Guidebook to the Geology of Northeastern Trujillo: Field Trip of the Sociedad Geologica De Venezuela Occidental; Guidebook no. 3, 33 pp.

Schlumberger, 1997, Well Evaluation Conference-Venezuela: Published by Schlumberger Surenco, C. A, Caracas, Venezuela, 345 pp.

Talukdar, S. C., O. Gallango, C. Vallejo, and A Ruggiero, 1988, Observations on the primary migration of oil in the La Luna source rocks of the Maracaibo basin, Venezuela: 2nd IFP Exploration Research Conference on " Migration of Hydrocarbons in Sedimentary Basins," Carcans, France, Edicion Technip, v. 43, no. 3, p. 357-370.

Talukdar, S. C. and F. Marcano, 1994, Petroleum systems of the Maracaibo Basin, Venezuela: in L.B. Magoon and W. G. Dow, eds., The Petroleum System- From Source to Trap: AAPG Memoir 60, p. 463-481.

Trump, G. W. and A Salvador, 1964, Guidebook to the Geology of Western Tachira, Boletin de la Asociacion Venezolana de Geología, Minera y Petroleo, 25 pp.

Yurewicz, D. A., D. M. Advocate, H. B. Lo, and E. A. Hernandez, 1998, Source rocks and oil families, southwest Maracaibo basin (Catatumbo Subbasin) Colombia: AAPG Bulletin, v. 82, p. 1329-1352.