Oil and gas exploration in Cuba began with the discovery of the Motembo oilfield in 1881, and some 25 oilfields have subsequently been discovered, the largest of which are Boca de Jaruco and Varadero.

Two oil-bearing provinces are known: the Northern Cuban Province, which includes the overthrust belt; and the Southern Cuban Province, to the south of the overthrust belt, which includes a number of Cretaceous-Tertiary basins.

Rocks in the overthrust belt are intensely faulted and folded, with folds trending NE in western Cuba and NW elsewhere on the island. The Northern Cuban Province is about 1,000-kms long and 80- to 100-kms wide; sediments here are generally 10- to 12-kms thick. Seven overthrust surfaces have been identified by drilling, and correspond to different oil zones, thus, oilfields are characteristically located within different tectonic-stratigraphic units.

The Southern Cuban Province covers an area of about 60,000 sq. kms, and is composed of several basins, whose development was different from those to the north. Oil has been located in the Central Basin, where oilfields are present in positive structures but not so far in any other basins here, although surface and subsurface oil seeps are common in this area.

INTRODUCTION

Exploration for hydrocarbons on the island of Cuba began at the end of the last century with the discovery of the Motembo oilfield (Echevarria, 1970; Socorro et al., 1981; Yparraguirre and Echevarria, 1989). Since then, 25 on- and offshore fields have been discovered, with reserves in each considered to be of medium or small size; all the fields are situated in the western and central parts of the island. Cumulative oil production is shown in Table 1. The most important exploration results have been obtained since the discovery in 1970 of the Boca de Jaruco and Varadero oilfields.

The object of this paper is to introduce the Authors’ ideas on the tectonic-structural evolution of the Cuban archipelago. The results of more than 50,000 kms of seismic lines (most of them marine) and many exploration wells have been synthesised and summarized. Different models of the evolution of the Caribbean-Gulf of Mexico region have been considered, and this information has been integrated with the geology of the discovered fields in order to determine prospective offshore and onshore areas.

Cuban petroleum geologists are convinced of the island’s oil and gas potential; the largest undeveloped reserves so far identified are believed to be offshore.
THE NORTHERN OIL PROVINCE

This province, located in the northern part of the island and the adjacent area offshore (Fig. 1), is over 1,000-kms long and 80- to 100-kms wide. Sedimentary thicknesses greater than 10 kms are present (Shein et al., 1975; Sherbakova et al., 1977).

Basement

Continental basement rocks are exposed near Sierra Morena in Central Cuba, and include marbles, siliciclastic metasedimentary rocks and the Rio Canas granite. Radiometric ages are: $^{40}\text{Ar}/^{39}\text{Ar} = 952 \pm 12$ to $719 \pm 9$ MM yrs; and K/Ar = 945 ± 20 to 910 ± 25 MM yrs. Ages for the granites are 172 ± 4 MM yrs and 150 ± 5 MM yrs respectively (Renne et al., 1989). The allochthonous nature of this basement is evidenced in the Menendez well, drilled in 1916 in the northern part of Matanzas Province, where a sequence of over 30 m of these rocks overthrusts Mesozoic carbonates at a depth of 716 m. Long-wavelength magnetic anomalies, which occur mainly offshore, indicate basement depths of between 10 and 12 kms (Hernandez et al., 1988).

There has been considerable debate about the genesis of this province, including the origin of continental material. Sediments have been deposited here since the Lower Jurassic—Cretaceous in stages corresponding to the structural evolution of a stable continental margin.

Lower—Middle Jurassic

Deposition of both continental-facies strata (the San Cayetano Formation, outcropping in Western Cuba), and lagoonal strata (the San Adrian and Punta Alegre formations, which outcrop in Western and Central Cuba) occurred during the first stage of basin evolution in the Lower to Middle Jurassic (Callovian). During this stage, deposition of a large volume of organic matter (predominantly humic) occurred in a confined environment (Diaz et al., 1988).

Metamorphic analogues of these rocks outcrop in Isla de la Juventud (formerly known as the Island of Pines), Escambray and Sierra del Purial (Fig. 1) (Somin and Millan, 1981). Also, the Jatibonico-78 well in Central Cuba found similar rocks at 3,900 m, with oil shows beneath volcanics (location in Fig. 8, p. 271).

Carbonate sedimentation began in the Late Callovian, Terrigenous and carbonate strata outcrop in western Cuba (La Esperanza and Francisco Formations) and Central Cuba (Constancia Formation), and have been penetrated by several exploration wells onshore (Sanchez et al., 1989).

Carbonate deposition dominated the Upper Oxfordian and continued into the Turonian, during the latter stage, in a number of separate tectonostratigraphic units...
(TSUs) or terranes (Hatten et al., 1989). From south to north, these are the Placetas, Camajuani, Remedios and Cayo Coco units (Hatten et al., 1958; Ducloz and Vuagnat, 1962).

The Placetas TSU is associated with carbonate and siliceous rocks deposited in a deep, pelagic environment, and the Camajuani TSU is also composed of pelagic carbonates, but with a lower siliceous content. The Remedios TSU includes both carbonate banks and dolomitised carbonates. Finally, the Cayo Coco TSU is composed of evaporites, carbonates and dolomitised carbonates deposited in a shallow-marine environment during the Upper Jurassic to Lower Cretaceous, and pelagic carbonate sediments and cherts deposited during the Middle and Upper Cretaceous. This last characteristic has been explained in terms of the existence from Albian to Senonian time of a palaeo-sea-way or channel south of the Bahamas Platform (Pardo, 1975) or, alternatively, by a reversal of the coast-line relative to the continent, probably suggesting another stable-margin episode, beginning in the Albian.

Stratigraphic sections compiled from surface and well data, and the variations in different TSUs, are shown in Fig. 2 (see also Fig. 8, p. 271).

Cretaceous overthrusting

The second stage of basin evolution was characterized by marked subsidence, and the accumulation of large volumes of organic matter. Evaporite sequences, formed during periods of continental rifting, were displaced, and developed diapiric structures due to sedimentary overburden, some of which outcrop in Punta Alegre, Loma Cunagua and Turiguano, at the contact between the Remedios and Cayo Coco TSUs in northern Ciego de Avila (Fig. 8). Other diapirs have been discovered by the Tina 1 and 2 wells. Palynological determinations indicate a Middle Jurassic age for the Punta Alegre
evaporites (Meyerhoff and Hatten, 1968); however, the present Authors believe that these diapirs correspond to the first stage of development of the southern North American continental margin. Development of a continental platform occurred in Albian-Cenomanian time, as a result of biogenic activity, which produced reefal carbonates and general bioclastic sedimentation.

The existing continental slope could have been the site of local turbidite sedimentation, resulting in accumulation of bioclastic sediments from reefs in deeper basinal sites. Evidence supporting this hypothesis has been found in the Colorados I and 2 wells in the Ramedios TSU (Sanchez et al., 1989). This data, which confirms the possibilities that carbonate rocks from the continental platform form oil reservoirs, has been analyzed in exploration of reefal structures (Socorro et al., 1986; Tenreyro et al., 1986; Rodriguez et al., 1989).

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**Fig. 2.** Stratigraphic columns for TSUs in the Northern Province (thicknesses in metres).
Fig. 3. Litho-stratigraphic cross-section across the Northern Province.
Volcanic activity occurred in the Lower Cretaceous: volcanism was associated with the formation of oceanic crust along the axis of the proto-Caribbean basin, and also with the initiation of the Greater Antilles arc, which, in the Authors’ opinion, took place to the SW of Cuba (modified from Ross and Scotese, 1988).

Radiometric analysis of rocks from the volcanic arc indicate Albian to pre-Campanian ages (Hatten et al. 1989). Arc volcanism was periodic, as indicated by intercalated carbonates such as Cenomanian rocks that are mainly represented by reefal limestones of the Provincial Formation.

NNE-ward movement of the Caribbean Plate, beginning at least in the Campanian, and further NE movement during the Palaeocene, resulted in collision of the Cuban arc with the North American continent, giving rise to a compressional orogen. Consequently, volcanic-arc and oceanic-crust material was thrust over the stable, continental margin, whose development therefore ceased. Iturralde (1988) believes that this compression is related to the formation of the South Atlantic Ocean.

Recent studies have suggested that ophiolitic rocks outcropping in northern Cuba, and overlying limestones or arkosic rocks, indicated by well data, are part of a segment of oceanic crust derived from an ancient marginal sea located between the Bahamas continental slope and the Cuban archipelago, and are not derived from the basement of the volcanic arc (Iturralde, 1988).

The present Authors believe that the two types of oceanic crust that have been described in Cuba (Somin and Millan, 1981) may be associated with crust formed in an internal part of the proto-Caribbean Basin and also with the basement of the Greater Antilles arc.

The magnitudes of the compressional forces were such that rocks from the stable margin (Placetas, Camajuani, Remedios TSUs) were also overthrust, both internally and over each other (Fig. 3). This process took place until the early Lower Eocene (Sanchez et al., 1985) in western Cuba, and until the Middle Eocene in central-eastern Cuba (Iturralde, 1988). The formation of as many as seven thrust surfaces resulting from this collision has been verified by a number of exploration wells (Fig. 3). The distribution of seismic velocities also confirms this model.

Overthrust volcanic-arc and oceanic-crustal rocks outcropping in different areas of the Southern Province have been synthesized as the “Zaza” unit (Ducloz and Vuagnat, 1962). The northern limit of its distribution is clearly determined by magnetic field surveys.

Volcanic-arc and oceanic-crustal rocks, as well as sequences from the internal continental margin, were overthrust during different time-intervals between the Campanian and early Lower Eocene (Rodriguez, 1983). Several stratigraphic levels in the Upper Cretaceous and Palaeocene contain shales which form good seals for oil and gas accumulations in carbonate reservoirs of Upper Jurassic and Cretaceous ages. Petrophysical and well-logging data show that the values of the coefficients of sealing of the rocks are 0.9-0.8 (Garcia, 1987). This allowed the preservation of fluids to occur during thrusting, which took place after deposition of the seal lithology. Also, it should be pointed-out that shaley layers with sealing potential are present within the reservoir interval (typically in the Varadero oilfield).

**Eocene post-orogenic stage**

A post-orogenic stage was initiated, with predominant carbonate sedimentation, in the late Lower Eocene in western Cuba, and the Middle Eocene in the most eastern part of the Northern Province. Offshore seismic lines indicate the existence of terrigenous material, capable of acting as a seal, above hydrocarbon-generating Tertiary rocks.

**Source rocks**

The most important source rocks in the Northern Province are Upper Jurassic to Aptian in ages. Oil generation may also occur in Albian-Turonian sequences, and even
Fig. 4. Seismic section A — A', Northern Province (location on Fig. 8). Dashed lines are faults. Seismic horizons: I: Tertiary sediments; V-V': Upper Cretaceous; VI — VI': Upper Jurassic. SB: sea-floor. Scale bar is 5 kms.
those of late Upper Cretaceous and Middle Eocene ages or younger. The most recent correspond to post-orogenic sequences.

The dominant type of organic matter in all these sections is sapropelic, although some mixtures with humic material are present (Pairazian et al., 1975). The volume of humic matter increases in the Upper Jurassic sediments of westernmost Cuba (Diaz et al., 1988; Lopez, 1988); larger volumes of organic matter and bitumens are present in older sequences, and volumes decrease in younger rocks (Table 2).

Temperature measurements in Meso-Cenozoic sediments show that the geothermal gradient is somewhat less than normal and varies from 23.1 to 23.6°C/km (Tenreyro et al., 1987).

**OIL POTENTIAL OF THE NORTHERN PROVINCE**

Twenty-one medium and small-sized oilfields have been discovered in the Northern Province (Tables 3 and 4: pp. 273, 274), of which Varadero and Boca de Jaruco are the most important in terms of volumes of recoverable reserves.

Hydrocarbon traps are associated with asymmetric folded structures, with dimensions in the south of between 3.0-5.0 and 1.5-2.0 kms. Further north, the dimensions of fold-structures increase to 30-40 sq. kms or more. These structures are located offshore, mostly near the limit of the overthrust belt. According to seismic data (CDP), it is possible to identify relatively-flat (25-30°), incoherent, non-extensional and irregular seismic horizons, which correspond to thrust surfaces between different or the same TSU (Fig. 4). In the upper parts of the sections, flat-lying, continuous, uniform, extensive reflections can be correlated (Hernandez et al., 1988). Their depths are limited by a prominent reflection event, related to the seismic impedance contrast associated with the base of post-orogenic Middle Eocene-Quaternary sediments of the Northern Oil Province (Figs. 3 and 4).

The oil and gas accumulations so far discovered are associated with four allochthonous TSUs (Zaza, Placetas, Camajuani and Remedios) (Fig. 3), which are located partially offshore in western Cuba, and onshore in central and eastern Cuba. The overthrust belt is bounded to the north by an area of differing structural and sedimentological configuration corresponding to the Florida-Bahamas carbonate platform.

In seismic sections across the northern platform area, extensive flat-lying reflections are revealed, those with the highest amplitudes being associated with the Upper Cretaceous unconformity (i.e. the MCU of Ball et al., 1985); high acoustic impedance is observed in all lines. Fig. 5 indicates fold structures which are considered to be suitable targets for oil and gas exploration. This sector corresponds to the Bahamas Platform.

Further south, after displacement by a normal regional fault, the same sections are present, although with interruptions. This area is associated geologically with a platform
Fig. 5. Seismic section B — B', Northern Province (location on Fig. 8). Dashed lines are faults. Seismic horizons: I. Tertiary sediments; V — V': Upper Cretaceous; VI — VI': Upper Jurassic, SB: sea floor. Arrows identify target fold structures. Scale bar is 5 kms.
edge, which is described here as the “broken platform”. Its southern limit indicates the northern end of the folded belt, which is located in deep and also shallow waters.

The “broken platform” is defined as a transitional zone with normal and reverse faults between two different structural areas, with and without overthrust movements respectively (Fig. 4).

Rocks corresponding to both the true platform and the “broken platform” are present in the Cayo Coco TSU (Figs. 1 and 3).

**Structural and lithological traps (Fig. 3)**

The Zaza TSU is oil-bearing, with small accumulations located in fractures. Reservoir traps in the three thrust-sheets of this unit are lithologic-stratigraphic (Fig. 3), depending on the nature of the seal, which could be either non-fractured rocks of this unit, or rocks of Maestrichtian age (Socorro and Sanchez, 1989).

Oil accumulations discovered in the Placetas TSU are present in three overthrust sheets. Accumulations discovered in the innermost sheets are present as layered deposits bounded by reverse faults, which the present Authors have named the Cantel and Varadero Sur oil- and gas-bearing zones (Socorro and Sanchez, op. cit.) (Fig. 3).

The outermost sheet of the Placetas TSU hosts a large accumulation trapped in an asymmetric fold, bounded by a reverse fault. To the south, possibly south of Cantel, the Placetas TSU underlies the Zaza TSU.

The Camajuani TSU is composed of two thrust-sheets, which together form the oil-bearing Chapelín zone, in which large accumulations are present in the same setting as above, namely asymmetric folds bounded by reverse faults.

The Remedios TSU is composed of three thrust-sheets, the innermost hosting the largest oil accumulations. The existence of hydrocarbons in the other sheets is probable, but no wells have been drilled on them since they are offshore and have not yet been fully explored. It is suggested that large accumulations in asymmetric folds are also present in these zones.

There are no oil- or gasfields in the Cayo Coco TSU. Wells drilled here (all more than 25 years ago) did not have sufficient justification from a structural point of view, which is why only oil shows or sulphur brines were reported in the Cayo Coco 2 well (Meyerhoff and Hatten, 1974).

**THE SOUTHERN PROVINCE**

This Province occupies practically the whole onshore area, and extends to adjacent offshore areas to the south (Fig. 1). It is composed of several basins formed during the Upper Cretaceous—Tertiary. Oilfields have so far only been discovered in the Central Basin, in which most wells have been drilled (Table 3).

The Province is composed of the Western (Los Palacios, Vegas and Mercedes), Central (Central and Ana Maria) and Eastern (Cauto, Nipe and Guantanamo) Basins. Sediments in the Western and Central Basins were deposited from the Upper Cretaceous (Campanian) onwards, while those in the Eastern Basin date from the Lower Eocene. Terrigenous-carbonate sedimentation took place in subsiding areas of the extinct volcanic arc in the Cretaceous and Paleogene, probably in a “piggy-back” type basin.

Stratigraphic sections corresponding to the different basins of this province are shown in Fig. 6.

The Central Basin is composed of two depocentres (Ana Maria and Central), the first being located offshore in the Caribbean Sea. The Basin is composed of a NE-striking graben, bounded by deep faults (Fig. 7). On a gravimetric map, it is represented by a minimum (-36 mgal) bounded by strong gradient zones, and its dimensions are 80 kms long and 25 - 50 kms wide. The basin is divided into fault blocks, which are thicker in the basin centre than on the margin.
Fig. 6. Stratigraphic columns for the Cretaceous-Tertiary basins in the Southern Province.
Organic material in Central Basin sediments is sapropelic, but overall concentrations are much lower than in the Northern Province (Table 2), the highest values being present in syn-orogenic deposits (of late Upper Cretaceous - early Middle Eocene age), which are here considered to be source rocks. However, it has been calculated that there is insufficient organic matter present in the orogenic sediments within the “oil window” to produce the hydrocarbon reserves present. According to geochemical data (Table 2), and the organic matter and bitumen contents in rocks, the volume of hydrocarbons recovered (totalling some 2MM tons) was generated both from Upper Cretaceous sources within the basin, and additional sources. This idea agrees with the model presented in this paper, with the Placetas and Camajuani TSUs underlying the frontal overthrust volcanic arc, and migration occurring along faults in a NE-SW direction (Kleschov et al., 1978).

Oil potential of the Central Basin

Oil production in the Central Basin began during the 1950s with the discovery of several fields (Tables 3 and 4), and other deposits have subsequently been found. In 1989, an oilfield was discovered in the Pina area to the NE.

Oil comes from the topmost volcanic island-arc sequences and from clastic-carbonate rocks of Maestrichtian age. This basin extends south into the Caribbean Sea, where oil shows have been reported in small keys. Structurally, the deposits are associated with uplifted blocks bound by normal and reverse faults (Fig. 7). Stratigraphic-type reservoirs may be found on the basin margins.

The rest of the Southern Province

No oilfields have been found in the Western and Eastern Basins of the Southern Province. However, oil shows have been reported in wells and at the surface in keys in the south, associated with mud volcanoes (Tenreyro and Echevarria, 1986).

Seismic reflection lines in the three basins of the province give a good structural picture, including the upper part of the island-arc association (Hernandez, 1986), in which sedimentary thicknesses of 5-6 kms have been identified.

CONCLUSIONS

1. Structural development of the Northern Oil Province was in three stages, the first and second of which were associated with accumulations of large volumes of organic matter (initially humic, then sapropelic). Upper Cretaceous — Palaeogene basins contain sapropelic OM. Oil and gas accumulations so far discovered are associated with four allochthonous terranes—the Zara, Placetas, Camajuani, and Remedios TSUs—located both on- and offshore.

2. Most oilfields (21) are located in the northern overthrust belt; Varadero and Boco de Jaruco are volumetrically the most important in terms of recoverable reserves. Production comes from folded and fractured limestones in overthrust sheets.

3. Production in the Southern Province (Central Basin) is related to top-most island-arc sequences, and from clastics of Maestrichtian age. Similar oil and gasfields may be located by seismic reflection on uplifted blocks in the eastern and western parts of this Province.

REFERENCES


Fig. 7. The Central Basin, Southern Province: (a) general cross-section; (b) structural map; (c) geological section of the Cristales oilfield (location in Fig. 1).

Fig. 8. Location map, with TSU boundaries, seismic lines, and exploration wells.


### Table 3. Cuban oilfield discoveries, 1881-1990.

<table>
<thead>
<tr>
<th>Name</th>
<th>Year</th>
<th>Lithology</th>
<th>Age</th>
<th>Depth (m)</th>
<th>Tectonostratigraphic Unit</th>
<th>Method of Discovery</th>
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<tr>
<td>Motumbo</td>
<td>1881</td>
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<td>Pre-Cam.</td>
<td>200</td>
<td>Zaza</td>
<td>Gas Seeps</td>
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<td>1914</td>
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<td>Pre-Cam.</td>
<td>800</td>
<td>Zaza</td>
<td>Oil Seeps</td>
</tr>
<tr>
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<td>1600</td>
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<td>Development Well</td>
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<td>Pre-Cam.</td>
<td>800</td>
<td>Zaza</td>
<td>Oil Seeps</td>
</tr>
<tr>
<td>Peñas Altas</td>
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<td>Pre-Cam.</td>
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<td>Oil Seeps</td>
</tr>
<tr>
<td>Guanabo</td>
<td>1968</td>
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<td>Pre-Cam.</td>
<td>900</td>
<td>Zaza</td>
<td>Surf. Geo.-Seismic</td>
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<td>Pre-Cam.</td>
<td>900</td>
<td>Zaza</td>
<td>Seismic</td>
</tr>
<tr>
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<td>Pre-Cam.</td>
<td>900</td>
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<td>Development Well</td>
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<td>Subsurface correlation</td>
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<td>Tertiary</td>
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### Table 4. Physico-chemical characteristics of Cuban oils.

<table>
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<tr>
<th>Oilfields</th>
<th>Density (g/cm³)</th>
<th>°API</th>
<th>Viscosity, cp</th>
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<th>Asphaltenes %</th>
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<tr>
<td>Motumbo</td>
<td>0.733</td>
<td>61</td>
<td>1.92</td>
<td>0.004</td>
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<td>24</td>
<td>50.3</td>
<td>1.03</td>
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<td>Santa Maria</td>
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<td>6.14</td>
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