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HYDROCARBON POTENTIAL OF THE TRINIDAD AREA - 1977

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ABSTRACT

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It is now recognized that deltaic and associated sands, together with porous marine limestones, form the vast majority of the reservoirs in the major accumulations of hydrocarbons throughout the world. The source of the hydrocarbons is now thought to be kerogen which is generated from the organic content of principally marine shales which are formed in or near the continental shelves.

The Trinidad area contains several sedimentary sub-basins, most of which consist largely of deltaic and associated sediments. These sediments, like most of the ancient deltas of the world, contain major reserves of oil and gas. Other less important reserves should occur in sporadic (time-wise) porous limestones.

The total proven and probable reserves of the Trinidad area are around 5 billion barrels of oil, of which 1.6 billion barrels have already been produced, and over 47 trillion cubic feet of gas.

INTRODUCTION

The original version of this paper was first presented at the first exposition of the Trinidad Chapter of the Society of Petroleum Engineers, in April 1976. It now has been extensively revised, especially in the area of reserves, and hydrocarbon potential, to take into account the intensive exploration drilling activity that has occurred since the original presentation.

ORIGIN OF HYDROCARBONS

Current thinking assumes that petroleum mostly is generated in marine shales which are relatively rich in organic content. Briefly, the organic content is changed under reducing conditions to kerogen or a kerogen-like substance which is the precursor of petroleum and petroleum-like products. The kerogen, under the correct conditions of pressure and temperature, is then converted to hydrocarbons. These conditions are generally met if the shales are buried to several thousand feet in an area of normal temperature gradients. The hydrocarbons are generally thought to migrate soon after generation into whatever reservoir rocks lie nearby.

RESERVOIR TYPES

In broad terms two types of reservoir rocks trap over 95% of the known hydrocarbon accumulations. These are sandstones and limestones. The majority of these accumulations are found to be those associated with deltas and porous limestones. The reasons for this are:

(1) they generally interfinger with organic marine shales which act as source rocks; and

(2) they are broadly either lenticular in nature or affected by growth faulting and/or folding caused by plastic flow of underlying shales, i.e. shale diapirism (in the case of deltaic sands) so that traps exist even before hydrocarbon generation and migration begin.

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[2] The author takes this opportunity to thank Trinidad and Tobago Oil Company Limited for permission to publish this paper.

[3] All estimates, opinions and views expressed are solely those of the author and do not necessarily reflect those of Trinidad and Tobago Oil Company Limited.

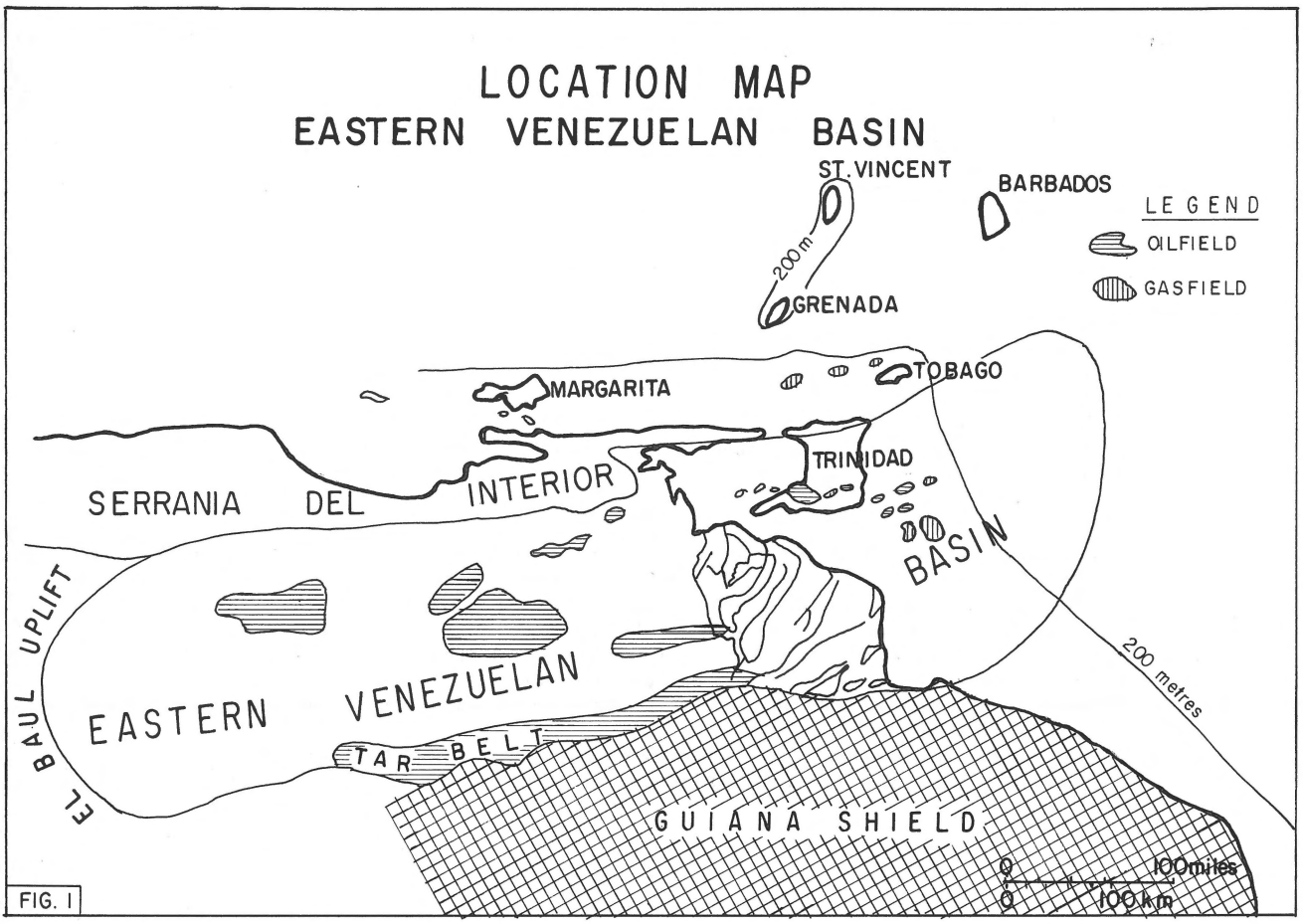

Fig. 1
Location map of the Eastern Venezuelan Basin.

In other words, all the pre-requisites for hydrocarbon generation and trapping are generally present in areas of deltaic deposition or where limestone deposits interfinger with highly organic marine shales. The Trinidad area contains several sedimentary sub-basins which have mostly had a history of deltaic deposition. In fact the Trinidad area forms the eastern culmination of the Eastern Venezuelan Basin as well as a major part of the proto-Orinoco Delta Province (Fig. 1). Because of this, its sedimentary sub-basins are all highly prospective for hydrocarbons both onshore and offshore.

The hydrocarbon potential of each sedimentary area will be dealt with separately. Two uplift areas, the Tobago uplift and the Northern Range uplift, consist mostly of pre-Tertiary metamorphic and igneous rocks, and are non-prospective.

RESERVES[5,6]

Reserves are categorized into major types as follows:

PROVEN RESERVES – reserves estimated to exist on the basis of wells drilled into the reservoirs;

SEMI-PROVEN RESERVES – reserves credited to known, but incompletely delineated, fields;

PROBABLE RESERVES – reserves which are expected to be found assuming that all the potential structures/features are drilled, taking into account historic and projected discovery ratios, percentage fill-up of structures, nett pay, hydrocarbon saturation, etc;

POSSIBLE RESERVES – additional reserves which might be expected based on geologic concepts, but which have yet to be proven by drilling.

[5] Note that the categories of reserves used here do not conform with the API categories favoured by engineers.

[6] Reserves, as used throughout this paper refer to total estimated recoverable reserves, unless otherwise indicated.

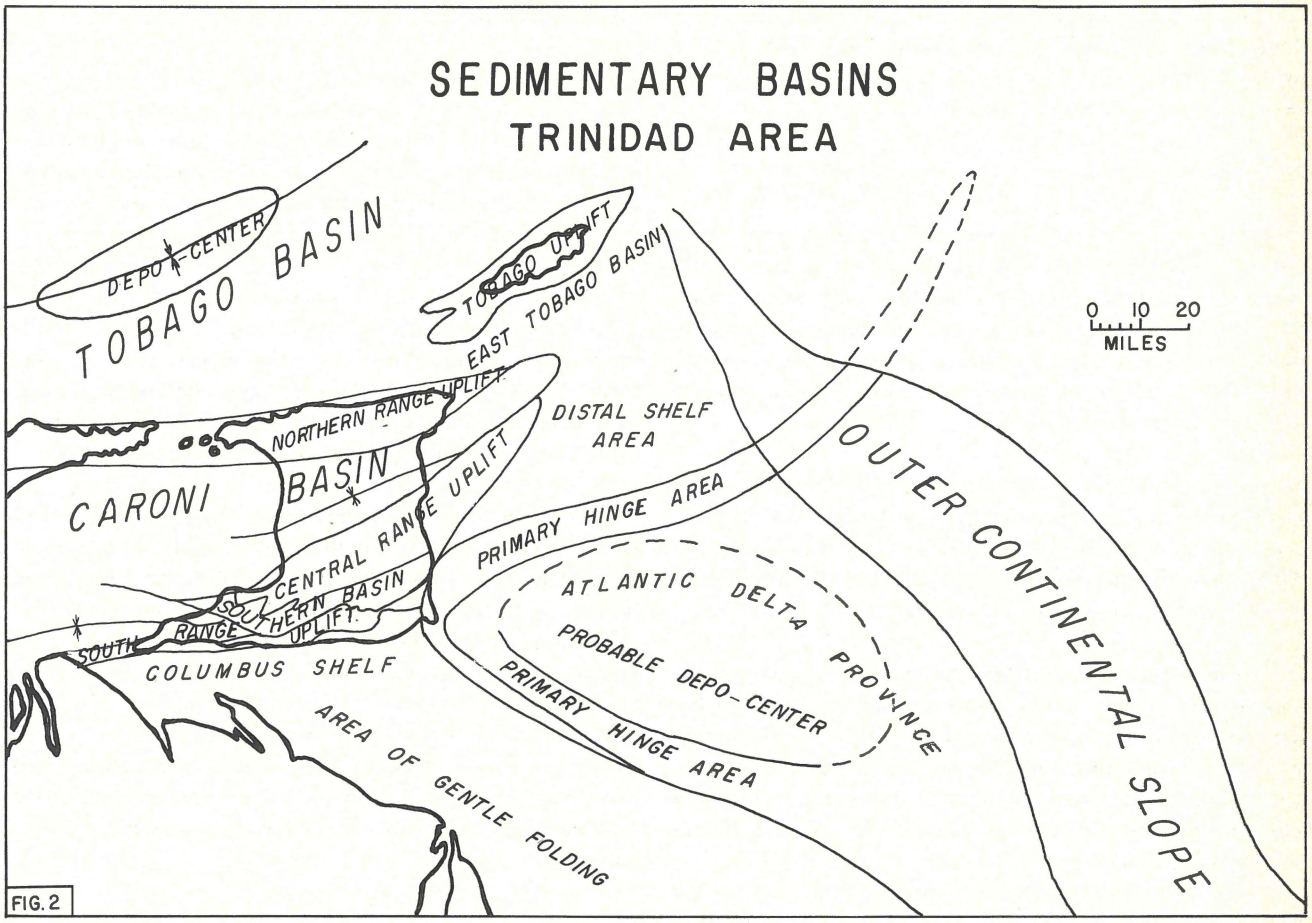

Fig. 2
Sedimentary basins and sub-basins in the Trinidad area.

SEDIMENTARY SUB-BASINS

Tobago Basin

Regional geology - The Eastern part is a sediment-starved limestone shelf, with Tertiary patch reefs.

The Western part is a graben-like structure and contains several 4-way closed structures, fault closed structures as well as potential for trapping in stratigraphic wedges. This western part forms part of the Tobago-Margarita-Grenada Trough and contains in its axial regional over 20,000″ of sediments, principally conglomerates overlain by a thick sequence of marine shales (Fig. 2).

History of exploration - All drilling to date has been based on modern[7] seismic work which was run in 1968-1969, or after. By May 1977 three wells had been drilled in the East Tobago Basin, all reportedly dry.

In the West Tobago Basin, eight wells have been drilled in six separate structures. No details have been released, but the government has announced the finding of significant reserves in the area. It is estimated that three potential gas fields have been discovered to date.

Hydrocarbon potential - The East Tobago Basin seems to be primarily a sediment-starved limestone province, with a thin Tertiary sequence. To date no discoveries have been made in this area and no probable or possible potential is credited to it.

The axial region of the West Tobago Basin contains about 20,000 feet of Tertiary sediments. All drilling has to date been in the South-western flank on six separate structures. The three potentially commercial fields mentioned previously are estimated to have (proven, semi-proven) reserves of about 6 trillion cubic feet. Additional probable potential for this portion of the basin is estimated to be 4 trillion cubic feet.

The North Western Flank of the Tobago Basin should

[7] Modern seismic denotes digitally recorded 'stacked' seismic.

contain similar sediments, thicknesses and structures to the South-west flank and it is credited with the possibility of a further 10 trillion cubic feet of gas, occurring however under extremely deep waters (> 2000'').

Caroni Basin (onshore)

Regional geology - The onshore portion of the Caroni Basin consists, like the West Tobago Basin, of a graben-like structure with over 15,000'' of sediments in the axial region. The Tertiary sediments consist of near deltaic and shallow marine sands and conglomerates with occasional scattered limestones, and marine shales overlain by Plio-Pleistocene fluvio-continental gravels.

History of exploration - Old wells drilled by DOMOIL were based on old analog data and gravity and magnetics. In 1976, about 50 miles of modern C.D.P. seismic was run in the Mahaica area, where one small gas field has been found to date, from five wells drilled by DOMOIL.

Hydrocarbon potential - Good potential for gas is thought to exist in closures similar to those that are found in the Tobago Basin area. The area has not been adequately explored and additional modern seismic work is necessary. The presence of a large number of industries in the area plus the fact that discoveries would be on land should encourage exploration for gas.

Probable reserves are conservatively estimated at 200 billion cubic feet, but are subject to upgrading on further exploration. Possible reserves are greater and are estimated to be about 3 trillion, in anticlinical traps en echelon to, and controlled by, expected east-west down-to-the-basin faults.

Central Range Uplift

Regional geology - This area is historically a zone of preferred uplift, and has a related suite of flysch and wild-flysch, and reworked sediments. The structural picture is extremely complex because of several phases of severe faulting including thrusting, and structures are generally small. In addition, erosion has stripped most of the Mio-Pliocene sediments, leaving Nariva and older sediments as the only potential reservoirs.

History of exploration - No modern seismic work has been run. About 20 exploratory wells have been drilled with some minor successes including one minor producing field.

Hydrocarbon potential - Because of the structural complexity and the small size of the individual prospects, the area is considered to have no potential for major reserves.

Southern Basin

Regional geology - This area historically forms part of one of the lobes of the Tertiary Orinoco delta and contains a suite of deltaic and near-deltaic deposits. At times the area was almost completely inter-deltaic with marine shales, barrier bars, turbidites etc. predominating. Also present are Cretaceous sandstones which form potential reservoirs.

History of exploration - This area is historically one of the oldest producing provinces in the world, dating back to the nineteenth century to the days of the old cable tool rigs, and prior to electric logging. All the major shallow, and some deep prospects have been extensively drilled and over one billion barrels of oil have already been produced to date.

Hydrocarbon potential - In addition to the remaining proven reserves which largely lie in the producing Mio-Pliocene and Oligocene fields, and which comprise some 350 million barrels, a further 400 million barrels are considered as probable reserves. These are divided as follows:

Cretaceous	– 50 million barrels
Oligocene	– 150 million barrels
Mio-Pliocene	– 200 million barrels

This gives a total of about 1.75 billion barrels oil (already produced, proven and probable). The area is an oil prone province and has been credited with no significant new natural gas reserves.

Gulf of Paria

Regional geology - This area contains the western portions of the two major sub-basins found on land, i.e. the Caroni Basin and the Southern Basin. It generally contains similar sediments to these basins except with differring sand percentages regionally because of being nearer to, or further away from, the sediment source. In addition, because of lesser influence of island tectonism, growth faulting is evident in certain areas.

The Cretaceous contains porous limestones overlain by or fringing, appreciable thicknesses of anhydrites.

History of exploration - This is the second oldest producing province in Trinidad, the initial discovery having been located by Marine Seismic. Modern seismic work exists over the area, in addition to several hundred wells, which encompass several producing fields (including the Soldado complex) and about 25 wildcats.

Hydrocarbon potential - By the end of 1976, 310 million barrels of oil had been produced (together with associated gas). Remaining proven, probable, and possible reserves are of the order of 900 million barrels oil from reserves ranging in age from Cretaceous to Mio-Pliocene. The remaining proven and semi-proven reserves from the Soldado Field

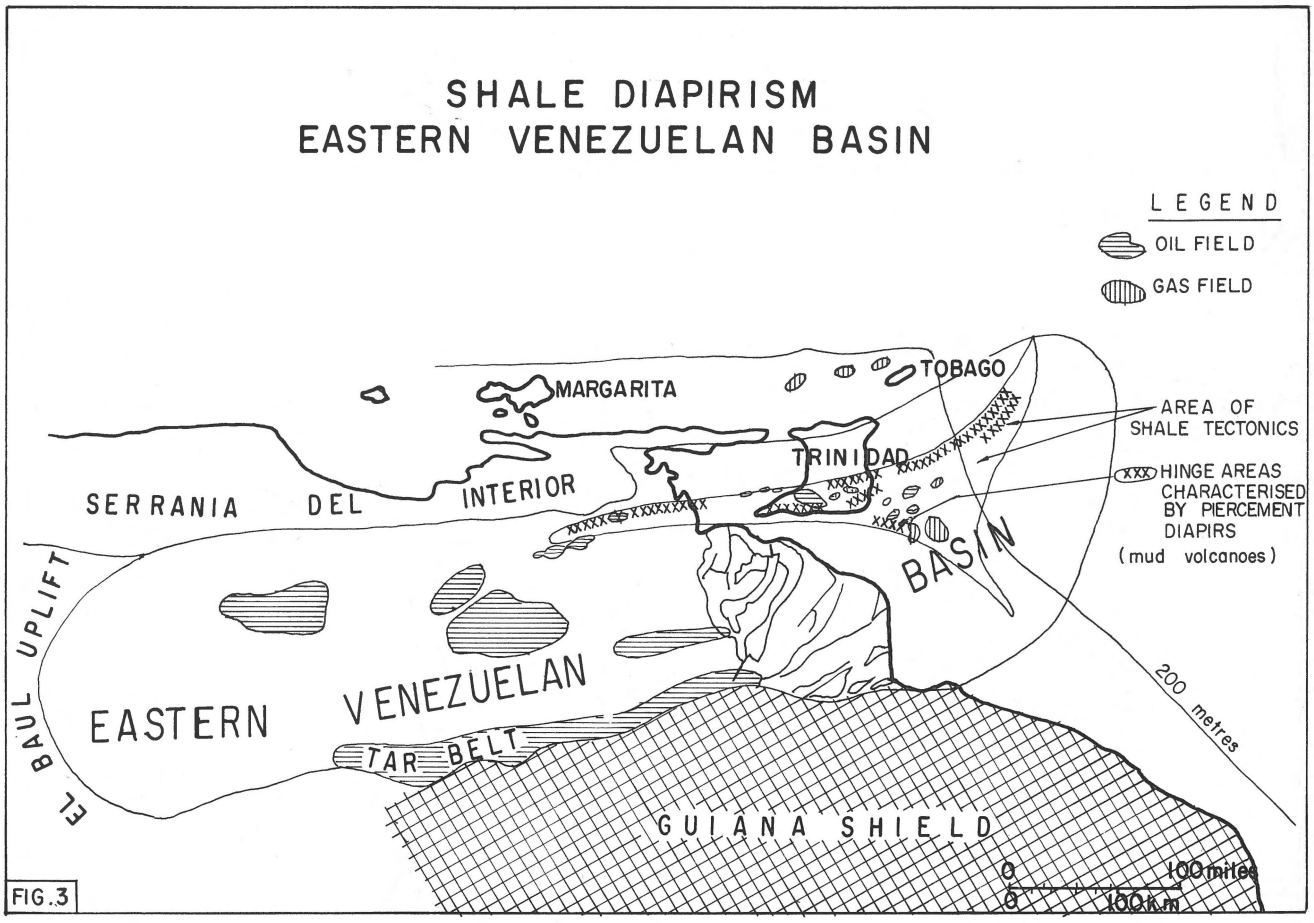

Fig. 3
Shale diapirism in the Eastern Venezuelan Basin.

complex are estimated at about 225 million barrels oil.

Additional probable reserves, from the entire Gulf of Paria area, including the Caroni Basin are expected to be about 300 million barrels of oil from reservoirs ranging in age from Cretaceous to Pliocene as well as from secondary recovery operations in the major fields (which may account for up to 50 million barrels of production). A further 400 million barrels are estimated as possible reserves, which may occur in Cretaceous reefs which are thought to occur on the fringes of the deep anhydrite basin.

It is expected that most of the reserves remaining to be found will lie in structural traps or structurally controlled traps.

Columbus shelf

Regional geology - The northern part of this shelf area more or less coincides with the southern flank of the Southern Range anticline. This anticlinal trend coincides with a line of shale diapirism and is generally poorly productive.

South of this, however, the sediments lie even nearer the deltaic suite than the Southern Basin itself and should contain high sand percentages. Several structures are known to exist, and there is a possibility of another anticlinal trend onshore in Venezuela in the 'Delta Area'.

History of exploration - Seismic coverage is incomplete and exploratory drilling is sparse, only about ten wells having been drilled to date. One small gas discovery has been made, and one or two wells had oil shows. No modern seismic work exists over the bulk of the shelf.

Hydrocarbon potential - This sub-basin lies in a geologically favourable area having good sand percentages, and an abundance of source rocks. Undoubtedly modern seismic work and additional drilling will find good prospective structures. In addition the potential for stratigraphic trapping against the southern flank of the Southern Range anticline is considered great.

The probable reserves given for this area are conservatively estimated at 50 million barrels oil and 500 billion cubic feet gas. Possible reserves are greater, and may be an

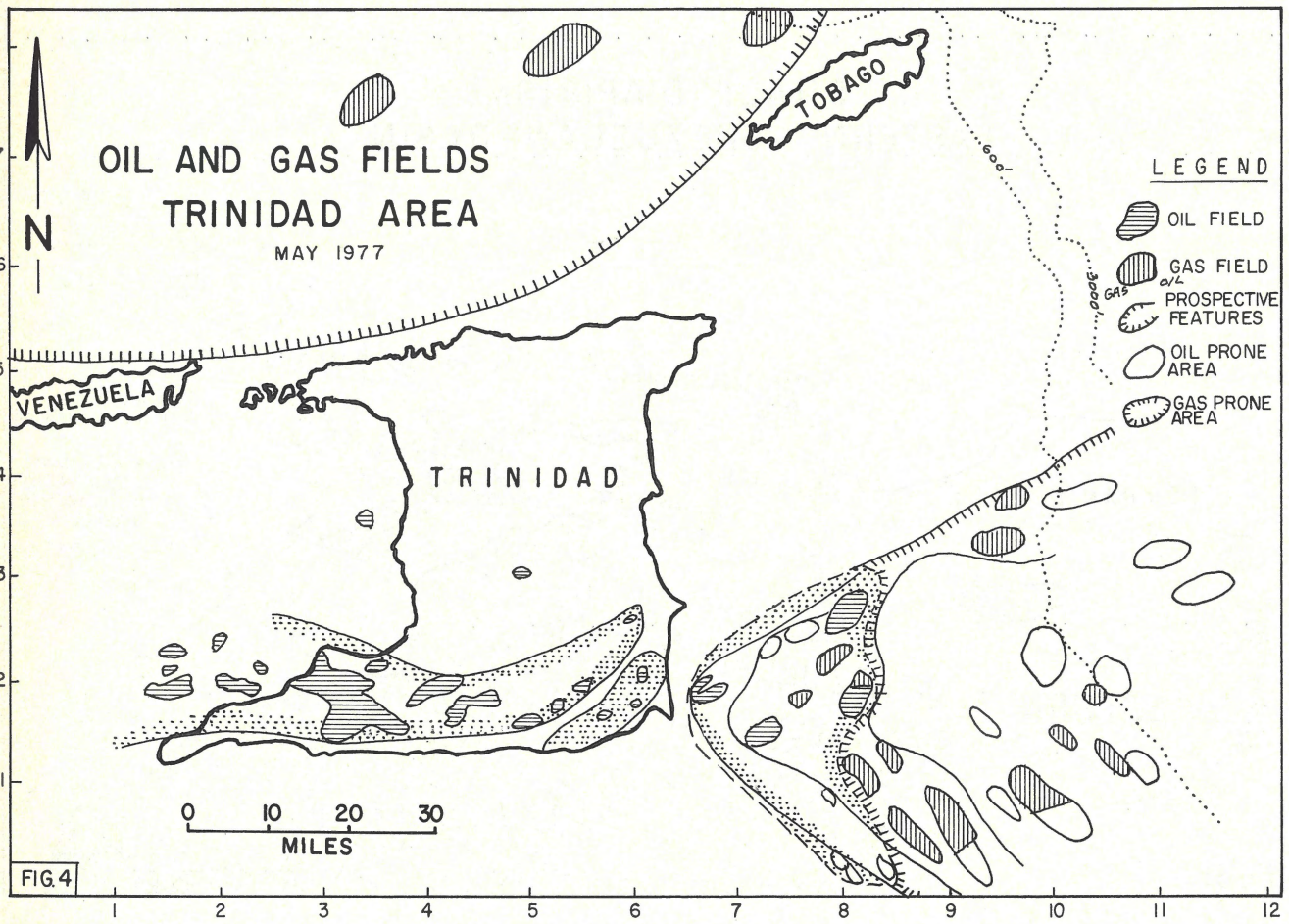

Fig. 4
Oil and gas fields in the Trinidad area.

additional 250 million barrels of oil and 1.500 trillion bcf. in possible stratigraphic and structural traps.

Atlantic province

Regional geology - This entire area contains north-eastward continuations of most of the major sub-basins already dealt with plus one major growth fault province not found elsewhere. It also contains extensions of the El Pilar - Northern Range uplift and the Central Range uplift neither of which are considered highly prospective (Fig. 2). It contains several sub-basins including:

(1) Caroni Basin - eastward extension
(2) Distal Shelf Area
(3) Orinoco Delta Province - a major growth fault province

The major growth fault province, termed here the Atlantic Delta Province, contains over 35,000″ of Miocene and younger sediments. It was historically a major lobe of the Orinoco delta in the Trinidad area. It is separated from the distal shelf area to the north and Columbus shelf area to the south by two major hinge areas, which, in the Galeota Point Area, meet at an apex.

The sedimentary basins north of the northern hinge belt are thinner (15,000″ maximum) and the sand percentage decreases eastwards and northwards until the basin becomes completely sediment starved, and becomes a limestone province.

In the northern hinge area, and the western part of the Orinoco Delta Province, there are numerous NE-SW trending tectonic ridges which lie en echelon with, and are genetically similar to, the Southern Range Anticline. These tectonic ridges are the surface and sub-surface manifestations of a series of shale diapirs, intrusive and extrusive. These shale diapirs are also recognisable along the southern hinge line of the Orinoco Delta Province, as well as along the other hinge areas of other deltaic lobes in Trinidad and Venezuela (Fig. 3).

Within the Atlantic Delta Province, delta-front sheet sand zones are distinguishable for different horizons in the Miocene, Pliocene and Pleistocene and it is possible to trace these, together with their corresponding suite of deltaic and near-deltaic sediments over the entire area.

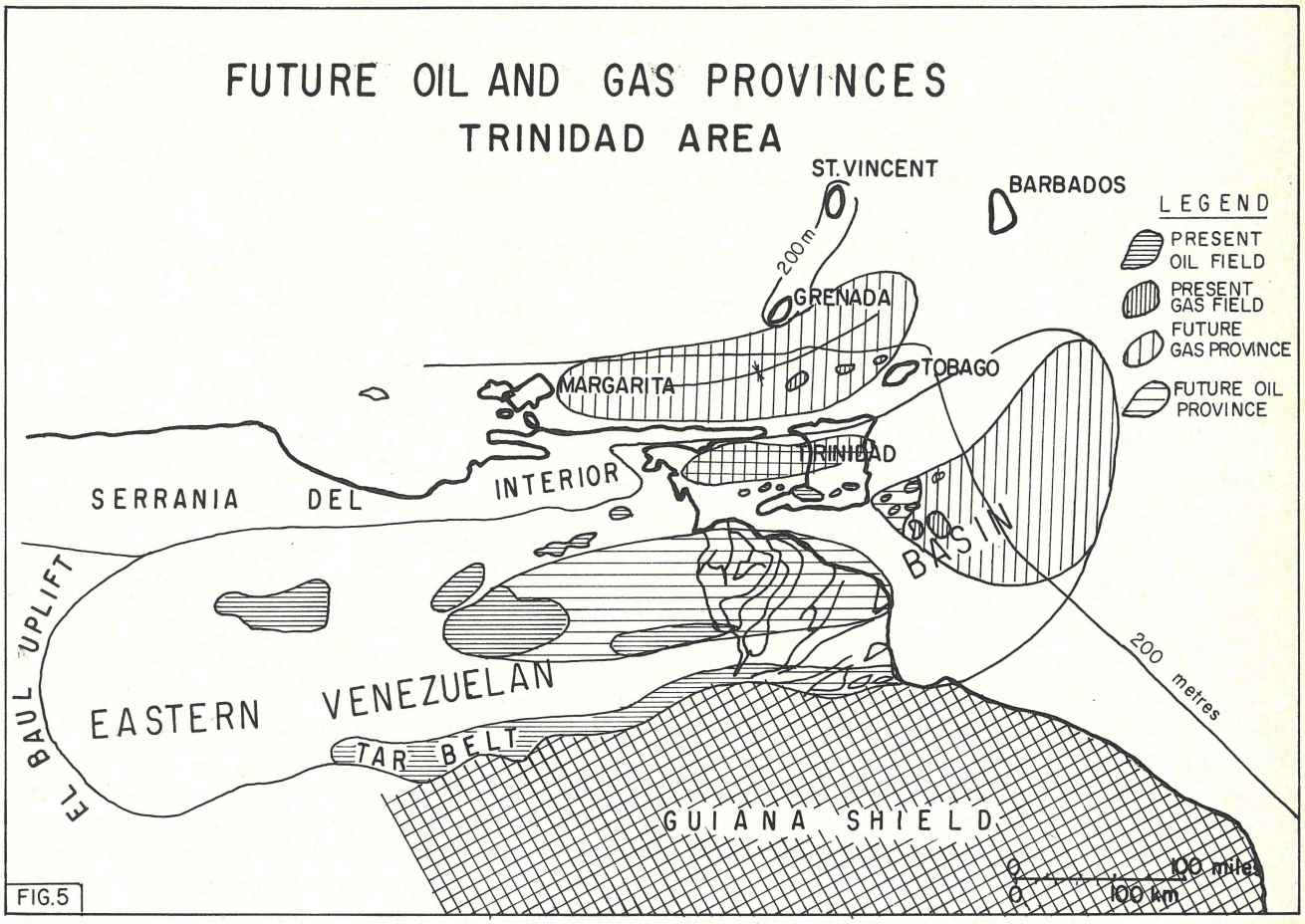

Fig. 5
Future oil and gas provinces in the Trinidad area.

The Atlantic Delta Province is characterized by very pronounced growth faulting, trending NNW - SSE (downthrown to the East). There is an area, in the western part of the Atlantic Delta Province, where the growth faults are intersected by the NE - SW, diapirically controlled, tectonic ridges, and where the basin shallows rapidly towards the north and northwest. In this area all the oil discoveries have been made (together with some gas discoveries). Outside of this oil prone area, within the Atlantic Delta Province, all discoveries to date have been gas (Fig. 4).

It is considered that the deep gas generated in the basin has caused the majority of the oil to migrate updip basinwards (i.e. westwards), where it has become trapped in primarily diapirically controlled ridges and domes, which trend for the most part NE - SW, with other smaller accumulations probably occurring in growth fault related traps. This is the area which is estimated to contain the greatest potential for major oil discoveries in the Trinidad Area. Similarly, the remaining portion of the Atlantic Delta Province is thought to contain great potential for further major gas discoveries.

History of exploration - Several rank wildcat wells were drilled by DOMOIL in the early sixties based on old analog seismic work and gravity and magnetics, with some minor success. Since then the area has been extensively surveyed by modern marine seismics and some fifty or so exploratory wells have been drilled, and have resulted in the discovery of several major oil and gas fields, all within the Atlantic Delta Province.

Hydrocarbon potential

Caroni Basin extension - This area lies outside the Atlantic Delta Province (in fact it is sourced from the SW) and has a thin section with few clastics. Hydrocarbon potential is considered minimal and no reserves are credited for the area.

Distal shelf area - This area lies in a 'distal deltaic area' and although exhibiting growth faulting has a relatively thin section and low sand percentages, and in large part forms part of a limestone province. Hydrocarbon potential is small, and the area is credited with no reserves.

AREA	RESERVES (MM. Barrels Oil)				
	ALREADY PRODUCED	PROVEN (SEMI-PROVEN)	PROBABLE	POSSIBLE	TOTAL
A. Land	1100	350	400	Nil	1850
B. Gulf of Paria	310	225	300	400	1235
C. Columbus Shelf	Nil	Nil	50	200	250
D. Tobago Basin	Nil	Nil	Nil	Nil	Nil
1. Atlantic Offshore Distal Shelf Area	Nil	Nil	Nil	Nil	Nil
E. 2. Atlantic Delta Province	195	1055	500	Nil	1750
TOTALS	1605	1605	1250	600	5085

Table I
Oil reserves in the Trinidad area.

Atlantic delta province - The Western or oil prone area of the Atlantic delta province is a prime area and is known to contain three major (and one minor) oil fields, which have to date produced almost 200 million barrels of oil. Current production from these fields is over 130,000 bopd. Remaining proven reserves in the area are estimated to be about 1055 million barrels of oil; about 20% of the total reserves are estimated as coming from waterflooding of the three major fields, now in initial stages. Additional probable reserves are estimated at about 500 million barrels of oil, from several undrilled structures.

The remaining gas prone portion of the Orinoco delta province has had several major gas discoveries to date, with total proven and semi-proven (in partially delineated finds), gas reserves estimated to date at about 24 trillion cubic feet of gas (Fig. 4). Additional probable reserves are estimated to be 12 trillion cubic feet.

Large additional potential is expected to exist (about 20 - 50 trillion cubic feet) in deep structures (14 - 20,000′), trapped in major growth anticlines, trending NNW - ESE, which have been to date largely untested to this depth. Numerous piercement type shale diapirs occur along the north-east portion of the northern hinge area of the Atlantic delta province. It is possible that large reserves of gas have been trapped on the flanks of these diapirs. The total estimated as additional possible reserves (from 'deep' gas and gas trapped on the flanks of shale diapirs) is estimated to be about 25 trillion cubic feet, but could be much higher.

Outer continental shelf - In the Outer continental shelf to the Northeast and East of the Atlantic delta province it is probable that shale diapirism and growth faulting are both present in association with large thicknesses of Miocene and younger sediments, in water over 2,000″ deep. It is considered very likely that large reserves, probably of gas, could occur in this area (Fig. 5).

No definite reserve figure has been credited to this area because of its uncertainty and the very great depth of water involved. It is felt, however, that within a few years technology will be advanced enough to explore and develop reserves in this kind of environment and re-assessment can then be done.

Comparison of previous estimate

The previous estimate of reserves done by the author in 1976 indicated about 7 billion barrels of oil and 32 trillion cubic feet of gas (already produced, proven and probable). The present estimate totals approximately 5 billion barrels of oil and 47 trillion cubic feet of gas in the same categories.

The reason for the difference has been the fact that in the last few years all the major discoveries are thought to be gas rather than oil. Because of this the oil potential has decreased, but the gas potential has increased correspondingly, as the success ratio has been as good as, or better than, expected.

CONCLUSIONS

It is generally considered by the energy experts, that the development and universal use of nuclear fusion as the prime energy source and hydrogen as fuel will not become realities until near the middle of the twenty-first century. It is their opinion that until that time the fossil fuels comprising oil, gas (and coal) will remain in the forefront as the major energy

AREA	RESERVES (Trillion Cubic Feet Natural Gas)				
	ALREADY PRODUCED	PROVEN (SEMI-PROVEN)	PROBABLE	POSSIBLE	TOTAL
A. Land	Nil	Nil	0.2	3	3.2
B. Gulf of Paria	Nil	Nil	0.3	Nil	0.3
C. Columbus Shelf	Nil	Nil	0.5	1.5	2.0
D. Tobago Basin	Nil	6	4	10	20
1. Atlantic Offshore Distal Shelf Area	Nil	Nil	Nil	Nil	Nil
E. 2. Atlantic Delta Province	Nil	24	12	25	61
TOTAL	—	30	17	39.5	86.5

Table II
Gas reserves in the Trinidad area.

sources and fuel, and regard this era as an energy bridge which mankind has to cross before the nuclear era is ushered in.

The remaining proven and probable reserves of oil and gas in the Trinidad area which are estimated to be about 3.0 billion barrels of oil and 47 trillion cubic feet, are enough to enable oil production to continue at levels significantly above 100,000 bopd until after the year 2000 and above 25,000 bopd until 2040, and to enable sustained gas production at 2 billion cubic feet per day for over 60 years, or around 2045 (assuming start of production at this level around 1985). Two billion cubic feet of gas per day is equivalent to about 300,000 bopd (energy equivalent) or about 100 - 150,000 bopd (revenue equivalent). In other words, using only proven and probable reserves of oil and oil equivalent, the Trinidad area has enough potential to produce over 225,000 barrels oil equivalent per day (current level of oil production) for over 60 years or until the world has crossed the energy bridge into the true nuclear era.

It must be stressed, however, that a large portion of the probable reserves, and all the possible reserves are as yet undiscovered, and that the economics of their discovery and development have not been considered in the preparation of this paper.

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