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AN OUTLINE OF THE GEOLOGY OF TRINIDAD

- by -

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INTRODUCTION:

The following outline is being presented to set the scene of this Fourth Caribbean Geological Conference, to place in perspective specific papers on Trinidad in relation to the overall situation, and particularly to provide a background to the field excursions which will follow the technical sessions.

In considering Trinidad itself an account of the general geology and structure will be given, but no attempt will be made to elaborate on the petroleum geology, as this will be the subject of several papers in the economic section.

Both geographically and in a sense geologically, Trinidad forms the eastward extension of the South American mainland of Venezuela — although as we shall see later there are a number of striking differences. Certainly the fold-belt of the Northern Range is the direct continuation of the Coast Range of Eastern Venezuela and thus stands as the extreme outpost of the eastern branch of the Andean mountain system. For the rest, the geology of Trinidad has many local peculiarities largely arising from the fact that relative to eastern Venezuela it lies on the mobile northern side of the eastern Venezuela basin and was characterized, particularly during Tertiary times, by intermittent tectonic activity which interrupted and profoundly modified the sedimentation. As a result, several local facies were developed which have no direct counterparts in eastern Venezuela.

A generalized geological map of Trinidad is given as figure 1, which serves as a basis for the following discussion.

Morphologically, Trinidad falls into five distinct units which are closely related to the gross geological structure; from north to south these are:-

The Northern Range, a deeply-dissected mountain range with a marked east-west trend, and composed of an upfolded, upthrust region of relatively old, low-grade metamorphic rocks. The eastern end of the Range will be studied on the second field trip to the Toco area. Maximum elevations are at El Tucuche, 3,075 ft. and El Cerro del Aripo, 3,083 ft.

The Caroni Plains, a generally low-lying area of terraces, alluvial plains and swamp deposits, occupying a synclinal basin infilled with young Tertiary to recent deposits. It appears to be sharply separated from the Northern Range, the morphological boundary trends conspicuously east-west and is probably a major fault. To the south the terrain rises gradually to form the northern slopes of the next feature, the Central Range.

The Central Range culminates in a line of low hills aligned north-east-southwest, running diagonally across the island. It is essentially an asymmetrical anticline, southward-directed, and having a strongly folded core of lower Tertiary and Cretaceous rocks. The onlapping upper Tertiaries include reefal limestones which form several of the conspicuous elevations as at Mt. Tamana (1009 ft.), Brigand Hill, and the Guaracara hills.

To the north the younger Tertiaries dip off regularly (northward) into the Caroni syncline, interrupted by several local flank folds, such as at Talparo and Sangre Grande. These north-flank Miocene beds crop out as a series of excellent sections along the east coast in Matura and Manzanilla Bays, and will be the objective of the first field excursion.

The western end of the Range, with its associated sharply folded structures and sedimentary phenomena ("wild flysch") will be seen during the fourth excursion, in addition to a visit to the Mio-Pliocene type localities of the north flank.

The Naparima and Southern Lowlands, south of the Central Range, is a broad belt of low, rolling, rather characterless country. Geologically, this consists of rather sharply-folded Tertiary clays and sands of monotonous character, with a few anticlinal inliers of older Tertiary or Cretaceous rocks which form local features as at San Fernando, Ben Lomond and Charuma. Still further south, low-lying, rolling country prevails, with wide alluvial belts and some swampy tracts. This is the locus of the Southern (synclinal) basin which spans the south of the island from east to west and is infilled with younger Tertiary deposits. The rims of this basin are locally complicated by folding and faulting which are economically important as several of these form the oil-producing structures of the south of the Island.

Situated on one of these subsidiary folds is the famous Pitch Lake of La Brea (Brighton), a large-scale asphalt seepage whose origin will be discussed in a paper on "Sedimentary Volcanism" by H.G. Kugler, and which will be visited during field excursion No.6 to that area.

The Southern Range, a line of low, discontinuous hills, forms the southern margin of the Island, and is graced with the name of the "Southern Range". The maximum elevation of just over 900 ft. is in the south eastern Trinity Hills, which by repute were the first land-fall sighted by Columbus on his 1498 expedition.

Geologically, this is, broadly speaking, on anticlinal trend, but the structures are small, discontinuous and separated by numerous faults. Much of the folding is of the strong, diapyroid type, and this is the area in which most of Trinidad's active mud-volcanoes are situated.

The lithologies of the younger Tertiary beds and some of the oilfield structures will be seen on excursion No.6A, which will include a visit to a mud-volcano at Palo Seco. An account of a recent mud-volcano eruption which formed an island off the south coast will also be given as a paper by G.E. Higgins & J.B. Saunders.

So much then for the broad picture. A short, general account of the stratigraphy follows, and reference will be made to the major subdivisions as shown in the stratigraphic chart, figure 2.

The oldest known formations in Trinidad are found in the Northern Range, which is made up of low-grade metamorphosed phyllites, quartzites, and recrystallized limestones generally accepted as upper Jurassic in age — although for the most part they are unfossiliferous. The upper Jurassic reference stems from the discovery of a few ammonites at Cuare Reservoir in the eastern part of the Range which were determined as Perisphinctes transitorius, of Tithonian age. Still further east on the coast in somewhat younger beds, a Barremian ammonite fauna has been found. At the eastern end around Toco a more varied lithology of shales, phyllites, sandstones, quartzites and limestones of Cretaceous age can be subdivided in some detail and the examination of these rocks will be undertaken on excursion No.2 to the Toco district. This eastern area also includes Trinidad's only igneous rocks, some interbedded basaltic volcanics, including ashes, breccias and flows occurring among the lower Cretaceous shales. These volcanics form the prominent topographic feature on the north coast around Sans Souci from which they take their name.

Certain aspects of Northern Range geology will be covered by H.C. Potter in his paper on the eastern part of the range, and also by M.A. Furrer in an account of a study of thin sections from the Rio Seco and Grande Riviere Formations.

Before leaving the Northern Range, it is notewerthy that there is a narrow band of uppermost Cretaceous semi-phyllitic shale along much of the north coast and again along the southern margin. Closely associated with the latter outcrop is the Laventille Formation with its feebly fossiliferous limestone, which also extends westward through Pt. Gord and Gaspar Grande island. In this same trend is the gypsum deposit of St. Joseph, a small linticular body whose field relationships are obscure, and whose origin has been a matter of controversy. Further light on this problem and the stratigraphic position of the Laventille Limestone may be expected from a discussion of possibly equivalent beds to be presented in a paper on the Paria Peninsula of Venezuela by Gonzalez de Juana, Munoz and Vignali.

Lower Cretaceous. In addition to the known lower Cretaceous of the eastern Northern Range, beds of similar age and rather comparable lithology occur in the eastern part of the Central Range forming the core of the structure. As in the north, they consist mainly of dark shales, with subordinate quartzites and rare exogenous limestone blocks, and are known as the Cuche Formation. Some examples of these exotic limestones and their mode of recycling in successively younger "wildflysch" conglomerates will be demonstrated briefly in the Pointe-a-Pierre area during Excursion No.4. A short period of diastrophism with local folding and erosion occurd about Albian to Cenomanian, and resulted in the unconformable relationship between upper and lower Cretaceous.

<u>Upper Cretaceous.</u> With the exception of the upper Cretaceous shales and sandstones of the Northern Range, the predominant lithology in Southern Trinidad is a curious silicified siltstone/claystone referred to colloquially as "argiline" or "argillite", which forms the upper part of the Naparima Hill Formation. Blue-grey when fresh, it weathers to a light-coloured, friable silt-stone; it usually contains a variable proportion of shale and is locally cherty. It passes downwards transitionally into dark, calcareous shales of the underlying Gautier Formation which is known from wells and from small exposures in the core of the Central Range. This lithology is quite widespread as it is found in numerous deep wells throughout southern Trinidad and also occurs in the Serrania del Interior of Eastern Venezuela. It must reflect rather uniform, quiescent conditions during upper Cretaceous times. The uppermost Cretaceous (Maestrichtian) shows again a reversion to a uniform dark calcareous shale, the Guayaguayare Formation. These conditions were brought to an end by renewed earth-movements with local uplift and erosion which preceded the Palaeocene transgression.

The Gautier, Naparima Hill, and Guayaguayare formations contain only very scarce megafossils, but are quite rich in microfossils. The planktonic and benthonic foraminifera suggest deposition in deep, open seas, though in the Gautier and perhaps the lower part of the Naparima Hill conditions of deposition may have been almost euxinic. The biozonation of this sequence has been erected on planktonic foraminifera, mainly as species of Globotruncana.

The late Cretaceous movements seem to have left the Central Range uplift zone as a shoal area which was potentially active and at times emergent. This tectonically active trend persisted throughout the Tertiary and resulted in the more or less effective separation of the Northern and Southern basins, the sedimentary histories and biofacies development of which followed differing courses. Whilst little is known of the lower Tertiaries of the Northern Basin, and the possibility is that they may be thin and at least partially absent, certainly from the Oligocene onwards, the stratigraphy of the two areas is quite distinct. The presence and periodic activity of the Central Range uplift is reflected in the localized development of conglomerates and "wildflysch" sedimentation in the adjacent areas throughout lower and middle Tertiary times.

Paleocene. The Paleocene transgression seems to have been rapid and widespread. The deposits are generally argillaceous and two distinct litho- and bio-facies are recognized, the more open-water calcareous shales of the Lizard Springs Formation and the more neritic non-calcareous shales and subordinate sandstones of the Chaudiere formation, which occurs generally in proximity to and over the old Central Range Uplift.

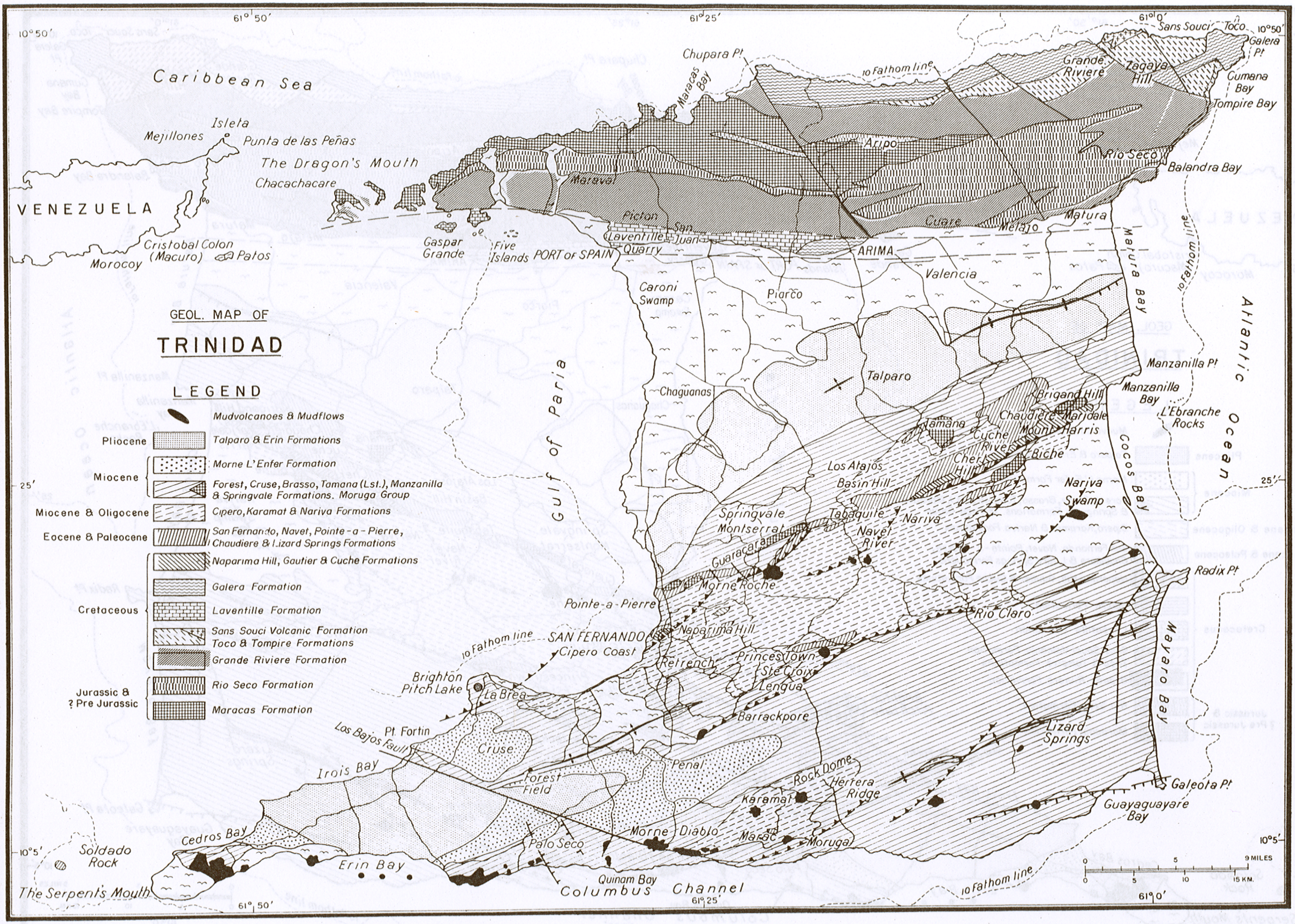
Tectonic activity along the old Cretaceous axes of uplift occurred during the deposition of the Chaudiere and Lizard Springs Formations as evidenced by the occurrence of "wildflysch" conglomerates with exotic blocks and large slip masses of different Cretaceous Formations including numerous fossiliferous lower Cretaceous limestones not known in situ in Trinidad.

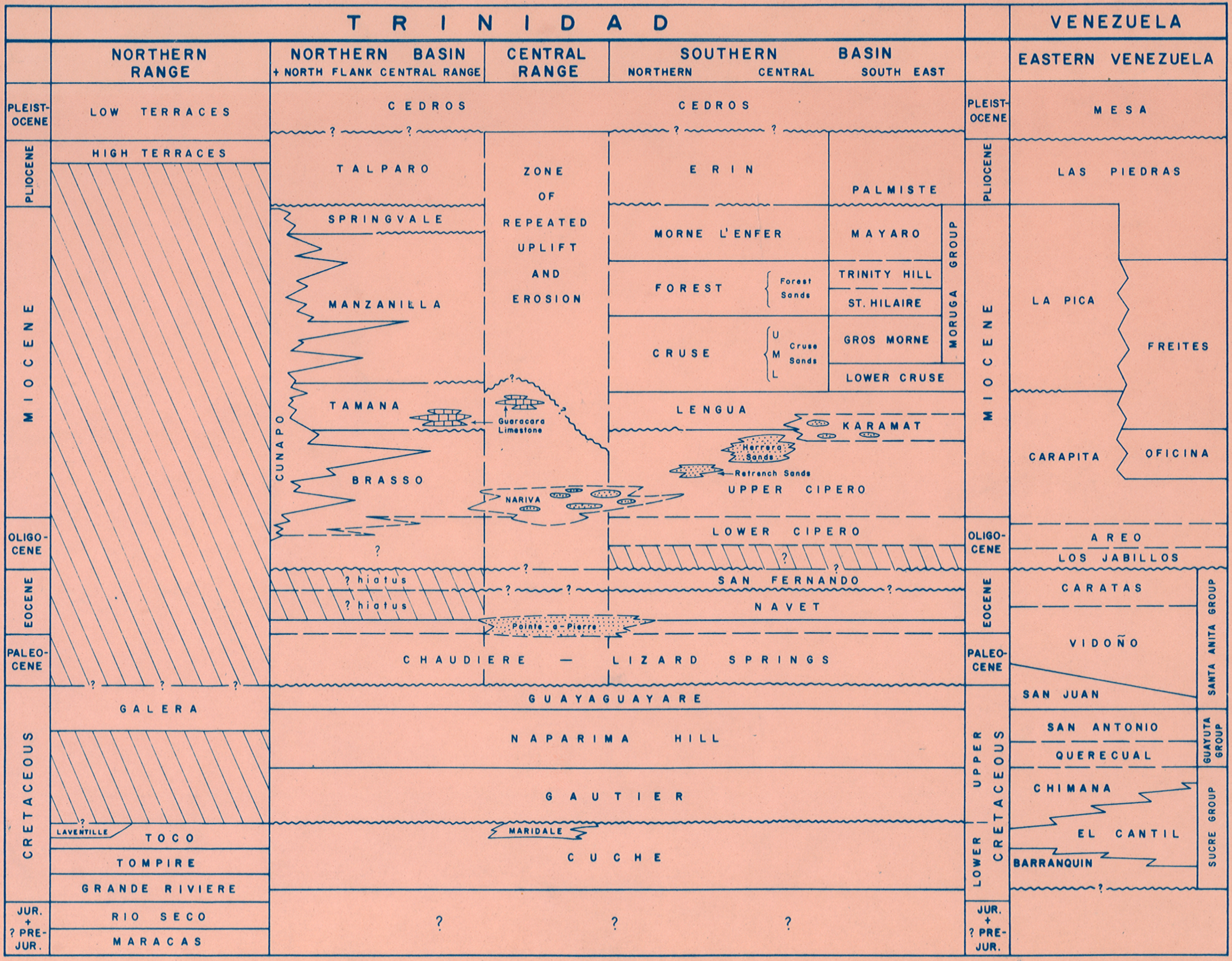
The calcareous shales of the Lizard Springs Formation contain a rich foraminiferal fauna of planktonic and benthonic types; the biozonation is based mainly on species of Globorotalia. The non-calcareous shales of the Chaudiere Formation, on the other hand, carry a predominantly benthonic arenaceous foraminiferal assemblage which seems to indicate relatively deep turbid water conditions.

The Paleocene appears generally transitional to the overlying Eocene.

Eocene. This is characterized by widespread deposits of highly foraminiferal marls and calcareous shales of the Navet Formation during lower and middle Eocene times, representing a continuation of the quiet depositional conditions established during the Paleocene. Along the old Central Range uplift a non-calcareous shale and gritty sandstone facies occurs, the Pointe-a-Pierre Formation; this is a flysch type deposit with evidence of turbidity current action and carries an entirely arenaceous foraminiferal fauna. Although it has sometimes been considered a shallow-water deposit, these factors suggest a deeper water environment. Further south the light coloured chalky marls of the Navet Formation are widespread. They contain a rich, mainly planktonic fauna which has been used to establish a detailed biozonation.

In Upper Eocene times earth movements again set in with the reactivation and erosion of old uplift areas. Shallow-water neritic deposits of the Upper Eocene followed, this phase being generally correlatable with the widespread "Jacksonian" transgression. Coarse clastics and conglomerates occur in local uplift areas, and rapid lateral facies changes are characteristic of this phase. Some examples of the varying lithologies will be studied in the San Fernando area during excursion No.4.


GEOL. MAP OF
TRINIDAD
LEGEND
Mudvolcanoes & Mudflows
Pliocene
Talparo & Erin Formations
Miocene
Morne L'Enfer Formation
Forest, Cruse, Brasso, Tamana (Lst.), Manzanilla & Springvale Formations. Moruga Group
Miocene & Oligocene
Cipero, Karamat & Nariva Formations
Eocene & Paleocene
San Fernando, Navet, Pointe-a-Pierre, Chaudiere & Lizard Springs Formations
Naparima Hill, Gautier & Cuche Formations
Galera Formation
Cretaceous
Laventille Formation
Sans Souci Volcanic Formation
Toco & Tompire Formations
Grande Riviere Formation
Jurassic & ? Pre Jurassic
Rio Seco Formation
Maracas Formation
Caribbean Sea
Atlantic Ocean
Gulf of Paria
Columbus Channel
VENEZUELA
Mejillones
Isleta
Punta de las Peñas
The Dragon's Mouth
Chacachacare
Cristobal Colon (Macuro)
Patos
Morocoy
Gaspar Grande
Five Islands
PORT of SPAIN
Maraval
Picton
Laventille Quarry
San Juan
Chupara Pt
Maracas Bay
10 Fathom line
Aripo
Grande Riviere
Zagaya Hill
Sans Souci
Toco
Galera Pt
Cumana Bay
Tompire Bay
Rio Seco
Balandra Bay
Cuare
Melajo
Matura
Matura Bay
ARIMA
Valencia
Caroni Swamp
Piarco
Chaguanas
Talparo
Manzanilla Pt
Manzanilla Bay
L'Ebranche Rocks
Brigand Hill
Tamana
Chaudiere
Maridale
Mount Harris
Cuche River
Cher Hill
Biche
Los Atajos
Basin Hill
Nariva Swamp
Cocos Bay
Springvale
Montserrat
Tabaquite
Navet River
Nariva
Guaracara
Morne Roche
Pointe-a-Pierre
SAN FERNANDO
Naparima Hill
Cipero Coast
Retrench
Princes Town
Ste Croix
Lengua
Rio Claro
Radix Pt
Mayaro Bay
Brighton
Pitch Lake
La Brea
Barrackpore
Pt Fortin
Los Bajos Fault
Cruse
Irois Bay
Forest Field
Penal
Rock Dome
Herrera Ridge
Karamat
Lizard Springs
Galeota Pt
Guayaguayare Bay
Cedros Bay
Soldado Rock
The Serpent's Mouth
Erin Bay
Palo Seco
Morne Diablo
Marac
Moruga
Quinam Bay
61° 50'
61° 25'
61° 0'
10° 50'
25'
10° 5'
9 MILES
15 KM.


TRINIDAD
VENEZUELA
NORTHERN RANGE
NORTHERN BASIN + NORTH FLANK CENTRAL RANGE
CENTRAL RANGE
SOUTHERN BASIN
NORTHERN
CENTRAL
SOUTH EAST
EASTERN VENEZUELA
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
CRETACEOUS
UPPER CRETACEOUS
LOWER CRETACEOUS
JUR. + ? PRE-JUR.
LOW TERRACES
HIGH TERRACES
GALERA
LAVENTILLE
TOCO
TOMPIRE
GRANDE RIVIERE
RIO SECO
MARACAS
CEDROS
TALPARO
SPRINGVALE
MANZANILLA
TAMANA
BRASSO
CUNAPO
? hiatus
? hiatus
ZONE OF REPEATED UPLIFT AND EROSION
Guaracara Limestone
NARIVA
Pointe-a-Pierre
ERIN
PALMISTE
MORNE L'ENFER
MAYARO
FOREST
Forest Sands
TRINITY HILL
ST. HILAIRE
CRUSE
U M L
Cruse Sands
GROS MORNE
LOWER CRUSE
MORUGA GROUP
LENGUA
KARAMAT
Herrera Sands
Retrench Sands
UPPER CIPERO
LOWER CIPERO
SAN FERNANDO
NAVET
CHAUDIERE — LIZARD SPRINGS
GUAYAGUAYARE
NAPARIMA HILL
GAUTIER
MARIDALE
CUCHE
MESA
LAS PIEDRAS
LA PICA
FREITES
CARAPITA
OFICINA
AREO
LOS JABILLOS
CARATAS
VIDOÑO
SAN JUAN
SANTA ANITA GROUP
SAN ANTONIO
QUERECUAL
GUAYUTA GROUP
CHIMANA
EL CANTIL
BARRANQUIN
SUCRE GROUP

Oligocene. Fairly widespread but irregular movements seem to have interrupted deposition between Eocene and Oligocene with disconformity in some areas and apparently continuous deposition in others. About this time, the Central Range uplift seems to have been active and now forms a more or less persistent barrier between the northern and southern depositional basins, which is reflected in the differing stratigraphic succession in the two areas (see figure 2). In the Oligocene also there is a third facies — the Nariva Formation — peculiar to the immediate neighbour of the Central Range itself.

In general a rather rapid deepening of the seas seems to have occurred in both basins with initially the deposition of fairly deep-water marine foraminiferal clays and marls of the lower part of the Cipero Formation. Thereafter, the two basins become differentiated; in the Northern Basin progressive shallowing occurred with the establishing of open-shelf conditions, whilst deep-water conditions persisted in the Southern Basin.

In the Northern Basin the lower Cipero is followed by the Brasso Formation, predominantly calcareous clays and silts with abundant micro- and mega-fossil faunas. The latter suggests deposition in the outer neritic zone of an open-shelf environment. Around the Central Range the Nariva Formation of non-calcareous sands and clays occurs and appears to interfinger both with the Brasso facies to the north and the open water marine facies to the south.

The Nariva Formation again demonstrates the occurrence of renewed tectonic activity in the Central Range area as it contains zones of "wildflysch" facies deposits including large slip-masses of older formations some of which include secondarily derived components from the earlier Paleocene wildflysch.

In the typical Nariva deposits the microfauna consists mainly of benthonic foraminifera with a preponderance of arenaceous types. The environment of deposition is still not clearly understood but it may have been relatively deep with turbid water conditions which inhibited the planktonic species.

In the Southern Basin the persistent open marine facies is reflected in the rather uniform calcareous clays and marls of the Cipero Formation with their abundant foraminiferal faunas. The latter suggest upper bathyal conditions of deposition.

Both the Cipero and Brasso formations contain rich microfaunas, including planktonic foraminifera, based on which a detailed and precise biozonation has been established which enables a correlation between the two facies provinces to be made.

Opportunities to collect type locality samples from the Cipero Formation will be afforded on <u>Excursion No. 3</u>; a more general review of the stratigraphy will be given on <u>Excursion No.4</u>, which will also include a visit to some Brasso Formation localities.

Miocene. Over recent years the range of the Miocene has been considerably extended downwards; the base is now defined palaeontologically as sedimentation is unbroken. As a result, the major part of the Cipero Formation is now referred to the lower Miocene. However, in the northern basin the Brasso Formation does not begin until lower Miocene. Although the Nariva facies first appears in upper Oligocene, it is predominantly lower Miocene (see figure 2). Within the Upper Cipero Formation of the southern basin an economically important group of sands occur — the Herrera sands, which are often oil-bearing. The sedimentology of these sands is of considerable interest and will be discussed in a paper by W.G. Poole.

Towards the upper part of the lower Miocene another diastrophic phase occurs with widespread folding and local emergence. In the Southern Basin deposition was renewed with the relatively deep-water clays of the Lengua Formation, while in the Central Range area the more neritic Tamana Formation (clays) are associated with small reef limestones in the shoal areas — as at Guaracara, Mayo, Tamana, Tabaquite, and Brigand Hill. It seems that at this time the Central Range uplift formed a clear separation between the Northern and Southern basins, which persisted throughout the remainder of the Mio-Pliocene and is reflected in their differences in facies and depositional history.

In the Northern Basin the Tamana clays are succeeded by the lower, silty San Jose member of the Manzanilla Formation, followed in turn by the Telemaque member, the greater part of which consists of even-bedded sandstones with subordinate clay layers.

The San Jose silts contain a rich molluscan and foraminiferal fauna which indicates deposition in the inner neritic zone. Planktonic foraminifera are rare, possibly due to restricted ocean water circulation consequent upon the shallowness of the environment.

Between the San Jose silts and the Telemaque member occurs the Monserrat Glauconitic Sandstone member. This is an interesting rock, being in fact not really a sandstone but a glauconitic "pellet rock". It was evidently a shoal deposit as the abundance of *Amphistegina* testifies, whilst the abundance of reworked foraminifera points to an erosional period.

These members of the Manzanilla Formation will be seen during Excursion No. 4 to the Western Central Range. The Manzanilla sequence will also be studied in some detail on the east coast on Excursion No. 1, with particular reference to the sedimentary features and environmental character.

In general, the Manzanilla sequence reflects a progressive infilling and shallowing of the Northern Basin, and it is followed by the neritic Springvale Formation consisting of shallow water silts and sands which are locally glauconitic and in places have a rich molluscan fauna. The type area of the Springvale Formation will be visited on Excursion No. 4.

In the Southern Basin the Lengua Formation is followed by deposits predominantly of the clay-silt-sand facies, which record the progressive infilling of the basin as reflected in an increasing content of sandy sediments of successively more shallow-water aspect. The process, however, was not uniform, but was made up of several transgressions and regressions which form the basis of the subdivision of the series. Thus, in ascending order there are the Lengua, Cruse, Forest and Morne l'Enfer formations. With the exception of the entirely deep-water Lengua Formation, each starts with an open-water clay phase and progresses through increasing sand content to a predominantly sandy end phase. A fuller discussion of these and other aspects will be given in a paper on Forest Reserve Oilfield by T.H. Bower. This series has received a good deal of attention, as it is from the sands of the Cruse and Forest formations that the bulk of Trinidad's oil has been produced. The foraminiferal faunas of the Forest and Cruse formations are the subject of a paper by D.A.J. Batjes, while their particular development in the Forest Reserve Oilfield area is discussed by V.F. Hunter in T.H. Bower's paper.

The Cruse and Forest formations are also notable for interesting sedimentation features, submarine slump structures being plentiful in some areas. Some examples of these will be seen during <u>Excursion No.6A.</u> The upper Miocene Morne l'Enfer formation consists mainly of well-bedded sands with clays interbeds of shallow water origin. An account of some of the associated sedimentary phenomena will be presented in a paper by J.B. Saunders and J.E. Kennedy dealing with the coastal exposures west of La Brea. This shallow-water deposition persisted into the lower Pliocene in the southern basin with only a minor disconformity.

<u>Pliocene.</u> The lower Pliocene records the final infill phase in both the Northern and Southern Basins, although the lithofacies differ markedly in the two areas. About mid-Pliocene the final and culminating phase of the Andean orogeny took place, when the final molding of the structures of northern, central and southern Trinidad took place, bringing to an end the long, and only intermittently broken, depositional history which began in Paleocene times. From upper Pliocene onwards the history is chiefly one of successive periods of uplift and erosion, with the formation of terrace and flood plain deposits in low-lying areas. In the case of the Northern Range, it is probable that most of the structures pre-date this late-Andean episode and that the effect there was mainly one of consolidation and uplift. Elsewhere, the older structures were re-emphasized and the folded structures around and within the Northern and Southern basins were developed. These movements also set in motion the hydro-dynamic processes which led to the accumulation of oil in the Tertiary sediments within the newly-formed structures.

Following closely upon these movements, or perhaps concomitant with them, as a result of the release of the accumulated stresses, a number of lateral wrench fault movements took place which appear to have cut and displaced several of the recently-formed structures. The most prominent of these is the Los Bajos Fault crossing the southwestern part of the island. The effects of these fault movements will be further discussed in the section dealing with structure.

As noted above, the Northern and Southern Basins remained distinct, with differing sediment deposition. In the Northern Basin, the shallow-water Springvale Formation is succeeded with sharp transgressional unconformity by the Talparo Formation, a predominantly clayey series, but containing several thick and persistent sand members in its lower part. These are locally important as fresh-water aquifers which have been tapped for water supply purposes. In the Southern Basin a minor unconformity separates the lower Pliocene Erin Formation from the underlying Morne l'Enfer Formation but thecharacter of the sedimentation is almost unchanged and in places it is very difficult to distinguish the two formations lithologically. The Erin Formation consists mainly of thick, predominantly regularly bedded sands with interbeds of grey silty clay. In detail, however, many of the individual sand layers are current bedded. The silt layers are commonly lignitic, and sometimes contain well-preserved leaf impressions. Of particular interest are the numerous occurrences of naturally burnt clays, locally termed "porcellanite", which are bright brick-red in colour and appear to be due to the spontaneous combustion (probably by oxidation of pyrites) of the lignitic beds along the outcrop. The resulting hard, but rather brittle, rock is used locally for road metal. Plant leaf impressions are often excellently preserved in these porcellanites. An example of this unusual lithology will be seen in the Brighton area on Excursion No.6A.

By mid-Pliocene times both the Northern and Southern Basins were virtually filled; the area then came under diastrophic control and was folded and uplifted. The subsequent history is not well documented; probably most of the upper Pliocene was a period of uplift and erosion, and some of the high-level terraces of the Northern Range may belong to this period.

During the following Pleistocene and sub-recent periods there were doubtless several major changes in sea level, some of which are recorded in the various terrace levels on the flanks of the Northern, Central, and Southern Ranges.

STRUCTURE:

As already noted, there is a simple relationship between the gross structure and the morphology of the island, with the five-fold subdivision into the Northern Range uplift complex; the synclinal Northern Basin; the Central Range uplift, and associated "foothill" complex of the Naparima belt; the Southern Basin, again synclinal, and the Southern Range anticlinal complex.

The structures south of the Northern Range show a general tendency towards southward-directed asymmetry, expressed in southward overfolding and in some cases overthrusting of the individual structures.

In addition to faulting directly associated with the fold movements, later systems of faulting occur which in several cases appear to be in the nature of lateral or "wrench" fault movements. Some of these are probably related to regional systems.

The general situation is illustrated by H.G. Kugler's 1/100,000 scale map of Trinidad and accompanying cross-sections. The generalized geological map (figure 1) and the schematic cross-section (figure 2) appended will serve to illustrate the following discussion. We may now consider each of these units in a little more detail.

1) The Northern Range

This is composed of low-grade, regionally metamorphosed sedimentary rocks, which throughout much of the range dip rather uniformaly southward at about 30° to 40°. However, there is frequently an increase in dip, together with local structural disturbance along the southern edge. It is thought that this southern margin, with its very consistent east-west alignment is strongly faulted and is in fact an extension of the regional El Pilar fault system, generally regarded as a right lateral wrench fault. New evidence bearing on the nature of the El Pilar Fault system in Venezuela will be given in a paper by H.L. Metz. Although in Trinidad the contact between the Northern Range metamorphics and the younger Tertiaries to the south is everywhere masked by terraces and alluvial deposits, there can be little doubt that a fault of large magnitude is involved, with effective downthrow to the south. A branch of this system — "the Arima fault" — separates the Lower Cretaceous Laventille Formation with its important limestone masses of Laventille, Point Gorde and Gaspar Grande from the older Northern Range series.

The structure of the Northern Range itself is by no means satisfactorily resolved. Throughout the western and central parts the dip is uniformly southward; however, the minor structural features and to some extent the lithologies suggest that it is not a simple monocline but may contain overfolded, even recumbent structures. With this goes the possibility that, in contrast to the central and southern parts, the structure may be asymmetric towards the north. This may imply some conflict with regional concepts, but in truth further work is required to resolve this problem. H.C. Potter's paper on the eastern part of the range is expected to add to this discussion.

Towards the eastern end of the range the structure steepens, becoming apparently more complex in that a series of well-defined anticlinal structures have been delineated. At the same time there is a general northeastward swing of the structural strike. This, it has been suggested is the result of the gradual "righting" of the overturning element coupled with a swing towards the trend of the Antillean island arc. A well-defined right-lateral wrench fault crosses the eastern end of the range and brings the strongly-folded lower Cretaceous series of the Toco district against the Northern Range metamorphics. Some of the structural features in this area will be seen during the Second Field Excursion. Unfortunately, time does not permit a visit to the central/western part of the range. Anyone with time to spare can obtain a good impression of the western section on the drive along the North Coast Road to Maracas Bay, where the regular south-dipping series is well displayed in road cuttings.

2) <u>The Northern Basin</u> (Caroni Syncline)

The northern rim and axial parts are almost entirely obscured by terraces, alluvial and swamp deposits; however at Melajo, a shelly beach deposit of upper Miocene age rests with strong unconformity on up-turned Northern Range phyllites. To the south of the geographic axis the southward rising foothills comprise the north-dipping limb of the syncline which becomes the north flank of the Central Range structure. A line of en echelon subsidiary anticlinal structures interrupt the flank — the Freeport, Mahaica and Sangre Grande anticlines, with sharp, local dip reversals. Continuing southward the dip of the flank increases steadily to 40°-45° as the core of the Central Range is approached. The extent of this north flank and the progressive southward steepening of the dip will be seen on the Manzanilla (East) Coast <u>Excursion (No.1)</u> and again on the West Central Range <u>Excursion No.4.</u>

3) <u>The Central Range</u>

In the eastern sector, centering on Mt. Harris, the core of the structure is composed of an extensive outcrop of lower Eocene, Paleocene and upper and lower Cretaceous rocks, lying unconformably below the upper Tertiaries, and in places sharply and severely folded. The oldest, lower Cretaceous beds — mainly strongly sheared and disturbed shales — crop out along the southern margin of the range, and the asymmetric arrangement implies strong faulting along the south flank. This faulting appears to be in part southward-directed thrusting, but there is some evidence that lateral faulting may also be present. In the western part of the range the pre-Tertiary core is lacking — represented only by large allochthonous masses in the lower Tertiary "wildflysch". Several minor structures are present — the sharply-folded Forres Park anticline, the Guaracara syncline, the Montserrat anticline and Basin Hill Syncline. Some of these, especially the Forres Park structure appear to be in the nature of second order folds possibly related to a first order shear along the southern margin of the range. This feature, referred to as the Central Range Fault, is not yet fully understood; it has the characteristics of a wrench fault in some areas or of a southward thrust in others. It may be an old wrench modified by later tectonics. In the western sector the structure becomes sharply pinched together with dips locally approaching vertical.

Immediately to the south of the Central Range is a belt of steeply northward-dipping and in part strongly folded succession of Oligocene and lower Tertiary beds, sometimes referred to as the "Naparima Fold Belt" and about 4 to 6 miles in width. Whilst severe folding and faulting are present, structures tend to be small and discontinuous, so that with few exceptions the area lacks structural character. The exceptions are a well-defined series of southward overthrust anticlines which run as a discontinuous chain across the island — the San Fernando structure (to be seen on <u>Excursion No.4</u>) the Corial-Ben Lomond, and Biche-Charuma anticlines, all of which expose lower Tertiaries, and in the case of the first the upper Cretaceous is also exposed.

In this area also the combination of folding and the "wildflysch" lithology with its exotic slip-masses has produced some pseudo-tectonic lenses of a variety of older formations. Earlier attempts to explain these as thrust scales led to an over-complication of the tectonics with complex zones of imbrication. The recognition of the "wildflysch" origin of these exotic — largely due to the work of H.G. Kugler — has greatly simplified the situation as far as the structure is concerned.

The Naparima Fold Belt terminates in an irregular line of sharp folds which in effect form the northern edge of the Southern Basin — the Siparia-Ortoire Syncline, and the older formation dips steeply into the depths of this basin. Along the rim of the basin, a series of westward-pitching folds occur, and these have become the economically important oil-bearing structures of the south and southwestern part of the island. The northernmost fold of this system, quite gentle as far as the superficial Miocene beds are concerned, but overlying a buried, sharply folded Cretaceous structure, is the locale of the famous Pitch Lake of Brighton (La Brea) which will be visited on Field Excursion No.6 (A & B). This huge asphalt seepage, undoubtedly derived from the underlying Cretaceous rocks, has many curious features which will be discussed in H.G. Kugler's paper and will be seen during the visit to the Lake. The presence of numerous asphalt dykes and sills, as well as the old overflow channels from the lake, has resulted in a great deal of soil instability with frequent troubles to brick buildings and to the roads in the neighbourhood.

The next wave of folding to the south of the Brighton structure is the Forest-Fyzabad anticline, which, with its reoriented continuation as the Point Fortin anticline, is the most important and prolific oil-bearing structure in the south of the island. In passing, it may be noted that a general account of the oilfields of Trinidad will be included in the section on economic papers, as well as more detailed descriptions of certain specific fields, so that no attempt will be made to elaborate on the petroleum geology at this stage.

The Forest-Fyzabad structure is a somewhat asymmetrical anticline with a more steeply-dipping south flank, associated with numerous secondary dip strike faults. The broad anticlinal trend is characterized by several domal culminations. Stratigraphically, the middle Miocene, Forest Formation is the oldest exposure. The oil-bearing formations comprise the well developed sands of the Forest and Cruse formations, which exhibit a high degree of lenticularity and lateral variation. In addition to such normal variations, localized submarine slumping has produced contortion and disorientation of the beds, sometimes on a quite spectacular scale. Taken as a whole, the middle and upper Miocene deposits thin northward and northwestward towards the Brighton uplift which seems to have been an axis of intermittent uplift during Miocene times.

The stratigraphy and structure of Forest Reserve Field is the subject of a paper by T.H. Bower. A more general account of the oilfields of the south will be given in a paper by K. Ablewhite and G.E. Higgins.

Towards the west, the anticlinal trend comes up against the Los Bajos fault and appears to be deflected to run parallel to the fault as the Pt. Fortin Anticline, which then continues out to sea west of Pt. Fortin.

Towards the east the Forest-Fyzabad anticline becomes more sharply-folded and merges in the general fold complex along the southern margin of the Naparima fold belt.

The rim of the southern basin is then taken over by another distinct fold trend, the Penal-Barrackpore anticline which continues somewhat disjointly as the Tableland and Balata anticlines towards the east coast. The south flank of this fold trend is again sporadically oil-bearing at Penal and Barrackpore. In addition to the oil measures of the middle Miocene Forest/ Cruse Formations, the lower Miocene Herrera sands are also locally oil-bearing.

4) The Siparia-Ortoire Syncline and Southern Range Anticline

This well-defined syncline can be traced right across the south of the island from Mayaro in the east, passing south of Barrackpore, through Siparia extending westward to cross the north Cedros coast in Granville Bay and passing seaward into the Gulf of Paria. To the south lies an irregular line of anticlinal folds broadly referred to as the Southern Range Anticline. The largest single element is the broad uplift of the Rock Dome-Herrera anticline which exposes lower Miocene beds in a broadly elongate core. The north flank is very regular, the south flank is strongly faulted and overthrust towards the south. Towards the east this structure dies away and givs place to the series of en echelon folds of

Singuineau, Lizard Springs and Mayaro, south of which lies yet another trend of sharply-folded, partly diapyroid structures from Guayaguayare to Moruga, with associated mudvolcanoes. To the west a sharp diapyroid anticline takes over running close to the south coast from Morne Diablo to Erin and striking out to sea across Erin and Islote Bay. Numerous mudvolcanoes lie along this trend, including those responsible for the periodic submarine outbursts in Erin Bay, a recent example of which will be described in a paper by G.E. Higgins & J.B. Saunders. The structure re-crosses the land at Icacos Point and then continues west-southwestward toward the Pedernales anticline of S.E. Venezuela. South again of the Southern Range anticline geophysical work suggests that the south flank descends steadily and regularly towards a deep synclinal axis lying some 6 to 8 miles offshore.

This whole structural pattern is cut and disrupted by a major right lateral wrench fault — <u>the Los Bajos Fault</u> which runs across the south-western part of Trinidad from Pt. Ligoure to near Pt. Negra on the south coast in an east-southeasterly direction, cutting and displacing all pre-existing structures in a right-lateral sense. The maximum displacement along the fault amounts to some seven miles which is amply demonstrated by the displacement of outcrops and structural axes, and by the remarkable correlation of some of the wells on either side (C.C. Wilson, Jour. Inst. Petr. Vol. 44 (No.413) 1958 pp.124-136).

The seaward extension of the fault into the Gulf of Paria has been traced by geophysical surveys and was a decisive factor in determining the oil-prospectiveness of the southern part of the Gulf, as it was found that the western extension and counterpart of the oil-bearing Forest Reserve-Fyzabad structure could be defined on the western side of the fault. This structure has subsequently been developed as the Soldado Field, which has contributed significantly to the island's production, at present accounting for approximately one-third of the daily output of some 110,000 B.O.P.D. A visit to the surface installations of the Soldado Field by launch has been arranged as an alternative Excursion No.5, in the latter part of the program.

So much then for the general structure of the island, and it now remains to say something of the regional relationships. The broad structural features of Trinidad and the surrounding area are shown in figure 4, on which the trend of the regional negative gravity axis is also given. It is at once evident that the Northern Range is the extension of the Coast Ranges of eastern Venezuela, where comparable low-grade metamorphic rocks also occur. Towards the east the negative gravity axis swings northeastward passing through Barbados and along the outside of the West Indian island arc. Trinidad thus seems to lie at a structural hinge point where the predominantly east-west structures of northern and eastern Venezuela turn sharply towards the generally northward-trending arc of the West Indies. However, when the time factor is introduced the relationship may be less direct; the Venezuelan Coast

Range-Northern Range rocks are Upper Jurassic to Cretaceous in age, whereas the oldest known formation of the lesser Antillean arc proper are Eocene, although there is evidence of Cretaceous components in wildflysch deposits in Barbados. Nevertheless, it is very probable that the Northern Range trend was tectonically active at intervals in post-Cretaceous times and thus some continuity between the Antillean arc and the coast range structure may be inferred. It is therefore possible that some of the marked lateral faults which appear to be mainly late Tertiary to subrecent in age may have been generated as relief faults consequent upon the reorientation of the stress pattern between these two fold directions. Among the later events to affect the area were a series of strong east-west directed lateral wrench faults which appear to have dominated the late Pliocene period. These are expressed in the east-west El Pilar fault system along the southern margin of the range. The remarkably aligned north coasts of Trinidad and eastern Venezuela may also imply the presence of comparable east-west wrench faulting along the north of the range. Analogous wrench faulting probably also exists on the northern margin of the Caribbean and such prominent oceanographic features as the Barlett Trough and the Puerto Rico Trench may in part be directly related to wrench faults as suggested many years ago by Hess (1938). This concept envisaged the general eastward movement of the central Caribbean relative to its margins. Of recent years there has been a renewal of interest in the idea of continental drift, in which very broadly speaking the "drift" of Wegener's original concept is replaced by the more positive process of convection currents in the mantle. This line of thought opens up numerous possibilities as far as the Caribbean in general, and Trinidad in particular, are concerned which unfortunately are beyond the scope of this paper, but which perhaps may come in for some discussion arising from papers which are to be presented in subsequent sessions. One or two questions may perhaps be posed at this stage — for instance — do the structures of Trinidad and particularly of the fold system of the Northern Range swing northward into the Antillean arc or may they link up — via the mid-Atlantic ridge with north Africa? While lateral wrench faulting could well be associated with continental movement, and the presence of numerous, well-defined fracture zones in the deep ocean basins is surely significant in this respect, Ewing and his colleagues of the Lamont Geological Laboratory, have argued (on the basis of much excellent data) for the existence of tension phenomena, with associated graben formation, as being a major factor in the gross structure of the Caribbean region. (Ewing et al. 1948 to present). This seems particularly significant in relation to some of the linear deeps — one thinks of the Bartlett Trough — which could have originated in this manner.

And lastly, the convection hypothesis implies zones of convective down-turn and up-welling as well as horizontal movement. It seems possible therefore that the volcanicity of the Antillean arc, and the evident severe tectonics associated in places — such as in Barbados — may be related to one or other of these zones in which movement in a vertical sense has predominated. Perhaps some of the data presented and the ensuing discussion during this conference may bring us a little nearer to a solution to some of these larger problems.

Text Figures:

Figure 1 - Generalized Geological Map of Trinidad

Figure 2 - Summary Stratigraphic Chart of Trinidad Formations

Figure 3 - Schematic North-South Cross-section of Trinidad

Figure 4 - Regional Map showing generalized structural relationships of Trinidad and surrounding areas

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The above publications contain more extensive bibliographies to which reference may be made for further details.