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Jurassic to recent sedimentary environments in Trinidad

by H. G. KUGLER[1])

Abstract

It is suggested that many of the formerly assumed tectonic complexities in Trinidad are in reality the result of turbidity currents and submarine sliding and slumping. A total thickness of 18.000 meters of Upper Jurassic and Lower Cretaceous sediments, of which the greater part is altered by low grade metamorphism, is considered to be mainly the result of ponding connected with turbidity currents. These sediments are compared with the «schistes lustrés» of the Alps and in turn with the «Flysch». The unmetamorphosed Cretaceous sediments of Trinidad and Eastern Venezuela are likewise reviewed in the light of environmental conditions. Special attention is paid to the large slump masses of the Paleocene and the term «MORROS» is suggested for the orographic feature-forming components. The Midwayan Soldado Formation is redefined and the boundary with the Lower Eocene discussed. Facies conditions during Eocene and Oligocene time give rise to additional comparison with the alpine Flysch and «Wild Flysch». The Upper Oligocene and the Lower Miocene neritic deposits are correlated with their contemporaneous Globigerina marls of the continental slope and the still deeper cold water deposits of the Cyclammina clays. The Upper Miocene and Pliocene paralic greywackes of Trinidad are considered to be typical Molasse but not the product of an early Orinoco. The origin of the Orinoco is brought in connection with the Pliocene down warp of the Eastern Venezuela geosyncline which caused the capture of the former head waters of the Rio Negro.

Ever since the appearance of the classic synthesis «Das Antlitz der Erde» by Edward Suess, geologists intensified the studies of island arcs in an attempt to arrive at a closer apprehension of the geologic problems they have to face in mountain ranges such as the Alps. Extensive investigations have already been carried out in Indonesia and similar ones are in progress in the Caribbean region (Hess and Maxwell 1953). No suggestion is made, however, to try a renewed incorporation of Trinidad in the frame of Antillean geology. The purpose of this paper is to draw attention to sedimentary conditions in Trinidad which show affinities to Cretaceous and Tertiary ones of the Alps and the Swiss Molasse basin. In paying greater attention to past sedimentary environments we are able to contribute to the understanding of some geologic observations which, hitherto, have been subject to speculation and caused the assumption of unnecessary complex tectonics. Wiedenmayer's (1950) publication on the structural development of areas of Tertiary sedimentation in Switzerland induced the writer to honour the memory of his valiant friend with a contribution to a subject always close to his heart.

North of the stable region of the Guayana mass a mobile orogenic belt stretches from east to west including Trinidad, the Coast Range of Venezuela and extending into the Andes. The surface of the Guayana basement is known in Eastern Venezuela

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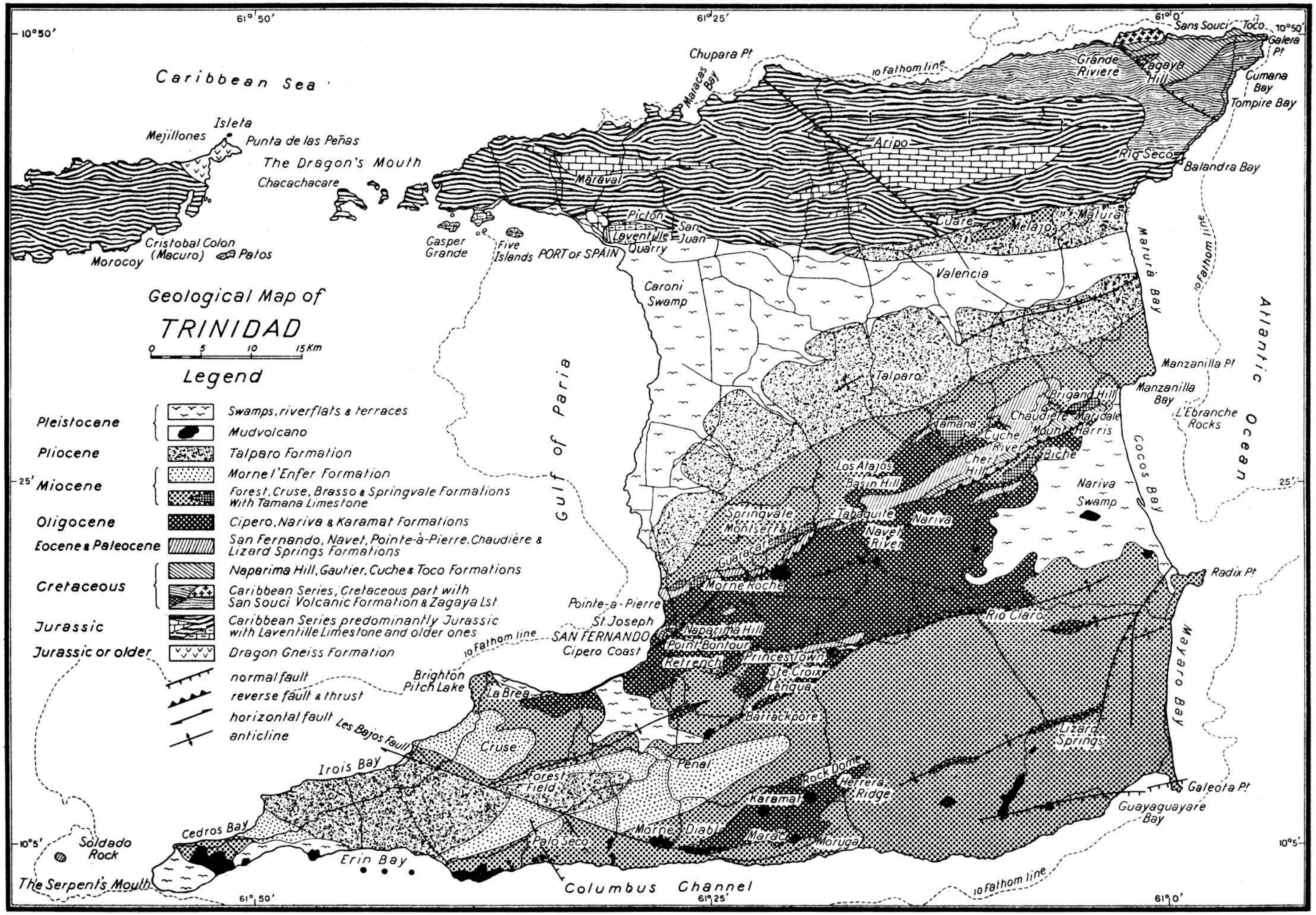
from boreholes and seismic refraction work to a depth of at least 2000 m. A northward extrapolation of this known slope would indicate a depth of about 13,000 m along the southcoast of Trinidad. This extrapolation agrees well to a depth of 7000 m where basement was found by Worzel and Ewing (1948) N. E. of the mouth of the Orinoco by seismic refraction shooting. The basement showed a velocity of 21,750 feet per second. Above followed a layer of 4850 m of beds with a velocity of 11,250 feet/second, above this 1130 m of 7770 feet/second, then 430 m of 6580 feet/second and on top 500 m of 5470 feet/second. However, in the Gulf of Paria between Cedros and the mouth of the San Juan River the following seismic section was obtained: 3720 m of beds with a velocity of 16,890 feet/second, above this follow 3140 m of 10,300 feet/second and on top 560 m of 1860 feet/second. This would mean a thickness of sediments of only 7420 m on top of the basement at this spot of the Gulf of Paria. The 16,890 feet/second layer could, however, well include the Cretaceous and the Caribbean Series resting on the basement of 21,750 feet per second. The position of the axis of the geosynclinal trough is not known but conditions in the Venezuelan Andes suggest it could be expected not far off the north coast of Trinidad, if not below the Northern Range itself. This geosynclinal basin has been filled with Mesozoic sediments known as *Caribbean Series* since the days of Wall and Sawkins who wisely refrained from attributing any age to this series of monotonous rocks which in its physical aspect can be compared with the Casanna and moreso with the Bündner Schiefer or «schistes lustrés» of the Alps. The striking similarity between the Caribbean Series and the Bündner Schiefer induced Suter (1951, Part I, p. 206) to call this type of monotonous masses of rocks of universal occurrence at different epochs the «Grison formation» or simply «Grison». He qualifies this term by stating: «This would complete the set of geosynclinal tectofacies terms, and there would be therefore the name *Flysch* for the mixed sediments of the orogenetic zones, *Grison* (or Grisons) for the pelitic sediments of the centre, and *Molasse* for the sandy and usually younger sediments of the more epeirogenetic part and/or phase of the geosyncline.»

The Caribbean Series

The Caribbean Series represents a group of formations which is still poorly known as far as its relative age and structural position is concerned. The Northern Range shows a regional dip to the east and thus suggests a search for the oldest formations to the west. Here Wall and Sawkins (1860, p. 105) discovered a gneiss formation at the eastern end of the peninsula of Paria between Punta de las Peñas and Mejillones. They observed that the south dipping, well-layered gneiss contains green and light red mica and is cut at a slight angle by chloritic, sericitic layers or dykes that may suggest igneous rocks. At Mejillones they found that the gneiss loses its tabular structure thus becoming more massive and somewhat granitoid. Proceeding from Punta de las Peñas to the south they observed that the gneiss alternates with greenish talcose rock which in turn changes to quartzose and mica slates. Still farther to the south and farther away from the gneiss they observed the normal phyllites known to them from the Northern Range of Trinidad and concluding they write: «The impression conveyed by an inspection of the above sections was, that a passage from the gneiss to the slates exists.»

The writer had recently an opportunity to visit the same coast but could only land at Punta de las Peñas, at Cristobal Colon (Macuro) and Morocoy. The fundamental correctness of the early observations of Wall and Sawkins can hardly be doubted. The


Geological Map of
TRINIDAD
0 5 10 15Km
Legend
Pleistocene
Swamps, riverflats & terraces
Mudvolcano
Pliocene
Talparo Formation
Miocene
Morne l'Enfer Formation
Forest, Cruse, Brasso & Springvale Formations With Tamana Limestone
Oligocene
Cipero, Nariva & Karamat Formations
Eocene & Paleocene
San Fernando, Navet, Pointe-à-Pierre, Chaudière & Lizard Springs Formations
Cretaceous
Naparima Hill, Gautier, Cuche & Toco Formations
Caribbean Series, Cretaceous part with San Souci Volcanic Formation & Zagaya Lst
Jurassic
Caribbean Series predominantly Jurassic with Laventille Limestone and older ones
Jurassic or older
Dragon Gneiss Formation
normal fault
reverse fault & thrust
horizontal fault
anticline
Caribbean Sea
Atlantic Ocean
Gulf of Paria
Columbus Channel
The Dragon's Mouth
The Serpent's Mouth
Isleta
Mejillones
Punta de las Peñas
Chacachacare
Cristobal Colon (Macuro)
Patos
Morocoy
Gasper Grande
Five Islands
PORT of SPAIN
Chupara Pt
Maracas Bay
Maraval
Picton
Laventille Quarry
San Juan
Aripo
Cuare
Melajo
Matura
Valencia
Caroni Swamp
Talparo
Grande Riviere
Zagaya Hill
Sans Souci
Toco
Galera Pt
Cumana Bay
Tompire Bay
Rio Seco
Balandra Bay
Matura Bay
Manzanilla Pt
Manzanilla Bay
L'Ebranche Rocks
Brigand Hill
Chaudière
Mundale
Mount Harris
Cuche River
Biche
Cheri Hill
Tamana
Los Atajos
Basin Hill
Nariva Swamp
Cocos Bay
Springvale
Montserrat
Tabaquite
Nariva
Navet River
Guaracara
Morne Roche
Radix Pt
Pointe-a-Pierre
St Joseph
SAN FERNANDO
Cipero Coast
Naparima Hill
Point Bontour
Retrench
Princes Town
Ste Croix
Lengua
Rio Claro
Mayaro Bay
Brighton Pitch Lake
La Brea
Barrackpore
Lizard Springs
Les Bajos Fault
Cruse
Irois Bay
Forest Field
Penal
Rock Dome
Herrera Ridge
Karamat
Galeota Pt
Guayaguayare Bay
Cedros Bay
Soldado Rock
Erin Bay
Palo Seco
Morne Diablo
Marac
Moruga
10 Fathom line
10°50'
10°5'
25'
61°50'
61°25'
61°0'

Rock of Punta de las Peñas is a pinkish weathering, typical augengneiss, seemingly alternating with greenish chloritic schists. This same formation could be observed to extend at least to Isleta near Mejillones Bay. With a regular dip of 55° to SE the thickness of gneiss involved is about 2000 m. On account of its importance to the regional geology it is herewith termed *Dragon Formation* because its sheer cliffs jut out into the Dragon's Mouth passage between the Gulf of Paria and the Caribbean Sea. The Dragon gneiss appears to be a paragneiss, although the possibility of a granitic basement is not excluded. It is reminiscent of the augengneiss of the *Peña de Mora Formation,* described by Dengo (1953) from the Quebrada Tacagua between Caracas and Maiquetia, although no aplitic or granitiferous rocks have so far been observed in the Dragon Formation. Dengo considers the Peña de Mora Formation to be a migmatitic gneiss corresponding to a part of the *Las Brisas Formation* of uncertain Cretaceous age or older. Similarly there is no direct indication of the age of the Dragon Formation although it is apparently less metamorphosed than the Peña de Mora Formation. Grade of metamorphism, however, has no direct bearing on age. Well-bedded quartz-mica schists must be superimposed on the Dragon Formation to judge from pebbles collected at Cristobal Colon in a river with its head in the high mountains west of the gneiss outcrop. These greenish quartz-mica schists are comparable with the «epi-quartzites» of the *Maracas Beds* of Suter (1951, p. 190). The seemingly consistent SSE dip of the entire coast section between Punta de las Peñas and Cristobal Colon indicates that a thickness of at least 3000 m of Caribbean Series rests on the 2000 m of the Dragon Formation. If the lower part of this series can be correlated with the Maracas Beds then one must consider the upper part to be the equivalent of the phyllites, calc-schists and recrystallised dark flaggy limestones of Suter's *Maraval Beds* of about 2100 m thickness at their type section. These beds form the islands in the Dragon's Mouth and the high hills of the western part of the Northern Range. Support for such correlation was found at Cristobal Colon and Morocoy where quarries are opened in massive banded gypsum of about 25 m thickness with an intercalation of 3 m of «Rauwacke». This gypsum is probably lenticular and normally bedded between silvery and red weathering, satiny, sericitic phyllites rich in graphitoids and with lenses and flaggy layers of silty, blue-grey, crystalline limestone. These rocks are in every respect comparable with the Maraval Beds north of Port-of-Spain where small lenses of gypsum are occasionally exposed in road cuttings. Farther to the east, and in the same strike, gypsum was mined at St. Joseph where an old quarry still shows a face of 10 m of massive, banded gypsum with some rare and small crystals of pure sulphur. This gypsiferous zone of a length of at least 60 km may become of importance in any future correlation of the Caribbean Series of Venezuela and Trinidad for it is, undoubtedly, witness of semi-arid land conditions in pre-Cretaceous time. Searching for rocks that may corroborate such assumption one cannot avoid thinking of the mighty conglomerates, sandstones and pinkish shales of the *Roraima Formation* of the Guayanas or of the ferruginous quartzites (Kamen-Kaye 1942) underlying the Cretaceous of the Machete well in the State of Guarico. The *Hato Viejo* and *Carrizal Formations* of at least 700 m thickness, and unconformably below the Cretaceous *Temblador Formation,* must also be considered. Their dense argillites with fine to coarse grained pinkish sandstones together with quartzitic cobbles and finer conglomerates (Hedberg 1950, p. 1184) would admirably fit between the Roraima conglomerates to the south and the gypsum of Macuro to the north. Hedberg rightly pointed to the similarity of the Hato Viejo and Carrizal

Formations with the *La Quinta Formation* of the Venezuelan Andes. The La Quinta Formation was always placed somewhere in the Triassic or Jurassic. Finally one may remember the sketch map by Imlay (1952) in which he shows the Callovian saliferous red beds of the Preuss sandstone possibly extending into the Caribbean region north of Venezuela. A Callovian age for the gypsum deposits of the Gulf of Paria area is feasible but this depends on the determination of the age of the Laventille limestone.

The *Laventille Formation* of about 270 m thickness consists of various limestone members separated by sericitic phyllites. The lowest exposed limestone of about 15 m thickness is a silty, bluish rock full of calcite veins and containing Pteromya? laventillensis which Harris (Waring 1926, p. 90) considered to be of post-Paleozoic age. The cephalopod which Guppy had found and which he identified as a Goniatite was mainly responsible for attributing Paleozoic age to the Caribbean Series for such a long time. Craig (1907) who saw the specimen, before it was lost in a fire, declared it to be an ammonite of a type not earlier than Jurassic, an opinion held before. Guppy (1877) mentions that Prof. Tate was of the opinion that the whole of the Caribbean Series is Jurassic. In the upper part of the Laventille Formation, near Fort Picton, the well-bedded *Picton Limestone* is dense, light-grey, blotchy, partly oolitic with more numerous remains of fossils. Trechmann (1925) found in this limestone a slender Nerinea of «a decidedly Jurassic aspect».

Parallel with the indicated gypsiferous zone one observes the Laventille Limestone to strike westward and to form the «Five Islands» and Gaspar Grande, and probably to extend to Patos Island situated SE of Cristobal Colon. Patos is an asymmetric anticline formed of about 80 m of the Picton limestone member which in its upper part carries an increasing number of angular and subangular components ranging from grains to blocks of several cubic meters. This *Patos conglomerate* (Kugler 1936) is composed of dominantly pink and crimson coloured quartzitic sandstone which has already been compared with the Roraima sandstone. Less common components are: 1) blue crystalline limestone of the Maraval Beds, 2) silty limestone of Lower Laventille type with ?Pteromya, 3) vein quartz, 4) dense coquina limestone with well preserved small gastropods (a rock type not yet known from Trinidad), 5) oolitic limestone with molluscs and 6) gritty and silty limestone pieces. In the limestone matrix of the «conglomerate» which would be better called a breccia, a few remains of smaller and larger molluscs were found, as well as a specimen of a branching coral with fine corallites. A few phyllitic shale layers are interbedded in the conglomerate and main limestone mass but their metamorphosis has advanced too far to allow the preservation of foraminifera. There is little doubt about the off-shore nature of the Patos conglomerate and this may indicate some relationship with the gypsiferous Macuro zone below the Laventille Formation.

The younger formations of the Caribbean Series have been carrefully studied by Barr (1953) whose manuscript is ready for publication. He describes a sequence of essentially phyllitic rocks of a least 10,000 m thickness. These phyllites with occasional layers of quartzitic sandstone and crystalline limestone grade imperceptibly into unmetamorphosed Lower Cretaceous calcareous, fossiliferous shales with reefal limestone lenses, grits and conglomerates in a silty environment.

The oldest beds mapped by Barr are grouped together as the *Rio Seco Formation*, consisting of calc-phyllites and thin layers of limestone containing some very rare Aptychi. These rocks of over 1000 m thickness are tentatively correlated with the beds containing the *Cuare Limestone Member* with Perisphinctes transitorius of

Tithonian age (Spath 1939). Though there are many lithologic affinities between the rocks of the Rio Seco Formation and Suter's Maraval Beds, one is not justified in correlating them until future mapping has proved their identity. The similarity amongst this type of rocks is of little assistance in correlation nor is the degree of metamorphic changes, for Barr has shown the metamorphic boundary line to be of no stratigraphic significance «but rather that it represents a metamorphic front, a tecto-facies line which may transgress the stratigraphic zones». Until the nature of the great NW-SE fault between Chupara Point and Valencia is better known it is inadmissible to consider a correlation of the Laventille limestone with that of Cuare or Aripo as suggested (Kugler 1950), but one must look upon the Rio Seco Formation as being younger than the Laventille Formation.

Barr's *Grande Riviere Formation* of at least 2500 m thickness which is superimposed on the Rio Seco Formation, starts with a well defined sandstone, grit and conglomerate zone of about 200 m thickness. The conglomerate contains exotic igneous components not exposed in Trinidad. The grits are graded and show the typical characteristics of turbidity flow deposits with certainly no signs of shore environment. The rest of the formation is essentially a monotonous sequence of sericitic non-calcareous phyllites with occasional layers of quartzites. This formation is considered to be Lowermost Cretaceous although no fossils have been found as yet. Lithologic conditions change in the normally superimposed *Cumana Formation* of about 700 m thickness. The glossy, fine-bedded phyllites with sericite and graphitoids alternate with calc-phyllites and occasional fine-textured limestones. In the calc-phyllites Barr discovered, at two places, a relatively rich fauna of small pyritised ammonites which belong to such genera as Protancycloceras, Pulchellia, Karstenia, Nicklesia, Barremites, Melchiorites, Saynoceras, Leptoceras, Ancyloceras and Phylloceras. Imlay considers the abundance of Pulchellidae and the absence of such typical Upper Barremian genera as Holcodiscus and Costidiscus to be indicative of a Lower Barremian age for at least the fauna of the Tompire Bay zone of the Cumana Formation. This important discovery allows us to make an approximation of the thickness of sediments deposited during the Barremian stage.

The *Galera Formation* of about 1600 m thickness merges downward into the Cumana Formation but can be separated from the latter by the absence of calc-phyllites and the appearance of thick masses of quartzitic arkosic sandstones of which the *Galera Grit Member* of the lower part of the formation attains a thickness of almost 700 m. This grit, like that of the Grande Riviere Formation, is the product of turbidity current transport and the large grains of feldspar show hardly any weathering. A foraminiferal fauna was found in thin, slightly metamorphosed silt layers between the blocky weathering grit masses and its identification points to a Lower Barremian age and as such is practically identical with that of the unmetamorphosed shales of the superimposed Toco Formation. The upper boundary of the Galera Formation with its low-grade metamorphosed phyllites merges imperceptibly into the non-metamorphosed shales of the Toco Formation.

The *Toco Formation* of about 2300 m thickness has attracted geologists ever since Trechmann (1935) discovered fossils in irregular limestone lenses in the shales of Toco Bay. Subsequently quite a rich fauna was gradually brought together of which the caprinids and corals showed that the Toco Beds could be compared with the *Cuche Formation* of the Central Range and the *Barranquin Formation* near Barcelona in Venezuela. Some of the blocks of reef limestone seem to have slipped down the marine slope as their haphazard position in the shales cannot be explained by tectonics alone. Similar conditions were also observed by Barr (1952) in the Central Range. The normally interbedded massive *Zagaya Limestone Member* attains a thickness of over 200 m. Thick-shelled bivalves are found in similar dense crystalline limestone which, together with the caprinid and coral bearing bioherm limestone, are indicative of relatively shallow water conditions. In this respect the limestone is somewhat reminiscent of the Laventille Limestone which likewise seems to have been deposited at the end of a sedimentary cycle of great thickness of phyllites. The megafauna of the Toco Formation is considered to be of Lower Cretaceous age, the foraminifera are Barremian and Wells compared the coral fauna with the Urgonian facies of the Barranquin Formation. According to Barr the broad conclusion is that the age of the Toco Formation is mainly Barremian but possibly ranging to Aptian or even Albian. The shallow water conditions of the Toco Formation, and even more so of the Barranquin Formation with its Amphitriscoelus reef, as found on Isla Caribe off Barcelona, would make its unconformable overlap on some older rocks possible (Hedberg 1950) although these older rocks would hardly have been metamorphosed since metamorphic changes took place subsequently to the deposition of the Barranquin Formation. This assumption is supported by the discovery by Smith (1953) of a Cenomanian limestone pebble in the metamorphosed Paracotos Formation of Central Venezuela.

The youngest rocks of the Northern Range comprise Barr's *San Souci Volcanic Formation* of over 3000 m thickness. It is a series of consolidated volcanic tuffs, tuff breccias, agglomerates and lava flows of an andesitic composition. The lava baked the contemporaneously deposited clay and engulfed large blocks of limestone and sandstone. Geologic conditions of the San Souci area indicate that these lava flows are not younger than Albian age and that the centre of volcanic activity must have been to the north of San Souci, although volcanic activities must have started earlier to judge from thin layers of tuff in the Toco Formation and perhaps already during the deposition of the Maracas Beds. The San Souci Volcanic Formation is possibly related to Smith's (1953, p. 58) *Tiara Volcanics* and to a part of Mencher's (1953, p. 13) *Arrayanes Formation.*

The rather condensed description of the Caribbean Series indicates a rough sequence of formations and their approximate thicknesses which is shown as follows:

San Souci Volcanic Formation	3000 meters
Toco Formation	2300 meters
Galera Formation	1600 meters
Cumana Formation	700 meters
Grande Riviere Formation	2500 meters
Rio Seco Formation	1000 meters
Laventille Limestone Formation	270 meters
Maraval Beds	2100 meters
Maracas Beds	3300 meters
Dragon Formation	2000 meters
Possible total	18770 meters

A total thickness of over 18 km of Mesozoic geosynclinal sediments is almost inconceivable and one can understand why Heim (1922, Part II, p. 579) refused to accept a thickness of 15 km for the Bündner Schiefer and explained it as being the result of a compound isoclinal system of recumbent folds. Amongst supporting evidence for this assumption Heim mentions repetition of petrographically similar zones and the occurrence of older rocks in zones or imbrics (Schürflinge). It should be amply clear that lithologic repetitions must be expected if the sediments deposited in the geosyncline cause subsidence at regular intervals. Many of the so-called imbrics (Schürflinge, Klippen und Schüblinge) may well be slipped masses only.

But even if we reduce the thickness of the Caribbean Series to one-third it would still give sufficient cause to wonder about the marine environment in which such a great thickness of sediments came to rest. There is, however, no indication in the Northern Range of Trinidad of the existence of a compound isoclinal system. Barr was well aware of the possibility of isoclinal folding. His map and sections show the normal folds which can be observed. He established the fact that the Barremian stage alone embraces a thickness of over 3000 m of sediments, a thickness unknown from any neritic development during this or any other stage. If such a thickness is possible for a single stage then there should be no hesitation in ascribing older or younger stages with similar thicknesses as long as the same type of sediments is involved. Thus a thickness of 18 km would not seem to be out of order even if one takes into account a lateral migration of the axis of the trough and thus a parallel shift of the maximal thickness of the ponded sediments.

In the Caribbean Coast Range, as in the Alps, there is clear evidence of signs of increased metamorphism with increased thickness or depth of burial, and both are apparently directly related to the distance of the geosynclinal axis from the outer rim of the neritic zone or from the rim of the Continental Shelf of any stage. Heim (1922, Part II, p. 580) pointed to the close relationship between the basement rock and the Grisons, and the same exists between the Caribbean Series and the Guayana basement. No great thickness of neritic sediments is, for example, present between the Grisons and the Central Massif of the Alps. The basal part of the Caribbean Series seemingly rests with the same facies on the basement rock as is suggested by the superposition of the Las Brisas conglomerate on the Sebastopol orthogneiss south of Caracas (Smith 1953). Sericitisation takes place in the way suggested by Heim (1922, p. 917) who considers load pressure and stress to be the cause of this low grade type of metamorphism. Bucher (1953) has recently discussed the environmental conditions of the Grisons and has given sound reasons for the almost total absence of mega- and especially micro-fossils. He refers to the recent discoveries of marine geologists and rightly stresses the importance of turbidity currents in the formation of great thicknesses of ponded sediments. Turbidity currents are undoubtedly also responsible for the great thickness of the Caribbean Series and sufficient field evidence is available to prove this to be the case at least wherever arenaceous members can be studied. The original sediments must have been essentially dark clays and silts alternating with calcareous silts and clays carrying a microfauna which today is completely destroyed because of the larger size of the newly formed minerals (Bucher 1952, p. 293). One would probably not be far wrong in assuming the unaltered sediments to have had the same aspect as the black Flysch of the Alps (Gignoux 1936). The calcareous and arenaceous Flysch would find their equivalents in the calc-phyllites and quartzites and it would only remain to determine the topographic position of these sediments in the basinal region. On this point we have very little evidence as yet. Supported by the available information it is reasonable to assume the environment to have been the Continental Slope formed by the sinking of the Basement. The coarse conglomerates could hardly have been deposited far below the shelf and the same holds good for the reefal limestones. The presence of the gypsiferous zone in the upper part of the Maraval Beds and the large block conglomerate of Patos (which in many respects reminds one of «Wildflysch») point to nearness of land. If, as should be, no age connotation is attached to the term «Flysch» then it appears that the Grisons are a Flysch and the suggested tectofacies term «Grison» for basinal clay sediments becomes reduntant.

STRATIGRAPHIC TABLE

EPOCH	BIOZONES	NORTHERN & CENTRAL RANGE	SOUTH TRINIDAD
Holocene		Terraces, Swamps and Mudvolcanoes	
Pleistocene	Rotalia rosea	Terraces, Naparima Peneplain	
Pliocene	Eponides repandus Uvigerina isidroensis	Matura Formation Talparo Formation	Morne l'Enfer F.
Miocene	Quinqueloc. fusca Reusella byramensis Textularia cf. pozoensis Globorotalia menardii Globigerina mayeri Globorotalia fohsi	Springvale-Melajo F. Brasso F. (upper Part) } Tamana F. } Brasso Form. Brasso F. (lower part) }	La Brea F. Forest F. Cruse F. Lengua F.
Oligocene	Globigerinatella insueta Globigerina dissimilis Globigerina cf. concinna	Nariva F.	Cipero F.
Eocene	Hantkenina alabamensis Globigerina cf. mexicana Hantkenina mexicana	San Fernando Formation Navet Formation	
Paleocene	Globorotalia velascoensis Globorotalia wilcoxensis	Pointe-à-Pierre F. Chaudiere F. Soldado F.	Lizard Springs F.
Upper Cretaceous	Various Globotruncana and Globigerina Zones	Point Bontour F. Naparima Hill F. Gautier F.	Guayuta Group
Lower Cretaceous	Typical arenaceous Foraminifera and Ammonites	Caribbean Series: Sans Souci F. Toco F. Galera F. Cumana F.	Maridale F. } Cuche F. } Sucre Group
Jurassic	Perisph. transitorius	Grande Riviere F. Rio Secco F. Laventille F. Maraval Beds Maracas Beds	
?		Dragon F.	

Lower Cretaceous Sucre Group of Central and South Trinidad

Hedberg (1950) divided the Cretaceous sediments of Eastern Venezuela into the older Sucre Group and younger Guayuta Group.

The lower part of the Cretaceous has already been discussed in connection with the Caribbean Series, and in order to follow the stratigraphic sequence it is desirable to start with the Toco Formation which is represented in the Central Range by the *Cuche Formation.* The oldest, identifiable part of the Cuche Formation is the *La Carriere Member* of Pointe-a-Pierre. It is closely related to Barr's Cumana Formation but contrary to the latter it is not a satiny calcareous sericitic phyllite but a dull grey calcareous, silty shale in which the writer found rare remains of ammonites identified by Dr. R. W. Imlay as belonging to the genera Ancyloceras, Melchiorites, Pulchellia and Karstenia. This fauna is also considered to be of Barremian age. Accompanying the ammonites are commonly found long, tape-like, pyritised ?algae and a relatively rich foraminiferal fauna which allows for wide range correlation. Included in highly contorted shales, which are seemingly in normal contact with the ammonite bearing ones, is the lenticular «*Remanié Bed*» of Lehner (1935). This bed furnished the first Lower Cretaceous fossils found by Wall and Sawkins in the Caribbean region.

Dr. L. R. Cox has recently finished his studies on a large collection forwarded by the writer to the British Museum and amongst the 20 recognisable forms he identified such thick shelled genera as Exogyra, Neithea, Lopha, Prohinnites, Spondylus, Gryphaea, Pterotrigonia and Harpagodes. A number of corals and Choffatella decipiens (det. P. Bronnimann) also indicate Barremian age though it must be admitted that a certain amount of reworking of the fossils took place. The somewhat heterogeneous character of the exposed beds is indicated by the fossils, washed out by wave action. A Middle Albian Hoplites and a block of micaceous sandstone with a Didymotis of probable Turonian age was found amongst the coast rubble. Along another part of the coast of Pointe-a-Pierre large blocks rich in a coral and caprinid fauna, are exposed. This fauna is considered representative of an Urgonian reef facies. Other blocks with Orbitolina may even be slightly younger. The reef limestones of Toco, like the reef limestones of Pointe-a-Pierre, are unmistakable signs of inner neritic conditions and for this reason the paper by Hedberg and Pyre (1944) is most informative on this subject. From it one will conclude a close relationship of the La Carriere member of the Cuche Formation with the highly fossiliferous neritic Barranquin Formation as exposed for example on Isla Caribe north of Barcelona in Venezuela where Amphitriscoelus forms a reef-like layer and Pterotrigonia is a common and superbly preserved fossil quite unlike the black silty and worn specimens of Pointe-a-Pierre. The occurrence of fossil plants (Weichselia) in the lower part of the Barranquin Formation, as well as the cross-bedded thick sandstone layers, suggests the nearness of the Guayana Shield from where all the detrital material was derived. Small plant remains are not uncommon amongst the coarse, gritty layers of the Cuche Formation in Trinidad and a peculiar type of red claystone conglomerate, with a coarse grit matrix, has been noticed in Barcelona (Venezuela), Central Range, and Toco, thus suggesting a similar environment during Upper Barremian time when coastal swamps and shallow sea with caprinid reefs fringed the nothern part of the Guayana Shield.

The Cuche Formation consisting mainly of shale with intercalations of hard, arkosic quartzites in its upper part, carries increasingly more yellow weathering calcareous mudstone with belemnites of Aptian age and a foraminiferal fauna of

Aptian-Albian aspect. These calcareous mudstones and accompanying marls have been included in the *Maridale Formation.* The total thickness of the Cuche-Maridale Formations is not known nor is the contact with the younger Gautier Formation. To judge from observations made in Eastern Venezuela it must be greater than 1600 m, a thickness reached by the Barranquin Formation in the Aragua de Maturin area from where no Aptian belemnite-bearing shales are known.

The Albian of Trinidad is only known from a few remnant fossils and for this reason one has to return to Eastern Venezuela for additional information. Here one finds the *El Cantil* and the next younger *Chimana Formation* normally resting on Barranquin Beds. Their lithology and fossil content indicate marine neritic conditions and inasmuch as their age is considered to be Aptian to Lower Albian they agree with the remnant blocks of the Central Range in Trinidad. No Upper Albian sediments have as yet been reported from this part of the Caribbean region. It may well be that a stratigraphic gap or a very thin layer of neritic sediments characterise the end of the Lower Cretaceous. The occurrence of glauconite on top of the Chimana Formation, as mentioned by Hedberg (1950, p. 1190), would support the assumption of a stratigraphic gap of non-deposition.

Upper Cretaceous Guayuta Group

There is a profound difference between the character of the Lower Cretaceous Sucre Group and the Guayuta Group of sediments with its dominantly thin-bedded, almost laminated black pyritic bituminous shales with discoidal and flaggy limestones belonging to an almost euxinic environment. Hedberg (1950, p. 1190) assigns a thickness of 1000 to 1300 m to these uniformly developed sediments starting with the *Querecual Formation.* The lower part of this formation is represented in Trinidad by the *Gautier Formation* which is poorly exposed but has been studied in detail in several bore holes. Remnant blocks had already provided Turonian and Coniacian fossils, and more information has since been obtained from the study of the Globotruncanae and Globigerinidae by Bolli (1951a) and Bronnimann (1952c) who were able to subdivide these laminated, pyritic, black bituminous shales into biozones belonging to the Cenomanian, Turonian and perhaps Coniacian stages. Based on his study of the Globigerinidae, Bronnimann (1952c) suggests a disconformity between the Cenomanian and Turonian. The Gautier Formation is at least 200 m thick but as already mentioned the base of it is not yet known.

The *Naparima Hill Formation* is the best known part of the Upper Cretaceous of Trinidad on account of the excellent exposures in the quarries at San Fernando where it forms the prominent Naparima Hill. This formation is included in Hedberg's *San Antonio Formation* and together with the Querecual Formation represent the most prominent key-formation of the Southern Caribbean region. In Barbados the Naparima Hill Formation is present as blocks in the Eocene Joe's River mudflow. The equivalent San Antonio Formation is found as *Tachira Chert* and *Colon Shale* in Western Venezuela and as the *Guadalupe Formation* in Colombia. The Naparima Hill Formation is a well-bedded flaky weathering siltstone with calcareous streaks. It is dark and bituminous when fresh and weathers to light yellow tinges. The more siliceous part of this formation in the Central Range is mostly blotchy and contains nodules and layers of chert, hence it was called Chert Hill Formation. The average thickness of the Naparima Hill Formation is about 300 m of which the major part belongs to the Globotruncana lapparenti zone of typical Senonian age. The top part of the Naparima

Hill Formation reaches, however, into the Maestrichtian which is considered by Bolli (1951a) to be defined by several typical Globotruncana species. This Maestrichtian part of the Naparima Hill Formation is more calcareous, better bedded and less indurated than the «Argiline» which it appears to overlie unconformably. The term «Argiline» was formerly used for these calcareous siltstones. Like the Gautier Formation, it must have been deposited in a very quiet, deep and widespread basin with euxinic bottom conditions at certain stages to judge from the bituminous character and common content of pyrite and marcasite. The sea was deeper than that of the Cuche Formation and larger fossils have rarely been found in the Naparima Hill Formation though occasional thin layers of fine quartzose sand that may have been carried by turbidity currents, do occur. Indications of intraformational slumping are to be seen in the quarries of San Fernando and these may be due to ponding of unstable masses of sediments or action of deeper sea currents.

These quiet sedimentary conditions must have changed at the end of Maestrichtian time. Although there are no normal exposures known or sections met in a bore hole in Trinidad, sufficient information is available from remnant blocks to indicate a shallowing of the sea and an increase in coarser clastic sediments. Whether this change is due to epeirogenic movements, or to the start of the Laramide phase of orogeny, cannot be decided. A block of glauconite sand full of teeth of Selachii was identified by Leriche (1938) as being representative of the Belgian Maestrichtian. Waring (1926, p. 97) mentions a fauna found by the writer in large, loose blocks of grey glauconite sandstone occurring in Oligocene clays at Point Bontour. This *Point Bontour Formation* of Harris contains Roudairia auressensis var. bontourensis, Ostrea tripolitana, and Psilomya typical for Maestrichtian age in Africa. A subsequent find of Hamulus onyx and a Sphenodiscus (Rutsch 1939) supports the earlier discoveries. The nature of the fine-grained, greywacke sandstone with large shells, such as Ostrea, certainly points to neritic conditions at the end of Cretaceous time at least in parts of Trinidad and it is, therefore, only reasonable to assume that such neritic conditions may also have existed at the beginning of Paleocene time. The writer is of the opinion that the Soldado Formation, with its many affinities to Danian, most likely belongs to this cycle of neritic deposits.

Paleocene

Nowhere in Trinidad does one find the *Soldado Formation* in a normal section and hence it is advisable to look to Venezuela for enlightenment. There the *Rio Guasare Limestone* of the Maracaibo Basin was always considered to be a homologous development of the Soldado limestone. Liddle (1946, p. 274) states: «Sediments which Hedberg includes in his Rio de Oro formation, along the Sierra de Perija, are actually parts of two formations, the lower portion (Maestrichtian Cretaceous) is part of the *Mito Juan Formation,* and the upper portion (Midwayan Eocene) is part of the Rio Guasare formation.» In the opinion of Gonzales de Juana (1951, p. 212) the Paleocene is resting without break on the Uppermost Cretaceous. The first Paleocene formation he mentions is the Guasare Formation without offering a clear definition of the beds immediately below the Guasare Formation, except that it rests concordantly on the La Paz clay. The geologists of the Staff of the Caribbean Petr. Co. (1948, p. 599) place the *Guasare Formation* temporarily into the Cretaceous probably on account of the foraminiferal fauna of the La Paz shales, but here again there is no statement regarding the stratigraphic position of the Rio Guasare Limestone sensu stricto. Van Raadshoven (1951) reviewed and described some larger foraminifera from the Upper Misoa River which he compares with those of Beds 3 and 4 of Kugler (1938a) from Soldado Rock. Van Raadshoven assigns the beds containing this fauna to the «Guasare formation» but this extension of the term Guasare is not permissible since it was restricted by Liddle (1946, p. 301) to the more or less 100 m thick limestone of the Guasare River. This limestone is a glauconitic coquina with a Midwayan fauna which is alien to the orbitoids described by Van Raadshoven.

The type locality of the Soldado Formation is the Soldado Rock (Kugler 1938a). The stratigraphic position of the Soldado Formation is one of the major unsolved problems of the stratigraphy of Trinidad and the writer is partly responsible for this ambiguity by the unfortunate inclusion of *Bed No. 3* into his Soldado Formation. Beds No. 1 and 2 represented the original Soldado Formation of Maury and we must revert to this original definition. These two lower beds consist of the well known glauconitic coquina of comminuted shells and attain a combined thickness of 22 m. The slip-mass of Soldado Formation of the Marac Quarry completely agrees in lithology with that of Soldado Rock and although its richness in nautiloids is only faintly repeated at Soldado Rock, there is no doubt about the identity of the rich molluscan fauna. In the midst of the glauconitic limestone of Marac we have succeeded in finding a lens of a glauconitic marl with an assemblage of small arenaceous foraminifera which turned out to be different from any other fauna known from Trinidad. This completely excludes Bed 3 from the Soldado Formation, which in its original definition represents the Midway stage of the Gulf Coast. Bed 3 is 70 cm thick and contains in its lower part a fine-grained, well-bedded, brown sand and silt with some quartz pebbles of the size of a cherry stone and thus suggests a stratigraphic break. This break is indicated by a fauna of small foraminifera reminiscent of the Paleocene to which we shall return when dealing with the Eocene.

At the San Fernando type section of the Naparima Hill Formation of Senonian age a conglomerate is found to be resting on top of this formation. This conglomerate is called «*St. Joseph Boulder Bed*» (Bolli 1952, p. 671) and separates the Naparima Hill Formation from the Paleocene *Chaudiere Formation* with its typical rich arenaceous foraminiferal fauna of which Rzehakina epigona and Rzehakina epigona var. lata are key forms. The main development of the Chaudiere Formation is in the Central Range where it can attain a thickness of about 800 m. It consists mainly of greenish grey shale barren of any larger fossils but with occasional layers of sandstone and grit, especially in its upper part. Any geologist familiar with Alpine Tertiary would call the Chaudiere Formation a Flysch of a facies closely related to the calcareous type. He would, therefore, not be surprised to find that the Chaudiere Formation interdigitates with calcareous shales of increasingly thicker development as one goes southward from the Central Range. These calcareous shales and marls constitute the well known *Lizard Springs Formation* with the rich foraminiferal fauna described by Cushman, Jarvis, Renz, and Bronnimann.

We have no knowledge as to the relationship between the Chaudiere-Lizard Springs Formations and the Soldado Formation but the writer assumes their superposition on the Soldado Formation because Bed 3 of Soldado Rock contains a high percentage of Lizard Springs smaller foraminifera of an aspect that suggests reworking.

Attention has already been drawn to the possibility of orogenic movement at the end of Cretaceous time but it is only during the deposition of the Chaudiere Formation that unmistakable evidence is supplied in the existence of the St. Joseph conglomerate at San Fernando and the Ganteaume, and possibly other block conglomerates in the Central Range. A most important discovery was made by Dr. K. Rohr during extensive excavations at Pointe-a-Pierre. He found a large rounded block of about 1 m diameter of higly fossiliferous Gautier Formation in the midst of a large mass of greenish Chaudiere shale that had slipped into Oligocene Nariva Beds. The block of Gautier Formation is covered with about 5 cm of cone-in-cone calcite as a result of interaction between the two rock types. A few meters from the Gautier block is a large block of over 10 cubic meter of Naparima Hill Formation of which more than three-quarters are embedded in the Chaudiere shale whereas the rest is in contact with the Oligocene Nariva Formation. This important proof of the existence of a kind of «Wildflysch» led to the investigation of the nature of the Lower Cretaceous Cuche outcrops at Pointe-a-Pierre which formerly were considered to be associated with intensive thrusting, culminating in the formation of imbrics thrust one on top the other. It was found that some of the masses of Cuche shale, previously thought to represent a solid unit, carried intercalations of Chaudiere shale to such an extent as to necessitate the assumption of a mass of Chaudiere shale full of reworked Lower Cretaceous. The slump masses of Cuche shale of the Pointe-a-Pierre railway cut are mixed with some Aptian belemnites and lenses of Upper Cretaceous foraminiferal marl with Chaudiere shale on either side of this rubble mass. Such an interpretation of the geologic conditions also fits the occurrence of heterogeneous Lower Cretaceous rock types along the Pointe-a-Pierre coast where Chaudiere shale exists above and below the Cretaceous submarine slump masses representing Barremian, Aptian, Albian and ?Turonian stages inside a coaststrip of 50 m. Some of the slumped components are several hundred meters long and thus can be considered to be a «Wildflysch» of Paleocene age.

If we suggest «Wildflysch» for the almost chaotic conditions in parts of the south foot of the Central Range, tectonic conditions can be explained in a more reasonable manner.

In Eastern Venezuela the Chaudiere-Lizard Springs Formation seems to form a part of Hedberg's (1950, p. 1193) *Santa Anita Group* of «several thousand feet of quartzitic sandstones, dolomitic and calcareous sandstones and siltstones, grey shales, and glauconitic rocks forming a more or less continuous series of outcrops along the southern border of the Serrania del Interior of Eastern Venezuela from Puerto La Cruz on the west to Rio Guayuta near Aragua de Maturin on the east.» This group starts at the type section with about 100 m of *San Juan Sandstone* overlain by 300 m of *Vidoño Shale.* The sandstone grades westward into Vidoño shale and eastward into the «*Aragua Sandstone*» of more than 300 m thickness. The Aragua sandstone grades downward into the cherty beds and thin sandstones of the Upper Cretaceous Guayuta Group. At the Querecual type section the contact between the San Juan Sandstone and the underlying Guayuta Group is abrupt but despite this it is Hedberg's opinion that the sandstone is Cretaceous because of the Upper Cretaceous age of the foraminiferal fauna of the Vidoño Shale. There is, however, sound evidence for a correlation of the Vidoño Shale with the Chaudiere-Lizard Springs Formations of Trinidad, but until further information is forthcoming this controversial subject can be shelved, for there is still a possibility of the Vidoño Shale being representative of the uppermost part of the Maestrichtian. Such is possible if the San Juan-Aragua Sandstone is homologous with the neritic

Maestrichtian Roudairia and Hamulus sandstones of Trinidad. Of particular interest is the great thickness of the Aragua Sandstone which must have been deposited in a relatively shallow sea thus temporarily ending the geosynclinal infill in Upper Cretaceous time and at the same time introducing the more frequent orogenic movements.

The *Pointe-a-Pierre Formation* of Trinidad is perhaps related to the Aragua sandstone and is at least 200 m thick. It is, in parts, a sequence of excellently graded, well-bedded, cubical fracturing, quartzitic sandstone interbedded with thinner layers of fine-bedded silt, often containing very fine laminae of carbonaceous matter. The underside of some of the sandstone beds shows typical flow casts such as depicted by Rich (1950) on figures 6 and 8 and the sandstone itself also shows interstratal flowage (Rich 1951, pl. 3, fig. 1). The first few centimeters of silty clay below the sandstone generally contain a distinct arenaceous foraminiferal fauna; otherwise larger fossils are missing excepting a peculiar track once called «Bullia» or «Bilobites» and also some tracks of worms and Helminthoides. Some layers of up to 5 m thickness of coarse grit, or fine conglomerate, contain poorly sorted, flat but rolled blocks of silty shale of up to 10 cm diameter. These layers together with graded bedding, are typical for sediments deposited under turbidity flow conditions and represent the normal sequence following the «Wildflysch» deposits of the Chaudiere shales. At the type locality of the Chaudiere Formation one observes a complete gradation from this formation into the superimposed Pointe-a-Pierre Formation and this observation has been confirmed at Pointe-a-Pierre. The foraminiferal arenaceous fauna of the Pointe-a-Pierre Formation is indicative of a Paleocene — Lower Eocene age. The top of the formation is not yet known.

The *Caratas Formation* of Eastern Venezuela which in the Rio Querecual type section follows above the Vidoño shale, consists of 330 m of blue grey, hard calcareous and dolomitic siltstones and impure silty, and commonly dolomitic, limestone (Hedberg 1950, p. 1194). According to Hedberg the «shaly portions of the Caratas Formation carry a meager fauna of small foraminifera of which most of the species are also present in the underlying Vidoño shale.» It is, therefore, quite possible that this lower part of the Caratas Formation is actually homologous with the Chaudiere Formation and this would not be contradictory to the existence of a Discocyclina and Miscellanea bearing horizon in a glauconitic grit near the top of the formation. Unfortunately the stratigraphic relationship of the limestone of Cerro Corazon with its planicostate Venericardia is not sufficiently known to form an idea as to the age of the beds below it.

The Morros and Wildflysch

Hedberg (1950) in studying the nature of the western extension of the Santa Anita Group, came across the same perplexing problem which is still an enigma to geologists. We refer to the «morros» found all along the southern part of the Serrania del Interior from the western boundary of the State of Anzoategui to San Juan de los Morros. These castellate limestone masses with their bold, ragged silhouettes stand in a softly sculptered landscape which in its general aspect is reminiscent of the Alpine Flysch. Already Karsten has found Lower Cretaceous fossils in some of these limestones but most of them are white, barren rocks that seemingly defy indentification of their age as is possibly also the case at the type locality for these «morros» viz. *San Juan de los Morros.* Here the writer found exceedingly rare fossil remains in the dense massive limestone of La Puerta. This limestone reminded him of the limestone of Laventille in Trinidad. The finding of «Hippurites» by Karsten (Bucher 1952, p. 54) in the reef limestone certainly does not agree with the Paleocene, and most likely Wilcoxian age, of the orbitoidal fauna described by Caudri (1944). It is difficult to conceive how some of the other «morros» should occur in such isolated positions in the midst of Guayuta, Vidoño or even younger shales. It is almost impossible to visualize them piercing vertically through some black shale, considered to be Guayuta shales, as suggested by Liddle (1946, p. 344) for the morros north of Alta Gracia de Orituco. This is especially so as the Eocene Guarumen group extends almost to this limestone and thus might suggest a different solution to the riddle. The writer is not convinced of the correctness of Liddle's (1946, p. 277) section through San Juan de los Morros. The section of Aguerrevere (Caudri 1944, p. 26) is a more likely interpretation of observed facts. His section does not suggest a sharp syncline as shown by Liddle, an interpretation hardly conceivable in view of the massive character of the «Morros limestone». Aguerrevere's section allows for the possibility of a large mass of massive limestone having slumped into the now metamorphic green schists of Cretaceous age. The limestone was subsequently surrounded by Lower Eocene neritic deposits. Bucher (1952, p. 54) could not see a clear relation between the Paleocene limestones described by Caudri and the main body of the Morros and suggests that «they may be an integral part of it, grading down into the main mass of reef limestone imperceptibly, or they may be a part of a transgressing series».

As already pointed out, large masses of Cretaceous rocks have slipped and slumped into the Paleocene Chaudiere shale in Trinidad and it could be expected that something similar happened also in Eastern Venezuela wherever an isolated mass of Lower Cretaceous limestone is found surrounded by younger shales. The peculiar way in which such limestones may slip is suggested for example by Patos Island. The limestone of this island is completely penetrated by caves. Like Gaspar Grande Island it stands in the sea like a sponge. At Gaspar Grande the sea level can be reached from above through the limestone. Almost in the centre of the island one finds marine fishes darting about in the dark water of the caves. It needs little submarine erosion through the Bocas to cause large masses of Patos to slump down onto the cleanly swept phyllites of the channel wall or deeper into the mud of the channel bottom. This process has already started to judge from the large blocks of limestone at the fringe of Patos Island.

«Marac» is a Trinidadian local name for «morro» and it is interesting that this isolated mass of Soldado Formation of about 200 m length, 100 m width, and 20 m height should be «swimming» in Oligo-Miocene clay and form a conspicuous hill in the clay landscape. Other «morros» in South Trinidad, which, like that of Marac, are generally quarried because they offer the only road material in a wide area, are: 1) Morne Roche of Upper Eocene age, 2) Morne Diablo of Upper Oligocene age, and 3) Whitestone Hill of the Upper Cretaceous Naparima Formation. These «morros» are rootless masses in Oligocene and Lower Miocene clays, whereas the mass of Soldado Formation at Soldado Rock is a huge block mixed with Wilcoxian rubble in Upper Eocene silt.

The «morros» of Trinidad are large blocks, and as such belong to the «Wildflysch» known for a long time from the Alps (Heim 1922, p. 349) and recently again studied in greater details in the Habkern valley (Gigon 1952). Contrary to the former assumptions of essentially tectonic origin of the larger components termed «Klippen» and «Schürflinge» one realises increasingly the purely sedimentary origin of their emplacement. Unfortunately the term «Wildflysch» has been used with a connotation of time and Leupold (1942, p. 250) is completely right in condemning such usage. However freed from such an attribute, and only used to describe huge submarine slump masses, it still serves its purpose as will be seen later on.

Rock masses of Wildflysch aspect are known from many parts of the world. Block and boulder clay were described from Peru and Ecuador (Baldry and Brown 1938). Doreen (1951) again described these from Peru and showed to what extent turbidity currents and subaqueous mudflows were responsible for the formation of rubble bedding following subaqueous tectonic movements. The sands and shales of the Talara Formation are considered to be the normal sequel to rubble-bedded deposits.

The submarine slip-masses of Cambrian and Ordovician rocks between Gaspé and Quebec City are already well known (Bailey et al, 1928). Of particular interest are conditions described by King (1951, p. 148) from Ouachita Mountains where the Mississippian Stanley and Jackfork Formations from a mass of clastic rocks of almost 6000 m thickness. These rocks are a monotonous sequence of shales and sandstones lacking in fossils. The early Pennsylvanian John's Valley Shale contains remarkable boulder beds of transported fragments up to several hundred feet long of older Paleozoic rocks. A similar boulder bed occurs in the Haymond Formation of the Marathon uplift. The boulders are presumed to have originated from submarine landslips or density currents. Large boulders of Devonian novaculite and Pennsylvanian limestone up to 100 feet diameter are lying between thin bedded sandstone and shale below and conglomeratic arkose above.

A particular kind of large scale slumping and submarine sliding is known from Daghestan on the Caspian Sea (Kugler 1939). Well-bedded Senonian marly shales and argillaceous limestone together with Paleocene beds slipped into Upper Eocene argillaceous Lyrolepis marl. Subsequently masses of Lyrolepis marl of several kilometers in length and several hundred meters in thickness slipped and are found today completely enveloped in sandy clays of Oligocene age.

Summarising one could state: the «morros» are part of the Wildflysch and as such they represent huge masses of rock resistent to weathering and are of older age than the surrounding formation.

Eocene

The oldest Eocene rocks known in Trinidad are the «*Pellatispirella* and *Discocyclina limestones*» of Beds 3 and 4 on Soldado Rock. Reasons have already been given for a separation of Bed 3 from the Midwayan Soldado Formation. Vaughan and Cole (1941) who described the Miscellanea (formerly Pellatispirella) and Discocyclina fauna came to the conclusion that this fauna is to be correlated with that of the upper part of the Nanafalia Formation of the Wilcox group. According to U. S. Geol. Survey the Wilcox belongs to the base of the Eocene but according to European usage it is still attributed to the Paleocene which comprises Montian, Thanetian and Sparnacian of which the latter is correlated with the Nanafalia Formation. Cushman and Renz (1942) described the smaller foraminifera of Bed 3 and considered them to be closely related to Midwayan faunas of Alabama and Texas. The fauna is also related to the Wilcox Eocene, especially to that of the Salt Mountain Formation of Alabama and the fauna from Ozark, Alabama. Referring to this fauna and comparing it with that of the Lizard Springs Cushman and Renz (1946) later on placed the fauna of Bed 3 above the upper zone of the

Lizard Springs Formation or at the base of the Navet Formation but still considering Bed 3 to be Midwayan Soldado Formation. The foraminiferal fauna of Bed 3 of Soldado Rock has a Midwayan aspect but in the writer's opinion must be considered as reworked.

It is still hoped that a better and more normal section of the Wilcox Beds of Trinidad will be found, otherwise it may be necessary to introduce a term such as «*Serpent Formation*» for Bed 3 or adopt a well defined stratigraphic term from Venezuela, but certainly not Guasare Formation. On the other side one may look to Barbados where the Miscellanea limestone block of the Joe's River mudflow may ultimately be found to form a part of the Lower Scotland Formation. Caudri (1948, p. 471) lists a fauna of larger foraminifera from the Lower Scotland Formation which she considers to be of Lower Eocene age but which is similar to that of the Upper Scotland Formation.

The cycle of depositions which started in Lower Eocene time seem to have developed in Trinidad in two different facies, one is the open sea *Navet facies,* and the other the neritic and marine slope facies, which we call the *Scotland facies* for want of a local term.

The *Navet Formation* attains a thickness of 400 m and is normally superimposed on the Upper Chaudiere-Lizard Springs Formation and as such can only be separated from the latter on paleontologic grounds. Lithologically there is hardly any difference, at least when it is compared with the more calcareous Lizard Springs Formation. The Navet Formation is made up of light grey and greenish-grey marls and marly clays which are very rich in Globigerinidae and occasionally Radiolaria. Cushman and Renz (1948) tentatively established a stratigraphic sequence consisting of 4 zones. According to Dr. H. Bolli (oral communication) 8 clearly defined biozones are now recognisable. These biozones include the Wilcoxian, Claibornian and the lower part of the Jacksonian. The Dunmore Hill member is interesting because of the occurrence of orbitoids which seem to indicate an age slightly younger than Beds 3 and 4 of Soldado Rock but perhaps still Lower Eocene (Caudri 1948, p. 479).

Along the southern foot of the Central Range one observes imbrics of silty and sandy beds with a typical form of Gaudryina. These beds seem to bear some relationship to the Pointe-a-Pierre Formation, although no proof is as yet available. A correlation of the Pointe-a-Pierre Beds with the Lower Scotland Formation of Barbados has always been seriously considered. In bore holes near Biche (NE end of the Central Range) a fauna of larger foraminifera was found which Caudri (1948, p. 479) placed between the Wilcoxian fauna of Bed 3 of Soldado Rock and the Middle Eocene (Claibornian) fauna of Vaughan from the Upper Scotland Formation of Barbados. The occurrence of Helicolepidina cf. spiralis in the fauna of Biche is not indicative of Upper Eocene as was formerly assumed. Van Raadshoven (1951) has clearly shown its Middle Eocene age. A typical form of the Middle Eocene fauna of Barbados is Tremastegina senni (Bronnimann (1950). This was also found in one of the bore holes in Biche as well as in the Charuma area and other places in the Central Range. The above are the only Middle Eocene faunas known in Trinidad from the Scotland facies of the Eocene.

The Scotland Formation of Barbados is at least 1600 m thick according to Senn (1940). It is probably very much thicker because the Miscellanea fauna known from the Joe's River mudflow blocks is nowhere exposed and certainly belongs to the Scotland Formation to judge from conditions in Trinidad.

The Scotland Formation, including the Pointe-a-Pierre Formation of Trinidad, is a typical Flysch deposit of great similarity to parts of the Niesenflysch of the Alps. The Scotland and Pointe-a-Pierre Formations have also great similarity to the Misoa-Trujillo Formation of the Maracaibo region and Falcon. As far as Trinidad is concerned this essentially arenaceous Flysch was probably deposited along the southern slope of the rising Caribbean Range of which the Northern Range was the final offspring. This rising was foreshadowed by the Wildflysch in the Chaudiere Formation with the blocks of Cretaceous that once covered the emerging range that must have extended far to the east to judge from the present trunk of the Guayana Shield. To the south of the belt of sands and silts the foredeep was filled with the essentially calcareous Flysch of the Lizard Springs and Navet Formations. The southward migration of the foredeep started at the end of the Cretaceous and, as will be seen later on, followed roughly along the lines shown by Hedberg (1950, p. 1177) in his sketch of the hypothetical position of the axis of deposition at various stages in the development of the Eastern Venezuelan geosyncline.

The first, almost paroxysmal, widespread and clearly defined orogenic movement took place in Upper Jacksonian time and its effect is exposed in the sections of San Fernando in Trinidad. After the deposition of the highly foraminiferal *Hospital Hill Marl* of the Lower Jacksonian part of the Navet Formation, a series of glauconitic sands together with a coarse block conglomerate containing dominantly Senonian, but also Maestrichtian and Midwayan components, forms the lower part of the *San Fernando Formation*. The conglomerate is a near-shore deposit and is followed by impure sands, silts, lenses of glauconite and calcareous foraminiferal clay with bioherms of orbitoidal limestone containing a rich fauna described by Guppy, Jeannet, Schilder, and Vaughan and Cole who identified it as being typical Jacksonian. This rapid change from an open sea facies (Hospital Hill Marl) to a neritic near-shore facies within the same stage is very significant for the duration of an orogenic phase of the Caribbean region and is reminiscent of a similar rapid change observed in the Oligocene of Falcon. The rubble masses of the Soldado Formation and of the Lower Eocene Pellatispirella and Discocyclina limestones in silt of the San Fernando Formation have already been mentioned from Soldado Rock. At Point Bontour one observes similar conditions in the same silt, and blocks of Discocyclina limestone were at one time considered to be an integral part of this silt.

Lenses of sand and calcareous sandstone with fish remains form a part of the San Fernando Formation of about 300 m thickness. These sands appear to increase in a northerly direction. At Morne Roche, one of the «morros» in Oligocene clay, the sands have changed to a coarse, calcareous grit with a rich fauna of Tubulostium, Orbitoids, Echinoids and Oysters. Upwards these grits grade into a typical Lithothamnia reef limestone full of Orbitoids and finally into a glauconite rock. The clean quartz grit received its components from the Pointe-a-Pierre grit which must have been exposed to the north, because at Pointe-a-Pierre (Plaisance) one finds a block conglomerate composed of every type of older rock but with Upper Eocene foraminifera in the clay matrix. A bit farther north (Hermitage) large, partly rounded blocks of Cretaceous and Paleocene are cemented together with coarse grit forming a deposit which shows every sign of a shoreline condition. The Central Range had certainly emerged in Jacksonian time and was fringed to the south with Lithothamnia-Orbitoid reefs to be found occasionally as remnants in rubble masses of younger beds.

The Upper Jacksonian unconformity is known throughout the southern part of the Caribbean region. The description given by Hedberg (1950, p. 1196) of the *Tinajitas Formation* of about 200 m thickness fits in every respect.

Oligocene

The Oligocene epoch coincides fairly closely with the deposition of the *Cipero Formation* as defined by Stainforth (1948) in his important study. He subdivides the formation from bottom to top into the following biozones: 1. *Globigerina* cf. *concinna,* 2. *Globigerinatella insueta* and 3. *Globorotalia fohsi.* This tripartite division is considered to agree roughly with the Lower, Middle, and Upper Oligocene but at the same time it is fully realised that not enough is known of the Oligocene of the Caribbean region for it to be more than an approximation. Lateron Bolli (1951b) established the *Globigerina dissimilis* zone between the concinna and insueta zones and divides the Globorotalia fohsi zone into 4 subzones. Tertiary stratigraphy, hence its terminology, is established on molluscan faunas and these are relatively rare or non-diagnostic as far as Trinidad is concerned. On the other hand the study of the foraminiferas (especially the planktonic ones) at the classic localities of the Tertiary, has not advanced sufficiently to make possible such correlation with the better known foraminiferal biozones of the Caribbean region. It is for example most likely that a part or the whole of the Globorotalia fohsi zone may finally have to be attributed to the Lower Miocene.

According to Stainforth the thickness of the Cipero Formation at the type section is about 700 m. The section is disturbed and incomplete, however, as is indicated by thicknesses of between 1500 m and 2700 m in other parts of South Trinidad. A band of Upper Eocene marl of a few meters thickness occurring in the midst of the Cipero section is explained by Stainforth as being due to thrusting (p. 1289). This Eocene marl is in contact with his «Flat Rock tongue». The latter has a neritic aspect with an orbitoidal and molluscan fauna and is known to occur at the base of the Cipero Formation. It is most likely that these two types of sediments occurring as they do in an abnormal environment are simply slip-masses. Such conditions are common to the south of the San Fernando uplift where even the type locality for the Hospital Hill Marl was found to be a slumped mass completely inside Oligocene clay.

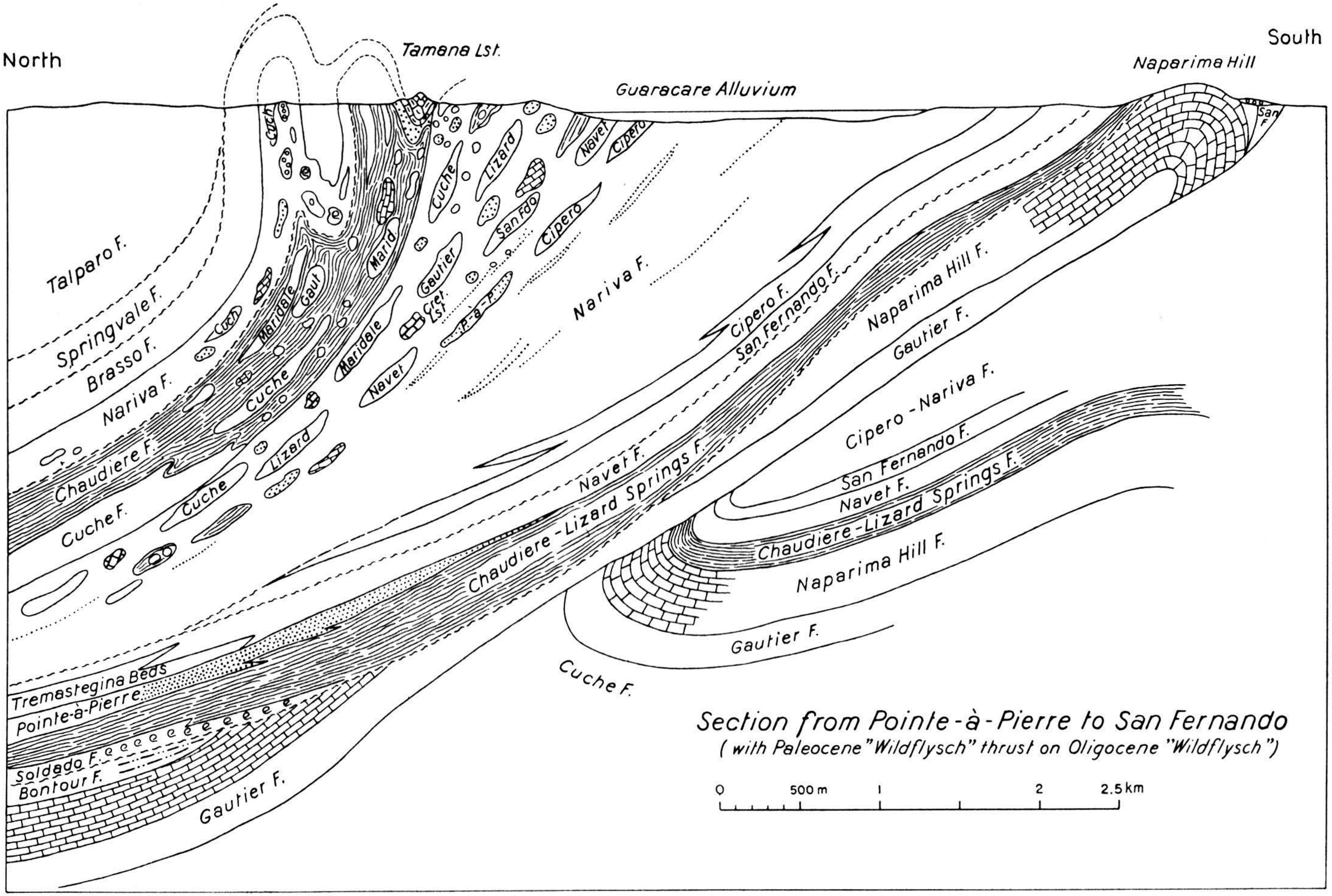
The Cipero Formation represents a group of alternating clays, rendered calcareous on account of the mass of foraminifera, and massive to bedded Globigerina marls, which often resemble soft chalk. The similarity of some of these more indurated marls to some of the Navet Formation misled geologists into correlating them in the early days when the stratigraphy based on foraminifera was not yet established.

Stainforth considers these sediments, including the Radiolaria bearing Retrench marls, to be indicative of a sedimentary environment of 400—500 m depth, which is rather on the shallow side when compared with the excellent graph of distribution of some recent foraminifera from the Mississippi Delta region by Lowman (1949, fig. 13). However, we do not know the recent conditions of foraminiferal distribution in this part of the Caribbean region and, therefore, cannot finally settle the point.

Starting with these basinal deposits of the true Cipero Formation, Stainforth shows how the facies of part of this formation changes on approach to the Central Range where the *Nariva Formation* gradually replaces it. Tongues of the Cipero Formation reach far north into the foothills of the Central Range, whereas tongues of the Nariva Formation are found even in the Southern Range. No typical Nariva Formation is known outside the Globigerina dissimilis zone. The Nariva Formation of up to 2000 m thickness or more is barren of any larger fossils but contains an arenaceous foraminiferal fauna indicative of a turbid water environment (Stainforth 1948, p. 1317). Lehner (1935) was one of the early geologists who drew attention to the piedmont character of the Nariva Formation and in private reports mentioned the «gritty clays» as being characteristic of it. The lower part of the Nariva Formation is essentially a monotonous series of red weathering clay with occasional lenses of clean, saccharoidal sand and frequent mudstones. Some of the mudstone lenses are characterised by their «cone-in-cone» calcite coating mixed with gypsum. This might indicate a possible migration of carbonates which once constituted the tests of calcareous foraminifera. The upper part of the Nariva Formation is mainly silt and sand with occasional plant leaves and thin layers of lignite.

At Pointe-a-Pierre where the Nariva facies is frequently found alternating with the Cipero facies of *Globigerina dissimilis zone* age, one observes a most extraordinary type of «Wildflysch». Every formation known from the Central Range, together with some remnant blocks of unexposed formations, occurs in large block and slip-masses in the upper part of the Nariva clay and just below the unconformably overlapping reef limestone of the Miocene Tamana Formation. The rubble mass consists mainly of more or less pebbly clay of Pointe-a-Pierre and Chaudiere type with angular blocks of older rocks amongst which the Pointe-a-Pierre grits dominate. Some of the blocks show striae and the aspect of the rubble mass is not unlike that of a tillite. Only occasionally does one find a foraminiferal marker indicative of Nariva age, such is the predominance of the derived material. Amongst the slumped masses we mention only the most prominent. The «Stack Rock» of Pointe-a-Pierre with its Urgonian caprinid and coral fauna is oriented at a right angle to the general strike. A slip-mass of greenish Chaudiere shale of about 25 $\times$ 15 m is completely surrounded by red weathering Nariva clays and contains the blocks of Turonian limestone and Naparima Hill Formation, previously mentioned as one of the proofs of the existence of Wildflysch conditions in Chaudiere time. Lower Cretaceous La Carriere shale is represented by a mass of 45 $\times$ 120 m; Lower Cretaceous Bon Accord marl 60 $\times$ 15 m; Naparima Hill argillite 12 $\times$ 30 m; Paleocene Lizard Springs marl 120 $\times$ 600 m; Middle Eocene Navet marl 30 $\times$ 100 m; Pointe-a-Pierre grit 150 $\times$ 900 m; Upper Eocene calcareous sandstone with its own rubble mass of Navet and Naparima Hill Formations 15 $\times$ 180 m; Globigerina cf. concinna clay of the Cipero Formation 6 $\times$60 m. The soft clay and marl slip-masses are generally surrounded by a halo of reworked material which gradually merges into the Nariva clay in a distance of a few meters. From a study of the regional arrangement of these slip-masses one gets the general impression that the youngest components occur in the older part of the Nariva clay, and that on approaching the capping Miocene limestone, Lower Cretaceous blocks are more prevalent. At the base of the Miocene transgression one finds fossiliferous Brasso silt of about 10 m thickness below the actual Tamana reef limestone. Blocks of Turonian and Cuche shale with Aptian belemnites are mixed with Miocene Brasso silt which starts with a layer of calcareous silt rich in foraminifera amongst which Operculinoides tuxpanensis is prevalent. The occurence of slip- masses of younger age in older Nariva clay and vice versa may be connected with a rising hinterland, or an advancing thrust mass such as the core of the Central Range, which would firstly shed its youngest capping rocks and subsequently older ones.

The effect of such movements in the Central Range and Northern Range is also noticeable along other mobile belts in the southern part of Trinidad. Submarine ridges were raised into the zone of wave action. Large orbitoids such as Lepidocyclina undosa, gigas and favosa flourished together with echinoids, corals, and



Section from Pointe-à-Pierre to San Fernando
(with Paleocene "Wildflysch" thrust on Oligocene "Wildflysch")

molluscs in Lithothamnia reefs. These limestones of Middle Oligocene age are well known throughout the Caribbean region. In Falcon they form the mountain range of San Luis where they were observed to be unconformably resting on previously folded silt and muddy limestone containing almost the same fauna, a fact already mentioned when reviewing the Jacksonian unconformity of San Fernando. The *San Luis Limestone* of Venezuela, like the *Antigua Limestone* of the Antilles, and the Lepidocyclina undosa bearing limestones of Trinidad, has always been considered to be of Middle Oligocene age but there is little evidence as yet to prove this. Bronnimann (1950) has recently questioned the occurrence of Lower Oligocene Beds at the Cipero type section, a possibility that has occupied the minds of palaeontologists for a long time since no identifiable Lower Oligocene is recorded as yet from the Caribbean region although there is sound reason to expect its existence. That morphologically identical forms of Miogypsinas are generally evaluated somewhat older in America than in Europe, Near East or Indonesia has lately been mentioned by Drooger (1952) but fortunately there is now a tendency amongst American micropalaeontologists to remedy this aspect especially for the Tertiary (Ellisor 1940).

Another facies of the Cipero Formation is the *Ste. Croix Member* which belongs to the *insueta-dissimilis zone* which places it between the Retrench and Princes Town Members of the Cipero Formation. The Ste. Croix Member is characterised by occasional small coral reefs, calcareous sands and marine conglomerates within completely argillaceous beds with calcareous clays containing a foraminiferal assemblage indicative of shallow water conditions. The Ste. Croix Member appears to have been deposited under conditions similar to the Oligocene Lithothamnia limestone as mentioned above.

Towards the latter part of the deposition of the Cipero Formation an important group of oil bearing sands, the *Herrera sands,* appeared in the southern part of Trinidad in the fohsi zone. In their nature of occurrence they are reminiscent of the older Nariva sands and are certainly also the product of turbidity currents and mudflows. The term «mudflow» in this sense must not be confused with the ordinary mudflow of mud-volcanoes, which is generally free of large components. Whereas the belt of the main development of the Nariva sands follows the Central Range, one finds that of the Herrera sand farther to the south thus clearly pointing to a migration of the fore-deep. The Herrera sands are characterised by their «pepper and salt» aspect caused by whitish quartz and black chert and limestone grains. The thickness of these sands can change from a few meters to 500 m or more in a distance of a kilometer. Several layers of poorly sorted conglomerates in a silty matrix are found overlain by graded sandstone in a number of bore holes. Amongst the chert and limestone pebbles occur flat pebles of shale carrying an older Oligocene foraminiferal fauna. Occasionally, large blocks of white Oligocene coral limestone and pieces of lignite are entombed in the black silt and are strikingly out of place in this muddy environment, otherwise lacking in larger fossils. The appearance of reworked foraminifera is common and in some places a reversed series of sediments might be thought to exist if the greatest care is not taken in the search for the true markers.

Towards the top of the Oligocene, and extending into the Miocene is a non-calcareous, red weathering series of clays and silts that has been termed the *Karamat Formation.* This is a muddy water facies limited to the SE part of Trinidad. The few lenticular sands and conglomerates are in every respect comparable with Herrera sands, not only from a petrographic view point but also as regards mode of origin. The Karamat Formation represents a further southward displacement of the foredeep. In certain parts of SE Trinidad one finds the Karamat Beds associated with large slip-masses which remind one of the Nariva rubble masses with the exception that no components have been found to be older than Cenomanian argillite.

In the Central Range, especially in the crestal region and the north flank, all the four Globorotalia fohsi subzones and the Globigerinatella insueta zone of the Cipero Calcareous clay facies are replaced by a silty facies of the lower part of the *Brasso Formation.* This formation of about 1800 m thickness is easy recognisable by its dark bluish grey, calcareous silts with a relatively rich fauna and occasional layers of well preserved white molluscs of a neritic environment. In this respect the Lower Brasso Formation is lithologically reminiscent of the dark silt with fossils from the «Flat Rock» Member of the Cipero coast, thus indicating the close relationship with the Cipero Formation. The molluscan fauna of the Lower Brasso Formation occurs mainly in the upper part of the Globorotalia fohsi zone. It has been studied by Guppy, Mansfield, Harris and Maury who all agreed on its Miocene age. Rutsch (1934) came to similar conclusions as a result of a study of the pteropods of Ste. Croix and various localities of the Central Range which belong to the Lower Brasso Formation. He considered the pteropods of the Ste. Croix Beds to show clear relationship to those of the Upper Italian Burdigalian and Helvetian and if this could be proved to be correct it would mean that already the «insueta zone» is of Miocene age. Such age was also suggested by Duncan (1868) on a study of the corals of the Ste. Croix Quarry although his identifications are often doubtful.

A considerable thickness of limestone alternating with silty shales of the fohsi zone forms the Basin Hill. These limestones carry a small type of orbitoid.

The following paleogeographic picture for the so-called Upper Oligocene fohsi and insueta zones has been revealed. To the north, and probably covering the Northern Range, was a neritic sea responsible for the Lower Brasso clays which reached to the present south foot of the Central Range but which at that time formed the upper part of a marine slope. The lower part of the slope received the great thickness of the Cipero Formation with the typical Globigerina marls and marly clays. Still farther to the south, and deposited at greater depth than the Cipero marls, follows the belt of Herrera sands of the Globorotalia fohsi zone with the ponded turbidity flow material such as the conglomerates with pieces of lignite and some corals. It seems possible therefore that the range formed during Nariva time, which was responsible for the Wildflysch formation, was completely eroded, or submerged, before the Lower Brasso clays came to rest. Such an orogenic event could not have taken place without some reflection in the basinal region and hence it is not surprising to find a biostratigraphic break at the base of the dissimilis zone.

We have mentioned the almost parallel southward migrations of the axis of the main sand developments from the older Nariva to the Herrera and finally Karamat sands. Each reflects a short orogenic phase of which at least the Nariva phase has been noticed in other parts of the Caribbean region.

The provenance of the Cipero sediments is most likely from E and SE, for there is no reason why the South Equatorial Current should not have been flowing round the NE end of the Guayana Shield during Oligocene time. There is every reason to believe that this sea extended westward through the East Venezuelan Basin, deposited the Carapita shales, the Oligocene shales of Guarico and probably reached into the Agua Salada basin of Falcon through the gap of Barquisimeto. The eastward rise of the Central Range and possibly also of the Southern Range of Trinidad could have provided all the Flysch sediments for the southward migrating foredeep.

Miocene

In Trinidad, the start of the Miocene has, up to the present been placed at the base of the *Lengua Formation.* Not only were the greenish calcareous clays recognised by most of the early geologists but also their unconformable nature on earlier beds. The basal *Rio Claro Boulder Bed* was found throughout the Naparima area, as far west as the Pitch Lake and in the uplift zones of the Southern Range. At its type locality it consists of large and small blocks of clay and marl belonging to the Cipero Formation and embedded in the calcareous clay matrix of the Lengua Formation. Illing (1928, p. 24) called it «Green clay breccia» and mapped it in the Naparima area over a distance of 20 km. He noticed the fragments of marl and shining polished pebbles, and the slightly rolled aspect of larger blocks. In the south part of Trinidad the Rio Claro Boulder Bed can be developed in a regular «Wildflysch» facies with huge blocks of hard rocks of Senonian and younger age and with slipped masses of various Oligocene clays. The «morro» of Morne Diablo is one of the outstanding Oligocene limestone masses that belongs to this rubble bed. East of the Pitch Lake the Rio Claro Boulder Bed assumes a great thickness amounting to 500 m or more, and on account of its unbedded nature and comparatively light material, it is one of the most incompetent formations to be found in Trinidad. Under orogenic pressure, and the weight of the denser silt and sands of the flanks, it moves almost like a salt mass and can ascend vertically through tension cracks as is known from the Forest field (Bower 1951, Suter 1951). A number of wells have penetrated the mushroom-like mass of boulder bed of close to 100 million cubic meters and situated between the Cruse and Forest Formations of the Forest field. Part of this «laccolith» is in a secondary position on top of the Forest Formation having spread laterally on the sea floor. This indicates vertical migration during each folding phase. On account of its incompetent nature the boulder bed is one of the causes for the existence of diapiroid structures and scruff-folds. These folds can be completely detached from any structures in the Paleocene-Cretaceous substratum, as has been found to be the case with the Forest anticline (Suter 1951, fig. 5). Most of the clay breccias with blocks found in mud volcanoes, are, in reality, ordinary hydroclasts as Lehner surmised when the writer considered them to be connected with sedimentary volcanism (Kugler 1932). They are marine-slope clay-breccias with slumped blocks. Where they break through gas, oil, and water bearing beds they carry along these substances. It seems that gas can accumulate in or round these boulder masses and assist in throwing them out during isostatic adjustments or orogenic movements. Usually ordinary mud volcanoes produce only mud, silt and sand with occasional lumps of detached country rock, but never the variety of blocks which are reported from so many places and quite recently also from Borneo (Reinhard 1951).

The *Lengua Formation* is divided into a lower Globorotalia mayeri and an upper Globorotalia menardii zone of a combined maximal thickness of about 600 m. There are no sands known from the Lengua Formation although some could be expected at the outer fringes of the boulder bed. Some shelly limestone lenses occur at Freeman's Bay, in the Naparima area, and occasionally along the Southern Range. These muddy limestones often form a coquina with a Thyasira-Pleurophopsis fauna indicative of a cold water environment and a depth of several hundred meters.

The *Lower Cruse Clay* is intimately connected with the Lengua Formation and, on acount of its well-defined microfauna, deserves its own designation and separation from the younger part of the *Cruse Formation.* However, in the field such separation is not possible. The Lower Cruse clay, like the Middle and Upper Cruse clays, is a gypsiferous, grey, red weathering unctuous clay with crimson weathering claystone nodules and occasional layers of sand. It attains an average thickness of 1200 m. No larger fossils are known from this clay and the foraminifera are essentially arenaceous. Amongst them are typical forms such as a large Hormosina, a Bigenerina and Discamminoides tobleri which represent good markers. The common occurrence of large specimens of Cyclammina cancellata is the reason for the early designation «Cyclammina Clay», but as these are also found in higher Cruse clays, and in the Nariva clays, the term has only a lithologic and environmental significance. These large and robust forms together with Guppyella and Alveovalvulina (Bronnimann 1951) represent a particular depositional environment which Stainforth (1952) suggested was controlled by turbid water conditions. He assumed the Cruse clays to be deltaic. No such recent faunal assemblage is known, however, from any tropical shallow water though some similar faunas occur in cool, deep water. Phleger (1951) states that Cyclammina cancellata is found deeper than 400 m and is most abundant between 400 m and 1000 m. Similar observations were made by Lowman (1949, fig. 13) whose Haplophragmoides-Trochammina-Cyclammina-Glomospira assemblage is found in his bathyal (200 to 2000 m) zone with an optimum development at 1400 m and a shallowest depht of 300 m. Referring again to figure 13 of Lowman's important paper we are led to believe that the Lengua Formation represents a shallower environment than that of the Lower Cruse clay. The deep water environment of Lower Cruse makes the large masses of mudflow found in it more understandable. These mudflows are mainly found in the SE part of Trinidad. Thus we come to the conclusion that the Lower Cruse clay with its mudflows and fringing sands is the last of the major submarine turbidity deposits of a number of southward migrating foredeeps which succcessively were filled by turbidity current carrying great quantities of fine and sometimes coarse detrital material, amongst which reworked foraminifera are an integral part (Heezen 1952).

The rest of the *Cruse Formation* is more arenaceous and at its type locality attains a thickness of 750 m. These Middle and Upper Cruse sands are major oil producers as could be expected from their deposition in a foredeep or slope gradually filling with sediments. Although the Cyclammina clays are still found to be interbedded with these sands there are also clear indications of shallower water conditions, though still below the 200 m line, i. e. outside the neritic belt. Such conditions might exist today north and east of Trinidad where the sediments carried by the Orinoco and San Juan Rivers are dumped, and where channels must exist on the undulating marine platform of which the one starting in the Dragon's Mouth is the most prominent as far as can be detected from marine charts. Any orogenic movement, a change in the physiography of the land or a shift of marine current may lead to infilling of such channels and cutting of new ones. A detailed study of the mode of occurrence of the Cruse sands, and even younger ones, seems to indicate such a possibility. A glance at Suter's sections 5, 6, and 13 shows to some extent the influence of such channelling and infilling but there are better examples known from detailed mapping of the surface. Along the undisturbed north flank of the Rock Dome anticline one observes the Lower Cruse clay to be 200 m thick at one place. Along the strike and in a distance of only $5^1/_2$ km it is 1300 m thick. This channel is coated with a silt carrying a slightly clearer water fauna, different from that of the Lower Cruse clay, and more related to the Lower Forest Formation. In the Guayaguayare area we believe we have found Middle and Upper Cruse channels cut into Lower Cruse clay and likewise Forest Formation channels into Middle and Upper Cruse, as well as into Lower Cruse Formation. The channel walls and bottoms are often coated with a thin veneer of mudflow or at least with silt and sand carrying a heterogeneous assemblage of foraminifera. In places this mudflow can be up to 100 or more meters thick and can carry such an overwhelming number of derived foraminifera, such as Lower Cruse or older, that the identification of the true age of the adjoining beds is made most difficult. This is particularly the case where the derived foraminifera are often still noticeable for a long distance from the channel wall and inside the younger infill. Under orogenic pressure this wall plastering mudflow can be injected into every tension crack of the massive silts and sands of the infill (Kugler 1932, photos 3 and 4) and although Paleocene foraminifera are found in the mud dykes of Guayaguayare they are not indicative of the depth of the dyke material as assumed by the writer (1938) when mentioning a source 5000 feet deep. The most outstanding feature of the channel infills is generally their monotonous great thicknesses of well-bedded silt and sand almost completely barren of fossils even foraminifera. This is certainly the case with the *Moruga Formation* found to be developed in the SE part of the island between Moruga and Radix Point. The Moruga Formation is at least 3000 m thick at the type locality and seemingly embraces the entire Miocene above the Lower Cruse clay. The sequence of monotonous well-bedded, graded silt with clay films is occasionally interrupted by thick layers of greywacke sandstone and silty clay. In the upper part of the Morugas, which are probably already equivalent to the Forest Formation, one observes calcareous sandstone lenses with large plant leaves, ripple marking and occasionally thin shell beds which together are proof of paralic sedimentation (Tercier 1939) and which caused the Swiss geologists working in Trinidad to use the term «Moruga Molasse» for the entire complex of this lithofacies. The monotony of the Moruga Molasse is sometimes interrupted by excellent examples of intraformational slumping, as depicted in the publications of Fairbridge (1946), Rich (1950), Kuenen (1950) etc. At one place along the Moruga coast a thickness of over 100 m of fine-bedded silt with sand lenses show the most fantastic contortions over a strike distance of almost 3 km. Above and below this slump are perfectly normal dipping beds.

The transgressive nature of the Lengua Formation shows itself along the south foot of the Central Range in the strong unconformable overlap of the Globorotalia mayeri zone on any older formations. Here, however, this zone is developed as a thin calcareous silt belonging to the upper part of the *Brasso Formation* and containing a rich fauna with Operculinoides tuxpanensis and Planorbulina. This calcareous silt which was already mentioned from the base of the *Tamana Formation* at Pointe-a- Pierre is called the *Concord Member* to replace the old term «Ditrupa beds» used by Guppy of which the type locality cannot be found any more. The type locality of the Concord Member is the Concord Quarry at Pointe-a-Pierre. It has been traced along the south foot of the Central Range almost to the east coast, always accompanying the reef limestone. The Tamana Limestone of about 100 m thickness stretches all along the Central Range under such names as Guaracare, Biche, Tabaquite and Brigand Hill Limestone apparently all of the same Miocene age.

The limestone rests unconformably on Nariva, Middle Eocene and Lower Cretaceous thus clearly testifying to the great unconformity involved. Starting in the thinly developed Concord Member one first observes a few meters of silty Amphistegina limestone. This is followed by Amphisteginas mixed with a small type of Lithothamnia and then series of larger nodules of Lithothamnia with layers of Porites and some small head-forming corals. The reef generally ends with several meters of large nodular Lithothamnia. The nature of these reefs indicates a submerged Central Range crowned with small «keys» or «cayos» which received some clastic sediments. The rare occurrence at the base of the limestone of scattered pebbles of a dacitic rock, which is not known from Trinidad, would point to rafting. Some claystone pebbles with Pholas-holes are indicative of the shallow water conditions of these fringing reefs to the south of a larger island including perhaps the Northern Range.

Above the Lower Brasso clay of the type section in the Caparo valley one observes the scarp-forming, fossiliferous, neritic *Los Atajos Member* of the Upper Brasso Formation with a conglomerate at its base. This Brasso conglomerate which consists mainly of white vein quartz and of black Cretaceous cherts and limestones, decreases towards the west and is replaced by the glauconitic *Montserrat Sand Member* of the Upper Brasso Formation. Eastward the Brasso conglomerate increases in thickness and in places transgresses almost on to the Cretaceous. The Los Atajos Member is younger than the Tamana Limestone Formation and its base might be correlated in age with the transgression of the Forest Formation whereas the base of the Tamana Formation is to be correlated with the Lengua Boulder Bed.

The *Forest Formation* is the main oil producer in Trinidad. At the type locality it is about 600 m thick. It consists of a series of alternating sands, silts and clays which in its upper part shows clear indications of paralic sedimentation such as the presence of plant leaves, echinoids and some molluscs.

Along the north flank of the Central Range the Forest Formation appears to be replaced by the upper Brasso and *Springvale Formations*. The latter starts with the *Telemaque Sand Member,* which is followed by the well known Springvale glauconite with its rich marine molluscan fauna described by Guppy, Maury, Vokes, and Rutsch who considered it to be of Middle to Upper Miocene age. The top of the Springvale Formation is formed by the *Mamural Clay Member*. The total thickness of the Springvale Formation is about 1100 m and its neritic nature is indicated by the molluscan fauna and the occurrence of occasional lignitic streaks which point to the nearness of coastal swamps.

On the southern border of the Northern Range, near Matura, is exposed the silty *Melajo Clay Member* of the Springvale Formation. It rests directly on the phyllites of the Northern Range with a basal conglomerate of about 1 m thickness and consists of small quartz and phyllite pebbles. This conglomerate changes upwards into a $1^1/_2$ m thick limestone full of large Dosinias and other molluscs known from Springvale. Some pebbles of vein quartz and quartzitic sandstone are also scattered in this limestone. Next follows a bed of coarse sand of about 1 m thickness formed mainly of quartz and phyllite grains and rich in well-preserved Springvale fossils. This sand is overlain by the main mass of the Melajo clay, with occasional layers of thin shelled molluscs, layers of greenish sand consisting of phyllite grains and of silty clay. The Melajo Member of the Springvale Formation represents a typical Miocene shore-line deposit and its contact with the phyllites is the only one known to the writer in Trinidad. The nature of the shore-line deposits seem to suggest the absence of a high range to the north of it, otherwise one would expect a much coarser and thicker basal conglomerate to be present. The gentle dip of about 5° shown by the Melajo beds, indicates, moreover, that they have not been affected to the same degree as their more southern equivalents which along the south coast of Trinidad stand in places almost vertically. The southward shift of the major phase of diastrophism is again indicated in the Upper Miocene beds.

Above the Forest Formation of the Brighton (Pitch Lake) area one finds the *La Brea Formation* which probably represents the youngest Miocene in Trinidad with Ostrea virginica falconensis (det. by Dr. Woodring) forming the Vessigny oyster bed. The relatively rich fossil bed of Point Courbaril may already be early Pliocene according to Dr. Woodring.

Miocene — Pliocene

The upper part of the Miocene is not yet separable from the Pliocene in Trinidad on account of lack of diagnostic faunas in the relatively thick series of marine, brackish water and coast swamp deposits.

In South Trinidad the Miocene appears to end with the *Morne l'Enfer Formation*, which is typically a sequence of about 500 m of greywacke sand and silt without any fossils and in every respect reminiscent of the Moruga Molasse. The Morne l'Enfer Formation may correspond to the lignitic Moruga Formation but this cannot be verified.

In the SW part of Trinidad the Morne l'Enfer Formation is overlain by typically paralic sediments belonging to the *Talparo Formation* which has its main development between the Central and Northern Ranges. It has a thickness of about 1000 m starting with marine clays with Anadara patricia and arenaceous foraminifera continuing with a series of alternating thick brackish water sand and silts deposits with Cyanocyclas, Hyria, and Hemisinus. It ends with lignitic beds, which, when ignited, baked the accompanying clay and silt to bright, brick-red «Porcellanites», forming very conspicuous scarps east of Sangre Grande and also in the SW part of Trinidad.

The late Pliocene *Matura Formation* with its thin shell bed is the last marine transgression known.

Pleistocene

The major orogenic movement must have taken place during the early part of Pliocene time because the above mentioned formations have all been folded with the exception of the Matura Formation. The Miocene Tamana Limestone occurring in the Central Range and the youngest Moruga sandstones of the south coast have been pushed into vertical positions and in places have even been overturned. If the Caribbean Coast Range of today is of such a young age one is not forced to assume a proto-Orinoco to account for the Pliocene sediments of Trinidad which could well have been a part of the extensive coast swamp in front of the Guayana Shield. Hyria of the Talparo Formation is a species found in the Amazon River basin and apparently not in the Orinoco. One could visualize the Orinoco River as having formed a part of the Rio Negro-Amazon system by following a southern course from the Apure junction.

During the early Pliocene orogeny a shallow depression was formed between the northern rim of the Guayana Shield and the rising ranges to the north. Consequently the sea broke in from the east and probably extended far into the present Llanos region of Eastern Venezuela. The effect of this depression was to change the course of the northern part of the Rio Negro River system and to cause it to flow eastward and fill in the existing sea. The youthful Orinoco still captures parts of the Rio Negro in the famous Casiquiare region.

The Gulf of Paria came into existence not more than 10,000 years ago, to judge from the freshness of the submerged and extinct coral reefs west of Port-of-Spain. The sea broke in through the faulted Dragon's Mouth and gradually expanded southward until it met the lower Orinoco embayment. Today the Orinoco is refilling this gap though the Southeast Equatorial Current is doing its best to carry the sediments of the Orinoco and San Juan Rivers through the Dragon's Mouth and dump them to the north of Trinidad.

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