Zeitschrift: Eclogae Geologicae Helvetiae

Herausgeber: Schweizerische Geologische Gesellschaft

Band: 68 (1975)

Heft: 2

Artikel: Geology and paleontology of Soldado Rock, Trinidad (West Indies). Part I, Geology and biostratigraphy

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DOI: https://doi.org/10.5169/seals-164394

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Eclogae geol. Helv.	Vol. 68/2	Pages 365–430	8 figures in the text and 2 plates	Basle, July 1975

Geology and Paleontology of Soldado Rock, Trinidad (West Indies)

Part 1: Geology and Biostratigraphy[1]

By HANS G. KUGLER[2] and C. M. BRAMINE CAUDRI[3]

ABSTRACT

The little islet called Soldado Rock, off the Southwest tip of Trinidad, is but a Paleocene and Eocene olistostrome mélange in Miocene turbidites. Compared with the former interpretation of the stratigraphic sequence of beds (KUGLER 1938), showing a gap between Paleocene and Late Eocene rocks, there is now clear evidence also of the presence of the Lower Middle Eocene (or very high Lower Eocene = Boca de Serpiente Formation), and of the Lower Upper Eocene.

Soldado Rock is the type locality of 11 Smaller Foraminifera, 20 Larger Foraminifera, 54 mullusks, 2 brachiopods, 3 echinoids and 5 ostracods.

In the paleontological part of this monographic study[1] forty-nine species and varieties of Larger Foraminifera from the Paleocene, early Middle Eocene and Upper Eocene of the Soldado Rock are described, ten of them new: *Operculinoides trinitatensis* var. *granulata*, *Operculinoides spiralis*, *Neodiscocyclina mauryae*, *Asterocyclina soldadensis*, *Amphistegina undecima*, *Amphistegina pauciseptata*, *Amphistegina grimsdalei*, *Lepidocyclina peruviana* var. *nana*, *Lepidocyclina pustulosa* var. *compacta* and *Lepidocyclina spatiosa*. Special attention has been paid to the stratigraphical significance of *Helicostegina soldadensis* GRIMSDALE [here renamed *Helicosteginopsis soldadensis* (GRIMSDALE)] and to the fauna and general nature of the Boca de Serpiente Formation, which at the moment is known only from this islet, in the form of a remnant slump mass. The recognition of heavy reworking in the upper part of the section has changed older ideas about the vertical range of several of the species described before.

CONTENTS

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[1] Part 2: "*The Larger Foraminifera*" will appear towards the end of this year, in Eclogae geol. Helv., Vol. 68, No. 3.

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Introduction

The Soldado Rock stands sentinel in the strong tidal currents of the shallow Southern passage, called the Serpent's Mouth, between Trinidad and the South American mainland, about 10 kilometers West of Columbus Bay on the Cedros Peninsula.

The Rock comprises an area of about 6500 square meters. From its Northern point, which carries the trigonometrical signal, and which is 36 meters above sea level, one can see the flat Pedernales area at the Northern end of the Orinoco delta. The coordinates of this point are: Latitude 10° 04′ 24″, Longitude 62° 00′ 56″. To the South of the highest point there follows a saddle of softer beds and then another, lower, elevation. During the breeding season the intruder is greeted by the shrieks of terns and other guano producing birds. The guano and its resulting phosphate of lime cover the island from the top to the high-water level.

Though Amerindians, and later on fishermen of Trinidad, regularly collected eggs during the breeding season of the terns, one cannot expect anyone to visit the inhospitable Soldado Rock excepting biologists, surveyors and geologists. The first geologist to have visited Soldado Rock known to us was V.C. Veatch, whose collection of fossil shells, together with some stratigraphic details, was described by MAURY in

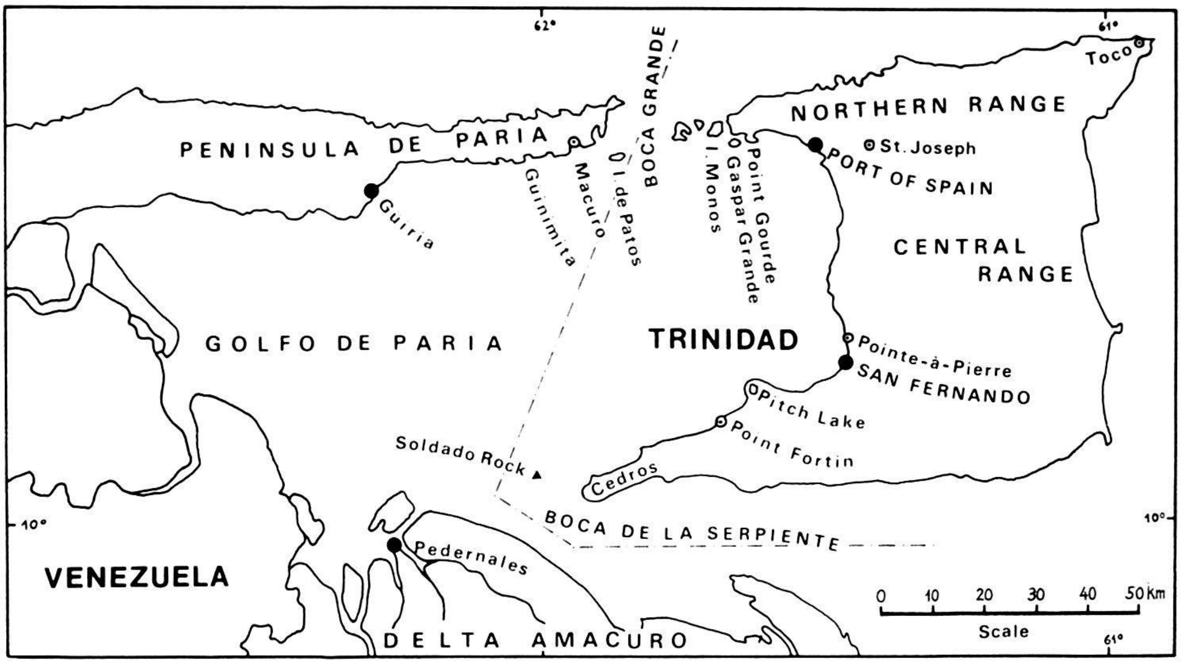

Fig. 1. Geographical position of Soldado Rock.

1912. Unfortunately, although the collection is now deposited in the Paleontological Research Institution at Ithaca, N.Y., the original correspondence and fieldbooks cannot be located. Samples of Larger Foraminifera studied by DOUVILLÉ, and echinoids described by JEANNET, were collected by F. Zyndel in March 1916.

The last paper on the geology of the Soldado Rock was published by KUGLER in 1938. Additional visits to the Rock were subsequently made by the present authors, as well as by T. F. Grimsdale, E. Lehner, Axel Olsson, H. H. Renz, J. B. Saunders, K. Schmid, etc., who all collected more samples. In February 1973, P. Jung and R. Panchaud of the Natural History Museum in Basel spent three days on Soldado Rock collecting additional fossils. On the advice of J. B. Saunders, bottom samples were taken in the waters West of the Rock by P. Percharde. The results of the study of all these samples demanded a revision of the former interpretation, particularly since the magnitude of reworking of older fossils, and their deposition in younger sediments, had previously been underestimated.

The great amount of additional material studied made it necessary to draw a new map showing the position of each sample (see Pl. I). For quick orientation the map is subdivided into squares of 20 × 20 meters, marked and designated A–G and 1–6. In the text we have added the position of each locality to the observation number – for instance, K.3692, which can be found in square B–2, is referred to as K.3692 (B–2).

When visiting Soldado Rock in May 1946, considerable changes were noticed as compared with pre-war conditions. The Rock was used by the Royal Air Force for target practice with bombs and machine guns. Some bullets were found sticking in the rocks like belemnites. The formerly important localities on the southern tip, K.2948 to K.2950(C-5) were blown away, and so was the shallow cave, in its time known as the "abri-sous-roche" at K.10718(B-2).

Despite these changes and newly gained interpretations we shall here, for the sake of continuity, describe the formations and members along the same lines that

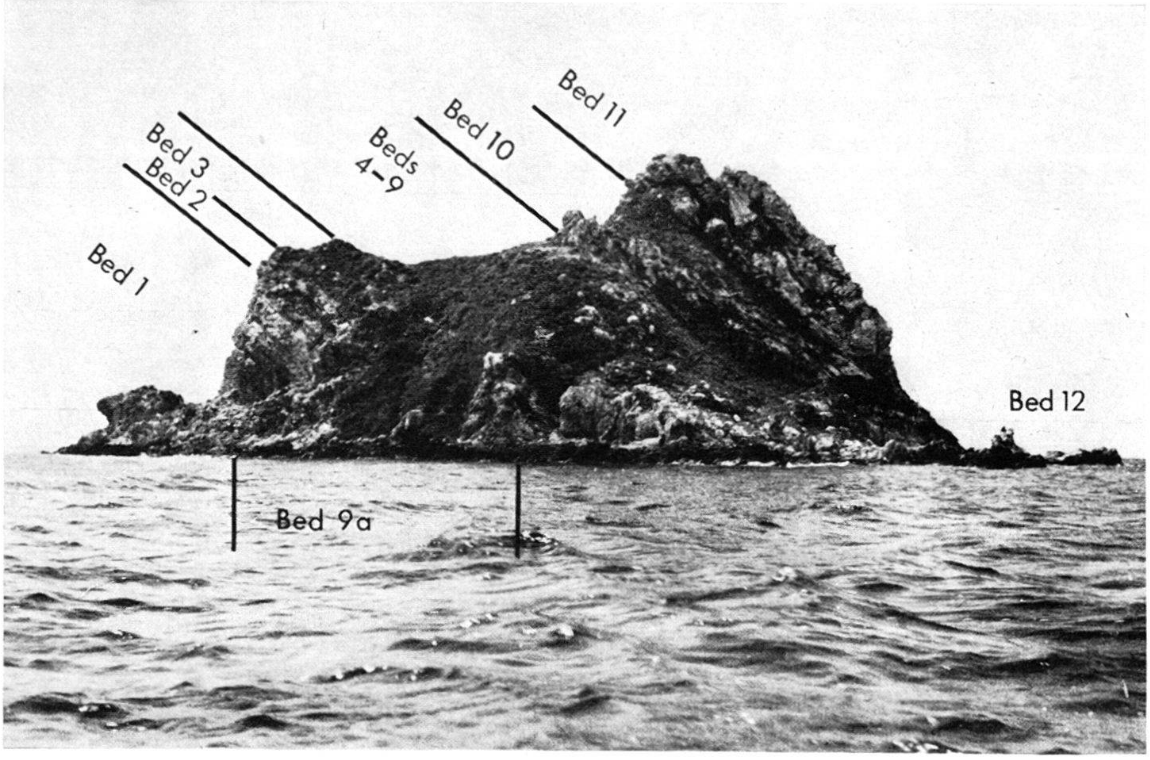

Fig. 2. Soldado Rock seen from the east (photo H. Stauffer 1933).

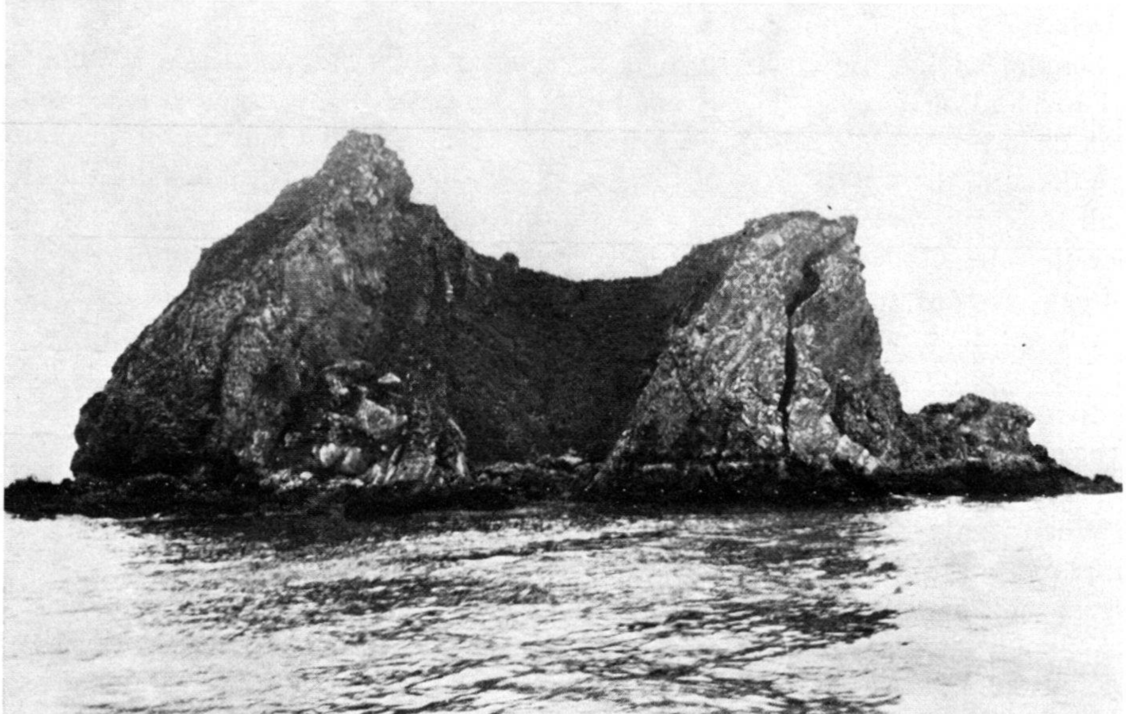

Fig. 3. Soldado Rock seen from the west (photo H. G. Kugler 1946).

were adopted in KUGLER's 1938 paper, in which, in a roughly South–North section, twelve different rock units were recognized. Amongst these, Beds 1–2 correspond with the level from which MAURY (1912) described the Paleocene mollusk fauna and which afterwards was called the "Soldado Formation", and Bed 11 includes her "Boca de Serpiente Formation". All these units are discussed in extenso in the following pages, whereby the senior author (H.G.K.) is responsible for the geological part of the present paper, and the junior author (C.M.B.C.) for the determination of the Larger Foraminifera and the age correlations based on them.

For the nomenclature of these fossils, used in the present text and fossil lists and in the Distribution Chart (see Pl. II), we refer to *Part 2* of this study on Soldado Rock. For technical reasons, publication of the paleontological descriptions had to be deferred to No. 3 of this same Volume of the "Eclogae". The new species and varieties, presented here as mere "nomina nuda", will then be fully established and the necessity of creating a new generic name (*Helicosteginopsis*) for *Helicostegina soldadensis* GRIMSDALE will be clear.

A. THE SOLDADO FORMATION

Author of name: MAURY (1925*a*, p. 42)
Original reference: MAURY (1912, p. 28–30): "Eocene fossils from Soldado Rock"
Original description: idem

Bibliographic history

MAURY (1912) published the fauna of a section from Soldado Rock, studied and sampled by A. C. Veatch who recognized 8 beds, of which Beds Nos. 2 and 8 carried a molluscan fauna. MAURY (p. 28) stated: "The basal bed, No. 2, is an extremely hard, greyish to reddish limestone containing quantities of shells which have become an integral part of the rock, from which they have been brought into high relief by the erosive action of the waves that constantly beat upon them. This bed lithologically is the exact counterpart of Midway Eocene near Ripley (Mississippi), Fort Gaines (Georgia), and Clayton (Alabama). Some samples of these various localities and Soldado cannot be distinguished from one another, and this resemblance is still more striking when fragments of rock from these widely separated places contain the same fossils." MAURY described 44 species of mollusks, several of which (amongst others *Venericardia planicosta*) formed a firm base for her correlation; 22 species and 3 varieties were new, apart from a new subgenus and species: *Veatchia carolinae*. Her complete list is given on page 375 of this paper.

MAURY (1913, p. 92–96) referred to her publication on the Paleontology of Trinidad. In a stratigraphical table she correlated the Midway fauna of Soldado Rock and Pernambuco with that of the Gulf States. A similar correlation she suggested for the next younger Lignitic fauna corresponding to the Nanafalian stage of Alabama. Both are brought into connection with a hypothetical land route between South America and Africa.

VAN WINKLE (1919, p. 19–23), from material collected by A. C. Veatch, described 7 new species of shells (see p. 376).

VAUGHAN (1919, p. 578) considered Bed 2 to be of Wilcox rather than Midway age.

KUGLER (1923) gave a new stratigraphic description of the beds exposed on Soldado Rock. His lower limestone group "A", estimated to be about 40 meters thick, is essentially a hard, crystalline rock with thick-shelled mollusks, and partly rich in glauconite. The uppermost layer, full of mollusks, such as *Venericardia planicosta* was identified with Bed 2 of MAURY. KUGLER considered the Soldado Rock to form part of a structure of which the nearby Pelican Rocks present the crestal region. The Pelican Rocks, situated between $^1/_2$ and 1 mile South of Soldado Rock, consist of almost N–S directed masses of marlstone, then thought to be of Late Cretaceous age (we now know that they are large slip-masses of Middle Eocene Navet Formation and, like Soldado Rock, are exotic elements in much younger beds).

MAURY (1925*a*, p. 43) established the term "Soldado Formation", with Bed 2 as the type of all the Basal Eocene of Northern South America and the Antilles in general. She mentions the extension of the Soldado Formation to Trinidad, and in the other direction to the islands of Margarita (off Northern Venezuela) and Toas (at the mouth of Lake Maracaibo).

MAURY (1925*b*, p. 159) referred to the commingling of Brazilian and Alabamian species in the fauna of Bed 2.

WARING (1926, p. 40) established the name "Marac Formation" for limestones of the Marac Quarry of South Trinidad. He mentioned several guide fossils of the Midway Eocene to occur in the limestone. (Although no mention is made of the Soldado Formation it is obvious that the term Marac Formation is a junior synonym of it).

HARRIS (in WARING 1926, p. 100) equated the fauna of the Marac Quarry with that of Soldado Rock.

LIDDLE (1928, p. 223, etc.) stated: "At the Southwestern end of Isla Soldado in the Gulf of Paria, gray, calcitic, hard limestones, interbedded with calcareous shales stained reddish from limonite, are filled with comminuted shell fragments as well as recognizable fossils, which place them into the Lower Eocene about Midway or Wilcox in age." Referring to MAURY (1912) he listed the fauna described by her. However, on page 225 he described the Soldado Formation as being of Late Eocene age and stated: "At the type locality on Isla Soldado the Soldado formation overlies about 100 feet of Middle and Lower Eocene limestone, which is the lowest horizon exposed and consequently there is no means of determining if the equivalent of the Misoa-Trujillo formation of Venezuela, or the Pointe-à-Pierre formation of Trinidad, which is basal Eocene in age, underlies the Middle Eocene in the Gulf of Paria near this island. Unconformably above the Soldado formation at its type locality, and separated from it by a brecciated conglomerate, are marls, coquinas, dolomitic limestones, and shales, which are distinctly Oligocene." (LIDDLE thus erroneously included in his Soldado Formation the Late Eocene sandstone–marl group "B" proposed by KUGLER in 1923.)

JEANNET (1928, p. 16) described the new species *Linthia caraibensis* from the Jacksonian of Soldado Rock. [This echinoid came from a block (K.1317) containing mollusks belonging to Bed 2 (Midwayan), as pointed out by RUTSCH (1943, p. 148). HARRIS (1926, p. 100) mentioned *Linthia alabamensis* CLARK as being fairly common in the Marac Quarry].

WOODRING (1928, p. 39) attributed a Thanetian–Ypresian age to the faunas of Soldado Rock and of the Marac Quarry.

MAURY (1929, p. 177) pointed out the fallacy of LIDDLE's application of his term "Soldado Formation", re-established Bed 2 as the type-locality, and assigned a Montian–Thanetian age to it.

SHIMER (1934, p. 909) accepted LIDDLE's designation of the term Soldado Formation.

MAURY (1935, p. 192) criticized SHIMER's mistake and stressed the priority of the term "Soldado Formation, MAURY 1925".

SCHUCHERT (1935, p. 701), in support of LIDDLE, erroneously attributed MAURY's beds 6 and 8 to the Soldado Formation.

RUTSCH (1936*a*, p. 150–188), in his study of *Venericardia planicosta* and related forms, implies that the specimens from Soldado Rock and the Marac Quarry are to be placed in *Venericardia* cf. *parinensis* OLSSON rather than *V. planicosta*. RUTSCH correlated the Soldado Formation with the Salina Formation of Peru, with the Wilcox of the Gulf Coast, and with the Landenian of the Paris Basin.

RUTSCH (1936*b*, p. 188–207) questioned *Venericardia beaumonti* as an exclusive index fossil of the Upper Cretaceous. Forms belonging to this group occur also in the Soldado Formation. He included MAURY's *Venericardia thalassoplekta* of Bed 2 in this group (p. 201), and provisionally assigned a Wilcoxian age to it.

KUGLER (1936, p. 1443) suggested that the Soldado Formation with its glauconitic shell-bed presents shallow water conditions along zones of limited uplifts, whereas elsewhere throughout

Early and Middle Eocene times open sea conditions prevailed and produced the deposition of highly foraminiferal marls.

MACKENZIE (1937, p. 263, 280), following LIDDLE's nomenclature, correlated the Soldado Formation with the Upper Eocene Rio Caus limestone of Western Venezuela.

KUGLER (1938) described from Soldado Rock 12 different beds, which he integrated in his subdivision of 1923, and as far as possible in that of A. C. Veatch (MAURY 1912). He included Beds 1–3 in the Soldado Formation, and presented lists of mollusks and echinoids from Beds 1 and 2 according to preliminary determinations by RUTSCH. Based on a private report by VAUGHAN & COLE on the Larger Foraminifera, he established the term "Pellatispirella limestone" for the calcareous upper part of Bed 3 and that of "Discocyclina limestone" for a limestone of apparently the same age that was found as an erratic block in the Upper Eocene part of the section.

SCHILDER (1939) described from Bed 2 of the Soldado Formation the following two Cypraeacea: *Archicypraea trinidadensis trinidadensis* n. sp. and *A. trinidadensis degenerata* n. subsp.

RUTSCH (1939*d*, p. 366–368) suggested an old Paleocene age for the molluscan fauna of the Soldado Formation. The gastropod *Clinuropsis diderrichi* VINCENT from Soldado Rock has as yet only been known from the limestones of Landana, Congo.

SENN (1940, p. 1574) correlated the fauna of the limestone blocks in the Joes River mudflows of Barbados with the "Pellatispira limestone" (Bed 3) of Soldado Rock.

VAUGHAN & COLE (1941) described the Larger Foraminifera from Bed 3 [*Miscellanea antillea* (HANZAWA), *Miscellanea soldadensis* VAUGHAN & COLE, *Discocyclina (Discocyclina) barkeri* VAUGHAN & COLE, *Discocyclina (Discocyclina) grimsdalei* VAUGHAN & COLE] and from the block of Discocyclina limestone [*Pseudophragmina (Athecocyclina) soldadensis* VAUGHAN & COLE]. The fauna was compared to the Nanafalia Formation of Alabama (as was the molluscan fauna of MAURY 1912), and the age was given as "Lower Eocene" (in the terminology of the U.S. Geological Survey: in European usage it would be "Paleocene").

CUSHMAN & RENZ (1942) described the Smaller Foraminifera (exclusive of the Globigerinidae s.l.) of Bed 3. The fauna was considered as Midwayan in age, but also shows a distinct relationship to the Lower Eocene (Wilcox), especially to the Salt Mountain Formation and the Ozarks, Alabama.

RUTSCH (1943) described the mollusks of the Soldado Formation collected by H. G. Kugler (see list on p. 376 of the present paper). The age was given as Paleocene. RUTSCH on p. 187 also considered a position between the Maastrichtian and Midwayan stages.

CAUDRI (1944, p. 378, 382) listed the Larger Foraminifera from Bed 3, adding *Discocyclina aguerreverei* CAUDRI, *Discocyclina "crassa"* (as figured by VAUGHAN & COLE), *Hexagonocyclina meandrica* CAUDRI, *Hexagonocyclina* n. sp. and *Ranikothalia tobleri* (VAUGHAN & COLE) to the list given by VAUGHAN & COLE in 1941. She correlated the fauna with that of the Paleocene of San Juan de los Morros in Central Venezuela and the Chicontepec Formation of Mexico, the Lizard Springs Formation in Southern Trinidad, and the remnant blocks in the Joes River mudflows of Barbados. She included Bed 3 in the Soldado Formation and considered the age as Midway (Paleocene).

VAUGHAN (1945, p. 1, 19, 104) gave a list of the Paleocene Discocyclinidae of Soldado Rock and stated that the Discocyclinidae of the limestone blocks in the Joes River mudflows of Barbados can be safely put down as early Lower Eocene or late Paleocene because of their similarity to those of the Soldado Formation (meaning Bed 3 and the "Discocyclina limestone"). Again, he does not take a stand in the controversy Paleocene – Lower Eocene in America.

CUSHMAN & RENZ (1946) placed the foraminiferal fauna of Bed 3 at the level above the upper zone of the Lizard Springs Formation of Trinidad, or perhaps even at the base of the Navet Formation (Ramdat Marl), but still within the Midway.

LIDDLE (1946) brought the difinition of the Soldado Formation into line with that of MAURY 1912, KUGLER 1938 and VAUGHAN & COLE 1941.

CUSHMAN & RENZ (1948, p. 2) repeated their opinion that the Soldado Formation (Bed 3) may be the equivalent of the basal part of the Navet Formation of Trinidad.

CAUDRI (1948, p. 478) gave the first complete list of the Paleocene Larger Foraminifera in Bed 3 (mainly K.2951) and in the rubble of Bed 4, which clearly originates from the Paleocene. In modernized form, this list is presented below (Paleontology, p. 383). CAUDRI correlated the assemblage with the Joes River blocks, the limestones of San Juan de los Morros in Central Venezuela and the Valle Hondo Formation ("Guasare Formation" according to SUTTON 1946) in Western Venezuela.

VAN RAADSHOVEN (1951, p. 478) placed the Paleocene foraminiferal beds on the upper reaches of the Rio Misoa and in the Rio Carache area (Western Venezuela), which are comparable with those on Soldado Rock, in the Guasare Formation.

BOLLI (1952, p. 671, 675, Tables 1 and 2) stated that the *Globigerina–Globorotalia* fauna of Bed 3 is closely related to that of the lower zone of the Lizard Springs Formation of Trinidad.

BRÖNNIMANN (1952, p. 153, 155) described five species of *Globigerina* from 11 samples from the "type locality of the Soldado Formation". Location numbers are not given but reference to the material of VAUGHAN & COLE 1941, CUSHMAN & RENZ 1942 and BOLLI 1952 (non 1950) makes it clear that the forms are from Bed 3. In agreement with BOLLI, he correlated this bed with the lower zone of the Lizard Springs Formation of Trinidad, but there are indications of a slightly younger age (still within BOLLI's *Globorotalia wilcoxi* var. *acuta* Zone). However, the fauna also shows a great resemblance to the Lower Eocene base of the Navet Formation (Ramdat marl).

KUGLER (1953, p. 39) accepted VAN RAADSHOOVEN's correlation (1951) of some Larger Foraminifera from the upper reaches of the Misoa River in Western Venezuela with those from Bed 3 on Soldado Rock, but protested against using the term "Guasare Formation" for the beds carrying that fauna (compare: CAUDRI 1948). Extending the "Guasare" that way is not permissible, since the name was restricted by LIDDLE (1946, p. 301) the the ± 100 m thick section of glauconitic coquina on the Guasare River itself, which carries a Midwayan mollusk fauna and corresponds with Beds 1 and 2 on Soldado. KUGLER further deplored his earlier inclusion of Bed 3 in the Soldado Formation and suggested adherence to MAURY's original restricted definition. Bed 3 he placed in the Lower Eocene (Wilcox), explaining the Midwayan character of its Smaller Foraminifera as the result of reworking. On page 44 he stated: "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'." (Note: even if we should ever need to distinguish the limestones of Bed 3 as a separate formation, which now seems hardly the case (see p. 378), the unfortunate term "Serpent Formation" will never be re-introduced; see DE RIVERO's objection, 1956*a*; p. 413, this paper). It was further suggested that the Soldado Formation occupies a lower level of the Paleocene than the Lizard Springs – Chaudière Formations in Trinidad.

DE RIVERO (1956*b*, p. 555, etc.) gave a very clear summary of all the various conclusions on validity and age of the Soldado Formation. Contrary to KUGLER 1953, she retained Bed 3 in that formation as a mere faunizone of a different character from the rest. She did not support a Wilcox age for this bed, nor did she agree with KUGLER's assumption that the Soldado Formation is older than the Lizard Springs – Chaudière beds of Trinidad, thus denying that there would be a large stratigraphical gap between Bed 3 and the underlying Midwayan limestone. She also suggested that the term "Soldado Formation" be used only locally for the Soldado Rock itself, and not be applied to formations of the same age anywhere else.

KUGLER (1956*b*, p. 97) referred to a meeting of geologists from Trinidad at which it was agreed that the term "Soldado Formation" should be declared valid despite the fact that its known exposures in Trinidad (including Soldado Rock) are nowhere in situ but represent nothing else but large slip-masses.

COLE (1959, p. 377 and Table) created the name of "*Operculina catenula* Zone" for the widely distributed level throughout the Caribbean area which carries a fauna dominated by that species. The fauna of Bed 3 is included in this zone. The age is given as Upper Paleocene.

TAYLOR (1960) correlated MAURY's mollusks of the Soldado Formation with the Paleocene Larger Foraminifera fauna determined by BRÖNNIMANN from the Los Bagres Formation of Margarita Island off Eastern Venezuela.

SALVADOR & STAINFORTH (1968, Fig. 3) correlated the basal limestone of the Vidoño Formation with the Soldado Formation. In Monagas (Eastern Venezuela) this basal limestone rests on the San Juan Formation of Maastrichtian age.

CAUDRI (1972*b*, p. 227) confirmed the correlation of the Joes River limestone blocks of Barbados with the "Pellatispirella limestone" of Soldado Rock; for the latter, she introduced the modernized term of "Ranikothalia limestone".

Type locality and type section

The type locality of the Soldado Formation is in the Southern part of the Soldado Rock. The section is represented by a huge rootless slipmass of limestone. In 1938, KUGLER subdivided the Soldado Formation into three beds. Additional investigations have clearly indicated that one of those, Bed 3, belongs to the Upper Eocene (see p. 388, 392) and that only Beds 1 and 2 can be assigned to thisfo rmation. Erratic blocks of Paleocene age, in Bed 3 and through the rest of the Eocene section, also represent the Soldado Formation.

Bed 1

a) Stratigraphic relationship

The *bottom* of Bed 1 is unknown on account of the fact that the limestone is only a rootless remnant. The *top* is K.2946(C-5), a dense, grey hard limestone with scattered grains of glauconite and brown, angular specks. This limestone underlies K.2947, a grey, highly glauconitic marlstone with indurated streaks full of shell remains, which forms the base of Bed 2.

b) Thickness

As far as one can observe, at least 20 meters of limestone are exposed.

c) Lithology

Bed 1 consists of massive layers of pale-brown and whitish, impure, glauconitic limestone containing scattered oysters, up to 15 cm in size, and nests of comminuted shell fragments with streaks of echinoderm breccia. The upper part of the bed is more glauconitic, which shows in the form of crimson patches and yellow specks. The limestone weathers with a rugged, sharply pitted surface on which scattered, more or less silicified fossils are visible, such as oysters showing rings of silica. The samples collected from this bed are: K.1314(C-5), 10704(D-5), 10705(C-5), 10706(D-5) and P.J.1152(C-5), of which sample K.10704 is considered to be the type sample.

- K.1314, light grey, brown speckled limestone with broken shells and echinoderm remains.
- K.10704, brown speckled limestone with some glauconite grains and a matrix full of microscopically small rhomboid calcite crystals, abundant molluscan fragments, bryozoans, echinoid spines and Smaller Foraminifera, such as Globigerinidae, but no Larger Foraminifera.
- K.10705, brown speckled limestone with the same matrix as K.10704 but with more glauconite, and less well preserved shells, with ostracods and Smaller Foraminifera.
- K.10706, grey limestone, light brown speckled, glauconitic, with rhomboid calcite crystals in the matrix. Abundant mollusks, algae and rather common Smaller Foraminifera, such as *Textularia* s.l.
- P.J.1152, brown limestone consisting of angular to rounded grains of broken shells, echinoid spines and tests of Foraminifera. Among the bivalves is a 3 cm thick oyster with a prominent umbo, possibly *Ostrea thirsae* GABB.

d) *Paleontology*

Noted mollusks, identified by H. G. Kugler, are:

Ostrea cynthiae MAURY
Ostrea thirsae GABB
Cucullaea (Latiarca) hartii RATHBUN
Venericardia cf. *ameliae* PERON
Tubulostium sp. (a small, flat, spirally wound form of gastropod, also known from the Marac Quarry of Trinidad)

Echinoids: *Linthia* sp., *Salenia* sp.

In general, mollusk fragments and algae are predominant. Smaller Foraminifera, bryozoans and echinoid remains occur in fair amount, but no trace of Larger Foraminifera was found.

e) *Age of Bed 1: Paleocene*

MAURY (1912, p. 35) correlated the mollusk fauna of the overlying Bed 2 with the Midwayan faunas of Alabama and the other Gulf States, and with that of Pernambuco. The field relationship and the general similarity of Beds 1 and 2 leave no doubt that both belong to the same formation. The age of Bed 1 is therefore also considered to be Midwayan, Paleocene.

f) *Paleoecology*

The presence of large oysters and common algae indicates shallow water conditions during the deposition of Bed 1, within the reach of wave action.

g) *Remnant blocks of Bed 1*

The remnant block, K.1317(D-5), a component of the conglomerate of Bed 4 (Upper Eocene), obviously has its origin in Bed 1. It is a dense, grey limestone, a breccia of mollusks and algae with Smaller Foraminifera and echinoid remains.

Bed 2

a) *Stratigraphic relationship*

The *bottom* of Bed 2 is formed by 40 cm of marly limestone [K.2947(C-5)], resting on bed K.2946 of Bed 1. The *top* of Bed 2 is indicated in the field at K.2949(C-5), where the glauconitic limestone is overlain by brown sand and silt with quartz pebbles of the size of cherry stones (K. 2950), which forms the base of Bed 3.

b) *Thickness*

Bed 2 ist 2 meters thick.

c) *Lithology*

Bed 2 consists of three separate units which form bottom to top are:

1. K.2947(C-5), 40 cm of very glauconitic grey marlstone with indurated streaks, mainly composed of leached fossils forming a shell bed.

2. K.2948(C-5), 50 cm of brown silt and sandy limestone with fossil remains. K.1315(C-5) is a good example of this siltstone; it is brown to pink mottled and non-calcareous. The same rock was also observed in the Marac Quarry of Trinidad.
3. K.2949(C-5) starts with 20 cm of leached, calcareous sandstone with fossil remains. Above this follow 90 cm of sparry, brown limestone, the top of which consists of 30 cm of hard glauconitic limestone full of fossils; this is the fauna listed by Maury in 1912.

   Z.444B(probably B-4) is a brown-grey lumachelle limestone (4 thin sections with annotation on label "Soldado Rock, Cardita Schicht, oberste Bank"):

   - *Amphistegina?* (rather coarse and big, one or two fragments only)
   - Smaller Foraminifera (rare)
   - Pelecypods and gastropods (abundant)
   - Bryozoans div. (very rare)
   - Echinoid spines (very rare)
   - Dasyclad algae? (very rare)

   P.J.1165(B-4) supplied a number of poorly preserved pelecypods and gastropods, together with three echinoids (*Salenia* sp.). This locality is almost identical with the locality E.L.1575, where several specimens of *Salenia* sp. were found.

   K.9454(B-4) collected from the vertical wall of the cliff (Bed 2), is a white to light yellow shell limestone with burrows, in which the mollusk fauna consists of nothing but large oysters, and which carries large *Lithothamnium* s.l., and other smaller algae. It is of particular interest because it contains a few Larger Foraminifera, listed on page 377.

K.2949 is the type locality of Bed 2.

d) Paleontology

On account of their weathered state, comparatively few fossils were extracted from the type bed itself at locality K.2949. Most of them were collected from loose blocks exposed to wave action. At this spot, Bed 2 carries the famous mollusk fauna which characterizes the Soldado Formation. Maury (1912, p. 28) determined the following species:

Pelecypods:

Ostrea crenulimarginata Gabb
Ostrea cynthiae n. sp.
Ostrea cf. *percrassa* and *compressirostris* Say
Ostrea pulaskensis Harris
Ostrea thalassoklusta n. sp.
Cucullaea hartii Rathbun
Glycymeris (*Axinea*) *viamediae* n. sp.
Venericardia alticostata Conrad
Venericardia planicostata Lam.
Venericardia thalassoplekta n. sp.
Callista mcgrathiana Rathbun
Callista mcgrathiana var. *rathbunensis* n. var.
Chione paraensis White var.

Gastropods:

Caricella ogilviana n. sp.
Caricella perpinguis n. sp.
Volutilithes pariaensis n. sp.
Lyria wilcoxiana var. *aldrichiana* n. var.
Levifusus pagoda Heilprin
Fusus colubri n. sp.
Fusus bocaserpentis n. sp.
Fusus meunieri n. sp.
Fusus mohrioides n. sp.
Fusus sewalliana n. sp.
Fusus sirenideditus n. sp.
Clavella harrisii n. sp.
Clavella hubbardanus? Harris
Latirus tortilis Whitfield
Strepsidura? soldadensis n. sp.
Pseudoliva bocaserpentis n. sp.
Trophon progne? White
Cassis togatus var. *soldadensis* n. var.
Cypraea bartlettiana n. sp.
Cypraea vaughani n. sp.
Calyptraphorus velatus var. *compressus* Aldrich

Veatchia carolinae n. subg., n. sp.
Cerithium soldadense n. sp.
Turritella humerosa var. *elicitatoides* n. var.
Turritella mortoni Conrad
Turritella nerinexa Harris
Turritella soldadensis n. sp.
Mesalia pumila var. *allentonensis* Aldrich
Mesalia pumila var. *nettoana* White
Calyptraea aperta Sol.
Amauropsis caloramans n. sp.

Van Winkle (1919, p. 19–23) added to these:

Astarte mauriana n. sp.
Astarte trinidadensis n. sp.
Marcia pariaensis n. sp.
Macrocallista? veatchi n. sp.
Levifusus whitei n. sp.
Pseudoliva soldadoensis n. sp.
Erato vaughani n. sp.

Schilder (1939, p. 15–17) determined the following gastropods: *Archicypraea trinidadensis trinidadensis* n. sp., n. subsp., *Archicypraea trinidadensis degenerata* n. subsp.

Rutsch (1943, p.184) listed the following mollusks collected by the senior author:

Pelecypods:

Cucullaea (*Latiarca*) *hartii* (Rathbun)
Glycymeris viamediae Maury
Propeamussium sp. indet.
Ostrea cf. *pulaskensis* Harris
Ostrea kochae Gardner?
Ostrea sp. indet.
Astarte trinidadensis van Winkle
Venericardia aff. *parinensis* Olsson
Venericardia (*Baluchicardia*) cf. *ameliae* Perron
Macrocallista (*Costacallista*) *rathbunensis* (Maury)
Corbula (*Caryocorbula*) sp. indet.

Gastropods:

Mesalia scotti n. sp. (type locality: K.1315, C-5)
Mesalia aff. *nettoana* White
Mesalia sp. indet. A.
Turritella (*Torquesia*) *elicitatoides* Maury
Turritella sylviana Hartt?
Vermetidae gen. indet.
Cerithium (*Nerineopsis*?) *buarquianum* (White)
Calyptraphorus velatus compressus (Aldrich)
Veatchia carolinae Maury
Cromium? sp. indet.
Archicypraea trinidadensis Schilder
Archicypraea trinidadensis degenerata Schilder
Priscoficus jonhstoni nov. sp. (type locality: K.1315, C-5)
Pseudoliva soldadensis van Winkle
Pseudoliva bocaserpentis Maury
Harpa (*Eocithara*) *soldadensis* (Maury)
Athleta (*Volutocorbis*) *pariaensis* (Maury)
Lyria? *wilcoxiana aldrichiana* Maury
Clinuropsis cf. *pagoda* (Heilprin)
Clinuropsis diderrichi Vincent (mentioned in 1939)

Cephalopoda: *Hercoglossa* cf. *harrisi* Miller & Thompson.

Echinoids:

Jeannet (1928, p. 16) described *Linthia caraibensis* n. sp. from the Jacksonian of Soldado Rock. However, this echinoid is derived from the block K.1317A(E-5) which carries a molluscan fauna typical of Bed 2.

Kugler (1938, p. 12) mentioned *Salenia* sp. from Bed 1. Later on, 8 specimens of *Salenia* were found in Bed 2. Dr. Porter M. Kier of the National Museum of Natural History, Washington, received from the senior author echinoids from the Soldado Rock and wrote (private letter 29 October 1971):

"Four species are represented in the collection. One of these species is a very poorly preserved fragment that can be definitely identified as belonging to the genus *Rhopostoma*. Only one species is known of this genus, *Rhopostoma cruciferum* (Morton), from the Paleocene Vicentown Sand (Rancocas Group, exposed in New Jersey; author's note). The Trinidad fragment may belong to this species. This fragment is numbered E.L.1575".

"There are eight specimens belonging without question to the genus *Salenia*. These specimens are distinct from any other species of this genus in the New World. In particular, they are easily distinguished from the only other Paleocene species in the New World, *Salenia tumida* Clark from the Paleocene Vincentown Sand. Probably these specimens represent a new species. They are numbered K.2948".

"There is one crushed fragment of a spatangoid. It is too poorly preserved for generic identification. It might be a *Hemiaster*, but it is distinct from the three species that are known of the genus from the Paleocene Vincentown Sand. This fragment has been numbered K.2951". (Author's note: K.2951 is in Bed 3, but the specimen may be reworked.)

"Two fragments can be referred to *Cidaris* sp. Likewise they are distinct from any of the New World species of this genus. Their number is E.L.1575".

Foraminifera, etc.:

The sample K.9454(B-4) contains the following fossils:

Ranikothalia sp., small rolled fragments of thick-walled forms
"*Discocyclina*" (*Neodiscocyclina*?) sp. indet., very small (rare)
Textulariidae
Miliolidae
Globigerinidae
Oysters, large (abundant)
Corals (few)
Algae, large and small (abundant)

e) Age of Bed 2: Paleocene

Rutsch (1939*d*, p. 621) suggested that the Soldado Formation indicates very old Paleocene, probably Montian. The gastropod *Clinuropsis diderichi* Vincent, of which several specimens were found in the equivalent of the Soldado Formation in the Marac Quarry of Trinidad, was previously only known from a Paleocene limestone of Landana in the Congo.

Rutsch (1943, p. 187) was of the opinion that the Soldado Formation might represent an intermediate position between the Maastrichtian and the Midway Formation, for the Soldado Formation contains forms such as *Venericardia* (*Baluchicardia*) *ameliae* Peron, which are known from the Upper Cretaceous of North Africa.

f) Paleoecology

The coquina layer of Bed 2 is a marine shallow water deposit. The common presence of glauconite suggests quiet sedimentary conditions along a rocky coast far from the mouth of an important river. The numerous broken shells may point to the presence of larger predators feeding on mollusks.

g) Remnant blocks of Bed 2

These are partly large blocks in Beds 4–9. The most conspicuous ones are: K.1317A(E-5), limestone, very rich in fossils but with little glauconite; K.3742(B-5), limestone with oysters which are partly replaced by hematite; a limestone sample collected by C. Joos, light grey, full of crab remains (*Callianassa*?).

Dr. P. Jung and Mr. R. Panchaud collected the following samples from blocks considered to belong to Bed 2, because they carry a more or less rich fauna of mollusks, echinoids, etc: P.J.1148, 1149, 1150, 1151, 1158(=K.1317A), and 1167.

Remnant blocks of the Soldado Formation, not directly connected with Beds 1 and 2

If we call Beds 1 and 2 the "type section" of the Soldado Formation, we should not forget that the whole complex is nothing but a rootless block which represents but a small part of the entire Paleocene section as it was originally deposited.

Apart from Beds 1 and 2, where the Paleocene appears more or less in natural sequence in the limestone mass which forms the Southern part of Soldado Rock, the whole of the islet is strewn with blocks and boulders of erratic material, many of which we can directly or indirectly trace to the same formation.

In the typical Soldado Formation of Beds 1 and 2, Larger Foraminifera are extremely rare. However, there are strong reasons for believing that the foraminiferal limestones and marls, which form the clastic material of the Upper Eocene Bed 3 belong to the same sedimentary cycle as the underlying beds. At first, this Bed 3 was considered to be a sound stratigraphical unit, grading from bottom to top from a marl with calcareous lenses into banks of dense limestone and spathic limestone, but it is now considered as a marl choked with masses of slumped older material. The marl matrix (K. 2950, 2951, C-4) is full of loose Paleocene Larger and Smaller Foraminifera, but at its top the bed consists of practically undisturbed banks of foraminiferal limestone which have slumped into this younger deposit. It is this limestone (not the marl) which deserves the name of "Pellatispirella limestone" (KUGLER 1938, p. 214) or, as we call it now in agreement with more modern nomenclature: the "Ranikothalia limestone" (T.L.L.125, C-4). Its fauna, in which *Ranikothalia* is the predominant form, is typical of the Paleocene and of a lagoonal habitat.

A shift in the quantitative relation between the components of this assemblage leads to the development of a reef limestone in which *Neodiscocyclina* predominates over *Ranikothalia*. This "Neodiscocyclina grimsdalei limestone" is linked to the former type of rock by gradual transitions. It is not known from Bed 3, but only as scattered blocks elsewhere.

Apart from the rather common foraminiferal limestones there are blocks of two other, rarer, kinds of limestone, which are mainly built up by algae. In one of them, *Athecocyclina soldadensis* (VAUGHAN & COLE) is locally abundant and, accordingly, it is called here the "Athecocyclina limestone" (= the "Discocyclina limestone" of KUGLER 1938, p. 216). The other one is a dense pseudo-oolitic limestone composed exclusively of the elements of dismembered Dasyclad algae. Also an *Amphistegina – Lithothamnium* reef deposit may have to be included in the description of the formation (K.S.25, p. 379).

The stratigraphical relationship between these limestones is anybody's guess, but because paleontologically the Dasyclad algae limestone seems to be closest to Bed 2, we put this at the bottom of the list. The Ranikothalia limestone may be a little younger than the Athecocyclina reef as here and there it contains fragments of the latter. For these reasons we have listed those remnants as follows, from bottom to top: Dasyclad algae reef, Athecocyclina reef, Ranikothalia limestone (with its lateral variant, the Neodiscocyclina grimsdalei limestone), but there cannot be a great difference in age between them.

Dasyclad algae limestone

a) Description of the samples

One of the types of old limestone, represented by erratic blocks at K.10711(D-2), K.10724(D-1), J.S.1949(D-1) and J.S.1954(C-1), is a dense "porcellaneous" rock of pseudo-oolitic aspect, exclusively built up of tiny fragments of disintegrated calcareous algae (illustrated in Part 2, Paleontology, Pl. 29, Fig. 14; Pl. 30, Fig. 1, 2). J. B. Saunders of Pointe-à-Pierre calls this a "biomicrite". Provisionally, CAUDRI considers these algae as belonging to the Dasycladaceae, but more expert investigation is necessary. From the rock sections of J. S. 1954, Dr. E. Gasche of the Basel Museum determined the following forms (which do not belong to the Dasycladaceae): *Ovulites* cf. *elongata* LAMARCK (the single tubes, loc. cit., Pl. 29, Fig. 14), *Marinella* n. sp., Corallinaceae div. gen., sp., sp. indet. More material of this type of limestone, also from localities outside Soldado Rock (San Juan de los Morros, Venezuela) is needed for a specialized study.

- K.10711(D-2), whitish highly recrystallized pseudo-oolitic limestone (one of the components of the dense limestone blocks that carry the trigonometric mark on the highest top of the Rock); Dasyclad algae (rock-building); echinoid spines (rare).
- K.10724(D-1), whitish dense recrystallized porcellaneous-looking limestone (as K.10711); Dasyclad algae (rock-building); gastropods (very rare).
- J.S. 1949(D-1), dense porcellaneous limestone (with clear crystalline matrix) (as J.S.1954, but occurring as rounded pebbles in a more opaque groundmass carrying the same fossils; deposit formed under the influence of tidal currents); Dasyclad algae (rock-building); other algae (rare); gastropods (small, rare).
- J.S.1954(C-1), dense porcellaneous limestone (with clear crystalline matrix); Dasyclad algae (rock-building).
- K.3876(F-3), blocks in the conglomeratic rubble.

a) grey, highly crystallized limestone without glauconite.

Pelecypods (common)
Gastropods (common)
Dasyclad algae (abundant)

b) grey, highly crystallized, somewhat glauconitic algae limestone, locally full of mollusk fragments.

Smaller Foraminifera (scarce)
Ostracods?
Pelecypods (common)
Gastropods (common)
Algae, small rounded forms of Corallinaceae?
  (aff. *Lithothamnium*) (abundant)
Dasyclad algae (scarce), concentrated especially
  in the cavities of the Gastropods

There are also indications of the presence of these algae in the sample K.S.25(G-3), an *Amphistegina–Lithothamnium* reef of a quite unique nature for Soldado Rock: a light greenish-grey, white-spotted recrystallized limestone with a fair amount of markasite but nearly free of glauconite, which contains:

Amphistegina (abundant)
Miliolidae (scarce)
Gastropods (scarce)

Echinoids (scarce)
Lithothamnium, fairly large specimens
  (abundant)
Dasyclad algae? (very rare)

b) Age of the Dasyclad algae limestone

Traces of doubtful Dasyclads were found also in the main mass of the Soldado Formation (sample Z.444B, Bed 2; see p. 375), and also the lithology and the fauna of K.3876 suggest that this "pseudo-oolitic" limestone has very close links with Bed 2.

The Dasyclad algae limestone corresponds further with the pseudo-oolitic limestones carrying "tubiform ooliths" described by CAUDRI (1944) from San Juan de los Morros in Central Venezuela. In that area, the peculiar algae are accompanied by a typical Paleocene fauna of Larger Foraminifera: *Neodiscocyclina aguerreverei* (CAUDRI), *Athecocyclina* cf. *cookei* (VAUGHAN), *Hexagonocyclina meandrica* CAUDRI, *Actinosiphon barbadensis* (VAUGHAN), *Ranikothalia antillea* (HANZAWA) and *Ranikothalia tobleri* (VAUGHAN & COLE). We do not hesitate to place the blocks from Soldado Rock also in the Paleocene, though locally they lack these index fossils.

Unidentified fossiliferous limestone

Apart from the Dasyclad algae limestone, the composite sample K.10711(D-2) contained also a boulder of a different kind of recrystallized organic limestone (illustrated in Part 2, Paleontology, Pl. 30, Fig. 3, 4). The unidentified tubular organisms which fill this rock are much larger than the scattered fragments of the Dasyclads and their texture seems to be different, but also they may turn out to be algae.

Provisionally, this limestone is likewise assigned to the Paleocene, as a local development of the Soldado Formation.

The Athecocyclina limestone

Author of the name: CAUDRI (1966, private letter) suggested introducing this name to replace KUGLER's term "Discocyclina limestone" which was rendered obsolete by VAUGHAN & COLE's re-determination of the predominant "*Discocyclina*" as *Pseudophragmina* (*Athecocyclina*) *soldadensis* in 1941.

Original description (as "Discocyclina limestone"): KUGLER 1938, p. 216.

a) Bibliographic history

VAUGHAN & COLE (1941, p. 62) described *Pseudophragmina* (*Athecocyclina*) *soldadensis* from K.2851. VAUGHAN (1945, p. 101) supplied some additional information on the same material.

b) Description of the samples

The limestone is found in the form of erratic blocks only, embedded in the conglomeratic part of Bed 4 (Upper Eocene). The type sample K.2851(E-4) is the largest of these blocks, the one which furnished the material for VAUGHAN & COLE's description of *Athecocyclina soldadensis.* It is a grey, silty, somewhat glauconitic reef limestone, which weathers to a nodular cavernous mass of corrugated layers and irregular pockets through which the faunal elements are unevenly dispersed. Shells, wafer-thin tests of *Athecocyclina* (illustrated in Part 2, Paleontology, Pl. 11, Fig. 2), Smaller Foraminifera (chiefly Globigerinidae s.l.), echinoid detritus and algae are concentrated in separate nests. The sample contains:

Athecocyclina soldadensis (VAUGHAN & COLE) (locally abundant)
Neodiscocyclina aguerreverei (CAUDRI) (one specimen observed)

Smaller Foraminifera (*Nodosaria* s.l., Rotaliidae,
Globigerinidae s.l., *Textularia* s.l., etc.) (locally abundant)
Pelecypods (amongst others: "*Pecten*") (locally abundant)
Gastropods (scarce)
Echinoids, detritus (locally abundant)
Corals (scarce)
Algae (locally abundant)

Another enormous block of the same aspect as K.2851, lying in Bed 4 at K.1318 (F-3), was carefully measured. It is about 10 m long and wide, and 7 m thick.

Fig. 4. K2851(E-4) Athecocyclina limestone, 2.5 m thick. Bird (Noddy tern) in centre is about 15 cm high (photo H. G. Kugler 1934).

Other blocks of this same limestone (not studied in detail) are: K.1319, K.2850 and K.2849, all in F-3 on the map. K.10720(B-2) and Cd.22 and 23(G-3) were studied for their fossil contents by CAUDRI. A small pebble of the same kind of limestone was found embedded in the *Ranikothalia*-bearing limestone at K.3740(E-4):

- K.10720(B-2), dense whitish limestone with hardly any glauconite, full of badly preserved Larger Foraminifera (block resting on top of the Boca de Serpiente glauconite K.10719).
- Cd.22(G-3), dense grey glauconitic limestone, full of very small algae, echinoid fragments and Globigerinidae.
- Cd.23(G3), dense grey limestone, as Cd.22 but without any Larger Foraminifera:

Rotaliidae (abundant)
Globigerinidae and *Globorotalia* (common)
Arenaceous foraminifera (scarce)
Pelecypods and gastropods (scarce)
Echinoids (common)
Algae, very small (abundant)

- K.3740(E-4), pebble of grey glauconitic limestone, lithologically as Cd.22 and 23, with Smaller Foraminifera, numerous worm tubes and abundant small algae (enclosed in a block of glauconitic sandy limestone carrying a doubtful *Ranikothalia* fauna; see under "Ranikothalia limestone", p. 383).

c) *Age of the Athecocyclina limestone*

Because this limestone is known in the form of erratic blocks only, we are not sure where exactly it should be placed in the Soldado section. Though special environmental conditions have favoured the development of one single species of "orbitoid", the fauna of this reefal deposit is essentially the same as that of the Ranikothalia limestone, and its age cannot be too different.

Because of its position in the field, KUGLER (1938) originally assumed that the Athecocyclina limestone would perhaps represent a slightly higher level than the Ranikothalia limestone, but it has become clear that, if anything, it might be a little older (see enclosure in *Ranikothalia*-bearing rock at K.3740).

The Athecocyclina limestone has been compared by VAUGHAN & COLE (1941) with the upper part of the Nanafalia Formation of Alabama which VAUGHAN (1945) calls Upper Midway.

The Ranikothalia limestone

Author of name: CAUDRI 1972*b*, p. 227
Original description (as Bed 1 of group "B"): KUGLER 1923, p. 256
Type sample: T.L.L.125(C-4)

a) *Bibliographic history*

KUGLER (1923, p. 255) described from Soldado Rock a sandstone–marl group ("B") composed of four different beds, overlying group "A" of which MAURY'S Bed 2 forms the top. Bed "B-1" is a brown, silty limestone containing *Nummulites* and *Orthophragmina*, to which an Auversian age was assigned. This limestone was grouped together with a superimposed conglomerate.

LEHNER (1935, p. 696) mentioned a Nummulite limestone resting on Venericardia limestone.

KUGLER (1938, p. 214) stated that the top part of his new Bed 3 is formed by about 50 cm of dense brown silty limestone and yellowish white dense limestone. From this limestone VAUGHAN & COLE (in a private report for Trinidad Leaseholds Ltd.) mentioned the following Larger Foraminifera:

Pellatispirella antillea HANZAWA
Discocyclina sheppardi BARKER
Discocyclina grimsdalei n. sp.

Kugler suggested that this limestone be called the "Pellatispirella limestone".

VAUGHAN & COLE (1941, p. 24–26) listed from Bed 3 (the limestone T.L.L.125 and the marls K.2950 and 2951, all in C-4) the following species:

Miscellanea antillea (HANZAWA) (new determination of "*Pellatispirella*" *antillea*)
Miscellanea sp. cf. *M. antillea* (HANZAWA)
Miscellanea soldadensis VAUGHAN & COLE n. sp.
Miscellanea sp. cf. *M. soldadensis* VAUGHAN & COLE
Discocyclina (*Discocyclina*) *barkeri* VAUGHAN & COLE n. sp.
Discocyclina (*Discocyclina*) *grimsdalei* VAUGHAN & COLE n. sp.

Like SENN in 1940, the authors compared this assemblage (in combination with the Athecocyclina limestone) with the limestone blocks in the Joes River mudflows of Barbados, and correlated the fauna with that of the upper part of the Nanafalia Formation in Alabama (Lower Eocene in U.S. terminology; Paleocene according to European usage).

CAUDRI (1944, p. 378) added *Athecocyclina soldadensis*, two species of *Discocyclina* and two species of *Hexagonocyclina* to VAUGHAN & COLE'S list of Bed 3. She substituted the new name of *Ranikothalia* for their *Miscellanea.*

VAUGHAN (1945, p. 1, 19, 104) correlated, on the basis of the Discocyclinidae only, Bed 3 with the blocks in the Joes River mudflows, and with the upper part of the Midway in the Gulf States (either Lower Eocene or Paleocene).

Caudri (1948, p. 478) repeated the 1944 list of Larger Foraminifera of Bed 3, including the limestone banks at the top.

Drooger (1960*b*, p. 450) reported from the Basses Plaines Formation of French Guyana a microfauna containing *Ranikothalia soldadensis* and concluded; "there is a remarkable agreement with the Paleocene fauna described from Soldado Rock".

Caudri (1972*b*, p. 227) changed the term "Pellatispirella limestone" to "Ranikothalia limestone" in accordance with the modernized generic name of its index fossil.

b) Description of the blocks of more or less intact limestone, slumped into Bed 3

- T.L.L.125(C-4), type sample of the Ranikothalia limestone: yellowish-brown limestone with "*Nummulites*".
- K.906(C-4), brown dense muddy limestone, greyish-green in fresh condition; matrix full of tiny calcite rhombohedrons.
- K.10701(D-4), brown recrystallized limestone with scattered small fossils and algae fragments in a matrix of minute rhomboid calcite crystals.
- K.10702(D-4), as K.10701 but highly fossiliferous: a breccia of badly preserved Larger Foraminifera in a matrix of micro-crystals of calcite; algae (*Archaeolithothamnium* and others).
- Rz.252(C-4), hard yellowish-brown muddy limestone with common Larger Foraminifera and a multitude of small algae fragments.

c) Description of the isolated blocks scattered throughout Beds 4-11

- K.3694(D-2), brown pitted limestone with abundant "*Nummulites*", up to 9 mm in diameter.
- K.3739(G-3), foraminiferous breccia.
- K.3740(E-4), block of glauconitic sandy limestone (lithologic description somewhat doubtful), enclosing pebbles of grey glauconitic recrystallized algae limestone (see under "Athecocyclina limestone", p. 381)

  Ranikothalia antillea? (scarce)
  Neodiscocyclina cf. *grimsdalei*? (scarce)

- K.3876(F-3), one of several blocks of limestone (see also under "Dasyclad algae limestone", p. 379).

  Ranikothalia sp.
  Neodiscocyclina sp.

- K.10708(D-3), dense white marble-like algae and foraminifera limestone, embedded in marl K.10707 (Bed 10); small specimens of algae only.
- K.10725(B-3), brown foraminiferal limestone, in part highly recrystallized, but partly with well preserved fossils.

d) Paleontology

The hard limestones enclosed a large amount of Larger Foraminifera in an excellent state of preservation, but the fauna has become known in all its fullness only from the detached specimens which have been washed out of pockets and layers of interbedded softer material, and are now found redeposited in the marly part of Bed 3, and the matrix of the rubble of Bed 4.

In Bed 3, the fauna of the samples K.2950 and K.2951(C-4), and Rz.255(D-4), is nearly exclusively Paleocene, so as to obscure the Upper Eocene evidence of the deposit, and also in K.2951B (Bed 4, C-4) the Paleocene forms are by far in the majority.

The combined Paleocene fauna of Larger Foraminifera in these samples consists of:

Ranikothalia antillea (Hanzawa)[4]
Ranikothalia tobleri (Vaughan & Cole)[4]
Ranikothalia soldadensis (Vaughan & Cole)[4]
Athecocyclina soldadensis (Vaughan & Cole)
Neodiscocyclina barkeri (Vaughan & Cole)
Neodiscocyclina cf. *caudriae* (Vaughan)

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[4] Presumably all three are varieties of *Ranikothalia catenula* (Cushman & Jarvis)

Neodiscocyclina grimsdalei (Vaughan & Cole)
Neodiscocyclina aguerreverei (Caudri)
Neodiscocyclina fonslacertensis (Vaughan)
?*Neodiscocyclina mestieri* (Vaughan)
Hexagonocyclina meandrica Caudri
Hexagonocyclina inflata (Caudri)
Actinosiphon barbadensis (Vaughan)

Amongst the Smaller Foraminifera of the marl samples K.2950 and 2951, determined by Cushman & Renz in 1942, the following also showed a distinctly Midwayan character:

Gaudryina soldadensis Cushman & Renz
Nodosaria affinis Reuss
Vaginulina plumoides Plummer
Vaginulina robusta Plummer
Guttulina sp.
Globulina gibba d'Orbigny
Siphogenerinoides eleganta (Plummer)
Gyroidina subangulata Plummer
Nonionella soldadensis Cushman & Renz
Eponides elevata (Plummer)
Pulvinulinella obtusa (Burrows & Holland)
Anomalina acuta Plummer

In view of the heterogeneous nature of the material, the affinities of the other species mentioned in their paper are left out of the discussion here, but several of their new forms may likewise prove to be characteristic of the Paleocene. The same may apply to the additional species determined by T. F. Grimsdale and by K. Schmid, mentioned by Kugler in 1938 (p. 215).

Cristellaria rotulata (Lamarck)
Vaginulina gracilis Plummer
Eponides lotus Schwager
Valvulineria cf. *wilcoxensis* Cushman & Ponton

e) Age of the Ranikothalia limestone: Paleocene

Faunistically, the Ranikothalia limestone is linked to the coquina of Bed 2 by the contents of the oyster bed at K.9454(B-4), which carries both shells and Larger Foraminifera. Though from its position in the field it seems probable that the Ranikothalia reef was originally the highest unit of the now missing part of the section above the shell bed, there cannot have been much of a difference in time between their deposition, and we are inclined to consider the two as practically contemporaneous. The development of the foraminiferal reef seems to represent the latest phase in the cycle of sedimentation within the Soldado Formation itself.

Vaughan & Cole (1941), and Vaughan (1945) give as the age of the fauna in Bed 3 (limestone and marl combined): Upper Midway (correlative with the Nanafalia Formation).

In America, a certain controversy is still going on over the question whether this level should be called early Lower Eocene or Late Paleocene, but we follow the terminology of Bolli (1952) and Brönnimann (1952), who correlated the planktonic foraminifera of Bed 3 with those of the lower part of the Lizard Springs Formation in Trinidad, which was placed in the Paleocene. Because of its relationship to the underlying shell beds, the Ranikothalia limestone is probably Late Paleocene in age. It is the equivalent of Cole's "*Operculina catenula* Zone" (1959).

The Neodiscocyclina grimsdalei limestone

This is a reefal variant of the Ranikothalia limestone, in which large forms of *Neodiscocyclina* predominate over the Ranikothalias and often take over as rock-building elements. In most cases the species can be identified (in rock sections) as *N.*

grimsdalei (VAUGHAN & COLE), showing the typical central depression of the test and here and there the characteristic embryonic apparatus with its "floating" protoconch. But even where these features are not evident, the determination will generally be correct or not too far off: the forms are always flat and have the same type of lateral chambers as *N. grimsdalei*. The only alternative would be *N. aguerreverei* (CAUDRI).

This Neodiscocyclina grimsdalei limestone has been found in scattered blocks only, in Bed 9 and in Bed 11. It is also known as blocks in the Upper Eocene of Point Bontour in the San Fernando area of Trinidad.

a) *Typical examples of this limestone*

- K.9453(G-3), large blocks of dense yellowish-brown limestone full of large flat *Neodiscocyclina* and bryozoans.
- K.10724(D-1), whitish limestone (one of the blocks at this locality; the other is a Dasyclad algae limestone).

b) *Transitions*

The following samples form transitions to the Ranikothalia limestone:

- K.10710(D-3), whitish algae breccia full of the fragments of Larger Foraminifera, rather large algae and other fossils; matrix full of minute rhomboid calcite crystals (compare K.10701, 10702, 10710; Rz.248).
- K.10717(B-2), huge block of light brown foraminiferal limestone; matrix as K.10710.
- Rz.248(F-3), yellowish-brown highly recrystallized algae and foraminifera limestone; matrix as K.10710.

c) *Age of the Neodiscocyclina grimsdalei limestone: Paleocene*

The age of the Neodiscocyclina grimsdalei limestone is the same as that of the Ranikothalia limestone. They are local variations of the same kind of reef system.

Reworking of the Paleocene fauna into the younger sediments

As can be expected, not only entire blocks and boulders of hard Paleocene limestone lie scattered throughout the younger beds of the Soldado section, but also a great many detached specimens which have their origin in the softer more marly components of the Soldado Formation.

The heaviest reworking was observed in the transgressive beds of Early Late Eocene age: the marls of Bed 3 (K.2950 and 2951; Rz.255), and the rubble and the indurated limestone lenses of Bed 4 (K.2951B; K.S.23 and 24), where the predominance of Paleocene forms over the autochthonous markers is so overwhelming that it masks the genuine age of the deposits (see p. 390–391 and 394–395). For further details of this phenomenon of reworking we refer to the "Distribution Chart".

Occurrence of equivalents of the Soldado Formation

Shell limestones and foraminiferal reefs with a Paleocene fauna comparable with the Soldado Formation have been found in several places in the Caribbean area and along the West Coast of South America.

Trinidad

Also in nearby Trinidad no continuous section of the transition from Cretaceous to Paleocene in the shallow water facies is exposed, but blocks of shell limestones of that age occur in the Southern half of the island. The Maastrichtian (in general the Guayaguayare Formation) is represented as a shallow water deposit by the Bontour Formation of HARRIS (1926, p. 97). It is, however, a "remnant formation" in the sense of SUTER (1951, p. 192) and is known only as large blocks of mainly grey calcareous quartzose sandstone, partly fine conglomeratic, with such fossils as *Roudairia*, *Psilomya*, *Ostrea tripolitana* KRUMBECK, etc. This aspect points to inner shelf conditions and it is, therefore, not surprising to find also the next younger deposit, the Soldado Formation, developed in a similar facies: as an impure glauconitic coquina of large shells. The environment may have been a little different, but the formation was likewise deposited in shallow water on the inner shelf. Since none of these Maastrichtian or Paleocene shell beds has been observed anywhere in Southern Trinidad in normal sequence, the conclusion is that the blocks have been transported from the North, either from the Central Range, or even from farther away.

The blocks of Paleocene coquina occur in the Late Eocene Plaisance conglomerate along the South foot of the Central Range from Pointe-à-Pierre in the West to near the Nariva Swamp in the East. In the Southern Range it is the Marac Quarry which has furnished the richest collection of Midwayan shells.

Apart from the typical Soldado coquina, also traces of the other units of the Soldado Formation are found in Trinidad. The best example of these are the blocks of Ranikothalia – Neodiscocyclina grimsdalei limestone embedded in the Upper Eocene at Point Bontour near San Fernando, the fauna of which consists of *Ranikothalia antillea*, *Neodiscocyclina grimsdalei*, *N. aguerreverei*, *N. fonslacertensis*, *N. barkeri*, *Athecocyclina soldadensis*, *Hexagonocyclina meandrica*, *H. inflata* and *Actinosiphon barbadensis* (CAUDRI 1944, 1948). Loose specimens of these forms are scattered throughout the Middle Eocene Navet and the Upper Eocene San Fernando Formations at several localities.

On account of the Larger Foraminifera fauna, the Lizard Springs marl at its type locality Mky 102b III is considered to be the direct age equivalent of the Ranikothalia limestone of Soldado.

Other Caribbean islands, Venezuela and elsewhere

During the excursion to Barbados, organized by the Fourth Caribbean Geological Conference in April 1965, a large block of fossiliferous limestone, reminiscent of the typical Soldado Formation, was found in the Chalky Mount Formation of Middle Eocene age.

MAURY (1925, p. 412) reported from Margarita Island "beds with *Venericardia planicosta*" belonging to the Midwayan Paleocene. These beds have, however, never since been located on the island, and it is probable that they were represented by blocks only.

SALVADOR & STAINFORTH (1968, p. 33) mentioned from the State of Monagas, Eastern Venezuela, the occurrence of a shell limestone at the base of the Paleocene part of the Vidoño Formation, overlying the Maastrichtian San Juan Formation. According to the faunal contents of this limestone, correlation with the Soldado Formation is suggested. Previously, LIDDLE (1928, p. 182) and SENN

(1940, p. 158) had already reported a similar limestone, full of shells of the *Venericardia planicosta* group, from an outcrop in the State of Anzoategui (Cerro Corazon, north of Urica). According to HEDBERG (1937, p. 1996), this limestone is believed to belong to the Caratas Member of the Santa Anita Formation.

The Stratigraphical Lexicon of Venezuela (1956, p. 155 and 233) refers to Paleocene mollusks in the Caratas Formation of Anzoategui and the Guarico Formation in the area of San Juan de los Morros.

MUÑOZ (1966, p. 139) observed a coquina carrying *Venericardia* cf. *planicosta* in the lowest part of the Humocaro Formation of the Andes in the State of Lara.

BUTTERLIN (1956, p. 188) discussed a questionable occurrence of Paleocene with *Venericardia parinensis* on Curaçao.

LIDDLE (1928, p. 184, and 1946, p. 301) equated the Soldado Formation with the Rio Guasare Formation in Trujillo. In the Rio Cachiri section (1946, p. 304) he found the Rio Guasare Formation to include at its base 350 feet of solid limestone. This limestone is also present in small outcrops on Toas Island at the mouth of Lake Maracaibo. Several mollusks are listed from this formation (1946, p. 301), amongst others *Venericardia planicosta* and *Turritella mortoni*, which, according to WEINGEIST (Stratigraphical Lexicon of Venezuela 1956, p. 377), should be identified as *Venericardia* (*Venericor*) *toaensis* DUSENBURY and *Turritella mediavia* BOWLES, respectively. RUTSCH (1936*a*, p. 172) reported other localities in Venezuela where forms of the "*planicosta* group" have been observed. Also mentioned are localities in Barbados, St. Bartholomew, Panama, Colombia, Peru and Chile.

The above refers only to the shell limestones, the direct equivalent of Bed 2 on Soldado Rock. If we do not restrict ourselves to those, but include also the foraminiferal reefs that on Soldado are represented by the Ranikothalia limestone and its variations, the Athecocyclina limestone and the reefs of Dasyclad algae, we can extend the correlation even more.

COLE's "*Operculina catenula* fauna" (1959) (to us: the *Ranikothalia* assemblage) is found in many places in the Caribbean area and around the Gulf of Mexico.

First to be mentioned are the remnant blocks in the Joes River mudflows of Barbados (SENN 1940; VAUGHAN 1945; DE CIZANCOURT 1948; CAUDRI 1948, p. 476, and 1972*b*, p. 226).

Then, there are several records from Venezuela: the reef limestones of San Juan de los Morros in Guarico, where the foraminifera are accompanied by Dasyclad algae such as are known from the blocks at K.3876, K.10711, K.10724 and J.S. 1949 and 1954 on Soldado Rock (CAUDRI 1944), the base of the middle part of the Humocaro Formation in Lara, above the Venericardia limestone (CAUDRI 1961, p. 256; MUÑOZ 1966, p. 139–140), the foraminiferal beds included in the "Guasare Formation" by SUTTON, in Trujillo (CAUDRI 1948, p. 479) and the many limestones described by DE CIZANCOURT in 1951 as belonging to her "zone des nummulites cordelées" in Western and Central Venezuela.

The fauna is also known from Jamaica (ROBINSON 1968, p. 190), Haiti (COLE 1959, p. 378), Cuba (PALMER 1934; CAUDRI 1948, p. 475, footnote 7; BRÖNNIMANN & RIGASSI 1963), Mexico (Chicontepec Formation, CAUDRI 1948, p. 377) and Georgia (COLE & HERRICK 1953).

In a reworked condition, many Paleocene forms also occur in the Middle Eocene Upper Scotland Formation of Barbados (DE CIZANCOURT 1948; CAUDRI 1972*b*).

B. THE SAN FERNANDO FORMATION

The Upper Eocene part of the Soldado section is correlated with the San Fernando Formation of Trinidad. It comprises Beds 3 through 10 of KUGLER's 1938 section, as well as the blackish Asterocyclina marl (9a), which originally was included in Bed 9, but which we now consider as a separate unit. Bed 11 does not belong to the San Fernando Formation: it is a slump mass of older material which has become embedded in the Upper Eocene.

In 1938, KUGLER included Bed 3 in the Soldado Formation, because in the field no definite break was visible between this marly deposit and the Paleocene coquina (Bed 2), and also because the preliminary determination of the Larger Foraminifera by T. W. Vaughan and W. S. Cole seemed to indicate this age. Continued work on both Larger and Smaller Foraminifera by C. M. B. Caudri and by J. B. Saunders has since brought to light that there are also minor amounts of Late Eocene Foraminifera in the marls and calcareous silts, which proves that Bed 3 belongs to the San Fernando Formation, and not to the Paleocene.

Bed 3

a) Bibliographic history

Apart from the literature already mentioned on p. 269–373 and 382–383, the following publications refer more specifically to Bed 3:

KUGLER (1938, p. 214, 220) described Bed 3 as a series of marls and calcareous silts including calcareous lenses, and towards the top even whole banks of limestone. After the predominant fossil in it, determined by VAUGHAN & COLE as "*Pellatispirella antillea*", this limestone was given the name of "Pellatispirella limestone" (now modernized to Ranikothalia limestone, see above). A few Larger and Smaller Foraminifera were listed.

VAUGHAN & COLE (1941) studied some of the Larger Foraminifera from the type section of Bed 3 (K.2950, K.2951, T.L.L.125, all in grid C-4 of the map). They described *Miscellanea* ("*Pellatispirella*") *antillea* (HANZAWA), *M.* cf. *antillea*, *M. soldadensis* n. sp., *M.* cf. *soldadensis*, *Discocyclina grimsdalei* n. sp. and *D. barkeri* n. sp. and, from a block of "Discocyclina limestone" (K.2851, E-4): *Pseudophragmina* (*Athecocyclina*) *soldadensis* n. sp. The age of these fossils was given as Lower Eocene (see discussion of the Paleocene/Lower Eocene controversy on p. 371 and 384 of this paper).

RENZ (1942, p. 533) listed 18 Smaller Foraminifera from Bed 3 and suggested a ?Maastrichtian to Lower Paleocene age for the assemblage.

CUSHMAN & RENZ (1942, p. 1814) described 36 Smaller Foraminifera, nearly all benthonic, from sample K.2950. The fauna was determined as Midwayan (Paleocene), but also showed affinities to the Wilcox (Lower Eocene).

CAUDRI (1944, p. 378) gave a more complete and modernized list of the Larger Foraminifera of Bed 3 (including in it the Athecocyclina limestone K.2851, and a "tubiform oolith", which do not belong to it but are older erratic blocks). She erroneously included Bed 3 in the Soldado Formation, the type deposit of the Paleocene in the Caribbean region, but the age determination of the reworked assemblage as Paleocene is correct.

CUSHMAN & RENZ (1946, p. 2) placed the Soldado Formation (meaning Bed 3!) above the upper part of the Lizard Springs Formation of Trinidad as possibly equivalent to the Lower Eocene base of the Navet Formation.

LIDDLE (1946, p. 310) referred to KUGLER's 1938 paper and concluded: "Conglomerate and rubble from various sources, with silt, sand, shale and marl comprises the base of the Upper (Jacksonian) Eocene which rests on the Soldado Formation. At least 2000 feet of Middle Eocene which are found in Venezuela and Trinidad are not present on Isla Soldado. Of the possibilities non-deposition, removal by erosion, or concealment by folding and faulting, erosion is the most satisfactory explanation." In this context is it not quite clear whether he considered the broken banks of "Pellatispirella limestone" of Bed 3 as belonging to the Paleocene Soldado Formation, or to the rubble of the Jacksonian transgression.

CUSHMAN & RENZ (1948, p. 1, 2) again mentioned the correlation of the Soldado Formation (Bed 3!) with the base of the Navet Formation (Ramdat marl) of Trinidad.

CAUDRI (1948, p. 478) gave a still more extensive list of the Paleocene Larger Foraminifera of Bed 3, including the forms redeposited in the rubble of Bed 4. The unnamed new *Hexagonocyclina* was determined as *Bontourina inflata* n. sp., *Discocyclina "crassa"* was changed to *D. fonslacertensis* VAUGHAN, and *"Lepidorbitoides* cf. *planasi"* and *Discocyclina caudriae* VAUGHAN were added to the 1944 list. She repeated the error of including Bed 3 in the type deposit of the Caribbean Paleocene.

GRIMSDALE (1951, p. 471) stated that the planktonic form determined as *Globorotalia wilcoxensis* var. *acuta* TOULMIN by CUSHMAN & RENZ (1942) is so close to *Globorotalia velascoensis* (CUSHMAN) from Mexico that he was inclined to unite these two forms entirely. He remarked that "*Globorotalia velascoensis* is not found in the oldest layers of the Velasco Formation in eastern Mexico. Nor does it reach down as far as the base of the Tertiary column in Syria. On the other hand, specimens very close to the typical form are recorded (as *G. wilcoxensis* var. *acuta*) from the Salt Mountain limestone (supposedly of Wilcox age) in Alabama and from the top of the Soldado Formation on Soldado Rock (correlated with the Midway). It is worthy of note that GLAESSNER records his *Globorotalia aragonensis* var. *caucasica* from Lower Eocene and not from Paleocene, and this is a typical *G. velascoensis*." Further, the variety *G. wilcoxensis* var. *acuta* "has not been separated from *G. velascoensis* in the range chart. Its range in the Western Hemisphere is early Lower Eocene; in the Middle East it is very rare, but provides occasional examples in the Lower Eocene, associated with *G. aragonensis* and *G.* aff. *globigeriniformis*."

BRÖNNIMANN (1952, p. 155) placed the planktonic fauna of sample K.2950 in the *Globorotalia wilcoxensis* var. *acuta* Zone.

BOLLI (1952, p. 671, 674, 675, Tables 1 and 2) reported from sample K.2950: *Globorotalia wilcoxensis* var. *acuta* and *G. grassata* var. *aequa*. He concluded: "The Soldado Formation considered by CUSHMAN & RENZ (1942, 1946) to be the top of the Lizard Springs Formation, is in fact an age equivalent of the lower zone of the Lizard Springs Formation."

KUGLER (1953, p. 39, 42–44) discussed the Paleocene and Eocene of Soldado Rock in connection with similar units in Trinidad, Venezuela and Barbados. He separated Bed 3 with its (possibly reworked) foraminiferal fauna of Wilcox age from the Soldado Formation (Beds 1–2) and tentatively proposed the term "Serpent Formation" for it. The whole mass of Beds 1 to 3 was described as a rootless block slipped into Upper Eocene silts comparable to various slipmasses in Southern Trinidad, for instance, the Paleocene Marac limestone.

BOLLI (1957*a*, p. 65) stated: "The *Globorotalia* species from the type sample (K.2950) of Bed 3 from Soldado Rock off Trinidad (KUGLER 1938; CUSHMAN & RENZ 1942) have been reinvestigated and determined as follows:

G. velascoensis (CUSHMAN) (determined as
  G. wilcoxensis var. *acuta* TOULMIN by CUSHMAN
  & RENZ 1942, and by BOLLI 1950, 1952*b*)
G. aequa CUSHMAN & RENZ
G. whitei WEISS
G. elongata GLAESSNER

These species correspond with those characterizing the *Globorotalia velascoensis* Zone, which is the highest zone of the lower Lizard Springs Formation. CUSHMAN & RENZ compare the 'Bed 3' foraminifera with Midwayan faunas from Alabama, but also point to a relationship with the Salt Mountains and the Wilcox of Ozark, Alabama. A stratigraphic position of 'Bed 3' of Soldado comparable with that of the uppermost lower Lizard Springs agrees also with the views of BRÖNNIMANN (1952)."

Van den Bold (1957, Table 1) listed 25 ostracods from K.2950 and K.2951. He stated: "The Ostracoda from Kugler's Bed 3 on Soldado Rock, from Marac Quarry, and from the core samples from wells FC-98 and Rochard-1 show affinity to the Midway fauna of the United States Gulf Coast and to the Guasare limestone of Western Venezuela."

Bolli (1966, p. 9) suggested a possible correlation of the planktonic foraminifera of Bed 3 with the *Globorotalia pseudobulloides* and the *Globigerina eugubina* Zones.

b) Type section of Bed 3

On the South side of the Southern top, from K.2950 to K.2951(C-4) and beyond.

c) Stratigraphic relationship

Bottom: there is no conspicuous break between Bed 2 and Bed 3, but the contact between the coquina and the marl is considered to be the bottom of Bed 3.

Top: the top is formed by the banks of Ranikothalia limestone which are covered by the rubble of Bed 4.

d) Thickness

2.2 meters.

e) Lithology

For the lithology of Bed 3 we have to rely on Kugler's description of 1938. When visiting Soldado Rock in 1951, Kugler found that target shooting of the Royal Air Force during the Second World War had blown away the entire section.

According to the original observation, Bed 3 consisted of two layers of silty marl, described as follows from bottom to top:

- K.2950(C-4) represents the lower bed of 70 cm thickness. It is a light yellowish-brown highly fossiliferous marl and calcareous silt with fine sand, in part finely bedded, containing scattered quartz pebbles the size of cherry stones and pieces of decalcified Soldado Formation. Indurated streaks with quartz grains were noticed to the West of the trench cut from K.2950 to K.2951.
- K.2951(C-4), 1.5 m thick, is essentially an irregular rubbly layer of flat-lying lenticular masses of Ranikothalia limestone embedded in light yellowish-brown fossiliferous marl and partly calcareous silt and sand with grains of bluish quartz. Towards the top, the limestone lenses grade into whole banks of solid limestone, which are partly brecciated on account of weathering. The horizontal banks of Ranikothalia limestone formed the flat top of the southern peak of Soldado Rock.
- Rz.255(D-4) was taken from the same marl as the previous numbers. The Ranikothalia limestone is represented by the samples: T.L.L.125(C-4), K.906(C-4), K.10701(D-4), K.10702(D-4) and Rz.252(C-4). Samples Rz.254(D-4) and Rz.256(C-4) are taken from grey barren silts.

f) Paleontology

The microfauna of Bed 3 (K.2950, K.2951 and the hard Ranikothalia limestone) was divided into four groups, each studied separately by different specialists: the Larger Foraminifera by Grimsdale, by Vaughan & Cole, and by Caudri, the mainly benthonic Smaller Foraminifera by Cushman & Renz, the planktonic foraminifera by Bolli and by Saunders, and the ostracods by van den Bold.

1. The list of Larger Foraminifera runs as follows:

Ranikothalia antillea (Hanzawa)
Ranikothalia tobleri (Vaughan & Cole)
Ranikothalia soldadensis (Vaughan & Cole)
Neodiscocyclina grimsdalei (Vaughan & Cole)
Neodiscocyclina aguerreverei (Caudri)
Neodiscocyclina barkeri (Vaughan & Cole)

Athecocyclina soldadensis (VAUGHAN & COLE)
Hexagonocyclina inflata (CAUDRI)
Hexagonocyclina meandrica CAUDRI
Operculinoides soldadensis VAUGHAN & COLE (one specimen in K.2950)
Lepidocyclina pustulosa (H. DOUVILLÉ) forma *trinitatis* H. DOUVILLÉ (one specimen in K.2951)
Amphistegina cf. *undecima* CAUDRI n. sp. (one specimen in K.2950)

2. CUSHMAN & RENZ (1942) listed the following Smaller Foraminifera:

Ammomargulina sp.
Gaudryina soldadoensis CUSHMAN & RENZ
Quinqueloculina sp.
Robulus cf. *rosetta* (GÜMBEL)
Robulus sp.
Marginulina cf. *scitula* (BERTHELIN)
Nodosaria affinis REUSS
Vaginulina plumoides PLUMMER
Vaginulina robusta PLUMMER
Guttulina sp.
Globulina gibba D'ORBIGNY
Pseudopolymorphina sp.
Sigmomorphina soldadoensis CUSHMAN & RENZ
Nonionella soldadoensis CUSHMAN & RENZ
Gümbelina trinitatensis CUSHMAN & RENZ
Siphogenerinoides eleganta (PLUMMER)
Bulimina kugleri CUSHMAN & RENZ
Augulogerina cf. *parvula* (CUSHMAN & THOMAS)
Trifarina herberti CUSHMAN & RENZ
Ellipsonodosaria sp.
Spirillina sp.
Discorbis midwayensis CUSHMAN var. *soldadoensis* CUSHMAN & RENZ
Discorbis midwayensis CUSHMAN var. *trinitatensis* CUSHMAN & RENZ
Gyroidina subangulata PLUMMER
Eponides elevata PLUMMER
Cancris mauryae CUSHMAN & RENZ
Pulvinulinella obtusa (BURROWS & HOLLAND)
Globorotalia crassata (CUSHMAN) var. *aequa* CUSHMAN & RENZ
Globorotalia wilcoxensis CUSHMAN & PONTON var. *acuta* TOULMIN
Anomalina acuta PLUMMER
Anomalina basilobata CUSHMAN & RENZ
Anomalina sp.
Cibicides praecursorius (SCHWAGER)
Cibicides howelli TOULMIN
Cibicides cf. *semiplectus* (SCHWAGER)
Cibicides cf. *williamsoni* GARRETT

In 1972 (private communication), J. B. Saunders spotted in sample K.2950: *Bulimina jacksonensis* CUSHMAN.

3. The planktonic foraminifera of K.2950 were re-determined by BOLLI (1957*a*) as follows:

Globorotalia velascoensis (CUSHMAN)
Globorotalia aequa CUSHMAN & RENZ
Globorotalia whitei WEISS
Globorotalia elongata GLAESSNER

SAUNDERS stated in 1972 (private letter) that the planktonic fauna of K.2950 consists mainly of Middle to Lower Eocene forms of *Globorotalia* and *Truncorotaloides*, but he also found: *Globorotalia centralis* CUSHMAN & BERMUDEZ (some specimens trending towards *Globigerina ampliapertura* BOLLI).

4. Ostracods are not numerous in K.2950 and K. 2951, but represented by many different species. VAN DEN BOLD (1957) listed:

Platella kellettae MUNSEY
Cytherella sp. sp.
Cytherelloides sp.
Propontocypris sp.
Paracypris communis VAN DEN BOLD
Bairdia dolicha VAN DEN BOLD
Bairdia soldadensis VAN DEN BOLD
Bairdia aff. *hondurasensis* VAN DEN BOLD
Bairdia sp.
Eucythere sp.
Cytheromorpha sp.
Munseyella kyalokystis (MUNSEY)
Buntonia alabamensis (HOWE & PYEATT)
Puriana sp.
Trachyleberis ? *spinisissima* (JONES & SHERBORN)
Pterygocythereis sp.
Hermanites ? *collei* (GOOCH)
Hermanites ? *grimsdalei* VAN DEN BOLD
Brachycythere kugleri soldadensis VAN DEN BOLD
Brachycythere kugleri var.
Cytheretta arrugia VAN DEN BOLD
Eucytherura decorata WEINGEIST
Loxoconcha nuda ALEXANDER
Xestoleberis mauryae VAN DEN BOLD

The above microfauna of Bed 3 is supplemented by small amounts of bryozoans, brachiopods, echinoids and algae. Part of those are doubtlessly also reworked. Mollusks are absent in the marl.

g) *Age of Bed 3: Late Eocene*

In 1938 KUGLER included Bed 3 in the Soldado Formation, mainly because there is no visible break between this marly deposit and the Paleocene coquina of Bed 2. The determination of the rich microfauna at first confirmed this age. The larger Foraminifera determined by VAUGHAN & COLE (1938, in KUGLER; 1941) were comparable to the fauna of the Paleocene Lizard Springs Formation of Trinidad, and also the Smaller Foraminifera seemed to indicate the same age (CUSHMAN & RENZ 1942). These latter authors compared their faunal lists with the Lower Lizard Springs Formation and with the Midway Group of Alabama and Texas, and came to the conclusion that Bed 3 must be of Midway age, although they also drew attention to a certain relationship with the Wilcox of the Salt Mountain Formation and the Ozarks in Alabama and, through this, to the Middle Eocene of North Africa. BOLLI (1957*a*) determined the level of K.2950, on account of the planktonic species, as the *Globorotalia velascoensis* Zone, the top zone of the Lower Lizard Springs Formation.

Subsequent studies of the fauna by CAUDRI (Larger Foraminifera, present paper, Part 2), and SAUNDERS (Smaller Foraminifera, 1972, private correspondence) have, however, unmistakably proved the presence of Late Eocene foraminifera in the marls and calcareous silts of this bed. The overwhelming amount of forms, suggestive of the Lower Lizard Springs Formation, against the negligible traces of Late Eocene Larger Foraminifera have lead both KUGLER and CAUDRI to believe for years that the occurrence of the latter was unreliable and caused by contamination, either in the field through dry season cracks, or in the laboratory, where so much rich Late Eocene material was being processed at the same time. But after SAUNDER'S observation on the planktonic forms, this assumption can now be ruled out. An important stratigraphical break between Bed 3 and the Paleocene coquina is, to a certain extent, supported by the presence of the small quartz pebbles in Bed 3, near the contact, and by the conspicuous absence of all shell material.

Both the Larger and Smaller post-Paleocene Foraminifera indicate a Late Eocene age (*Operculina soldadensis*, *Lepidocyclina pustulosa* forma *trinitatis*, *Bulimina jacksonensis*, *Globorotalia centralis*), but at the same time, side by side with the flood of Paleocene detritus, the influence is noticed of reworking from the Middle Eocene (*Amphistegina* cf. *undecima*, Middle Eocene species of *Globorotalia* and *Truncorotaloides*). SAUNDERS' impression is that there was heavy reworking of Navet Formation (Middle Eocene of Trinidad) into shallow water Late Eocene sediments. These Middle Eocene specimens must have been washed in from somewhere else (compare Bed 11!) but the horizontal lenses and banks of Ranikothalia limestone, together with all the loose material of Paleocene foraminifera, have slumped into the Late Eocene marl on the spot, practically without any lateral transportation. The stratigraphic relationship between the Paleocene and Bed 3 is further discussed below (p. 428).

Bed 4

a) *Bibliographic history*

JEANNET (1928) mentioned K.1321 as one of the localitites of newly described echinoids.

KUGLER (1938, p. 215, 220) gave a detailed description of this conglomeratic rubble bed and correlated it, on the basis of its stratigraphical position, directly with the conglomerate at Mount Moriah (Trinidad), which there rests on the Middle Eocene, and forms the base of the San Fernando Formation in its type area.

b) *Type section*

At K.2951B(D-4).

c) *Stratigraphic relationship*

Bottom: Bed 4 distinguishes itself from Bed 3 by its more rubbly and conglomeratic aspect. Although at the type locality the rubble likewise consists mainly of detritus from the Ranikothalia limestone, the conglomerate itself grades laterally into a mixed assortment of blocks of different origin, irregularly laid down and not in horizontal layers like the limestone lenses and banks in Bed 3.

Top: marked off by the contact with the sands of Bed 5.

d) *Thickness*

Variable and difficult to ascertain because of lateral silt interdigitations. At the type locality only 1.5 meter of section is exposed, but the block conglomerate further to the NNE is more than 10 meters thick.

e) *Lithology*

At the type locality (K.2951B) the matrix of Bed 4 is a yellowish-brown, finely sandy, slightly glauconitic marl full of fragments of yellow and brown Ranikothalia limestone, and with a very rich fauna of Larger Foraminifera. Towards the West, this rubble changes into a weathered breccia and thin conglomerate, in which there are occasional pebbles of mudstone with *Pholas* holes, and which is almost completely covered by low vegetation and guano (Rz.253, D-4). At K.1321(B-3) the marl is indurated to a limestone lens with the same mixed fauna as in the type sample. The typical marl bed of K.2951B(D-4) can also be traced to the East and NE, but there it becomes more silty and its nature changes from a rubble bed to a block conglomerate of considerable thickness, which stretches right down to the East point of the islet. Common interdigitations of sand, glauconitic sand, silt and clay represent the matrix, which in general is less fossiliferous here than at the type locality. An exception forms the indurated lens of grey glauconitic, somewhat markasitic limestone Rz.247(F-3) which carries a very rich nearly pure Late Eocene fauna. Such limestone lenses occur also at K.3739, K.S.23 and K.S.24 (all in G-3), but their fauna is predominantly composed of reworked Paleocene forms. To a great extent, this local induration of the marl may be ascribed to the abundance of "spathic" calcite particles, reworked clastic material from the Paleocene (K.3739). Locally, Bed 4 carries mollusks, e.g. at K.3877 (G-3), a dark grey, non-calcareous siltstone of the same lithological aspect as the Mount Moriah siltstone of Trinidad (San Fernando area).

The erratic components range from small pebbles to blocks weighing several tons and reaching dimensions of 10 × 10 × 7 meters. The deposition of the bigger blocks is chaotic, but the partly rounded smaller boulders and pebbles are sometimes arranged in definite beds separated by sandstone layers 20 to 40 centimeters thick. The average dip of these beds is 60° NNW. The blocks and boulders are derived from various deposits, mainly (or exclusively) from the Soldado Formation (Beds 1 and 2): coquinas, pseudo-oolitic Dasyclad algae limestone, Athecocyclina limestone, Ranikothalia limestone, Neodiscocyclina grimsdalei limestone, etc. Special attention is called to the conspicuous and lithologically peculiar remnants of the Athecocyclina reef: K.2851(E-4), K.1318(F-3), K.2850(F-3), K.1319(F-3), Cd.22(G-3) and Cd.23(G-3), which are arranged in a roughly continuous SW–NE line and seem to have come from the same bed. None of the blocks found here is representative of the Lower Middle Eocene (see Beds 10 and 11).

These erractics can be grouped as follows:

Beds 1-2 (chiefly Bed 2, coquina):
K.1317(D-5), K.1317A(F-4), K.1318(F-3, in part), K.1319(F-3), K.2653(E-4), K.2849(F-3), K.3736(F-3), K.3742(B-5) and K.3875(G-3).

Dasyclad algae limestone:
K.3876(F-3, part of the blocks), ?K.S.25(G-3).

Athecocyclina limestone:
K.1318(F-3, in part), K.1319(F-3), K.2850(F-3), K.2851(E-4), K.3740(E-4, in part), Cd.21(F-3), Cd. 22 and 23 (G-3), and P.J.1159 and 1160(E-4).

Ranikothalia limestone:
K.2951(D-4, solid component of rubble), K.3739(G-3, in part), K.3876(F-3, one of the blocks).

Discocyclina grimsdalei limestone:
K.9463(G-3).

Odd samples:

- K.1317(D-5), boulder of fine-grained sandy algae- and mollusk-limestone, full of *Pholas* holes.
- K.3876(F-3), part of the blocks from this locality, a fine-grained, dark crystalline limestone common on the East point of the Rock.
- K.10714(B-3), quartzitic sandstone.
- Cd.24(G-3), highly recrystallized, finely markasitic coral limestone with some mollusks (a rarety on Soldado Rock).
- K.S.27(G-3), barren, non-calcareous, hematitic mudstone nodule.

f) Paleontology

At the type locality (K.2951B, D-4) the matrix of the rubble bed carries a wealth of Larger Foraminifera. The overwhelming part of these represent a reworked Lizard Springs fauna, even more complete than that which we have found in Bed 3. However, in contrast to Bed 3, the autochthonous fauna of Late Eocene Larger Foraminifera, although far in the minority, is well established here. There are also traces of reworking from the Middle Eocene.

In the following complete faunal list of this heterogeneous assemblage (K.2951B), the Paleocene forms are marked with an asterisk(*) and the Middle Eocene ones with two asterisks (**); the relative frequency of the Larger Foraminifera is given in the "Distribution Chart".

**Ranikothalia antillea* (HANZAWA), with transitions to *R. tobleri* (VAUGHAN & COLE)
**Ranikothalia tobleri* (VAUGHAN & COLE), A-form
**Ranikothalia soldadensis* (VAUGHAN & COLE) (diameter 4–9 mm)
**Neodiscocyclina grimsdalei* (VAUGHAN & COLE), A-form and large B-form
**Neodiscocyclina ? aguerreverei* (CAUDRI)
**Neodiscocyclina fonslacertensis* (VAUGHAN), A- and B-form

*_Neodiscocyclina barkeri_ (Vaughan & Cole), typical A-form
*_Neodiscocyclina barkeri_ (Vaughan & Cole), B-form
*_Hexagonocyclina inflata_ (Caudri)
*_Athecocyclina soldadensis_ (Vaughan & Cole), A- and B-form
*_Actinosiphon barbadensis_ (Vaughan)
**_Neodiscocyclina ? bullbrooki_ (Vaughan & Cole), B-form
**_Proporocyclina tobleri_ (Vaughan & Cole)
Operculinoides soldadensis (Vaughan & Cole)
Asterocyclina asterisca (Guppy), large and small A-forms
Asterocyclina asterisca (Guppy), B-form
Lepidocyclina pustulosa (H. Douvillé), A- and B-form
Lepidocyclina peruviana Cushman
Helicolepidina spiralis Tobler, A- and B-form

Smaller Foraminifera: benthonic species determined by H. H. Renz as Late Eocene (private report 1941); J. B. Saunders (private communication 1972) encountered Early Eocene Globorotalias but no Late Eocene planktonics.

Gastropods (scarce), brachipods (scarce), echinoderms (scarce), algae (scarce).

The other samples collected from the marl and silt matrix of the bed have not contributed anything new:

- Rz.253(D-4) carries _Ranikothalia antillea_, common _Neodiscocyclina barkeri_ and some _Neodiscocyclina grimsdalei_, in combination with small but typical _Asterocyclina asterisca_ and some non-foraminiferal fossils: the washed residue was flooded with recent fish remains from the guano.
- K.3877(G-3) does not carry a microfauna and the gastropods it contains are inconclusive.

As to the hard limestones of Late Eocene age:

- K.1321(B-3) is a breccia full of Ranikothalia limestone fragments and its Larger Foraminifera fauna seems to be directly comparable with K.2951B(C-4).
- Rz.247(F-3) is the only sample in which the Late Eocene fauna predominates and the Paleocene elements are rare. It contains common _Operculinoides_ sp. sp., _Asterocyclina asterisca_, _Lepidocyclina_ cf. _pustulosa_ forma _trinitatis_ (and _L. peruviana_?),), perhaps also some _Helicolepidina spiralis_ and abundant _Amphistegina_ (presumably _A. grimsdalei_), as against rare specimens of _Neodiscocyclina barkeri_ (A- and B-forms).

The other limestones contain a predominantly Paleocene fauna.

- K.3739(G-3) yielded various boulders, one of which seems to be a straight Ranikothalia limestone; in another one, only _Lepidocyclina_ was observed, but its matrix consists entirely of minute calcite rhombohedrons which are probably washed in from the disintegrating Ranikothalia limestone.
- K.S.23(G-3) is an unevenly recrystallized rock in which the fauna is also chiefly Paleocene, with some rare _Lepidocyclina_ cf. _pustulosa;_ in K.S.24, from the same locality, no _Lepidocyclina_ was observed but paleontologically as well as lithologically it is so much like K.S.23 that it can be considered as coming from the same lenticular limestone body.

The contents of the limestone blocks of Paleocene origin have been described above, in the chapter on the Soldado Formation.

g) _Age of Bed 4: Late Eocene_

Although the Late Eocene fauna in Bed 4 is sparse and not fully developed, there is little doubt that this deposit belongs to the Upper Eocene. The absence of _Helicosteginopsis soldadensis_ seems to be significant for a more refined age determination (see below, under "Geological History", p. 428), but none of the samples yielded an autochthonous pelagic fauna which would permit correlation with an exact planktonic zone.

Bed 5

a) Bibliography

KUGLER (1938, p. 217, 220) correlated this bed, along with Beds 6 to 9, with the San Fernando Formation of Trinidad. At the time he also included in this bed the conglomerate at K.1317(D-5), which today is considered as belonging to Bed 4.

b) Type section of Bed 5

This bed, like beds 6 to 9, has been exposed by a trench cut along the crest of the saddle between the Southern point of the Rock, formed by Beds 3 and 4, and the foot of the cliff which bears the trigonometric signal on the Northern summit.

c) Stratigraphic relationship

Bed 5 is a lenticular sand body between the rubble bed (Bed 4) and the well-bedded silts of Bed 6. Its type locality is K.2956(D-4).

d) Thickness

About 5 meters.

e) Lithology

A fine-grained, bright yellow calcareous quartzose sandstone, with large quartz grains, some chert particles and a layer of white non-calcareous grit. To the West (K.1495, D-4) the colour changes to light-grey and the sandstone becomes non-calcareous and contains a layer of quartz grains with vugs. Similar quartz sandstone lenses are found all along the SE slope of the Rock.

f) Paleontology

The deposit is barren.

Bed 6

a) Bibliography

KUGLER (1938, p. 217, 220).

b) Type section

As Bed 5: type locality K.2955(D-4).

c) Stratigraphic relationship

The bed separates the sandstone of Bed 5 from the fossiliferous marl of Bed 7.

d) Thickness and dip

The bed has a thickness of 4 meters and dips 50 degrees to the North.

e) Lithology

Bluish-grey silt with intercalated thin layers of muddy sand, and a band of glauconitic sand of about 20 cm thickness. A few blocks of limestone lie scattered in the silt. Such silts occur in many spots along the SE slope of the Rock.

f) Paleontology

The deposit is barren.

Bed 7

a) Bibliography

Kugler (1938, p. 217, 220) gave a lithological description and a list of Smaller Foraminifera, including such forms as *Bulimina jacksonensis* and *Hantkenina alabamensis* var. *primitiva* (see below). The marl represents a more open sea facies than the surrounding silts and was compared with the Late Eocene "Hantkenina marl" of the San Fernando area of Trinidad.

b) Type section

As Bed 5: type locality K.2954(D-4).

c) Stratigraphic relationship

This marl is intercalated between the bluish-grey silts of Bed 6 and the silver-grey carbonaceous silts and clays of Bed 8.

d) Thickness and dip

The bed is about 3 meters thick and has an almost vertical dip.

e) Lithology

The type sample K.2954 is a yellowish-brown calcareous clay with scattered Larger Foraminifera. Its washed residue is full of fibrous calcite.

Following the strike to the NE, we also include in this bed the dark-brown glauconitic orbitoidal marl K.2855(F-3), which in its residue proves to be full of minute calcite rhombohedrons probably derived from the disintegrating Ranikothalia limestone (compare K.3739, Bed 4).

f) Paleontology

The marl at K. 2954 is highly fossiliferous, especially rich in excellently preserved Smaller Foraminifera. The Larger Foraminifera fauna is rather poor; the fossils are white or brown in colour and in a weathered crumbly condition. On the other hand, K. 2855 is very rich in Larger Foraminifera.

Kugler (1938, p. 217) listed the following benthonic Smaller Foraminifera from K.2954, determined by H. Naegeli, H. H. Renz and K. Schmid:

Bulimina jacksonensis
Cassidulina subglobosa
Robulus cf. *arcuato-striatus* var. *carolinianus*
Pseudoglandulina conica
Plectofrondicularia cf. *mexicana*
Plectofrondicularia vaughani
Vaginulina elegans mexicana
Nonion cf. *pompilioides*
Gyroidina soldanii
Hantkenina alabamensis var. *primitiva*
Textularia cf. *pala*
Sigmoidella elegantissima
Saracenaria aff. *italica*

as well as undetermined forms of the genera *Uvigerina*, *Cibicides*, *Bolivina*, *Cristellaria*, *Buliminella*, *Textularia*, *Nodosaria*, *Siphonodosaria*, *Triloculina*, *Globorotalia*, *Globigerina*, *Massilina*, *Marginulina*, *Ellipsoglandulina*, *Vulvulina*, *Haplophragmoides*.

Caudri later determined the Larger Foraminifera in the samples K.2954 and K.2855. A difference in facies between the deposits at these two localities finds its expression in the composition of their fossil assemblages (see "Distribution Chart"). The combined fauna of Bed 7 is as follows:

Operculinoides soldadensis Vaughan & Cole
Operculinoides ocalanus (Cushman)
Operculinoides kugleri Vaughan & Cole
Operculinoides trinitatensis (Nuttall)
Proporocyclina mirandana (Hodson)
Asterocyclina asterisca (Guppy)
Asterocyclina soldadensis Caudri n. sp.
Lepidocyclina peruviana Cushman
Lepidocyclina pustulosa s.s. (H. Douvillé)
Lepidocyclina pustulosa forma *trinitatis* (H. Douvillé)
Lepidocyclina pustulosa forma *tobleri* (H. Douvillé)
Lepidocyclina pustulosa var. *compacta* Caudri n. var.
Lepidocyclina sp. indet. 1
Lepidocyclina sp. indet. 2
Helicolepidina spiralis
Amphistegina grimsdalei Caudri n. sp.
Helicosteginopsis soldadensis (Grimsdale)
Sphaerogypsina globulus s.l.
Cycloloculina jarvisi Cushman

Saunders (private correspondence 1972) reported that the assemblage of planktonic and calcareous/arenaceous benthonic Smaller Foraminifera in K.2954 includes:

Bulimina jacksonensis Cushman
Vaginulina mexicana Nuttall
Globorotalia cerroazulensis Cole (small, but with acute periphery)
Globorotalia centralis Cushman & Bermudez
Globigerinatheca tropicalis (Blow & Banner)
Globoquadrina venezuelana (Hedberg)

The Smaller Foraminifera of K.2855 were determined as Late Eocene by H.H. Renz.

g) Age of Bed 7: Late Eocene (*Globorotalia cerroazulensis Zone*)

With the help of the Larger Foraminifera, Bed 7 can be correlated with the Upper Eocene of the San Fernando area in Trinidad, and the planktonics of K.2954 pin the age down to the *Globorotalia cerroazulensis* Zone (*G. cocoaensis* Zone of Bolli)[5]).

The difference in preservation between the Larger and the Smaller Foraminifera in sample K.2954 suggests that the marl was deposited at some distance from the shore, and that the former were swept in by turbidity currents or slumping. At K.2855 everything seems to be in place (fore-reef facies).

Along with the autochthonous fauna, a small amount of reworked material was also deposited in the sediment: *Ranikothalia* from the Paleocene in K.2954, and *Proporocyclina tobleri* and *Neodiscocyclina bullbrooki* from the Lower to Middle Eocene in K.2855. We have no information on the Smaller Foraminifera in this respect, but also there the influence of reworking must be insignificant.

Bed 8

a) Bibliography

Kugler (1938, p. 218, 220).

b) Type section

As Bed 5; type locality K.2953(D-4).

c) Stratigraphic relationship

Bed 8 is a silty deposit in sharp contrast with the marl of Bed 7. It is separated from Bed 9 by a layer of glauconitic sand.

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[5]) According to Cole (1960*b*, p. 57), the name *cerroazulensis* Cole has priority over *cocoaensis* Cushman by about four months. Bolli (1957*b*, p. 169) chose *cocoaensis* as the valid name for his planktonic zone.

d) Thickness and dip

The bed is about 4 meters thick and dips with 80 degrees to the North.

e) Lithology

Silver-grey silts with clay layers, showing carbonaceous specks, the joints coated with yellow powdery jarosite.

f) Paleontology

The deposit is barren.

Bed 9

a) Bibliographic history

Kugler (1938, p. 218, 220) attached much more importance to Bed 9 than at present. He wrote: "This bed resembles typical Mount Moriah silt (of Trinidad) and is well exposed all along the SE shore of Soldado Rock, where it can best be studied at low tide." Since then the "silts" (actually marls) along the SE shore have been recognized as a separate stratigraphical unit distinguished under the name of "Asterocyclina Marl" (see below, Bed 9a).

Apart from the type sample K.2952, Kugler also mentions K.1316, K.1499 and K.2854, and gives the list of Larger Foraminifera in this mixed lot as determined by Vaughan & Cole. Of these samples only K.1499 is now considered as belonging to Bed 9, and the fossil list is of no value.

Vaughan & Cole (1941) determined the following Larger Foraminifera from the sample K.1499:

Operculinoides ocalanus (Cushman) Hanzawa
Operculinoides kugleri Vaughan & Cole (type material!)
Operculinoides trinitatensis (Nuttall)
Discocyclina cubensis (Cushman)
Discocyclina (Asterocyclina) asterisca (Guppy)
Discocyclina (Asterocyclina) vaughani (Cushman)
Pseudophragmina (Proporocyclina) flintensis (Cushman)
Lepodocyclina (Pliolepidina) pustulosa (H. Douvillé)
Lepidocyclina (Pliolepidina) pustulosa forma *trinitatis* (H. Douvillé)
Lepidocyclina (Pliolepidina) pustulosa forma *tobleri* (H. Douvillé)
Lepidocyclina sp. indet. No. 2
Helicolepidina spiralis Tobler
Helicostegina soldadensis Grimsdale (abundant)
Amphistegina sp. indet. n. (= *Amphistegina grimsdalei* Caudri n. sp.)

Cole (1961, p. 137) mentions material from his "locality 2" which is a mixed sample from Soldado Rock: K.1316 and K.1499 (K.1316 belongs to Bed 9a!).

b) Type section of Bed 9

As Bed 5, at the North end of the trench: type sample K.2952(D-3).

The lateral extension of Bed 9 is rather vague. The sandstone lens at K.905(D-3) lies interbedded in it. The bed can further be followed towards the NE, where the samples K.1499(E-2), K.2856(E-2), K.3678(E-1), Rz.249(E-1), E.L.1441(E-1) and E.L.1571(E-1) were collected from it. The fauna in K.3677(E-1) proved to be quite different from K.1499 and more like that of Bed 10; the sample is considered to be a block of Bed 10 which has fallen down from the steep cliff formed by that bed. Further to the East, on the slope down towards the shore, the bed merges into the undifferentiated mass of beds 4–9.

c) Stratigraphic relationship

Bed 9 is separated from the silt of Bed 8 by a layer of glauconite. It is sharply set off against the marlstone and marls of Bed 10.

d) Thickness and dip

At the type locality (K.2952, D-3) the thickness is about 10 meters, and dips varying from 80 degrees (E.L.1441, E-1) to 90 degrees (Rz.249, E-1), to the WNW, were measured.

e) Lithology

At the type locality (K.2952) the bed consists of prismatically jointed silt and silty sand with finegrained quartzose sandstone lenses and thin layers of glauconitic sand. The deposit resembles the Mount Moriah silt of the San Fernando Formation in its type area. The quartzose sandstone at K.905(D-3) is similar to that in Bed 5 (K.1495, D-4), but it is gritty and does not show vugs. A similar assemblage of streaks and lenses occurs at E.L.1441(D-3), where a brown weathering sandstone with a bluish core rests on a calcareous silt. Such barren calcareous silts were also observed at Rz.249(E-1); they are associated with foraminiferal marls (K.1499, E-2).

f) Paleontology

The only foraminiferal sample that was collected from Bed 9 is the brown-grey marl K.1499(E-2) which carries a rich Larger Foraminifera fauna and a fair amount of Smaller Foraminifera:

Ranikothalia antillea (HANZAWA), one specimen
Operculinoides soldadensis VAUGHAN & COLE
Operculinoides ocalanus (CUSHMAN)
Operculinoides kugleri VAUGHAN & COLE
Operculinoides trinitatensis (NUTTALL)
"*Discocyclina*" sp. indet., very small (VAUGHAN & COLE's "*Discocyclina cubensis*")
Asterocyclina asterisca (GUPPY)
Asterocyclina vaughani (CUSHMAN) (determination by VAUGHAN & COLE 1941), one specimen
Asterocyclina aff. *monticellensis* COLE & PONTON, one specimen
?*Proporocyclina* cf. *tobleri* (VAUGHAN & COLE)
Proporocyclina mirandana (HODSON)
Lepidocyclina pustulosa (H. DOUVILLÉ) s. s. (megalospheric form, abundant)
Lepidocyclina pustulosa (H. DOUVILLÉ) (microspheric form, common)
Lepidocyclina pustulosa forma *trinitatis* (H. DOUVILLÉ) (common)
Lepidocyclina pustulosa forma *tobleri* (H. DOUVILLÉ) (scarce)
Lepidocyclina spatiosa CAUDRI n. sp.
Helicolepidina spiralis TOBLER
Amphistegina grimsdalei CAUDRI n. sp. (abundant)
Helicosteginopsis soldadensis (GRIMSDALE) (common)
Helicosteginopsis soldadensis (GRIMSDALE), microspheric form (one specimen)

Smaller Foraminifera: *Gaudryina*, Miliolidae, *Robulus*, *Lenticulina*, *Nonion*, *Bolivina*, *Uvigerina*, *Valvulineria*, *Eponides*, *Cibicides*, *Globigerina*, *Globorotalia*, etc.

g) Age of Bed 9: Late Eocene

The Larger Foraminifera fauna of Bed 9 is typical of the Upper Eocene, and is directly comparable with that of the San Fernando Formation of Trinidad. We have no information on the planktonic foraminifera. Reworking from older deposits (*Ranikothalia*, "*Discocyclina*", *Proporocyclina* cf. *tobleri*) has been observed but is of minor importance.

Bed 9a («Asterocyclina marl»)

a) Bibliographic history

KUGLER (1938, p. 218) showed on the geological map a belt of foraminiferal marly clay exposed along the SE coast (samples K.2651, K.2854, K.1316, K.2650, K.3741 and others) which, at the time, was not recognized as a separate unit but was included in Bed 9.

Vaughan & Cole (1941) did not make any differentiation either. From this particular marl they had at their disposal only the sample K.1316 (mixed with material from K.1499, Bed 9), and K.2854. They determined from these: *Operculinoides ocalanus*, *Asterocyclina asterisca*, *Lepidocyclina pustulosa* s.s. and forma *trinitatis*, *Lepidocyclina ocalana* var. *pseudocarinata* and *Lepidocyclina macdonaldi*. Many of their photographs of *Lepidocyclina pustulosa* illustrate specimens from K.2854.

Grimsdale (1941, appendix to Vaughan & Cole 1941, p. 86) described the new foraminiferal species *Helicostegina soldadensis* from "black silts exposed on the south shore of Soldado Rock" (the type locality has now been traced to Gr. 33 = K.2854(E-5); see Part 2 of present paper).

Cole (1960*a*, p. 133) discussed the variability of *Lepidocyclina pustulosa*, using in part material from K.2854.

Cole (1961, p. 137, etc.) described *Operculinoides trinitatensis* and other forms from mixed material of K.1316 and K.1499 (Bed 9).

Cole (1963, p. 10, plates 1, 2, 3, 5, 10) included many specimens from K.2854 in his study of the embryonic chambers of *Lepidocyclina pustulosa*.

b) Type section of Bed 9a

No actual type section was established. The type sample is K.2854(E-5) and dips of 70–80 degrees were measured around K.1316 and K.2650(D-5).

c) Stratigraphic relationship

No clear-cut contacts with the surrounding beds could be established for the Asterocyclina marl. To the SE and South it is cut off by the sea, and on the land side it is smothered in loose blocks of various origin which we have in part called the block conglomerate and described as one of the lateral derivates of Bed 4 (see p. 393). Paleontologically, however, there is no close relationship to Bed 4.

d) Thickness

Unknown.

e) Lithology

The Asterocyclina marl is a dark-coloured (brown to blackish) deposit which differs from the other foraminiferal marls of Soldado Rock by the almost complete absence of clastic material. It hardly contains any silt at all, and reworked Early or Middle Eocene Foraminifera, which are so commonly mixed with the fauna in the other Upper Eocene beds, are extremely rare here.

For paleontological reasons, i.e. because it contains the most complete combination of Larger and Smaller Foraminifera, K.2854 is designated as the type sample of this bed.

f) Paleontology

As soon as the importance of this marl as a separate sediment had been realized, a number of additional samples were collected by J. B. Saunders, who also undertook to study the planktonic elements in them. Most of the samples carry a rich fauna of planktonic as well as calcareous benthonic forms. For the planktonic fauna, the following samples were examined: J.S.1030(F-3), J.S.1029(E-4), K.2651(E-4), J.S.1223(D-5), J.S.1224(E-4), K.2854(= Gr. 33, E-5), K.1316(D-5), K.3741(D-5) and K.2650(D-5). J. B. Saunders determined the following foraminifera from this material:

Globorotalia cerroazulensis (Cole)
Globorotalia cerroazulensis, transition to
  G. centralis Cushman & Bermudez
Globorotalia centralis Cushman & Bermudez
Globorotalia centralis transition to
  G. ampliapertura (Bolli)
Globorotalia opima nana Bolli
Globorotaloides suteri Bolli
Globigerinatheka tropicalis Blow & Banner
Globigerinatheka dissimilis
  (Cushman & Bermudez)
Globigerinatheka lindiensis Blow & Banner
Globigerina angustiumbilicata Bolli
Globigerina tripartita tripartita Koch
Globigerina parva Bolli
Globigerina ciperoensis ciperoensis Bolli
Globigerina ciperoensis angulisuturalis Bolli
Globigerina anguliofficinalis Blow
Globigerina cf. *G. trilocularis* d'Orbigny
Hantkenina alabamensis Cushman
Hantkenina primitiva Cushman & Jarvis
Globoquadrina venezuelana (Hedberg)
Bulimina jacksonensis Cushman
Vaginulina mexicana Nuttall

During the routine picking of K.1316 for Larger Foraminifera, Caudri noted down the following genera:

Robulus div. (large)
Frondicularia
Glandulina (large)
Guttulina (large)
Sigmoidella
Bolivinopsis
Bulimina jacksonensis Cushman
Uvigerina (small)
Pullenia
Nonion
Eponides (large)
Cibicides
Miliolidae (large, elongate)
Textularia

The sample P.J.1147 yielded *Bathysiphon;* P.J.1162 contained *Bulimina jacksonensis* and common *Glandulina*, subglobular Miliolidae and *Haplophragmoides* (the latter also present in P.J.1146 and 1147). Other samples contained: *Gypsina*, *Carpenteria* and *Rupertia.*

Larger Foraminifera were obtained from the following samples: K. 1316, K.2650, K.2651, K.2854, K.3737, K.3741, J.S.1223 and P.J.1146, P.J.1147 and P.J.1162. The richest concentration of these fossils occurs at K.1316, K.2651 and K.2854. The sample J.S.1223 contains essentially a Smaller Foraminifera assemblage, but also a certain number of small specimens of Larger Foraminifera, abundant *Helicosteginopsis soldadensis*, common *Amphistegina grimsdalei*, a few non-typical juventile specimens of *Helicocyclina paucispira* and many initial stages of *Lepidocyclina pustulosa.*

The Larger Foraminifera fauna of the Asterocyclina marl as a whole consists of:

Asterocyclina asterisca (Guppy), A-form
Asterocyclina asterisca (Guppy), B-form
Asterocyclina soldadensis Caudri n. sp.
Proporocyclina mirandana (Hodson)
Lepidocyclina peruviana Cushman
Lepidocyclina pustulosa s. s. (H. Douvillé)
Lepidocyclina pustulosa forma *trinitatis*
  (H. Douvillé)
Lepidocyclina pustulosa forma *tobleri*
  (H. Douvillé)
Lepidocyclina pustulosa (H. Douvillé), B-form
Lepidocyclina spatiosa Caudri n. sp.
Lepidocyclina subglobosa Nuttall
  (one specimen in K.3741)
Lepidocyclina ? *sanfernandensis*
  Vaughan & Cole, B-form
Helicolepidina spiralis Tobler, A- and B-form
Operculinoides soldadensis Vaughan & Cole
Operculinoides ocalanus (Cushman)
Operculinoides kugleri Vaughan & Cole
Operculinoides trinitatensis (Nuttall)
Operculinoides, transition between
  O. trinitatensis and *O. kugleri*
Operculinoides spiralis Caudri n. sp.
Amphistegina grimsdalei Caudri n. sp.
Helicosteginopsis soldadensis (Grimsdale)
Helicosteginopsis soldadensis, transition to
  Helicocyclina paucispira
Helicocyclina paucispira
  (Barker & Grimsdale)
  (not typically developed)

The relative frequency of all these forms is given in the "Distribution Chart".

Accessory, mostly scarce organisms are further: pelecypods (very small specimens, sometimes abundant, for instance at K.2854), gastropods, scaphopods, brachiopods, bryozoans, echinoderms, corals, fish otoliths, crab remains, and locally common worm tubes. The last three may in part be Recent additions.

Traces of reworking of older material into this extremely rich Late Eocene assemblage are restricted to an obviously reworked specimen of *Proporocyclina tobleri* in K.1316, one specimen of *Amphistegina undecima* in P.J.1146 and another doubtful one in K.2854, both species originally from the Proporocyclina tobleri limestone zone (see Bed 11). At K.3737, pebbles and blocks from older formations got mixed up with the marl (surface contamination). J. B. Saunders pronounced the Asterocyclina marl the cleanest of all the Upper Eocene deposits, also with reference to the planktonic fauna.

g) *Age of the Asterocyclina marl (Bed 9a): Late Eocene (G. cerroazulensis Zone)*

According to SAUNDERS, the Asterocyclina marl is the equivalent of the *Globorotalia cerroazulensis* Zone (= *Globorotalia cocoaensis* Zone; see footnote on p. 398). The work of TOUMARKINE & BOLLI (1970) suggests that it would be the lower part of the zone. SAUNDERS declares that he has seen nothing that can with confidence be put in the upper part: nothing can be proved to be as high in the section as the *Globorotalia cocoaensis cunialensis* Zone of TOUMARKINE & BOLLI. In other words: no great difference was found between this marl and Beds 7 and 10, as far as the planktonic foraminifera are concerned. Unfortunately there is no information on Bed 9 in this respect.

This is a rather puzzling result (as we shall see from the discussion of the geological history of Soldado Rock, p. 429), because the information obtained from the Larger Foraminifera is somewhat at variance with it.

The Larger Foraminifera assemblage contains such forms as *Lepidocyclina subglobosa* and *Helicocyclina paucispira*, perhaps *Lepidocyclina sanfernandensis*, and even a variety of *Lepidocyclina pustulosa* with thin-walled rhomboid equatorial chambers reminiscent of *L. yurnagunensis* (P.J.1147, P.J.1162). These species characterize, in the San Fernando area of Trinidad, the uppermost part of the Upper Eocene as encountered on the Vistabella Estate (in a surface section and in the calyx wells), in the highest part of the section at Point Bontour (where the Eocene merges into the Oligocene Cipero Formation) and in the marl exposed behind the former San Fernando Railway Station. The junior author is, therefore, under the impression that the Asterocyclina marl can, at least in part, be correlated with this very high Eocene level and that it is definitely the youngest of all the beds of the Soldado section. Unfortunately, the most important samples in this respect (K.3741, J.S.1223, P.J.1147 and P.J.1162) are all essentially Smaller Foraminifera marls in which, probably on account of greater depth or perhaps through passive selection, Larger Foraminifera are very rare and represented chiefly by juvenile specimens and fragments. Apart from the convincing but isolated specimen of *Lepidocyclina subglobosa* in K.3741 (illustrated in Part 2, Paleontology, Pl. 26, Fig. 10, 11) the evidence for this correlation with Trindidad is slim.

Bed 10

a) Bibliography history

Maury (1912, p. 30, 31) described as "Bed 6" of her section a highly fossiliferous horizon, which in accordance with later studies should be placed within our Bed 10 (Kugler 1938). This horizon "contains myriads of Foraminifera, especially Orbitoids, Echinoids and one imperfect *Ostrea* shell, probably of *Ostrea crenularimarginata*" (a species also mentioned by her from the Paleocene, Bed 2).

R. M. Bagg (in Maury 1912, p. 31) determined the Orbitoids as follows:

Orbitoides papyracea (Boubée)
Orbitoides aspera Gümbel (*O. faujasii*)
?*Orbitoides mantelli* (= *O. forbesii*)
Tinoporus vesicularis
Tinoporus baculatus

Maury stated: "The evidence furnished by both Foraminifera and mollusks points definitely to Lower Eocene".

Remark: with our present knowledge of the Soldado section and its various faunas, both Bagg's faunal list and the age determination are easily challenged. A deposite of this type, so much higher in the section than the Paleocene, can only have come from what we now call Bed 10, and we can safely take Bagg's list as referring to a Late Eocene *Lepidocyclina–Asterocyclina* assemblage. The oyster (if correctly identified) may be reworked, as perhaps also some of the Orbitoids in as far as they are not Lepidocyclinas (*O. papyracea* = *Proporocyclina tobleri* ?).

Douvillé, H. (1917, p. 844) described Larger Foraminifera collected by F. Zyndel in Trinidad and Soldado Rock. From the latter he mentioned *Asterodiscus asteriscus* and the new species *Isolepidina pustulosa*, two characteristic species which he placed into the basal Stampian and not into the Lower Eocene as suggested by R. M. Bagg.

Maury (1925*b*, p. 160) changed her opinion on the age: "Bed 6, characterized by Foraminifera, is now thought to be Upper (Jacksonian) Eocene, ..."

Jeannet (1928) described from the indurated lowest orbitoid reefs in this bed (K.903; and also from K.1321, Bed 4) the following new echinoids: *Oligopygus zyndeli* and *Oligopygus kugleri* (together with *Oligopygus christi*, which was already known from Venezuela).

Gorter & van der Vlerk (1932, p. 107) mention "from San Fernando and Soldado": *Lepidocyclina (Lepidocyclina) pustulosa* H. Douvillé, *Lepidocyclina (Pliolepidina) tobleri* H. Douvillé, *Discocyclina (Asterocyclina) asteriscus* (Guppy), *Camerina floridensis* Heilprin. According to Rutsch (1939), their material came (at least in part) from Bed 10 of Soldado Rock.

Kugler (1938, p. 218, 220) gave a short description of Bed 10, mentioning Maury's *Ostrea* and the echinoids of Jeannet. From the soft silty marl of the uppermost layer he mentioned the common occurrence of the fine-ribbed brachiopod *Terebratulina kugleri* Rutsch which at the time had not yet been published officially (see below). No foraminifera were determined. Good pictures of the outcrop and the general lithological aspect of the bed accompany the description. Six samples were listed but no type sample was designated.

Rutsch (1939*b*, p. 517) described *Terebratulina kugleri* n. sp. from a mollusk-bearing horizon (K.3692) near the top of the bed, situated in the section between the two main mollusk faunas, the Soldado Formation and the Boca de Serpiente Formation (see under Bed 11). This is the horizon called "Bed 6" by Maury and "Bed 10" by Kugler. Unfortunately, the mollusks proved to be indeterminable. The genus *Terebratulina* is very rare in the Eocene and cannot yet be used as an age indicator. Rutsch used Gorter & van der Vlerk's Larger Foraminifera, which he claimed came from Bed 10, to determine the age of the *Terebratulina* as Late Eocene.

Vaughan & Cole (1941, p. 14, 15, 18–23) had material from several samples of Bed 10: K.296 (= K.903), K.1500, K.3689, K.3691, and K.3692. The very incomplete fauna they mentioned from these include:

Operculinoides ocalanus (Cushman)
Operculinoides soldadensis n. sp.
(type locality: K.3692)
Operculinoides kugleri n. sp.
Discocyclina (Asterocyclina) asterisca (Guppy)
Discocyclina (Asterocyclina) vaughani Cushman

Pseudophragmina (Proporocyclina) tobleri n. sp.
Helicolepidina spiralis TOBLER
Lepidocyclina pustulosa (H. DOUVILLÉ) s.s.
Lepidocyclina pustulosa (H. DOUVILLÉ) forma *trinitatis* (H. DOUVILLÉ)

COLE (1962*a*, p. 30, 38), in his study of the variability and systematic value of the embryonic chambers of *Lepidocyclina*, mentioned and figured specimens from Bed 10 (K.903, K.3677 and K.3692). The material from K.903 contained forms of *Lepidocyclina pustulosa* with an abnormal embryonic development, but no typical *Lepidocyclina pustulosa* forma *tobleri* was found.

COLE (1962*b*, p. 146, 147, 149, 150) discussed the nepionic development of *Helicolepidina spiralis* in sample K.3692 in comparison with others. The larger Foraminifera of this sample were listed as follows:

Asterocyclina asterisca (GUPPY)
Camerina floridensis (HEILPRIN)
Camerina trinitatensis (NUTTALL)
Helicolepidina spiralis TOBLER
Lepidocyclina pustulosa (H. DOUVILLÉ)
Pseudophragmina (Proporocyclina) tobleri VAUGHAN & COLE (one reworked specimen)
Cycloloculina jarvisi CUSHMAN

This assemblage indicates a Late Eocene age.

The planktonic species in this sample, determined by Miss Ruth Todd, were:

Globigerina yeguaensis WEINZIERL & APPLIN
**Globigerapsis kugleri* BOLLI, LOEBLICH & TAPPAN
Catapsydrax dissimilis (CUSHMAN & BERMUDEZ)
**Globorotalia aspensis* (COLON)
Globorotalia bolivariana (PETTERS)
**Globorotalia bullbrooki* BOLLI
Globorotalia centralis CUSHMAN & BERMUDEZ
Globorotaloides suteri BOLLI
**Truncorotaloides rohri* BRÖNNIMANN & BERMUDEZ
Truncorotaloides topilensis (CUSHMAN)

According to COLE, the species marked with an asterisk(*) seem to indicate that the planktonic fauna represents the *Globigerapsis kugleri* Zone of BOLLI (corresponding with the Middle Eocene Navet Formation of Trinidad), but the assumed that, along with the specimen of *Proporocyclina tobleri*, also the planktonics are reworked into the Late Eocene deposit of Bed 10.

COLE (1963, p. 10, 24, 25) included *Lepidocyclina pustulosa* from K.903 in his comparative study of the measurements of that species in various localities, resulting in the diagram on p. 25.

KIER (1967) redescribed JEANNET's echinoids (on p. 61 and 69, respectively).

b) *Type section of Bed 10*

On the South side of the highest top, including the type sample K.3692(D-3).

c) *Stratigraphic relationship*

Both the upper and lower contact of Bed 10 is abnormal; their true nature is discussed in extenso below (p. 428–429).

The transition from Bed 9 to Bed 10 is marked by an abrupt change from silts, silty marls and sands to a series of rugged marlstone and marls full of orbitoids and algae. In the Northern area (E-1, D-1) the base of Bed 10 is a breccia with a dip of 40 degrees, resting on the sandstone E.L.1441(E-1) of Bed 9, which has a dip of 80 degrees. In the steep wall at K.2652(D-1) indications of a mylonite were observed.

At the top, the well-bedded marlstone series of Bed 10 is clearly set off against Bed 11 which consists of masses of glauconite ("greensand") and autoclastic breccia of highly glauconitic limestone.

The sample K.3692(C-3) is, for stratigraphical as well as paleontological reasons, chosen as the type sample of Bed 10.

d) Thickness and dip

Bed 10 is 11 meters thick. No dip was established in the Southern part of the exposure (area B-3, C-3, D-3), but in the area D-1 and E-1 a dip of 40 degrees was measured. This observation is probably of very little importance as the sediments do not seem to be in place (see p. 428–429).

e) Lithology

Bed 10 is built up mainly of layers of grey glauconitic orbitoid marlstone with intercalated softer marls. The lowest 4 meters are composed almost entirely of the tests of orbitoids and colonies of calcareous algae (*Lithothamnium* s.l.), fine brecciated rubble of the same material and echinoids. Typical of the lower part are the samples Rz.251, J.S.1024, K.903, K.1500 (all in square B-3 of the map).

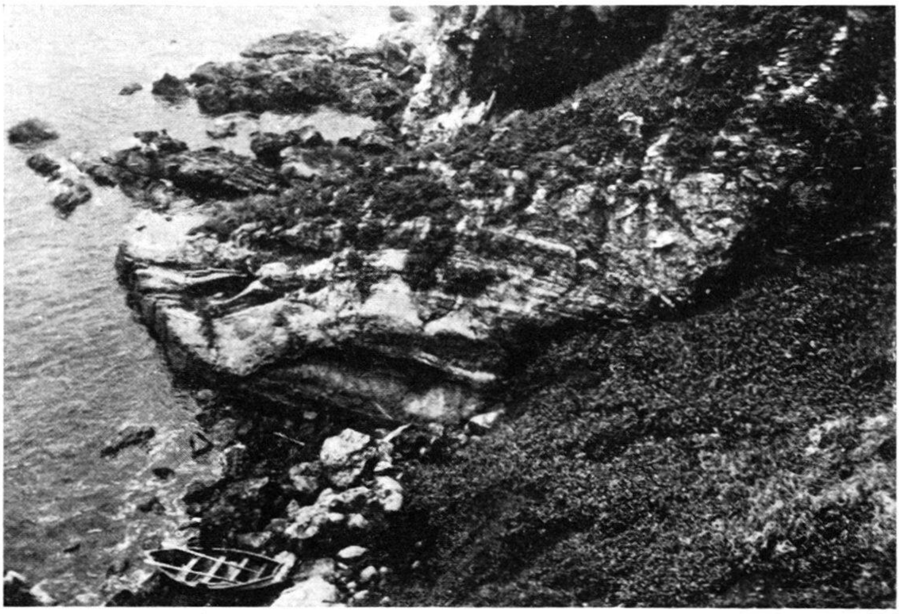

Fig. 5. Landing place with orbitoidal limestone (B-3) of Bed 10 (photo E. Ganz 1922).

In the upper part (about 7 meters) layers of marlstone, varying in thickness from a few centimeters to more than a meter, alternate with soft silty marl and occasional layers of glauconitic "sand". The uppermost layer (1.5 meter) is a soft foraminiferal marl, the contents of which lent themselves particularly well for a detailed study. The type sample K.3692(C-3), situated about 1 meter below the contact with Bed 11, comes from this marl. This sample also yielded an, unfortunately, indeterminable mollusk fauna and it is the type material of the brachiopod *Terebratulina kugleri* Rutsch (1939*b*).

The repetition of beds of different resistivity to weathering increases the already rugged appearance of the orbitoid and algal reef marlstones in themselves. Moreover, numerous erratic blocks of Ranikothalia limestone, Proporocyclina tobleri limestone (see Bed 11), fine-grained crystalline limestone, quartzites, etc. are scattered throughout the bed.

The rugged and heterogeneous nature of Bed 10 should not, however, lead to the conclusion that it was deposited under turbulent water conditions. Apart from those blocks, and a fair amount of reworked finer calcareous matter, there is very little

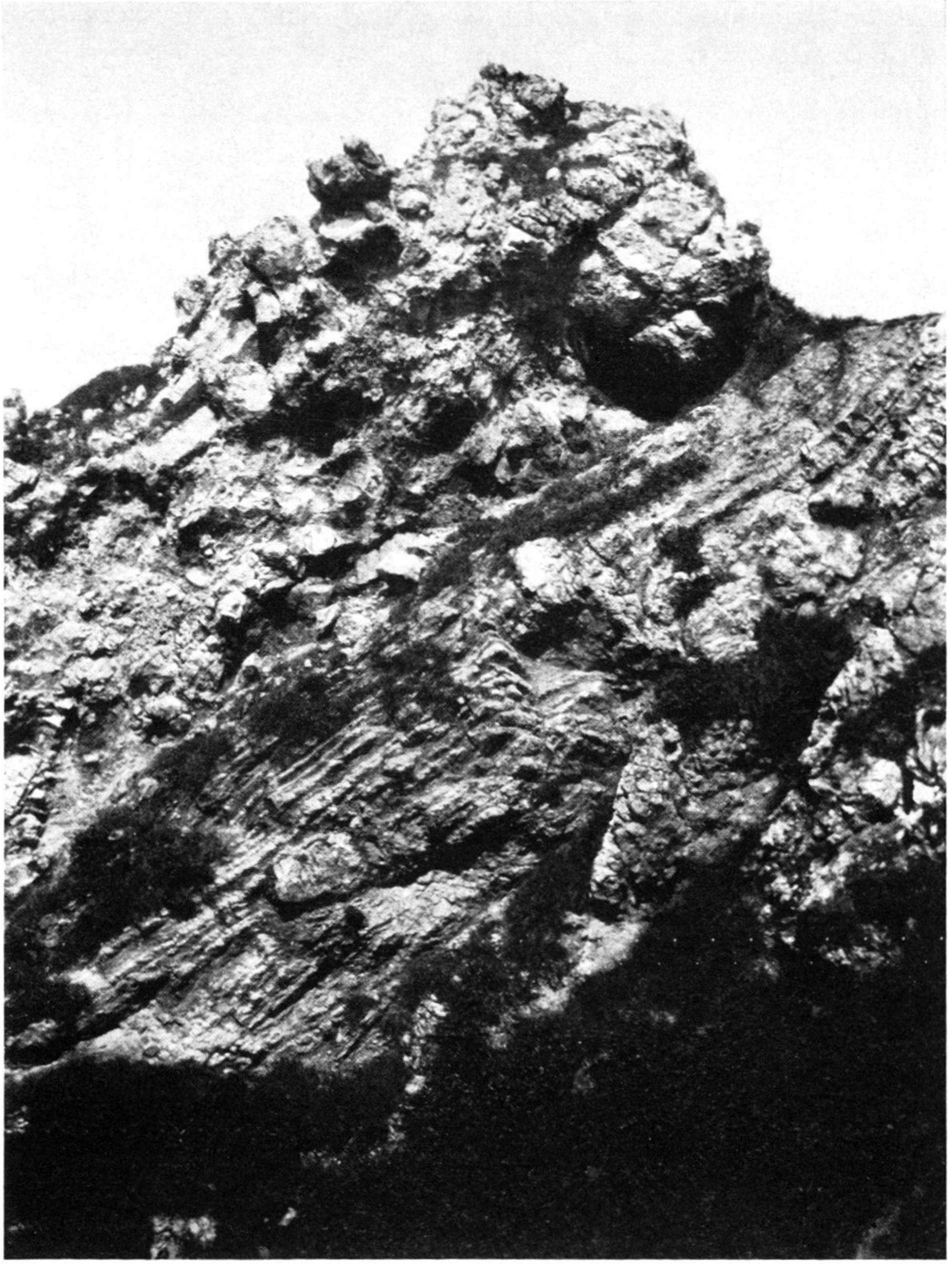

Fig. 6. Bed 10 of well-bedded Late Eocene marls with Paleocene and Middle Eocene remnant blocks superimposed by slump mass of Bed 11 (D-3) of Middle Eocene age (photo H. Buess 1936).

clastic material in the residues. The matrix is marly, mixed at the most with some fine silt, but there are no sands. In several samples, the most important Larger Foraminifera (*Asterocyclina asterisca*, *Lepidocyclina pustulosa*, *Lepidocyclina peruviana*, *Helicolepidina spiralis*, *Operculinoides soldadensis*) are represented by entire populations, unsorted or graded according to size or to shape, which points to an undisturbed sedimentation in their own habitat. The foreign material, large and small, was not introduced by strong lateral currents, but most have fallen and slid into the organic ooze from a nearby exposure. The presence of glauconite would suggest the nearness of a steep unbroken rocky coast, but more possibly these grains got somehow washed in from the Boca de Serpiente Formation (see Bed 11). J. B. Saunders' observations on the planktonic foraminifera in Bed 10 suggested shallow water conditions during sedimentation (private information).

f) Paleontology

The following samples were studied for Larger Foraminifera: Area A-2, A-3, B-3, C-3 and D-3: K.3689, Rz.251, K.903 (= old sample number K.296, mentioned by Vaughan & Cole in 1941), K.1500, K.3690, K.10718, K.10716, K.3691, K.3692, K.10707, J.S.1956 (K.10715, in this same area, is an erratic block originating from Bed 11).

Area D-1 and E-1: K.2652, J.S.1950, Rz.250, K.3677 (a block of Bed 10 fallen from the cliff onto Bed 9). The rich orbitoid fauna of Bed 10 is obviously of Late Eocene age. It is, however, heavily mixed with reworked material, not only in the form of the large blocks mentioned above, but also as detached Larger Foraminifera, and especially also planktonic forms which must have come from totally disintegrated marl deposits. In those planktonic forms, the Middle Eocene element predominates, and reworking is in places so overwhelming as to obscure the genuine age of the bed. Amongst the Larger Foraminifera both the lower Middle Eocene and the Paleocene are represented. The difference between the autochthonous fauna and the foreign material is often traceable by the state of preservation. This is particularly clear in the sample K.10716(B-3): the Late Eocene specimens are porous and tend to disintegrate, and boiling them in Canada balsam turns their colour to deep brown, whereas the reworked ones are solidly recrystallized and retain a light whitish brown colour. In sample Rz.250(D-1), on the other hand, the well preserved members of the true fauna are yellowish-grey and the sugary recrystallized older forms are dark brown.

The autochthonous fauna of Larger Foraminifera of Bed 10, all samples combined consists of:

Operculinoides soldadensis Vaughan & Cole
Operculinoides ocalanus (Cushman)
Operculinoides kugleri Vaughan & Cole
Operculinoides trinitatensis (Nuttall)
Operculinoides ? *spiralis* Caudri n. sp.
Asterocyclina asterisca (Guppy); also rare B-forms
Asterocyclina vaughani (Cushman)
Proporocyclina mirandana (Hodson), A- and B-forms
Helicolepidina spiralis Tobler, A- and B-forms
Lepidocyclina pustulosa (H. Douvillé), s.s.
Lepidocyclina pustulosa (H. Douvillé), forma *trinitatis* (H. Douvillé)
Lepidocyclina pustulosa (H. Douvillé) forma *tobleri* (H. Douvillé)
Lepidocyclina pustulosa (H. Douvillé), B-form (undifferentiated)
Lepidocyclina peruviana Cushman
Sphaerogypsina globulus s.l.
Amphistegina grimsdalei Caudri n. sp.
Amphistegina cf. *lessonii* ?
Cycloloculina jarvisi Cushman

Reworked from the Paleocene are:

Ranikothalia antillea (Hanzawa)
Ranikothalia cf. *tobleri* (Vaughan & Cole)
Neodiscocyclina grimsdalei (Vaughan & Cole)
Neodiscocyclina cf. *aguerreverei* (Caudri)
Neodiscocyclina fonslacertensis (Vaughan)
Neodiscocyclina barkeri (Vaughan & Cole)
Neodiscocyclina ? sp. (thickwalled specimen in K.10707)
Hexagonocyclina inflata (Caudri)

Reworked from the lower Middle Eocene (see Bed 11) are:

Proporocyclina tobleri (Vaughan & Cole), A- and B-forms
Neodiscocyclina bullbrooki (Vaughan & Cole), A- and B-forms
Amphistegina undecima Caudri n. sp.
Amphistegina pauciseptata Caudri n. sp.

The relative frequency of these species in the various samples is indicated in the "Distribution Chart".

Benthonic Smaller Foraminifera are comparatively scarce in Bed 10, and they have not been given much attention. Around 1941, H. H. Renz in Pointe-à-Pierre determined those in sample K.3692 as being of Late Eocene age, and also J. B. Saunders mentions forms like *Bulimina jacksonensis* from a couple of samples (private information). Locally, forms of *Rupertia* and *Carpenteria* have been observed in the reef limestones.

More emphasis was laid on the planktonic foraminifera. The first determinations were given by Ruth Todd in 1962 (see p. 405). J. B. Saunders studied 15 samples from Bed 10, some of which carried a great number of planktonic forms whilst others were very poor. His general conclusion was that Bed 10 was a shallow water deposit, heavily contaminated with reworked material from the Middle Eocene. Specially mentioned in his letter are:

- K.1500(B-3): crushed *Globorotalia centralis*
- K.3677(B-1): strong *Uvigerina* assemblage and planktonics; *Bulimina jacksonensis*, *Bolivina*, etc.; planktonics Middle Eocene
- K.3690(B-3): common Middle Eocene planktonics, rounded *Globorotalia cerroazulensis* and *Globigerinatheca tropicalis*
- K.10716(B-3): strong Middle Eocene, weak Upper Eocene, *Globorotalia cerroazulensis*, *Globorotalia spinulosa*, *Globigerinatheca tropicalis*
- K.10718(B-3): planktonic foraminifera small and almost all Middle Eocene
- Rz.250(D-1): Middle Eocene planktonics
- Rz.251(B-3): *Truncorotaloides rohri*
- J.S.1024(B-3): small planktonic foraminifera common, mainly Middle Eocene, but also Upper Eocene present (probably *Globorotalia cerroazulensis* Zone)
- J.S.1026(B-2): strong planktonic fauna, mainly Middle Eocene, but also Upper Eocene present (probably *Globorotalia cerroazulensis* Zone)
- J.S.1032(B-3): small planktonic forms, mostly Middle Eocene, some Upper Eocene present (probably *Globorotalia cerroazulensis* Zone)
- J.S.1220(B-3): mixed Middle and Upper Eocene planktonics (probably *Globorotalia cerroazulensis* Zone)
- J.S.1950(D-1): poor in planktonics, mainly poorly preserved Middle Eocene forms

Apart from the foraminifera, the fauna of Bed 10 also comprises a certain amount of mollusk material (of both pelecypods and gastropods, especially near the top, K.3692; see RUTSCH 1939*b*). MAURY reported an oyster of doubtful origin (p. 404). Further, there are a few brachiopods, especially in the uppermost layer (*Terebratulina kugleri* RUTSCH in K.3692 and K.10716), bryozoans, ostracods, echinoids (JEANNET 1928, KIER 1967). Locally there are great concentrations of calcareous algae of the *Lithothamnium* type.

General remarks on the Larger Foraminifera

The most remarkable observation made on the very rich, complete and undisturbed fauna of Bed 10 is the total absence of *Helicosteginopsis soldadensis* (GRIMSDALE), so common and conspicuous an element in several of the other beds of the Soldado section, and also in the Upper Eocene of Trinidad and of many other places in the Caribbean Region.

Further, it is worth mentioning that several species of Larger Foraminifera are represented in flood abundance and as complete populations, ranging from embryos to fully developed large specimens in all their morphological variations, in both megalospheric and microspheric form. This is, for instance, the case with *Lepidocyclina pustulosa* (sensu stricto and forma *trinitatis*), *Lepidocyclina peruviana*, *Helicolepidina spiralis*, *Asterocyclina asterisca* and *Operculinoides soldadensis*. The bed thus provides excellent material for a specialized paleontological study of these forms. Also *Cycloloculina jarvisi*, both in the megalospheric and microspheric form, is consistently present in the marls, and is particularly frequent in the sample K.3692 from the top layer. Noteworthy is that practically all the specimens of *Asterocyclina asterisca* in this bed (apart from the rare B-forms) are 4-rayed.

Typical *Lepidocyclina "tobleri"* (*L. pustulosa* forma *tobleri*, in terms of VAUGHAN & COLE) was found (common!) only in one rather excentric spot: K. 2652(D-1), considered to be the top of Bed 10. The cases of a "multilocular embryonic apparatus" recorded by COLE from K.903(B-3) and K.3692(D-3) (1962*a*, p. 38, Pl. 7, Fig. 6 and 1962*b*, Pl. 27, Fig. 3, respectively) are too doubtful to be determined as such. Similar deviations from the normal embryonic pattern in this species were also observed at K.1500(B-3) and K.10707(D-3), but they do not go further than the development of irregular gigantic periembryonic chambers, or of twin bilocular nucleoconchs. In sample K.1500 some tricarinate monstrosities of *Helicolepidina spiralis* were encountered.

g) *Age of Bed 10: Late Eocene*

The first age determination of this bed proposed by MAURY has already been discussed and dismissed above (p. 404).

In spite of the above mentioned differences with the Vistabella fauna of the San Fernando area in Trinidad, there can hardly be a doubt that the Larger Foraminifera assemblage in Bed 10 belongs also to the Late Eocene. None of the samples contains any forms that would point to a late Middle Eocene age (*Polylepidina*, *Helicolepidina polygyralis*, *Neodiscocyclina* cf. *marginata*, Asterocyclinas of the group characterized by radiating rods of solid shell material, etc.).

The main difference with the typical Upper Eocene of San Fernando (Vistabella, Point Bontour) lies in the total absence of *Helicosteginopsis soldadensis*. As all the other forms with which this species is usually associated are present in abundance, we must assume that in principle the habitat in which the fauna was developed was favourable also for *Helicosteginopsis*. The most logical explanation for its absence is that it just had not come into being at the time Bed 10 was deposited. In other words, Bed 10 is slightly older than the San Fernando Formation at Vistabella and corresponds more closely to the glauconitic silt that used to be exposed on the top of the Mount Moriah hill in San Fernando before the locality was walled up. This silt, stratigraphically at the base of the Upper Eocene directly overlying the Middle Eocene Navet Formation, is likewise devoid of *Helicosteginopsis soldadensis*. Bed 10 and this Mount Moriah silt also have in common an abundance of *Lepidocyclina peruviana* and *Operculinoides soldadensis*.

This would mean that Bed 10 is older than Beds 7, 9, and 9a of the Soldado section itself. Another indication may be found in the monotony of the 4-rayed pattern of *Asterocyclina asterisca* in comparison with the increased frequency of 5-rayed forms and the general morphological variability of the species both at San

Fernando and in the Asterocyclina marl (Bed 9a) of Soldado Rock. In its lack of *Helicosteginopsis*, Bed 10 corresponds with Bed 4. This correlation is further discussed below, in the chapter on the "Geological History of the Rock".

The planktonic foraminifera do not offer much support to these detailed correlations. On their evidence J. B. Saunders states that he "would place Bed 10 in the *Globorotalia cerroazulensis* Zone (= *G. cocoaensis* Zone) rather than lower in the Upper Eocene, but it is not the topmost Eocene". On the other hand, also many samples of Beds 7 and 9, and the Asterocyclina marl are assigned to this zone, in some cases rather to the lower than to the upper part of it.

C. THE BOCA DE SERPIENTE FORMATION

Author of name: MAURY (1929, p. 180)
Original description: idem

Bed 11

a) Bibliographic history

MAURY (1912, p. 28–31) described the highest of Veatch's fossiliferous horizons on Soldado Rock (his Bed 8) as an indurated rock noticeable from being stained deep red with hematite, and greenish and purplish with other forms of iron, and gave a list of 28 species of mollusks and one brachiopod, most of them new (see under "Paleontology", p. 418). Mainly on the abundant presence of *Ostrea thirsae* GABB, this fauna was correlated with the "Lignitic" fauna of the Gulf Coast of the United States; G. D. Harris considered this Soldado horizon to be the equivalent of the Nanafalia Formation (Wilcox) of Alabama.

KUGLER (1923, p. 258) failed to locate MAURY's "Bed 8" during his short visit to the Rock, but assumed it to form part of his "Limestone Complex C", which included the yellowish and red, nodular, in part sugary deposit forming the highest top of Soldado, and which rests on the well-bedded orbitoidal Bed B-4a; their contact is shown in Fig. 3. Since this Bed B-4a was recognized as being of Priabonian age, the "Complex C" was assigned a possible Oligocene age on the assumption that it would later prove to carry an *Isolepidina–Eulepidina* assemblage such as was known from Trinidad (an assumption that was not confirmed).

MAURY (1925*c*, p. 160) stated: "The age of Bed 6, characterized by foraminifera, is now thought to be Upper (Jacksonian) Eocene, and that of Bed 8 either uppermost Eocene or, less likely, basal Oligocene. Its fauna is not very decisive".

LIDDLE (1928, p. 227) wrote: "Though there is no discordance of dip between the Eocene and Oligocene on Isla Soldado, an angular brecciated conglomerate indicates that considerable erosion has occurred between these two periods". On p. 231 a translation of KUGLER's description of the upper "Limestone Complex C" is given, whereby "knaurig" was erroneously translated as "lenticular conglomerate" instead of "nodular". LIDDLE's reproduction of Kugler's photo of the contact between the "Orbitoidal Marlstone B" and the "Limestone Complex C" is of much better quality than that in the original paper. Also LIDDLE assumed that the fossiliferous Bed 8 of VEATCH and MAURY has to be included in the upper limestone formation, but his conception of MAURY's faunas is rather confused.

MAURY (1929, p. 180) stressed the marked difference between the fauna of her Bed 2 (Soldado Formation) and that of Bed 8. For Bed 8 she established the term "Boca de Serpiente Formation" and the age was given as "Uppermost Eocene, equivalent to the European Ludian". No type locality was specified.

MAURY (1935, p. 192) repeated her age determination of Bed 8 as Ludian, and compared its fauna to a horizon East of El Carmen in Northern Colombia (later described by CLARKE & DURHAM in 1946).

KUGLER (1938, p. 219–221) distinguished the upper "Limestone Complex C" of his previous paper as Bed 11 of his new detailed subdivision of the Soldado section. This bed starts with a zone of glauconitic sand mixed with an autoclastic breccia of orbitoidal limestone of the same appearance as that forming the main mass of the summit. Further North, there are steeply dipping layers of dense limestone and thick beds, pockets and dykes of glauconite with green and copper red tinges. "It is in these glauconitic masses that are found the remains of those fossils described by MAURY as belonging to her Bed 8 and named by her the Boca de Serpiente Formation." From these glauconites RUTSCH determined six mollusks and one brachiopod (see p. 418). The material is deposited in the Natural History Museum in Basel.

Lithologically, Bed 11 seemed almost indistinguishable from the underlying orbitoidal Bed 10 (previously called: Bed B). KUGLER remarked that, if orbitoids in both beds should turn out to be the same, he would not hesitate to include Bed 11 in the San Fernando Formation, and to abandon the term "Boca de Serpiente Formation" altogether. (Note: VAUGHAN & COLE's work in 1941 proved the faunas to be different).

RUTSCH (1939*a*, p. 238) referred to the *Tubulostium* in his first fossil list (KUGLER 1938) as "*Tubulostium* aff. *leptosoma clymenoides*", as he was not sure it was completely identical to that species as found in the Vistabella Quarry in Trinidad. Correlation with the Trinidad Upper Eocene (Jacksonian) seemed probable but not certain. On the other hand, the presence of *Tubulostium* excludes an Oligocene age of Bed 11.

RUTSCH (1939*b*, p. 517) wrote: "Re-examination of the mollusks has shown that in all probability the Boca de Serpiente Formation may be correlated with the fauna from the Vistabella Quarry on Mount Moriah in Trinidad, and that it is definitely younger than Wilcox, and older than Vicksburg. Its age is probably Jacksonian (Upper Eocene)."

VAUGHAN & COLE (1941, p. 27) found that the Larger Foraminifera fauna of the basal glauconitic limestone of Bed 11 (K.3878) consisted exclusively of two new species: *Discocyclina* (*Discocyclina*) *bullbrooki* and *Pseudophragmina* (*Proporocyclina*) *tobleri*. As the horizon at which they occur lies above the typical Jacksonian of KUGLER's section (Beds 9 and 10), a certain stratigraphical importance was attached to this combination, but the age is still given as Upper Eocene. On p. 41 of their paper, they made the unfortunate mistake of stating that "*Operculinoides soldadensis* is an abundant species in the lower part of bed no. 11, at several places in bed no. 10, etc.", which is an obvious error. What they meant is: "the lower part of Bed 10, several placed in Bed 9" (compare loc. cit., p. 18–19). Bed 11 has yielded only one specimen of *Operculinoides* of this type (see below).

RENZ (1942, p. 541) included the Boca de Serpiente Formation in the San Fernando Formation.

CAUDRI (1944, p. 385, 386) pointed out that the exclusive *Proporocyclina tobleri* – *Discocyclina bullbrooki* fauna of Bed 11 (K.3878) had nothing in common with either the Paleocene or the typical Upper Eocene of Soldado Rock, and that the general character of these fossils seemed older, not younger, than that of comparable species in the underlying Jacksonian. She suggested that the fossil material in Bed 11 was of high Paleocene to basal Middle Eocene origin, redeposited in a barren post-Jacksonian sediment. On p. 386 is stated that, according to H. H. Renz, the benthonic fauna of Smaller Foraminifera in this sample has many species in common with the Paleocene fauna described by CUSHMAN & RENZ in 1942.

VAUGHAN (1945, p. 94, 106, 108, 112, 115) placed both species of Larger Foraminifera in the Upper Eocene.

LIDDLE (1946, p. 352–357) extended the term "Boca de Serpiente Formation" to include all the Upper Eocene sediments on Soldado Rock, and correlated them with a number of Upper Eocene formations in Trinidad and Venezuela.

CAUDRI (1948, p. 478) added *Amphistegina* sp. div. to the typical foraminiferal assemblage of Bed 11 and repeated the suggestion that the fauna was reworked.

KUGLER (1956*b*, p. 44) reported that it had been decided at the Meeting of Geologists in Trinidad to include Bed 11 in the San Fernando Formation, and that the term "Boca de Serpiente Formation" had become obsolete.

DE RIVERO (1956*a*, p. 79–83) gave an extensive detailed account of the bibliography of the Boca de Serpiente Formation, which on p. 83 she closed with the remark: "The question of whether the name Boca de Serpiente is to be retained or not and, if so, what rank is to be assigned to it, is more properly a question for our Trinidadian colleagues. Since Soldado Rock is so isolated we would be in favor of using formational names limited to the island (even though the correlation with Trinidad may be indisputable). For this reason we would favour using 'Boca de Serpiente' according to LIDDLE's 1946 usage, even though it includes more than MAURY's original definition. MAURY's (1929) 'Boca de Serpiente', in our opinion having been defined by purely paleontologic criteria, really is more properly considered as a fauni-zone. It may be that Bed 11 represents a zone high in the Jacksonian, which might eventually merit distinction as a substage. In view of the fact that the name 'Boca de Serpiente' may be useful in the terminology of the Upper Eocene, we hope that Dr. Kugler will not insist (on his) tentative suggestion of (the term) 'Serpiente Formation' for Bed 3 of the Soldado section (which he now believes to be Wilcox, Lower Eocene, and would separate from the Soldado Formation)."

COLE (1959, p. 380) reported the find of *Discocyclina (Discocyclina) anconensis* BARKER, in association with *Pseudophragmina (Proporocyclina) tobleri*, in a second foraminiferal sample from Bed 11 (E.L.1440, near the North shore). He came to the conclusion that, seemingly, *Discocyclina bullbrooki* (of which at K.3878 only microspheric forms had been found) was the B-form of *Discocyclina anconensis*. As this species occurs all through the Upper Scotland Formation of Barbados (Middle Eocene), he provisionally also assigned a Middle Eocene age to the fauna in Bed 11, for which he proposed the name of "*Pseudophragmina (Proporocyclina) tobleri* Zone". The stratigraphical aspects of Bed 11 were left out of the discussion.

COLE (1962*b*, p. 148) repeated VAUGHAN & COLE's erroneous statement that the lower part of Bed 11 carries *Operculinoides soldadensis* in abundance.

COLE (1969*a*, p. 10–13, 48) discussed certain features of *Proporocyclina tobleri* from K.3878 and assigned a Lower Eocene age to the material (p. 48).

CAUDRI (1972*a*, p. 216) changed the generic name of *Discocyclina bullbrooki* to *Neodiscocyclina.*

JUNG (1972, private correspondence) stated that the Boca de Serpiente mollusk fauna is not diagnostic enough for an age determination. The fauna is not rich, there are relatively few species and the fossils are not well preserved. Conclusions obtained from the foraminifera would be more reliable than those based on the mollusk remains.

CAUDRI in the paleontological section (Part 2) of the present study draws attention to the presence of a small megalospheric *Neodiscocyclina*, associated with *Neodiscocyclina bullbrooki* and *Proporocyclina tobleri* at K.3878 and elsewhere, which is a far more likely companion for *Discocyclina bullbrooki* than COLE's form from E.L.1440. Also, the author does not agree with COLE's specific identification as *Discocyclina anconensis*, but considers the form in question as a new species (*Neodiscocyclina mauryae*). The "*Proporocyclina tobleri* Zone" should not be correlated with the San Eduardo Limestone of Ecuador (type locality of *Discocyclina anconensis*), or the Upper Scotland Formation of Barbados, but is probably slightly older (see further under "age of Bed 11"). The relationship between the fauna and the matrix in which it is embedded, Bed 11 as such, is extensively discussed on p. 415 and 419 (present paper). Apart from the already mentioned new *Neodiscocyclina*, also two new species of *Amphistegina* are described from the *Proporocyclina tobleri* assemblage (*A. undecima* and *A. pauciseptata*).

b) Type section of Bed 11

From the highest top of the islet down to the Northern shore (D-3, C-2, C-1).

c) Stratigraphic relationship

Bottom: the bottom of Bed 11, observed at K.3693(D-3), is formed by a 30 cm thick breccia of angular blocks of orbitoid limestone embedded in dark green glauconite (weathering to hematite) with abundant oysters, which rests on the thin-bedded, yellow and brown, glauconitic orbitoidal marl of Bed 10 (K.3692(C-3).

Top: the irregular masses of limestone and glauconite of Bed 11 are in obvious contrast with the lightbrown petroliferous sandstone of Bed 12 which emerges across the narrow channel just off the North shore of the Rock. The actual contact is eroded and remains below the low tide water level.

d) Thickness and dip

About 17 meters: steep dip from the summit down to the North shore.

e) Lithology

Bed 11 is built up of three different kinds of rock. Firstly, a mollusk-bearing highly glauconitic marlstone or marly limestone (MAURY's "Boca de Serpiente Formation" s.s.). Secondly, a glauconitic orbitoidal limestone, which occurs in the form of banks and autoclastic breccia and blocks around the triangulation signal and which (following COLE 1959) we shall call the "Proporocyclina tobleri limestone". Both these units are embedded in masses of glauconite which penetrates everywhere and fills up the gaps. Finally there is a dense barren limestone which dominates the acute scarp descending from the top to the North shore.

Apart from the dense limestones, no definite bedding was observed and there is no question of a consistent stratification. The whole is a tumbled mass of semi-autochthonous and erratic blocks, often internally cracked, filled in with large-grained glauconite and infiltrated by hematite and other consolidating substances.

The base of the bed, in the Southern part of the exposure, consists of a prominent autoclastic breccia of Proporocyclina tobleri limestone and more or less consolidated "greensand" which contains oysters and some echinoids (cf. *Linthia*, K.3693). The limestone itself has relatively little glauconite, and only locally carries any appreciable amount of molluscan material. Banks and blocks of the same limestone, together with other, erratic, limestone blocks form the summit of Soldado Rock (triangulation station). The erratic blocks are mostly of Paleocene age: Ranikothalia limestone (K.3694, K.10710), Neodiscocyclina grimsdalei limestone (K.10710, K.10717), Dasyclad algae limestone (K.10711). In some places the Proporocyclina tobleri limestone takes the form of a microbreccia of thin orbitoids (*Proporocyclina*), fossil fragments and abundant Globigerinidae, Miliolidae and Textulariidae in a clear recrystallized matrix (K.10712, C-3).

Towards the North, the deposit assumes the lithological aspect which corresponds more particularly to MAURY's original "Boca de Serpiente Formation". In this area recur thick layers, pockets and vertical dykes of glauconite penetrating between, and mingling with, the highly fossiliferous, slightly marly limestones. The glauconitic masses of this part of Bed 11 have yielded most of the mollusk remains which were studied by R. F. Rutsch and by P. Jung, and also MAURY's "Boca de Serpiente fauna" must have come from here.

Also in this Northern area there are erratic blocks, of the same nature as around the summit: Athecocyclina limestone (K.10720), Discocyclina grimsdalei limestone (K.10724), Dasyclad algae limestone (K. 10724, J.S.1949, J.S. 1954).

The lithological nature of the Northern limestone is interesting enough to be described in more detail. It is a red-weathering, often rather friable, in part marly glauconitic limestone, locally full of shell remains (amongst them, common "*Terebratula*") and orbitoids. The fresh rock is grey and full of bright green glauconite pellets. Sometimes pieces and lumps of pale red silt are enclosed. A typical sample of

Fig. 7. Erosional bench cut into Bed 11 at NNW end of Rock (B-2) (photo H. G. Kugler 1946).

this deposit is J.S.1955(B-1): red and green speckled, glauconitic and hematitic limestone with large grains of glauconite, many orbitoids and apparently abundant mollusk remains which, however, are replaced by hematite so that they are no longer recognizable in the rock sections. The Larger Foraminifera, though recrystallized, have kept their structure and have remained determinable. Lumps of green (fecal?) pellets occur in this rock, and also some curious chitinous organisms filled with small foraminifera and detritus. All these heterogeneous elements are joined together by a trellis-like network of infiltrated hematite. There exists a certain orientation of the shell remains, but this was not observed in the position of the Larger Foraminifera.

The fauna is not evenly distributed through the deposit. In some spots, there is a concentration of the thin *Proporocyclina tobleri*, in others large robust lenticular Neodiscocyclinas predominate, and then again there are parts in which Larger Foraminifera and *Amphistegina* are rare. This would point to selection by currents. Also, in this Northern area Globigerinidae are locally abundant, but likewise in a hard recrystallized matrix (K.10719, B-2).

The fossils in J.S. 1955 are often rolled, cracked and broken, sometimes showing a calcite or detritus coating, or a dark outline, but in this case those things are not to be taken as a sign of reworking. Often a specimen, especially a *Proporocyclina*, is cracked and broken up into many fragments, each with its dark hematite lining, but all the fragments are still lying together with hardly any displacement (see Part 2, Paleontology, Pl. 20, Fig. 1, 5, 6, 7). Damage (by pressure?) and infiltration are post-depositional.

The limestones of Bed 11 are not real reef limestones: they carry a negligible amount of coral fragments, and algae are practically absent. They were fore-reef ridges of loose material, probably swept together by currents. Their depositional environment is characterized by the abundance of coarse glauconite as a near-shore mud along a steep rocky coast devoid of large estuaries, into which those banks of contemporaneous limestone have slumped down. The nearby coast contributed very little: the curious chitinous organisms found in sample J.S. 1955 may be of terrestrial origin, but no reworked fossils were found in any of the samples. The erratic blocks seem to lie *on* the formation but not embedded in it.

f) Type samples

There is no doubt that the entire Bed 11 belongs to one formation for which we want to keep the name of "Boca de Serpiente Formation", extending the term over its full thickness and including the "Proporocyclina tobleri limestone", the mollusk banks and the dense barren limestones, wherever they prove to fit in.

Although no clear subdivision can be made in this bed, there are certain differences between the limestone in the South and that in the Northern part, the most important being that *Neodiscocyclina mauryae* n. sp. has been found thus far in the Northern beds only. As the facies is the same in both spots, the restriction in the range of this species seems to hint at a slight difference in age.

For the designation of one single type sample for Bed 11 we would have to choose between the mollusk-bearing glauconite masses in the North and the orbitoid breccia in the South, from which VAUGHAN & COLE (1941) and CAUDRI (present paper) described the peculiar Larger Foraminifera fauna, but neither sample would be representative of the whole. MAURY did not indicate a type locality for her Boca de Serpiente mollusk fauna, and the one chosen for RUTSCH's limited collection (K.1496, B-1) is not a very satisfactory proposal. VAUGHAN & COLE's type locality (K.3878, C-3), on the other hand, does not cover the mollusks. Instead of arbitrarily designating one particular locality, it seems better to choose a representative sample of each of the two types of rock:

1. K.3878(C-3), the type locality of the "Proporocyclina tobleri limestone", which lies near the base of the bed in the general line of the measured Soldado section;
2. J.S. 1955(B-1), the mollusk–orbitoid limestone typical of the matrix of the "Boca de Serpiente" mollusk fauna.

g) Paleontology

Microfossils

As representative of the microfauna of the Boca de Serpiente Formation we give the contents of the two samples mentioned above:

1. K.3878(C-3), friable yellowish-grey somewhat glauconitic marly limestone with a rich fauna. Larger Foraminifera strongly recrystallized so as to render them practically unrecognizable from the outside. Most of them with more or less well-developed pillars.

Neodiscocyclina bullbrooki (VAUGHAN & COLE), A-form (scarce)
Neodiscocyclina bullbrooki (VAUGHAN & COLE), B-form (common)
Proporocyclina tobleri (VAUGHAN & COLE), A-form (abundant)
Proporocyclina tobleri (VAUGHAN & COLE), B-form (common)
Amphistegina undecima CAUDRI n. sp. (abundant)
Amphistegina pauciseptata CAUDRI n. sp. (scarce)

Smaller Foraminifera, benthonic forms only, determined by H. H. Renz (common): *Quinqueloculina* sp., *Robulus* sp., *Eponides elevata* (PLUMMER), *Gyroidina subangulata* PLUMMER, *Pulvinulinella obtusa* (BURROWS & HOLLAND), *Anomalina* sp., *Cibicides praecursorius* SCHWAGER), etc.

Ostracods (scarce), crab claws (scarce), pelecypods (scarce), gastropods (scarce), worms ? (scarce), echinoids (common), corals (scarce).

Of this same horizon we also had the samples K.3693(D-3), K.10709(D-3), K.10712(C-3) and Gr. 627 (a "greensand", C-3). The only additions they furnish to the above list would be that K.3693 carries a lot of oysters and that one of the echinoids was determined as *Linthia*, that K.10712 is rich in Smaller Foraminifera (also planktonics, e.g. Globigerinidae, but alas in a hard recrystallized matrix), and that some Globorotalias in K.10709 can be determined as Middle Eocene (J. B. Saunders, private information).

2. J.S. 1955(B-1), hard highly glauconitic and fossiliferous, red and green speckled marly limestone (consolidated "greensand"); see above. Larger Foraminifera:

Neodiscocyclina mauryae Caudri, A-form (abundant)
Neodiscocyclina bullbrooki (Vaughan & Cole), A-form (probably common)
Neodiscocyclina mauryae and *bullbrooki*, undifferentiated B-forms (abundant)
Proporocyclina tobleri (Vaughan & Cole), A- and B-forms (common)
Amphistegina sp., in part clearly determinable as *Amphistegina undecima* (common)

Smaller Foraminifera: *Carpenteria* ?, Globigerinidae, *Globorotalia* ? (spinose forms), *Robulus* div. (rather frequent), "*Nodosaria*" s.l., Textulariidae.

Ostracods (very thick-walled forms) (frequent; in part perhaps brachiopods?, but walls seem imperforate).

Bryozoans (rare).

Mollusks (pelecypods and gastropods; probably common to abundant, but unrecognizable).

Echinoid spines and plates (common); among others a kind of large spine of very regular structure, in some cross sections resembling a *Sphaerogypsina*, but with a secondarily spinose surface as seen in other sections (Pl. 20, Fig. 2: see Part 2).

Corals (rare).

Fossils *incertae sedis*, shaped like an amphora with a chitinous(?) wall, filled with detritus (of non-marine origin?).

Algae (practically none: one small fragment observed only).

Of this kind of limestone we also had the sample K.1496(B-1) (mollusks; no microfauna studied), K.3696(B-2) (with "*Terebratula*"), K.10729(B-2) (abundant Globigerinidae in hard rock), K.10721(C-1), K.10722(C-1) and E.L.1440(C-1). K.10721, described as a "highly glauconitic disintegrating limestone belonging to the main glauconitic mass on top of orbitoidal limestone", contains, apart from the list given above, one small specimen of an *Operculinoides* of the type of *Operculinoides soldadensis* and one specimen of *Sphaerogypsina globulus* s.l. Both this sample and K.10722 have an abundance of *Amphistegina undecima*, A- and B-forms. E.L.1440 has frequent very small colonies of bryozoa, subglobular and lenticular kinds, and shows a wide range in the size of its mollusks, from microscopic to fairly large. It also carries very rare and small *Tubulostium*.

Smaller Foraminifera: These are chiefly present in the hard recrystallized limestones where they are totally indeterminable. Locally, Textulariidae, Miliolidae and especially Globigerinidae are predominant. H. H. Renz thought the benthonic forms in K.3878 to be of Paleocene age. The only more or less determinable planktonic material comes from the marl K.10709(D-3) and was described by J. B. Saunders as: "poor preservation, mostly casts; shallow water forms and planktonics; Middle

Eocene Globorotalias. Possibly Upper and Middle Eocene" (private correspondence).

Mollusks

Maury (1912, p. 30) determined from her "Bed 8", which has never been traced back again but must have lain in the Northern or North-western part of our present Bed 11, the following mollusk fauna:

Ostrea golfotristensis n. sp.
Ostrea thirsae Gabb
Spondylus sp. indet.
Modiola alabamensis Aldrich
Venericardia crucedemaionis n. sp.
Meretrix cf. *nuttalliopsis* Heilprin
Meretrix subimpressa var. *golfotristensis* n. var.
Venerupis atlantica n. sp.
Corbula (Cuneocorbula) subengonata Dall
Corbula (Cuneocorbula) weaveri n. sp.
Cyclichna solivaga n. sp.
Pleurotoma guppyana n. sp.
Caricella ? sp. indet.
Volutilithes sp. indet.
Fusus bocarepertus n. sp.
Fusus longiusculoides n. sp.
Fusus taeniensis n. sp.
Fusoficula juvensis Whitf.
Cassis (Phalium) guppyana n. sp.
Rimella fowleriana n. sp.
Rimella knappiana n. sp.
Cerithiopsis veatchiana n. sp.
Turritella mortoni var.
Solarium stephanephorum n. sp.
Natica cf. *semilunata* Lea var.
Amauropsis smithiana n. sp.
Liotia lillianae n. sp.
Dentalium microstria Heilprin

Her type specimens are kept in the Paleontological Research Institute at Ithaca, New York. Dr. Katherine V. W. Palmer, Director of the Institute, very kindly lent us some of the types for renewed study by P. Jung.

Rutsch's list (1938, private report; see Kugler 1938, p. 220) does not add much to that of Maury, apart from modernization of some of the names and the find of *Tubulostium*. He identified:

Ostrea sp. indet.
Tubulostium leptostoma clymenoides (Guppy) (one specimen)
Rimella (Ectinochilus) knappiana Maury
Terebellum sp. aff. *procerum* Merian
Pachycromium smithianum (Maury)
Callianassa sp. indet. (det. van Straelen)

The specimen of *Tubulostium*, re-determined by Rutsch in 1939*a* as "*Tubulostium leptostoma* aff. *clymenoides*" has been lost and is no longer accessible for checking. More material of *Tubulostium* (rare, very small specimens) have later on been found in the washed residue of sample E.L.1440, but these still await further expert study.

Brachiopods

In 1912 (p. 104), Maury described and figured *Terebratula stantoni* n. sp., which she considered to be different from the *Terebratula lecta* Guppy of the San Fernando Formation of Trinidad. Rutsch (1938), who changes the name to *Liothyrina stantoni* (Maury), remarked, however, that in his opinion the species was very similar to forms of *Liothyrina* described by Guppy (1866) from "gypseous marls containing *Orbitoides mantelli* and *Nummulina*, exposed near the town of San Fernando".

h) Age of Bed 11: Late Early to Early Middle Eocene

The age of the Boca de Serpiente Formation remains one of the greatest puzzles in the Caribbean Region. In the field section of Soldado, this bed appears to overlie the Upper Eocene. However, the foraminiferal fauna does not reflect the evolutionary level generally reached in a Late Eocene assemblage. The above bibliographic list shows clearly enough how the malacologists have been shifting their age determinations up and down between the Lower Eocene (Wilcox) and the Oligocene, and how in the end preference had to be given to the evidence of the foraminifera over that of the unsatisfactory mollusk remains. The Larger Foraminifera fauna proves to be a curiously restricted one:

Proporocyclina tobleri (VAUGHAN & COLE)
Neodiscocyclina bullbrooki (VAUGHAN & COLE)
Neodiscocyclina mauryae CAUDRI n. sp.
Amphistegina undecima CAUDRI n. sp.
Amphistegina pauciseptata CAUDRI n. sp.

Apart from reworked and slumped material, scattered in profusion throughout the beds of the saddle of Soldado Rock itself (especially Bed 10), this typical restricted fauna has been found elsewhere only once: in a limestone block in Southern Trinidad. Isolated specimens of *Proporocyclina tobleri* were spotted in the Middle Eocene Navet Formation of Trinidad, but we are not sure whether it is *in situ* there or reworked. Further, there are indications that a similar fauna may occur along the edges of the Caribbean Basin. *Proporocyclina tobleri* has been reported from Campeche (Mexico, Middle Eocene, but perhaps not in place; see BUTTERLIN 1968) and, more important, from the Walton County of Florida (subsurface Lower Eocene; see COLE & APPLIN 1964), but the assemblage is nowhere so well developed and characteristic as right here on Soldado Rock.

Because of the relatively primitive characteristics of both the *Proporocyclina* and *Neodiscocyclina*, CAUDRI attached a very late Early Eocene or a very early Middle Eocene age to this fauna (see Paleontological section of present paper). J. B. Saunders' badly preserved Globorotalias from K.10709 (p. 417) seem to advocate Middle Eocene rather than Lower.

The find of a small isolated specimen of "*Operculinoides soldadensis*" in K.10721 is no obstacle to this age determination. Though the species has originally been described from Bed 10 (K.3692, C-3) and also occurs in abundance in the Trinidad Upper Eocene, it has lately been found in great numbers also in the Upper Middle Eocene of Margarita Island (BUTTERLIN 1970; CAUDRI 1974). Moreover, because it is a fundamentally simple, non-specialized form, its roots may go deep into the section[6]). Its presence may, however, tip the scales in favour of a Middle rather than an Early Eocene age, as would also those Middle Eocene Globorotalias spotted in K.10709.

Our careful study of Bed 11 leads to the conclusion that CAUDRI's previous suggestion of wholesale reworking of the fauna into a barren deposit of Late Eocene age can be dismissed. Bed 11 is an undisturbed formation with a pure autochthonous fauna, and its age is as indicated by those fossils: very early Middle Eocene, or perhaps very late Early Eocene. How it came to lie in its present position, topographically overlying the Upper Eocene in the section, is discussed below, in the chapter on the "Geological History" of this complicated little chunk of rock.

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[6]) As has already been mentioned above (p. 412), VAUGHAN & COLE's statement (1941, p. 41) that *Operculinoides soldadensis* is an abundant species in the lower part of Bed 11 is an obvious error.

D. UNDETERMINED FORMATION

Bed 12

a) Bibliographic history

Kugler (1938, p. 220–221) described as Bed 12 the low bank of oil-bearing sandstone that emerges from the sea off the North shore of Soldado Rock. Its strike is oblique to the general strike of the Soldado beds themselves, perhaps as a result of uncomformable overlap.

b) Type section

Outcrop on the North shore.

c) Stratigraphic relationship

The nature of this sandstone is quite different from the "underlying" Bed 11, and no direct relationship could be established between the two. Their contact is strongly eroded and remains below the water level at low tide.

d) Thickness

Unknown; about 4 meters exposed.

e) Lithology

Near the contact with Bed 11, Bed 12 consists of fine-grained brown-weathering sandstone with a bluish calcareous core when fresh. This sandstone has nothing in common with the sandstones found in streaks and lenses on Soldado Rock itself: K.1497(C-1), for instance, is a very fine-grained dark-grey sandstone, totally different from such gritty white sandstones as K.905(D-3) or K.1495(D-4). Upwards, the calcareous sandstone changes into a dark-brown non-calcareous oilsand (K.1498, D-1).

f) Paleontology

The deposit is barren.

g) Age

Bed 12 shows affinities with sandstones known from the San Fernando (Mount Moriah) Formation of Trinidad, and also resembles the Nariva Sandstone and some of the sandstones of the Karamat Formation in that Island, but the total absence of fossils does not permit a definite comparison with any of these formations.

E. MIOCENE BEDS

Dr. P. Jung and Mr. R. Panchaud of the Natural History Museum, Basel, stayed on Soldado Rock from 25–28 February 1973 for the purpose of collecting additional fossils and to check some previous statements. On the first day they were accompanied by Messrs J. B. Saunders of Texaco Trinidad, Inc., and by P. L. Percharde of Trinmar Ltd. During the time Saunders assisted Jung and Panchaud in carrying out a short reconnaissance of the Rock, Percharde did some Scuba diving with a short core barrel to take sea-bottom samples. He started about 80 meters NW of the West end of Bed 2 and extracted ten samples, roughly 8 meters apart. Saunders examined the contents of these samples and, starting from the Rock in a NW direction (see map), he reported in a private letter the following results:

- J.S.3223: Block of fresh, hard silty clay with excellent fauna rich in planktonic foraminifera belonging to the *Globorotalia opima opima* Zone.
- J.S.3222: Block of silty sandstone with very rich, predominantly planktonic fauna of very constant small size, suggesting sorting. Mostly about *Globigerinatella insueta* Zone.
- J.S.3221: No bedrock present.
- J.S.3220: Barrel with a few siltstone fragments. Fauna as J.S.3223. Mainly small planktonics, brown and a few whites, possibly also *Globigerinatella insueta* Zone.
- J.S.3225: Barrel with crumpled, brown clay, calcareous. Sample somewhat contaminated. Rich *Globigerinatella insueta* Zone with a number of *Orbulina* and Recent mollusks.
- J.S.3219: Barrel with sandy siltstone fragments.
- J.S.3218: Barrel with silty clay fragments that were isolated for washing. Good fauna of *Globorotalia opima opima* Zone.
- J.S.3217: As J.S.3218, *Globorotalia opima opima* Zone.
- J.S.3216: As J.S.3218, *Globorotalia opima opima* Zone.
- J.S.3224: Barrel with good, steeply dipping, crumpled, brown clay, calcareous in bottom of barrel. Sample somewhat contaminated with silt. Mainly approximately *Globigerina ciperoensis ciperoensis* Zone with some *Globigerinoides* indicating Miocene.

J. B. Saunders summarizes these observations thus: "The samples so far obtained are somewhat puzzling. P. L. Percharde maintains that the silty clay (*G. opima opima* Zone) is widespread and represents bedrock. In fact the results suggest that this is not so and that, though predominant, the clay is really contained in a matrix of younger material. The youngest proven material is of probable *Globigerinatella insueta* Zone age though, again, some of this is in the form of boulders. A younger matrix may still be involved (vide Orbulinas) which, from our experience of wildflysch elsewhere, is most likely to be Karamat or even Lower Cruse in age."

The deposition of large slipmasses of older rocks in younger turbidites is commonly known in Trinidad in such features as Marac Hill, Morne Roche, Morne Diablo, etc., once called "morros" (KUGLER 1953, p. 41), and now known as olistoliths. An outstanding example of such olistoliths are the Pelican Rocks, situated between 1 and 2 kilometers South of Soldado Rock (Fig. 8).

Fig. 8. Southern end of Pelican Rocks with Soldado Rock in background (photo E. Lehner 1934).

They form four quite abnormal N–S directed rows of rocks consisting of chalk-like Navet Formation of Middle Eocene age. A lesser mass of Navet Formation was found in a bore-hole of the Forest Field in Trinidad inside the diapiroid core of mud-flow consisting mainly of Miocene Cruse clays. We, therefore, can assume that likewise the entire area between the Soldado Rock and the Pelican Rocks represents a diapiroidal mass of abnormally thick Miocene turbidites containing submarine slip-masses of older rocks.

F. RECAPITULATION OF THE SAMPLE LISTS OF VARIOUS BEDS[7])

Bed 1

P.J.1152(C-5), glauconitic limestone with oysters
K.10705(C-5), recrystallized glauconitic limestone with mollusks and Smaller Foraminifera
K.10706(C-5), recrystallized glauconitic mollusk–algae limestone with Smaller Foraminifera
K.10704(C-5), recrystallized coquina; some Smaller Foraminifera

Bed 2

K.2948(C-5), silt with *Amphistegina*
K.2949(C-5), MAURY's mollusk bed (Bed 2, 1912)
K.9454(B-4), mollusk–algae limestone with common large oysters and scattered microfossils, also some small Larger Foraminifera
Z.444B(B-4), lumachelle with some *Amphistegina* and Dasyclad algae
E.L.1575 and P.J.1165(B-4), limestone with echinoids (*Salenia*)
P.J.1143(C-5), limestone with poorly preserved mollusks

Slump masses and erratic blocks originating from the Paleocene

K.1317(D-5), mollusk–algae limestone with Smaller Foraminifera (as K.10705 and 10706, Bed 1)
K.2849(F-3), limestone with karren, full of mollusks
K.2875(G-3), limestone with *Venericardia*
P.J.1145(B-3), limestone with fragments of large oysters
P.J.1163(B-5), massive limestone with large oysters
P.J.1164(C-5), id.
P.J.1166(B-3), id.
K.1317a(F-4), coquina as in Bed 2
K.2653(E-4), id.
K.3736(F-3), id.
K.3742(B-5), id.
K.3873(F-2), id.
K.10713(B-3), id.
K.11445(B-3), id.
P.J.1148(F-3), id.
P.J.1149(F-4), id.
P.J.1150(E-4), id.
P.J.1151(E-4), id.
P.J.1158(E-4), id.

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[7]) Roughly in stratigraphical order, from bottom to top.
The initials preceding the numbers refer to the following collectors: T.L.L. = Trinidad Leaseholds Ltd.; K. = H. G. Kugler; Rz. = H. H. Renz; Cd. = C. M. B. Caudri; K.S. = K. Schmid; Z. or F.Z. = F. Zyndel; Gr. = T. F. Grimsdale; E. L. = E. Lehner; J.S. = J. B. Saunders; P.J. = P. Jung.

P.J.1167(B-3), id.
K.S.25(G-3), greenish-grey, white-spotted markasitic *Amphistegina*-algae limestone, with traces of Dasyclad algae
K.3876, pars (F-3), Dasyclad algae limestone
K.10711(D-3), id.
K.10724, pars (D-1), id.
J.S.1949 (D-1), id.
J.S.1954 (C-1), id.
K.2851(E-4), typical Athecocyclina limestone, with algae and with abundant echinoids, mollusks and Smaller Foraminifera in separate pockets
P.J.1159(E-4), «Athecocyclina limestone», locally without Larger Foraminifera: glauconitic sandy Globigerina limestone
P.J.1160(E-4), as P.J.1159
K.3740, pars (E-4), «Athecocyclina limestone», echinoid–algae limestone, locally without Larger Foraminifera (as Cd.22 and 23); pebble in a block of Ranikothalia limestone!
K.1318(F-3), typical Athecocyclina limestone (as K.2851)
K.2850(F-3), limestone, silty, glauconitic, knobbly weathering
Cd.21(F-3), «Athecocyclina limestone», locally a glauconitic Globigerina limestone as P.J.1159
K.1319(F-3), as Cd.21
Cd.22(G-3), typical Athecocyclina limestone with abundant Globigerinidae, echinoids and very small algae
Cd.23(G-3), as Cd.22, but locally without Larger Foraminifera
K.3876, pars (F-3), algae limestone resembling Cd.22
K.10720(B-2), typical Athecocyclina limestone with some *Ranikothalia* and common *Neodiscocyclina*
K.906(C-4), Ranikothalia limestone, slumped into Bed 3
K.10702(D-4), Ranikothalia limestone, slumped into Bed 3
Rz.252(C-4), id.
K.10701(D-4), id.
T.L.L.125(C-4), id.
K.2951B, pars (D-4), pebble of Ranikothalia limestone in Bed 4
K.3694(D-2), Ranikothalia limestone
K.3739(G-3), Ranikothalia–Neodiscocyclina grimsdalei limestone
K.3876, pars (F-3), id.
K.3740, pars (E-4), Ranikothalia–Neodiscocyclina grimsdalei limestone containing pebbles of algae limestone with Smaller Foraminifera and echinoids like the Athecocyclina limestone Cd.23
K.10708(D-3), Ranikothalia–Neodiscocyclina grimsdalei limestone
K.10725(B-3), id.
K.10717(B-2), Neodiscocyclina grimsdalei limestone with abundant *Ranikothalia*
Rz.248(F-3), Neodiscocyclina grimsdalei limestone with common *Ranikothalia*
K.10710(D-3), id.
K.10724, pars (D-1), Neodiscocyclina grimsdalei limestone
K.9453(G-3), pure Neodiscocyclina grimsdalei limestone

Bed 11

Lower part:

Gr.627(C-3), "greensand" (pure glauconite) with abundant *Proporocyclina tobleri*
K.3693(D-3), Proporocyclina tobleri limestone with abundant megafossils, amongst others echinoids (cf. *Linthia*) and oysters
K.10712(C-3), Proporocyclina tobleri limestone
K.10709(D-3), glauconite, interbedded in Proporocyclina tobleri limestone
K.10715(B-3), limestone block with poor *Proporocyclina* fauna tumbled down from the cliff of Bed 11 onto Bed 10
K.3878(D-3), friable highly glauconitic Proporocyclina tobleri limestone with rich fauna

Upper part:

K.3696(B-2), "greensand" (glauconite with *Proporocyclina tobleri* and "*Terebratula*")
K.10719(B-2), Proporocyclina tobleri limestone
K.1496(B-1), type sample of Rutsch's "Boca de Serpiente" mollusk fauna; *Tubulostium*. No foraminifera
J.S.1955(B-1), highly fossiliferous and glauconitic limestone (Neodiscocyclina mauryae limestone)
P.J.1157(B-1), glauconitic rock with hematitic crust
K.10721(C-1), friable glauconitic orbitoid limestone
K.10722(C-1), friable glauconitic limestone (as K.10721, but less fossiliferous)
E.L.1440(C-1), friable glauconitic limestone with foraminifera and some mollusks. *Tubulostium*

Bed 3

K.2950(C-4), marl, in itself nearly barren (very rare Late Eocene Larger and Smaller Foraminifera), but containing a very rich reworked Paleocene foraminiferal fauna
K.2951(C-4), marl; as K.2950
Rz.254(D-4), barren silt
Rz.255(D-4), marl; as K.2950
Rz.256(D-4), barren silt

Bed 4

K.2951B(D-4), marly rubble with a very rich foraminiferal fauna, predominantly reworked from the Paleocene; sparse Late Eocene assemblage
Rz.253(D-4), weathered fossiliferous earth with mixed Paleocene and Late Eocene foraminifera
Rz.256(C-4), barren silt
K.1321(B-3), hard limestone breccia full of Larger Foraminifera and fragments of Ranikothalia limestone and of highly recrystallized dense algae limestone
Rz.245(D-5), barren marl
K.2877(G-3), hard barren silt
K.3739(G-3), lense of highly crystallized limestone full of Paleocene detritus (calcite rhombohedrons), with poor Late Eocene fauna
K.3743(C-5), crumbly marl with echinoid and mollusk fragments, small solitary corals and a few Larger Foraminifera
K.S.24(G-3), grey-and-brown spotted limestone (as K.S.23) with reworked Paleocene fauna only
K.S.23(G-3), grey-and-brown spotted limestone with predominantly Paleocene fauna but also rare *Lepidocyclina*
Rz.247(F-3), lens of grey glauconitic limestone with a rich fauna of Late Eocene Larger and Smaller Foraminifera

Bed 10

J.S.1220(B-3), marl with a predominantly shallow water fauna of Smaller Foraminifera
K.1500(B-3), friable glauconitic limestone with oysters and a rich microfauna
P.J.1144(B-3), rubbly limestone with echinoids
J.S.1024(B-3), echinoid marl with Smaller Foraminifera
K.3677(E-1), marl with extremely rich foraminiferal fauna; undisturbed sediment containing entire populations of Larger Foraminifera, amongst others *Lepidocyclina pustulosa* (detached block fallen off the cliff of Bed 10 onto Bed 9)
Rz.250(D-1), marly glauconitic limestone
Rz.251(B-3), id.
K.903(B-3), friable foraminiferal limestone
P.J.1153(B-3), rubbly limestone with echinoids
K.10707(D-3), glauconitic marl
J.S.1032(B-3), silt interbedded with rubbly limestone, with Larger and Smaller Foraminifera
P.J.1154(B-3), limestone with algal nodules and mollusks
K.3689(A-3), foraminiferal limestone

K.3690(B-3), glauconitic marl
K.3691(B-3), id.
K.10716(B-3), marl full of badly preserved Larger Foraminifera and small megafossils, amongst others *Terebratulina*
J.S.1956(A-3), dense foraminiferal limestone
K.10718(B-3), glauconitic marl with recrystallized foraminifera
J.S.1026(B-2), sandy marl with Smaller Foraminifera
K.3692(C-3), highly fossilferous glauconitic marl with small megafossils, amongst others *Terebratulina kugleri*
K.2652(D-1), glauconitic orbitoid marl
J.S.1950(D-1), Operculinoides marl

Bed 5

K.2956(D-4), barren calcareous quartzose sandstone
K.1495(D-4), barren non-calcareous quartzose sandstone

Bed 6

K.2955(D-4), barren silt

Bed 7

K.2954(D-4), marl with poor Larger Foraminifera fauna but rich in Smaller Foraminifera ("Hantkenina marl")
K.2855(F-3), glauconitic marl full of Larger Foraminifera

Bed 8

K.2953(D-4), barren silt with clay layers and carbonaceous specks

Bed 9

K.905(D-3), sandstone lens, barren
E.L.1441(D-3), barren sandstone
K.1499(E-2), marl with very rich Larger Foraminifera fauna
K.2952(D-3), barren silt
E.L.1571(E-1), id.
K.2856(E-2), id.
Rz.249(E-1), id.
K.3678(E-1), barren silty limestone
E.L.1441(E-1), barren sandstone

Bed 9a (Asterocyclina marl)

P.J.1161(E-4), crumbly, somewhat silty marl; nearly barren
K.3737(E-4), calcareous silt with Paleocene blocks; very poor mixed fauna
J.S.1030(F-3), marl with Smaller Foraminifera
P.J.1146(E-4), marl with poor fauna, chiefly of Smaller Foraminifera
K.2651(E-4), marly clay with glauconite: very rich fauna of Smaller and Larger Foraminifera
J.S.1029(E-4), marl with Smaller Foraminifera
P.J.1147(E-4), marl (as P.J.1146)
K.2854(= Gr.33) (E-5), marl with a very rich Larger Foraminifera fauna (typical Asterocyclina marl) and relatively few Smaller Foraminifera
J.S.1224(E-4), marl with Smaller Foraminifera
J.S.1223(D-5), marl rich in Smaller Foraminifera and with a fair amount of small and partly juvenile Larger Foraminifera

K.2650(D-5), marly clay with abundant Smaller Foraminifera; Larger Foraminifera very rare
K.1316(D-5), calcareous silt with a very rich Larger Foraminifera fauna and relatively few Smaller Foraminifera
K.3741(D-5), marl with few Smaller Foraminifera and very rare Larger Foraminifera
P.J.1162(D-5), marl as P.J.1146 and P.J.1147, but fauna characterized by the relative abundance of Miliolids, *Glandulina* and *Haplophragmoides*

Blocks of unknown origin in Bed 4

K.3676(F-3), amongst other blocks: fine-grained dark-coloured crystalline limestone
K.10714(B-3), barren quartzitic sandstone
Cd.24(G-3), recrystallized coral limestone
K.S.27(G-3), barren silt nodule with orientated dark organic or crystalline elements

G. ANNOTATIONS TO THE DISTRIBUTION CHART

(see plate II)

1. In 1938, KUGLER added to his sample numbers the letter "b" or "B" in order to distinguish them from a set of duplicate field numbers from a totally different area. VAUGHAN & COLE (1941) reproduced KUGLER's map *with* this additional "B", but throughout the text the letter was omitted. We have done the same here (also on the map) but with one exception: K.2951B (Bed 4) is distinct from K.2951 (Bed 3).

2. In the chart, the order of the various beds is chosen not in accordance with their position in the field but with the age determination of the fauna they contain. Bed 11 is inserted between the Paleocene and the Upper Eocene; Bed 10 is considered as the fully developed deeper-water version of the transgressive Bed 4 and is followed by the younger sequence of Beds 5 to 9a.

Within each bed, the samples are arranged roughly in stratigraphical order, that is: from South to North for Beds 2 and 3, 7 to 9, and 10 and 11. For the chaotic deposit of Bed 4 and for Bed 9a, which latter was belatedly recognized as a separate unit and was not as consistently measured in the field as the rest, the sequence was chosen in a rather arbitrary way, from NW to SE, at right angles to the strike which is more or less parallel to the shore line.

3. The stratigraphical position of K.S.25 is uncertain. Lithologically, the sample is quite different from any of the others; only the possible presence of Dasyclad algae would hint at a Paleocene age.

4. Reworking of older forms into the Upper Eocene is not just a surmise: it is clearly demonstrated in samples such as K.10716 and Rz.250, where the derived specimens are strikingly different in colour and preservation from the autochthonous fauna, both in the Larger and in the Smaller Foraminifera.

No reworked Larger Foraminifera have been observed in sample K.3677 (Bed 10), but the planktonic forams are mainly Middle Eocene.

For convenience, the non-foraminifera are all entered in the chart as "autochthonous". In reality, also these groups are a mixture of older and younger forms.

5. The faunas in samples K.3689, 3691, 3693 and 3696, as marked in the chart, are incomplete. Only the species mentioned by VAUGHAN & COLE for these localities have been entered; we had no duplicate material in our own collection.

6. The "very small *Neodiscocyclina*" of K.9454 (no. 7 in the chart) is in all probability *N. barkeri*, but identification of the specimens in this hard rock remains speculative. Also the common specimens listed as *N. barkeri* for K.10701 seem really to belong to that species, although these forms are abnormally small. On the other hand, the "very small *Neodiscocyclina*" in K.10712 (one vertical section, in hard limestone) does not necessarily represent that same species.

7. The abundant *Amphistegina* in the hard limestone Rz.247 (Bed 4) is presumably *A. grimsdalei* (no. 49), but identification is based on random sections only.

8. "Smaller Foraminifera" (no. 2) include benthonic and planktonic forms, also Globigerinidae et al. in general. Only where this latter group occurs in excessive quantities is it listed separately as "Globigerinidae s.l." (no. 14). Globigerinidae also flood the assemblage of Smaller Foraminifera in some of the pockets of the Athecocyclina reef limestone, which locally are lacking in Larger Foraminifera and are therefore omitted in the chart (P.J.1159, 1160; Cd.21).

The composition of the Smaller Foraminifera assemblages is highly variable. Miliolidae are locally common in the Ranikothalia limestone (K.10701, 10708; pebble in K.2951B), in Bed 11 (K.10712, 10719), in Bed 4 (Rz.247) and in the Asterocyclina marl, Bed 9a (P.J.1162, together with *Glandulina* and *Haplophragmoides*). Textulariidae s.l. may also be common in the Ranikothalia limestone (K.10701) and predominate in some of the samples of Bed 11 (K.10709, 10712). *Robulus* is a conspicuous genus in J.S. 1955 (Bed 11) and in several samples from the Asterocyclina marl (P.J.1146, 1147 and 1162). *Bulimina jacksonensis* was spotted in Bed 3 (K.2950), in Bed 10 (K.3677), in Bed 7 (K.2954, in combination with *Hantkenina alabamensis*) and in the Asterocyclina marl (K.1316, P.J.1162).

9. The Soldado section comprises three conspicuous mollusk horizons: in Bed 2, at the top of Bed 10 and in the upper (northern) part of Bed 11. As a rule, such shell banks do not contain a representative foraminiferal fauna, though in Bed 10 both megafossils and microfauna occur sometimes together.

In the foraminiferal samples listed in the "Distribution Chart", the mollusks (no. 4) are in general represented by fragments of medium-sized shells and a multitude of very small to microscopic forms. Rich agglomerations of tiny shells of both pelecypods and gastropods are, for instance, found in Bed 11 (K.10709, 10721, 10722; E.L.1440), in Bed 10 (K.10707), in Bed 9 (K.1499) and in the Asterocyclina marl (K.1316, 2651, 2854; the samples P.J.1146, 1147, 1161 and 1162 contain, in addition, innumerable minute "seeds" of either mollusks or ostracods, or both.)

H. CONCLUSIONS: THE GEOLOGICAL HISTORY OF SOLDADO ROCK

The Soldado section, in which Jacksonian Upper Eocene lies sandwiched between the Paleocene and beds carrying an early Middle Eocene fauna, has for a long time presented a confounding enigma.

The age of the Soldado Formation (Beds 1 and 2) has been firmly established as Paleocene by MAURY's mollusk fauna in Bed 2 and by the Larger Foraminifera in the remains of the disintegrated foraminiferal deposits which must once have covered those shell limestones. As for the stratigraphical sequence of these denuded Paleocene units, we have assumed that the encroachment of the transgressive Late Eocene sea on the Paleocene land first caused the topmost part of the cliff, the lagoonal Ranikothalia limestone banks, to collapse and to be redeposited as nearly undisturbed slump banks at its foot. Then, as the sea level rose, also the deeper situated parts of the covering beds were affected and carried off by wave action and currents and all the erratics were spread out over the sea bottom. Of those beds, the Dasyclad algae banks seem to have been most closely linked to the shell beds and are therefore considered the oldest. Between the Ranikothalia limestone and the Dasyclad algae deposit we have placed the Athecocyclina- and algae-reef limestone with its pockets of "orbitoids", echinoid debris and Globigerina ooze. But, as we have to do with reefal conditions which are subject to abrupt lateral changes, they may all be contemporary.

The rest of the Soldado section (Beds 3 to 10, including the foreign body of Bed 11) has been correlated with the San Fernando Formation of Trinidad.

The transgression of the Late Eocene sea over a Paleocene coast shows clearly in the exposure on the Southern top of the islet. Bed 3 and 4 are seen to overlie the coquina of Bed 2 and are choked with reworked Paleocene material. Actually, the two are parts of one single deposit, different in lithological aspect only because of the nature of the foreign material they contain: slumped banks of limestone at the bottom (Bed 3), boulders of various origin in the upper strata which are called Bed 4. In themselves, these transgressive beds are nearly barren marls with lenses of silt and sand; only here and there a good foraminiferal fauna was swept into the rubble and preserved to prove their age. There are also traces of reworking from a younger, Middle Eocene, deposit that was exposed some distance away along the attacked coastline, but no larger remnants of that formation were found in the block conglomerate of Bed 4.

The section which follows (Beds 5 to 9, exposed in the 1938 trench) is an alternation of barren silts and highly fossiliferous marls. Beds 7 and 9 contain rich assemblages of Larger as well as Smaller Foraminifera which can be directly correlated with the Jacksonian Upper Eocene of the Vistabella Quarry in the San Fernando area of Trinidad. For Bed 7, the planktonics indicate the *Globorotalia cerroazulensis* Zone (= the *G. cocoaensis* Zone of BOLLI).

Up to this point, the section seems straightforward enough. The topographically overlying Bed 10, however, is not a continuation of this measured section. According to its foraminifera and echinoids, the age of this bed is without any doubt also Late Eocene, but instead of yielding at least the same fauna as Bed 7 and Bed 9, or perhaps even a still younger one comparable to that of the top part of the Upper Eocene of the San Fernando area, it suddenly drops back onto an older level. Even in such ideal complete populations of Larger Foraminifera as those preserved at K.1500 and K.3677, there is a total lack of the most typical index fossil of the Vistabella Eocene: *Helicosteginopsis soldadensis* (GRIMSDALE). The only explanation that can be given for this absence is that it did not yet exist at the time of deposition of Bed 10, not even towards the end when the fauna tended to change gradually with the advent of *Lepidocyclina "tobleri"*. In this respect, Bed 10 corresponds with Bed 4, the base of the transgressive Upper Eocene, and in a wider field with the basal transgressive silt of the San Fernando section, formerly exposed on the top of the hill called Mount Moriah before the road cut there got walled up. With the latter, Bed 10 also has in common the conspicuous abundance of *Lepidocyclina peruviana* and *Operculinoides soldadensis*, both species that are already fully developed in the Middle Eocene. In other words: both Bed 4 and Bed 10 represent the same Late Eocene transgression as observed in Trinidad and many other places, but the particular spot where Bed 10 was formed was in the open sea, whereas Beds 3–4 are nothing but a local deposit of shore rubble.

In 1938, KUGLER had already noticed a change of dips indicating a discontinuity of the section at this point and he placed a fault between Bed 9 and Bed 10. But in reality the abnormal contact has nothing to do with tectonics. The marl- and limestone-complex of Bed 10 is a slumpmass which has come to rest against Bed 9 with which it is only accidentally in contact.

Bed 11, the greatest of the puzzles because its old-type fauna is at variance with its high position in the section, has turned out to be an undisturbed formation of glauconitic foraminiferal limestones, sandstones and pure glauconite (Boca de Serpiente Formation), with an autochthonous fauna indicating that its deposition has taken place around the transition from the Early to the Middle Eocene. It is tempting to assume that Bed 10 represents the transgression over the older Bed 11 at a place where the attacked coast consisted mainly of Middle Eocene instead of Paleocene (more so because Bed 10 contains an enormous amount of reworked Middle Eocene foraminifera) and that the entire block is overturned. However, mechanically this is unacceptable as the delicate stratification of alternative limestones and soft calcareous marls exposed in the cliff of Bed 10 could not have survived such upsetting movements. What presumably happened is this: the Late Eocene sea did indeed transgress at this point over the Boca de Serpiente Formation, at first nibbling at it and causing considerable reworking of its washed-out fossils, but towards the end under-cutting the cliff to such an extent that a large mass of the formation slumped down onto the newly-formed sediment, right side up. The mylonite observed by KUGLER in 1938 in the steep wall at K.2652(D-1) furnishes the proof of slippage of Bed 11 onto Bed 10. Together, as one block, the two beds slumped afterwards against Bed 9.

The elusive Boca de Serpiente Formation has up to now nowhere been found in situ, although some deposits on the outskirts of the Caribbean Region can probably be correlated with it. The only other trace of it, apart from Soldado Rock, is a boulder of Proporocyclina tobleri limestone found in the Southern Range of Trinidad. The formation is not transgressive in nature as not a single reworked Paleocene fossil was found in Bed 11. The erratic elements that are found scattered in this area are lying *on* the formation, not *in* it; they were deposited there during the Late Eocene transgressive phase. The highly glauconitic sediment was laid down in quiet waters around the Paleocene rocks.

The relationship between the blackish-brown Asterocyclina marl (Bed 9a) developed along the SE shore of Soldado Rock to the section of Beds 3 to 9 is not yet fully understood. Both in the field and from its paleontology it has become clear that this Late Eocene marl is a separate unit and the youngest deposit on Soldado Rock. Lithologically, it is different and it is conspicuously poor in reworked material; the little of it that does occur is probably due to surface contamination from topographically higher older beds rather than to reworking during deposition. The planktonics continue to indicate the same age as given for the rest of the Upper Eocene: *Globorotalia* *cerroazulensis* Zone, lower rather than upper part. But in the Larger Foraminifera the hesitating appearance of such forms as *Helicocyclina paucispira* (BARKER & GRIMSDALE) and *Lepidocyclina subglobosa* NUTTALL expresses a tendency towards further phylogenetic development of the fauna, comparable to that in the highest unit of the Trinidad Upper Eocene where it merges into the Oligocene.

We are under the impression that the Asterocyclina marl is not simply the continuation of the sedimentary cycle of Beds 3 to 9. It rather looks as if not only Beds 10 and 11 form together one solid block, but that also the Southern part of Soldado Rock, composed of Beds 1 to 9, is a coherent block and that both these blocks, simultaneously but from different directions, have slumped into the quiet waters in which the Asterocyclina marl was being deposited. By then, Bed 9 must already have been sufficiently solidified to be included in the uplift and subsequent slump. This view would call for a slight local interruption in the sedimentation within the Late Eocene, a phenomenon that was not observed in Trinidad.

The general lack of coarse clastic material in the Soldado section and the widespread presence of glauconite are indications that the entire play of regressions and transgressions during the Paleocene and Eocene has taken place in an area of small steep-coasted islands and rocks. At the very beginning of the Middle Eocene the sea deposited limestone and glauconite banks around an island of Paleocene shell limestone which, in their turn, emerged at the next regression; during the great Late Eocene transgression the sea attacked this land of mixed Paleocene and Middle Eocene and covered it with several layers of marls and silts, after which the entire mass was uplifted to form a new island. Along its crumbling coast the Asterocyclina marl was formed around the big chunks of rock that had slumped back into the sea.

Finally, it should be kept in mind that the whole of Soldado Rock, including the Asterocyclina marl, is a rootless slipmass in the Miocene sediments of the bottom of the Gulf of Paria. This also applies to the disconnected rock ridges that emerge in its neighbourhood: Bed 12, which touches it, and the Pelican Rocks a little further South.

Acknowledgments

The authors are indebted to M. Helen Pollonais for retyping the manuscript, to P. Jung and R. Panchaud for obtaining additional samples from Soldado Rock, to P. M. Kier, H. H. Renz and J. B. Saunders for identification of echinoids and foraminifera, to P. L. Percharde for securing submarine samples, to Katherine V. W. Palmer for lending Maury's mollusks from the Boca de Serpiente Formation, and to W. Suter for preparing the photographs.

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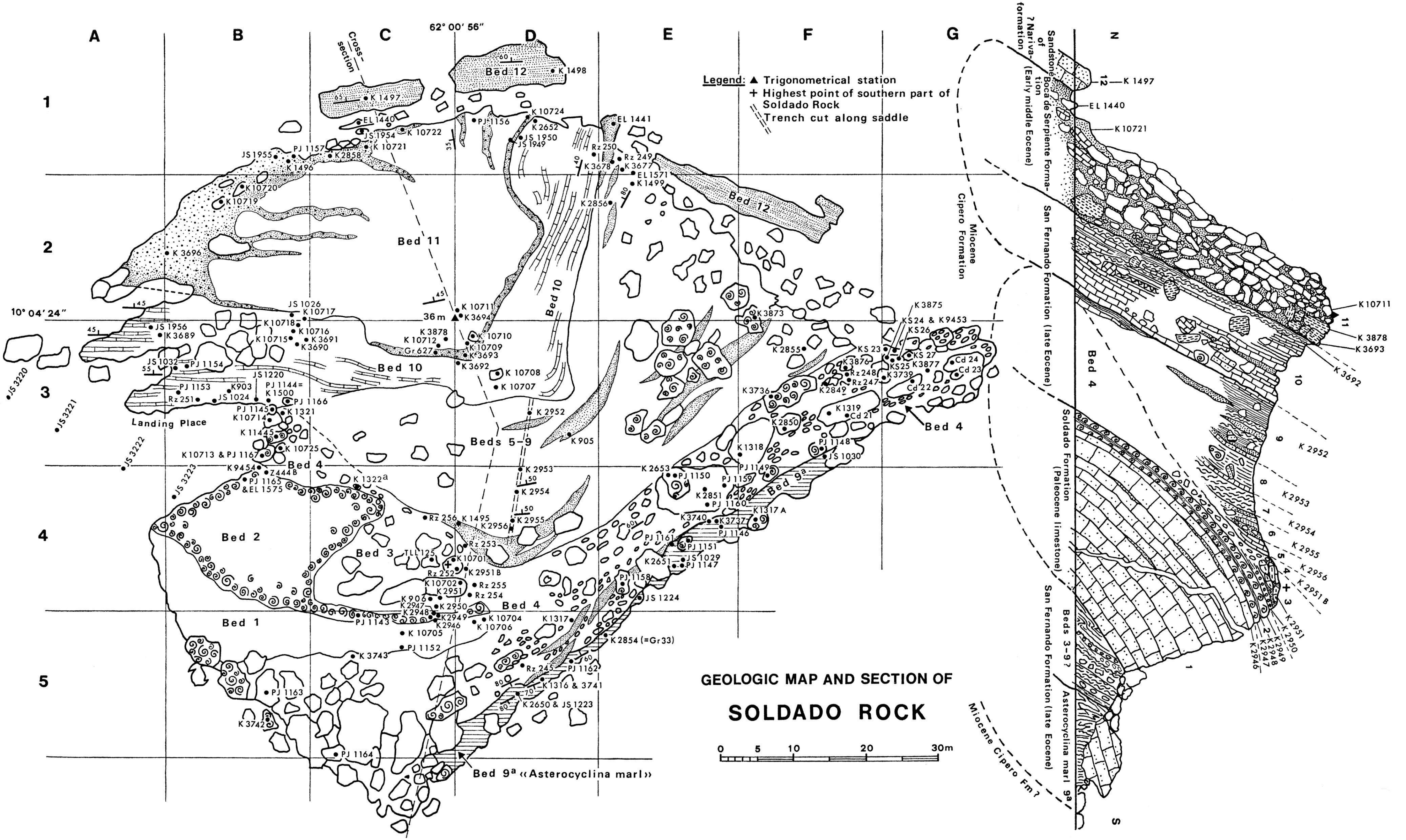
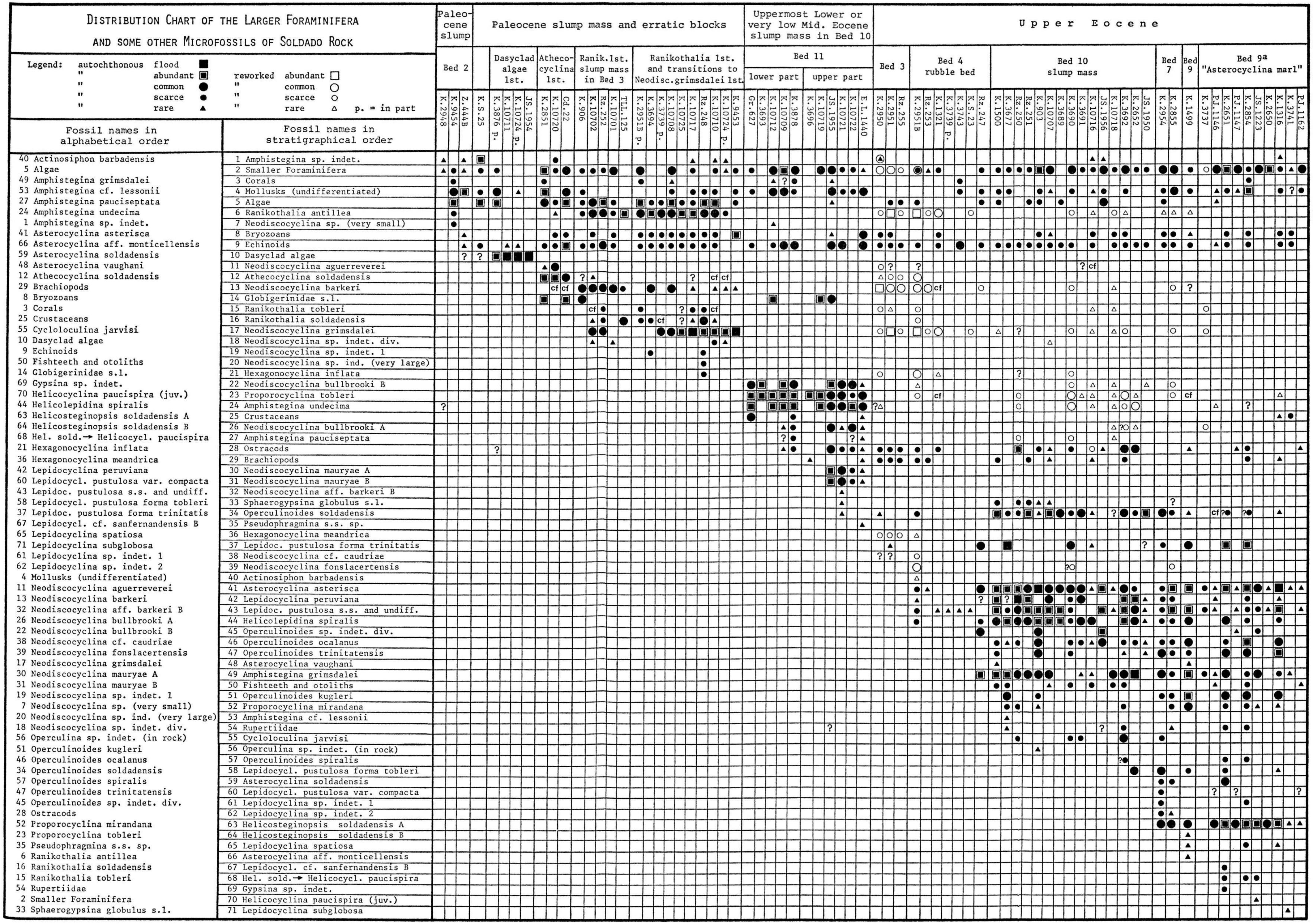


GEOLOGIC MAP AND SECTION OF

SOLDADO ROCK

DISTRIBUTION CHART OF THE LARGER FORAMINIFERA AND SOME OTHER MICROFOSSILS OF SOLDADO ROCK



Legend:

	autochthonous		reworked	
flood	■			
abundant	▣	abundant	☐	
common	●	common	○	
scarce	•	scarce	∘	
rare	▲	rare	△	p. = in part

Paleocene slump — Bed 2: K.2948, K.9454, Z.444B

Paleocene slump mass and erratic blocks: K.S.25; Dasyclad algae 1st.: K.3876 p., K.10711, K.10724 p., JS.1954; Athecocyclina 1st.: K.2851, K.10720, Cd.22; Ranik.1st. slump mass in Bed 3: K.906, K.10702, Rz.252, K.10701, TLL.125; Ranikothalia 1st. and transitions to Neodisc.grimsdalei 1st.: K.2951B p., K.3694, K.3739 p., K.10708, K.10725, K.10717, Rz.248, K.10710, K.10724 p., K.9453

Uppermost Lower or very low Mid. Eocene slump mass in Bed 10 — Bed 11: lower part: Gr.627, K.3693, K.10712, K.10709, K.3878; upper part: K.3696, K.10719, JS.1955, K.10721, K.10722, E.L.1440

U p p e r E o c e n e — Bed 3: K.2950, K.2951, Rz.255; Bed 4 rubble bed: K.2951B, Rz.253, K.1321, K.3739 p., K.3743, K.S.23, Rz.247; Bed 10 slump mass: K.1500, K.3677, Rz.250, Rz.251, K.903, K.10707, K.3689, K.3690, K.3691, K.10716, JS.1956, K.10718, K.3692, K.2652, JS.1950; Bed 7: K.2954, K.2855; Bed 9: K.1499; Bed 9a "Asterocyclina marl": K.3737, PJ.1146, K.2651, PJ.1147, K.2854, JS.1223, K.2650, K.1316, K.3741, PJ.1162

Fossil names in alphabetical order	Fossil names in stratigraphical order
40 Actinosiphon barbadensis	1 Amphistegina sp. indet.
5 Algae	2 Smaller Foraminifera
49 Amphistegina grimsdalei	3 Corals
53 Amphistegina cf. lessonii	4 Mollusks (undifferentiated)
27 Amphistegina pauciseptata	5 Algae
24 Amphistegina undecima	6 Ranikothalia antillea
1 Amphistegina sp. indet.	7 Neodiscocyclina sp. (very small)
41 Asterocyclina asterisca	8 Bryozoans
66 Asterocyclina aff. monticellensis	9 Echinoids
59 Asterocyclina soldadensis	10 Dasyclad algae
48 Asterocyclina vaughani	11 Neodiscocyclina aguerreverei
12 Athecocyclina soldadensis	12 Athecocyclina soldadensis
29 Brachiopods	13 Neodiscocyclina barkeri
8 Bryozoans	14 Globigerinidae s.l.
3 Corals	15 Ranikothalia tobleri
25 Crustaceans	16 Ranikothalia soldadensis
55 Cycloloculina jarvisi	17 Neodiscocyclina grimsdalei
10 Dasyclad algae	18 Neodiscocyclina sp. indet. div.
9 Echinoids	19 Neodiscocyclina sp. indet. 1
50 Fishteeth and otoliths	20 Neodiscocyclina sp. ind. (very large)
14 Globigerinidae s.l.	21 Hexagonocyclina inflata
69 Gypsina sp. indet.	22 Neodiscocyclina bullbrooki B
70 Helicocyclina paucispira (juv.)	23 Proporocyclina tobleri
44 Helicolepidina spiralis	24 Amphistegina undecima
63 Helicosteginopsis soldadensis A	25 Crustaceans
64 Helicosteginopsis soldadensis B	26 Neodiscocyclina bullbrooki A
68 Hel. sold.→ Helicocycl. paucispira	27 Amphistegina pauciseptata
21 Hexagonocyclina inflata	28 Ostracods
36 Hexagonocyclina meandrica	29 Brachiopods
42 Lepidocyclina peruviana	30 Neodiscocyclina mauryae A
60 Lepidocycl. pustulosa var. compacta	31 Neodiscocyclina mauryae B
43 Lepidoc. pustulosa s.s. and undiff.	32 Neodiscocyclina aff. barkeri B
58 Lepidocycl. pustulosa forma tobleri	33 Sphaerogypsina globulus s.l.
37 Lepidoc. pustulosa forma trinitatis	34 Operculinoides soldadensis
67 Lepidocycl. cf. sanfernandensis B	35 Pseudophragmina s.s. sp.
65 Lepidocyclina spatiosa	36 Hexagonocyclina meandrica
71 Lepidocyclina subglobosa	37 Lepidoc. pustulosa forma trinitatis
61 Lepidocyclina sp. indet. 1	38 Neodiscocyclina cf. caudriae
62 Lepidocyclina sp. indet. 2	39 Neodiscocyclina fonslacertensis
4 Mollusks (undifferentiated)	40 Actinosiphon barbadensis
11 Neodiscocyclina aguerreverei	41 Asterocyclina asterisca
13 Neodiscocyclina barkeri	42 Lepidocyclina peruviana
32 Neodiscocyclina aff. barkeri B	43 Lepidoc. pustulosa s.s. and undiff.
26 Neodiscocyclina bullbrooki A	44 Helicolepidina spiralis
22 Neodiscocyclina bullbrooki B	45 Operculinoides sp. indet. div.
38 Neodiscocyclina cf. caudriae	46 Operculinoides ocalanus
39 Neodiscocyclina fonslacertensis	47 Operculinoides trinitatensis
17 Neodiscocyclina grimsdalei	48 Asterocyclina vaughani
30 Neodiscocyclina mauryae A	49 Amphistegina grimsdalei
31 Neodiscocyclina mauryae B	50 Fishteeth and otoliths
19 Neodiscocyclina sp. indet. 1	51 Operculinoides kugleri
7 Neodiscocyclina sp. (very small)	52 Proporocyclina mirandana
20 Neodiscocyclina sp. ind. (very large)	53 Amphistegina cf. lessonii
18 Neodiscocyclina sp. indet. div.	54 Rupertiidae
56 Operculina sp. indet. (in rock)	55 Cycloloculina jarvisi
51 Operculinoides kugleri	56 Operculina sp. indet. (in rock)
46 Operculinoides ocalanus	57 Operculinoides spiralis
34 Operculinoides soldadensis	58 Lepidocycl. pustulosa forma tobleri
57 Operculinoides spiralis	59 Asterocyclina soldadensis
47 Operculinoides trinitatensis	60 Lepidocycl. pustulosa var. compacta
45 Operculinoides sp. indet. div.	61 Lepidocyclina sp. indet. 1
28 Ostracods	62 Lepidocyclina sp. indet. 2
52 Proporocyclina mirandana	63 Helicosteginopsis soldadensis A
23 Proporocyclina tobleri	64 Helicosteginopsis soldadensis B
35 Pseudophragmina s.s. sp.	65 Lepidocyclina spatiosa
6 Ranikothalia antillea	66 Asterocyclina aff. monticellensis
16 Ranikothalia soldadensis	67 Lepidocycl. cf. sanfernandensis B
15 Ranikothalia tobleri	68 Hel. sold.→ Helicocycl. paucispira
54 Rupertiidae	69 Gypsina sp. indet.
2 Smaller Foraminifera	70 Helicocyclina paucispira (juv.)
33 Sphaerogypsina globulus s.l.	71 Lepidocyclina subglobosa