THE TECTONOSTRATIGRAPHIC EVOLUTION OF THE CENTRAL RANGES AND SOUTHERN BASIN, TRINIDAD, WEST INDIES

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INTRODUCTION

Trinidad lies at the boundary of the Caribbean, South American and Atlantic plates. This boundary exhibits marked obliquity with Trinidad situated within its 'inflection zone'. The stratigraphy of the island records a complex interaction of the plate-scale forces which vary temporally and spatially creating several sedimentary basins bounded by fault systems. The Mesozoic-Cenozoic tectonic framework of Trinidad and, by extrapolation, the northern South American margin appears to be the product of rifting, drifting, compression, accretion of allochtonous terranes and strike-slip faulting.

The Southern Basin is an onshore basin bounded to the north by the Central Ranges and to the south by the Southern Range System. Approximately 1700 km^2 in size, it contains an exposed stratigraphic record (Figs. 1 & 2) spanning Mid-Cretaceous to Recent. The genesis and deformation of the Southern Basin was driven by the relative motion of the Caribbean (CARIB) and South-American (SOAM) plates.

A four-phase evolution (Fig. 3) of the Southern Basin is proposed :

- Phase I: Early Cretaceous to Late Oligocene, a passive margin system exhibiting features of a classic Atlantic type margin.
- Phase II: Late Oligocene to Middle Miocene, a southeast directed compressional system developed caused by the arrival of the Caribbean Plate in the vicinity north of Trinidad.
- Phase III: Late Miocene to Early Pliocene, a transtensional period caused by oblique divergence of the CARIB and SOAM plates.
- Phase IV: Upper Pliocene to Recent, a transpressional phase caused by the continued (but now oblique convergence) motion of the CARIB and SOAM plates.

This trip (Fig. 4) will attempt to relate the outcrop geology of the Central Ranges and the Southern Basin to this tectonic framework. The Central Ranges contain parauthochtonous sediments which hold some of the best clues to the tectonostratigraphic evolution of the Trinidad region, including evidence for the occurrence of inversion tectonics. Also present in the Central Ranges and Southern Basin are numerous mud volcanoes which were not created by 'passive' density inversion within a subsiding basin. but rather highlight a dynamic interplay between basinal fluids and tectonic deformation. These mud volcanoes are normally found along the thrust fault trends.

The trip will begin from Port of Spain and travel eastwards along the northern rim of the Caroni Basin into the easternmost Central Ranges where we will work our way south and westwards ending the trip at Naparima Hill, San Fernando, on the west coast. Due to time constraints we will not be able to visit the Cruse and younger formations; however, the Northern Basin Manzanilla and Springvale Formations will be substituted as 'proxies' for the deltaics of the Southern Basin.

The trip involves a medium degree of difficulty with long drives between outcrops and promises views of some of the more spectacular scenery of the island.

PLATE TECTONIC EVOLUTION

The investigation of the Caribbean-South American plate boundary spans approximately thirty five years with Molnar and Sykes (1969), Jordan (1975) and Ladd (1976) publishing some of the classic papers on the subject.

The literature records a great debate as to the plate tectonic evolution of the Trinidad area with opinions varying with every author. The only point of convergence among the various workers is that the Trinidad area is very complex. We will present an evolutionary story based on the current literature content and punctuate it with some critical comments.

The Trinidad region involves the interaction of three major plates :

- CARIB: Caribbean Plate: composed of modified oceanic crust.
- SOAM: South American Plate; continental crust.
- ATLANTIC: oceanic crust.

At least three kinematic models of the CARIB-SOAM plate boundary interactions have been formulated (Russo et al, 1992). These are :

- Molnar and Sykes (1969): hinge faulting and subduction of Atlantic oceanic lithosphere beneath a relative east moving Caribbean Plate.
- Jordan (1975): dextral oblique collision of the CARIB and SOAM plates.
- Sykes et al (1982): dextral oblique extension. The plate velocity magnitudes for this range of models vary from 0.5 to 4.0 cm yr^{-1} of eastward relative motion between the CARIB and SOAM plates.

No direct measurement of the CARIB-SOAM plate velocity is available and this is therefore measured indirectly from a plate circuit calculation :
(CARIB - SOAM)v = (CARIB - NOAM)v + (NOAM - AFR)v + (AFR - SOAM)v
where AFR is the relative velocity of the African Plate.
(CARIB - NOAM)v :- Rosencrantz & Slater (1986), spreading of the Cayman trough.
(NOAM - AFR)v :- Klitgord and Schouten (1986): Pindell et al (1988), North Atlantic magnetic anomalies.
(AFR - SOAM)v :- Cande et al (1988): Pindell et al (1988), magnetic anomalies.

From this circuit the CARIB-SOAM velocity is calculated as currently being approximately 1.0 cm yr^{-1} (Case, 1990). Russo et al (1992) noted that two data sets have been used to constrain the CARIB-NOAM motion: the ridge transform system at the Cayman Trough and the earthquake slip vectors of the northern Lesser Antilles subduction zone. Both data sets yield significantly different Euler poles. For the Cayman Trough data set an ESE vector with a rate of 1.5 cm yr^{-1} of CARIB-SOAM motion is predicted. Using the northern Lesser Antilles slip vectors an ENE vector, at 4.2 cm yr^{-1} at Trinidad, is predicted. The solutions and subsequent plate reconstructions are therefore heavily model dependent.

SEISMICITY

Russo et al (1992) review and discuss the seismicity (Fig. 5 a-d) of the southeastern Caribbean in detail. Frequent earthquakes of both shallow and intermediate depth occur in the region around Trinidad. Russo et al (1992) focus on the tectonic causes of these earthquakes, the locations and orientations of the boundaries they delineate and the senses of motion along these boundaries. They present data from fifty eight focal mechanism solutions and investigate the plausibility of two models of plate boundary zone interaction in the SE Caribbean, viz :

- Trench-Trench transform and hinge-faulting model

- Right oblique collision zone of the CARIB-SOAM plates.

Russo et al (1992) note that the earthquake distribution is very heterogeneous and that there is no through-going well defined fault zone. The clumping of seismic events creates a subdivision of the area into seismic and aseismic zones. The Paria cluster immediately off to the northwest of Trinidad, with its predominant RLSS earthquake mechanism, indicates that strike-slip motion occurs here but is not propagated along the same trajectory to Trinidad. This represents, in our opinion, a propagating fault tip. Historically this RLSS was extrapolated through Trinidad, called the El Pilar Fault and labelled as the southeastern boundary of the CARIB Plate. This is now considered to be incorrect. The shallow earthquakes possess quite variable focal mechanisms and are most likely the products of second order deformation caused by the propagating tip.

Based on the seismicity, Russo et al (1992) conclude that the most probable mechanism of the present-day CARIB-SOAM plate interaction is that of a right oblique collision model.

Within the Trinidad area geochronological work was conducted on the Northern Ranges by Speed (1992) and on the Central and Southern Ranges by Algar (1993). The Central and Southern Ranges sampling showed that there was insufficient magnetic material in most of the rocks to produce viable results. Foland and Speed (1992), using Ar^{40}/Ar^{39} results, established that the Northern Ranges underwent metamorphism less than 27 MYBP, and that the metamorphic temperature did not exceed 350^{0} C.

CARIBBEAN EVOLUTION

There are many published papers on the evolution of the Caribbean e.g. Ladd (1976); Beck (1983); Burke et al (1984); Ross and Scotese (1988); Pindell et al (1988); Erlich and Barrett (1990); Bosh and Rodriguez (1992). In general terms all these papers give a similar story. The timing of events are relatively similar and they all use the Cayman Trough spreading rates to provide the CARIB-NOAM component of the vector circuit. The differences in the models come from the local problems, for example, the emplacement of the Maracaibo block, where is the plate boundary expressed in Trinidad?, does the El Pilar fault exist in Trinidad? and other 'local' questions. We would examine a general Caribbean reconstruction adapted from Pindell et al (1988) (Figs. 6 a-d) and then discuss the tectonic evolution of Trinidad.

- Late Jurassic (Oxfordian): Crustal stretching, NW-SE divergence of NOAM and SOAM, seafloor spreading accretion of new oceanic crust in Central Atlantic; rise in eustatic sea-level.

- Early Cretaceous (Aptian): Change in the NW-SE divergence of NOAM-SOAM to one of E-W transform motion related to the opening of the South Atlantic.
- Early Campanian (Fig. 6a): Lateral expulsion of the Caribbean Plate from the Farallon Plate; initiates rapid NE motion of Aves Ridge/Lesser Antilles arc into the Proto-Caribbean.
- Middle Eocene (Fig. 6b): Seafloor spreading in the Cayman Trough. Volcanism begins in the Lesser Antillean arc. This arc moves rapidly eastwards with significant slip on left lateral strike-slip faults on the CARIB-NOAM boundary. The southern CARIB-SOAM would be experiencing a convergent margin caused by the opening of the Grenada Basin forming the Lara Nappes and Maracaibo foredeep.
- Middle Miocene (Fig. 6c): A 400 km westward translation relative to the Recent occurred. Shortening of the Perija-Merida Andes initiate slip on the strike slip fault system of northern Venezuela.
- Pliocene-Present (Fig. 6d): Eastwards translation of the CARIB plate relative to SOAM as defined by seismicity around the plate margin and subduction of the Lesser Antilles arc.

TRINIDAD EVOLUTION

From the earlier discussion two generalizations can be made about the Trinidad area :

- No through-going simple principal surface RLSS fault which defines the CARIB-SOAM boundary exists in Trinidad. Trinidad lies in an 'inflection zone' which exhibits RLSS motion immediately to the west of the island along its E-W 'asymptote', and subduction along a west dipping deformation front on its N-S 'asymptote'. Deformation in this 'inflection zone' is characterized by the flipping of principal stress axes causing hybrids of pure strike slip and pure compression resulting in an oblique slip deformational style. This deformation is caused by the interaction of CARIB and SOAM plates. Oblique motions tend to possess a non-plane strain, non-coaxial nature and this tends to make the identification of instantaneous strain axes difficult. Partitioning of strain is also a common feature of oblique deformation zones.
- Fault systems within this 'inflection zone' would more than likely follow the fabric of the rift margin faults generated with NOAM-SOAM divergence. The geomorphological units (eg. Central and Southern Ranges) probably reflect inversion sites of old rift margin faults.

TECTONOSTRATIGRAPHIC EVOLUTION

PHASE 1: EARLY CRETACEOUS - LATE OLIGOCENE; Passive Margin Phase

The Late Barremnian to Early Albian is represented by the Cuche Formation described by Kugler (1956) as micaceous, gritty carbonaceous silts with occasional layers of quartzitic grits. The Barremian-Aptian 'Remanie Bed' of the La Carriere member of the Cuche Formation at Pointe-a-Pierre contains a rich assemblage of thick-shelled molllusks. Late Aptian seems to be represented by the Maridale member of essentially brown-yellow silty limestones and marls. The Albian stage is known from a block of reworked, blue, silty limestone with *Distoloceras*. The Cennomanian is marked by the almost abrupt appearance of a uniform series of well-bedded, black, bituminous calcareous shales characterizing the Gautier Formation. This facies indicate a deep water setting. With the continued opening of the Atlantic and the addition of new sea floor, eustatic sea level rose with the concurrent deposition of the deep water Turonian-Lower Maastrictian Naparima Hill Formation.

This formation is a hemipelagic deposit locally called 'argillite' and is compositionally a calcareous organic rich siliceous mudstone representing a departure from the pre-existing shale-dominated formations. The majority of the Maastrictian is represented by the Guayaguayare Formation, a calcareous siliceous shale similar to the Naparima Hill Formation but separated from it by a stratigraphic break and characterized by a typical *Globotruncana* fauna. The Guayaguayare Formation may have been formed by a pulse of continued extension causing the rift margin faults to rotate (bookshelf mechanism), creating relief which was then eroded. It is found locally and usually in association with the Central and Southern Ranges.

The Paleocene is represented by the Soldado, Lizard Springs and Chaudiere Formations. The Soldado Formation contains a glauconitic sandstone representing a shelf sequence. The Lizard Springs Formation is a foraminifera rich green shale characteristic of a hemipelagic sediment. It possesses an arenaceous foramineferal assemblage which increases in abundance northwards toward the Central Ranges, interfingering with the Chaudiere Formation, a green shale which contains large blocks of Cretaceous argillites, cherts, shales and marls. The Paleocene reflects a time of basin filling with shelf sediments of the Soldado Formation, slope and basin deposits of the Lizard Springs, grading into basin floor turbiditic fans of the Chaudiere Formation. Sea level fluctuations occurred at this time, generally becoming lower compared to Cretaceous time with thermal subsidence continuing. Erosion activity is dominated by gravity slides and other mass movement processes. The end fo the Paleocene is marked by a second order global sea level drop of approximately 100m

The Eocene is represented by the arenaceous Pointe a Pierre Formation in the Central Ranges area and predominantly by the Navet Formation which represents an open sea pelagic facies approximately 100m thick. It is composed of rich calcareous foramineferal marls which allow the establishment of high resolution discrete biozones. These marls are transitional to the underlying Lizard Springs Formation. The Pointe a Pierre Formation is transitional to the underlying Chaudiere Formation and is composed of sandstones, siltstones and mudstones. Many of the beds show good grading with flow casts and other sedimentary flow indicators. The sandstone grains range in size from very coarse-grained to fine-grained. These rocks probably represent turbiditic flow (material sourced from the Guyana Shield) into the basin floor. The Eocene ends with the San Fernando Formation, found only in very localized outcrops in the Central and Southern Ranges. It comprises the Plaisance Conglomerate at its base grading into a series of sandstones and calcareous sandstones with vertebrate and invertebrate remains. These grade into an orbitoid bearing *Lithothamnia* reef called the Vistabella Limestone Member.

Kugler (1956) notes that 'the entire aspect of the San Fernando Formation has no resemblance to the chalky open sea deposits of the Upper Eocene part of the Navet Formation'. He concludes that the concurrence of the two facies suggests major orogenic movement. The San Fernando Formation was deposited by the activity of an uplift generated by a forebulge created by the crustal response to arrival of the Caribbean Plate in the Venezuelan area west of Trinidad. This forebulge also coincided with a relative drop in eustatic sea level, exposing and eroding Cretaceous to Lower Eocene rocks.

The Early Oligocene is heralded by an approximately 100m eustatic sea level rise. Thick open sea deposits of marls and clay of the hemipelagic Cipero Formation were laid down. The marls at times are composed of pure *Globigerina* species and the formation allows for very accurate biozonation.

PHASE II : -LATE OLIGOCENE - MIDDLE MIOCENE; COMPRESSIONAL PHASE

A southeast directed compressional system developed, caused by the arrival of the Caribbean Plate in the vicinity north of Trinidad. The Late Oligocene is characterized by lower sea levels (150m) than the Early Oligocene. The Nariva Formation represents the onset of the subdivision of the north-facing passive margin in the Trinidad area into separate fault bounded basins. Sediment input direction switches polarity from south to north, with foredeep creation caused by the advancing thrust front and syntectonic depostion being the dominant basin characteristics. The Late Oligocene marks the onset of fault controlled tectonic activity and heralds the first phase of deposition within the newly forming Southern Basin. The foredeep is caused by strong subsidence due to continental shortening and structural loading. Compression continued into the Miocene reaching its peak somewhere in the Langhian. The foredeep migrated southeastward with the fault-controlled bottom physiography acting as a channel for turbidity currents that deposited elongate bodies between the inner-slopes and the compressional faults growing outward. There was large scale reworking of sediments during this period. The late Oligocene to Late Miocene period is marked by the syntectonic arenaceous assemblages of the Nariva Formation, the Retrench and Herrera members of the Cipero Formation and the Karamat Formation. The Central Ranges became emergent at the end of the Middle Miocene, marking the subdivision of Trinidad into the Northern (Caroni) and Southern Basins. This period is capped by the Lengua Formation, a green calcareous clay with a clay-pebble bed at its base.

PHASE III: LATE MIOCENE - EARLY PLIOCENE; TRANSTENSIONAL PHASE

The beginning of the Late Miocene is marked by a major fall in sea level. The Caribbean Plate is now east of Trinidad and the direct compression effect of the CARIB-SOAM boundary now evolves into a transtensional system along an ENE vector. The Orinoco delta system is now active in the Trinidad area, with depositional rates jumping two orders of magnitude (Fig. 3) relative to the first two phases. The Cruse delta is deposited, marking the onset of the Orinoco delta progradation with extensional tectonics being dominant. Basin subsidence caused by sedimentary loading occurs with sedimentation rates being faster than those of subsidence. Eustatic sea levels were generally rising at this time following a 2 Ma cycle. At about 5 MYBP a eustatic rise in sea level took place (150m) representing a deepening of the Southern Basin. Deposition of the Forest Formation was initiated, resting unconformably on the Cruse Formation. Deltaic progradation continued marking a period of rapid basin fill. The Southern Basin began evolving from marine conditions to continental conditions with the deposition of the Morne L'Enfer Formation. Continental conditions prevailed at around 2 MYBP with the deposition of the Erin Formation.

PHASE IV: UPPER PLIOCENE TO RECENT; TRANSPRESSIONAL PHASE

During the deposition of the Erin Formation (2 MYBP) the regional stresses appear to switch from ENE directed transtension to ESE directed transpression. The primary signal of this latest phase of deformation is the transpressional faults showing features of partitioned strain where pure strike slip located along discrete zones of high deformation and thrust geometries paralleling the fault walls is recorded. The basin undergoes a period of possibly basement involved contraction forming a large amplitude fold/thrust system creating the Ortoire-Siparia, Pilote and Erin synclines. There was a large amount of uplift (about 2km) with high rates of erosion. Reshear along the old thrust fabric set up during Miocene times was common with these fault systems taking up significant magnitudes of contraction. The Warm Springs Fault was created and possibly merged with the Central Ranges Fault System, the Los Bajos Fault was reactivated, and the South Coast Fault System became active. This transpressional phase continues to the present and sets up the fields relationships (Fig. 7) seen today. It is responsible for the broad synclines generally bounded by more complex fold/thrust belts. The transpressional faults may be obscured in identity where they merge into the old structural fabric.

CONCLUSIONS

The Caribbean Plate was emplaced between the American Plates via a classic system of an east directed deformation front with strike-slip transform margins to both NOAM and SOAM. Trinidad is currently in the 'inflection zone' of the CARIB-SOAM-ATLANTIC interaction and observes pure strike-slip seen in Venezuela to pure compression seen in Barbados. The local structural fabric is quite varied reflecting that the strain was not coaxial. The stratigraphy of the Central Ranges and Southern Basin have been fashioned by eustacy, forebulge uplift, thrust-fold, transtension and finally transpression with the basin fill sediments characterized by numerous localized facies changes. The stratigraphy of the Southern Basin of Trinidad reveals a modified STRIKE SLIP CYCLE of basin evolution. The proffered four phase basin evolution contains the classic pre-flysch (Cuche) to flysch (Gautier-Lengua) to molasse (Cruse-Erin) cycles. Deformation was initially extensional, becoming compressional and then evolving into an oblique slip system. Over the Trinidad area several basins were formed partly simultaneously and partly diachronously, of which the Southern Basin is one.

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REFERENCES

Algar, S., 1993, Structural, stratigraphic and thermo-chronological evolution of Trinidad, Unpublished doctoral dissertation, Dartmouth College, Hanover, New Hampshire, USA.

Beck, C., 1983. The geodynamic evolution of the south-eastern Caribbean, Societe Geologique de France Bull., Series 7, v.25,n.2, p. 169-183.

Bolli, H., et al, 1994, Benthic foraminiferal biostratigraphy of the south Caribbean region, Cambridge University Press, 408p.

Bosch, M., and Rodriguez, I., 1992, North Venezuelan collisional crustal block: The boundary between the Caribbean and South American plates, Journal of South American Earth Sciences, vol. 6, no. 3 p. 133-144.

Burke, K., et al, 1984, Caribbean Tectonics and relative plate motions in Bonini, W., Hargraves, R., and Shagam, R., (eds), GSA Memoir 162, p. 31-64.

Cande, S.C., et al, 1988, Plate kinematics of the South Atlantic: Chron 34 to Present, Journal of Geophysical Research, v.91, p. 13479-13492

Erlich, R. and Barrett, S., 1990, Cenozoic Plate Tectonic History of the Northern Venezuela-Trinidad Area, Tectonics, vol. 9, no. 1.p. 161-184.

Case, J.E., MacDonald, W.D., and Fox, P.J., 1990, Caribbean crustal provinces; seismic and gravity evidence, in Dengo, G. & Case, J.E., (eds), The Caribbean Region, Geol. Soc. of Amer., DNAG Series, V. 4,p. 15-36.

Foland, K.A. and Speed, R.C., 1992, Geochronology of metamorphic rocks of the Northern Range. Geological Society of Trinidad and Tobago Symposium on regional structure and tectonic evolution of northern Trinidad and vicinity, 16th June 1992.

Geetan, S., 1990, The Geology of the Western Central Ranges, Trinidad, West Indies,unpublished B.Sc. Field Report,, U.W.I. Mona, Kingston Jamaica, 219p.

Jordan, T. H., 1975, The present day motions of the Caribbean Plate. Journal of Geophysical Research, v. 80,p. 4433-4439.

Klitgord, K., and Schouten, H., 1987, Plate Kinematics of the Central Atlantic, in Vogt, P.R., Tucholke, B.E., (eds), The Western North Atlantic Region. Geol. Soc. of Amer., DNAG Series, v. M, p. 351-378.

Koutsoukos, E.A. and Merick, K.A., 1985, Foraminiferal paleoenvironments from the Barremian to Maastrichtian of Trinidad, W.I. in Rodrigues, K. (ed) Transactions of the First Geological Conference of the GSTT, p. 85-101.

Kugler, H., 1953, Jurassic to recent sedimentary environments in Trinidad, Bull. ass. Suisse des Geol. et Ing. du Petrole, vol. 20, no. 59, p. 27-60.

Kugler, H., 1956, Trinidad, in Jenks, W.F., (ed), Handbook of South American Geology, GSA Memoir no. 65, p. 353-365.

Kugler, H., 1959, Geological maps of Trinidad - 1:50,000 and spot maps of various scales.

Ladd, J.W., 1976, Relative motion of South American with respect to North American and Caribbean tectonics, GSA Bull., v. 87, p. 969-976

Molnar, P. and Sykes, L., 1969, Tectonics of the Caribbean and Middle America region from focal mechanism and seismicity, GSA Bull., v. 80, p. 1639-1684.

Payne, N., 1990, An evaluation of Post-middle Miocene geological sequences, offshore Trinidad in K.A. Gillezeau (ed), Transactions of the Second Geological Conference of the GSTT, 1990, p. 70-87.

Pindell, J., et al, 1988, A Plate-Kinematic framework for models of Caribbean evolution, Tectonophysics, 155 (1988)p. 121-138.

Rodrigues, K., 1985, Thermal History Modeling in Petroleum Exploration: examples from Southern Trinidad in Rodrigues (ed), Transactions of the First Geological Conference of the GSTT, p. 217-226.

Rohr, K., 1939, Cross Section through Eastern Central Range & Northern Depression, Trinidad, Geological Conference, April 1939.

Rosencrantz, E., and Slater, J.G., 1986, Depth and age in the Cayman Trough, Eartand Planetary Science Letters, v. 29p. 133-144.

Ross, M.I. and Scotese, C.R., 1988. A heirachical tectonic model of the Gulf of Mexico and Caribbean region. Tectonophysics. v. 155p. 139-168.

Russo, R.M., Okal, E.A. and Rowley, K.C., 1992, Historical seismicity of the south-eastern Caribbean and tectonic implication. Pure and Applied Geophysics.

Speed, R.C., 1992. Regional tectonic units and motions of the southeastern Caribbean. Geological Society of Trinidad and Tobago Symposium on regional structure and tectonic evolution of northern Trinidad and vicinity, 16 June, 1992.

Suter, H., 1960, The General and Economic Geology of Trinidad, W.I. Overseas Geological Surveys. Her Majesty's stationary office, London. 145 pp.

Sykes, L.R., et al, 1982, Motion of the Caribbean Plate during the last 7 million years and implications for earlier Cenozoic movements, Journal of Geophysical Research, v. 87, p. 10, 656-10, 676.

Tyson, L. and Ali, W., 1990, Cretaceous to Middle Miocene Sediments in Trinidad in K.A. Gillezeau (ed), Transactions of the Second Geological Conference of the GSTT, 1990, p. 266-277.

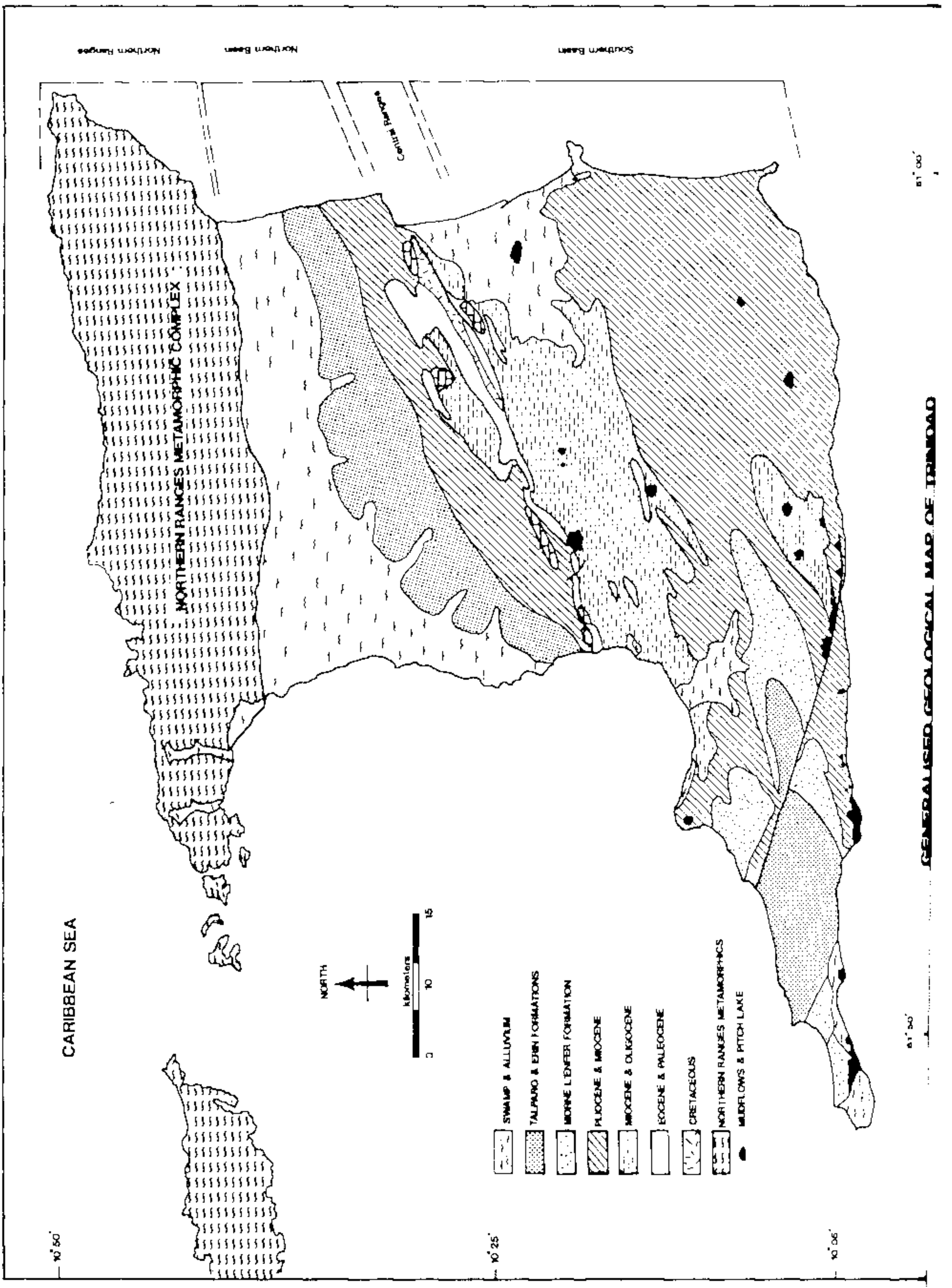

GENERALISED GEOLOGICAL MAP OF TRINIDAD
Northern Ranges
Northern Basin
Central Range
Southern Basin
NORTHERN RANGES METAMORPHIC COMPLEX
CARIBBEAN SEA
NORTH
kilometers
0
10
15
SWAMP & ALLUVIUM
TALPARO & ERIN FORMATIONS
MORNE L'ENFER FORMATION
PLIOCENE & MIOCENE
MIOCENE & OLIGOCENE
EOCENE & PALEOCENE
CRETACEOUS
NORTHERN RANGES METAMORPHICS
MUDFLOWS & PITCH LAKE
10°50'
10°25'
10°05'
61°00'
61°50'

Figure 1

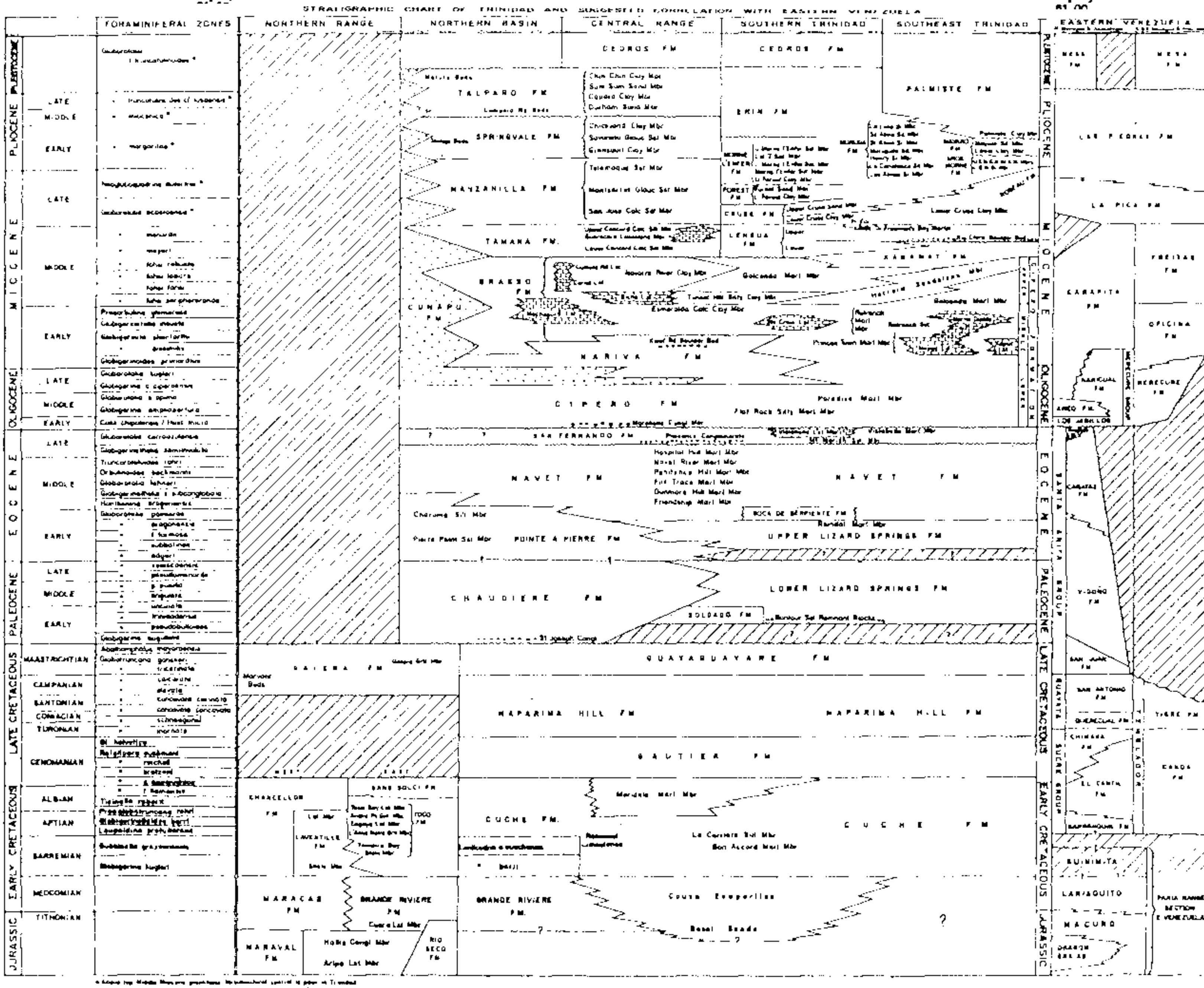


Figure 2
(Tyson & Ali, 1990)

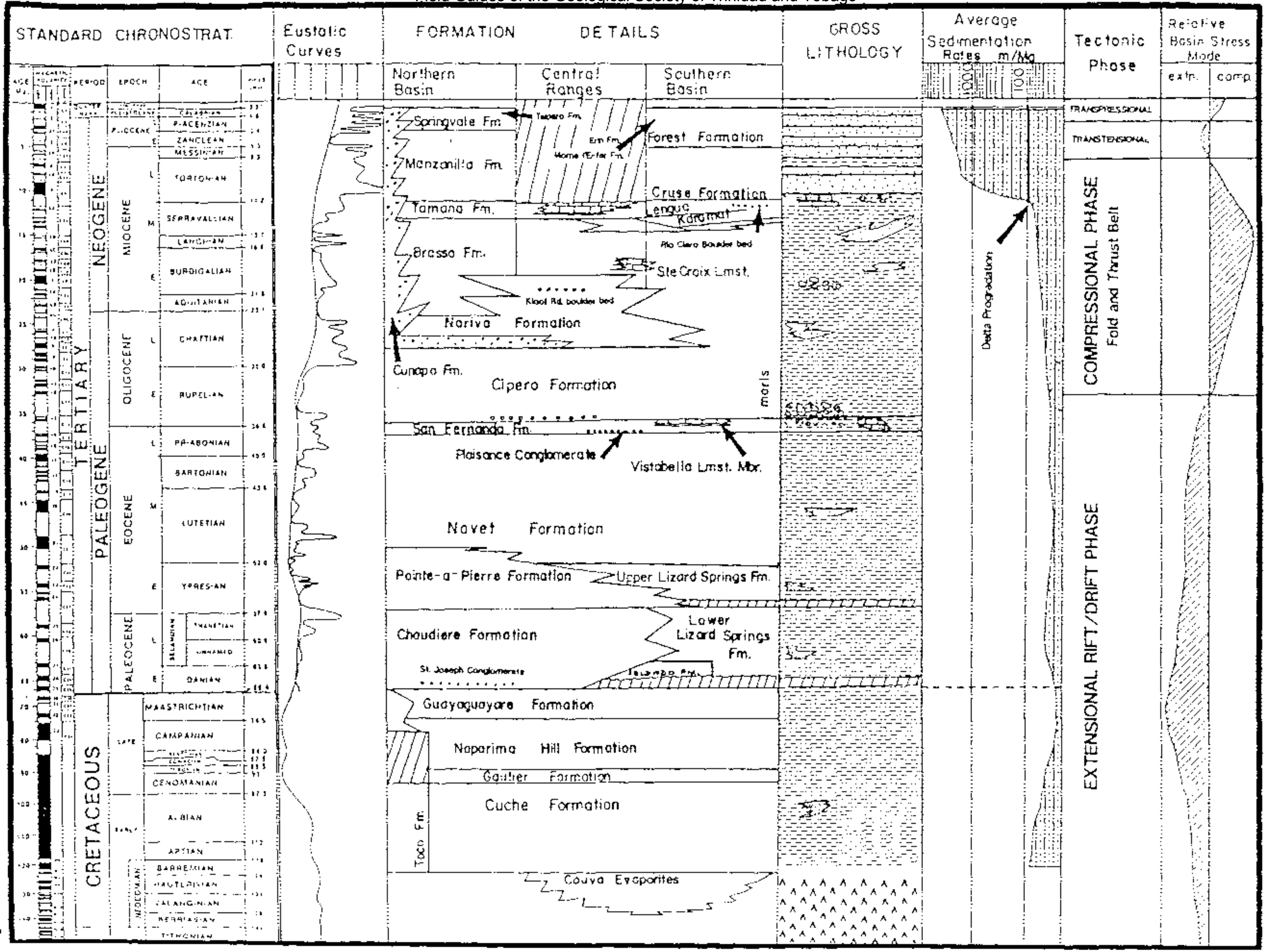
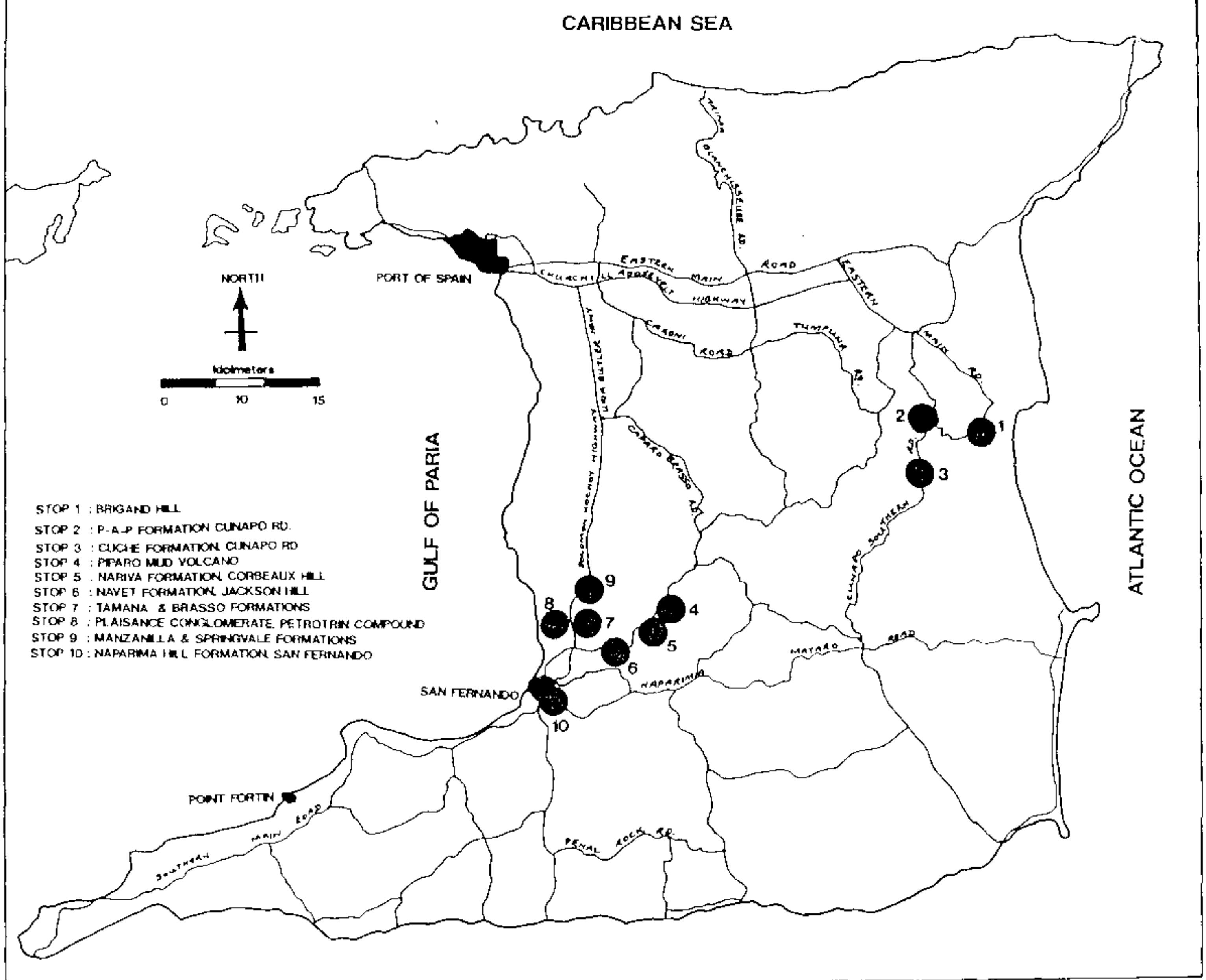
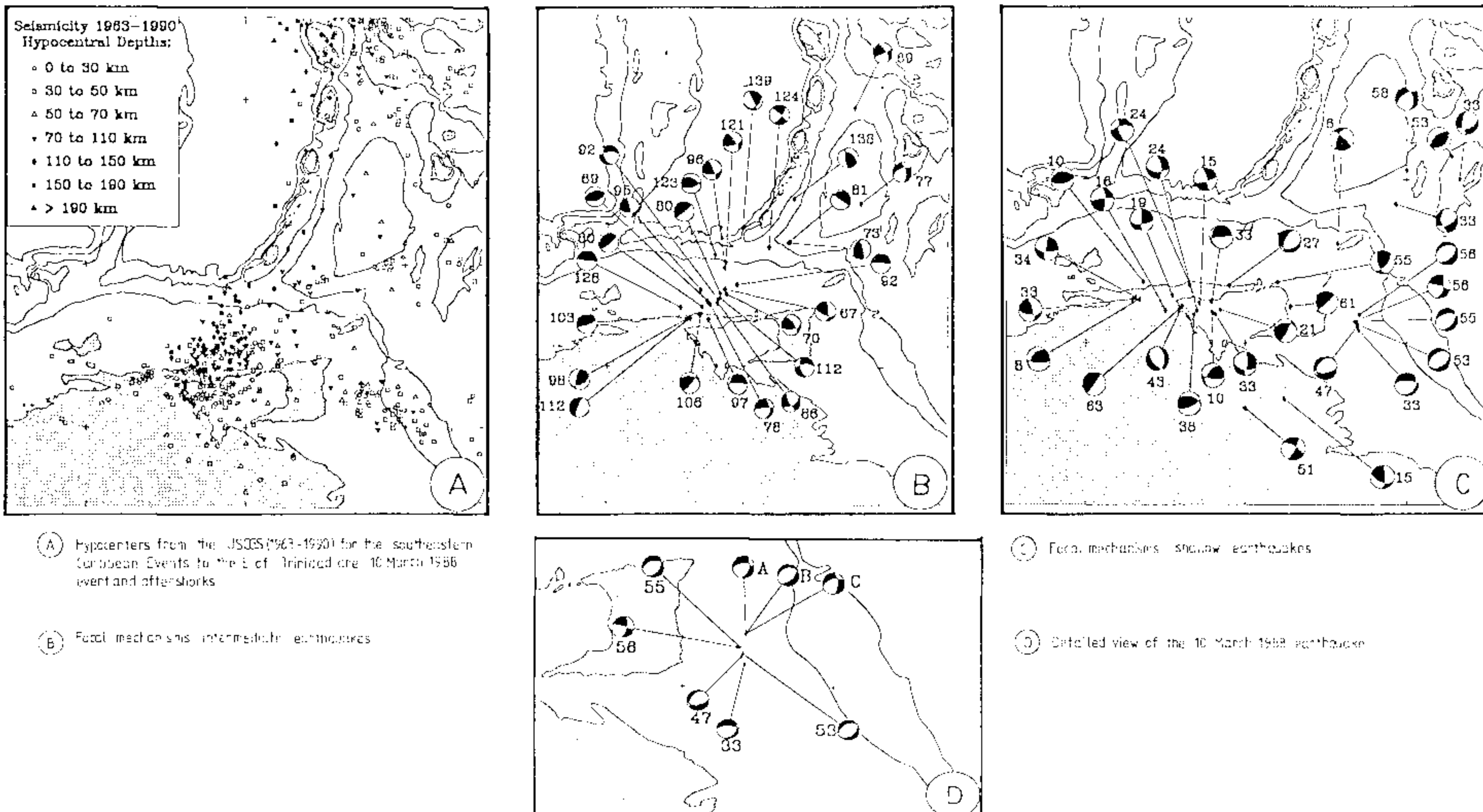

STANDARD CHRONOSTRAT.
Eustatic Curves
FORMATION DETAILS
Northern Basin
Central Ranges
Southern Basin
GROSS LITHOLOGY
Average Sedimentation Rates m/Ma
Tectonic Phase
Relative Basin Stress Mode
extn.
comp.
AGE
PERIOD
EPOCH
NEOGENE
PALEOGENE
TERTIARY
CRETACEOUS
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
PIACENZIAN
ZANCLEAN
MESSINIAN
TORTONIAN
SERRAVALLIAN
LANGHIAN
BURDIGALIAN
AQUITANIAN
CHATTIAN
RUPELIAN
PRIABONIAN
BARTONIAN
LUTETIAN
YPRESIAN
THANETIAN
DANIAN
MAASTRICHTIAN
CAMPANIAN
CENOMANIAN
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
TITHONIAN
Springvale Fm
Talparo Fm.
Erin Fm.
Morne l'Enfer Fm.
Forest Formation
Manzanilla Fm.
Cruse Formation
Tamana Fm.
Lengua
Karamat
Rio Claro Boulder bed
Brasso Fm.
Ste Croix Lmst.
Kloof Rd. boulder bed
Nariva Formation
Cunapo Fm.
Cipero Formation
marls
San Fernando Fm.
Plaisance Conglomerate
Vistabella Lmst. Mbr.
Navet Formation
Pointe-a-Pierre Formation
Upper Lizard Springs Fm.
Chaudiere Formation
Lower Lizard Springs Fm.
St. Joseph Conglomerate
Guayaguayare Formation
Naparima Hill Formation
Gautier Formation
Cuche Formation
Toco Fm.
Couva Evaporites
Delta Progradation
TRANSPRESSIONAL
TRANSTENSIONAL
COMPRESSIONAL PHASE
Fold and Thrust Belt
EXTENSIONAL RIFT/DRIFT PHASE
74
Figure 3

Figure 3



MAP OF TRINIDAD SHOWING FIELD STOPS

Figure 4



(A) Hypocenters from the USGS (1963-1990) for the southeastern Caribbean. Events to the E of Trinidad are 10 March 1988 event and aftershocks

(B) Focal mechanisms intermediate earthquakes

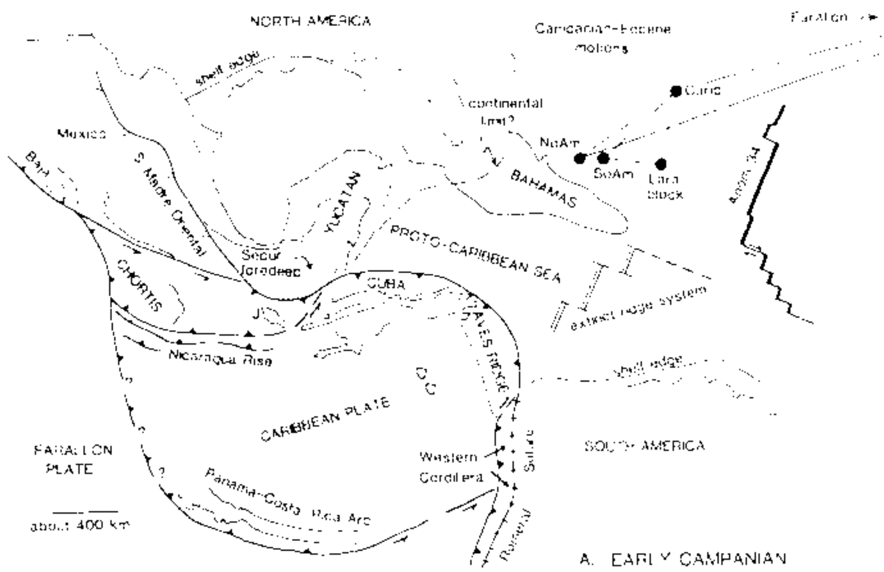
(C) Focal mechanisms shallow earthquakes

(D) Detailed view of the 10 March 1988 earthquake

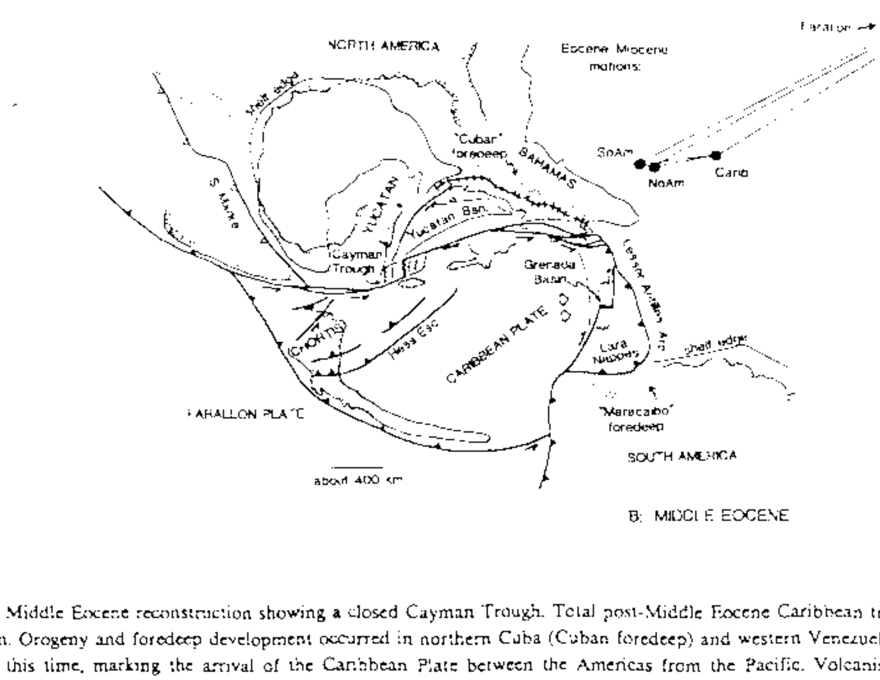
Three different solutions for the 10 March events are shown, the first motion solution from the USGS (A), the best-fit double couple (C), and the centroid moment tensor solution (B) from the Harvard group (Dziewonski et al., 1989a). Mechanisms for the aftershocks are all CMT's.

Fig. 5 (A-D) Seismicity in the Trinidad area (Russo et al 1992)
Numbers are hypocentral depths in km.

Figure 5



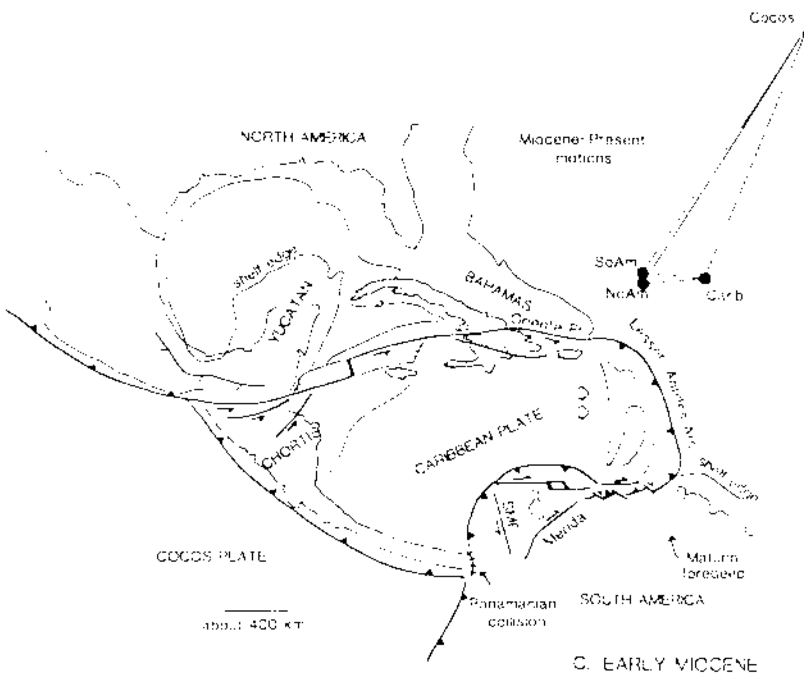
A. Early Campanian reconstruction showing the east-northeastward migration of the Caribbean Plate from the Pacific area, subducting crust of the Proto-Caribbean seaway, which by this time probably possessed no mid-ocean ridge system. Note that Late Cretaceous orogeny was pronounced in southern Yucatan (accompanied by development of the Sepur foredeep) and western Colombia (accretion of the western Cordillera at the Romeral Suture), but that eastern Yucatan, the Bahamas Bank and northern South America were relatively undisturbed at this time. Vector triangles (upper right) show approximate trends and magnitudes of relative motions of the various plates between this and the next reconstruction. *J*—Jamaica. *NoAm*—North America; *SoAm*—South America; *Carib*—Caribbean.



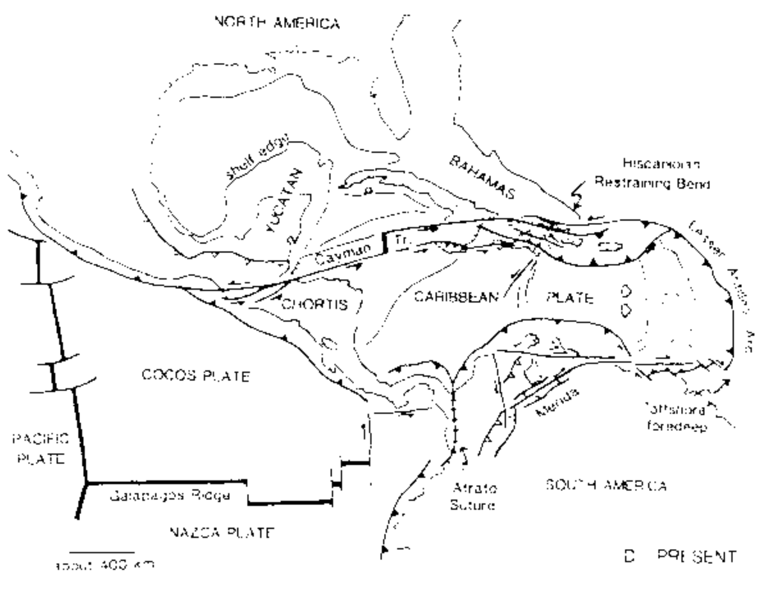
B. Middle Eocene reconstruction showing a closed Cayman Trough. Total post-Middle Eocene Caribbean translation is about 1100 km. Orogeny and foredeep development occurred in northern Cuba (Cuban foredeep) and western Venezuela (Maracaibo foredeep) at this time, marking the arrival of the Caribbean Plate between the Americas from the Pacific. Volcanism began at the Lesser Antilles Arc at this time. Vector triangles (upper right) show approximate trends and magnitudes of relative motions of the various plates between this and the next reconstruction.

(Pindell *et al*, 1988)

Figures 6(a-b)



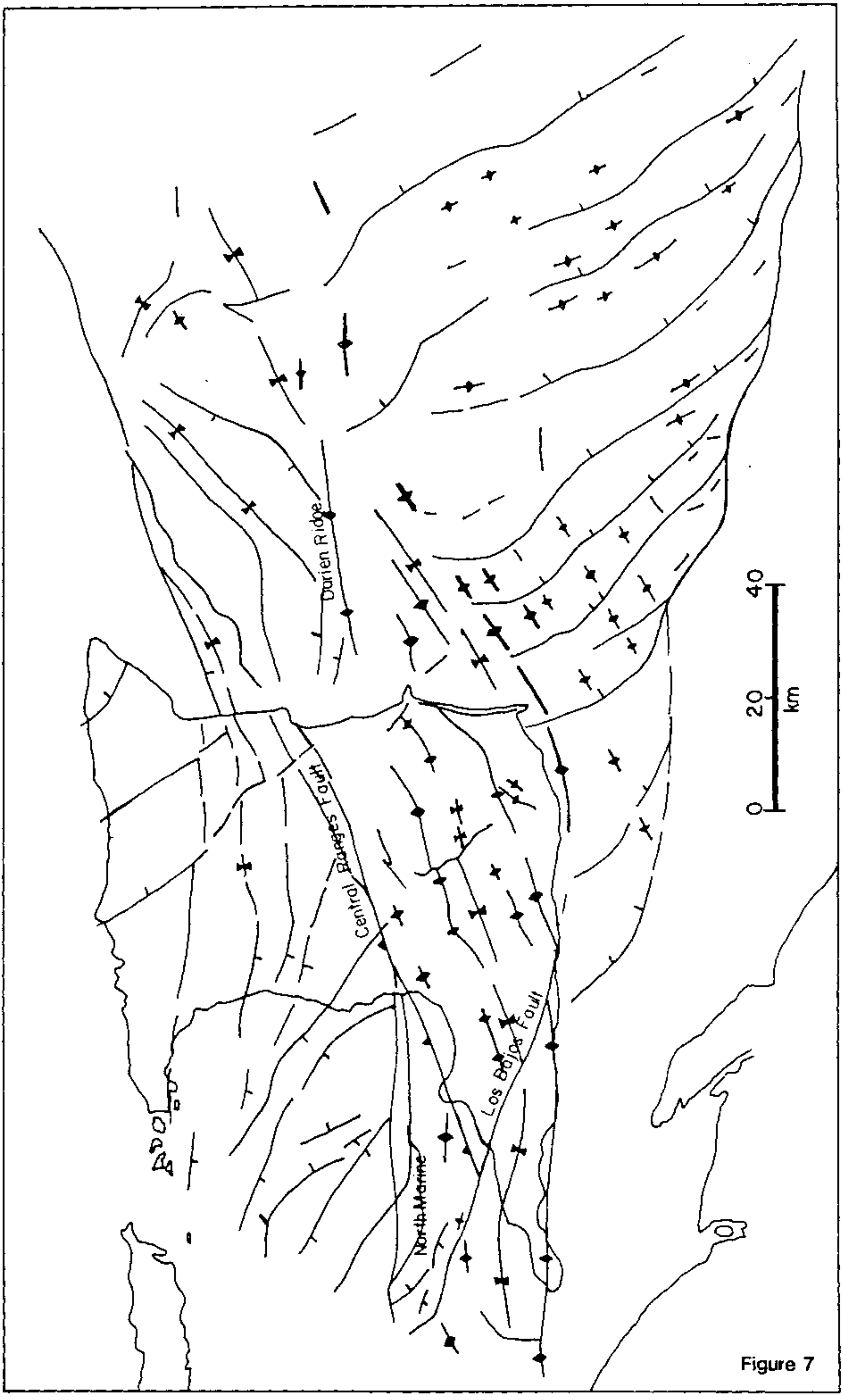
C. Early Miocene reconstruction (about 20 Ma), showing a 400 km westward translation of the Caribbean Plate relative to the present. Progressive emplacement of the Venezuelan allochthonous nappes had reached eastern Venezuela as recorded by Miocene foredeep development in the Maturin Basin. Northeastward migration of the Maracaibo Block probably began in Middle Miocene time, by strike-slip along the Merida Andes and the Santa Marta Fault (*SMF*). This migration was triggered by the beginning of the Panamanian collision and/or by a northward shift in the trend of subduction of the Cocos Plate (Fig. 3) beneath the northern Andes, and drove a wedge of northwestern South America out onto the Caribbean Plate, thereby obscuring the original transform boundary between South America and the Caribbean Plate. In the north, note the strike-slip assembly of Hispaniola by this time and initiation of strike-slip at the Oriente Fault between Cuba and Hispaniola. Vector triangles (upper right) show approximate trends and magnitudes of relative motions of the various plates between this and the next reconstruction.



D. Present-day major fault and plate boundary map of the Caribbean area. Eastward migration relative to the Americas is continuing, as defined by seismicity around the plate margins and subduction at the Lesser Antilles Arc.

Figures 6(c-d)

(Pindell *et al*, 1988)



FAULT TREND MAP (Payne 1990)

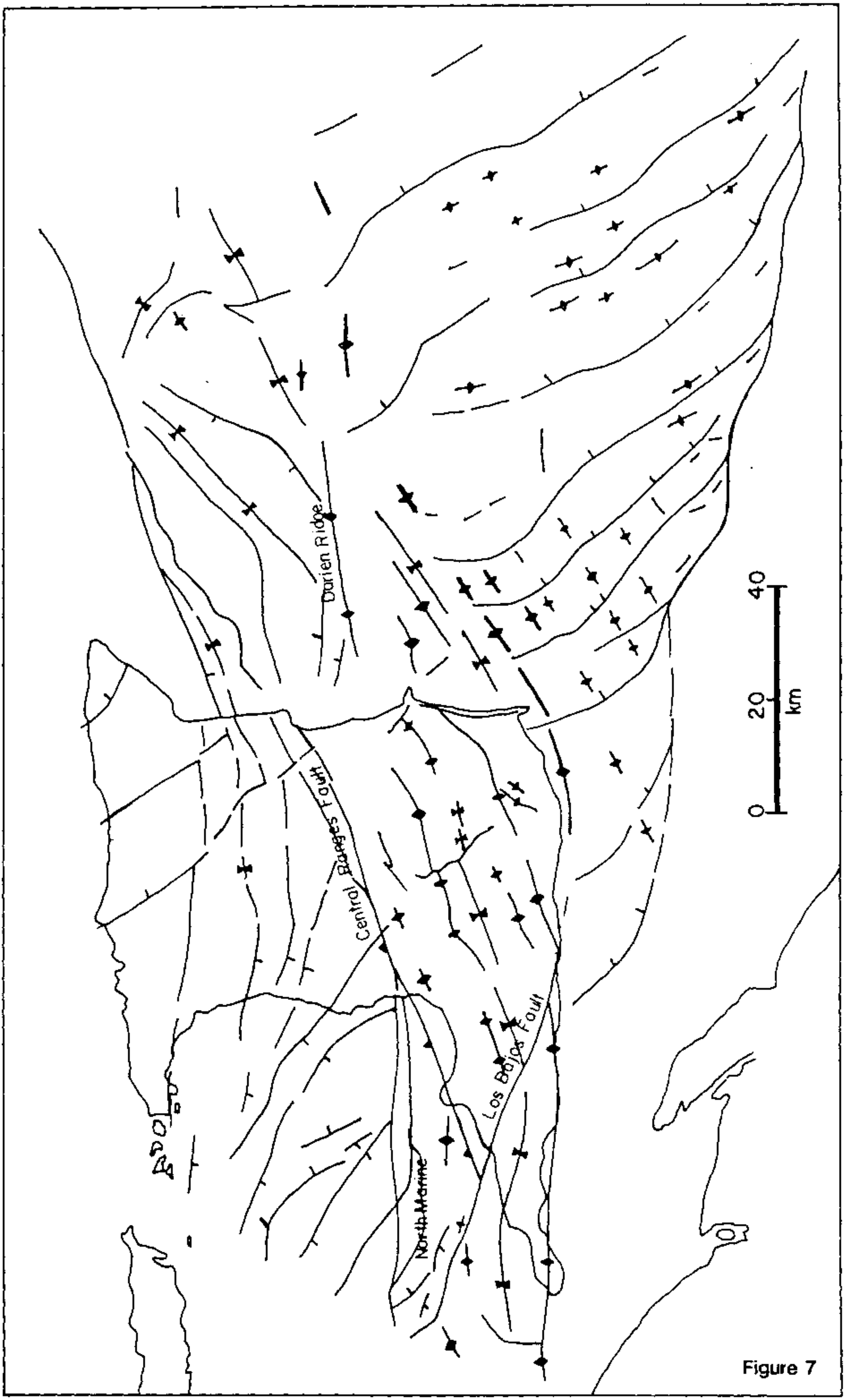


Figure 7

FAULT TREND MAP (Payne 1990)

STOP 1

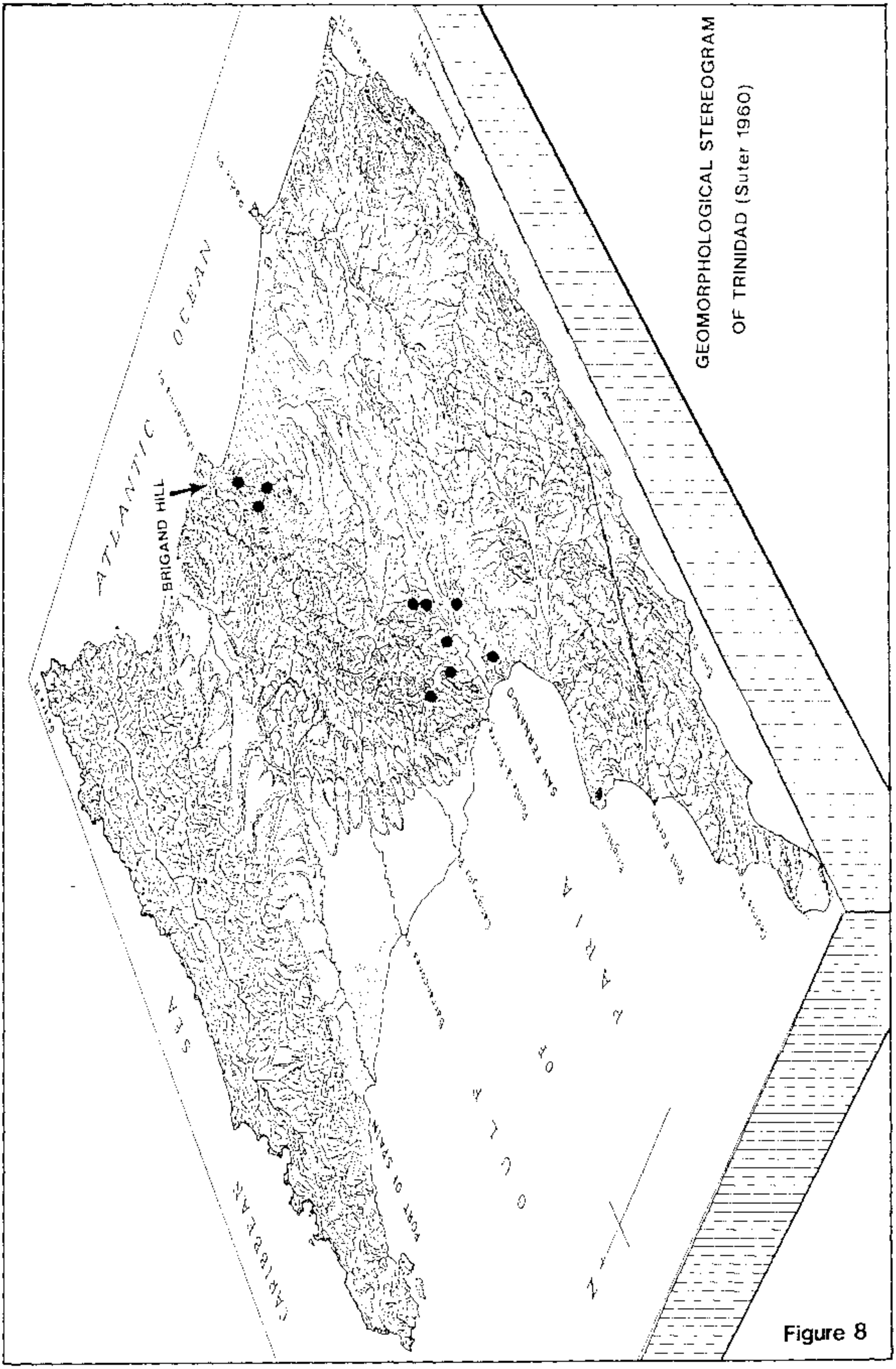
BRIGAND HILL - EASTERN CENTRAL RANGE
PHYSIOGRAPHIC OVERVIEW OF THE ISLAND.

The Brigand Hill communications tower is located on one of several resistant hills which trend northeast across the Central Range at an elevation of 226 m above sea level. The hills are composed of impure shelf-reefal limestones which are also well exposed at Gasparillo, Guaracara, Tabaquite, Tamana and Biche.

The tower offers a vantage point for several panoramic views of the geological setting of eastern Trinidad. These views include from north to south (fig 8):

- Eastern Northern Range
- Caroni (Northern) Basin
- Central Range and Mt. Harris (266 m, (888 ') above sea level)
- Nariva Swamp and Manzanilla Coast
- Point Radix and the Atlantic Ocean

Figures 9 & 10 show a geological map and cross-sections through the Brigand Hill area.



GEOMORPHOLOGICAL STEREOGRAM OF TRINIDAD (Suter 1960)

Figure 8

STOP 1

KUGLER (1959) SURFACE GEOLOGY MAP

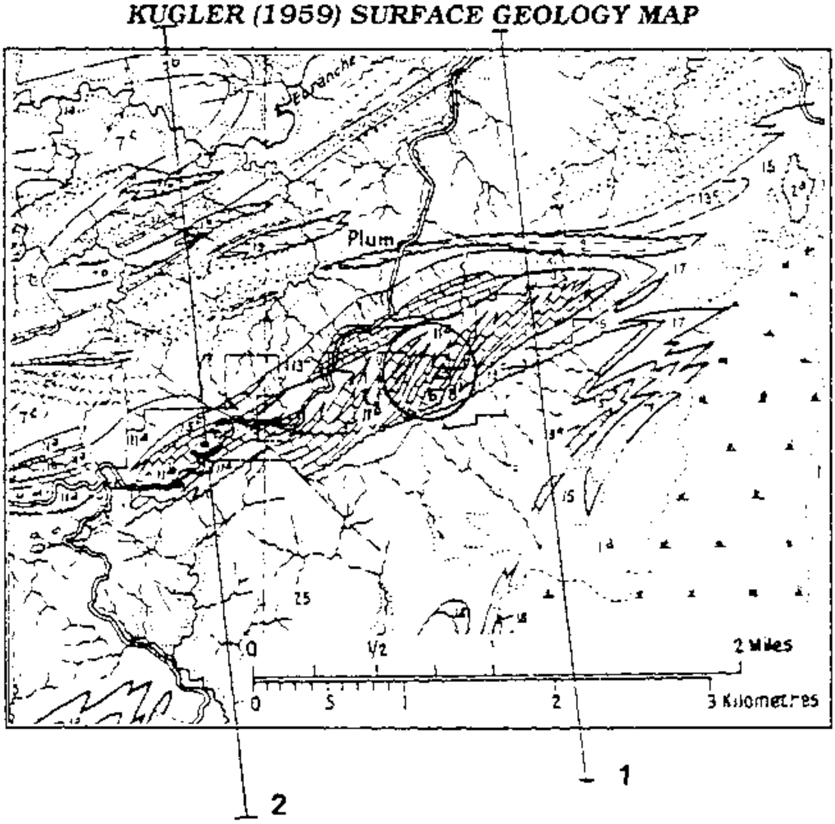


Figure 9

GEOLOGICAL CROSS-SECTION THROUGH EASTERN CENTRAL RANGES

Rohr 1939

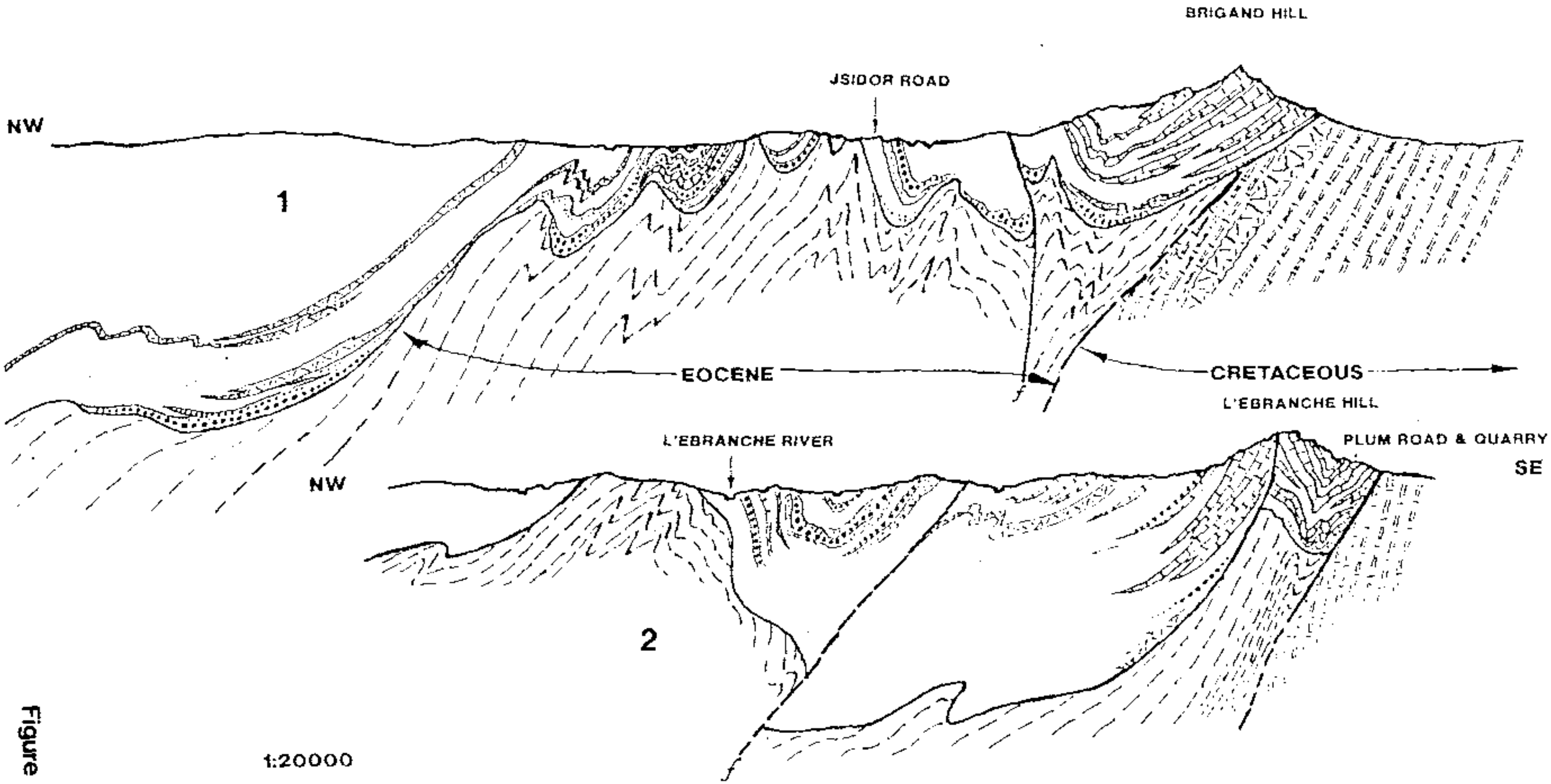


Figure 10

STOP 2

LOCALITY	**: JUNCTION OF CUNAPO SOUTHERN MAIN ROAD AND PLUM ROAD, EASTERN CENTRAL RANGE.**
FORMATION	**: POINTE-A-PIERRE FORMATION**
AGE	**: EARLY EOCENE**

Figure 11 is a composite of the roadside exposure mapped (Algar 1993) along the Cunapo Southern Main Road to the north of its intersection with Plum Road in the eastern Central Range. This stop views the southernmost portion of this section which corresponds to the bottom six meters of figure 11.

The majority of the exposed section is composed of very fine grained quartzose sandstones interbedded with thin mudstone laminae. The sandstone beds are not visibly graded but do contain ripple cross-laminations and water escape structures. Algar (1993) notes that the base of one sandstone bed is covered in an interconnecting array of unusually small flute casts (4 mm wide by 7 mm long by 2 mm deep) indicating a northeasterly directed palaeocurrent.

Figure 12 shows a geological map of the area.

Stratigraphic Section: Pointe-a-Pierre Formation (Algar, 1993)

Junction of Cunapo Southern Main Road and Plum Road, Eastern Central Ranges.

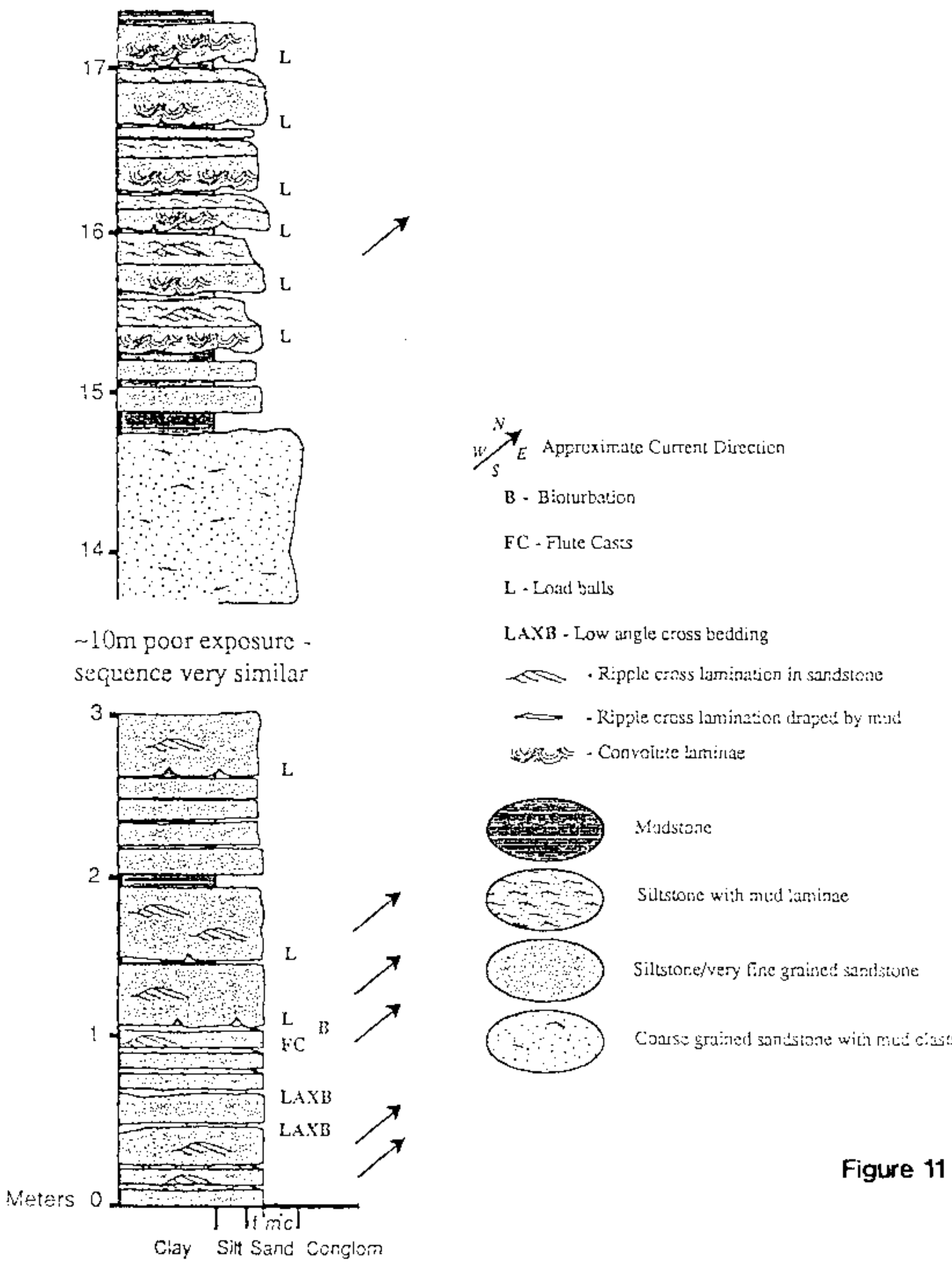


Figure 11

STOP 2

KUGLER (1959) SURFACE GEOLOGY MAP

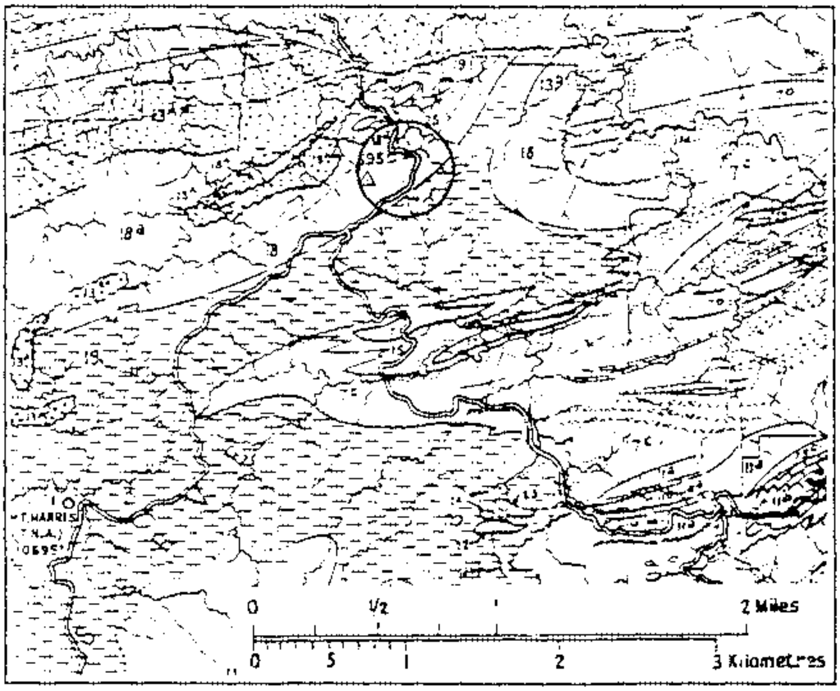


Figure 12

STOP 3

LOCALITY : CUNAPO SOUTHERN ROAD, EASTERN CENTRAL RANGE.

FORMATION : CUCHE FORMATION

AGE : EARLY CRETACEOUS-BARREMIAN THROUGH APTIAN

The Cuche Formation spans from Late Barremian to Early Albian and is composed of black grey shales with layers of coarse sandstone and occasional lenses of marls, conglomerates and limestone components. Bolli (1959) divided the Cuche Formation into two zones:

- *Lenticulina ouachensis* zone - the older of the two where benthic taxa strongly dominate over rare planktic foraminifera.

- *Leupoldina protuberans* zone - the younger zone which contains a rich and diversified planktic fauna probably representing a deepening of the basin due to continued normal fault activity.

Outcrops of the Cuche Formation occur in the core of the Central Range mainly on the eastern section of the island. This stop examines a road cut section and river cut section of the Cuche Formation and exposes a section through the *Lenticulina ouachensis* zone.

Along Road - In outcrop at least three lithotypes are recognized:
- Black, silty, micaceous with lignitic or carbonaceous laminae which appear to be slightly metamorphosed or have undergone considerable diagenesis.
- Moderately well sorted, very fine grained to coarse grained sublith arenites to quartz arenites. Contain mudstone rip-up clasts.
- Reddish-brown clay ironstone conglomerate with intercalations of grits; (cherry-cake conglomerate).

River cut - Dominantly a black laminated shale sequence similar to that found in roadside section.

Figure 13 shows a geological map of the area of exposure.

STOP 3

KUGLER (1959) SURFACE GEOLOGY MAP

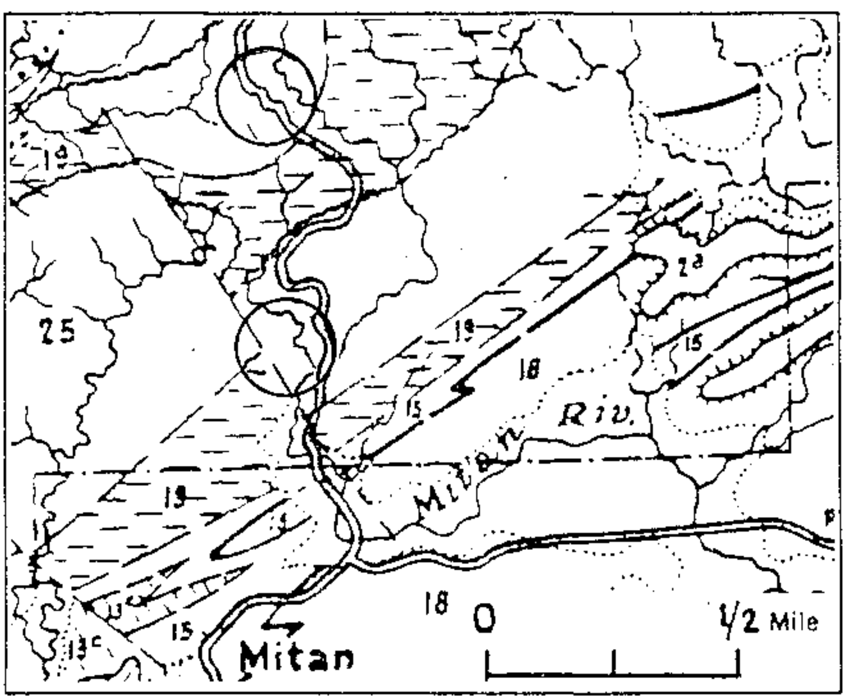


Figure 13

STOP 4

LOCALITY : **PIPARO MUD VOLCANO, PIPARO ROAD (NEAR INTERSECTION OF PASCUAL ROAD)**

FORMATION : **NARIVA FORMATION**

AGE : **LATE OLIGOCENE-MIDDLE MIOCENE**

The relief of this area was created by the activity of the mud volcano. The vents are short-lived and are relatively random in their surface expression. There is no definable tassik with the mud ejecta supporting the growth of the local vegetation (contrasting with the modification of local vegetation seen in many other mud-volcanoes within the Southern Basin). The mud is very viscous with small vents and no distinct cones. Historically the eruptions trigger land uplift and then subsidence in a radius of about 60 m from the focus of the eruption. This volcano is rather anomalous in that compared to most other volcanoes in the Southern Basin it does not contain entrained sand in the ejecta. Numerous exotics are recorded from the mudflow cap.

Figure 14 shows a geological map in the area of the volcano.

STOP 4

KUGLER (1959) SURFACE GEOLOGY MAP

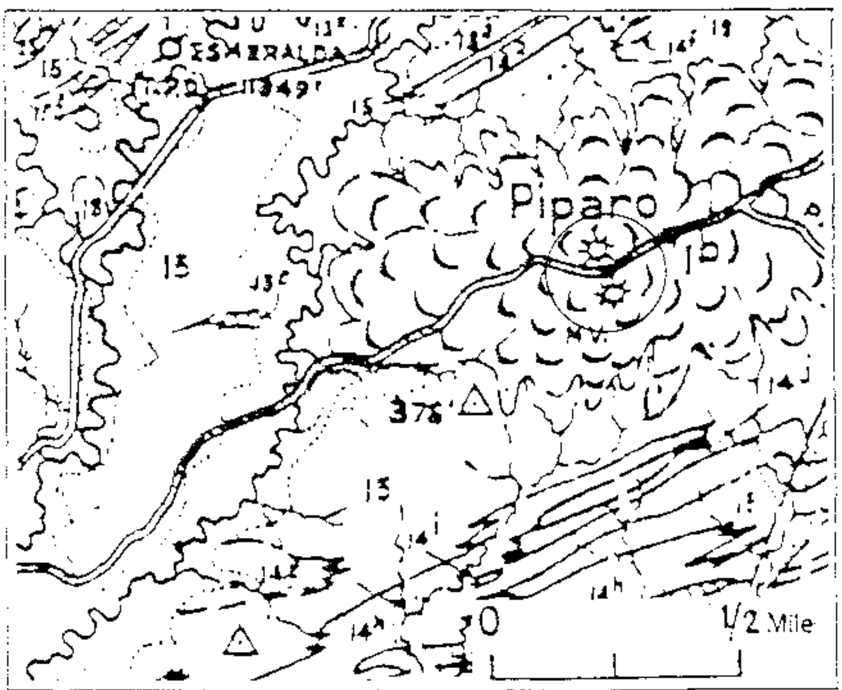


Figure 14

STOP 5

LOCALITY : CORBEAUX HILL, PIPARO ROAD (NEAR PIPARO MUD VOLCANO) - CENTRAL RANGE.

FORMATION : NARIVA FORMATION

AGE : LATE OLIGOCENE TO EARLY MIOCENE.

Exposure of the upper part of the Nariva Formation. The lowermost part of this formation is composed of a monotonous series of red weathering clays with occasional lenses of sand. The upper part contains a mixture of silt, coarse sand and lignites. Stratigraphic younging is towards the north. This locality has two outcrops, one along the roadway and the other beside the house. Figure 15 shows a stratigraphic section at this locality. The beds dip steeply (80 -85^{0}) in a NNE direction.

Along Road From south to north, five depositional units are present:

- Disturbed bedding, mudstone with rip-up clasts
- Graded to massive sandstones, usually coarse grained
- Classic turbidites, composed of rhythmic bedding, medium grained sandstones with plant and coal fragments
- Coal (disseminated but layered)
- Sandy shale

Unit (1) is a mudstone intensely deformed by faulting paralleling the contact with the sandstone. The mudstone is brownish grey and non-calcareous.

Unit (2) has a relatively planar base with load structures and rip-up clasts of mudstone possibly from the underlying unit (1). This unit develops eastward at the outcrop beside the house into a coarse grained 6 m deep quartz arenite channel with a scoured base.

Unit (3) fines upward through a series of rhythmic layers to a medium grained sandstone. Represents a classic turbidite deposit.

Unit (4) is composed of black bituminous coal beds, disseminated within the sandstone but at times forming a complete homogenous coal layer.

Unit (5) is a sandy-shale, rhythmically bedded.

Next to house - Beds (4) and (5) better exposed in this area. Note channel feature from Unit (2) on south side of outcrop. Figure 16 shows a geological map of the area.

Stratigraphic Section : Nariva Formation

Corbeaux Hill, Piparo Road

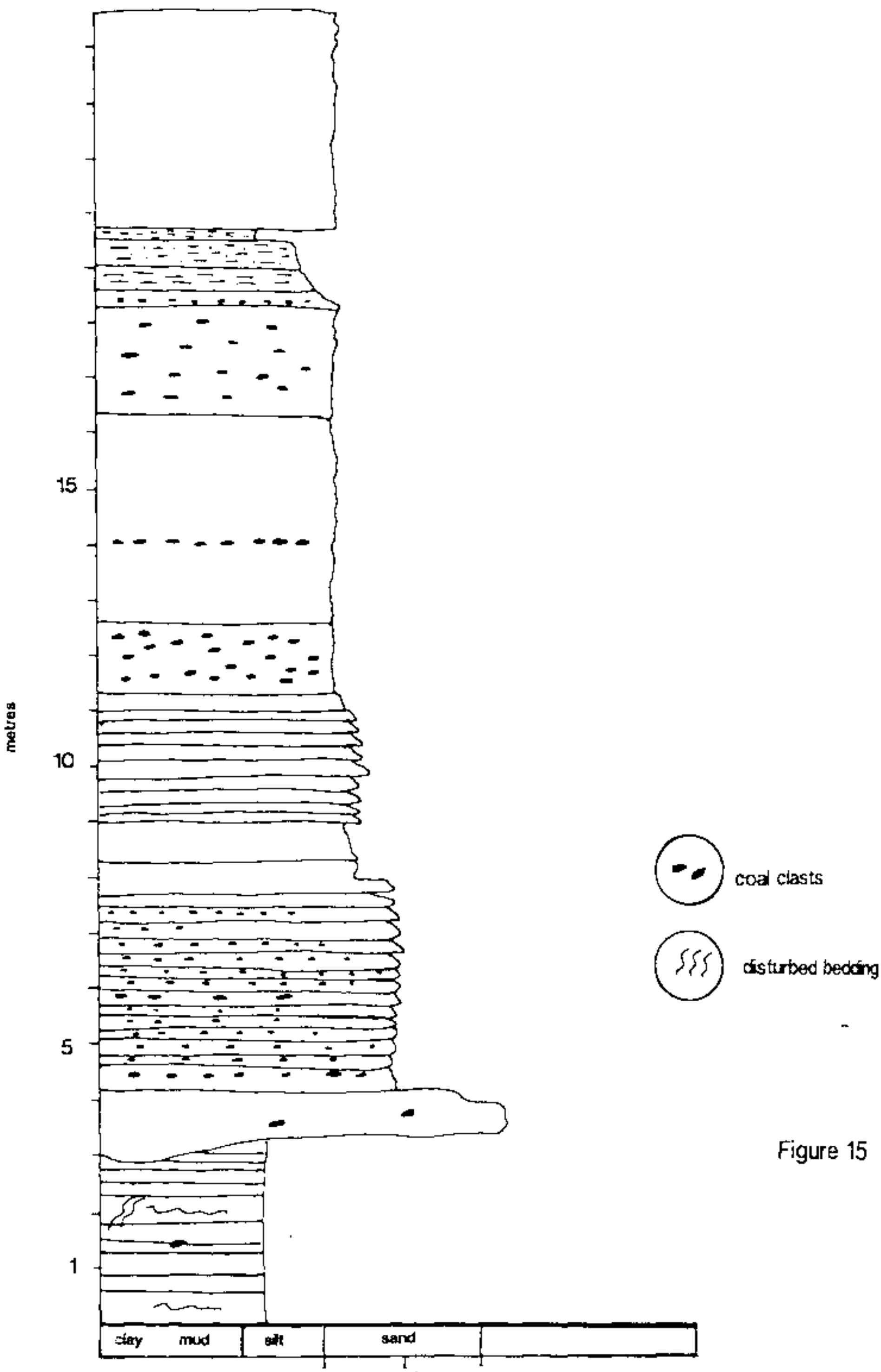


Figure 15

STOP 5

KUGLER (1959) SURFACE GEOLOGY MAP

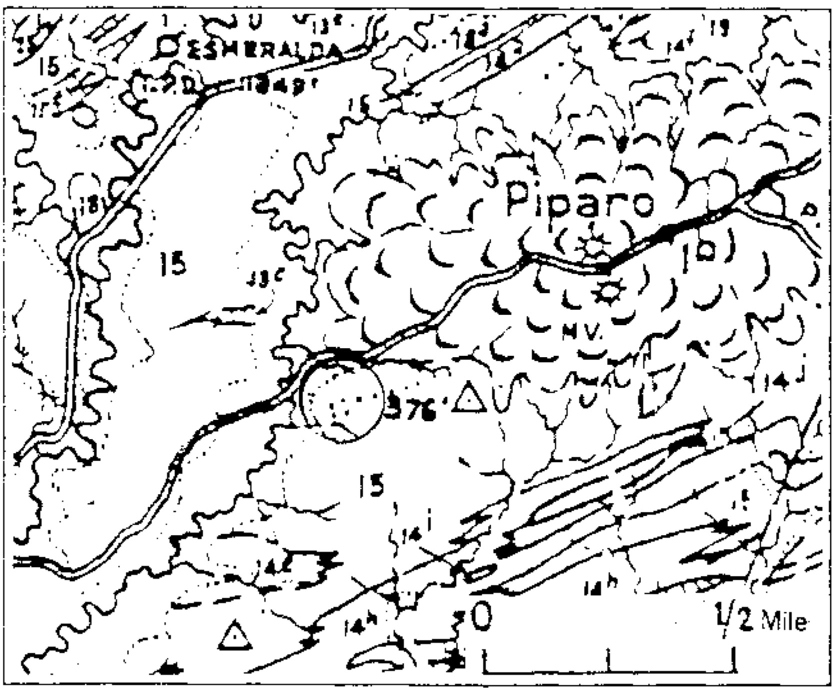


Figure 16

STOP 6

LOCALITY : JACKSON HILL, IERE VILLAGE

FORMATION : NAVET FORMATION

AGE : MID-UPPER EOCENE

The Navet Formation is Mid-Late Eocene and is dominated by light grey and greenish grey marls and marly clays rich in *Globigerinidae* and radiolaria. Locally there are interlaminations of silty and sandy beds some of which are glauconitic and phosphatic.

Description (After Algar 1993)
A subvertical sequence of predominantly white chalky marls (fig 17) interbedded with green sandy mudstones. Stratigraphic younging is to the south. The marls make up by far the greatest proportion of the unit. Variation in the relative proportions of clay and limestone varies the particular shade of white from a brilliant carbonate rich white to a creamy mud rich white. Bed transitions are both sudden and transitional. The clastic material comprises:

- Sub-rounded to well rounded; medium sized, clear quartz grains often coated with green or red iron oxides.
- Emerald to dark green coloured very well rounded grains of glauconite.
- Dark grey to black well rounded grains of phosphate or siltstones.
- Well rounded purple grains of uncertain composition.
- Angular grains of white limestone presumably from the underlying calcareous rich marl.

Roughly 90% of beds maintained their thickness over the 5 metres of exposure. Lensoid zones of conglomerates are present on the top surface of the outcrop along the bedding planes. These zones are up to 15 cm thick but thins laterally. Kugler (1953) estimates the Navet Formation is approximately 400 metres thick.

Figure 18 shows a geological map over the outcrop area.

Stratigraphic Section: Navet Formation (Algar, 1993)

Jackson Hill Outcrop.

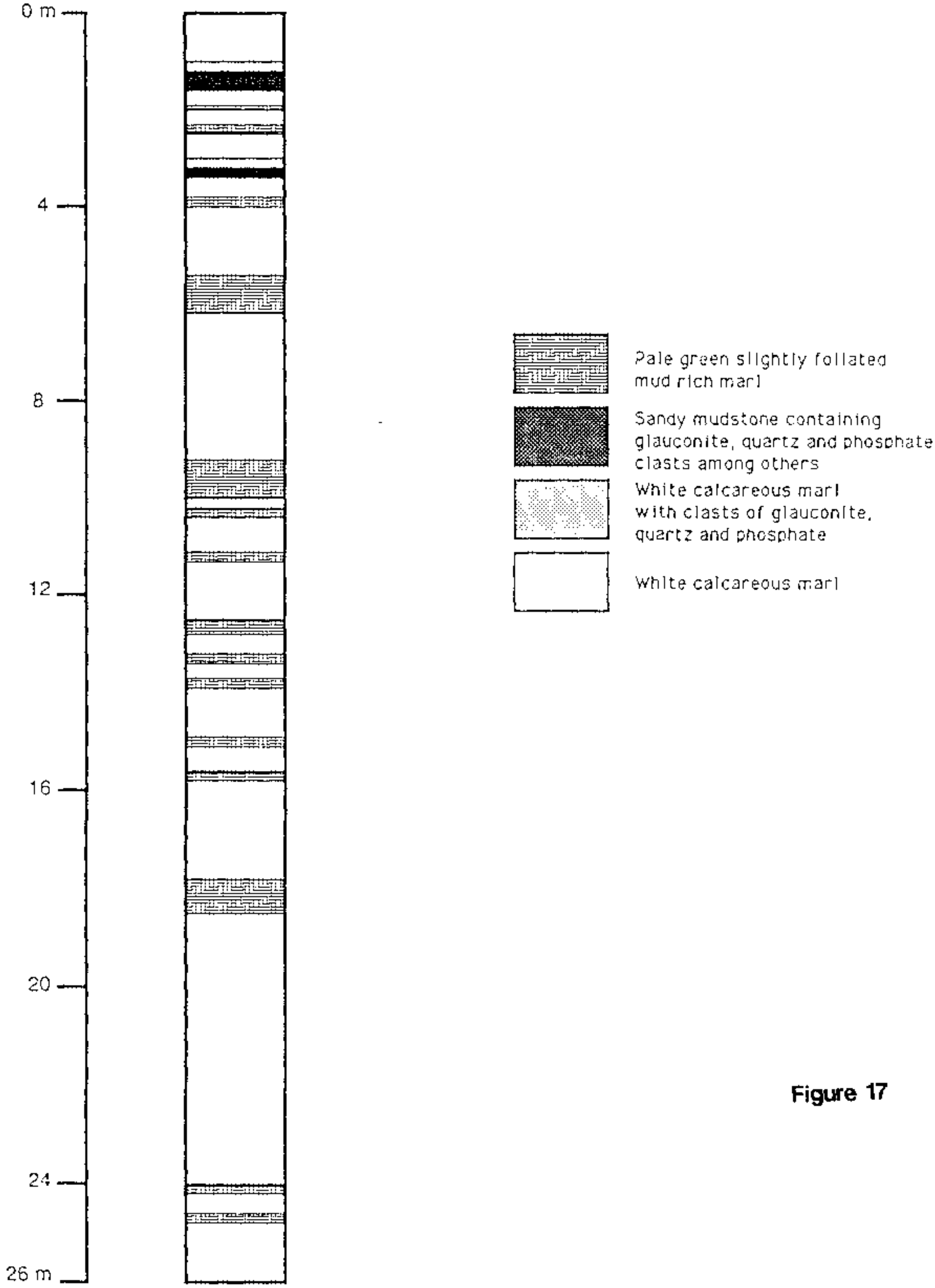


Figure 17

STOP 6

KUGLER (1959) SURFACE GEOLOGY MAP

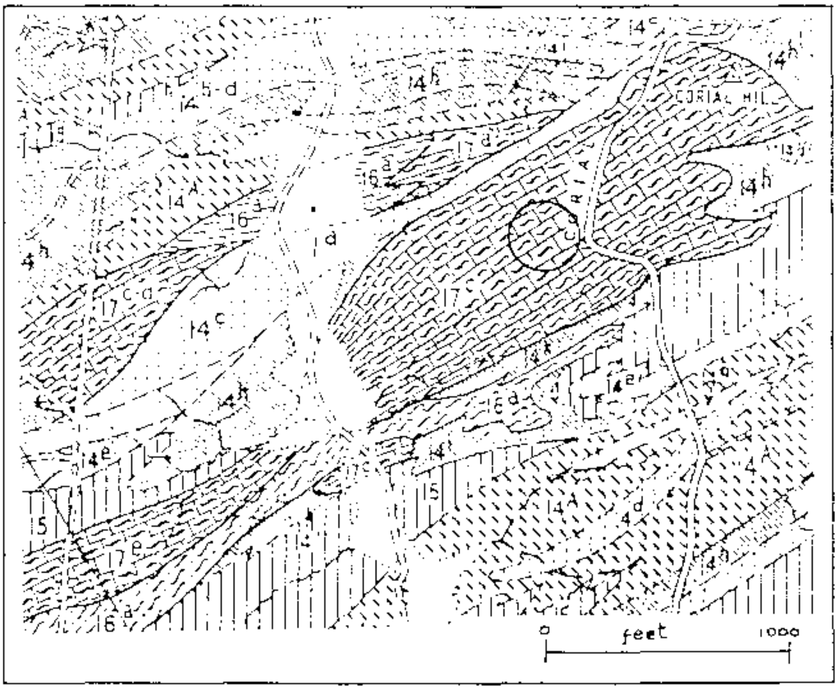


Figure 18

STOP 7

LOCALITY : CENTRAL QUARRY (EAST & WEST), GASPARILLO

FORMATION : TAMANA FORMATION

AGE : MIDDLE MIOCENE

The Tamana Formation receives its name from Tamana Hill, a conspicuous prominence in the north-central part of the Central Range. It consists of an alternating sequence of limestones and mudstones. The limestones are reef-algal in nature, sometimes massive, yellow to white in colour and vary from granular to crystalline in texture. The mudstone/siltstones are bluish grey in colour. The two quarries exposes essentially the same section. Figures 19 to 21 summarize the lithologic and paleoenvironmental characteristics of the section.

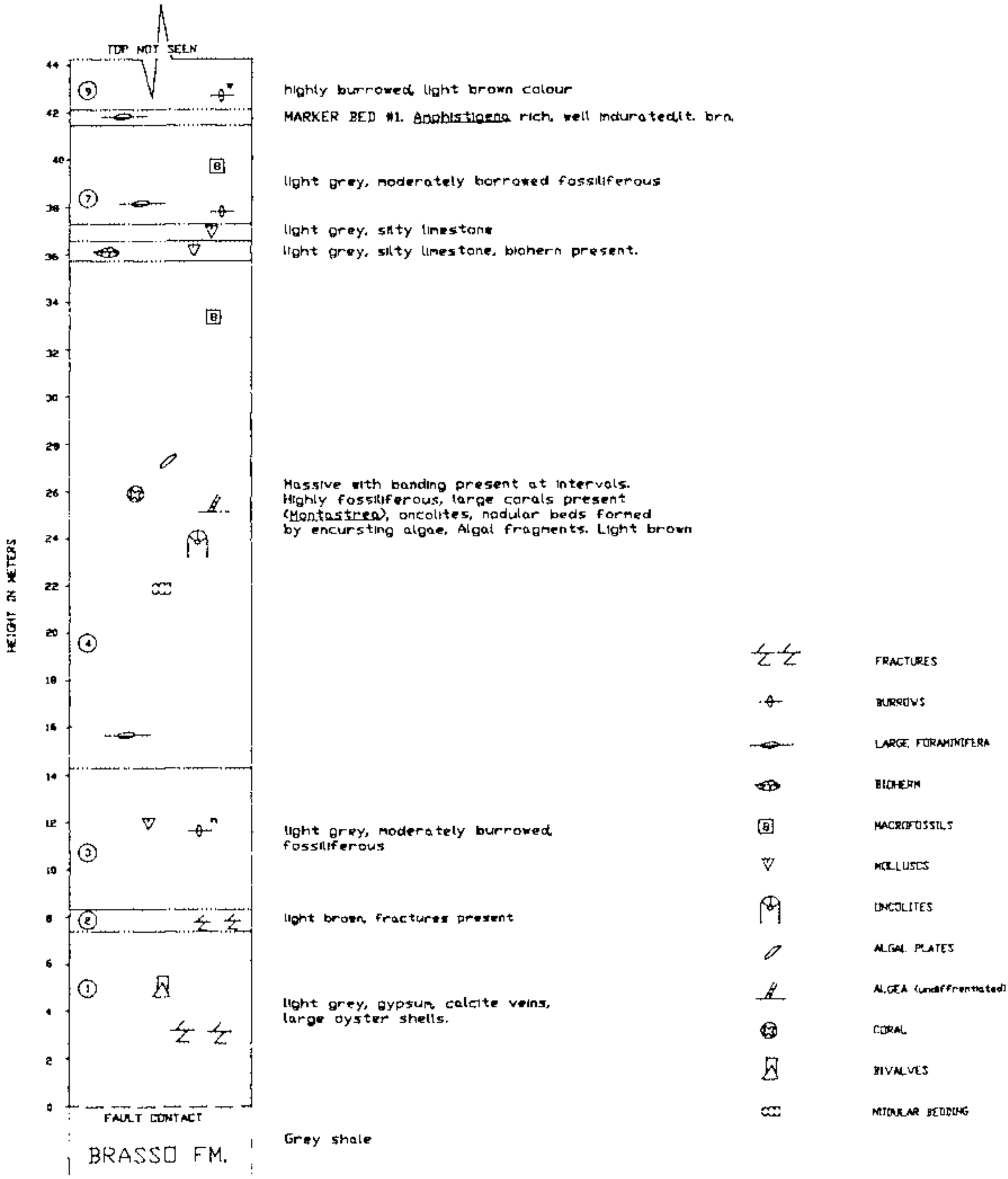
The beds all dip steeply (70 80^{0}) in a SE direction. NW / SE orientated normal faults are present and jointing is well developed. The Tamana is fault contacted with the Brasso Formation at these localities, possibly along a north dipping, NE striking reverse fault.

Figures 22 & 23 show thin sections through beds 2 and 7 respectively. Figure 24 shows a geological map over the outcrop area.

TAMANA FORMATION

Guaracara Limestone Member stratigraphic section

CENTRAL QUARRY (EAST)



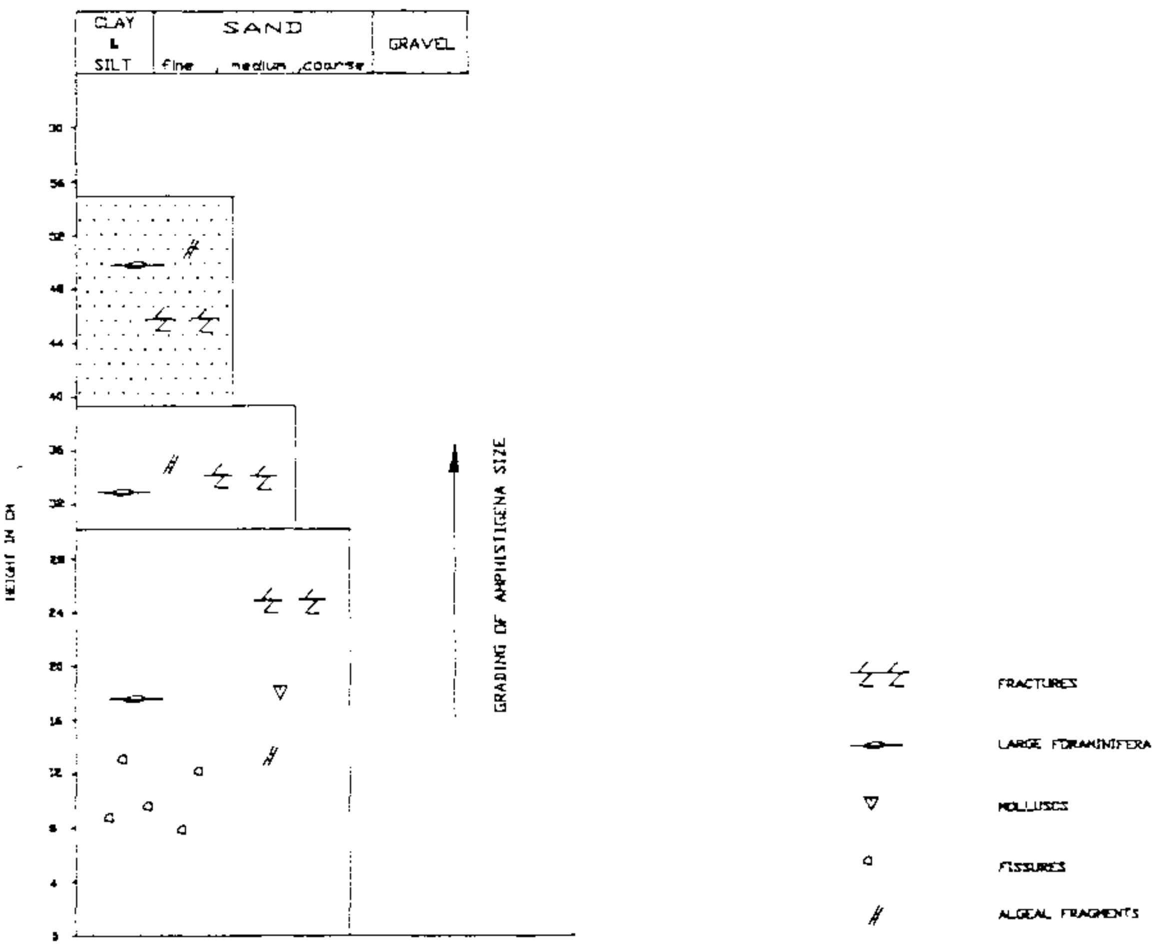
(Geetan, 1990)

Figure 19

TAMANA FORMATION

Guaracara Limestone Member
stratigraphic section
Marker Bed #1

CENTRAL QUARRY (EAST)



(Geetan, 1990)

Figure 20

SUMMARY OF THE PALAEOENVIRONMENT OF THE GUARACARA LIMESTONE SEQUENCE

BED NO.	CLASSIFICATION	FAUNA	FLORA	PALAEO-ENVIRONMENT	WATER DEPTH
1	Packestone	High diversity, planktonic forams, flat, lenticular & subspheroid rotaliines	Algal fragments Lithothamnium spp. Lithophyllum spp.	Open shelf	100 m
2	Wackestone	High diversity, planktonic & benthonic forams. molluscs	Algal fragments Lithothamnium spp. Lithophyllum spp.	Open shelf	100 m
3	Coral boundstone	High diversity. corals, molluscs, miliolids and small rotaliines	Algal fragments Lithothamnium spp. Lithophyllum spp.	Ecologic reef	< 10 m
4	Wackestone	High diversity, planktonic & benthonic forams, gastropods, bivalves, fish tooth (?)	Halimeda ? Lithophyllum spp.	Open shelf	100 m
5	Algal-foram Packestone-grainstone	Low diversity lenticular and sub-spheroid rotaliines	Liithothamnium spp. Lithophyllum spp.	Open platform	< 20 m
6	Algal-foram Packestone grainstone	Low diversity lenticular and sub-spheroid rotaliines	Lithothamnium spp. Lithophyllum spp.	Open platform - shelf sands	0-20 m
7	Algal boundstone	Barren	Algal laminations Lithothamnium spp. Lithophyllum spp. Goniolithon spp.	Foreslope	20-100 m

(Geetan, 1990)

Figure 21

Thin Section Description (Geetan, 1990)

Negative Print of Thin Section
Bed No.: 2

ALLOCHEMS: Codiacean algae *Halimeda* sp. probably present but dissolution removed skeleton leaving "holes". *Lithothamnium* spp. present as fragments. Diverse foraminiferal assemblage including *Orbulina*, *Bulimina* sp., miliolids (0.4 mm), rotaliines (*Amphistigena* sp.), mollusk fragments present, phosphatic fragments (fish teeth?).

CEMENT & MATRIX: Calcite cement, crystals gain size centrifugally. Micrite matrix exhibited by micritic envelopes (intragranular) and surrounding allochems (intergranular).

POROSITY: Mouldic porosity, 50%.

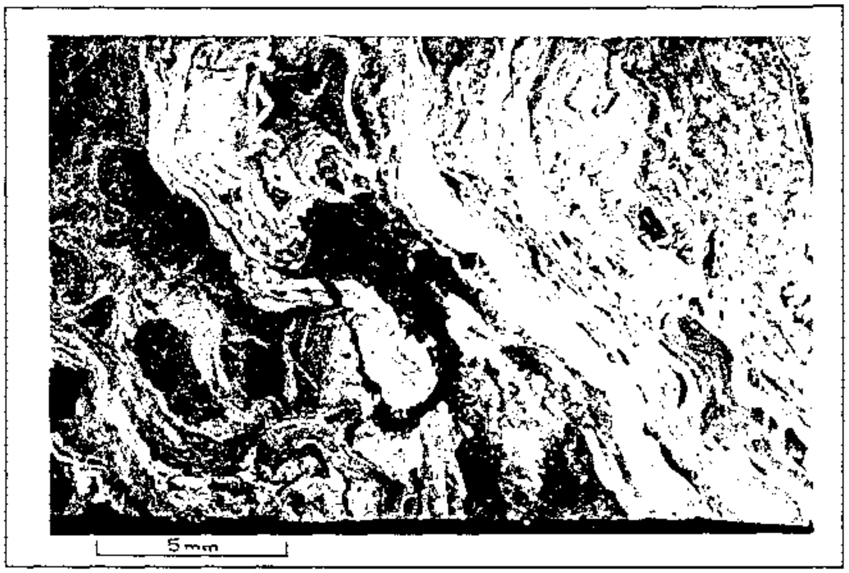
PERCENTAGE COMPOSITION:

Algae	20%
Forams	15%
Micrite	30%
Calcite	10%
Mollusks	15%
Others	10%

CLASSIFICATION: Wackestone

Figure 22

Thin Section Description (Geetan, 1990)



Negative Print of Thin Section
Bed No.: 7

ALLOCHEMS: Abundant filaments of coralline algae present consisting of *Lithophyllum* spp., *Lithothamnium* spp. and *Goniolithon* spp. Filaments organically bound together.

CEMENT & MATRIX: Micrite present as matrix within filaments, neomorphic spar present along boundaries of filaments. Grain boundaries cross into algal filaments. Sparite present within spaces between filaments, increases in size centrifugally.

POROSITY: Mouldic (10%).

PERCENTAGE COMPOSITION:

Algae	70%
Micrite	15%
Neomorphic Sparite	5%
Sparite	10%

CLASSIFICATION: Algal boundstone

Figure 23

STOP 7

KUGLER (1959) SURFACE GEOLOGY MAP

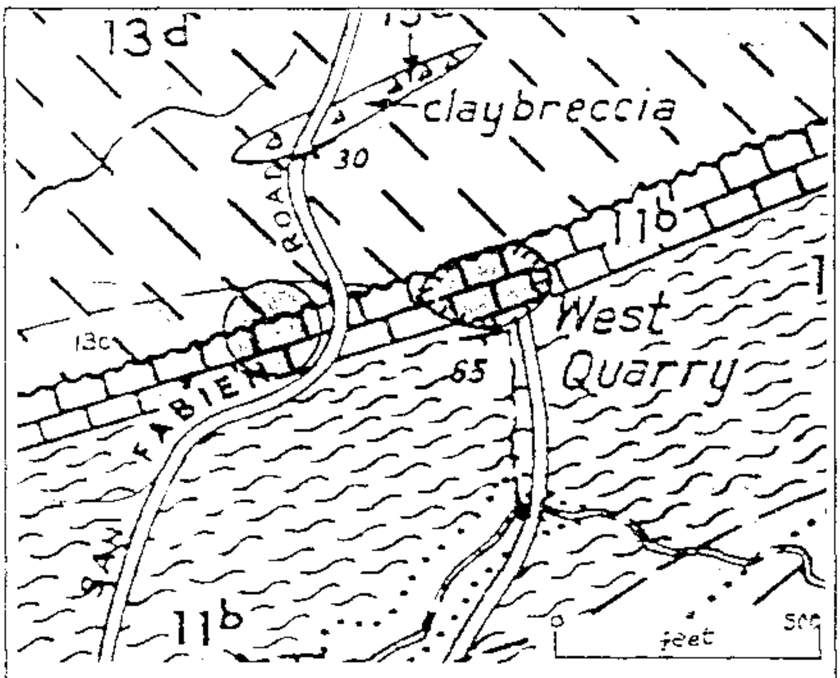


Figure 24

STOP 8

LOCALITY : NORTH SECURITY ROAD, PETROTRIN'S POINTE-A-PIERRE CAMP

FORMATION : SAN FERNANDO FORMATION, PLAISANCE CONGLOMERATE

AGE : LATE EOCENE

An outcrop of the Late Eocene San Fernando Formation. Described by Kugler (1953) as a series of sandstones, some calcareous with fish remains and local coarse grained grits rich in tubulostrium, orbitoids, echinoids and oysters. The Plaisance Conglomerate member was described as occurring at the base of the formation and it contained dominantly Mid to Upper Cretaceous but also Maastrichtian and Late Eocene rocks set in a matrix of coarse gritty sand.

Description (After Algar 1993)

The section is approximately 10 m high and is made up of graded units 3 m to 5 m thick with boulders up to 1.5 m long at the base, grading up rapidly into well rounded to rounded conglomerates and or coarse sandstones. The bedding planes are generally sharp and relatively planar. The larger clasts showed grain support but no convincing preferred alignment was apparent. Dominant clast types include a tan coloured siltstone, red hematitic clay, organic rich shales, fossiliferous limestones and pale grey micritic limestones. The matrix is a coarse grained quartzose sandstone local layers rich in bivalves.

At the top of the outcrop is an unconformity overlain by Nariva Formation sediments.

Conglomerates in a similar stratigraphic position and having similar lithologies have been encountered in wells in the Caroni Basin.

Figure 25 shows a geological map through the outcrop area.

STOP 8

KUGLER (1959) SURFACE GEOLOGY MAP

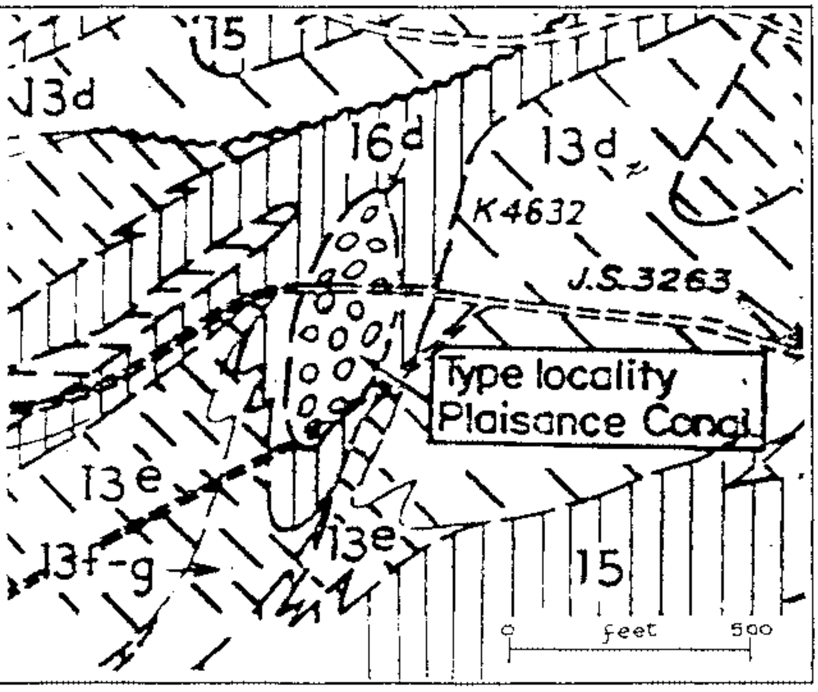


Figure 25

STOP 9

LOCALITY : SPRINGVALE QUARRY, SOLOMON HOCHOY HIGHWAY

FORMATION : MANZANILLA & SPRINGVALE FORMATIONS

AGE : LATE MIOCENE-PLIOCENE

The name Manzanilla Formation was derived from the geographical location of its type locality, the Manzanilla Bay. A complete stratigraphic section would include three (3) members: the basal San Jose silt member, the Glauconitic Sandstone member and the Telemaque Sandstone member which forms the upper part of the formation. This quarry exposes the Telemaque sandstone member dipping 42° NW unconformably overlain by the gentler dipping (10° NW) Springvale Formation expressed here as a calcareous rich shell bed.

The Manzanilla Formation at this locality is expressed as thick sandstone units, well bedded with interbedded rippled silt and thin sands. The sandstone is medium grained, subangular to sub-rounded with abundant mica. Jointing is well developed. To the base, a thin (15 cm) lignite band is present.

Skolithos burrows are common, dominated by two ichnogenera viz *Ophiomorpha* and *Thalassinoides*. Gypsum veining along bedding planes is common within the burrowed section. The Manzanilla Formation forms the prolific reservoirs of the North Soldado field in the Gulf of Paria area.

The Springvale Formation is a shale prone sequence consisting of three members, the lowermost Gransaull clay, a glauconitic sandy member called the Savaneta sand and the uppermost Chickland Clay member. It is up to 150 m thick. The sandstone units form part of the prolific reservoirs in the North Soldado area.

Figure 26 show a geological map over the outcrop area.

STOP 9

KUGLER (1959) SURFACE GEOLOGY MAP

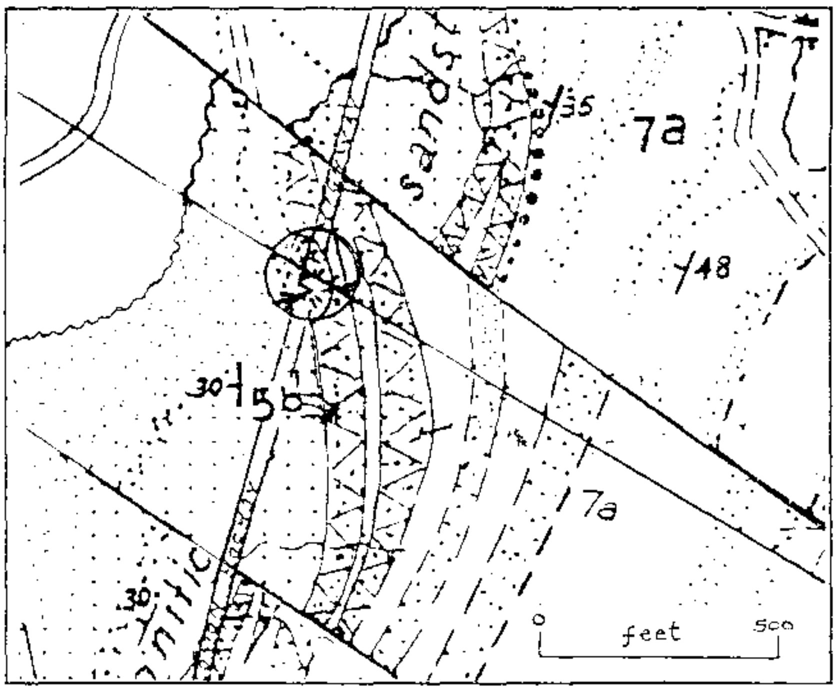


Figure 26

STOP 10

LOCALITY : NAPARIMA HILL, SAN FERNANDO

FORMATION : NAPARIMA HILL FORMATION

AGE : LATE CRETACEOUS (TURONIAN-CAMPANIAN)

The Hill is a Late Cretaceous inlier surrounded by Paleocene Lower Lizard Springs Formation on its northeast and Oligo-Miocene Cipero Formation on its southern boundary.

The Naparima Hill Formation is made up of a well-bedded indurated black to light grey mudstone (argilline) to siliceous claystone weathering to cream and white colours. The rock is very brittle and highly fractured and may contain chert nodules in parts. The average thickness of the formation may amount to about 400 m but thicknesses of 700 m are known from well data. A relatively rich, mostly benthonic, foraminiferal fauna can be obtained from some of the more shaley beds.

Palaeo-environmental studies (Koutsoukos and Merrick 1985) indicate that a progressive deepening occurred from Late Cenomanian to Santonian with environments ranging from deep neritic to upper bathyal (water depths 200 to 350 m). Late Campanian to Middle Maastrichtian benthonic foraminiferal indicate deposition under optimum marine conditions in water depths ranging from upper bathyal to abyssal (350 m to 3000 m). Frequent intermittent phases of restricted circulation and resultant poorly oxygenated water conditions occurred in the Coniacian to Santonian.

Geochemical analyses (Rodrigues 1985) indicate that the Naparima Hill Formation is characterized by relatively high TOCs (2.2% average) and amorphous Type II kerogens suggesting good to excellent oil source potential. Chromatographic characteristics and gross geochemical properties of produced oils correlate best with rock extracts from the Naparima Hill and (Gautier) Formations indicating a probable genetic association.

The fracturing is due to the low clay content and is a result of Middle Miocene deformation which formed the Naparima Hill thrust and associated anticline. In strike view the beds are disturbed by numerous anastomosing thrust faults. In dip view large scale dip panels are evident indicating the structure was controlled by brittle fault bend folding. Figure 27 shows a geological map across the area of outcrop.

STOP 10

KUGLER (1959) SURFACE GEOLOGY MAP

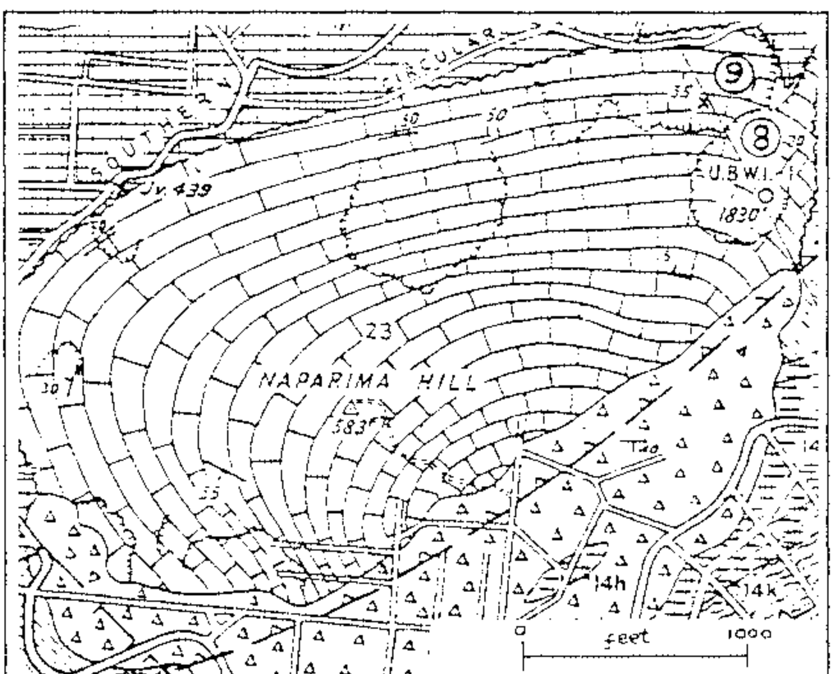


Figure 27