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Depositional environments and burial history of the Late Early Pliocene, Moruga Group, south coast, Trinidad, West Indies

Harry, Brian E., Ph.D.

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U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

DEPOSITIONAL ENVIRONMENTS AND BURIAL HISTORY OF THE LATE EARLY PLIOCENE, MORUGA GROUP, SOUTH COAST, TRINIDAD, W.I.

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Brian E. Harry

B. Sc., University of the West Indies, Mona, Jamaica, 1982

M. Phil., University of the West Indies, Mona, Jamaica, 1987

Committee Chair: Dr. Wayne A. Pryor

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I hereby recommend that the thesis prepared under my supervision by Brian E. Harry

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Approved by:

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ABSTRACT

The depositional style, biostratigraphy and burial history of the Late Early Pliocene, Moruga Group were studied in outcrop and the subsurface, along the south coast of Trinidad to determine its depositional environments, sediment sources, geologic age, and diagenetic history. This study fills a major gap in the Pliocene stratigraphy and paleogeography of the Tertiary Northern Venezuela Basin.

Convergent, right lateral, wench faulting was the dominant tectonic style along the Southern Caribbean Plate Boundary during the Mid-Eocene and continued through the Oligocene creating several structomorphologic areas of which the southern Trinidad basin was one. Uplift and erosion of the Andes Mountains and Guyana Shield in northern South America, provided large volumes of recycled orogenic sediments which were subsequently transported and redeposited in the Northern Venezuela/Columbus Basin.

During Late Miocene to Early Pliocene time the northerly prograding, ancestral Orinoco delta transported large volumes of terrestrially derived subarkosic and sublitharenitic sand to the Northern Venezuela/Columbus Basin area. The influence of sea level, coupled with tectonics provided a depocenter which adjusted to accommodate more than 1600 meters of Late Early Pliocene sandstones, siltstone and mudstones of the Moruga Group.

The Moruga Group was deposited by gravity flows and turbidity currents which were very effective in resedimenting the originally deltaic

sediments. Three distinct facies were identified on the basis of sandstone/mudstone ratio, sedimentary structures and bedding characteristics. The facies associations, together with the widespread occurrence of complete and truncated Bouma cycles, indicate deposition in a delta-fed submarine ramp environment, by high efficiency, turbidity currents and gravity flows. This system lacked some elements (eg. canyons) of classic turbidity current models. The Moruga Group was deposited as viscous sheet gravity flows, (turbidites) which were mobilized downslope from a line source as unstable sediments piled up on the prograding delta slope.

Petrography and heavy mineral analyses indicate that the sediments were derived from a mixed igneous and metamorphic source and were the result of rapid erosion and transportation from the Andes and Guyana Shield areas.

On the basis of biostratigraphic evidence the Moruga Group was determined to be of Late Early Pliocene age. Water depth estimates based on the flora and fauna indicate deposition in the outer shelf areas, where water depths might have reached 200 to 250 meters. The presence of terrestrially derived plant and algae suggest a continental assemblage deposited in an open marine environment.

The burial diagenetic history of the Moruga group was evaluated using data from clay mineralogy, organic and inorganic geochemistry. A typical Gulf Coast type clay mineral assemblage was recognized. Evidence suggest that source and depositional environment might have been the major control on the diagenetic mineral association encountered. Rock Eval Pyrolysis indicate that very large amounts of the organic geochemical components are reworked, and cannot be used in source rock evaluation of these sediments. Where rock eval pyrolysis was possible the sediments were determined to be gas prone but immature. Stable isotope data suggest no relationship between carbon and oxygen isotopic compositions, indicating a complex diagenetic history.

DEDICATION

"The credit belongs to the man who is actually in the arena, whose face is marred by dust and sweat and blood... who knows the great enthusiasm, the great devotions; who spends himself at a worthy cause; who at best knows in the end the triumph of high achievement, and... if he fails, at least fails daring greatly so that his place shall never be with those cold, timid souls who know neither victory nor defeat."

- John F. Kennedy

This dissertation is dedicated to those who were always there - in the arena:

My Mother and Father
Muhammad Akbar Shabbaz
Donna Miller-Ehard (In memory of my friend and confidante.)

"Magnum est QRC et semper prevalibat"

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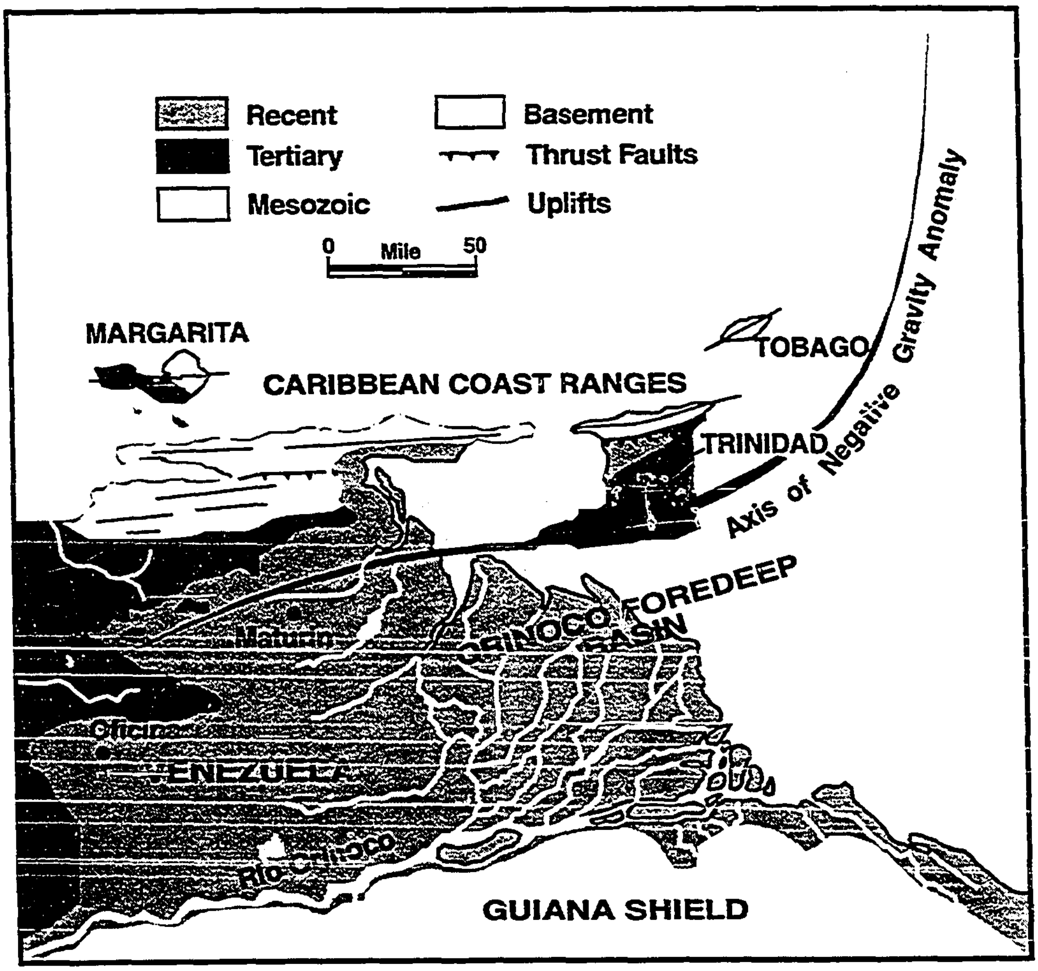
INTRODUCTION

A sedimentary sequence of low density Tertiary rocks off the south coast of Trinidad is estimated to be approximately 40,000 feet thick. This thick sequence is responsible for a strong negative gravity anomaly which begins in eastern Venezuela, trends eastward along southern Trinidad and up to Barbados. Figure 1 shows a simplified map of the regional geology of Trinidad and Eastern Venezuela, illustrating the close relationship between the geology of both territories.

Despite intense petroleum exploration activity in the producing basins, which hosts three giant oil fields and many smaller ones, there are large gaps in the knowledge of the sedimentology and stratigraphy which inhibit a clear understanding of the region's geologic history and the potential for future petroleum development. This study was designed to investigate the depositional and burial history of the Early Pliocene part of this sequence.

The study is focused on the Early pliocene stratigraphic section, and more specifically the Moruga Group. This group of rocks is exposed along the south and southeast coast and is also encountered in the subsurface of Trinidad (Fig. 2).

The Moruga Group in the subsurf ace is comprised of the Lower, Middle and Upper Gros Morne and the Mayaro Formations, (Figures 3 and 4). There is an unconformable relationship with the overlying palmiste Clay. In outcrop the equivalents are the Gros Morne Sandstone and Silt, the St. Hilaire Silt and the Trinity Hill Sandstone. The Las Tablas Silt and the Casa Cruz Sandstone are the outcrop equivalents of the Mayaro Formation.



(After Batjes, 1965)

Figure 1. Regional Geology Trinidad & Eastern Venezuela

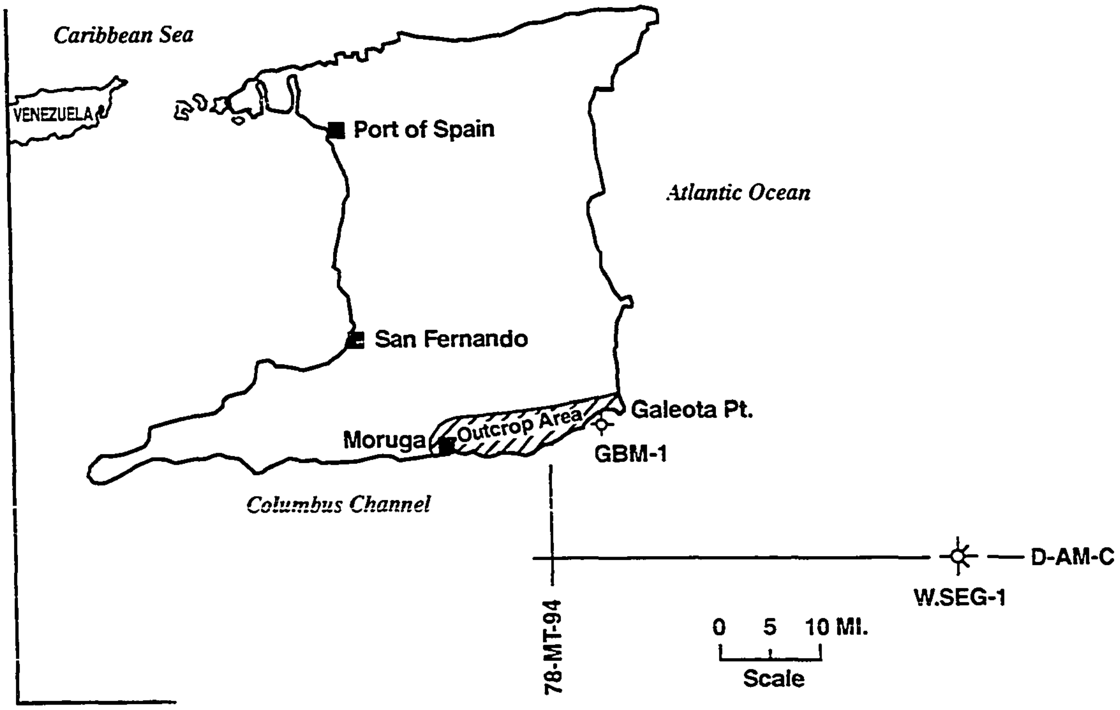
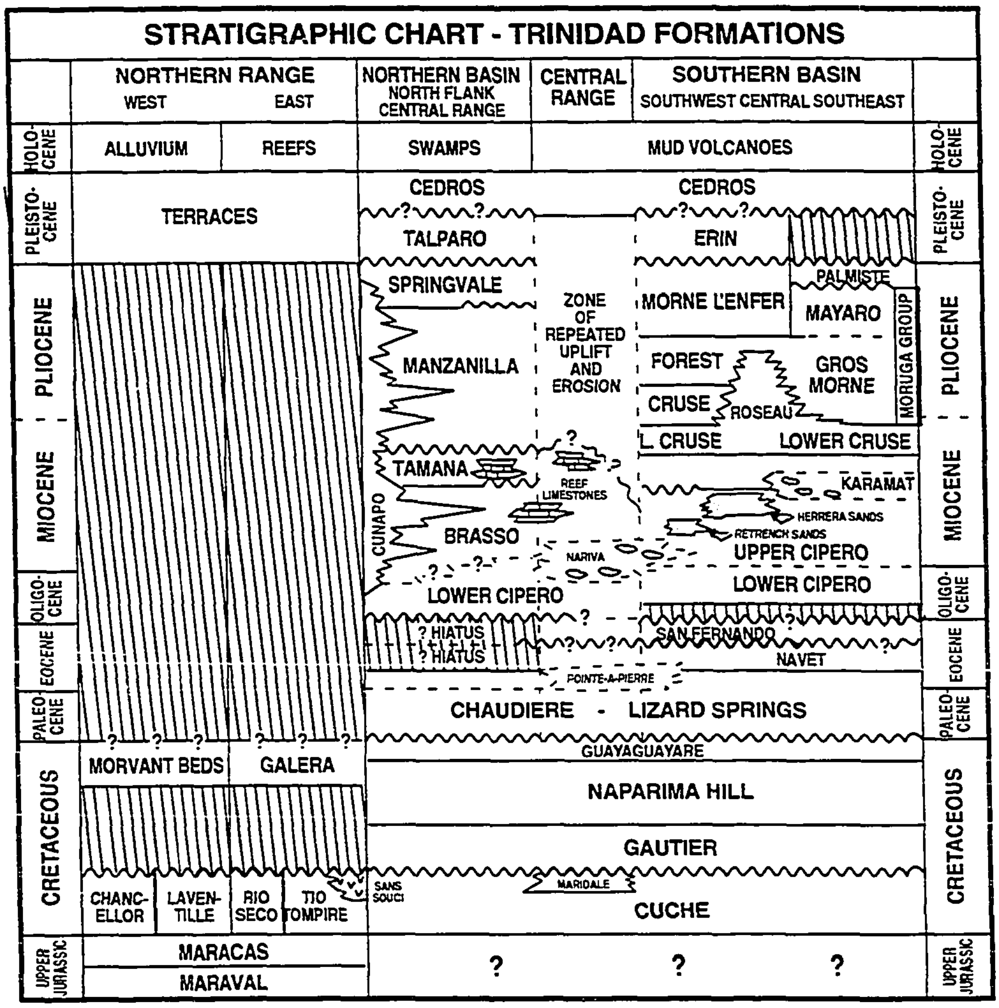


Figure 2. Location map showing outcrop area, seismic lines, and wells studied

These rocks may have been buried deeper than 15,000 feet evidenced by the depths at which they are encountered in the subsurface.

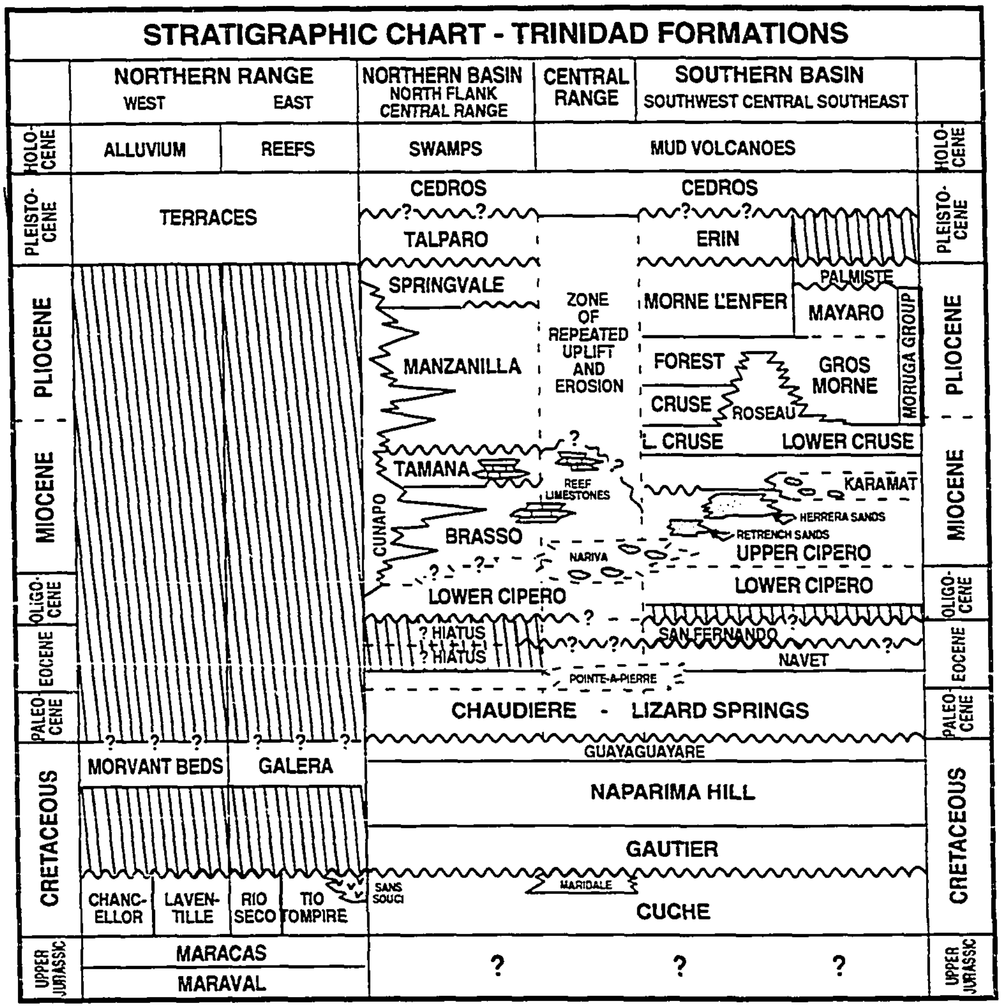
Published accounts of the geology and sedimentology of this area are sparse and fairly old and there is need for updating. Previous authors have suggested that the ancestral Orinoco River deposited fluvial and deltaic sediments during Miocene to Holocene time (Michelson, 1976 and Leonard, 1985). The Guiana Shield area, drained by the Orinoco River, has been suggested as the source of the deltaic sediments (Michelson, 1976). Such accounts of the sediments in the southeast coastal area are inadequate, and say very little about the potentially important (stratigraphic) relationships which may exist between these sediments.

This study focuses on determination of (a) the provenance and age of the section exposed along the southeast coast, (b) the depositional systems responsible for it's emplacement, (c) the geographic relationship between the source and depositional basin, (d) the extent of progradation of the Tertiary Orinoco Delta, generally accepted as the depositional agent for this sequence, (e) the depth to which these rocks were buried, and, (f) the stratigraphic and geographic relationship between the offshore section encountered in the WEST-SEG-I well and the stratigraphic section encountered onshore along the southeast coast.



Carr-Brown and Frampton (1979)

Figure 3. Stratigraphic Chart of Trinidad



Carr-Brown and Frampton (1979)

Figure 3. Stratigraphic Chart of Trinidad

Objectives and Scope

This study has three primary objectives.

1) The first objective is to determine the sedimentologic relationships between sedimentary facies of the Moruga group, present in the subsurf ace and outcrop. This will be achieved log considering the sedimentologic facies present, the geographic relationship between source and depositional basin and the provenance study which provides the link between source and sink. A detailed description and interpretation of the Early pliocene stratigraphic section encountered along the south coast of Trinidad is presented.

The goal is to characterize the various facies present and give a detailed account of the primary sedimentary structures encountered. An explanation and model for the origin and depositional environment of the sequence being investigated is presented. Such models will also be helpful to explorers seeking to locate significant bodies of sand.

The relationship of the south coast section to the West SEG-1 well will be discussed. The discussion will be based con the resemblances and similarities between the lithologic section encountered in the well (drawn from geophysical well logs) and the measured outcrop section. A small suite of seismic lines is used to establish a tie between the well and the outcrop belt and evaluate the effects of structure on this relationship.

2) To describe the mineralogy, provenance and age of sediments of the Moruga group exposed along the south coast of Trinidad and encountered in

the subsurface of the West SEG-I well. Mineralogy and provenance is determined on the basis of quantitative and qualitative petrographic data. The quantitative data is presented in ternary diagrams eg. Dickinson and Suczeck, (1979), and conclusions are made con a possible sediment source and tectonic terrain.

The interpretation of the ages of these sediments are based on paleontologic and palynologic data extracted from well cuttings (W SEG-1), outcrop samples collected during fieldwork and additional data from the Texaco GBM-1 well in the Guayaguare Bay area. Additional data was obtained from some unpublished studies done at Amoco Production Company. The age data also serve to establish age similarities between the two data sources.

3) To determine the burial history of the sediments of the Moruga Group by utilizing data from clay mineralogy, stable isotope geochemistry and organic geochemistry. These studies will allow consideration of the effects of temperature and burial in the sediments.

Observations are made on these burial-related diagenetic properties and data obtained is used to discuss the burial history of the sediments and their coil and gas potential.

Stratigraphy

There are many unsolved problems in the Cretaceous and Tertiary stratigraphy of Trinidad. Stratigraphic zonations and nomenclature are not always readily accepted and there is some uncertainty as to how and why such zonations were chosen and adopted. The stratigraphy presented here is simplified, and a distillate of the better known references. The aim of this section is to place the early pliocene units along the south coast into their proper stratigraphic framework. The stratigraphy presented is summarized in the Stratigraphic Chart of the Trinidad Formations after Carr-Brown and Frampton (1979), (Figure 3). A comparison of this data with that from Barr and Saunders (1965), (Figure 4) highlights some of the problems encountered when studying Trinidad's Miocene to Pliocene Stratigraphy.

Jurassic - The oldest rocks in Trinidad are of Jurassic age and crop out in the Northern Range; an extension of the Cordillera Oriental of the Andes (Figure 1). Hutchison (1958) recognized some Tithonian age ammonites (Perisphinctes transitorius) in the Maraval and Maracas Formations and placed them in the Upper Jurassic. The Maraval Formation consists of predominantly recrystallized massive and bedded limestones with some reefal patches. The Maracas Formation consists of interbedded quartzites and phyllites. Minor slates are present (Potter, 1976). Epidote greenschists in the Maracas Formation appear to have had a volcanic ash precursor (Carr-Brown and Frampton, 1979). The Maraval and Maracas Formations have not been found in the Central Range and Southern Basin.

Cretaceous - The Lower Cretaceous is represented by the Chancellor, Laventille, Rio Seco and Toco Tompire and San Souci Formations of the Northern Range. The Chancellor Formation has four members comprised of phyllites and limestone (Potter, 1976) and in the Western Northern Range rests unconformably upon the Maracas Formation. The Laventille Formation was earlier thought to be a less metamorphosed equivalent of the Chancellor Formation (Potter, 1976) and a Barremian-Aptian fauna described by Saunders (1972) is thought by Potter (1974) to be of the upper phyllites of the Chancellor Formation. This formation is mainly composed of poorly fossilized limestone and crops out along the southern margin of the Northern Range.

The Rio Seco Formation is a sequence of calcareous phyllites and limestones and is lithologically similar to the Toco Formation. Both formations are similar and share a similar relationship to the Chancellor and Laventille Formations. The phyllitic shales of the Tompire Formation are also equivalent to the Toco Formation. The only major outcrop of igneous rock in Trinidad belongs to the San Souci Formation; a series of basaltic volcanics that are placed within the Toco Formation (Barr, 1963). These basalts include ashes, breccias and flows interbedded with Cretaceous shales (Barr and Saunders, 1965).

The Cuche Formation, a seguence of dark shales with minor quartzites and limestone blocks, represents the lower Cretaceous of the Central Range (Barr, 1952). The foraminifera of the Cuche section were studied by Bartenstein, Bettenstaedt and Bolli (1957). An unconformable relationship exists between the Upper and Lower Cretaceous as a result of a short period of diastrophism with local folding and erosion around Albian to Cennomanian (Barr and Saunders, 1965).

In the Northern Range the Upper Cretaceous is represented by the grits of the Morvant and Galera formations (Carr-Brown and Frampton, 1979). The Guayaguare Formation of central and southern Trinidad is placed as equivalent of the uppermost Galera Formation based on the similarity of planktonic foramineral assemblages (Saunders, 1972). The Galera Formation of the Northern Range was dated using benthonic microfauna (Saunders, 1972) and placed in the Upper Cretaceous. The upper part of the Naparima Formation is equivalent to the Galera Formation.

The Naparima Hill Formation, a silicified siltstone/claystone unit that underlies the Guayaguare Formation in central and southern Trinidad. This lithology is quite widespread and is found in wells in Trinidad, the Serrania del Interior of Eastern Venezuela and DSDP drill cores of Southern Caribbean (Carr-Brown and Frampton, 1979). The Naparima Formation is indicative of uniform, quiet depositional conditions during Upper Cretaceous (Barr and Saunders, 1979). The Naparima is underlain by the dark, organic-rich calcareous shales of the Gautier Formation. The conditions which governed the deposition of this Upper Cretaceous sequence were brought to an end by renewed tectonism and local uplift and erosion that preceded the Paleocene transgression (Barr and Saunders, 1965).

Paleocene - Two distinct formations found in southern Trinidad are the result of a widespread Paleocene transgression. The Chaudiere Formation is comprised of non-marine shales and minor sandstones with an arenaceous benthonic fauna. This formation occurs generally in proximity to and over the old Central Range Uplift, (Barr and Saunders, 1965). The Lizard Springs Formation is a deeper water, generally calcareous shale, with a planktonic foraminiferal assemblage. Bolli's (1957) biozonation of the Paleocene was based on the fauna found in the Lizard Springs Formation. Slumping of deep-water unstable clays occurred with renewed tectonism and gave rise to early Tertiary olistostromes (Kugler, 1955, Higgins and Saunders, 1974, and Saunders, 1977).

Eocene - The Eocene is represented by the upper part of the Lizard Springs Formation, the Pointe-a-Pierre Formation and the Navet Formation. The Pointe-a-Pierre Formation is comprised of non-calcareous shales and coarse grained sandstones. The Navet Formation overlies the Lizard Springs Formation and Pointe-a-Pierre Formation and is comprised of richly foraminiferal deep-water marls and calcareous shales, (Carr-Brown and Frampton, 1979). The Eocene was characterized by a continuation of the quiet depositional conditions established during the Paleocene, (Barr and Saunders, 1965). During the Upper Eocene, earth movements resulted in the reactivation and erosion of old uplift areas and this phase is marked by rapid lateral facies changes, (Barr and Saunders, 1985). An excellent paleogeographic summary of the Cretaceous to Late Eocene time was presented by Bell (1972, see Figure 5).

Oligocene - Rapid subsidence following a hiatus (between Oligocene and Eocene) resulted in the deposition of deep-water, calcareous clays and marls of the Cipero Formation. A second period of olistostrome development took place during the deposition of the Nariva Formation. This formation is restricted to the southern flanks of the Central Range (Carr-Brown and Frampton, 1979). The Central Range Uplift became active during this time and formed a persistent barrier between the northern and southern depositional basins, thus the different stratigraphic succession in both areas. There was also a rapid deepening of the seas in both basins at this time (Barr and Saunders, 1985). The deeper water

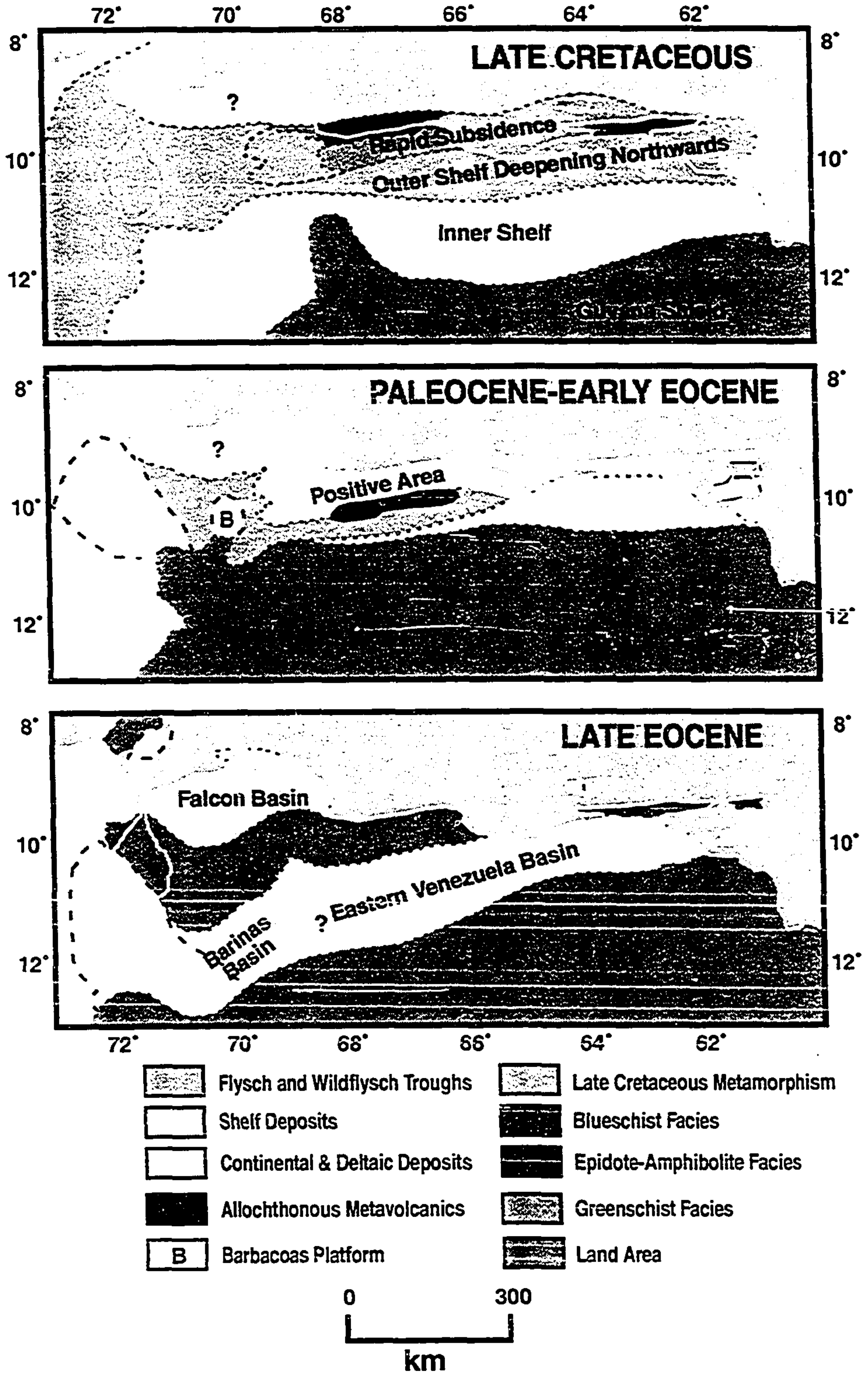


Figure 5. Paleographic Maps of Venezuela and Northern Trinidad

conditions resulted in the deposition of deeper water marine, foraminiferal clays (Lower Cipero Formation). The two basins then became differentiated after these events and the Northern basin shallowed progressively to produce open shelf conditions while deep-water conditions persisted in the Southern Basin.

Miocene - The Miocene was a period of tremendous sedimentary diversity. This diversity over such short distance is reflective of the active tectonism that took place during this time. The Lower Miocene is represented by a major part of the Cipero Formation and the Nariva Formation is also predominantly Miocene in age. Barr and Saunders (1965) report the presence of an economically important group of sands (in the Lower and Middle Miocene) - the Herrera Sands, which are generally oil bearing. During the upper Lower Miocene diastrophism gave rise to folding and emergence.

Deposition was renewed in the Southern Basin with the deep-water clays of the Lengua Formation. These are calcareous clays with a neritic foraminiferal fauna. The equivalent of the Lengua Formation in the Central Range are the shallow-water clays of the Tamana Formation which are associated with small reefal limestones. Upper Miocene and younger sediments are not found in the Central Range (Carr-Brown and Frampton, 1979). The reefal limestones and associated marine clays, silts and glauconitic sands which outcrop on the northern flanks of the Central Range, suggest that although the Central Range may not have been fully emergent at this time it formed an effective barrier isolating Upper Miocene to pleistocene deposition in the Northern and Southern Basins

(Carr-Brown and Frampton, 1979). In the Northern basin, the Tamana clays are unconformably succeeded by the Manzanilla Formation. The Manzanilla Formation is subdivided by Carr-Brown and Saunders (1979) into three members; San Jose Calcareous Silt, Montserrat Glauconitic Sandstone and the Telemaque Sandstone. This formation is thought by these authors to represent an infilling and shallowing of the Northern basin. The Manzanilla Formation is the main producing horizon in the Soldado Field (Carr-Brown and Saunders, 1979).

A major discrepancy presently exists in the interpretation of the Manzanilla Formation, figures 3 and 4. Barr and Saunders (1965) place this formation (unconformably overlain by the Springvale Formation) totally within the Miocene (figure 4) whereas Carr-Brown and Frampton (1979) believe that the greater part of the Manzanilla Formation is of pliocene age (figure 3).

Pliocene - Shallowing of the Southern Basin during a period of shifting transgressions and regressions gave rise to the predominantly shallow-water Cruse, Forest and Mon L'Enfer Formations. Carr-Brown and Frampton (1979) suggest that these formations record a period of deltaic infilling. The Cruse and Forest sands produce a significant proportion of Trinidad's oil. Deposition of these formations record the progressive infilling of the basin, often reflected in the increasing sand content toward the top, (Barr and Saunders, 1965). This shallow-water deposition persisted into the Pliocene with only a minor disconformity.

The Lower Pliocene records the final infill phase of the Northern and Southern Basins. This period of deposition, which began in the Paleocene, finally ended during the mid-Pliocene Andean orogeny (Barr and Saunders, 1965). The Plio-Pleistocene sequence may be as thick as 30,000 feet in the Columbus Channel and southern Trinidad and was described in detail by Leonard (1983). During Pliocene to Pleistocene the Orinoco River advanced toward Trinidad and deposited a major thickness of sediments. The rapid sedimentation caused the formation of major growth faults and rollover anticlines in the Trinidad east coast area. The onset of Pliocene deposition is thought to be represented by the Cruse and Gros Morne Formations (Figure 3, Carr-Brown and Frampton, 1979). The Early Pliocene Moruga Group which includes the Lower, Middle, Upper Gros Morne and Mayaro Formations is the subject of this study.

The Gros Morne Formation forms the base of this sequence and is comprised of two coarsening upward sequences. The lowermost sequence represents the first influx of clastic sediment attributable to the proto-Orinoco delta (Leonard 1983). The middle Gros Morne is composed of gray silts and sands while the upper Gros Morne is composed predominantly of sand (Barr and Saunders, 1965).

The Mayaro Formation is composed predominantly of thick, clean, fine grained sands with interbedded silts and clays (Leonard, 1983). This formation marks the beginning of the third sedimentary sequence and is succeeded conformably by the Palmiste Clay Formation a sequence of medium to fine grained sands with occasional silt and clay.

The Palmiste Formation is unconformably succeeded by the Erin Formation which marks the onset of Pleistocene sedimentation. This formation is composed of medium to fine grained sands with interbedded clays.

Southern Caribbean Tectonic History

Trinidad lies at the southeastern edge of the Caribbean Plate (Figure 6) and the fact that no satisfactory explanation of the tectonic history of the Caribbean Plate exists attests to the complex tectonic history of the area. Trinidad and Tobago and surrounding areas provide a good record of the effects of interaction between the Caribbean, South American and North American plates. This section attempts to place the study area within the proper tectonic context and probably explain some of the factors governing sedimentation. The account presented here is based on a seven stage model of Freeland and Dietz (1971) and supplemented by additional references.

The tectonic history of the area begins with the opening of the proto-North Atlantic and the Gulf of Mexico in the Late Triassic as Pangea broke apart (Freeland and Dietz, 1971). The Gulf of Mexico opened with a rift-type margin along northern South America as Gondwanaland (South America and Africa) moved southeastward away from North America (Bertrand and Bertrand, 1985). Rifting was associated with some sinistral shear along northern South America (Freeland and Dietz, 1971). Eastward movement of the Bahama Block began during this time.

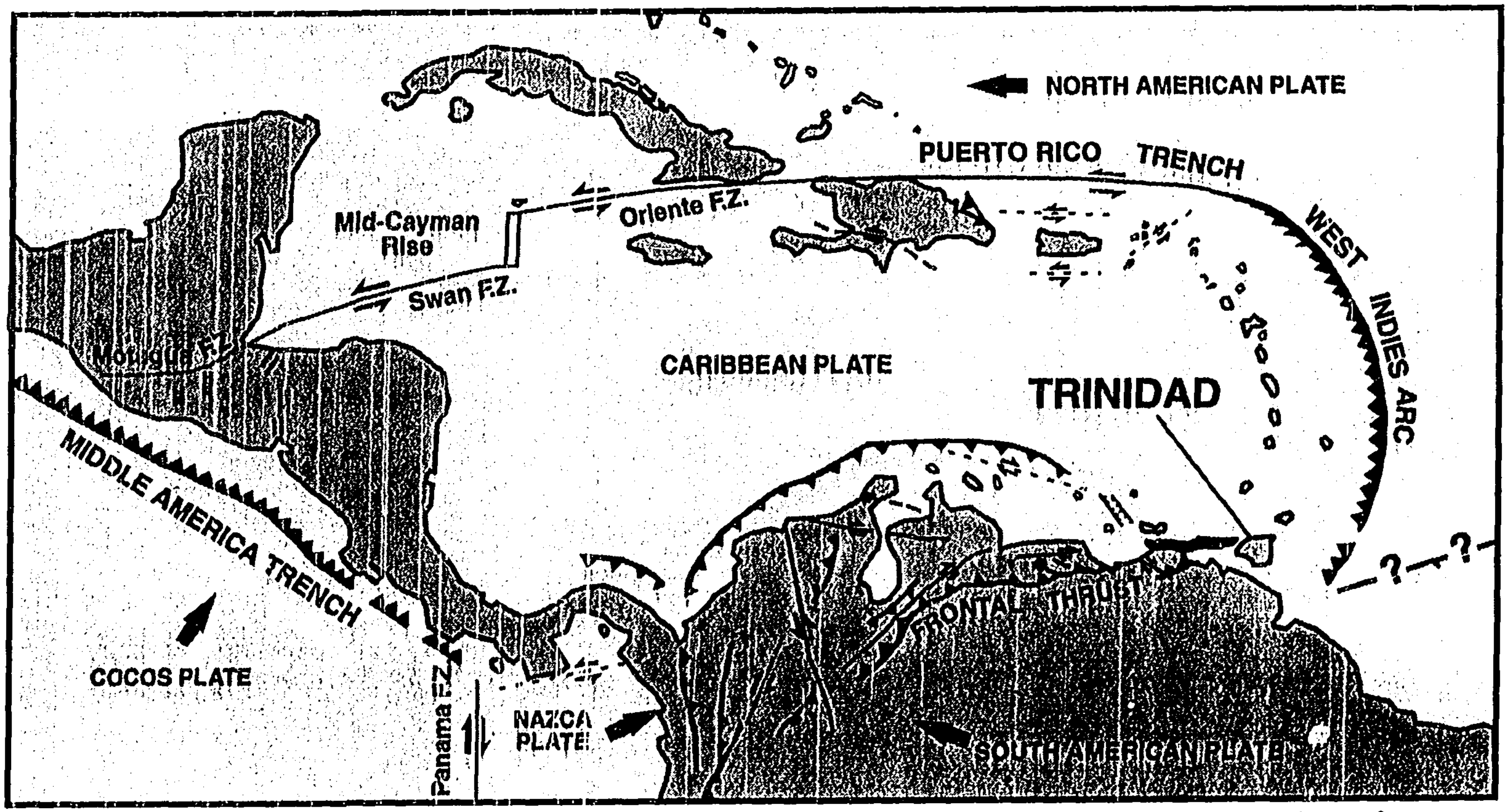


Figure 6. Plate Boundaries of the Caribbean Region, (Jordan, 1975)

During early Jurassic the south-westward movement of Laurasia was accommodated by sinistral shear along the Tethys seaway and the El Pilar fault zone of northern South America. Because the Gulf of Mexico, Caribbean Sea and North Atlantic Ocean were small ocean basins at this time with restricted circulation, deep-water evaporites were precipitated. These evaporites probably include those found in the Gulf of Paria, Trinidad (Persad, 1979).

The mid-Jurassic saw the continuation of salt deposition in the intracratonic ocean basins and left-lateral shear also continued along the Tethys and El Pilar zones. This period was also associated with some orogenesis and the Gautemalan foldbelt was formed. The positive areas formed became the sources of thick sequences of continental and marine sediments in Central America. This sedimentary wedge probably formed the nucleus of the Greater Antilles (Freeland and Dietz, 1971). The formation of the Gulf of Mexico was complete by this time.

During the early Cretaceous, as South America rifted away from Africa becoming a new plate, the North and South American Plates developed subduction zones along their western margins. Caribbean oceanic crust was formed during this period (Bertrand and Bertrand, 1985). The Caribbean Sea was opened (wider than it is today) as a result of northerly motion of North America relative to South America. During upper Late Early Cretaceous the South America Plate shifted to a more northerly location and associated with this was the cessation of strike-slip motion along the El pilar fault and the commencement of subduction, compression and orogeny along Northern Venezuela (Freeland and Dietz, 1971). By mid-Cretaceous the rate of sea floor spreading had increased dramatically (as the North

America Plate moved westward) and new spreading ridges such as the Aves Ridge were initiated (Bertrand and Bertrand, 1985). Cretaceous granodiorites dredged from the Aves Ridge suggest that this was a zone of active subduction (Walper, 1980). By latest Cretaceous time the thick Late Jurassic sequence deposited in northern Venezuela and Trinidad had been regionally metamorphosed and rapidly uplifted (Bell, 1972).

During the Paleocene, as South America moved southeast relative to North America, a period of divergent wrench tectonics occurred along the southern Caribbean boundary (Bertrand and Bertrand, 1985). Also during Late Cretaceous to Paleocene major uplift and normal faulting occurred in the southeast Caribbean, as subduction halted on the southern margin of the Caribbean Plate.

By the end of the Middle Eocene the Caribbean region had attained it's present configuration. Because North America drifted faster than South America, the Caribbean region closed slightly and the Caribbean Plate moved east (Freeland and Deitz, 1971; and Bertrand and Bertrand, 1985). This resulted in convergent right lateral wrench tectonics along the southern boundary of the Caribbean Plate, and initiated the ENE trending folds in Venezuela and Trinidad (Central Range) (Bertrand and Bertrand, 1985). Active subduction beneath the Lesser Antilles moved eastward to its modern position during Eocene time, possibly caused by the decrease in the North and Central Atlantic spreading rates (Larson and Pitman, 1972). During the Oligocene, changes between the North and South Atlantic Plates resulted in intensified convergent right-lateral wrench tectonism along the southern border of the Caribbean, which persisted until Late Miocene time (Larson and Pitman, 1972, and Bertrand and

Bertrand, 1985). Bassinger _et al_. (1971) suggest that wrench faulting might not have been as pronounced as suggested by other authors because there is no evidence for extensive translational movement. This suggestion is supported by Weeks _et al_. (1971), who, further suggest that the Pilar Block is a horst and graben structure and that the primary mode of movement on the El Pilar Fault was vertical with a small wrench component. Lau and Rajpaulsingh (1974) support the suggestion that the El Pilar Fault resulted from tensional stresses and is a normal fault. In their analysis the Los Bajos Fault was designated a right-lateral transcurrent fault.

Throughout the rest of the Cenozoic there was differential motion between the two American plates which are now separate entities separated by the Cayman-Puerto Rico megashear. The east-west plate boundary has therefore shifted from the northern margin of South America to the Cayman-Puerto Rican shear zone (Freeland and Dietz, 1971). Jordan (1975) indicates that present day movement of the Caribbean Plate is continuing at a rate of 2.1 cm/yr across the mid-Cayman rise.

Persad (1979) summarized the effects of the above outlined tectonic history and subdivided Trinidad into several structomorphologic units. He defines four uplift areas (the Tobago Uplift, the Northern Range Uplift, the Central Range Uplift and the Southern Range Uplift) and five sedimentary basin provinces (the West Tobago Basin, the Caroni Basin, the Southern Basin, the Columbus Shelf/Atlantic Delta Province, and a sediment starved Distal Shelf Area), (Figure 7). Lau and Rajpaulsingh (1974) discussed the forces that might have been responsible for the

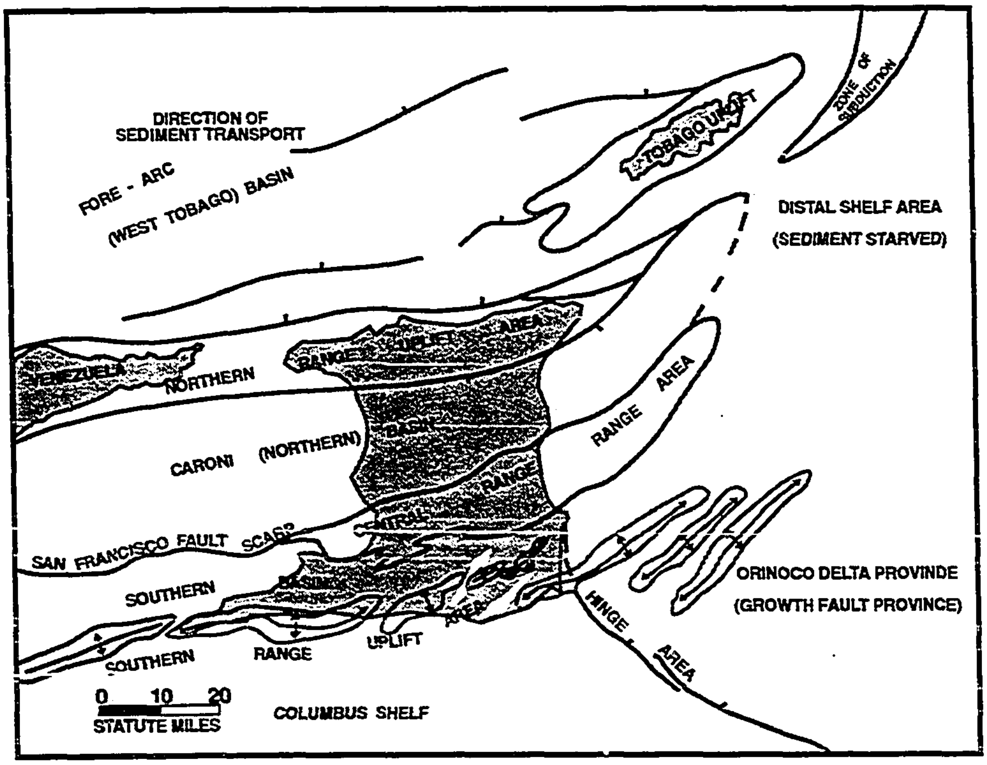


Figure 7. Structomorpholigic Units of Trinidad, (Persad, 1979)

structomorphologic features defined by Persad (1979). The El Pilar and Los Bajos faults which are important to their model have been linked to important structural features in Venezuela (See Table 1).

Previous Investigations

This section summarizes the previous work on the Miocene to Pleistocene sedimentary sequence in southern Trinidad.

Kugler (1953) has produced the most referenced and detailed document on Trinidad's geology. Since then modifications have been made (see Figure 8), but no publication has come close to his in terms of detail. Naturally it is important to discuss his thoughts elaborately as they formed the basis for subsequent publications on Trinidad's geology. A geological map produced by Kugler (1953) and updated in 1961 is still the only modern geological map available.

Kugler (1953) placed the transgressive Lengua Formation at the base of the Miocene sharing an unconformable relationship with the lower beds. Kugler speculated that the mud diapirism common in some parts of southern Trinidad was a direct result of incompetence associated with the Rio Claro Boulder Bed (the basal unit of this formation). He discussed the close relationship shared by the Lower Cruse with the Lengua Formation and presented evidence for turbid, cool, deep water deposition, though he indicates that the Lengua represents a shallower water lithology. The Middle and Upper Cruse sands are said to be the result of foredeep deposition and are major oil producers. Kugler maps the Moruga Molasse succeeding the Cruse and being 3000 meters

	Stress Type	Principal Stress Direction	Time	Major Resulting Structure
1.	Compressional	174°	Prt. Cret. - Lr. Tertiary	Northern Range Uplift
2.	Tensional	178°	Miocene - Recent	El Pilar Fault
3.	Compressional	154°	Miocene - Recent	Naparima - Nariva Thrust, Los Bajos Fault

After Lau and Rajpaulsingh (1975)

Table 1. Summary of Stress-Structure-Time Relationship

thick. The Manzanilla Formation of later authors was referred to as the Brasso Formation and the glauconitic Montserrat Sand Member was regarded as the equivalent of the Brasso conglomerate. Later authors have included the Montserrat Glauconitic Sand into the Manzanilla Formation.

Kugler then reported the Forest Formation as being succeeded by the Upper Brasso and Springvale Formation, of Middle to Upper Miocene age. He placed the Telemague Sand Member at the beginning of the Springvale. In the Northern Range Kugler reports an unconformable relationship between the Melajo Clay (of the Springvale Formation) and the Mesozoic phyllites.

This landmark publication explains the inability to separate the Upper Miocene from the Pliocene on account of the non-diagnostic faunas. Kugler, despite this difficulty assigns the Morne L'Efer as the end of the Miocene, and he highlights the resemblance of this formation to the Moruga Formation. The Miocene rocks were then folded during the Pliocene orogeny and capped by the Upper Pliocene Matura Formation.

According to Kugler the most significant event of the pleistocene was the opening of the Gulf of Paria.

Barr et al. (1955) presented an outline of Trinidad's stratigraphy similar to that presented by Kugler (1953). The discussion in this publication focused on the mode of oil occurrence. The major oil occurrences are reported to be associated with multiple sand reservoirs. This publication presents good descriptions of the Miocene formations; however the main concern is discussion of the distribution of sand bodies and trap types throughout the Miocene.

Ablewhite and Higgins (1965) reviewed the general structure and stratigraphy of Trinidad with their primary focus being the distribution of sandy reservoirs through the Miocene. This paper documents the lenticular geometry of the producing sands and the combined structural-stratigraphic mechanisms responsible for the oil accumulations.

Barr and Saunders (1965) presented a detailed outline of Trinidad's stratigraphy. In the context of the present study an important contribution of this publication is the stratigraphic summary which presents the Moruga Group in the Mid-to Upper Miocene (Figure 4). It is, however, not very clear why a Miocene assignment is made except that the Nariva and Lower Cipero formations were assigned to the lowest Miocene based on foraminiferal assemblages.

Metz (1965) worked in northern Venezuela and his investigation of the El Pilar Fault zone led to the conclusion that the strike-slip displacement was not as extensive as thought (10-15 km), but probably less than 5 km. Metz does not believe that the El Pilar Fault of northern Trinidad is related to the Venezuelan El Pilar Fault system.

Lau and Rajpaulsingh (1974) suggested that Trinidad was affected by three distinct stress systems from Cretaceous to present. Their findings are summarized and discussed in the previous section (see Table 1). This contribution based on an analysis of the structural features of Kugler's map has arrived at some interesting conclusions.

Michelson (1972) suggested that the proto-Orinoco delta prograded over the Trinidad area in Miocene times depositing the major oil producing sands of southern Trinidad (Figure 8). This once highly respected document on Trinidad's stratigraphy was based on sandstone thickness maps and limited paleontologic data. Subsequent paleontology, palynology and stratigraphic analyses refutes his stratigraphic summary (Figure 8).

Carr-Brown and Frampton (1979) made a sound contribution based on extensive oil company research. These authors placed the Moruga Group within the Early Pliocene thus refuting the earlier Miocene interpretation.

The Columbus Basin was the focus of Leonard's (1983) study which discussed the stratigraphy and hydrocarbon accumulations in offshore Trinidad. A relationship was discussed between thick Pleistocene sand deposits and low geothermal gradients which rendered the Pliocene sediments immature with respect to hydrocarbon generation. Leonard suggested that thicker Pleistocene sandstone sequences are more conductive and this leads to greater heat loss and lower thermal stress on the underlying buried rocks.

Frampton (1988) made some important statements concerning reworked sediments and fossil remains and poor correlations, while attempting to explain some of the problems encountered while using foraminifera in defining Trinidad's stratigraphic boundaries.

More recently the term Moruga Group has been applied to the suite of rocks which range from Lower Gros Morne to the Mayaro/Palmiste

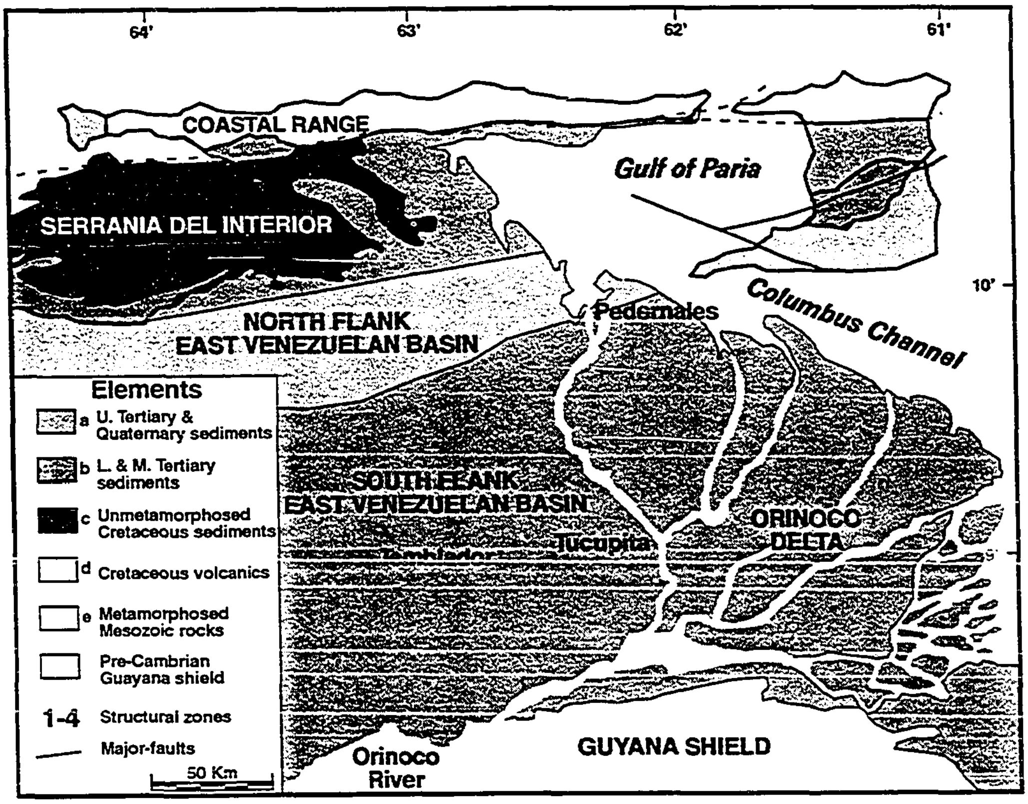


Figure 8. Trinidad: It's Relationship to the Orinoco Delta and Guyana Shield (Modified after Michelson, 1972)

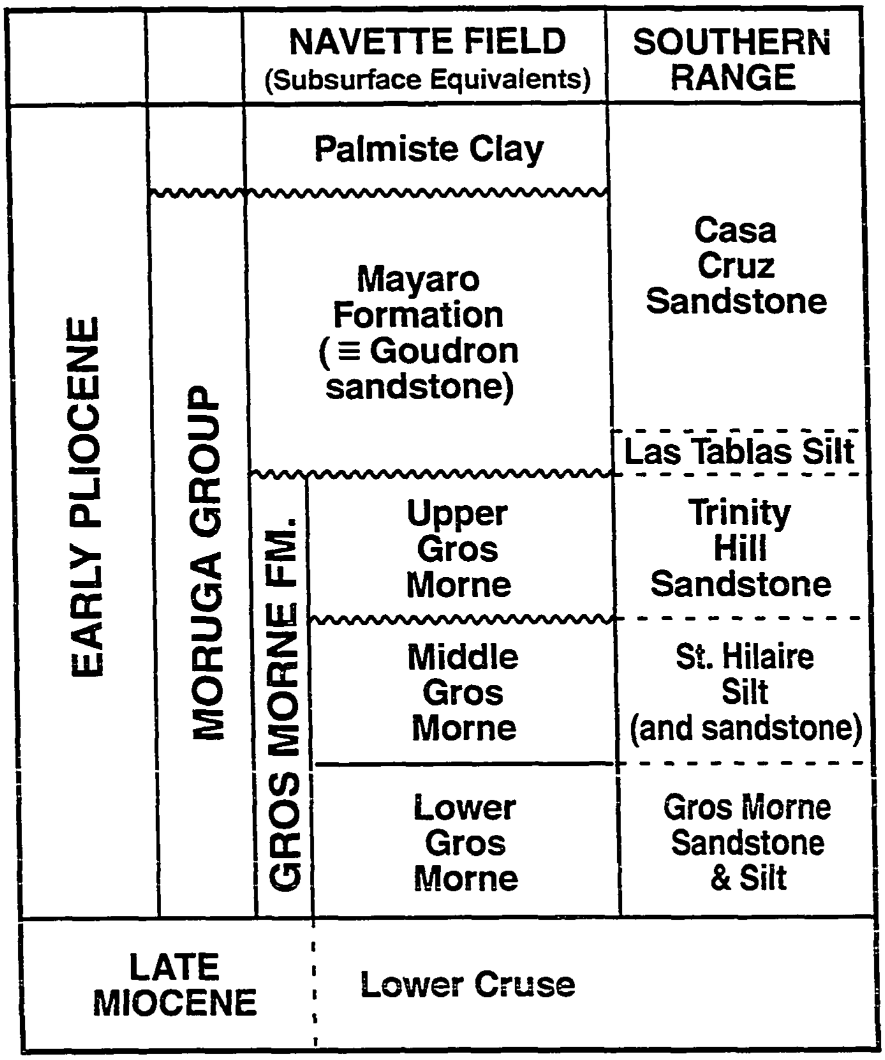
unconformity (Gene Rohr, pers. comm. 1988, Carr-Brown, pers. comm. 1989). Carr-Brown (ibid) has provided the accompanying zonation of this Early Pliocene sequence (Figure 9). Carr-Brown's interpretation is based on the paleontological and stratigraphic associations in subsurface and outcrop. Carr-Brown's study is used to place the sediments in this study into their proper stratigraphic perspective. All discussions based on the ages of the rocks studied have their roots in his interpretation.

It is important to note that adherence to the North American Stratigraphic Code (1983) is lacking in the stratigraphic nomenclature in Trinidad. There has been no coherent and consistent ranking of the litho-stratigraphic units encountered and this resulted in improper assignment of the various lithostratigraphic terms (eg. formation) in the subdivision of Trinidad's stratigraphy. Such a study is, however, beyond the scope of the present dissertation.

Methodology

Stratigraphic Analysis

The measured section of the Moruga Group is located along the south coast of Trinidad. More than 1600 meters of section were measured and described. Investigations began behind the Amoco installation at Galeota Point and ended on the coast of the fishing and agricultural village of La Lune.



(after B. Carr-Brown, pers.comm. 1988)

Figure 9. The Miocene-Pliocene Stratigraphy of Southern Trinidad

Field work was conducted using geological procedures outlined in contemporary textbooks Compton (1962), Kottlowski (1965), Barnes (1982)and Tucker (1982). The initial phase of these investigations involved a reconnaissance of the outcrop area in May, 1989, followed by a detailed description, which was completed in June, 1989. During the detailed mapping phase the vertical (stratigraphic) section was measured across strike (in the direction of dip) and care was taken to avoid repetition of section at various points along the coastline. The following instruments were utilized during measurement of the stratigraphic section: Jacob staff, Abney level, two Brunton compasses, hammer, chisel, hundred foot measuring tape, geologic scale for photography and a "dipdicator". 10% HCL and mineral oil was used to assist in sample description and characterization.

Sedimentary structures observed were photographed and described. Observations of the vertical and lateral variations of grainsizes, bed thicknesses and sand/shale ratios were made. Lateral outcrop continuity was severely limited in some areas and deep weathering sometimes made observation and description difficult. Bedding thicknesses were observed, measured and described using the following adjectives:

Thinly bedded - 30 cm

Medium bedded - 31 cm to 75 cm

Thickly bedded - 75 cm

During reconnaissance it was thought that these bedding terms and measurements best represented the spread of bed thicknesses encountered.

The data collected was then carefully examined upon returning to Cincinnati.

The stratigraphy of this area is a topic of intense debate. It was outside the scope of this study to divide the units using stratigraphic nomenclature (eg. formation names). One of the problems with the present stratigraphic divisions in southern Trinidad is the similarity in appearance of major horizons. This was indeed a problem along the south coast and necessitates a separate study using all the tools and techniques available to modern stratigraphic analysis. Since the present study is mainly concerned with interpreting depositional environments it was thought to be far more important to obtain a good vertical section than to focus on generalized field mapping and stratigraphy.

Petrology and Provenance

Throughout the study, care was taken to collect oriented samples wherever possible, so that thin sections for petrographic analysis were always cut perpendicular to bedding. A blue colored dye was added to epoxy resin for impregnation, to define porosity and preserve grain boundaries. One half of each thin section was stained for feldspars. The slides were examined using plane and polarized light, described and point counted. Twenty-eight thin-sections were studied.

Modal analyses were undertaken following the methods of Chayes (1956) and Griffiths (1967). The theory has since been refined and reapplied by Dickinson, (1970), Graham, et al. (1976), Dickinson and Suczek (1979) and Dickinson et al. (1983). The goal in this form of modal analysis is to identify the effects of all post-depositional processes and thus reconstitute the original sandstone composition so that accurate interpretations of sandstone source terrains may be made.

The samples were carefully chosen for modal analyses. Samples that were the least affected by weathering and those of a grainsize that best allowed for easy grain recognition were preferred. Sample selection spanned the length (thickness) of the sequence measured.

On the average six hundred and fifty (650) points per thin section were counted, on a 1 mm grid using a mechanical stage. Twenty eight thin sections were point counted. This number of counts ensures that counting errors for grain parameters are very likely much less than five percent (5%) of the whole rock for individual counts (van der plas and Tobi, 1965). The criteria used for distinguishing grain types, matrix and other components are those of Griffiths (1967), Dickinson (1970) and Graham et al. (1976). Standard textbooks on optical mineralogy were also consulted (eg. Kerr, 1977).

To better characterize the cements a mixture of Alizarin Red S in potassium ferricyanide was used. This stain renders calcite red, Fe-rich calcite purple and Fe-rich dolomite blue. In addition twelve outcrop samples were analyzed by XRD to better determine the composition of the cement. Two samples of cuttings were also analyzed by XRD and showed no carbonates due to low abundances of carbonate cement.

Monocrystalline grains larger than grains of very fine sand (.0625 mm) that occur within lithic fragments are counted as discrete quartz (Q) and feldspar (F) rather than rock fragments, since monocrystalline quartz and feldspar grains are contributed to the sediment by erosion and disintegration of such fragments (Dickinson, 1970).

Because the primary concern is with framework mineralogy the compositions were recalculated to one hundred percent (100%) neglecting minor constituents: those not included in the diagnostic provenance schemes of Dickinson and Suczeck (1979) and Dickinson et al. (1983). The raw point count data are presented in Appendix 1 (a) and the recalculated data are given in Appendix 1 (b). The recalculated data were then plotted onto the three ternary diagrams of Dickinson and Suczeck (1979) and two ternary diagrams of Dickinson et al. (1983). The meanings of the various characters in the ternary diagrams are given in Table 2.

SEM and XRD Study

Nine samples were examined and photographed using a Scanning Electron Microscope fitted with a KVEX elemental analyzer. Photographs were taken of the highly magnified images with special emphasis on clay minerals and authigenic overgrowths within pore spaces.

Heavy Minerals

Between 400 and 500 grams of five outcrop samples were placed in 10% hydrochloric acid for approximately three weeks to be disaggregated, so that determinations of the heavy mineral content of the sandstones could be made. The samples were not fully disaggregated; however, enough material was obtained to be used in these analyses. The disaggregated samples were washed in distilled water and acetone, then dried. Separation was effected using a Buchner Funnel and bromoform. The heavy minerals were then washed, dried and mounted at 120°C in Alo-Clor a thermal setting epoxy which has a refractive index of 1.677. Acceptable mounts of four heavy mineral suites were obtained. The grain mounts were examined, grains identified and point counted.

The ZTR index was calculated for each of the four samples on which heavy mineral analyses were done. This calculation was done by summing the number of grains of zircon, tourmaline and rutile and using them as a percentage of the total number of heavy mineral grains minus micas and authigenic minerals.

Palynology and Micropaleontology

Twenty-four sidewall cores (1550-12, 500 feet) and twelve cutting samples (860-15, 230 feet) from the Amoco West SEG-1 well, offshore Trinidad and nineteen outcrop samples from the south coast stratigraphic section, were analyzed for palynologic content.

The flora recovered were detailed in eight plates and presented as a photographic checklist.

During the identification of the palynomorphs the levels of carbonization were also noted and these data are presented.

Acknowledgements

The completion of this study dictates that I express my gratitude to many persons and organizations for their support - spiritual, intellectual and financial. I am indebted to the faculty of the Department of Geology at the University of Cincinnati for the friendly and cordial atmosphere within which tremendous learning took place. I have certainly benefitted from this atmosphere.

Special thanks must go to my advisors Professors Pryor, Huff and Maynard for the tangibles and intangibles, their guidance, motivation and support. Professor Pryor shared his great stratigraphic/sedimentologic and field experience with me both in the field and classroom. Professor Huff always offered ideas on clay mineralogy and diagenesis and professor Maynard was always of assistance in discussing geochemical ideas. My introduction to the Department of Geology and the University of Cincinnati was through Professor Paul Potter. Wanda Osborne has always been supportive and helpful in her own unique way!

My colleagues at the Geology Department provided sounding boards for my ideas refining them in the process. Thanks to Dan Petersen and Rich Terry for computing assistance, Kevin Savage for assistance with heavy mineral separates and Kenan Cetin for our many discussions of clay mineralogy.

Financial and logistic support was provided by Amoco Production Company and Amoco Trinidad Oil Company Limited, MOBIL New Exploration

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Individuals who assisted tremendously within these organizations were Shaffie Ali (Amoco Trinidad), Scott Urban (Amoco Production - thanks a million, Scott), the Trinidad Geophysical Staff, Brenda Claxton, Rick Tobin, Will Dorsey, John Farrelly (Amoco Production) and Tom Edwards (Amoco Research). Tim Tvrdik, Glen Pense and Tom Edwards of MNEV. Andrew Lamy generously contributed his vast knowledge and expertise with Trinidadian palynology and Rick Flugeman assisted with micropalaeontology.

The Lee Sing household, Sister Evangelista and the people of Moruga village were very hospitable during fieldwork. To the many fishermen who went off course to take me into perilous waters in the "wee" hours of the morning for field work, for the fishing lessons and for sharing their life philosophies - the experience was great!

As usual my family has been quite supportive and they have taught me the lessons necessary to succeed. I thank them for their moral support and the cultivation of my spirited drive.

Musical inspiration was provided by the late Robert "Bob" Nestor Marley and singer "Mighty Sparrow" Francisco.

"Thanks A Billion To All."

DESCRIPTIVE STRATIGRAPHY

Introduction: The Moruga Group; South Coast Trinidad

The clastic rocks which crop out along the southern Trinidad coastline are mainly fine grained sandstones with interbedded siltstones and mudstones of the Early pliocene Moruga Group. They outcrop along the coast in a coarsening and thickening upward vertical section at least 1,600 meters thick. Sandstones constitute approximately 50-55% of the section. The sandstones are poorly to moderately sorted and composed of sands which range from lower medium grained (250-350 microns) to lower very fine grained (52-88 microns). The most commonly found sedimentary structures are graded beds, plane parallel lamination, very low angle cross beds, ripples and ripple lamination, convolute lamination, convolute bedding, synsedimentary ptygmatic folds, small scale parallel lamination, load casts, flutes, grooves, striations, ball and pillow structures, and amalgamated beds.

Siltstones are also very common and often occur as a transitional phase from beds of sandstones to mudstones. They also occur as discrete beds of siltstone which grade upward into mudstones. Silts constitute approximately 20-25% of the measured section of the Moruga Group.

Mudstones are often capping the siltstone and sandstone beds and constitute about 20-25% of the measured section. In thin section mud also occurs as matrix. Mud is also encountered as "ripped-up clasts" within sandstone beds. The coverall mud content (especially interbedded mudstone) decreases upward over the length of the measured section.

Description of the Measured Section

The section described is presented in detail as Appendix A; however, a partially interpreted, summary section is included as Figure 10.

The base of the section began behind the Amoco plant at Galeota point in the fine grained sands, silts and mudstones of the St. Hillaire Silt (the Southern Range equivalent of the middle Gros Morne Formation). Here the sequence is comprised of interbedded dusky yellow to light olive sandstones and siltstones and shales which range in color from light olive to blackish gray. The dips are toward the southwest at approximately 60°. These dips become steeper up section and may be as high as 84°. The sandstones generally have flat, sharp often scoured bases, sometimes marked by flute casts, grooves and striations. Individual sandstone bed thicknesses range from 2 to 80 centimeters and they grade upward into siltstones and mudstones. Thin sandstone (1.5 to 5 centimeters), siltstone and mudstone beds were often observed interbedded as triplets. The individual sandstone beds are graded, poor to moderately sorted and comprised of very fine sand with a muddy matrix.

Petrographic studies show that the matrix also includes some crushed glauconitic pellets. The sandstone/mudstone ratio in this section is approximately 5/1. The most common sedimentary structure developed in the siltstones was plane parallel lamination, though some ripples were sometimes observed. Mudstones commonly showed ripples, convolute and ripple lamination.

KEY TO ABBREVIATIONS IN FIGURE 10.

DLSW - Down Lap Surface Wedge

PLSW - Prograding Lowstand Wedge

TST - Transgressive Systems Tract

DLS - Downlap Surfaces

LSW - Lowstand (prograding) Wedge

tsfs - top slope fan surface

FI - Facies I

FII - Facies II

FIII - Facies III

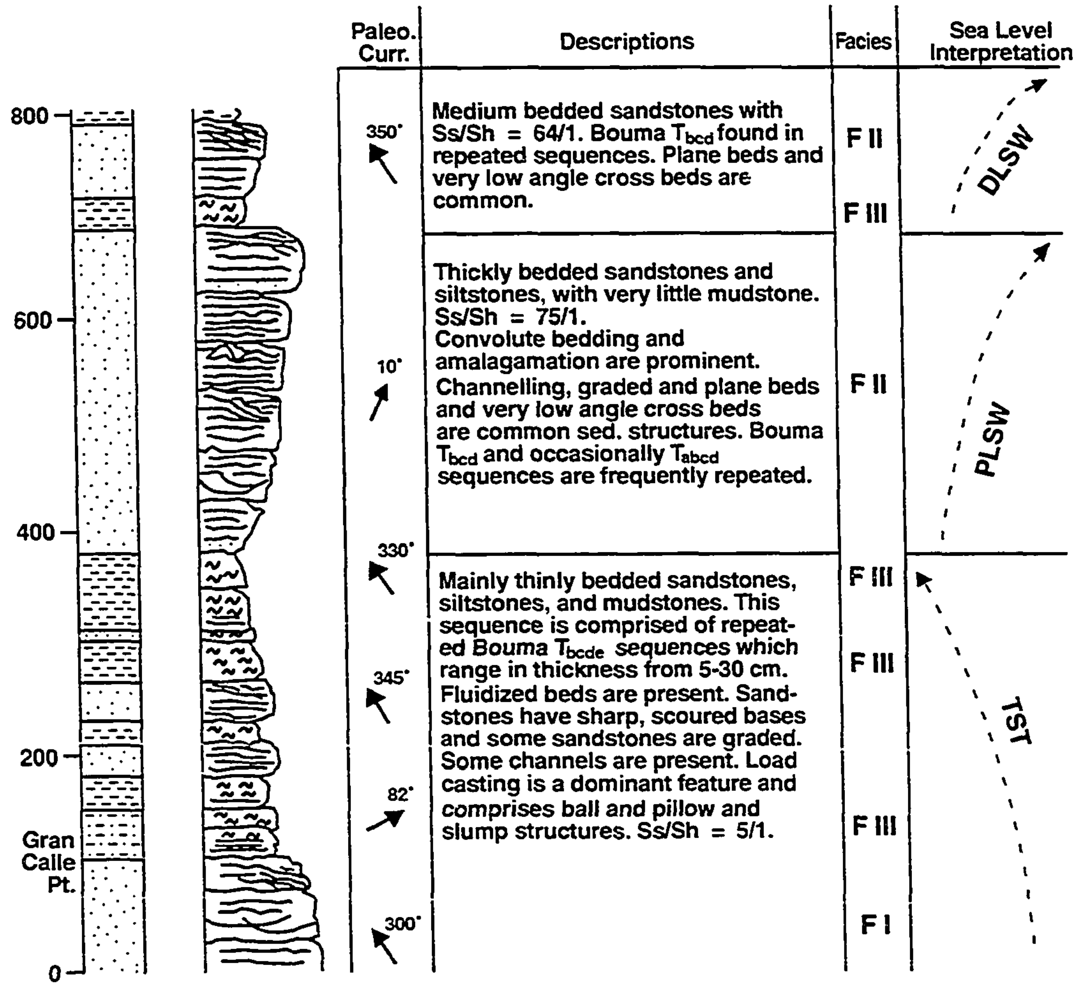


Figure 10. Summarized Measured Section, South Coast, Trinidad.

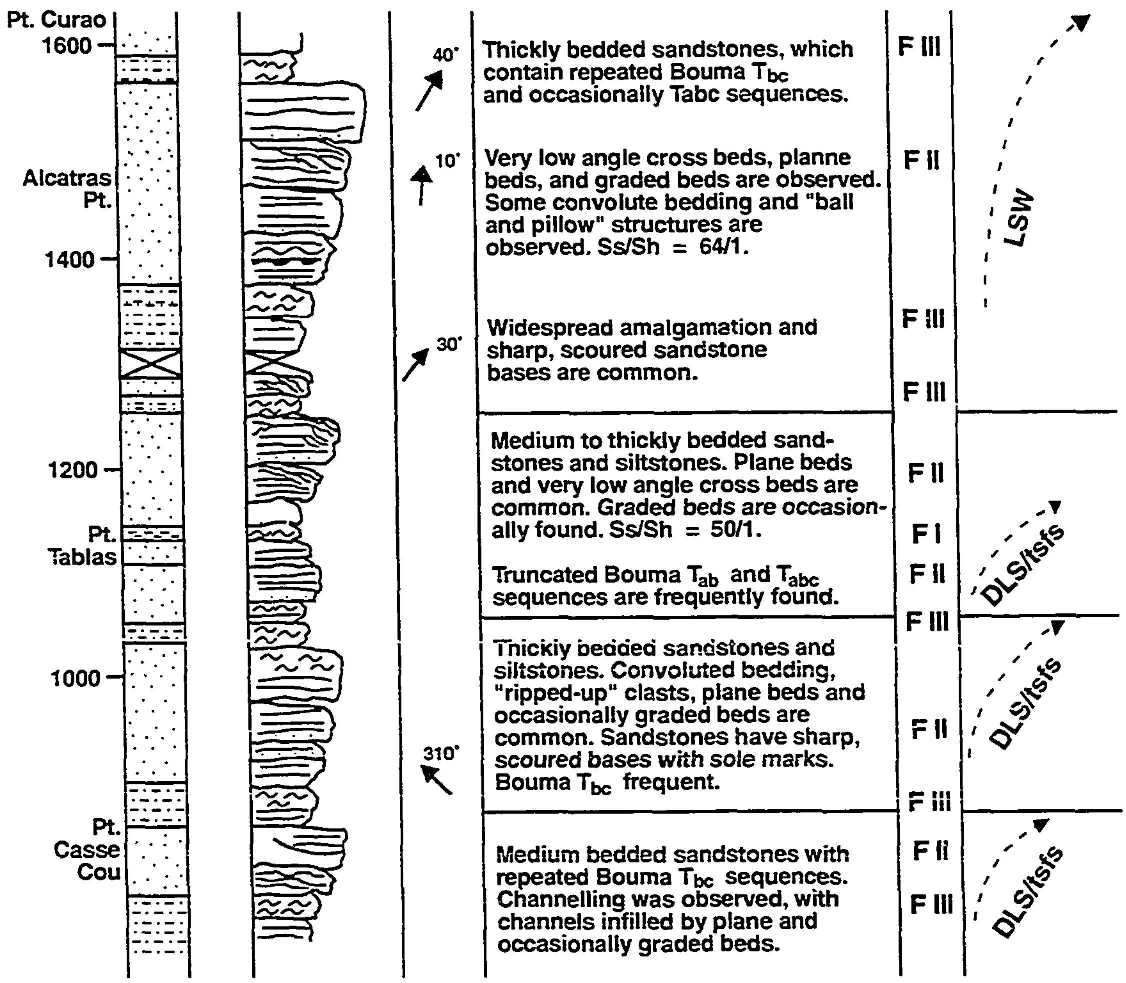


Figure 10. (cont'd)

Some of the more striking features observed at this outcrop include chaotic beds, channel scours and contorted bedding. These features together with some characteristic primary sedimentary structures, and the overall sand-shale ratio have led to this outcrop being included as part of Facies I which is described later in this chapter.

The chaotic beds are typically composed of broken pieces of fine grained sandstone and siltstone beds in a matrix of very fine sand. One very prominent bed of this nature was measured as being 1.7 meters thick (Figures 11 and 12). This feature is indicative of the fact that the thin sandstone beds were broken up soon after deposition and moved downslope as part of a larger flow unit. The chaotic beds also show a close affinity with convolute laminae and some poorly developed ball and pillow structures.

A very prominent channel feature was observed. This channel fill was a low amplitude, broad feature, approximately 1.8 meters deep, with a sharp erosional base and low angle cross beds (Figure 13). The very fine to fine grained sandstone infilling this channel is graded and poorly sorted showing plane parallel lamination, with a thin cap of rippled mudstone. Immediately following this channel two less prominent and smaller channels were observed with the same features.

Some contorted bedding was observed. These beds, comprised of fine sand show plane laminations at the bases and evidence of grading before breaking into numerous contortions on the upper surface. Contorted beds may be as thick as 0.6 meters (Figure 14).

Figure 11 - Chaotic bedding composed of broken beds of fine grained sandstones in a siltstone and mudstone matrix. This bed is located near Gran Calle Point.

Figure 12 - A close-up view of the above bed, illustrating internal lamination in broken sandstone beds.

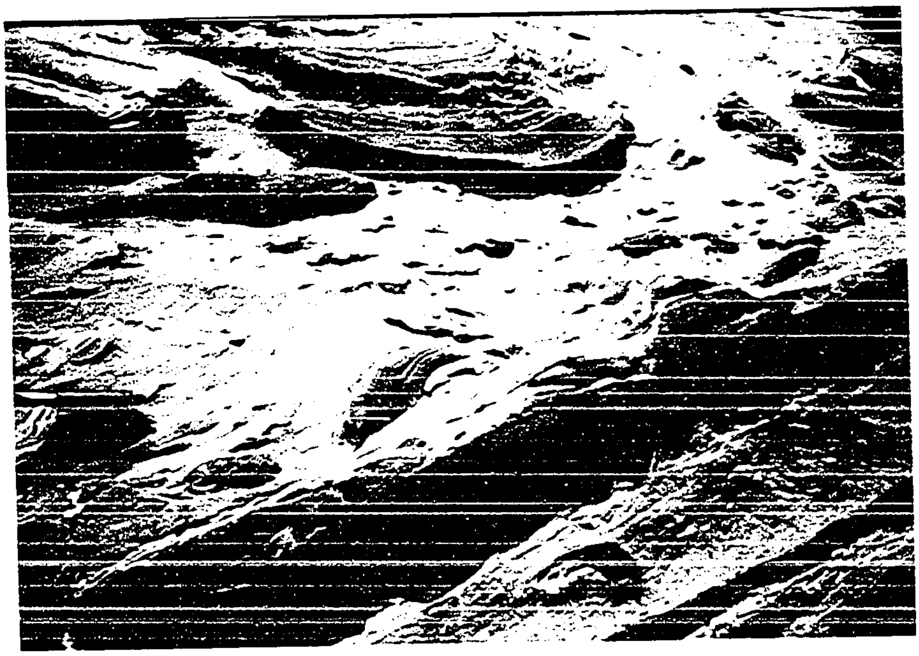
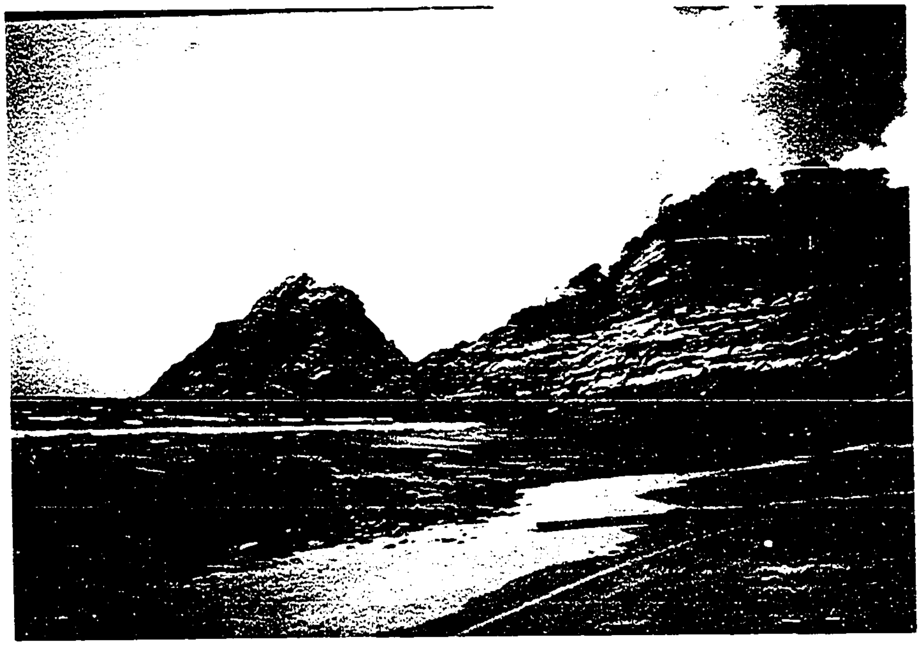
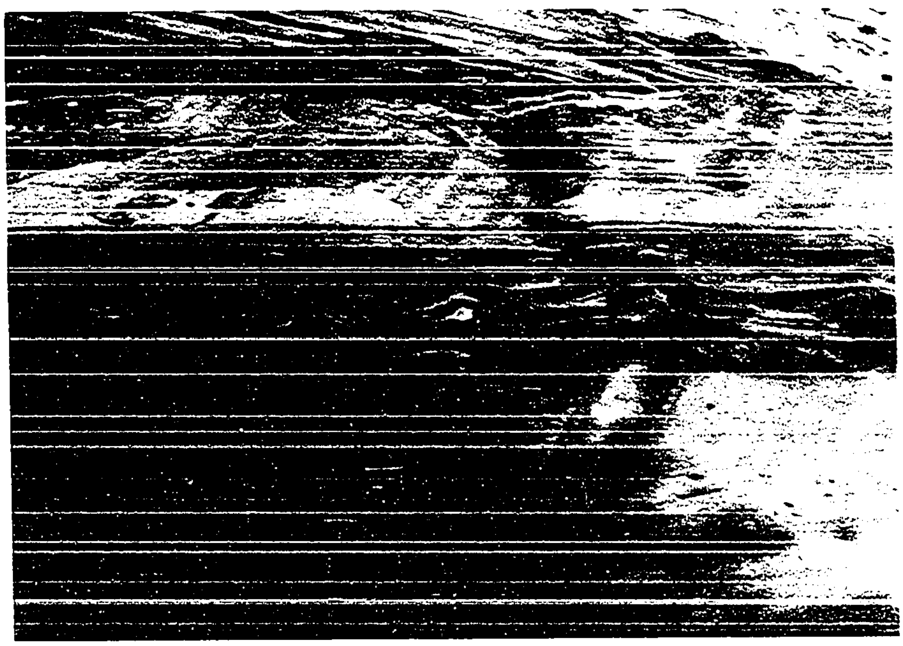


Figure 13 - Broad channel infilled by graded and poorly sorted fine grained sandstone. Channel feature located at the extreme tip of Galeota Point.

Figure 14 - Contorted bedding. This bed is approximately 35 centimeters thick and located west of Gran Calle Point.





Paleocurrent measurements were taken from assymetrical ripples at this section and they indicated variable flow directions which ranged from 320° to 42°. Paleoflow was generally in a northerly direction.

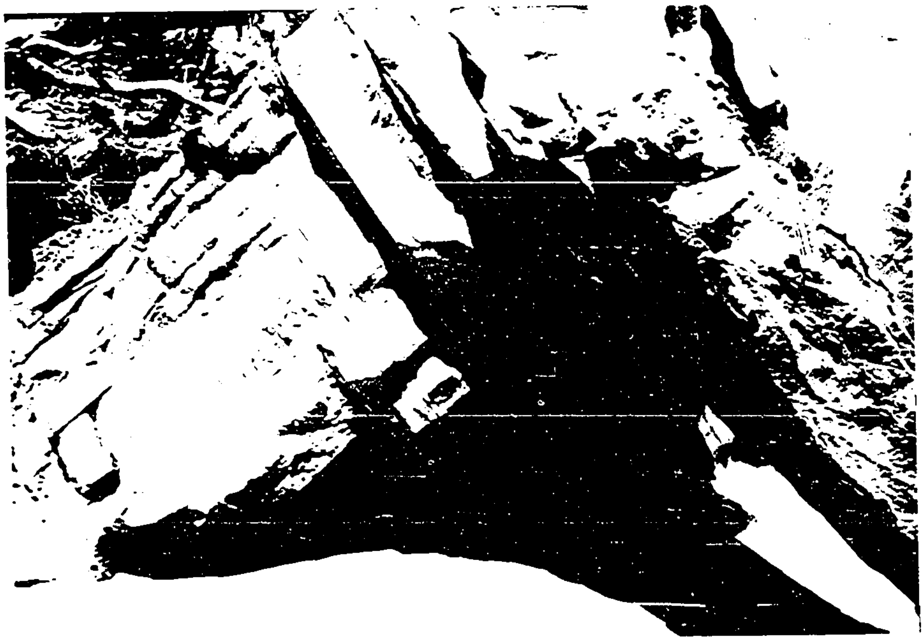
The measured section changed character about one mile west of Gran Calle point beyond which the two most obvious changes were (a) and drastic increase in the sand/shale ratio, and (b) a major increase in bed thicknesses and a slight increase in grain size as more medium and fine medium grained sandstones are observed. At Gran Calle point a very prominent synsedimentary ptygmatic fold (Figure 16) was observed and measured. This fold was found sandwiched between normally undeformed beds and the crest was approximately 2.9 meters high.

Beyond this point the sand/shale ratio increased to greater than 60/1 and at times as great as 75/1, for example at Canari point where almost no mudstone was present. Average sand/shale ratio for the rest of the measured section is approximately 40/1. Bed thicknesses show a marked increase and there is a greater amount of medium grained sandstone in the grainsize range 250-350 microns. Siltstone is the other prominent lithology. Sandstone beds range in thickness from 10 centimeters to 14.1 meters.

At Gran Calle Point the sequence is thickly bedded with beds up to 4.4 meters thick (Figure 15). These beds are composed of fine to medium grained sandstones. There is also a markedly large amount sandstone beds which contain very low angle cross beds. The very low angle cross beds are prominent in beds comprised of sandstone which range in grainsize

Figure 15 - Thickly bedded medium to fine grained sandstone bed at Gran Calle Point. This bed is 4.4 meters thick and contains pebbles and two exotic boulders of mudstone.

Figure 16 - Distorted core of a prominent ptygmatic fold at Gran Calle Point.



from 177-350 microns. These beds are succeeded by parallel laminated and rippled,very fine grained sandstone. Convolute beds are also present. These beds are approximately 25 centimeters thick and are observed to lie between beds which are otherwise laterally continuous and undisturbed.

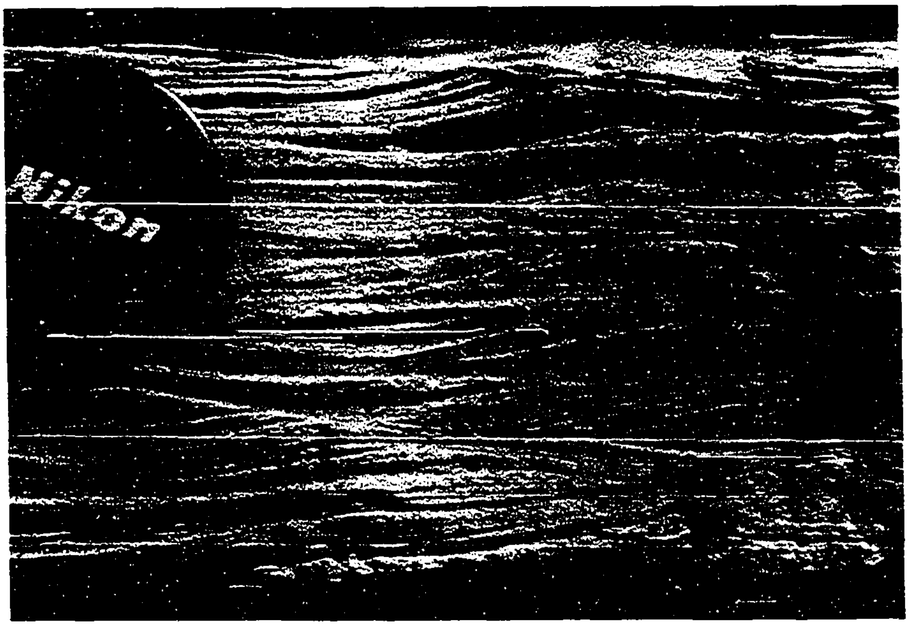
Approximately 500 meters before Point Casse Cou there are some well exposed bioturbated, thinly bedded sandstone, siltstone and mudstone with Cruziana and Skolithos trails and burrows. These beds are sandwiched between otherwise medium to thickly bedded very fine grained sandstones which were dominated by Bouma T_{ab} facies. These beds are moderately well sorted and contained "ripped-up" clasts of mudstones and siltstones.

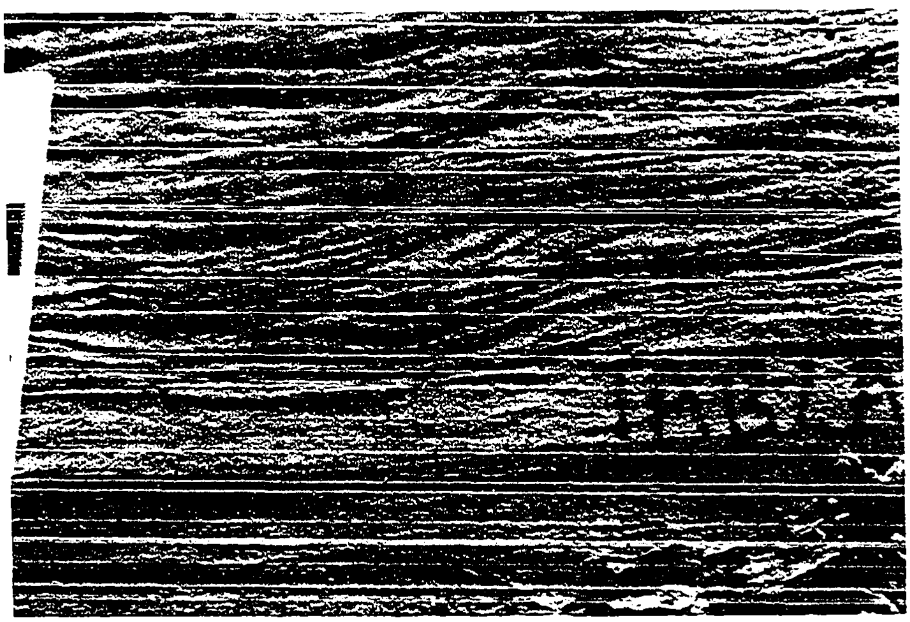
At point Casse Cou medium to thickly bedded sandstone beds were observed. These beds have sharp bases and are graded. Graded beds are followed by beds of plane parallel lamination and minor ripples. These beds also contain clasts of mudstone. Paleocurrent measurements indicate a current flowing 20° toward the northeast.

At Point Petit Casse Cou there are well exposed beds which demonstrate very low angle cross beds. These beds are thickly bedded (up to 2.1 meters thick), Figure 17. They generally succeed graded beds. Paleocurrent measurements indicate a current flow toward 40° northeast. Some package of thinly bedded sandstone, siltstone and mudstone were observed. These packages are strongly rippled. Convolute ripples are also present.

Figure 17 - Very low angle cross beds (HCS) developed in a fine grained sandstone bed at Point Petit Casse Cou.

Figure 18 - Very low angle cross beds in a fine grained sandstone bed at Point Tablas.



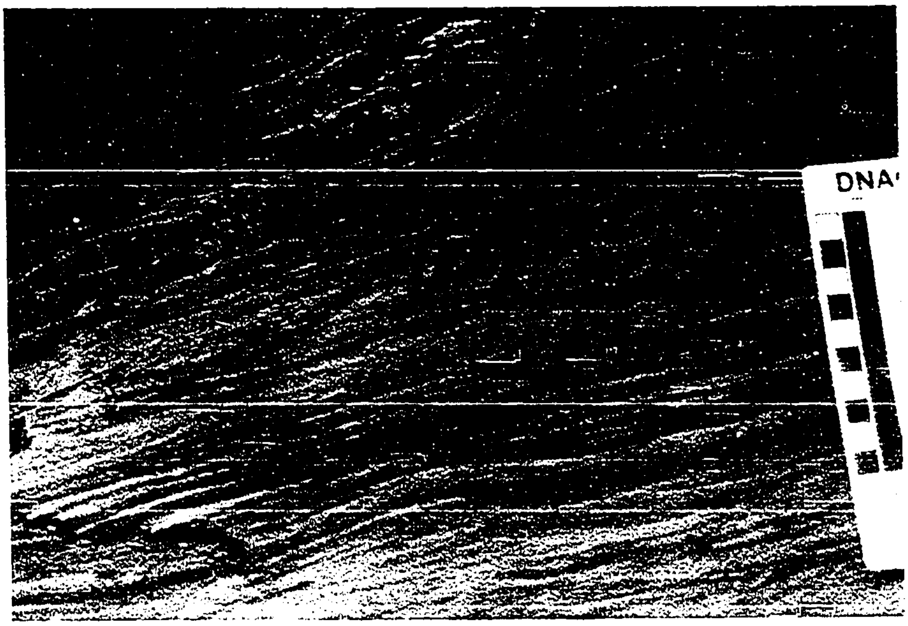


This style of bedding - medium to thickly bedded sandstones, which are graded and also contain plane parallel lamination and very low angle cross beds, (Figure 18), with occasional packages of thinly bedded rippled (Figure 19) and convolutely laminated sandstone, siltstone and mudstone continued up section to Point Tablas. At Point Tablas two very low amplitude channels were observed. These are infilled by graded sands which range in grainsizes between 125 to 300 microns. These channels are very broad structures with sharp bases which cut down into beds of fine grained sands and silts.

At Point Tablas, paleocurrents measured were obtained from ripples in sand and siltstone and indicate a current flow of 40° toward the norteast. Sandstone beds also contain lenses of "ripped-up" clasts of siltstone and mudstone and have bases ornamented with load casts and basal striations. At this location there are also some hardened oil seeps which left a tar like substance. Sulfur is closely associated with this hardened and degraded oil. Interbedded with the fine grained sandstones and siltstones was a large amount of plant debris, Figure 21. This plant material is clearly reworked and is found along laminae and infilling the troughs of the well exposed ripple forms. The most prominent sedimentary structures present here are climbing ripples. These ripples range from 10 to 16 centimeters in length and 2 to 6 centimeters in height. They have steep lee sides and and gentle stoss sides. Most of these ripples appear to be in phase and the internal foreset laminae dip predominantly in one direction. Very low angle cross beds were observed to be overlain by these wave forms. Triplets of very fine grained sandstone, siltstone and mudstone were found within this section.

Figure 19 - Current ripples and low angle cross beds developed in a fine grained sandstone bed at Point Tablas.

Figure 20 - Well developed plane bedding at Point Tablas.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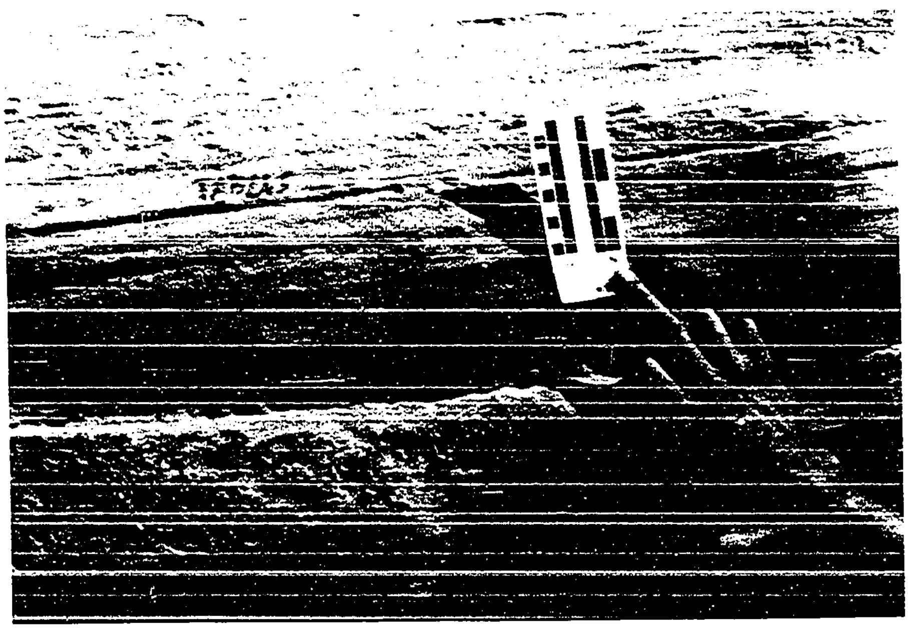

These triplets are grouped into packets which range in thickness from 2 to 6 meters.

This section from Pt. Tablas to Canari Point is composed mainly of medium bedded, medium to fine grained, laterally continuous sandstones. Grain sizes range from 125 to 250 microns. Graded beds, plane parallel lamination (Figure 20), very low angle cross beds and ripple structures are arranged in numerous repetitive Bouma cycles. Some climbing ripples were also found. Amalgamated bedding was observed (Figure 22). Beds have sharp, often ornamented bases (load casts and striations) and contain "ripped-up" mudstone clasts. Convolute bedding and "ball and pillow" structures are also present. There was a strong scent of sulphur over the length of this section.

These medium bedded sandstone at Canari Point passed into more thickly bedded sandstone about .6 km beyond Canari Point. The thickly bedded sandstones are dominated by Bouma T_{ab} subdivisions and planar cross beds are very widespread. A very thick amalgamated sandstone bed was observed. This bed 36.6 meters thick is composed of graded to massive medium to fine grained; and with plane parallel lamination within the top two meters. This bed also contains some wood fragments. These fragments are randomly dispersed through the bed and finer grained plant material was found along the laminae at the top.

Figure 21 - Reworked plant debris exposed on a bedding surface at Point Tablas.

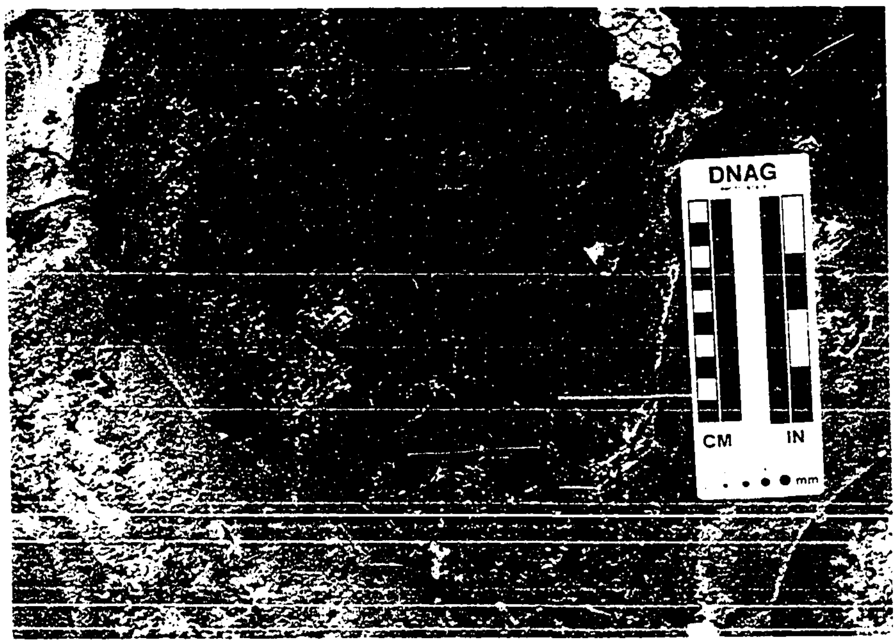
DNAG
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Figure 22 - Very thickly bedded and amalgamated sandstone beds about 200 meters west of Point Tablas. These beds dip at approximately 86° to the south. Top is towards the left and the central bed is 2.6 meters thick.

At Alcatras Point very thick sandstone beds were encountered. Some of these amalgamated beds are up to 60 meters thick. They range from massive to graded and also contain low angle planar cross beds (Figures 23 and 24), plane parallel lamination, ripples and convolute lamination, and convolute bedding. Bouma T_{abcd} subdivisions are very common. The thicker sandstones contain a large amount of "ripped-up" mud and silt clasts. Some plant debris is incorporated into these sandstones as transported material. Dried and oxidized oil was also found. Sandstone beds have sharp to scoured bases and flat tops. The tops are gradational into silt and sometimes mud. Very little mud is present. Amongst these thickly bedded sandstones are thinly bedded packets of fine grained sand, silt and mud which are strongly rippled and show some convolute lamination. These packets are similar to Bouma subdivisions T_{de} and occasionally when plane lamination is present to Bouma T_{cde}.

At Moruga Point low angle cross bedded sandstone continue to be dominant amongst thickly bedded sandstones. Minor amounts of wood and plant debris are incorporated into these beds. These sandstones also contain large straight crested ripples. Minor cuspate ripples are also present. The sandstones are graded and contain plane parallel lamination and convolute bedding amongst the most dominant primary structures. Bouma subdivisions T_{bcd} are most prominent. Bases of these sandstone beds are ornamented by load casts, flutes and striations. Two sets of paleocurrent measurements were obtained which indicate current flows northward toward 348° and 10°.

Figure 23 - HCS or truncated wave lamination exposed at Alcatras Point.

Figure 24 - HCS(?) or very low angle cross beds at Alcatras Point.


Nikon

At Morequite Point a thickly bedded section was observed. These beds are comprised of medium to fine grained sand (88-250 microns). They are massive to graded and contain plane parallel lamination, ripples, convolute lamination and low angle cross beds (Bouma T_{abcd}). The beds also incorporate mudstone pebbles and have sharp, scoured, ornamented (load casts and flutes) bases and gradational tops. See Figure 25.

At Point Otho thinly bedded packets of fine grained sandstone, siltstone and mudstone are present. These are interbedded with medium bedded sandstones which contain plane parallel lamination and very low angle cross beds. A major synsedimentary ptygmatic fold was observed with fold axes showing random orientations, Figure 26. The mud content of the overall section again increases and the sandstone/mudstone ratio decreases to approximately 35/1. Most of the mud was deposited in thin beds and interbedded with fine grained sand and silt. Some mud was also reminiscent of pelagic/hemipelagic sedimentation at the top of thicker sandstone beds.

The top of the measured section was at Point Curao. At this location minor plant debris is incorporated into beds which were otherwise graded and contain plane parallel lamination, low angle cross beds and convolute lamination. Some convolute bedding was also observed. Packets of sandstone/siltstone/mudstone triplets are interbedded within the more thickly bedded sandstones. These thinly bedded packages are dominated by ripples and thin laminations. Paleocurrent measurements indicate a northward current flow which ranged from 320° to 40°.

Figure 25 - Steeply bedded sandstones at Morequite Point. Note truncations (bold lines) associated with channels.

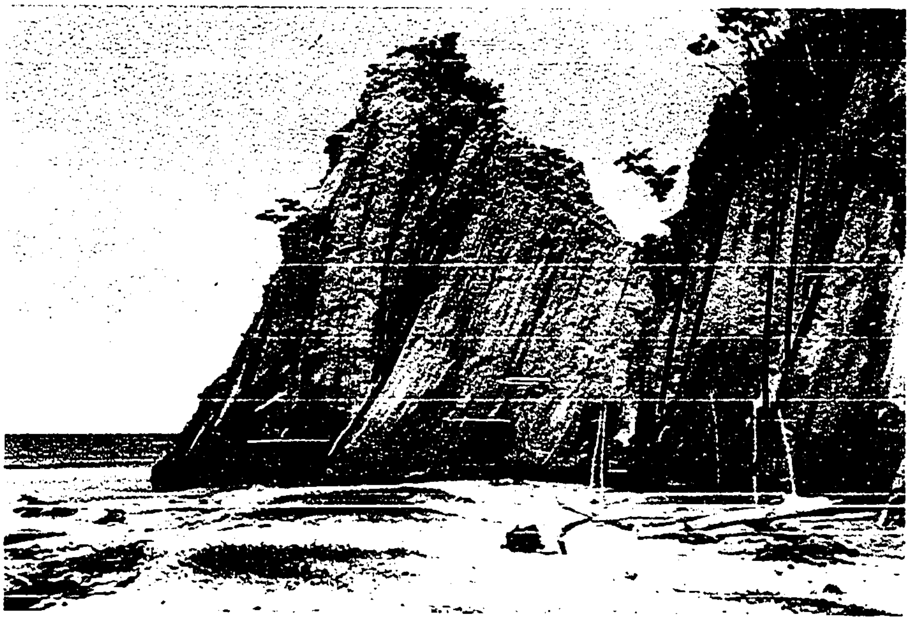


Figure 26 - Large ptygmatic fold at Point Otho.

Sedimentary Structures and Hydrodynamics

Primary sedimentary structures and sedimentary textures are the major sources of information regarding the medium, mode of transport and energy conditions at the time of deposition. Primary sedimentary structures are those features formed at the time of deposition or shortly thereafter and before consolidation of the sediments in which they are found (Pettijohn and Potter, 1964). Sedimentary structures are the result of hydrodynamic; processes operating on a given mass of sediment (collectively a group individual particles). These structures are the key to interpreting depositional environments as they are the result of interactions between gravity, the physical and chemical characteristics of the sediment and the fluid as well as the hydraulic environment.

Numerous others have attempted to graphically (mathematically) define the various parameters and limiting factors in a given fluid (or air) flow. Other mathematical relationships have been established between these variables and are represented by (a) the Reynolds Number (Re) and (b) the Froude Number (F). These equations are used to determine the hydrodynamic conditions of a flow. The equations representing both these numbers are given here:

(a) $Re = (VL)/m$ (a dimensionless number);

where V is the flow velocity, L is the length of flow and m is the kinematic viscosity.

The Reynold's Number is a mathematical determination of the critical value at which the flow of a fluid changes from laminar to turbulent. The

Reynold's Number of most natural flows is large which is not surprising as most natural flows are generally turbulent.

(b) $F = V/(gh)^{-0.50}$

where V = flow velocity, L = length of flow, g = acceleration due to gravity, h = depth of flow and, m = kinematic viscosity of flow.

The Froude Number defines of flow regimes which is critical to the hydrodynamic approach. When flow is tranquil $F<1$, bedforms of the lower flow regime are stable. Rapid flow is characterized by $F>1$ and upper flow regime bedforms are stable.

Furthermore Simmons et al. (1965) classified flow regimes and outlined their characteristics in the following Table 2.

The underlying premise is that given any "set" of parameters a particular suite of sedimentary structures will be formed. Sedimentary structures are indicative of processes and NOT environments. A suite of sedimentary structures, however, when placed within the vertical and lateral context of facies (lithologies) will then be diagnostic of sedimentary processes within a specific environment. The facies thus described are the building blocks of environmental determinations. Reineck and Singh (1978) states, "The presence or absence of individual features cannot generally be used as a positive sign in environmental interpretation. Most of the structures occur in several environments. It is generally the spectrum of sedimentary structures and their presence

Flow regime	Bedform	Bed material concentrations (ppm)	Mode of sediment transport	Type of roughness	Phase relation between bed & water surface
Lower regime	Small ripples	10-200	Discrete steps	Form roughness predominates	Out of phase
	Small ripples on megaripples	100-1200			
	Megaripples	200-2000			
Transition	Washed-out megaripples	1000-3000		Variable	
Upper regime	Plane beds	2000-6000	Continuous	Grain roughness predominates	In phase
	Antidunes	2000			
	Chutes and Pools	2000			

Table 2. Classification of Flow Regime and their Characteristics (After Simons et al., 1965)

in certain combinations that provide direct clues in environmental interpretation."

The Bouma Sequence

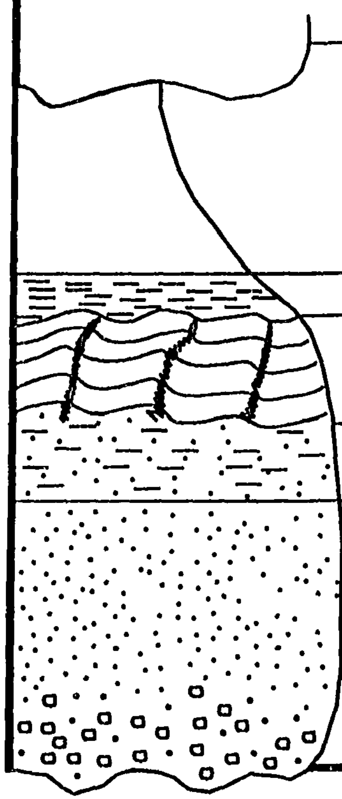
Bouma sequences are the most common set of sedimentary structures in the rocks of the Moruga Group, and include the graded beds described earlier. This association deserves some special treatment as these structures are diagnostically significant.

Kuenen (1953) defined a graded bed as a sandstone bed that contains a moderately high percentage of matrix and shows a definite vertical decrease in median grainsize. From flume experiments it has been ascertained that this change in size is determined by a gradual decrease in mean velocity from the front to the rear of a turbidity current (Kuenen and Migliorini, 1950; Simons et al., 1965). Bouma (1962) devised a model which characterized the vertical arrangement of sedimentary structures in a single turbidite and he proposed a convenient method of describing and defining these beds. Bouma (1962) suggested an ideal turbidite bed should consist of five elements (Bouma Cycle) and that these beds are repeated many times within a vertical sequence. Walker (1965 and 1970) analyzed this sequence in terms of flow regimes and hydrodynamics (Figure 27).

The elements of the complete Bouma Cycle are briefly described below, from bottom to top:

T_a - a lower massive or graded coarser sand division;

T_b - a lower division of parallel laminae or plane beds of coarser sand;



Grain Size		Bouma (1962) Divisions	Interpretations
Mud	E	Interturbidite (generally shale)	Pelagic sedimentation or fine grained, low density turbidity current deposition
Sand-Silt	D	Upper parallel laminae	? ? ? ?
	C	Ripples, wavy or convoluted laminae	Lower part of Lower Flow Regime
Sand (to granule at base)	B	Plane parallel laminae	Upper Flow Regime Plane Bed
	A	Massive, graded	? Upper Flow Regime Rapid deposition and Quick bed (?)

Figure 27. Complete Bouma Sequence

T_c - a division of ripple laminated sands which may also contain convolute lanimae and cross-bedding;

T_d - an upper division of parallel laminae of finer grained sands and silts; and

T_e - a division of clay and/or hemipelagic sediments.

Walker (1965 and 1970) suggested that the T_a and T_b divisions belonged to the upper flow regimes whereas the T_c, T_d and T_e divisions were characteristically lower flow regime structures.

The complete ideal Bouma sequence is not common and it is generally modified by truncation, nondeposition or a combination of both processes. Walker and Sutton (1967) described some variations in the bed configurations and suggested that they may also be deposited by a current so fast that no structures are formed or by very weak currents which do not allow ripple development.

Sedimentary Structures

Graded beds of the Bouma T_a type are commonly found in the study area. They range in thickness from 2 centimeters up to 4 meters. The graded beds observed almost always have sharp or scoured bases, often with load casts, flutes and grooves and striations. The beds also frequently contain pebbles of siltstone and mudstone - "ripped-up clasts." Graded beds of the south coast of Trinidad, except where amalgamated, pass upward into plane parallel laminations and sometimes very low angle cross beds.

Graded beds show a gradation in grainsize from coarse to fine, upward from the base to the top of the unit, and are formed when the local energy of the environment at first increased with the influx of sand and then decreased as sand deposition waned and the composition of the slurry changed becoming muddier. Kuenen and Migliorini (1950) express the view that turbidity currents are the probable cause of graded bedding.

Plane beds are common in the study area and are often found overlying graded beds. They were not observed to be associated with any particular sediment grain size or bed thickness. In those cases where they were not found overlying graded beds, they had sharp and often scoured bases. Where observed, amalgamated beds are composed of stacks of plane beds. These plane beds resemble those of Bouma T_b subdivision.

Plane beds or plane parallel lamination are features of the upper flow regime where bed material concentrations range from 2000-6000 ppm. Plane beds are stable at high flow velocities and very often are formed when mean flow velocity and bed shear stress increases thus washing out previously formed ripples, (Harms et al., 1982).

Very low angle cross beds (HCS) are a ubiquitous sedimentary structure in the study area. These structures were found mainly in the very fine sandstones and siltstones, and are closely associated with plane beds of Bouma subdivision T_b. The internal bedding or laminae are very gently dipping with erosional tops. Thicknesses of the internal sets range from 9 to 32 centimeters. Some of the laminae thicken laterally and dip randomly. Erosional surfaces within the beds also slope randomly, are often undulatory, and sometimes resemble reactivation surfaces. These beds are widespread and very closely associated with graded and plane beds (Figures 28 and 29). The beds sometimes alternate with plane beds and often overlie the graded bedding. Plane beds are also seen to pass upward into these bed forms.

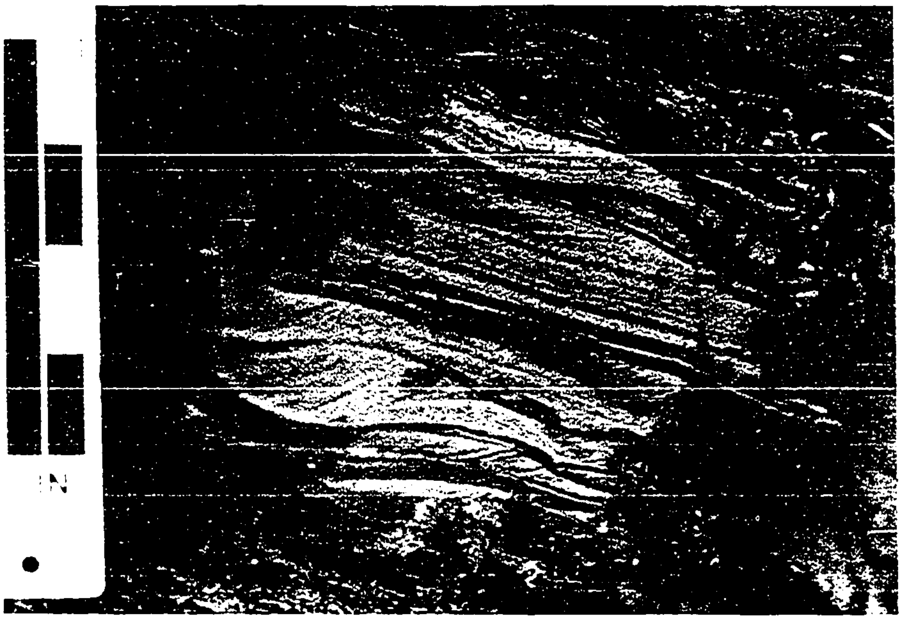
Beds of this description appear in the literature and since 1975 they have been referred to as hummocky cross-stratification (Harms, 1975). Campbell (1986) and Allen (1985) describe similar bed forms and referred to them as truncated wave ripple lamination while Hunter (1977) called them "translatent stratum".

Hydrodynamically "hummocky cross-stratification" (truncated wave ripple lamination) is thought to be diagnostic of the former action of storm waves. Some authors believe that hummocky cross-stratification originates under the influence of highly concentrated suspensions generated during storms by (1) bypassing of the littoral zone by river-derived floods and (2) offshore return of storm surges, (Hamblin, Duke and Walker 1979, AAPG v. 63: 450-461 and Wright and Walker 1981). Other authors favor an origin under purely oscillatory flows generated under storm conditions (Harms et al., 1975 and Dott and Bourgeois, 1982).

Ripples of the following types were observed in the study area: climbing ripples, undulatory current ripples and a small number of straight crested current ripples. Figures 30 and 31.

Figure 28 - An illustration of the very close relationship between plane parallel lamination on very low angle cross beds. Plane parallel lamination appear to pass vertically without a break into very low angle cross beds.

Figure 29 - Very low angle cross beds exposed at Alcatras Point. These are cut by a minor fault and laterally grade into plane parallel lamination.



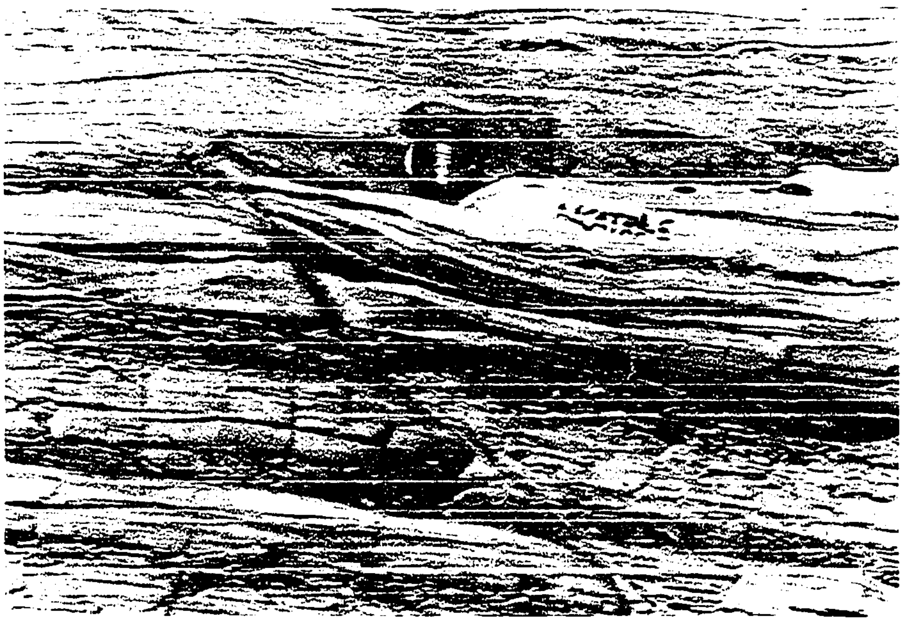
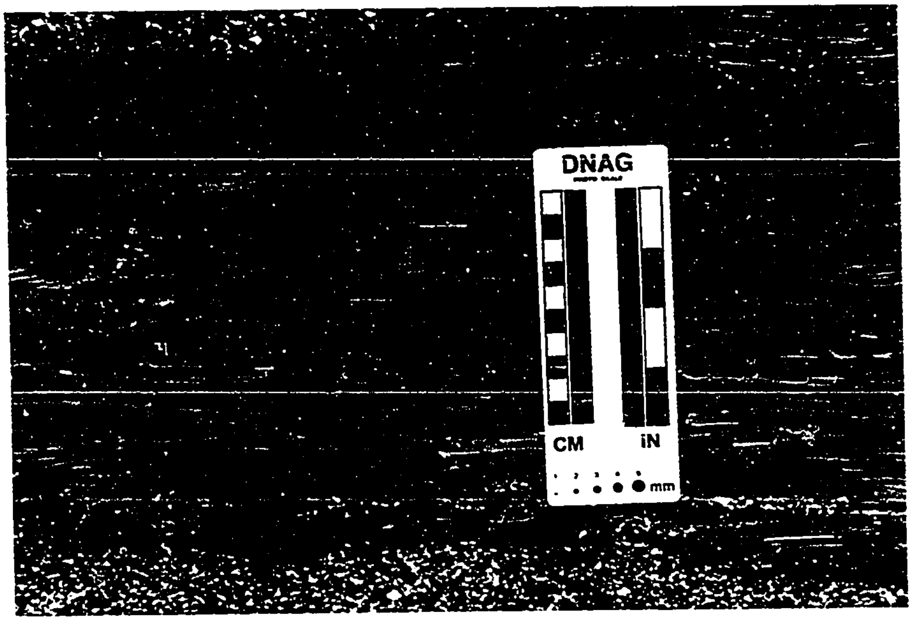


Figure 30 - Low amplitude current ripple field. Some ripple crests are truncated and the similarity to the HCS structure illustrated.

Figure 31 - Low amplitude ripples and low angle cross beds at Point Tablas.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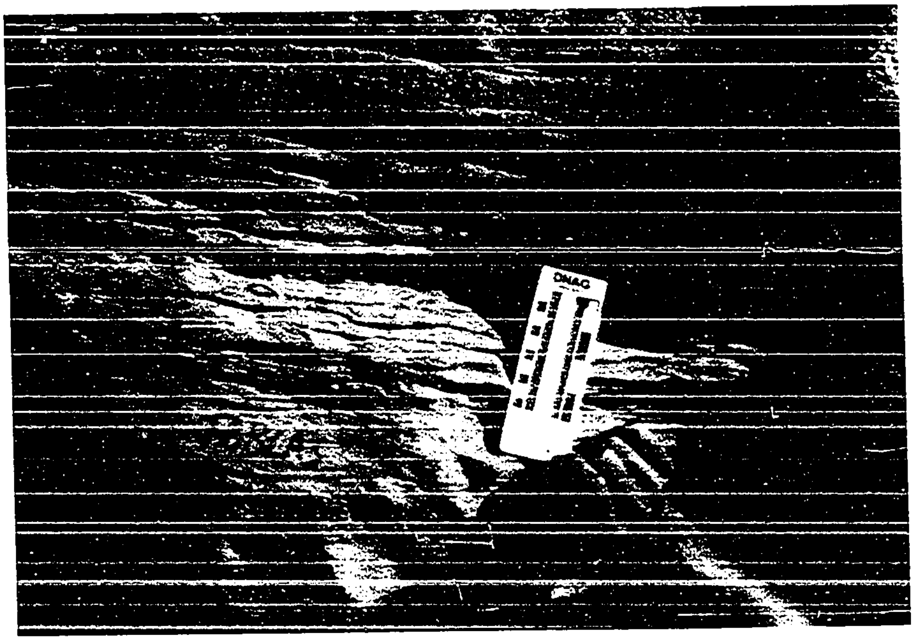

DNAG

Climbing ripples (Figure 31) were the most common ripple forms encountered. The ripples are asymmetrical in shape and were easily measured for paleocurrent analysis. These were found in sets which range from 4 to 15 centimeters thick. The climbing ripples encountered are mainly of the in-phase type though a small number of the in-drift variety are present. Some in-drift climbing ripples occur within thin, muddy interbeds. The in-phase climbing ripples had ripple crests which are superimposed one above the other.

Undulatory ripples (Figure 30) are common in the study area and easily lent themselves to paleocurrent measurements. Where inspection of a third dimension was possible some well developed festoon cross-bedding was observed. These structures were found mainly in very fine sand and silt often at the top of thickly bedded units just before passing into other thickly bedded units.

Straight crested current ripples were not common. However, where observed, they are present in very fine sandstone and siltstone beds. These bedforms have straight tco slightly sinuous crests, and occur at the very top of such beds. Sometimes they were observed to be closely related to planar cross-bedding.

Ripples are broadly of two types of ripple formations are known and both are present within the study area. These are symmetrical and asymmetrical ripples. Ripple marks are sand waves of the smallest scale and were once thought to have been formed from weaker currents than those which form dunes and generate the larger scale cross-bedding. Ripples form in a variety of environments and are the result of the action of moving water over noncohesive material. They are features of turbulent flow and are generally lower flow regime structures. Ripples change their form and size depending upon the following factors: availability of sediment, flow velocity, water depth and grainsize.

Climbing ripples are found where the rate of deposition of sediment by a current is decreasing less rapidly, with time than the rate of bed load transport (Allen, 1979). Generally sediment supply is high while the rate of reworking is low. Depending on the conditions at the time of deposition these requirements may be fulfilled during the deposition of Bouma T_c turbidites.

Undulatory current ripples represent a transition form between low-energy straight crested small ripples and higher energy linguoid ripples (Reineck and Singh, 1980). The crest of these ripples are undulatory or wavy. Allen (1968) also refers to these ripples as sinuous. In cross section these ripples give rise to festoon shaped bedding.

Convolute structures are very common within the study area and are not restricted to any particular horizon. Though more common in thinly and medium bedded they are also found along the upper parts of thick sand and silt units: generally they die out toward the bottom of the bed. The convolutions generally show continuous laminations from fold to fold, and some are characterized by small scale intrabed faults. These structures show marked crumpling or complicated folding of the laminae of a rather well defined sedimentation unit. They are associated with olistostromes and "ball and pillow" structures (Figure 32). Also observed within the study area are ptygmatic folds which involve a large number of beds often contorted and overfolded.

Convolute lamination and convolute bedding, also referred to as interstratal contortions and crinkled bedding, Pettijohn et al., 1987, are the result of soft sediment deformation. They are usually caused by loss of cohesion, by elutriation (pore water pressure changes) and movement in response to gravity, (Allen, 1977 and De Boer, 1979), and by downslope movement and current drag (Reineck and Singh, 1980). On a large scale these features are similar to ptygmatic folding. The synclines are broad and open while the anticlines are tight and peaked (Pettijohn, et al., 1987). Overturned folds on a bed scale are also included in this groupof deformation structures. Though not confined to, they are very typical of rapidly deposited, water laden sediments.

In the study area varying sizes of the following sole marks are present - load casts (.5-3 meters), flutes (.1-.85 meters) and grooves (.02 to 1.1 meters). These are common on the bases of sandstone and siltstone beds. The load casts are knobby, irregularly shaped bulges. Flutes and grooves gave an indicaticon of paleoflow and are subconical with rounded or bulbous upcurrent noses and with the other end flaring out and merging with the bedding plane. Grooves (also called drag marks, (Pettijohn et al., 1987), are often found associated with prod marks; and skip and bounce marks. Terminations are seldom seen.

Figure 32 - "Ball and Pillow" structure and contorted bedding at Gran Calle Point.

Sole marks are preserved on the lower side of a sand layer overlying a mud layer. These structures are the result of differential deposition and loading of sand over a hydroplastic mud layer which causes vertical and lateral movement. These structures are not restricted to any particular environment though they are very common in turbidite deposits, (Reineck and Singh, 1980).

Flutes and grooves are sole marks found on the bottoms of sandstone and siltstone beds and, are important and useful in determining paleo-currents and therefore deciphering paleogeography. The markings are the result of the action of currents on a mud surface, unequal loading of hydroplastic mud, (Pettijohn et al., 1987), and may also be formed by the sculpting action of objects transported within the currents being used as instruments for gouging the underlying beds.

Facies Descriptions: South Coast Trinidad

A "facies" is a body of rock with specified characteristics. In the case of sedimentary rocks, it is defined on the basis of color, bedding, composition, texture, geometry, fossils and sedimentary structures, (Selley, 1970). A facies therefore records information about the environment in which it was deposited. The relationship between individual facies was summarized by Walther in the "Law of Facies" which states that "*the various deposits of the same facies area, and similarly, the sum of the rocks of different facies areas were formed beside each other in space, but in a crustal profile we see them lying on top of each other....that only those facies and facies areas, can be superimposed without a break, that can be observed beside each other at the present* *time*". The observed facies associations are therefore the key to environmental interpretation and the individual facies are the basic building blocks of such inferences.

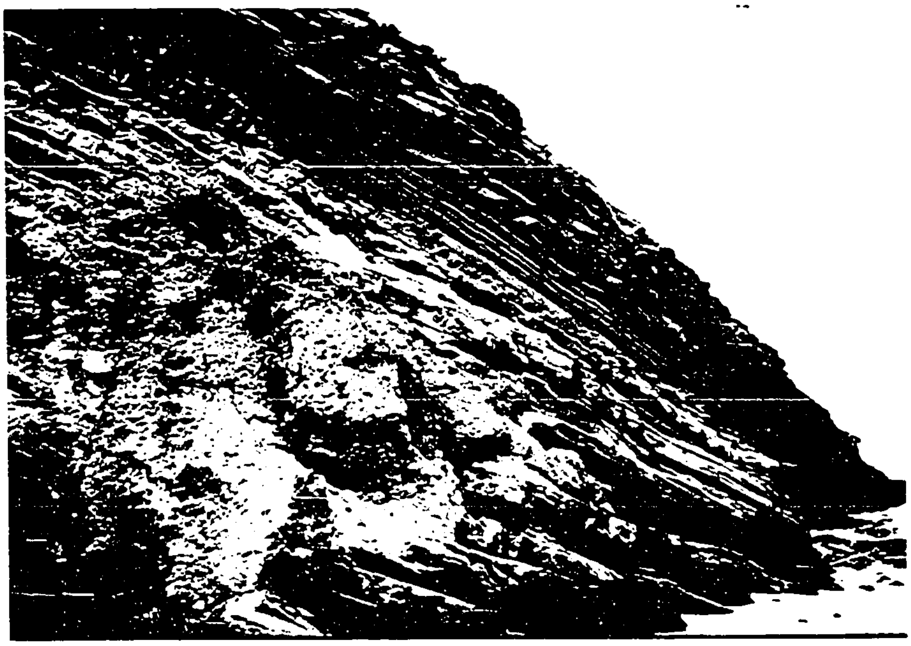
The Moruga Group along the south coast of Trinidad is monotonously bedded and one is hard-pressed to observe very clear changes up section. Three facies were differentiated on the basis of mud content, average bed thicknesses and primary sedimentary structures. The changes are generally subtle, however, a major change in bedding style occurs about a quarter mile before the bend at Gran Cayo (Calle) Point. Here the sand content of the sequence dramatically increased and the sandstone/mudstone ratio escalated to greater than 60/1.

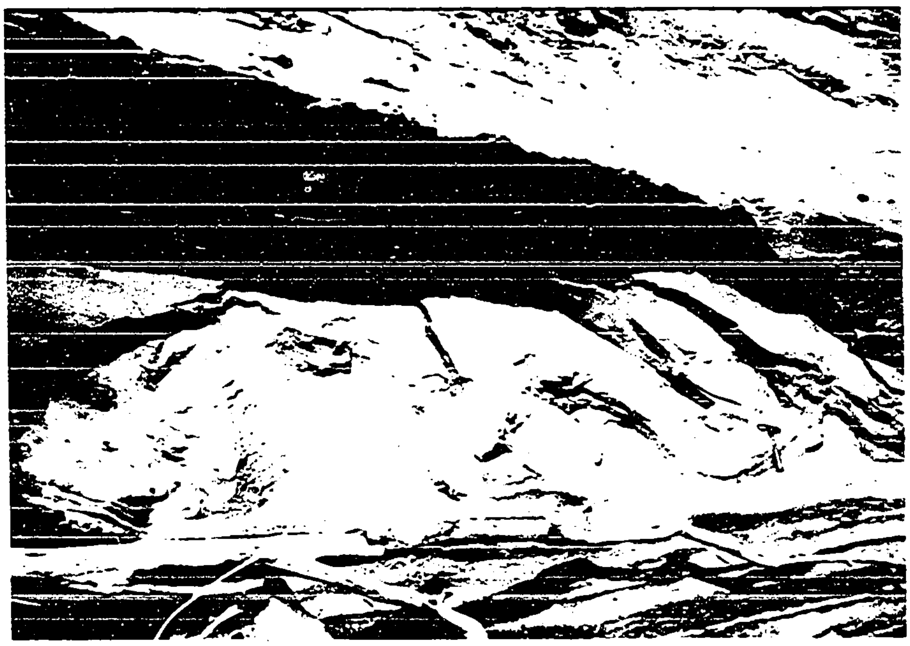
Facies I (Figure 33, 34 and 35) - This Facies forms the base of the measured section and is a part of the section measured by Farrelly (1987) as Outcrop 7 at Galeota point. Facies I also occurs at Point Tablas, see the measured section at 1125-1130. As stated earlier stratigraphy and the application of stratigraphic names is not a primary focus of this study.

This facies is composed of thin to medium bedded fine grained sand and silt with appreciable mudstone (claystone) interbeds. Sandstone/mudstone ratio in the section ranged from 5/1 to 20/1. The sands are graded, have sharp ornamented bases, are laterally continuous and often include pebbles of mudstone as "ripped-up clasts". Fluidization (soft sediment deformation), convolute bedding (Figure 34) and laminae, ball and pillow structures and load casts (Figure 35) are prominent sedimentary structures within this facies. One very striking ptygmatic fold was observed.

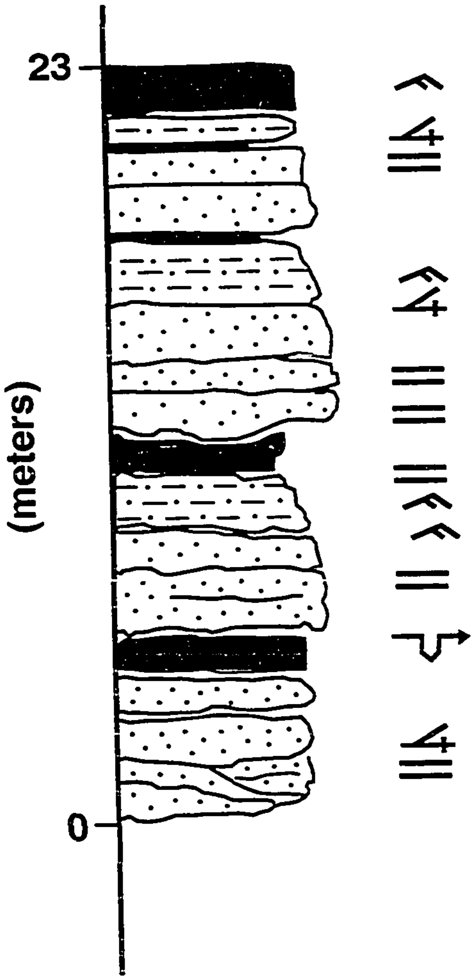
Figure 33 - Facies I developed at Galeota Point. Well bedded sandstones with interbedded mudstones.

Figure 34 - Distorted and convoluted bedding associated with Facies I.





Facies I

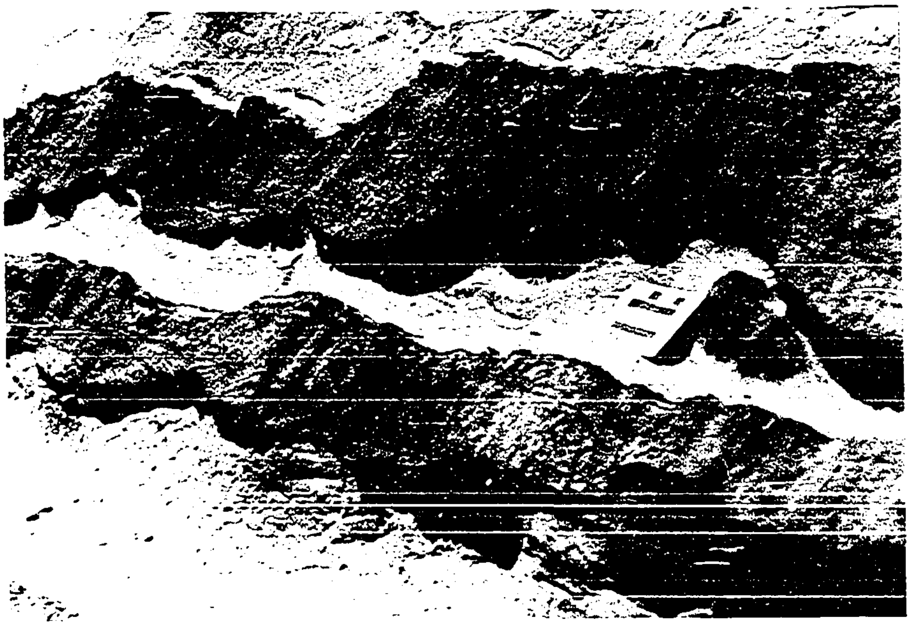


Medium bedded sandstones, siltstones and mudstones. Graded beds, plane beds and ripples are common. Sandstones have sharp, erosional bases and occasionally contain "rippled up" clasts of mudstones and siltstones Bouma Tcd are most common.

Sole marks are common found on the bases of the sandstone beds. Some channeling and convolute structures are present.
sst/mst ± 201.
This example comes from Galeota Point.

Figure 35

Figure 36 - Load casting at Galeota Point.



Some very low angle cross-beds or truncated current ripples are present. Another very important observation is the frequent occurrence of graded beds and truncated or complete Bouma cycles. These Bouma cycles often include the very low angle cross-beds. They are very closely related to the plane parallel lamination which are characteristic of the Bouma T_b subdivision. The two sedimentary structures often grade transitionally from plane beds into low angle cross beds. This made it difficult to determine whether they replaced the Bouma T_c division or formed part of the Bouma T_b division.

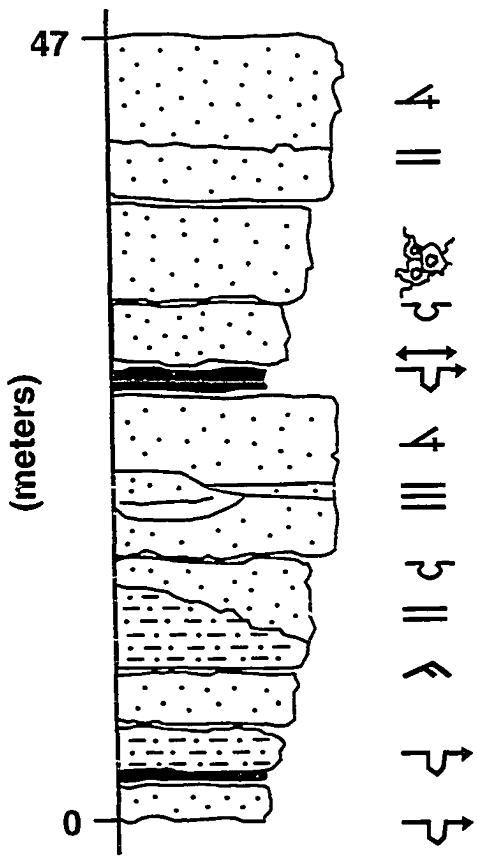
Facies II (Figures 37, 38 and 39) - This facies is similar in general appearance to Facies I except that it has a lower mud content and is clearly more thickly bedded. Some very low amplitude channels are sometimes associated with these more thickly bedded sandstones. Channels are infilled by graded sandstones and siltstones interbedded with thinly laminated mudstones.

This facies generally has a very low mud content, is medium to thickly bedded, with a sandstone to mudstone ratio often greater than 50/1. The monotonously bedded sandstones are generally graded, have sharp, often scoured bases and are laterally very continuous. They often contain "ripped up" clasts of mudstone and siltstone. Fluidization structures indicative of soft sediment deformation are common and included convolute bedding and lamination, broken beds, ptygmatic folding and load casting.

Figure 37 - Facies II beds up to 32 meters thick at Canari Point.

Figure 38 - Facies II. Very thickly bedded and amalgamated sandstones. Bold lines indicate possible channelling and truncations.

Facies II

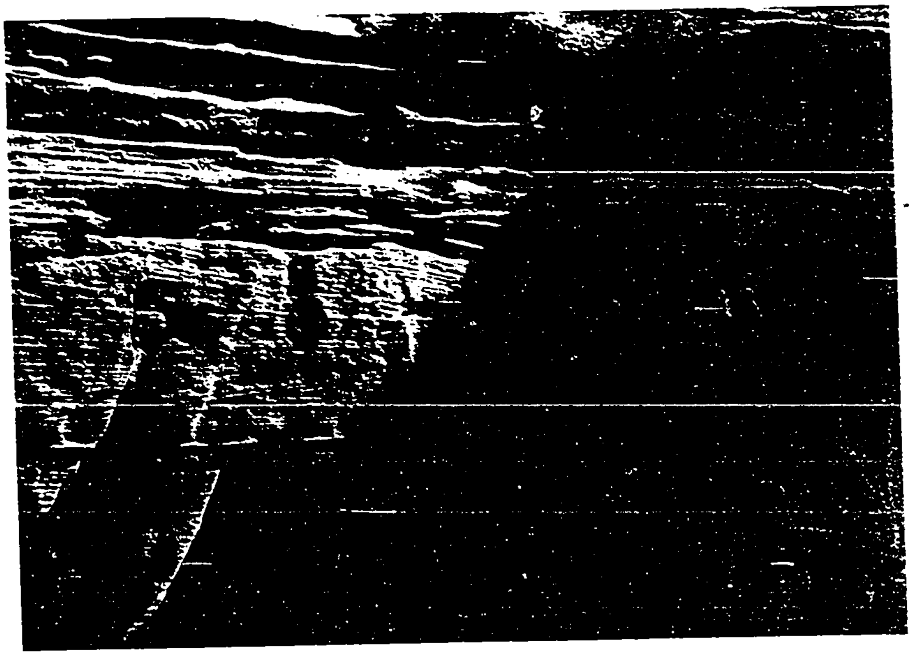


Thickly bedded sandstones and siltstones. Very little mudstone. Thickly bedded, sharp scoured bases, widespread amalgamation, load casting, "ripped up" clasts of siltstone and mudstone and convolute structures are common. Graded beds, plane beds, HCS are amongst the more diagnostic sedimentary structures. Channeling and truncations associated with channeling are also prominent features. Bouma Tabc and Tabcd are common. Some beds are as thick as 13 meters. This section was measured at Canari Point.
sst/mst ≅ 50/1

Figure 39

Figure 40 - Very low angle cross beds developed within a very thick bed belonging to Facies II.

Figure 41 - Triplets of thinly bedded sandstone/siltstone/mudstone, belonging to Facies III. In this illustration from Galeota Point, a thicker sandstone bed is interbedded within a unit of Facies III. This sandstoned bed shows well developed low angle cross beds.



Very low angle cross beds (Figure 40) or truncated ripple lamination are common, and together with complete and truncated Bouma sequences comprise the most common sedimentary structures. Figure 39 is a sketch illustrating the characteristics of Facies II.

Facies III (Figures 41, 42, 43 and 44) - cconsists of packets of fine grained sandstone/siltstone/mudstone triplets. These are characterized by thin laminae, ripples and pelagic mud representative of Bouma subdivisions T_{cde}. These packages are found interbedded with more thickly bedded sandstone, and siltstones. They may contain finely dispersed plant debris which was transported with the fine sediment, maybe as suspension loads.

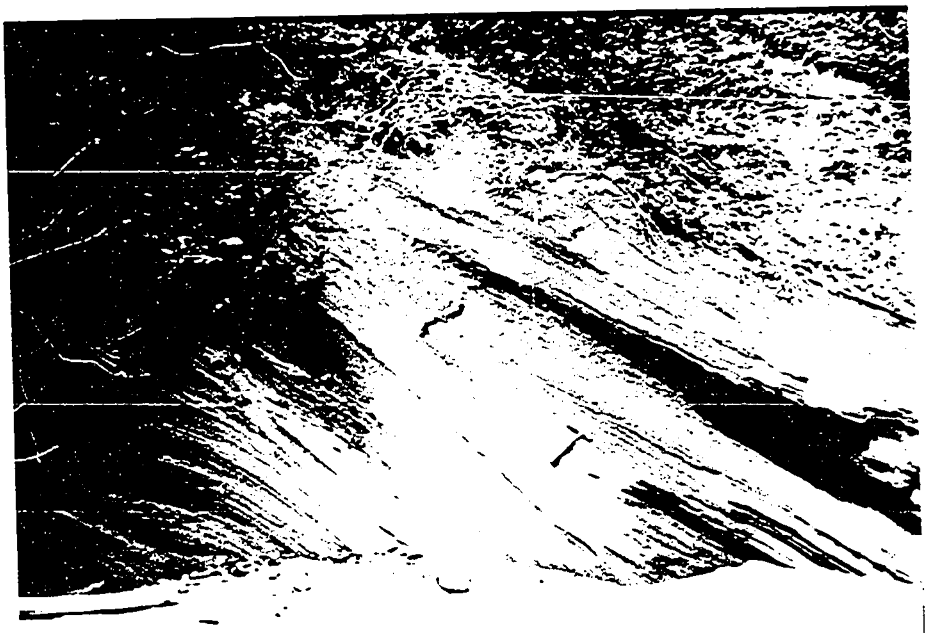
Figure 43 illustrates Facies III passing upward into Facies I and, Figure 44 is a sketch illustrating the characteristics of Facies III.

Paleocurrents

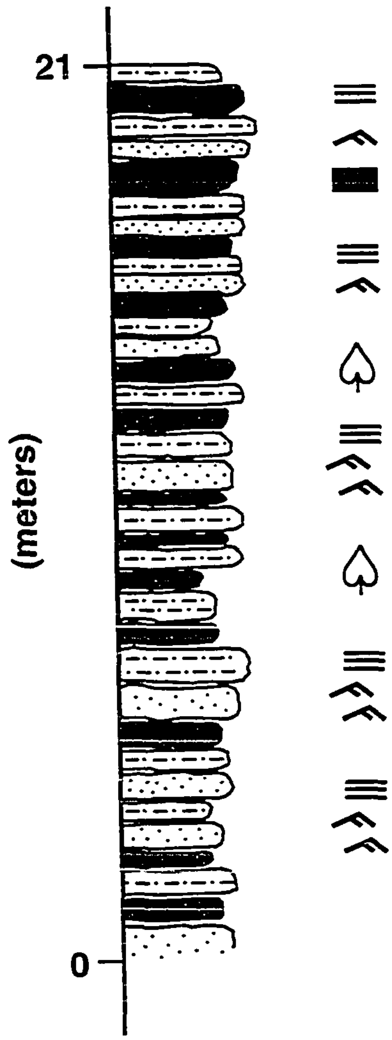
Two hundred and forty paleocurrent measurements were taken. These taken primarily from assymetrical ripples, indicate that the currents responsible for depositing the sediments generally flowed northward to northeastward. Measurements show a spread of paleoflow directions toward 300° (WNW) to 87° (ENE). Lamy (pers. comm. 1990) believes that the source of this sediment shifted eastward during the Late Pliocene and Early Pleistocene, and that most of the Pleistocene sediment was sourced from the northeast.

Figure 42 - Facies III passing upward into more thickly bedded sandstones.

Figure 43 - Facies III preceding beds of Facies I.



Facies III
eg. at Gran Calle Point



Thinly bedded sandstones, siltstones and mudstones. Ripples and thin laminates are very common sedimentary structures.

Some reworked plant debris is found lining the laminations and dispersed throughout the finer grained mudstones and siltstones. The vertical arrangement of primary sedimentary structures resemble Bouma Tcd and Tde sequences.

sst/mst≅3/1

Figure 44

Palynology and Micropaleontology

Data on the palynology and paleontology of the Moruga Group of the south coast stratigraphic section and associated sequences in the offshore area are presented. Since there have been discrepancies in the age assignment of these sediments, these data are used to (1) accurately assign an age to both the outcrop and subsurface sequences and, (2) to indicate a range of water depths and environmental conditions which were present during deposition of these sequences.

While most of the data are new some was derived from documents released for this study by oil companies and the Ministry of Energy, Trinidad. A considerable amount of the data used in the development of my ideas is propriety and cannot be presented or displayed in this dissertation.

Palynology is used in this study to assist in resolving some of the stratigraphic and paleogeographic problems encountered in Trinidad.

Observations based on the color of the palynomorphs encountered give important information on levels of carbonization and thus paleogeothermal conditicons. Some preliminary results are presented on the levels of thermal alteration (carbonization) and petroleum potential.

Using this data an age is assigned to the south coast stratigraphic section - exposed in outcrop and encountered in the West SEG-1 well. The age designation will be based mainly on palynologic studies conducted. Palynologic and palaeontologic data will be used to give an indication of the water mass conditions at the time of deposition. Such information is important in developing depositional models.

Results

Palynologic Summary

Samples were collected during fieldwork and the identification of the palynomorphs was done by Andrew Lamy (1989-1990). The diagnostic assemblage for the Late Early Pliocene of the West SEG-1 well is shown in Figure 52 (Plate VIII), numbers 1-13. Figure 45 (Plate I), numbers 1-13 depicts the Late Early Pliocene assemblage recovered from outcrop samples. Other taxa are illustrated on the attached Figures 46, 47, 48 and 49 (Plates II, III, IV, and V) for completeness of the outcrop section. These taxa are not known to have restricted ranges in the Plio-Pleistocene of Trinidad and Eastern Venezuela. Figure 50 (Plate VI) represents environmentally significant taxa and Figure 51 (Plate VII) illustrates reworked taxa of Early, Middle and Late Cretaceous. Figures 53 and 54 and 50 (Plates IX and X and Plate VI), number 5 illustrate common dinoflagellate cyst taxa encountered in the Plio-Pleistocene of the West SEG-1 well.

A table presenting data on age determinations and palynomorph assemblages in outcrop and cuttings is presented as an appendix.

Figure 45 - Magnification x1000, except Num. 1 and Num. 3 x630

1. Magnastriatites grandiosus (Kedves and Sole De Porta, 1963) Duenas, 1980. 76 micron.

2. Clavamonocolpites sp. 48 micron.

3. Polyadopollenites mariae Duenas, 1980. 60 micron.

4. Striasyncolpites sp. 24 micron.

5. Compositae sp. 28 micron.

6. Fenestrites spinosus Van der Hammen, 1956. 36 micron.

7. Striasyncolpites zwaardi Germeraad, Hopping and Muller, 1968. 20 micron.

8. Multiareolites formosus (Van der Hammen, 1956B) Germeraad, Hopping and Muller, 1968. 16 micron.

9. Echitricolporites mcneillyi Germeraad, Hopping and Muller, 1968. 16 micron.

10. Fenestrites sp. 16 micron.

11. Compositae, Ambrosia type, 16 micron.

12. Chenopodipollis multiplex (Weyland and Pflug) Krutzsch, 1966. 20 micron.

13. Compositae, Ambrosia type, 12 micron.

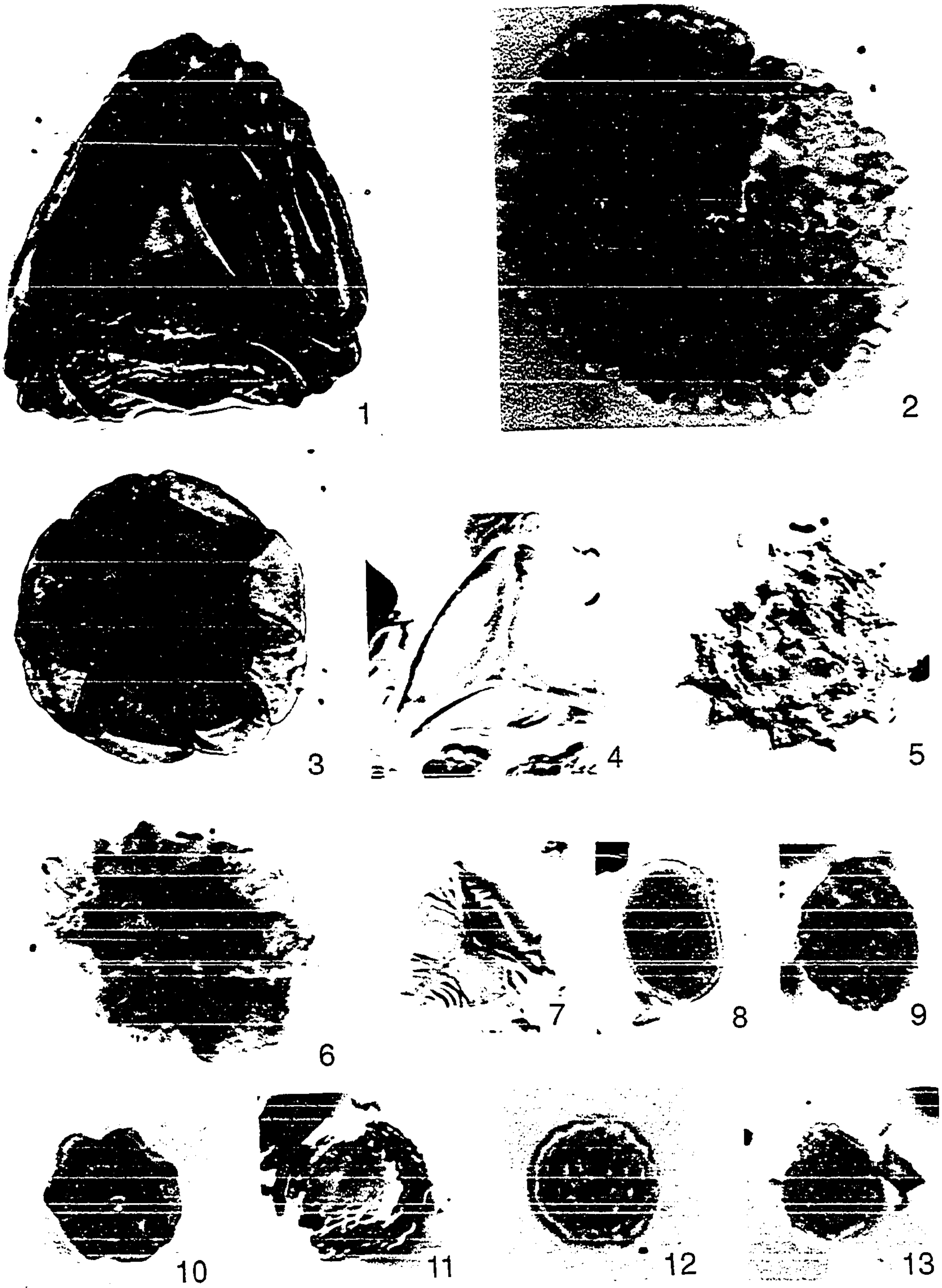

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Figure 46 - Magnification x1000, except Num. 1 and Num. 3 x360.

1. Convolvulaceae sp. 96 micron.

2. _Echiperiporites estelae_ (reworked) Germeraad, Hopping and Muller, 1968. 72 micron.

3. _Hibiscus_ sp. 72 micron.

4. _Stephanocolpites evansii_ Muller, de Di Giacomo and Van Erve, 1987. 36 micron.

5. _Mauritiidites_ sp. 32 micron.

6. _Spinizonocolpites baculatus_ (reworked) Germeraad, Hopping and Muller, 1968.

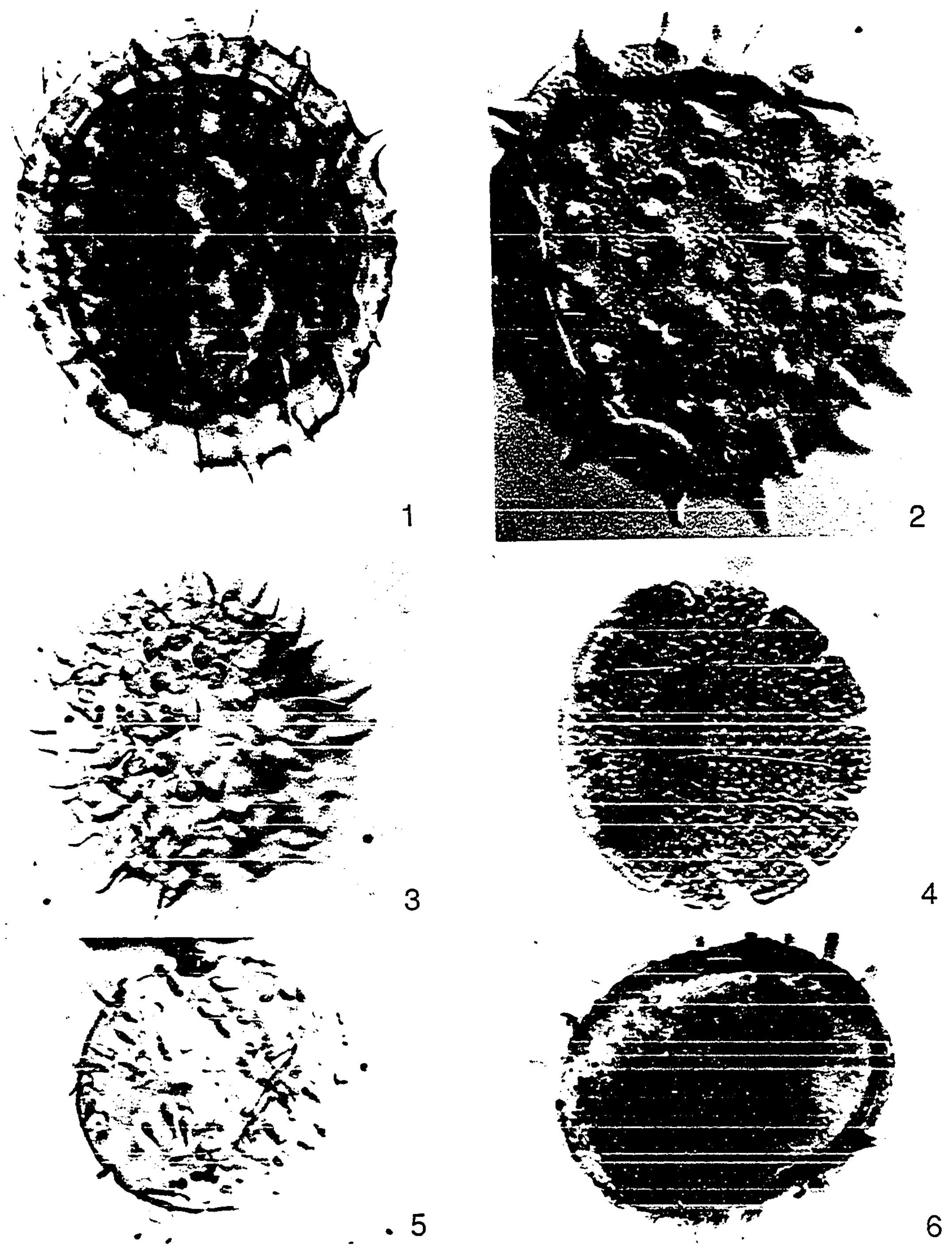
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Figure 47 - Magnification x1000, except Num. 1 x630.

1. Gemmastephanocolpites sp. 108 micron.

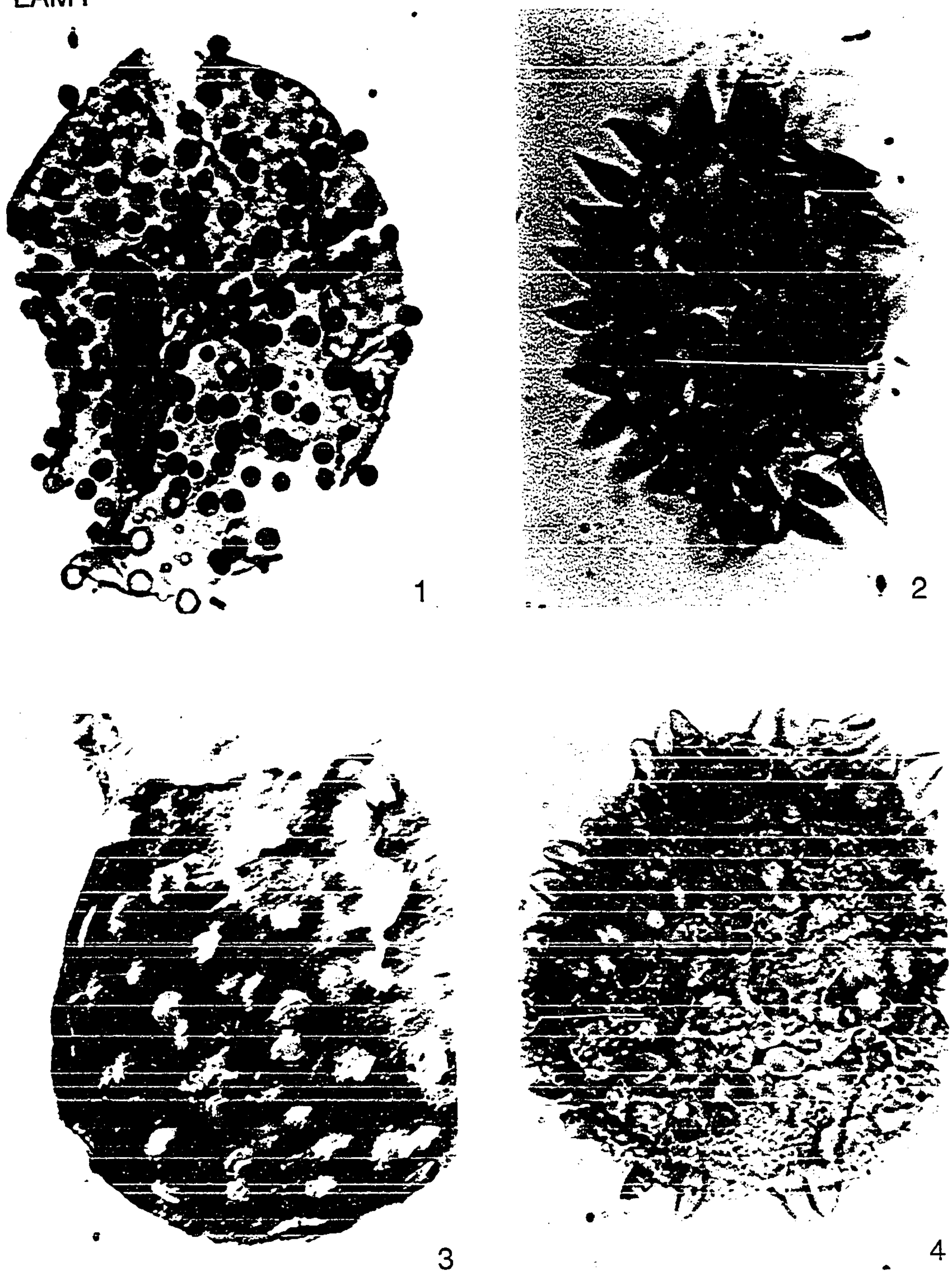
2. Echimonocolpites sp. 60 micron.

3. Psilaperiporites robustus Regali et al., 1974. 68 micron.

4. Echiinaperturites sp. 64 micron.

LAMY

PLATE III



1 2 3 4

Figure 48 - Magnification x100

1. Monoporites annulatus (Van der Hammen, 1954) Germeraad, Hopping and Muller, 1968. 32 micron.

2. Echinotricolpites sp. (reworked), 48 micron.

3. Echitriporites sp. 44 micron.

4. Phelodinium sp. 52 micron.

5. Mauritiidites franciscoi (Van der Hammen, 1956) Van Hoeken-Klinkenberg, 1964. 42 micron.

6. Retitriporites sp. 44 micron.

LAMY PLATE IV

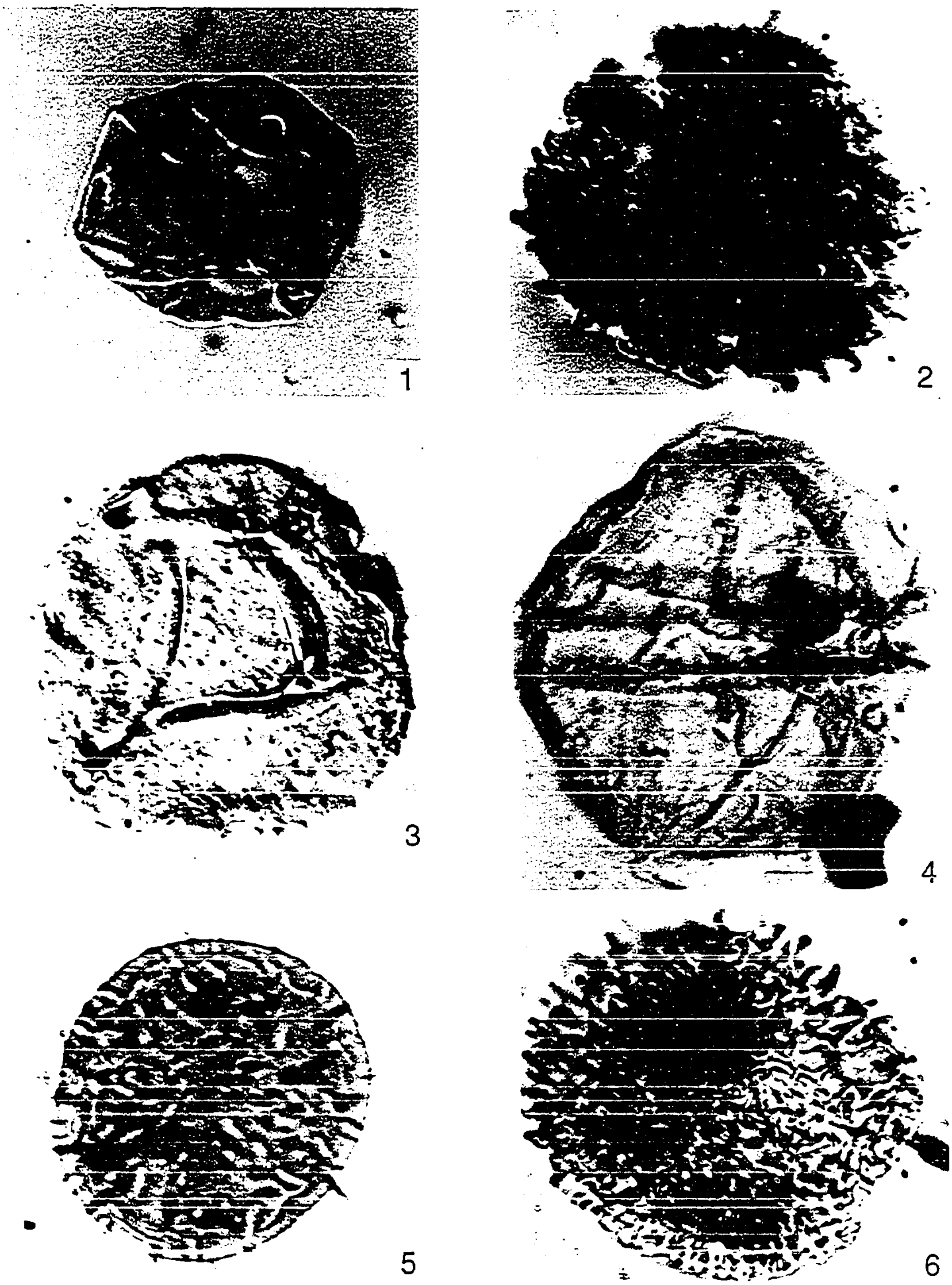


Figure 49 - Magnification x1000, except Num. 1 x630.

1. *Retistephanocolpites* sp. 65 micron.

2. *Retitricolporites* sp. 40 micron.

3. *Bombacacidites* sp. 44 micron.

4. *Echitricolporites maristellae* Muller, Di Giacomo and Van Erve 1987, 44 micron.

5. *Proxapertites* cursus (reworked) (Van Hoeken-Klinkenberg, 1966) Germeraad, Hopping and Muller, 1968. 44 micron.

6. *Multimarginites vanderhammeni* (reworked) Germeraad, Hopping and Muller, 1968. 44 micron.

LAMY

PLATE V

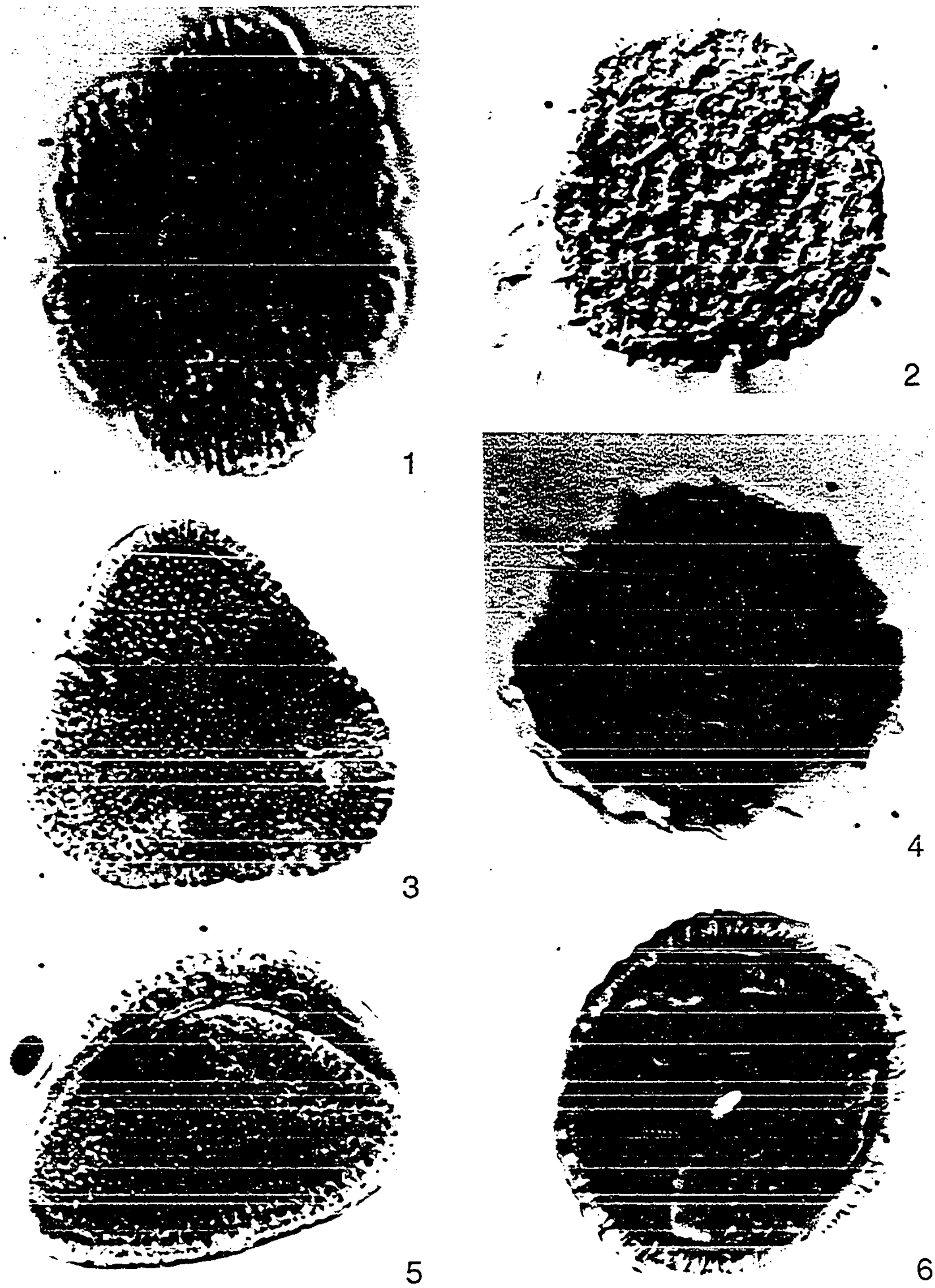


Figure 50 - Magnification x1000, except Num. 2, 5 & 7 x630 and Num. 8 & 9 x400

1. *Azolla* sp. 52 micron.

2. *Botryococcus* sp. 50 micron.

3. *Helicomyces roseus* (link ex Fr.) Elsik 1981. 44 micron.

4. Microforam 42 micron.

5. *Cannosphaeropsis* sp. 64 micron.

6. Acritarch sp. (reworked), 32 micron.

7. *Pediastrum* sp. 52 micron.

8. *Perithecites* sp. (Inflated fruiting body) 104 micron.

9. Scolecondont 105 micron.

LAMY

PLATE VI

Figure 51 - Magnification x1000, except Num. 3 x630.

1. Foveotriletes margaritae (reworked) (Van der Hammen, 1954) Germeraad, Hopping and Muller 1968. 40 micron.

2. Buttinia andreevi (reworked) (Boltenhagen, 1967) Germeraad, Hopping and Muller 1968. 40 micron.

3. Galeacornea sp. (reworked) Stover, 1963, 76 micron.

4. Cicatricosisporites dorogensis (reworked) (Potonie et Gelletich, 1933) Germeraad, Hopping and Muller 1968. 40 micron.

5. Verrucosisporites gabouensis (reworked) Couper, 1964. 44 micron.

6. Spiniferites sp. (reworked), 56 micron.

LAMY

PLATE VII

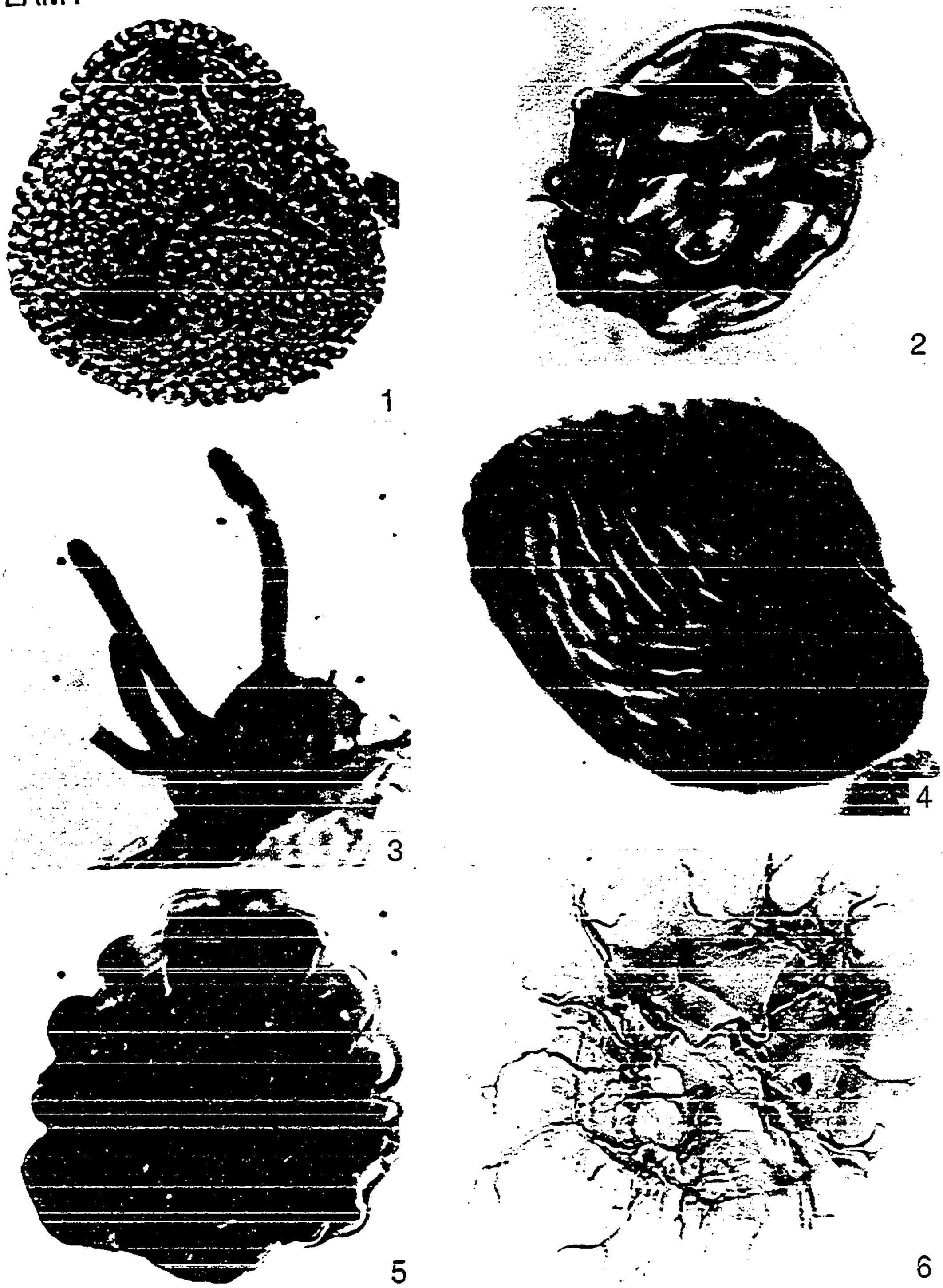


Figure 52 - Magnification x1000, except Num. 8 x400.

1. Clavamonocolpites sp. 52 micron.
2. Compositae, Ambrosia type, 16 micron.
3. Fenestrites sp. 16 micron.
4. Polyadopollenites mariae Duenas, 1980. 48 micron.
5. Chenopodipollis multiplex (Weyland and Pflug) Krutzsch, 1966. 24 micron.
6. Compositae sp. 28 micron.
7. Psilatricolporites caribbiensis muller, de Di Giacomo and Van Erve, 1987. 44 micron.
8. Magnastriatites grandiosus (Kedves Et Sole de Porta, 1963) Duenas, 1980. 92 micron.
9. Fenestrites spinosus Van der Hammen, 1956. 36 micron.
10. Striasyncolpites sp. 24 micron.
11. Striasyncolpites zwaardi Germeraad, Hopping and Muller, 1968. 16 micron.
12. Multiareolites formosus (Van der Hammen, 1965B) Germeraad, Hopping and Muller, 1968. 26 micron.
13. Echitricolporites mcneillyi Germeraad, Hopping Muller, 1968. 26 micron.
14. Echitricolporties mcneillyi Germeraad, Hopping and Muller, 1968. 24 micron.

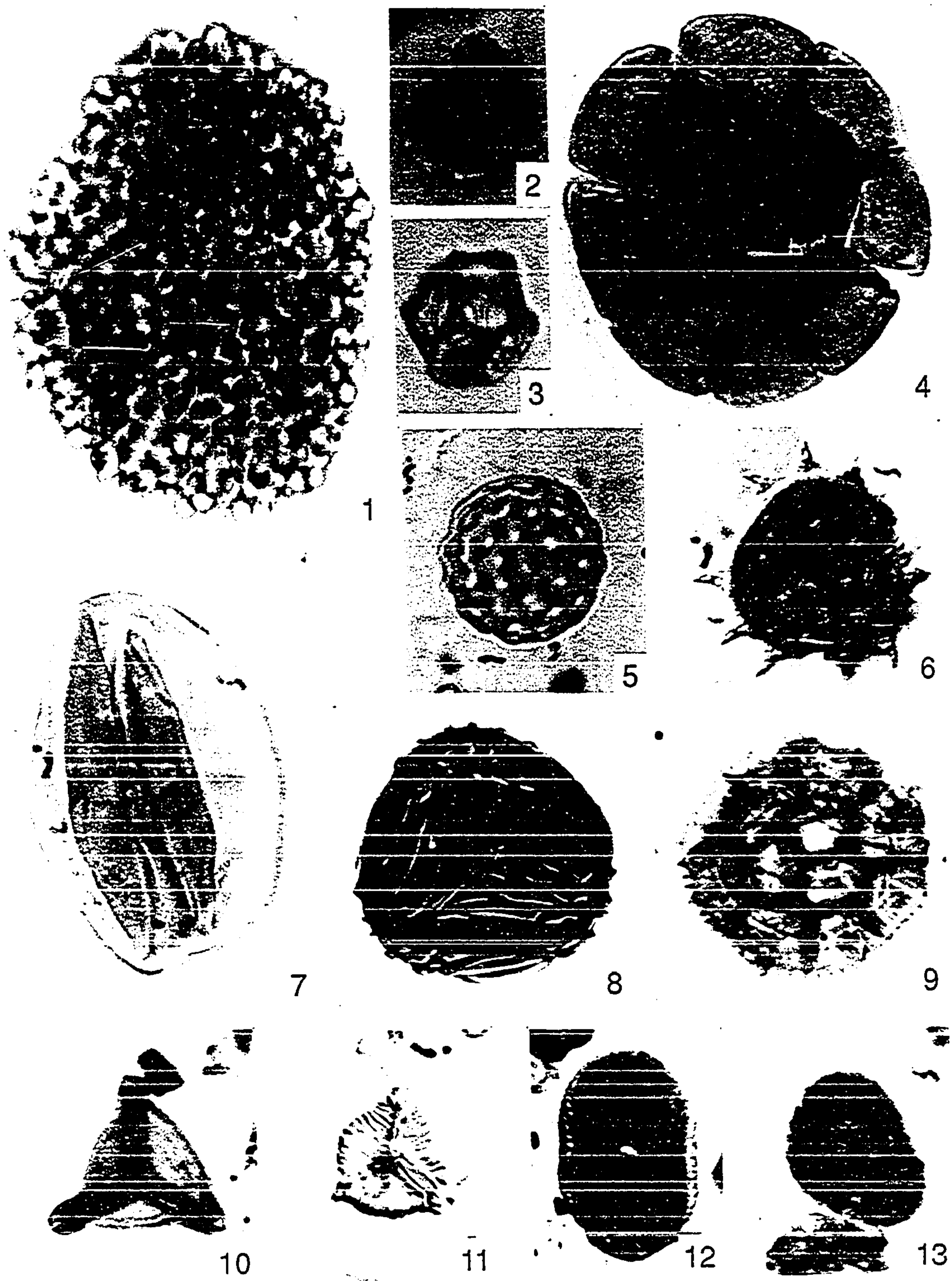

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Figure 53 - Magnification x100

1. Lingulodinium machaerophorum (Deflandre and Cookson) Wall 1967, 64 micron.

2. Nematosphaeropsis cf. N. rigida 56 micron.

3. Capidocysta sp. 60 micron.

4. Polysphaeridium zoharyi (Rossignol) Bujak et al, 1980, 68 micron.

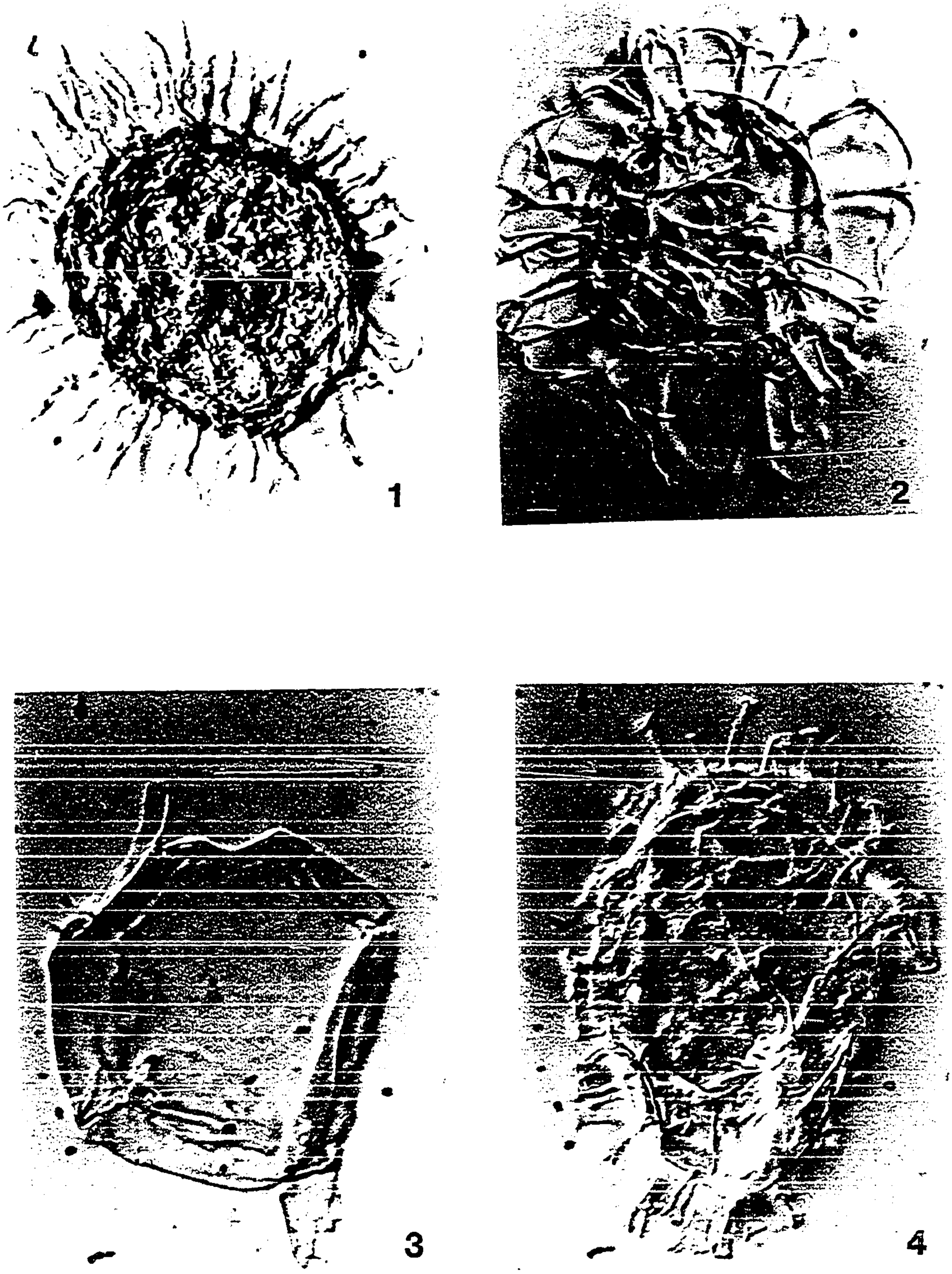
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Figure 54 - Magnification x1000, except Num. 4 x630, Num. 5 x400 and Num. 6 x250.

1. Spiniferites sp. A. 44 micron.

2. Spiniferites sp. B. 56 micron.

3. Hystricholòlpoma sp. 88 micron.

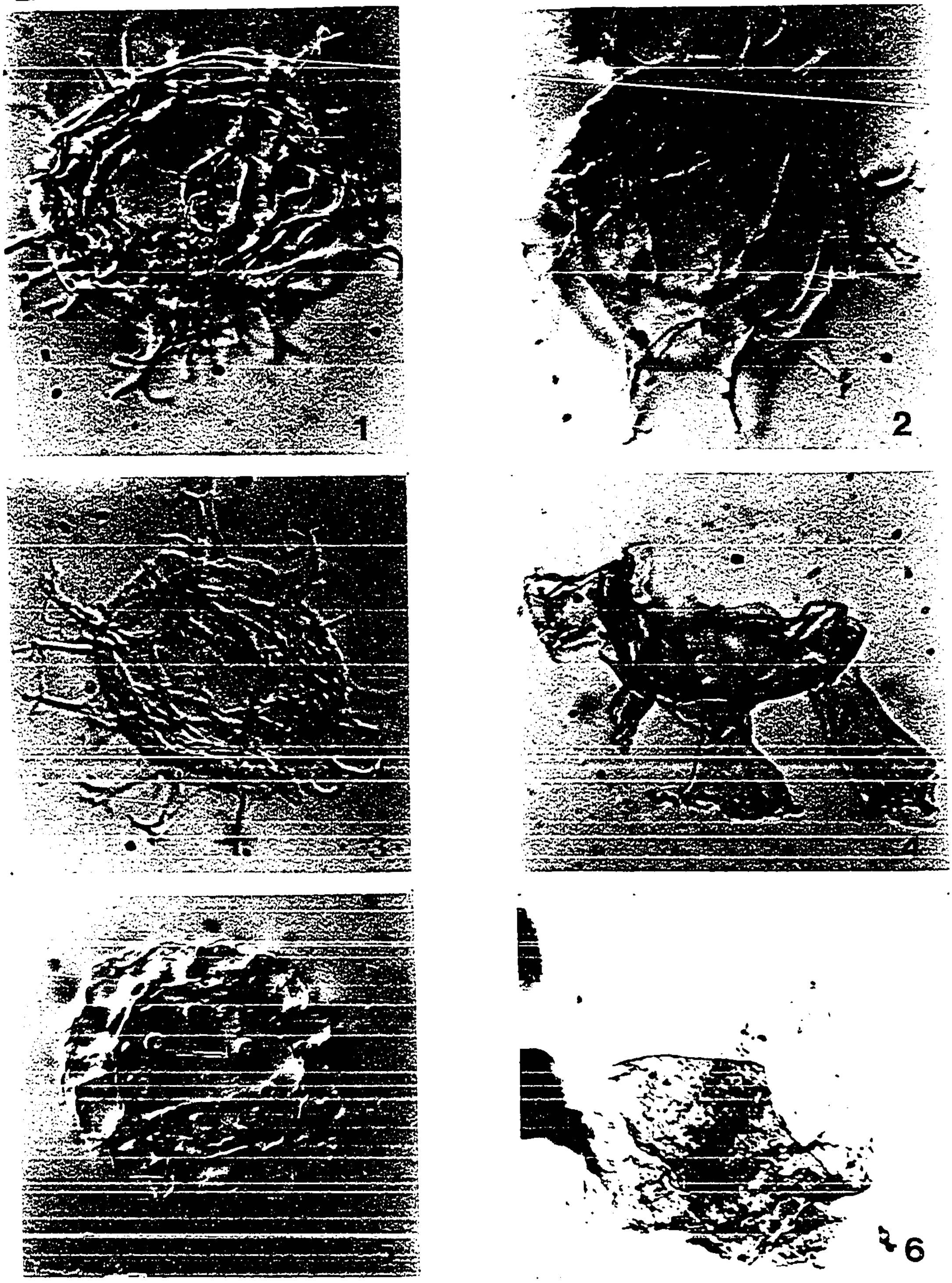
4. Spiniferites sp. C. 44 micron.

5. Tuberculodinium vancampoae (Rossignol) Wall 1967. 88 micron.

6. Rhizophagites sp. Wrenn and Kokinos 1986. 160 micron.

LAMY

PLATE X



Paleontologic Summary

Below is a list of key foraminifera encountered within the West SEG-1 well (this data was provided by Amoco Production Company and Amoco Trinidad Oil Company).

Depth in Well	Foram
2450-2480	Buliminella
3740-3770	Miliammina
4640-4670	Buliminella
5300-5330	Lenticulina
5570-5600	Amphistegina
7490-7520	Saccamina sp
8810-8840	Halophagmoides
9440-9470	Hapostiche
10040-10070	Haplostiche
11000-11030	Haplostiche
11330-11360	Bolivina
11930-11960	Textularia
11930-11960	Eggerella
13820-13850	Reticulophragmium
14840-14870	Alveovalvulina

The following is a list of foraminifera encountered in the GBM-1 well (the foraminiferal identification was done by Texaco Trinidad Inc. and the data was supplied by the Ministry of Energy, Trinidad and Tobago).

Depth in Well	Foram
630	Reworked fragments, Amphistegina sp.
840	Reworked reefal types, Amphistegina
1320	Amphistegina sp., Rotalia choctawensis
1470	Uvigerina, Buliminella 1/2
1560	Globorotalia limbata, Uvigerina
1590	Globorotalia dutertrei
1800	Globigerinoides conglobatus
2430	Reworked fauna with Amphistegina sp.
2760	Bolivina sp., Hormosina sp.
2910	Bolivina sp., Amphistegina sp.
3450	Haplostiche., Bolivina sp.
3510	Textularia, Vaivulina, Buliminela 1/2
3720	Sphaeroidinella sp.
4170	Haplophragmoides, Bolivina
7290	Haplostiche, Cyclammina
7380	Bolivina, Textularia, Buliminella 1/2
9120	" " "
9270	" " "
9420	" " "
9540	" " "
9630	Textularia, Amphistegina, Buliminella 1/2
9840	Bolivina, Amhistegina, Buliminella 1/2
9960	Textularia, Buliminella 1/2
10004	Textularia, Buliminella 1/2

Water Mass Conditions: Palynologic and Palaentologic Evidence

Evidence from palynology and paleontology is based on the presence of various assemblages indicative of various water depths and associated conditions.

Palynologically dinoflagellate cysts and few to common microforams indicate a marginal to open marine environment of deposition. Their association with a terrestrially derived pteridophyte spore, angiosperm pollen, fungal spores, wood fragments, plant tissue, fresh water algae and Botryococcus sp. suggest a continental assemblage deposited in marginal to open marine envirorments (Lamy, 1986).

Three distinct benthonic foraminiferal assemblages provided some paleontological estimates of the water mass conditions at the time of deposition of the Late Early Pliocene section. The assemblages indicate an outer neritic to upper bathyal environment. A Uvigeria assemblage associated with the oxygen minimum layer in the Gulf of Mexicco may indicate similar conditions during Tertiary southern Trinidad; or alternatively may indicate a marine environment in close proximity to one of reduced oxygen content. A Cyclammina association is suggestive of an area or period of reduced sedimentation locally or geographically nearby (Engelhardt-Moore pers. comm., 1991 and Murray, 1973).

Depositional Ervironments

Sedimentary structures suggest that the Late Early Pliocene sediments of the Moruga Group, south Trinidad onshore and in the subsurface was deposited rapidly and by fast-moving, gravity currents. The structures encountered are indicative of turbidity currents and gravity processes.

Fluidization structures are indicative of widespread sediment cover-load and instability. These structures indicate that the rapidly deposited, high water content sediments were unstable and continuously moved downslope in response to gravity.

Palynologic and palaeontologic studies suggest that the processes which deposited these sequences operated in water depths of up to 200 meters. The water depths inferred from the palynologic and palaeontologic data have been the subject of much debate (pers. comm., Quan, 1989, and van Niewnenhuse, 1990). In the absence of additional and conflicting data the paleodepth of 200 meters will be used here.

The presence of plant debris and a terrestrially derived flora suggest that a significant amount of sediment was derived from a continental area and brought to the marine environment before resedimentation. The modes of transport of the continental debris are fluvial and deltaic agents. The ensuing delta could possibly transport large volumes of sediment over great distances onto the shelf during progradation, thus providing a ready source of sediment to be remobilized by shelf currents. Significant relief may also be produced as a consequence of deltaic progradation onto the shelf. Prior et al., 1982, have discussed the emplacement of large masses of sediment in the Kitimat Fjord area on a relatively small slope of 0.5 degrees. They have inferred gravity skidding of the semi-consolidated sediments as the transport mechanism.

There is no evidence along the south coast that a delta was responsible for actually depositing the sequence as preserved. In normal deltaic deposition it is expected that the following facies and features will be represented along with some evidence of delta plain, delta front and prodelta complexes: channel fill, subaerial levee, swamp/marsh, crevasse splays, distributary mouth bars, lignitic horizons and abundant plant material.

A model must therefore be inferred, which is capable of rapidly depositing a large volume (thickness) of sediment in a relatively short period of time, in water conditions previously described.

The "HCS Problem"

Hummocky cross stratification or truncated wave ripple lamination has attracted the attention of many sedimentologists, and have come to be known as being attributable to storms, (Dott and Bourgeois, 1982). This obviously violates all hydrodynamic theories of sediment transport and deposition. If particular hydrodynamic conditions are favorable then it should be expected that any structure will be formed which is stable under such conditions. It is limiting to propose that specific structures are formed only by some erosional and depositional agents, rather than by a given set of hydrodynamic conditions. Truncated wave ripple laminations (HCS) have come to be associated with a trend of thought which obscures theory and introduces unwarranted dogma into the science while not considering the "Principle of Multiple Working Hypotheses", (Chamberlain, 1890).

In looking at the problem these observations pertaining to truncated wave ripple laminations, within the study area should be noted:

- There is a close association/relation to plane beds. Plane beds are often found passing upward into truncated wave ripple lamination ("HCS").

- Plane beds are often found replaced by truncated wave ripple lamination ("HCS") in cothervise typical Bouma sequences.

- truncated wave ripple lamination ("HCS") was found generally in silts and very fine sands.

Recent studies have indicated the following:

- Wright and Walker (1981) combined evidence from trace fossils to infer that this structure was the result of emplacement of sandstone beds by storm generated density currents with the same storm later imprinting the HCS on the deposit.

- Swift et al. (1983) believed it was likely that purely oscillatory flows are not responsible for HCS. They conclude that combined flow currents in areas where these currents were experiencing a downstream velocity decrease and sediment deposition throughout much of the storms deposition. Though they indicate storm association they have strongly inferred intense, turbulent, sand-rich flows and high suspended loads. The morphology and inferred flow characteristics provide evidence that this bedform was a transition-like bed regime.

- If HCS is formed under the influence of oscillatory flows then the dimensions of the hummocks should bear some relation to flow conditions and oscillatory flow theory should be able tco provide existence fields for these bedforms, (Allen, 1985). Allen has not found this to be the case and has concluded that these structures are not only produced under such conditions, but, however that gravity waves may play an important part in the formation of HCS by (a) enhancing the bed shear stress relative to that of a unidirectional current and (b) by introducing a strongly three- dimensional structure to near-bed water motion and preventing substantial bedform migration. These conditions are not unique to storm waves and surges.

- HCS may form from orbital ripples within the wave formed flat bed field, Duke and Leckie, 1986).

- Nottvett and Kreisa (1987) suggested that there is now some evidence for combined flows and that HCS may be a polygenetic phencomena. The evidence came from the presence of some weakly or strongly preferred dip direction amongst some laminae.

- Harms et al. (1990) suggested that HCS may often start with a plane bed; there is strong evidence that flows were oscillatory; confined to a particular grain size; there is some validity in referring to HCS as truncated wave ripple lamination and that three-dimensional wave ripples may grow from plane beds.

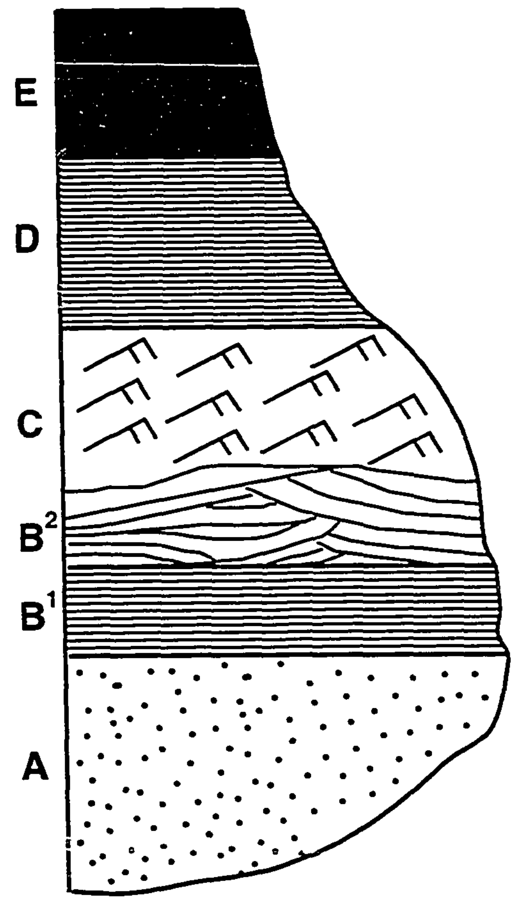
- Southard et al. (1991) also suggest that this is a polygenetic phenomena and that the structure may be produced by more than one set of conditions.

Given the above discussion it appears that HCS should not be considered to be diagnostic; only of storm deposits and that alternative interpretations are possible. A modification of the ideal Bouma sequence is being proposed here (Figure 55). This modificaticon is based on the preceding discussion and the evidence assembled from field studies.

Depositional Model

The sedimentary structures and sequences of the Moruga Group, encountered along the south coast of Trinidad represent turbidites depcosited by gravity currents on the front of the Orinoco Delta which prograded northward away from the South Anerican mainland during the Tertiary. These medium to thickly bedded sands and silts were the result of turbid and intense current activity as inferred from the freguency of scouring and erosional bases, ripped-up clasts of silts and muds, Bouma sequences (complete and truncated), amalgamated beds, plane beds and truncated wave ripple lamination and low mud content.

The necessary topographic relief was created by the progradation of the Tertiary Orinoco delta complex onto the shelf. This delta was also responsible for transporting the sediment which was later resedimented as sediment instability and "pile up" together with high water content gave rise to conditions conducive to slumping and turbidite flow initiation.



The modified sequence is based on the following conditions:

-High and rapid rate of sedimentation

-Sand-rich (fine sand/salt) system

-Highly viscous slurries

Under these conditions HCS may form by remobilization of silts and fine sand in the upper parts of the plane bed field by turbulent and oscillatory flows as the velocity of the turbidity current decreases

Figure 55. Proposed Modification to the Ideal Bouma Sequence

In these shelf settings storms cannot be totally overlooked as they may contribute to the creation of turbulence and dense suspensions. These processes become even more important on tropical shelves similar to the south coast of Trinidad. A storm association therefore cannot be ignored. However, whether storms were actually involved and the exact extent of their role is not known. It was not thought important to infer storm interference as an explanation for the sequence as found. It is also important to note that though HCS is common, sequences which are diagnostic of turbidity currents viz. Bouma sequences are more frequent relative to HCS. Evidence strongly suggest that HCS is probably a transition-like bedform which is the combined result of highly turbulent, sand-rich suspended flows. To what extent this structure can be formed in association with turbidite currents presents an idea for future research.

That the sequence thickened and coarsened upward is indicative of the relative basinward migration of the delta system. Over the length of the section mud content decreased upward probably suggesting winnowing of the finest material during transport and deposition or the lack of mud in the delta plain sand bodies which were remobilized and resedimented.

Turbidites are important processes on the shelves however, they are not the only producers of graded beds in these environments. Tillman (1985) suggested that when complete or nearly complete Bouma sequence are associated with these graded beds then turbidites may be the cause.

Turbidites are normally considered to form fans in deep water, however, more recent studies have indicated the possibility of turbidite sands in shelf areas, (Tillman, 1985). The classical picture of turbidite depositicon includes a point source where the current often originates, eg., canyons. These features have not been recognized along the south coast of Trinidad. More recently there has been evidence that these are not necessary and that turbidites may move downslope (a) along a line source in a series or network of channels along a topographic edge, Chan and Dott (1983) or, (b) in a delta-fed submarine ramp system (Heller and Dickinson, 1985) closely asscociated with a sandy delta prograded onto a shelf. Such studies also support the idea that many shelf turbidites are probably sheet-like in morphology. The above models receive support from Walker (1985) who states that shelf turbidite bodies are not necessarily characterized by submarine canyons and well defined channels as the sediment is moved from various parts of the shelf in response to the development of maximum turbulence. The turbidite bodies therefore develop as sheets which overlie each other rather than being consistently funnelled into specific lobes, (Walker's sheets of newspaper on the floor model).

Because it has been established that the Orinoco delta progaged northward during the Tertiary, the delta-fed submarine ramp model of Heller and Dickinson (1985) is preferred.

It has been established that the sequence was deposited in marginal to open marine conditions in water depths of up to and probably exceeding 200 meters. To accomodate the thick sequence encountered some subsidence of the basin must have occurred. This subsidence could have been (a) sediment load related, or (b) tectonically/structurally related to major and/or minor fault systems which were coincident with sedimentation. Both these mechanisms could have contributed to the thick sequence encountered in the study area. Sediment load related normal faults have been discussed and though not having the characteristics of typical growth faults they probably played an important role in accommodating the large volume/ thickness of sediment involved. The enclosed map illustrates the exact positions of the NW to SE normal faults probably had a role in the accommodation of the thick sequence encountered.

The sedimentary facies relationships and bedding style suggest some similarity to the model of prograding lowstand systems tracts (LST) (Vail, 1987). Low stand systems tracts are the response to high volumes of rapidly accumulated sediments, in tectonically active settings. The sands therefore aggrade and prograde leading to thickly bedded sands in thick sequences, and may be asscociated with delta-front slumping and debris flows. See Figure 10.

Within the context of the foregoing discussion of hydrodynamics and water mass conditions, the three facies described above were interpreted as parts of a shelf/slope fan sequence:

Facies I - Which is composed of thin to medium bedded fine grained sand and a sandstone/mudstone ratio ranging from 5/1 to 20/1 is here interpreted as distal middle to lower (medial to distal) fan deposits. The beds in this part of the fan system are laterally continuous and show mainly truncated Bouma sequences though scome complete sequences are present. Relative to the proximal fan environment there is also a higher mud content. These facies bear a resemblance to similar facies described by Walker and Mutti (1973), Walker (1978, 1984) and Ricci Lucci (1981).

In the submarine fan model proposed by Normark (1970) these deposits may be classified as outerfan deposits.

Fluidization is also evident amongst this facies and this can be attributed to spontaneous sediment failure, (Heezen, 1956). Fluidization may also be enhanced by the higher mud content of these sediments.

Facies II - Is interpreted as proximal midfan lobe facies, marked by intense scouring and the deposition of thicker beds. The characteristics noted suggest that these facies; may be the result of channel-filling (?) on the midfan. Though deeply incised channels have not been observed in this facies, the sharp, erosional bases may indicate deposition in the shallow termini of midfan channels, (Ricci Lucci, 1981). Beds are graded, show complete and truncated Bouma sequences, have a predominance cof amalgamated beds and contain very little mud. The sandstone/mudstone ratio is greater than 50/1.

The thick sequences which are comprised of these facies may suggest repeated deposition within the same channel or maybe indicative of braiding and regular channel and/or lobe switching (similar to lateral migration of lobes). Similar midfan sequences have been observed elsewhere, Nelson and Kulm (1973) and Nelson and Nilsen (1974). Some of the characteristics of these facies (viz. sheet-like geometry, laterally continuous bedding, very little mudstone partings, very thick sandstone beds, well developed Bouma sequences) suggest that they are similar to the depositional lobes of Shanmugam and Moiola (1991), who suggest that they form at the mouths of submarine fan channels. Though a classic well developed fan system is not being proposed as a model in this study, it is still conceivable that some deep scouring and possibly channelling took place as a result of the movement of large volumes of viscous sediment slurries.

Walker (1985) states that in shallow marine/shelf turbidite systems channel; and distinct switching lobes are rare. Walker (ibid.) also state; that in shelf turbidite systems channels are broader than they are long and have very low relief and that levees are rare while thinning/fining upward sequences are poorly developed or nonexistent.

Walker (1978), Mutti and Ghibaudo (1972) and Shanmugam and Moiola (1988) all suggest that both progradational (thickening upward) and aggradational (thinning upward) sequences are possible within this environment. Walker (1984) however has cautioned that thickening and fining upward sequences are subject to dual interpretations and may actually "be in the eye of the beholder."

Synsedimentary depositional structures associated with this facies are the result of soft sediment failure during pile up and mobilization. Sterling and Strohbeck (1975) in their studies of sediment deformation in the Mississippi Delta, suggested that large volumes of sediment may become liquefied and flow under their own weight, giving rise to fluidization structures.

Facies III - These are very thinly bedded triplets/packets of very fine sandstone/siltstcone/mudstone. Beds range from .5 cm to 10 cm and are often characterized by Bouma T_{cde} subdivisions. Facies III contain characteristics which suggest that these facies were deposited in fan or lobe fringe environments. It is also conceivable that these may be levee deposits, however in the absence of deeply incised channels this is a remote possibility. Walker (1984) suggest that similar facies may result from the shifting of deposition from a lobe to lobe fringe environment. Mutti (1973) reports similar depcosits and attributed them to deposition in fan fringe environments by dilute turbidity currents.

Influence of Sea Level

Shanmugam et al., 1985, have discussed the importance of sea level on turbidite deposition. Loading of shelves with huge volumes of detritus during progradation of shoreline and delta systems associated with sea level falls lead to large scale slope failure events and rapid fan growth. Tectonic factors may contribute to relative sea level falls, during which large volumes of detritus were supplied to the basin. The Late Early Pliocene, Moruga Group with it's extensive sandstone depositional lobes is closely comparable with modern medium to large sized systems fed by river deltas, (Stow et al., 1985). Hence by further comparison a mud-rich line source (eg. the Orinoco Delta) which supplied which supplied large volumes of material to the shelf can be inferred. The volume of material supplied to the shelf will have fluctuated with relative sea level fall, maximum delta prograde occurring during phases of sea level fall.

Summary

The sedimentary style which is demonstrated along the south coast of Trinidad seems consistent with the model of lowstand system tracts (LST) of Vail (1987). In these settings subsidence keeps pace with sedimentation, high volumes of sediments accumulate and, sands tend to aggrade and prograde leading to thickly bedded sands in thick sequences. Thick intervals of coarsening upward sands, delta front slumping, debris flows and massive sheet flows influenced by gravity processes are consistent with this model.

PETROLOGY AND PROVENANCE OF THE MORUGA GROUP

Introduction

This secticon presents data on the mineralogy and provenance of sandstones, of the Moruga Group exposed along the south coast of Trinidad. The discussion that follows seeks answers to questions pertaining to composition (mineralogy), classification, provenance. In general simple conventional methods were used to extract data from the samples collected. The Scanning Electron Microscope with an attached, KVEX Elemental Analysis system was used to extract additional data from nine samples with emphasis on the morphology and composition of authigenic components in pore spaces and along grain boundaries and contacts.

Light Minerals

The major and accessory framework mineralogy of the Moruga Group sandstones consists of quartz, chert, detrital mica, feldspar, glauconite pellets, lithic fragments, heavy minerals, opaques, mafics and chlorite. The other important constituents are authigenic calcite and clay minerals.

Mineralogy and Texure of Detrital Grains

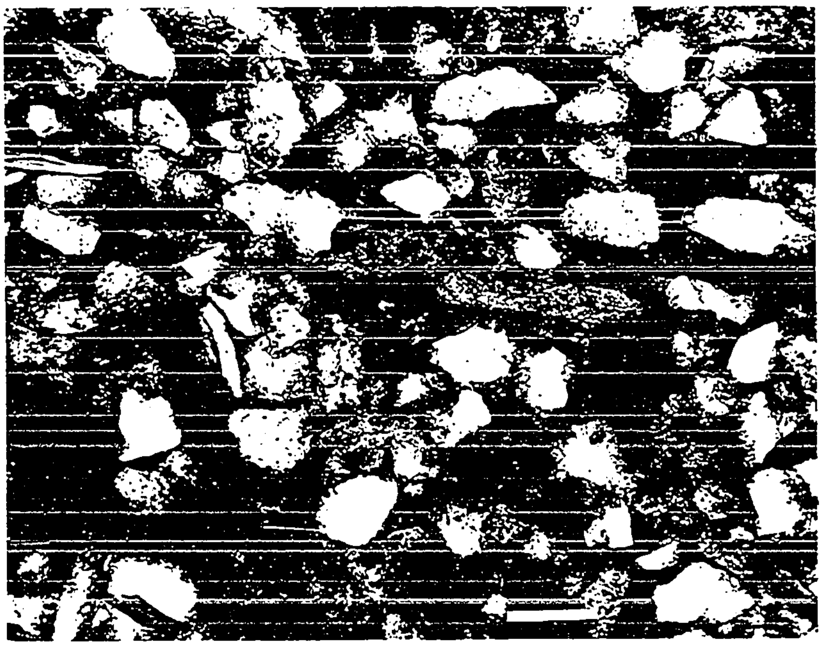
Quartz - Quartz grains range from angular to subrounded in shape and are of fine (62 micron-350 micron) to lowest medium sand grainsize. Some grains are well rounded and show rounded quartz overgrowths. Both monocrystalline (unit) and polycrystalline (composite) quartz are present. These grains have concentrations which average 37% and 6% of whole rock composition respectively. Monocrystalline grains show straight to slightly undulose extinction; very few grains are strained. These grains show some fluid inclusions, but they are generally clear. Polycrystalline grains show straight to slightly undulose extinction and the boundaries between internal grains are quite irregular, being sutured and crenulated in come cases. Crystals within these polycrystalline grains are generally of equal grainsize. In general, the grains showed no signs of physical and chemical corrosion or replacement, though calcite cement filled the cracks within fractured grains. No vertical or lateral variations of quartz grain types or concentrations were observed in the sequence. Figure 56 and Figure 57.

SUMS	SYMBOLS	GRAIN TYPES
Q = Qm + Qp	Q	Total quartzose grains
	Qm	Monocrystalline quartz Grains
	Qp	polycrystalline quartzose lithic fragments (chert etc.)
F = p + K	F	Total feldspar grains
	P	Plagioclase grains
	K	K-feldspar grain
L = Lv + Ls	L	Total unstable aphanitic lithic fragments
	Lv	Volcanic, hypabyssal, and metavolcanic aphanitic lithic fragments
	Ls	Lithic sedimentary fragments
Lt = L + Qp	Lt	Total aphanitic lithic fragments (both unstable and quartzose)

Table 3.
Explanation cof characters used in the ternary plots of sandstone modal data.

Figure 56 - Very fine grained, calcareous subarkose/sublitharenite with porosity cement. This sample is fairly well sorted. Fluid inclusions are present within some quartz grains but the majority are clear. Overgrowths are well developed and more frequent within this grainsize. Grains are subangular to subrounded. Sample BH 49, Late Early Pliocene, South Coast, Trinidad. Scale bar is 100 microns. Magnification x125.

Figure 57 - Very fine grained, poorly sorted, subarkose/sublitharenite with little or no porosity resulting from high matrix and cement content. Monocrystalline quartz grains are subangular to subrounded and record the presence of fluid inclusions, however they are generally clear. Some quartz grains show the development of overgrowths. Sample BH 9, Late Early Pliocene, South Coast, Trinidad. Scale bar is 100 microns. Magnification x125.



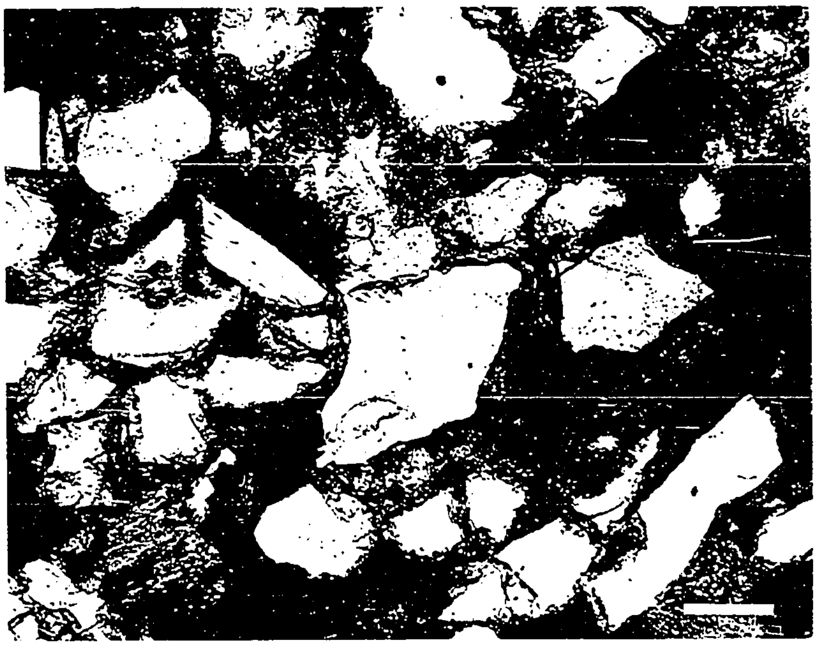
Feldspar - Volumetrically feldspars are not very important with concentrations that average 6 percent plagioclase and 3% potassium feldspar, respectively. Plagioclase feldspar grains show three levels of weathering appearance, (a) fresh grains that show no signs of weathering or corrosion, (b) grains that show signs of weathering, corrosion and abrasicon and (c) grains of both types that are wholly or partially replaced by authigenic calcite. Sericitization of some feldspar grains was observed. Cleavages of both potassium and plagioclase feldspars are well developed and the twin planes and lamellae of the plagioclase are very well developed. The grains are cracked and broken in some instances, an effect that appears to have been caused by compaction. Wherever this was observed, calcite infilled the cracks and fissures. Feldspar grains range from silt to very fine sand size, Figure 58.

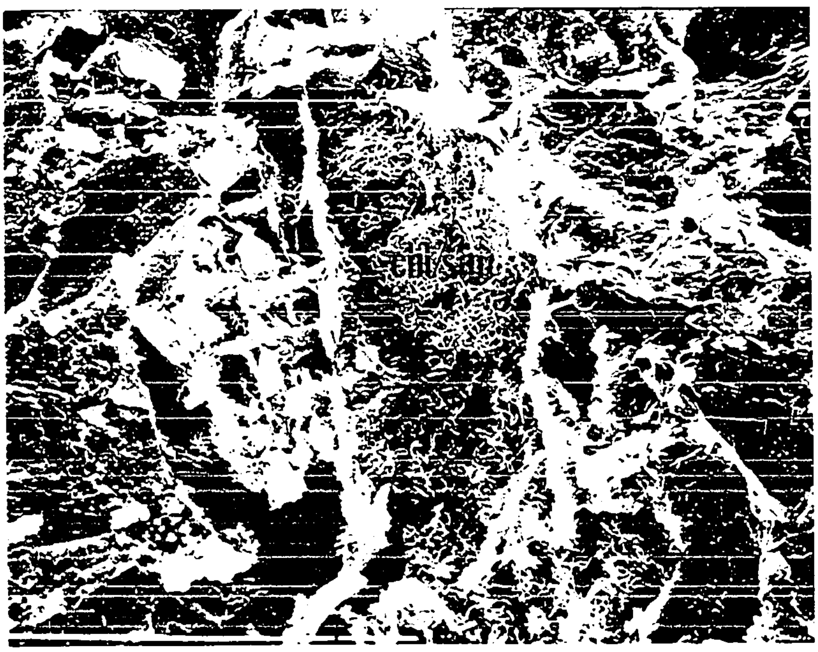
Investigation with the SEM shows some feldspar grains to have undergone partial dissolution. The micro-pore space formed by this process is marked by sericitization and sometimes lined by growth of authigenic chlorite. See Figure 59.

Lithic Fragments - Three classes of lithic rock types are represented in these sandstones. Average whole rock concentrations of the three lithic fragment types are: lithic; sedimentary 3%, lithic metamorphic 1% and lithic volcanic and plutonic 1.5%. The igneous lithic grains are mainly microcrystalline aggregates with a feldspathic groundmass and mafic materials. Vitric grains have also been observed in very small quantities. In some cases the groundmass has been chloritized. Unstable sedimentary lithic grains have been observed. These include fragments of mudstone

Figure 58 - Fine-grained, moderately well sorted calcareous subarkose/sublitharenite with a relatively open framework, however with pore space occluded by matrix and cement. The figure shows a fresh grain of plagioclase feldspar surrounded by quartz grains with numerous fluid inclusions. Grains are angular to subangular. Overgrowths are observed on some quartz grains. Sample BH 38, Late Early Pliocene, South Coast, Trinidad. Scale bar is 100 microns. Magnification x125.

Figure 59 - SEM photograph of a secondary solution microporosity within a plagioclase feldspar grain. Porespace is lined by authigenic growth of chlorite and smectite. Magnification x1300. The short scale bar is 10 microns. Sample BH 26, Late Early Pliocene, South Coast, Trinidad.





(some grains of which are very iron-rich), siltstone, very fine-grained sandstone, glauconitic and non-glauconitic pelloidal grains. Some of these pelloidal grains have been deformed during compaction and are squeezed in between framework grains, thus forming a matrix and occluding primary porosity. Low grade metamorphic lithic; grains were observed. These are mildly metamorphosed, argillaceous, foliated, mica-rich fragments. Figure 60.

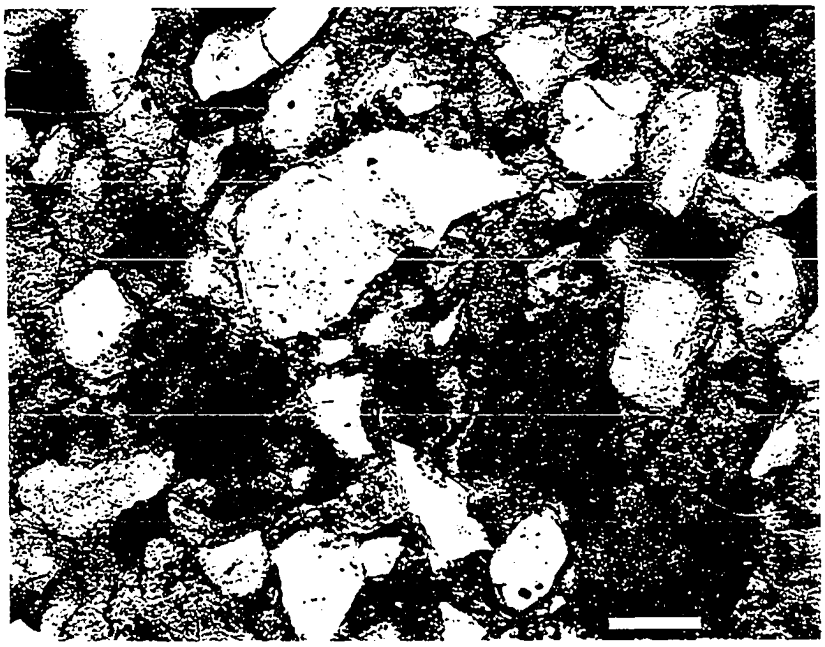
Chert - Grains of microcrystalline chert are present and average 3% of whole rock composition. Due to their very fine grained nature it is difficult to recognize internal structure within these grains. Figure 61.

Mica - These are of two types (a) muscovite (1.7%) and (b) biotite, which displays a pale green pleochroism (.5%). Mica flakes are often concentrated along laminae thus defining a rough flow pattern. These micas are often found bent between framewcork grains probably as a result of compaction. Figure 62 and 83.

Glauconite - Glauconite occurs mainly as very fine grained pelloids that are often found to be squeezed between more resilient framewcork grains, thus occluding pore space. These grains are generally oval shaped and yellow green in color. Glauconite in some instances may be mistaken for matrix and is also sometimes replaced by calcite cement. Figure 64 and 65.

Figure 60 - Argillaceous sedimentary lithic fragment squeezed between quartz grains. Similar lithic fragments are incorporated into the matrix in other areas. Note how the primary intergranular porosity is infilled by matrix comprised of argillaceous fragments. Sample BH 9, Late Early Pliocene, South Coast, Trinidad. Scale bar is 100 microns. Magnification x125.

Figure 61 - Very fine-grained calcareous subarkose/sublitharenite showing fragments of chert, opaques and quartz grains. Note also the lack of porosity and the tight cementation. Sample BH 58, Late Early Pliocene, South Coast, Trinidad. Scale bar is 100 microns. Magnification x125.



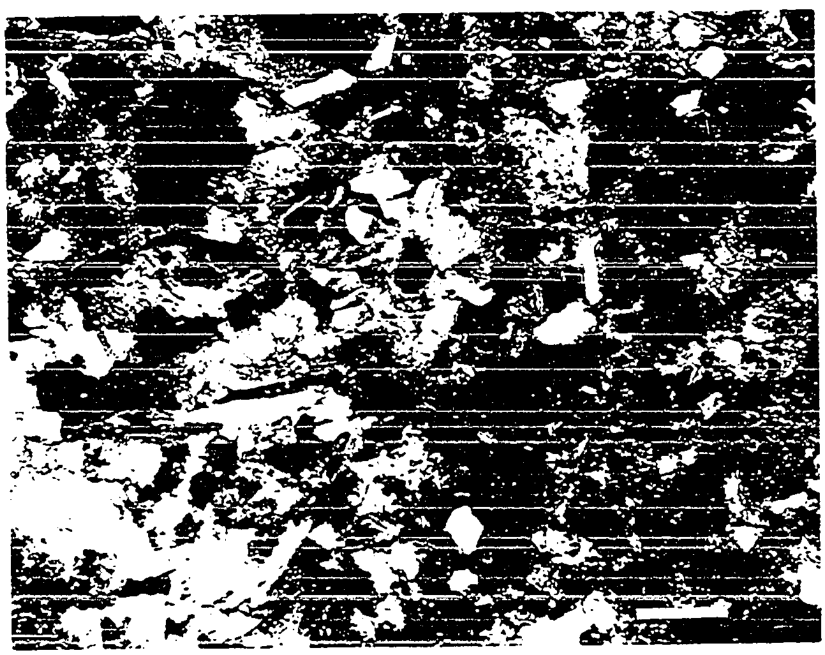
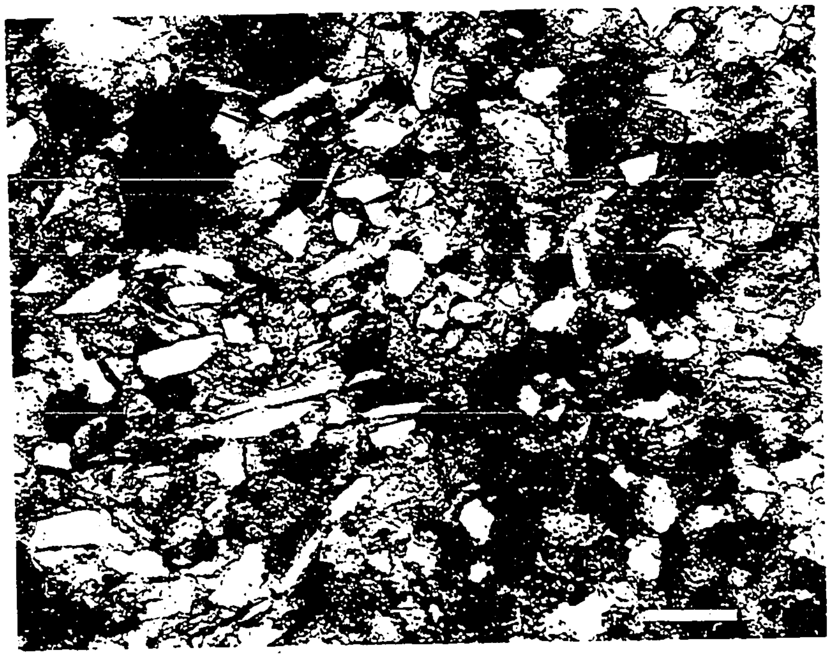


Figure 62 - Very fine-grained, moderately well sorted calcareous subarkose/sublitharenite with a elongate fragments of mica dispersed throughout. Other constituents include quartz and feldspar. Porosity is again occluded by matrix and cement. Sample BH 58B, Late Early Pliocene, South Coast, Trinidad. Scale bar is 100 microns. Magnification x125.

Figure 63 - Fine-grained moderately well sorted calcareous subarkose/sublitharenite. This sample shows a mica flake bent around a quartz grain during compaction. Grains are subangular to subrounded. A comparison of Figures 47 and 48 illustrates grading within a sandstone bed 2.1 meters thick. Figure 48 was taken from a sample collection 20 cm above the base of the bed while Figure 47 was taken from a sample at the top of the same bed. Sample BH 58A, Late Early Pliocene, South Coast, Trinidad. Scale bar is 100 microns. Magnification x125.



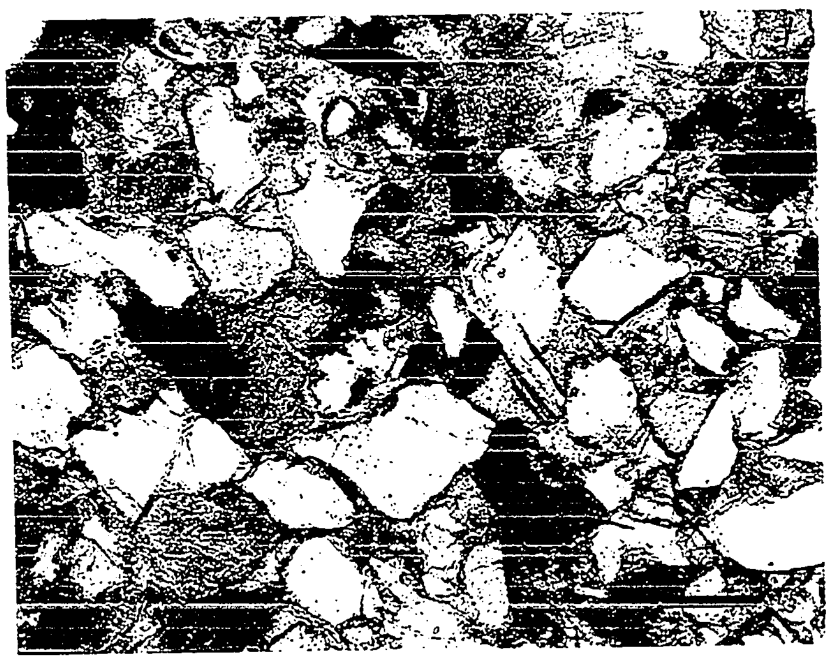
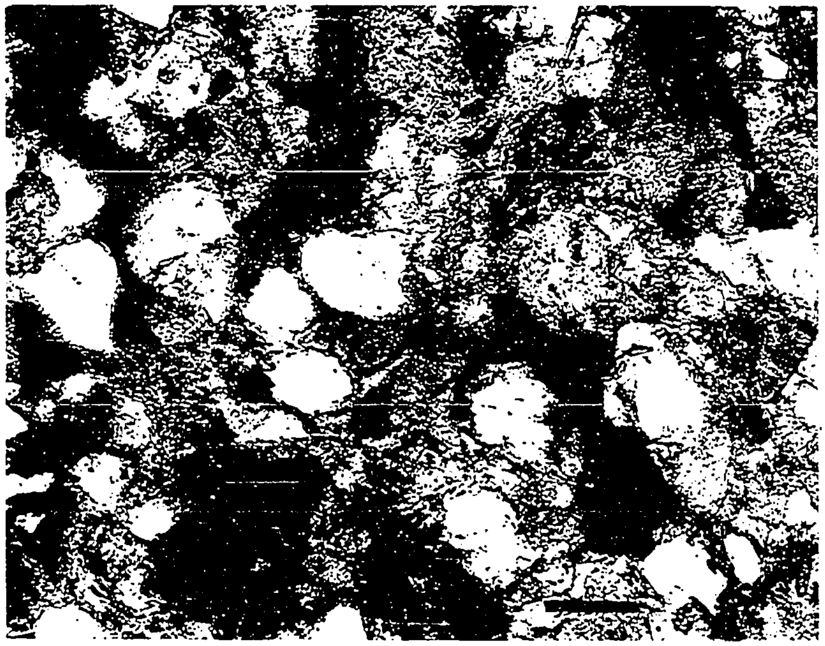
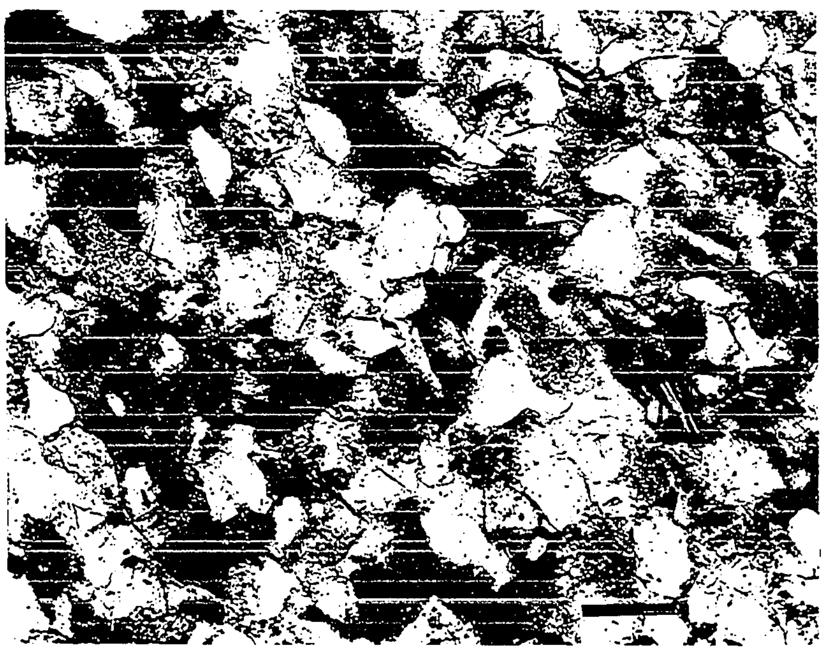


Figure 64 - Very fine-grained, moderately well sorted calcareous subarkose/sublitharenite with a high matrix and cement content and no porosity. Grains are subrounded and appear to float within the matrix and cement. The matrix contains a considerable amount of glauconitic grains/pelloids squeezed between the more resilient quartz. Sample BH 9, Late Early Pliocene, South Coast, Trinidad. Scale bar is 100 microns. Magnification x125.

Figure 65 - Very fine-grained, poorly sorted calcareous subarkose/sublitharenite with high matrix content. The matrix is comprised almost totally of glauconitic grains squeezed between more resistent quartz grains during compaction. As a result there is no remaining visible porosity. Sample BH 25, Late Early Pliocene, South Coast, Trinidad. Scale Bar is 100 microns. Magnification x125.





Mafics - These are not very important in these rocks. Chloritization of most of the mafic grains coupled with some replacement by calcite made identification difficult. From modal analyses, the average whole rock concentration of chlorite is estimated to be approximately 1%. Chlorite is found in the matrix of the sandstone and also in the groundmass of some lithic fragments. It also replaces and clouds some mafic minerals. Glauconite was observed mainly as pellets.

Authigenic Constituents

The authigenic components were examined by thin section, X-Ray Powder Diffraction and Scanning Electron Microscopy. Thin section examination allowed for easy optical identification and description of calcite. Clay-minerals are a major authigenic constituent of these sandstones and these are illustrated in the accompanying SEM photographs.

Calcite - Authigenic calcite cement is a volumetrically significant constituent of these sandstones, and accounts for up to 16% of the whole rock composition. Preliminary work with the SEM suggest that some siderite may be locally developed. This is confirmed by XRD analysis which shows two sandstone samples (BH-18 and BH-33) having 50% siderite and 50% calcite. SEM imaging indicates that calcite is developed as an early cement on most grains and occurs as small but blocky pore-lining and pore-filling crystals.

Staining of the carbonates suggests that much of the calcite has a high iron ccontent. KVEX analysis of calcite indicates small amounts of Fe within the calcite which supports the ferroan calcite inference.

Calcite partially replaces grains and grain boundaries of feldspar, rock fragments and mafics. Original outlines of grains sometimes occur as faint lines or shadows within the cement. Figures 66 and 67.

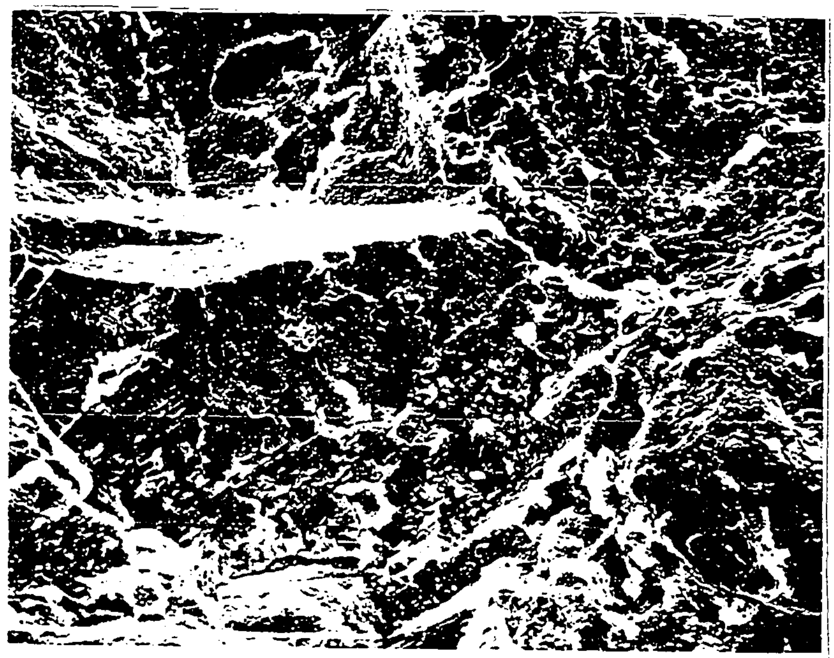
Kaolinite - Wherever found, this mineral is well crystallized and partially pore-filling. Kaolinite constitutes 15.7% and 4% of the clay mineral assemblage in outcrop and the subsurface respectively. Kaolinite occurs as face to face, hexagonal or psuedohexagonal sheets in packets called booklets which are diagnostic of this mineral. Some microporosity is associated with the occurrence of kaolinite. KVEX analysis shows large amounts of Si and Al but no potassium or iron, thus confirming the identification as kaolinite. Figures 68 and 69.

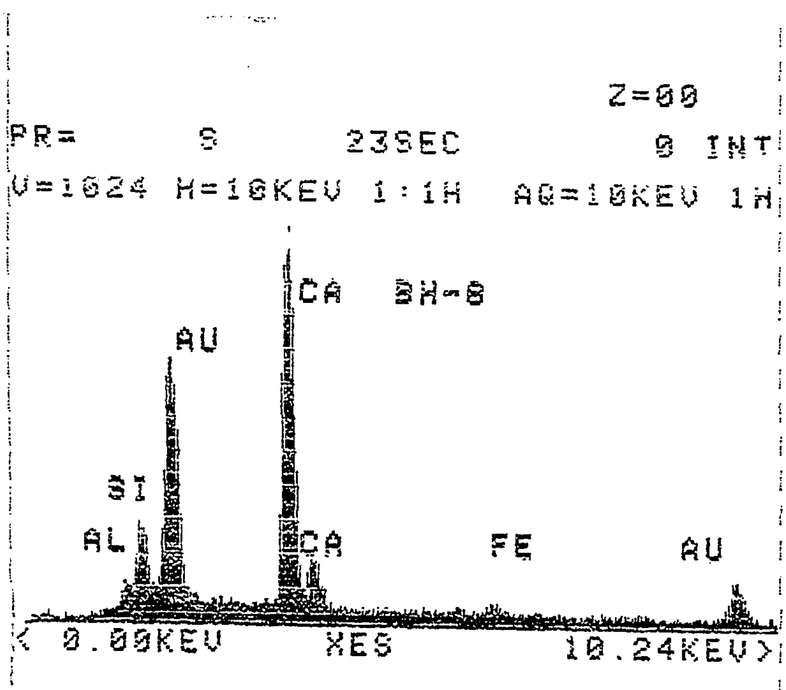
In samples of mud/clay the presence of Kaolinite was confirmed by X-Ray Powder-diffraction with peaks at approximately 13° (7.2 angstrom) and 26° two theta (3.6 angstrom). There was no response of these peaks to glycolation; however, they disappeared upon heating to 550°C.

Chlorite - Chlorite is a minor constituent which constitutes respectively 1.3% and 1.8% of the clay minerals in outcrop and the subsurface. Found in various forms (a) thick sets made up of shingled sheets which coat grain surfaces; (b) rare rosettes; and, (c) as a honeycomb coating around some grains that also effectively infills porespace. Some microporosity is associated with chlorite crystallization.

Figure 66 - SEM photograph of calcite cement coating a quartz (?) grain and infilling porespace. Note sucrosic texture of calcite, and possibly some microporosity developed within the cement. Small scale is 100 microns. Magnification x700. Sample BH 8.

Figure 67 - KVEX elemental analysis of sample BH 8 showing significant peaks for Ca and Si.

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CA BH-8
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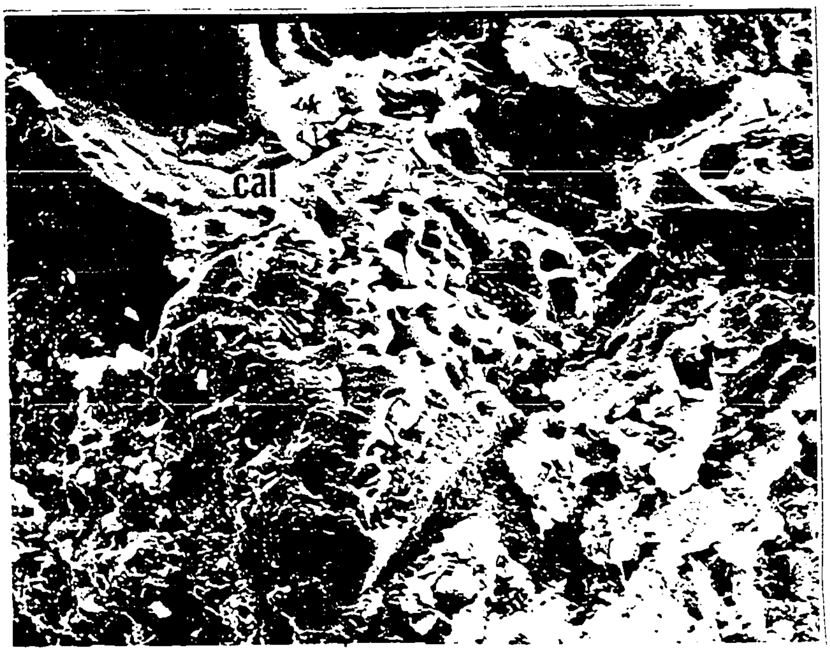
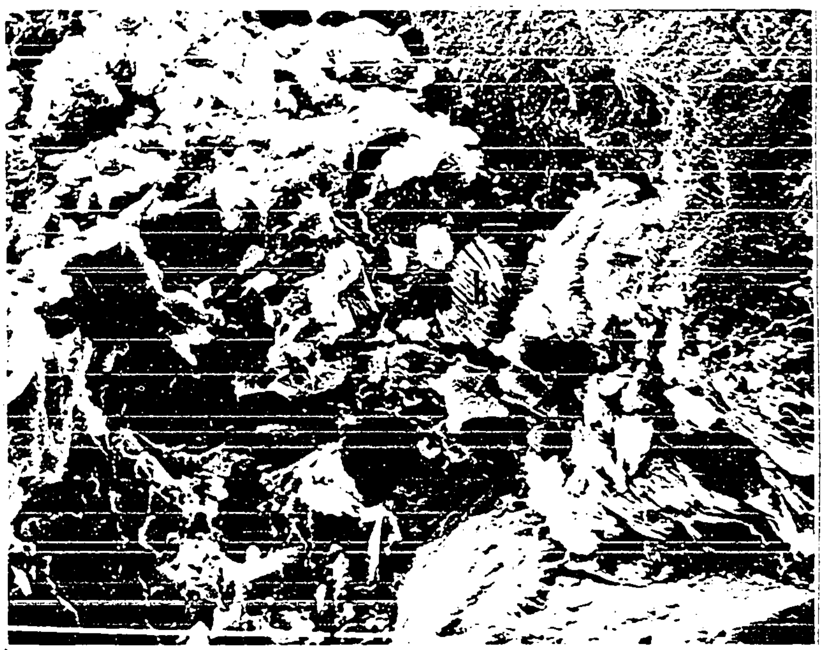
Figure 68 - SEM photograph showing calcite (cal) cement textures developed within porespace. Small scale is 10 microns. Magnification x1360. Sample BH 3, Late Early Pliocene, South Coast, Trinidad.

Figure 69 - SEM photograph of a porespace in sample BH 3 illustrating how porosity is occluded by authigenic growth of kaolinite (K) and calcite. The adjacent grain is quartz. Small scale is 10 microns. Magnificatin x1360. Late Early Pliocene, South Coast, Trinidad.


cal



No XRD pattern of chlorite was obtained during analysis of mud/clay samples. KVEX analysis of sandstone samples yield high concentrations of Si, Fe and Al which support the presence of chlorite. Figures 70, 71, 72 and 73.

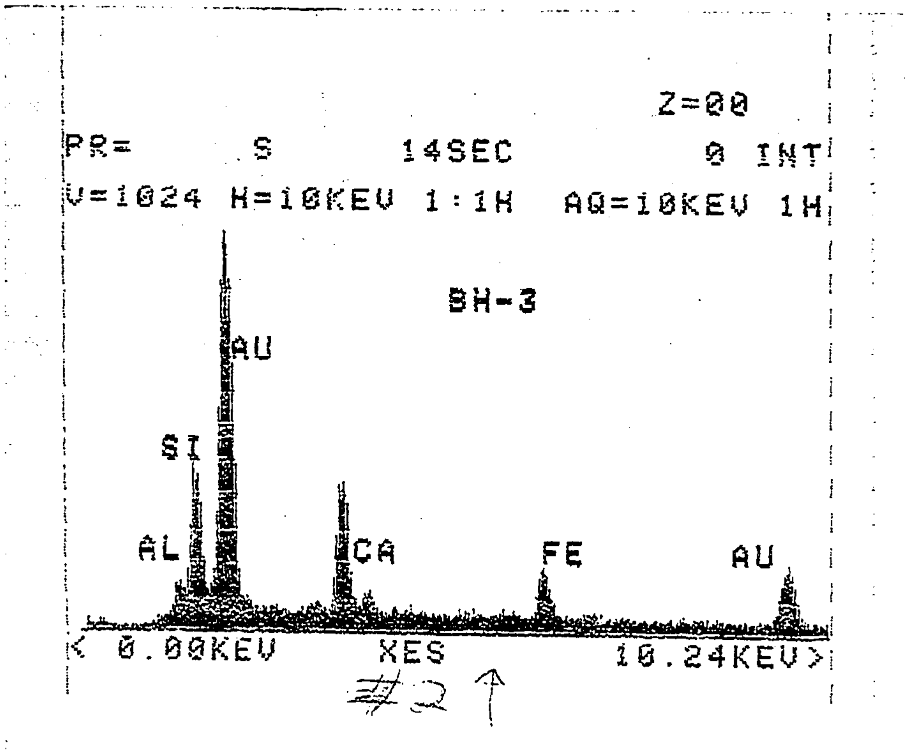
Illite/Smectite (I/S) - Mixed-layer I/S contributes 74.6% and 39% respectively of the clay minerals in outcrop and the subsurface. The presence of I/S is suggested by broad peaks at approximately 6.7 degrees two-theta. Some discrete illite is also suggested by peaks at 9.5 degrees two-theta (10.1 angstrom). Discrete illite is present in amounts of up to 10.9% and 27% respectively in outcrop and the subsurface. No I/S was identified during SEM viewing of sandstones. Welton (1984) emphasized the difficulty of identifying mixed-layer clays in the SEM. Huff (pers. comm., 1990) also suggested that, unless critical point drying is used, the filamentous I/S clays may be destroyed during sample preparation and not seen in the SEM.

Smectite/Chlorite - it is not clear that these occur as a mixed-layer pair in these sandstones. However a close chemical association is suggested by KVEX analysis yielding Si, Al, Fe, Ca and K. This composition is most often associated with the "honeycomb" type chlorite described earlier. See Figures 59 and 60.

Porosity - The early precipitation of carbonate cement and the presence of a high matrix content has obliterated all or most of the porosity originally present in these sandstones. There is little evidence of the widespread development of much secondary porosity. However, where

Figure 70 - KVEX elemental analysis of sample BH 3 showing intense peaks for Si and Ca and a fairly significant peak for Fe. The strong Si and Fe peaks probably indicate the presence of some smectite or chlorite.

Figure 71 - SEM photograph showing chlorite (chl) crystallized as shingled sheets which coat grain surfaces and grow into porespace. Small scale is 10 microns. Magnification x1400. Sample BH 11, Early Late Pliocene, South Coast, Trinidad.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BH-3
AU
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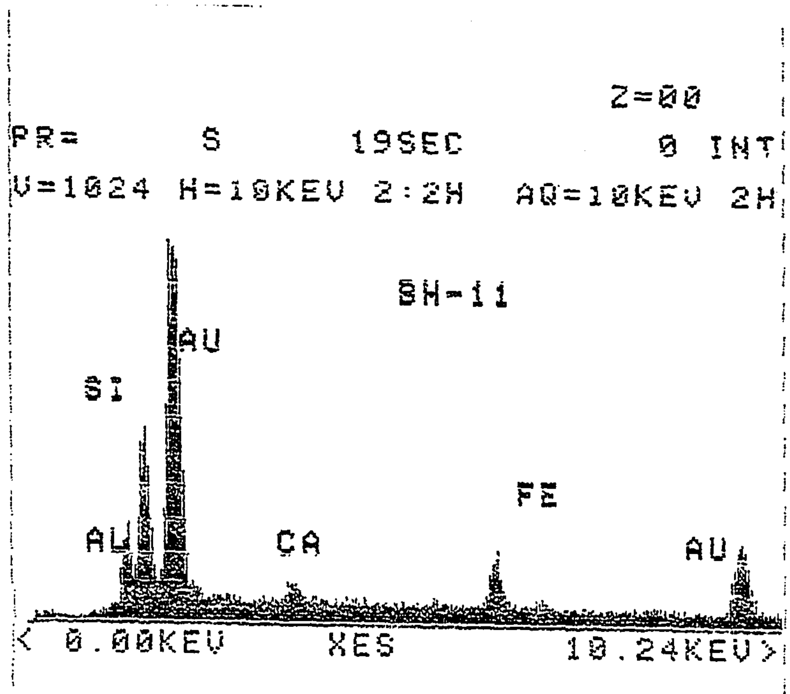
#2


chl

Figure 72 - KVEX elemental analysis confirming the presence of chlorite in sample BH 11.

Figure 73 - SEM photograph illustrating shingled sheet morphyology of chlorite (chl). Chlorite in this illustration infills a primary pore space and is very tightly packed. Calcite is cal. Sample BH 9, Late Early Pliocene, South Coast, Trinidad.



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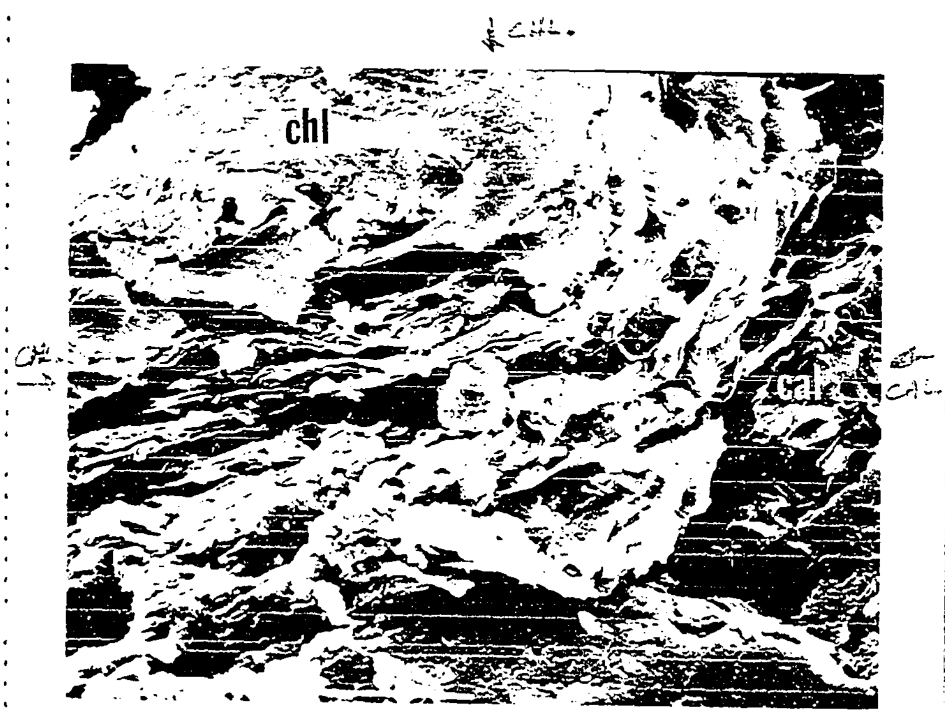
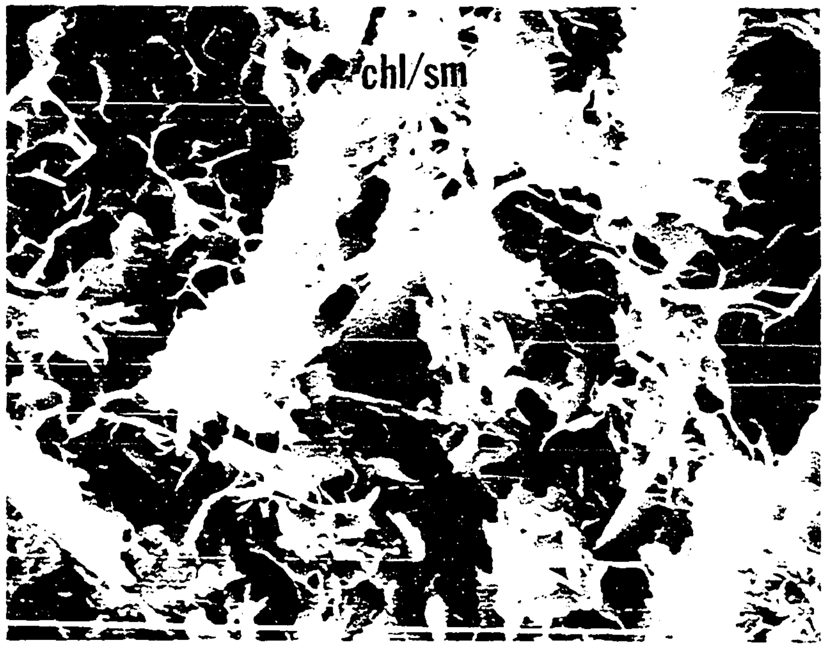
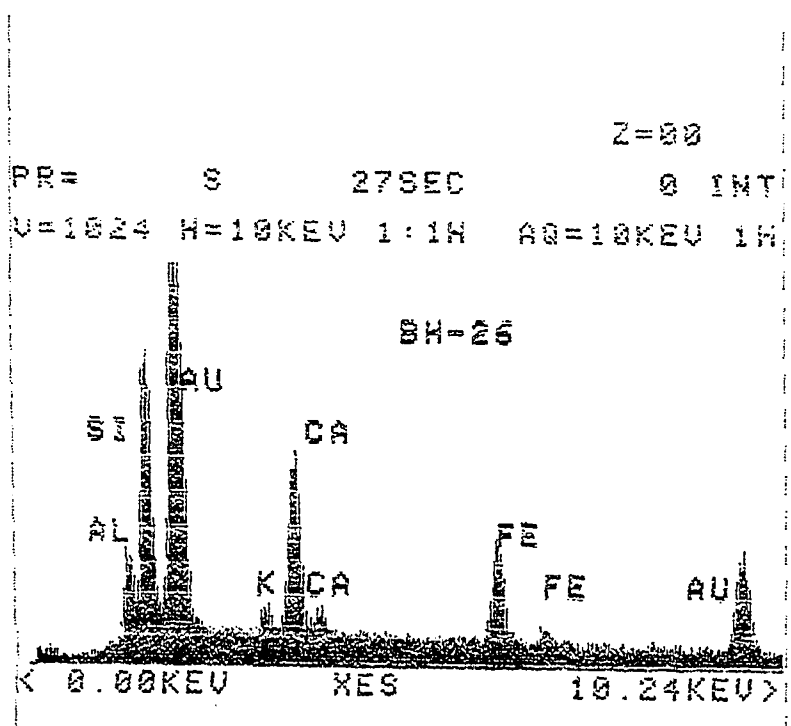


chl
cal

Figure 74 - SEM photograph probably indicating a close association of chlorite and smectite occupying a porespace. The "honeycomb" structure is typical of chlorite. Small scale is 5 microns. Magnification x6500. Sample BH 26, Late Early Pliocene, South Coast, Trinidad.

Figure 75 - KVEX elemental analysis confirming the presence of chlorite and smectite in sample BH 26.


chl/sm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secondary porosity is suggested, it was infilled by later stage calcite cement. The porosity present was observed during SEM viewing of the sandstones and this porosity was microporosity developed in association with clay precipitation and crystallization. Some microporosity was also developed through the weathering and dissolution of feldspar grains.

Sandstone Classification

Upon preliminary examination of these sandstones it was observed that there was a considerable amount of matrix/mud within interstitial spaces. This observation has traditionally led to debates about classification and the origin of this matrix in sandstones. The problem is briefly discussed and the sandstones classified.

Classification is a natural consequence of the systematic petrographic description of sandstones, for like all natural materials, sandstones differ from one another and a convenient practical shorthand is required to conveniently label and classify them, (Pettijohn et al., 1972). The choice of a classification is often one which reflects the subjective views of the operator. Though subjective, the classification scheme adopted for use should be chosen on the basis of carefully observed scientific properties which are reproducible by subsequent operators. Over the years classifications have been used and scrapped with similar ease as operators have attempted classifications which are based on composition, composition and texture and even composition, texture and genesis.

An example of the classification problems is the term greywacke. Some of the chaos associated with this term stemmed from the "matrix" problem, i.e., was matrix primary and depositional or secondary and diagenetic? The problem has been thoroughly discussed by Cummins (1962) and Hubert (1984) who have conclusively shown that the matrix of so called greywacke is diagenetic as Recent and Tertiary greywacke which were deposited by turbidity currents are practically free of detrital matrix. Their observations suggest that matrix may be the product of time and the breakdown of muddy and volcanic fragments. With time matrix can also be replaced by carbonate cement, (Pettijohn et al, 1972). This may very well be an important process in these sandstones from the south coast of Trinidad.

The reader is referred to Klein (1963) for a review of approaches to classification of detrital sediments. Commonly used classifications since then have been published by Folk et al., (1970), Folk (1978), Pettijohn (1975) and Selley (1970).

Folk et al., (1970) include quartz (Q) a term incorporating both mono and polycrystalline quartz, all types of feldspar (F) and rock fragments (R) as end members. Folk (1978) used quartz except chert, all feldspars (F) and all rock fragments (R) including chert, slate, volcanics, limestones, sandstones and shales as end members. Pettijohn et al., (1972) classification was a development frcom Dott (1964) and uses a three dimensional approach. This is an important scheme as it transcends the whole spectrum from clean sands to total mud; that is, arenites, wackes, and mudstones. Wherever the term arenite is used it refers to a sandstone with less than fifteen percent matrix material as opposed to "wacke" which has greater than fifteen percent matric. An obvious shortcoming of the latter classification is that inherent in the scheme are implications cof depositional environments and genesis.

Results

Two schemes were used to classify the sandstones of the Moruga Group. One is based solely on composition (Folk, 1978) whereas the other suggests the importance of depositional environment and probably diagenetic effects in the eventual composition of the sandstones (Pettijohn et al, 1972).

The claim that the (Pettijohn et al., 1972) classification is based strictly upon composition is debatable because terms such as "clean" are used in their discussion. It is well accepted within geologic literature that such terms make strong suggestions of winnowing by depositional agents during sedimentation. If we then consider that matrix may be diagenetic, then the classification falls short in that it has implications for post-depositional processes. Therefore it is not as clear whether or not this scheme attempts to represent the original sandstone composition as does Folk's (1978).

The classification of Folk (1978) yielded the following results: eleven (11) sandstones plotted as subarkoses, six (6) plotted as sublith-arenites and six (6) plotted as lithic arenites, Figure 76. The compositional maturity of these sandstones is therefore highlighted.

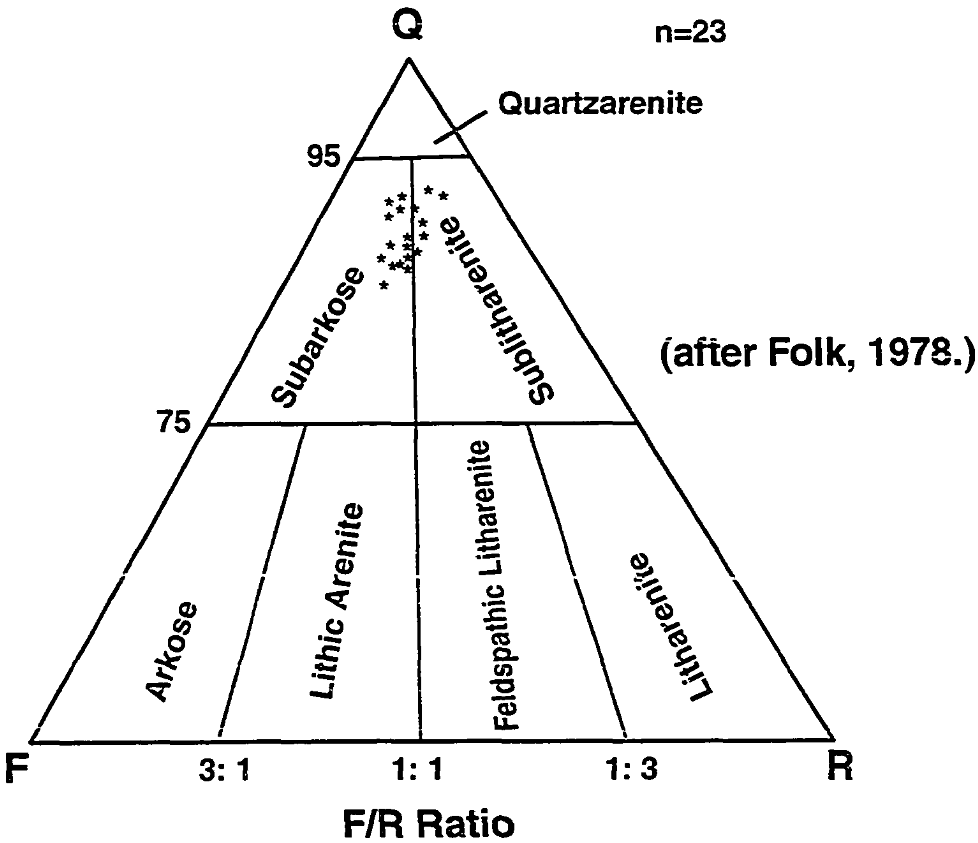


Figure 76. Classification of Sandstones

Petrographic analyses indicated that though matrix is important it does not exceed fifteen (15%) percent. The sandstones therefore plot in the arenite field of Pettijohn et al, (1972). This classification yields the following results: sixteen (16) sandstones plot as subarkoses, six (6) plot as sublitharenites and one (1) plot as an arkosic arenite, Figure 77. Again the compositional maturity of the sediment is highlighted.

Using an adjectival prefix to indicate the character of the cement (Pettijohn et al., 1972) these sandstcones will be referred to as calcareous subarkoses, calcareous sublitharenites and calcareous arkosic arenites.

Heavy Minerals

Because heavy minerals are not included in the scheme of Dickinson and Suczeck (1979) or Dickinson et al. (1985), the modal percentages of heavy minerals in these samples are not included in the analysis of provenance which follows. A seperate interpretation using the ZTR index demonstrates the use of heavy minerals in paleogeographic reconstruction. The heavy minerals encountered, and which account for approximately 0.9% by weight, of these sandstones, occurred in the very fine sand range (88 micron - 177 micron). Brief descriptions of the minerals encountered are given below together with the results of point counting approximately 100 grains per sample on four (4) samples.

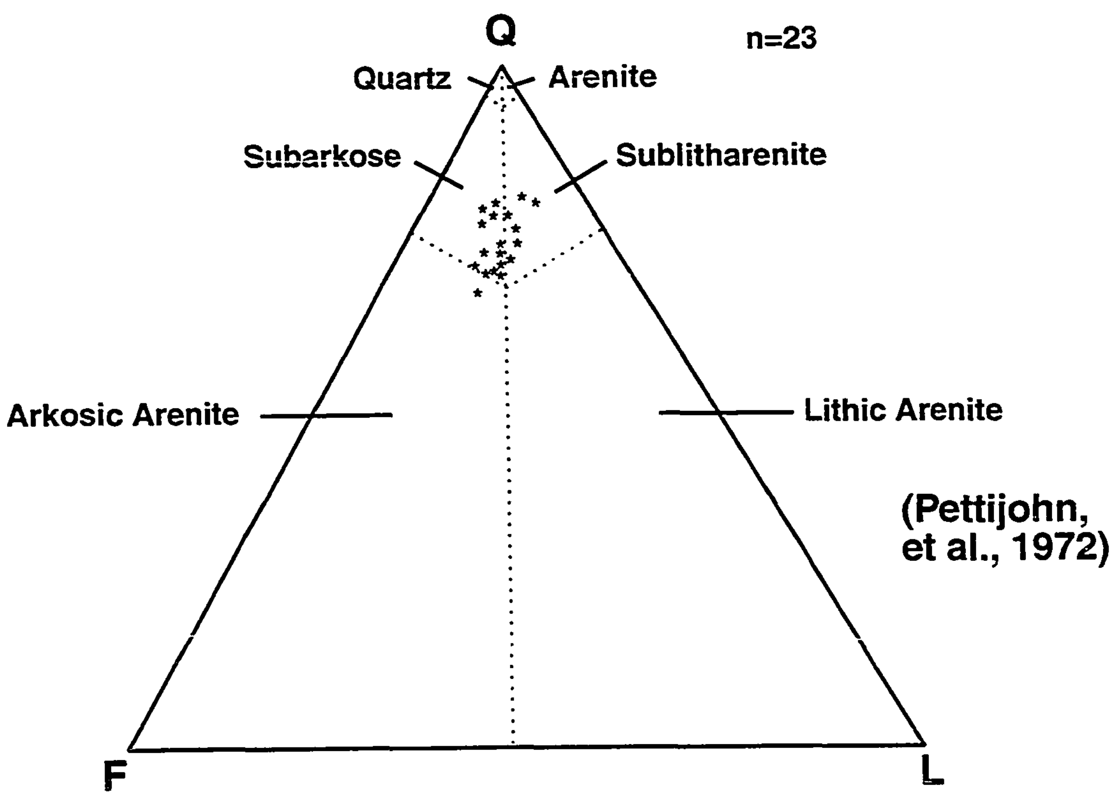


Figure 77. Classification of Sandstones

Generally, the heavy minerals encountered are subangular to subrounded in shape and do not appear to have been greatly affected by weathering. Some abrasion of surfaces was observed; however, the mineral grains are fresh and allowed for fairly easy description.

<u>Garnet</u> - The garnets are found as pale red to dark brown, isotropic, subrounded grains.

<u>Tourmaline</u> - Generally these are found as euhedral, elongate crystals which display strong pleochroism. The mineral is further characterized by it's high relief and birefringence.

<u>Zircon</u> - Some zoned zircons are present. Zircons are colorless and generally show two forms - stubby and elongate; have a high relief and parallel extinction.

<u>Rutile</u> - These are subrcounded crystals with parallel extinction and a high birefringence.

<u>Hornblende</u> - Found as pale green weakly pleochroic grains. Two directions of cleavage are present.

<u>Chloritoid</u> - Green and weakly pleochroic. Anhedral to subhedral crystal form.

<u>Titanite (sphene)</u> - Occurs as broken crystals that are pale yellow in color and non-pleochroic. Grains also show very high relief.

Discusson of Heavy Minerals and the ZTR Index

The ZTR index was introduced by Hubert (1962) as a measurement of mineralogical maturity in sandstones. The index is calculated as a percentage of the combined zircon, tourmaline and rutile grains among the transparent, nonmicacecous, detrital heavy minerals. A high value for the ZTR index indicates a high degree of mineralogic maturity. The index ranged from 48-53% for the four samples studied indicating moderate mineralogic maturity.

TABLE 4

	BH3	BH6	BH16	BH58
Garnet	14	8	16	17
Tourmaline	4	12	13	16
Zircon	34	29	28	28
Rutile	12	11	7	10
Hornblende	9	6	3	2
Staurolite	13	23	22	19
Chloritoid	7	4	6	3
Titanite	7	6	6	5
Mica	2	1	1	0
Total	105	100	102	98
ZTR	49	53	48	53

The heavy mineral suites encountered in these rocks have been described as stable to ultrastable by Pettijohn et al., (1972).

Heavy minerals provided additional information on the degrees of weathering and modification undergone by the sediments. Moderate values for the ZTR index indicate that there was no significant modification of the original sediment composition, and that transport and deposition were rapid processes. Heavy mineral suggest that the assemblage indicates a mixed source terrain consisting of two rock types (a) a low to medium grade metamorphic rock and, (b) an intermediate to acidic igneous rock.

Provenance

Provenance studies give information on the source terrains from which sediments were derived. Sediments have sources, various basin types harbor characteristic deposystems and linkages from provenance to basin carry information about tectonic setting. This statement summarizes some of the goals of this dissertation.

Earlier workers (eg. Middleton, 1950) recognized some of these relationships and demonstrated variations in sandstcone chemistry between the various geosynclinal components and complexes. The ideas of such early workers were then expanded by Crook (1974) and Schwab (1975).

Crook (1974) traced the origins of the hypothesis that sandstone (greywacke) composition provides important constraints on paleogeotectonic reconstruction back to three premises viz:

i) compositional differences between arenites are not accidental and reflect the systematic intervention of processes to give rise to different lithogenetic units.

ii) composition should not be the primary basis of discussion but rather we should begin to look deeply into the genesis of various members of a particular suite,

iii) each suite of sedimentary rocks is the result of sedimentary processes which differ from area to area and thus leads to variations in composition of arenites.

Crook (1974) subdivided sandstones into three major groups which correspond to three types of continental margins of Mitchell and Reading (1969).

i) Quartz-poor greywackes, indicative of magmatic island arcs

ii) Quartz-intermediate greywackes, of mixed provenance and indicative of active (Andean type) continental margins.

iii) Quartz-rich, associated with passive: (Atlantic type) continental margins.

Schwab (1975) examined sandstone suites on the basis of framework quartz and subdivided sandstones into three groups that correspcond to, and strongly support Crook's (1974) groupings viz:

i) sandstones that average fifty eight percent SiO_2 and K_2O/Na_2O or, quartz poor sandstones,

ii) sandstones which average seventy percent SiO_2 and $K_2O/Na_2O<1$ or quartz-intermediate sandstones, and,

iii) sandstones which average seventy percent SiO_2 and $K_2O/Na_2O>1$ or quartz-rich sandstones.

Schwab (1975) emphasized that the concept of plate tectonics provided essentially two contrasting source materials - quartz rich cratons and quartz poor vcolcanic arcs.

Dickinscon and Suczeck (1979) and Dickinson et al., (1983) have distilled the ideas of Crook (1974) and Schwab (1975) into convenient working models using ternary diagrams. Their models incorporated the data from at least four thousand sandstones from different tectonic settings with supporting data from modern ocean sands located in different tectconic settings. Dickinson and Suczeck (ibid.) recognized three broad provenance types and further subdivided each as follows:

Continental Block provenances

-craton intericor
-transitional
-uplifted basement

Magmatic Arc Provenance;

-undissected
-transitional
-dissected

Recycled Orogen provenances

- -subduction comple.
- -collision orogen
- -foreland uplift.

All the above studies concentrated on ancient sandstone suites and inferred tectonic settings from data other than sandstone compositions. Dickinson and Valloni (1980) and Valloni and Maynard (1981) have examined compositions of moden sands from known tectonic settings. The two data sets show close agreement.

The models of Dickinson and Suczeck (1979) have been used to interpret the tectonic setting of the sandstones of the Moruga group, southern Trinidad sandstones.

<u>Results</u>

QFL (Figure 78) - This triangle shows total grain population, and provides information about grain stability, weathering, provenance, relief and transport history as well as source rock. The sandstones plot toward the top as a quartz rich (at least 66% quartz) <u>Reclycled Orogen Provenance</u> suite. The paucity of unstable grains coupled indicates that the sediments were intensely weathered and the dominance of angular to subrounded grain types suggest that there was little alteration during transport. It is therefore difficult to reconstruct source rock type from the results of the QFL plot.

QFL Plot of Sandstone Petrographic Data

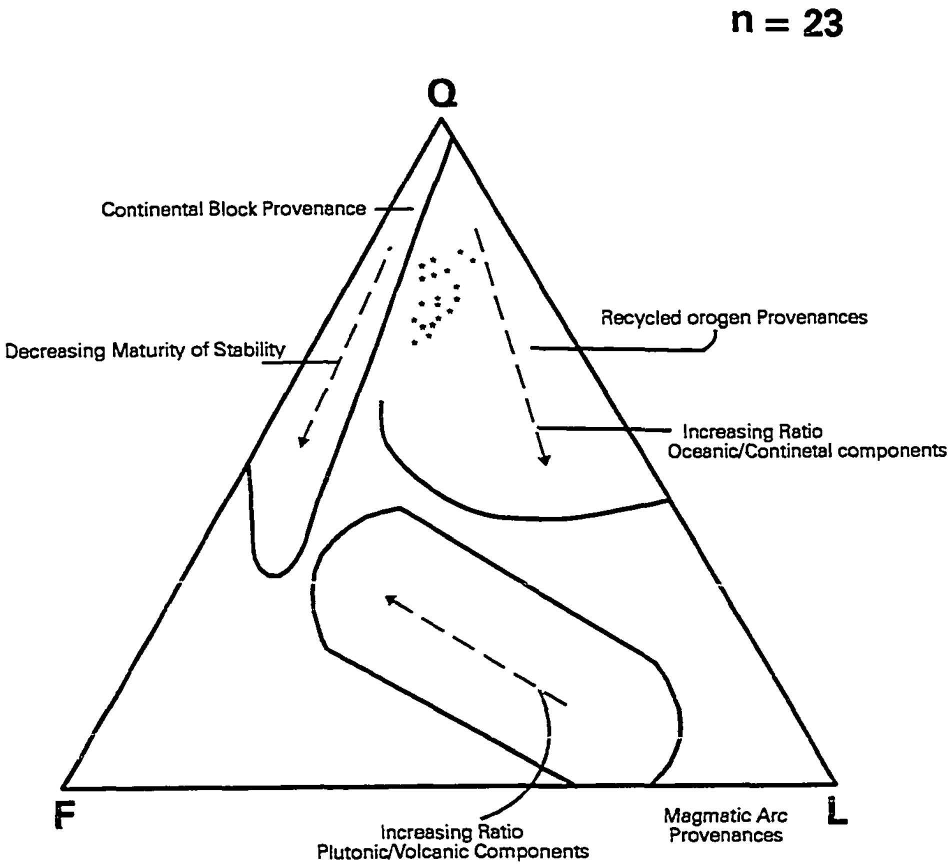


Figure 78

(After Dickinson and Suczeck, 1979)

Q_m F L_t (Figure 79) - This triangle also shows total grain populations. In this case however, all lithic fragments are plotted together at the L_t pole, thus the emphasis is on the grain size of the source rocks because finer grained rocks yield more lithic fragments in the sand size range. The compositions of sandstones from the south coast of Trinidad plot toward the top of the triangle with a minimum quartz content of 64%. The compositions plot at the intersection of the Continental Block and Recycled Orogen provenance fields. The compositional tables compiled by Dickinson and Suczeck (1979) allowed for easy comparison with the data from southern Trinidad. These comparisons suggest that the more likely provenance suite will be found in the recycled orogen provenance and more specifically in the collision orogen provenance. The sands from such terrains generally show Q_m content greater than 75% and plagioclase and potassium feldspar being almost equal or plagioclase in slight excess. Plotting the Q_m F L_t diagram enhances the conclusicons of the QFL diagrams which indicate low lithic and feldspathic contents of recycled orogen suites.

Q_p L_v L and Q_m P K - These plots depict partial grain populations but reveal the character of the polycrystalline and monocrystalline components of the framework respectively. The Q_p L_s L_v diagram (Figure 80) clearly suggest a Subduction Orogen source. Dickinson and Suczeck (1979) however, indicate the inability of the Q_p L_s L_v diagram to accurately characterize sands with a low lithic content. This shortcoming, inherent in the design, is emphasized by the results presented here. The Q_m P K triangle (Figure 81) indicate the overall dominance of Continental Block

Qm F Lt Plot of Sandstone Petrographic Data

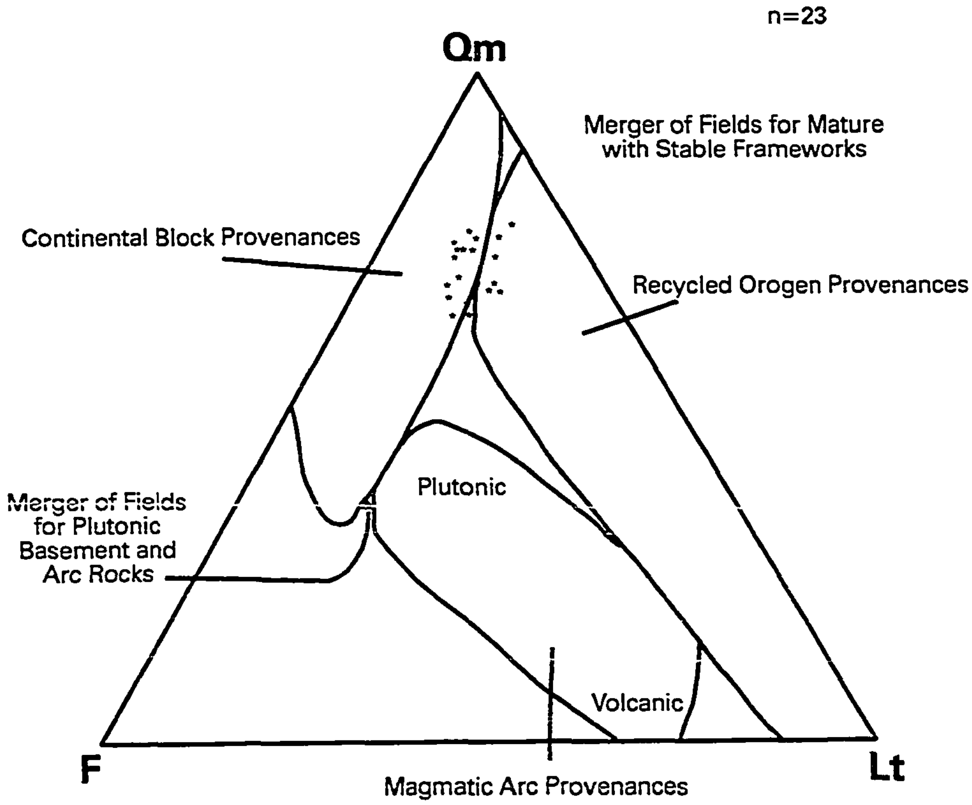


Figure 79

After Dickinson and Suczeck, 1979

QpLs Lv Plot of Sandstone Petrographic Data

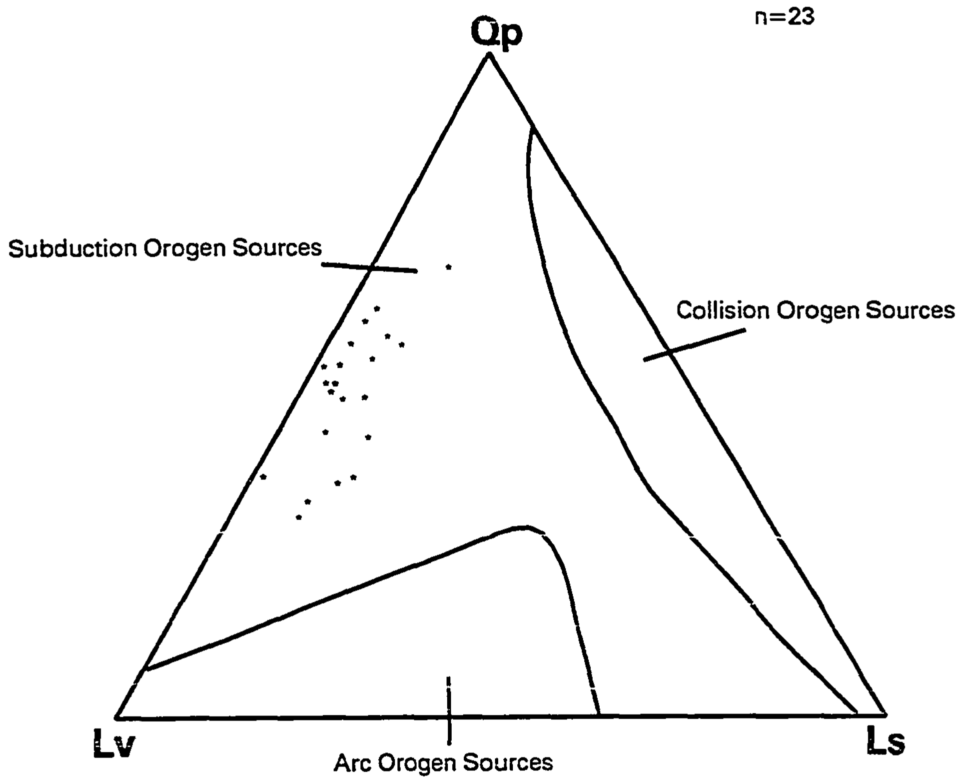


Figure 80

After Dickinson and Suczeck, 1979.

Qm Pk Plot of Sandstone Petrographic Data

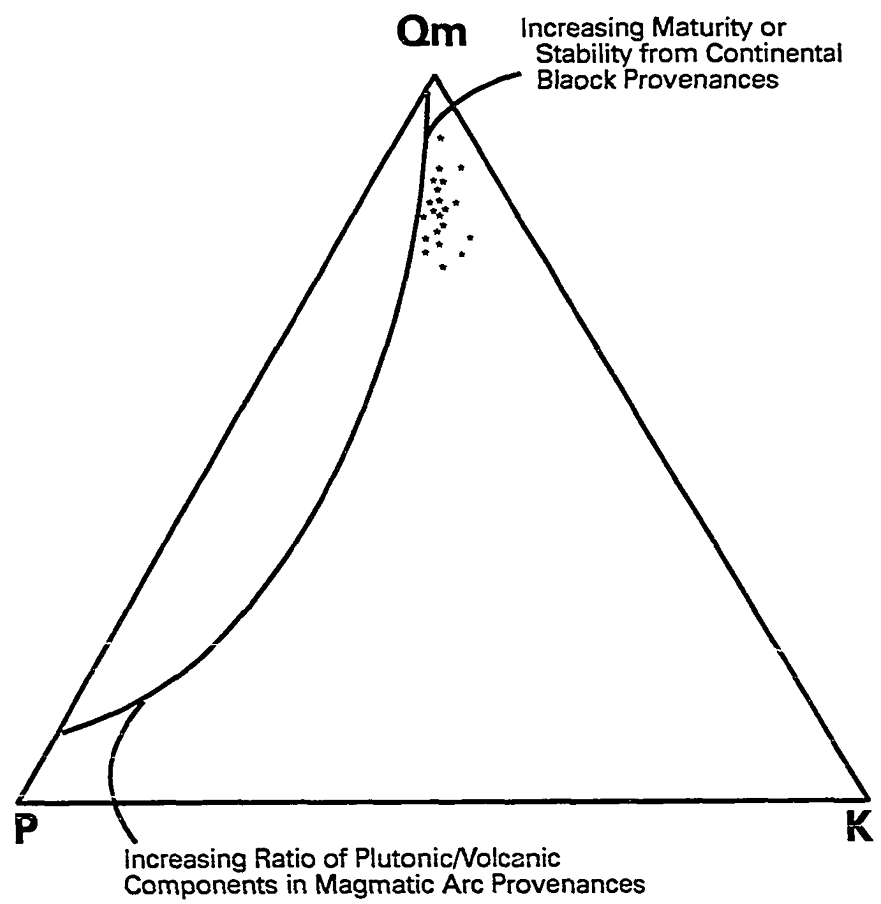


Figure 81

(After Dickinson and Suczeck, 1979.)

provenances as the sandstones plot closer to the Q_m pole reflecting the increased maturity of detritus from such sources.

Summary

Early cementation of the framework grains is indicated by the petrographic descriptions. This is reflected in the low number of grain to grain contacts and the high cement and matrix content.

The modal analyses presented suggest that these sandstones had their origin in a high quartzose source developed in a stable cratonic setting. The sandstones cof the Moruga Group probably had their provenance in a moderate to quartz rich, recycled orogen and/or subduction orogen source.

Sandstones plot somewhat anomalously on the Q_m F L_t diagrams and it is not clear what is the provenance indicator. Mack (1984) suggested some explanations for the anomalous plotting of modal compositions on ternary diagrams. Mack proposed four reasons why sandstone compositions may plot anomalously:

- transitions between tectonic regimes;
- modification of sandstone composition by weathering and depositional processes;
- tectonic settings unrepresented by sandstone petrographic data,

and,

- significant proportions of carbonate, and related grains. Of the above possibilities the last two may be dismissed as contributors to anomalous plotting of these data. The regional tectonic history of the Southern Caribbean plate boundary suggests that the Cenozocic was a time of convergent right-lateral motion, divergent wrenching, some subduction activity cor a combination of all three. Though not fully understood, it is possible that transitions between these tectonic styles did occur and might have affected sandstone compositions.

BURIAL DIAGENESIS OF THE MORUGA GROUP, SOUTH COAST, TRINIDAD

The purpose of this section is to evaluate the diagenetic, thermal and maturation histories of the rocks of the Moruga Group. The methods of evaluation chosen in this evaluation are organic geochemistry, clay mineralogy and stable isotope geochemistry. It will also compare the diagenetic history of the outcrop to a sequence penetrated in the West Seg-1 well offshore Trinidad. The use of these analyses in an area where sedimentation rate was high, and the tectonic setting complex is also tested.

The samples analyzed were both outcrop and well cuttings. For organic geochemistry and clay mineralogy an attempt was made to select only claystones/mudstones. However, because of the very high percentage of silt in the stratigraphic section, siltstcones, muddy siltstones or silty mudstones were often used. Study by isotope geochemical methods utilized samples of sandstones and siltstones.

Methods of Analysis

(i) **Clay Mineralogy** - Samples for clay mineral analysis were prepared as < 2 micrometer suspensions, separated by gravity settling. Some oriented clay specimens were prepared by filtering off < 2 micrcometer material onto a membrane filter and then contact transferring the clay onto a glass slide (Drever, 1973). Other clay specimens were prepared by pipetting 10-12 ml of the suspended clay onto glass slides and allowing the slide to dry in air.

X-Ray diffractograms and measurements were made using a Siemens D-500 and a Phillips Model APD 3720 X-Ray diffraction system. Both used copper K_a radiation in their operation.

X-Ray spectra were collected for each specimen after the following treatments:

a) after air drying;
b) after vapor saturation with ethylene glycol;
c) after heating to 375°C for thirty minutes; and,
d) after heating to 550°C for one hour.

In some cases steps (c) and (d) were combined at the MOBIL Laboratory into one treatment which entailed heating the clay sample at 400°C for two hours.

The peak areas for selected basal reflections were measured as the product of the peak height by the full width at half maximum. The area used to determine illite content was measured on the 8.9 degrees peak of the glycolated sample. The area used for illite/smectite was based on the increase in the 8.9 degrees peak after heating to collapse the expandable layers. The area of the 12.4 degree kaolinite plus chlorite peak was apportioned based on the intensity of the 18.7 degrees chlorite (003) peak.

Relative proportions of the clay mineral were determined using the theoretical mineral intensity factors (MIF's), that are calculated using a computer program developed by Reynolds (1985). The peaks and MIF's used are presented in the following tabulation:

Mineral	peak	MIF
Illite	8.9°	2.00
I/S (heated)	8.9°	2.00
Kaolinite	12.0°	3.06
Chlorite	12.4°	5.00

The fraction of smectite layers in the mixed-layer structure was determined using the shape of the 5.2 angstrom peak as compared to calculated diffraction profiles. Calculated diffraction profiles were based on a defect and particle size broadened structure.

(ii) **Organic Geochemistry** - Various techniques have been developed to assess the petroleum potential of sediments. Among the most used Rock-Eval Pyrolysis of organic matter developed by Espitalie et al., (1977). This method involves the progressive heating of pulverized cores and/or cuttings to 550°C under an inert atmosphere. Pyrolysis is probably the best routine tool for determining type and maturation of organic matter at the same time (Tissot and Welte, 1978). Additionally the method is the best simulation of burial conditions available.

Approximately 100 milligrams of washed, ground (60 mesh) whole rock sample was analyzed in the Rock-Eval/TOC unit. Organic rich samples were analyzed at reduced weights whenever the S2 value exceeded 40.0 mg/g or TOC exceeded 10%. The operating parameters were as follows:

- 300°C initial temperature isotherm for 5 minutes
- 25°C/minute temperature programming rate
- 600°C final temperature isotherm for 1 minute

- 580°C oxidation oven temperature
- 12 minute oxidation time.

(iii) **Stable Isotope Geochemistry** - powder samples of the whole rock were prepared and washed with 1% sodium hypochlorite solution to remove organic matter and organic compounds which can interfere with accurate isotope ratio determinations. Carbon dioxide was prepared from about 10 mg of the treated sample by reaction with 100% phosphoric acid at 25°C. The carbon dioxide was then analyzed using mass spectrometer and data were corrected using a reference sample of carbon dioxide prepared at the same time. Also oxygen isotope ratios were calculated to compensate for a different fractionation factor for acid decomposition which is assumed to be that for pure dolomite.

The oxygen stable isotope data was presented in PDB units. Conversion to SMOW uses the following formula (after Friedman and O'Neil, 1977):

$$^{18}O\ (SMOW) = 1.03086\ (PDB) + 30.86$$

Clay Mineralogy: Background to Investigations

Clay minerals are important constituents of some sedimentary rocks and are the result of weathering during the sedimentary cycle. Because of their small size and their integral role in many important diagenetic reactions they are of great interest to petroleum geologists.

The illite/smectite transformation has been noted as the major clay mineral transformation taking place during burial diagenesis. This change takes place via a series of mixed layer illite/smectite intermediates (Hower, et al., 1976). The transformation of smectite to illite releases large amounts of water, silica and other ions all of which may play important roles in the diagenesis of shales and adjoining sandstones. The change requires either the uptake of potassium in interlayer positions, and aluminum in tetrahedral positions (Hower et al., 1976), or the cannibalization of SiO_2 sheets which effectively increases the total layer charge (Boles and Franks, 1979). Silica is released in the process and this may contribute to the formation of quartz overgrowths. The illite/smectite transformation reaction may be represented by the following ionic reacticon:

$4.5K^{+} + 8\ Al^{3+}$ + Smectite ---> Illite + $3\ Si^{4+}$ + Cations + H_2O; (Hower et al., 1976).

There is some indication that clay minerals play an important role in the formation of petroleum from kerogen (Johns and Shimoyama, 1972; Goldstein, 1983). Further research (Goldstein, 1983; Tannenbaum et al., 1986) support that there is a direct relaticonship between %I in I/S, type of ordering and burial temperature. The reacticon follows first order kinetics and Weaver (1978) has demonstrated that ideas are in conflict with the more recent work of Ramseyer and Boles (1986), Freed and Peacor (1989) and Hillier and Clayton (1989) which indicate that residence time at any given temperature and not the temperature itself may be a more important cconsideration in the smectite to illite transformation. The burial diagenetic reaction of which this transformation is a part is schematically represented as:

smectite ---> I/S random (R=o) ---> 1/S ordered (R=1) --->
I/S ordered (R=3) ---> illite (1M) ---> mica.
(Eslinger and Peaver, 1988).

During the I/S transformation the following mineralogical changes have been documented:

(a) Decrease in the expandable layers of the interlayered clay mixture, thus smectite was either absent or considerably reduced below certain depths. This was often manifested as an increase in the number of illite layers (in I/S) from less than 20% to greater than 80% over the depth range; Burst (1959; 1969), Weaver (1967), Perry and Hower (1970), Hower et al., (1976) and Boles and Franks (1979). Boles and Franks (1979) have referred to this reaction as "cannibalization"' of smectite and represented the reaction as:

$$2.5\ K^{+} + \text{smectite} \text{ ----> } 0.54 \text{ illite} \div 15.7\ Si^{4+} + \text{cations and water.}$$

As a result of this change the expandability of I/S should decrease as the number of expandable smectite layers decrease.

(b) Decrease in kaolinite as kaolinite becomes a source of Al during the transformation reaction. This is represented as: $4.5\ K^{+} + 8\ Al^{3+} +$ smectite -----> illite + 3 Si^{4+} + cations and water, (Hower et al., 1976).

This decrease in kaolinite was also reported by Weaver (1957), van Moort (1971), Hiltabrand et al. (1973), Foscolos and Powell (1978) and Boles and Franks (1979).

(c) There is an associated increase in the chlorite content during the smectite/illite transformation. This has been documented by Weaver (1967, 1979), Perry and Hower (1970) and Hower et al., (1976).

In this study the role of clay minerals in deciphering the burial history of the Tertiary sedimentary basin of southeast Trinidad was examined. In light of extensive reworking of organic matter it was thought that clays may give additional information on changes undergone during burial of the sequence.

Results

The following table contains data which was derived by the methods previously described. The data is used in the upcoming discussion and in drawing conclusicons regarding the clay mineral assemblages encountered.

West Seg-1 Cuttings

Depth	Ill	I/S	%I**	Kao	Chl	R
1130	19	44	53	37	1	0
1580	20	31	54	49	2	0
3170	27	31	56	42	1	0
4010	24	48	58	30	2	0
5570	20	42	53	38	1	0
5840	21	33	54	46	1	0

6650	21	26	56	54	2	0
7400	25	30	58	45	3	0
8360	20	48	51	32	1	0
9380	30	36	59	34	1	.5
10070	23	50	52	27	2	1
10700	29	43	55	29	2	.5
11000	37	31	59	31	2	.5
11960	28	34	53	38	4	1
12260	26	47	54	27	3	1
12860	27	52	58	21	1	1
12890	29	41	55	31	2	.5
13580	31	42	55	27	2	.5
13940	28	37	57	34	2	.5
14780	38	36	59	27	2	1
15020	30	39	54	31	2	1
15170	37	34	57	28	2	.5
Averages	**27**	**39**	**55**	**34**	**2**	

2) South Coast Stratigraphic Section

Sample#	Ill	I/S	%I**	Kao	Chl	R
PC4	10	77	45	14	1	0
LL2	3	88	35	9	1	0
BH4	8	75	41	17	1	0
BH7	14	73	45	13	0	0
BH20	17	62	51	21	1	0
BH44	5	81	38	14	1	0
BH31	8	80	39	12	2	0
BH32	10	70	41	21	1	0
BH48	13	71	39	16	2	0
BH50	14	69	41	18	3	0
Averages	**11**	**75**	**42**	**16**	**1**	
(*BCH28	21		50	29	1	44 0)

*BCH28 is an outcrop sample of the palmiste Clay which is included for comparison.

** % refers to %I in I/S.

Clay Mineralogy: Discussion

Mudstones from outcrop and cuttings from the West Seg-1 well were analyzed. They consist of mixed-layer illite/smectite, kaolinite, discrete illite, and a trace of chlorite. This is a typical U.S. Gulf Coast clay mineral assemblage similar to that described by Burst (1959 & 1969) and Hower, et al., (1976). There is some variability and differences between outcrop and subsurface samples in the following results:

- percentage discrete illite
- percentage I/S
- percentage kaoloinite
- expandability of illite/smectite.

The following table is included to highlight the comparison and all numbers are average percentages and n is the number of samples analyzed:

	Outcrop (n=11)	Subsurface (n=22)
Illite	11	27
I/S	75	39
%I in I/S	42	55
Kaolinite	16	34
Chlorite	1	2

Supporting paleontological and palynological data suggest that the outcrop section along the south coast of Trinidad is older than the section encountered in the subsurface. If burial of the stratigraphic section proceeded along a linear path, and if indeed the outcrop, section was buried as deeply as the subsurface section, then the following changes would be expected, according to perry and Hower (1970) and Hower, et al., (1976):

- the outcrop section should show a smaller number of expandable smectite layers,
- the outcrop section should show a lower kaolinite content,
- the outcrop should show higher chlorite content.

The type of interlayering in I/S was examined. The methods used were those of Srodon (1980) and Moore and Reynolds (1989). Srodon states that peaks between 5.3 and 8.7 two-theta indicate ordering, whereas Moore and Reynolds indicate that a peak close to or approximating 5 degrees two-theta indicates random interstratification while a peak close to 6.5 degrees two-theta indicate some ordering. This analysis proved to be somewhat difficult as the presence of small amounts of chlorite may produce a small peak or shoulder in the region of 5.5 and 6.5 degrees two-theta. This was considered using the difference between the air dried and glycolated patterns, as chlorite will not be affected by the latter treatment. The air dried patterns, however, showed a major broad peak in this region which separated upon glycolation and often produced a shoulder. It is therefore not clear whether this shoulder is the result of chlorite or interlayering. The 002 and 003 peaks were therefore used according to the method of Moore and Reynolds (1989). The method of Moore and Reynolds (1989) uses the difference between the two-theta values to estimate the degree of ordering and indicates that all samples in West Seg-1 below 8390 feet probably have Reichweite numbers of .5 to 1 indicating minor ordering with 50 to 60% illite layers. The outcrop samples showed little or no shoulder attributable to chlorite. Investigation was thus possible using both methods - the peaks in the 5.5

to 6.5 two-theta range and the two-theta difference between the 002 and 003 peaks. This investigation suggests that the outcrop samples were all randomly interstratified with 35% to 50% illite layers. There is, therefore, no indication of long period of burial which would effect a greater decrease in the number of expandable layers.

The percentage of discrete illite differs greatly from well to outcrop. The averages are 11% in outcrop versus 27% in the subsurface. There is a slight increase in the content of discrete illite with depth in the subsurface (Figure 82).

Figure 82 indicates a minor increase in the content of discrete illite with depth in the West Seg-1 well. Boles and Franks (1979) and Pollastro (1985) documented a similar occurrence in the Rocky Mountains and ascribed this to the selective cannibalization of smectite layers to make a more illitic I/S. Discrete illite is formed in the reaction. Pollastro suggested that this mechanism would explain mineralogic changes in restricted or relatively closed geochemical systems, eg., early cemented rocks with low permeabilities and little or no potassium feldspar. Ehrenberg and Nadeau (1989) suggested that some illite may be formed by reaction of potassium feldspar with kaolinite or by the alteration of micas. Hansen and Lindgreen (1989) also suggested that discrete illite may be formed by erosion of lightly weathered source rocks. Hansen and Lindgreen also state that illite and I/S becomes more abundant with increasing distance from shore.

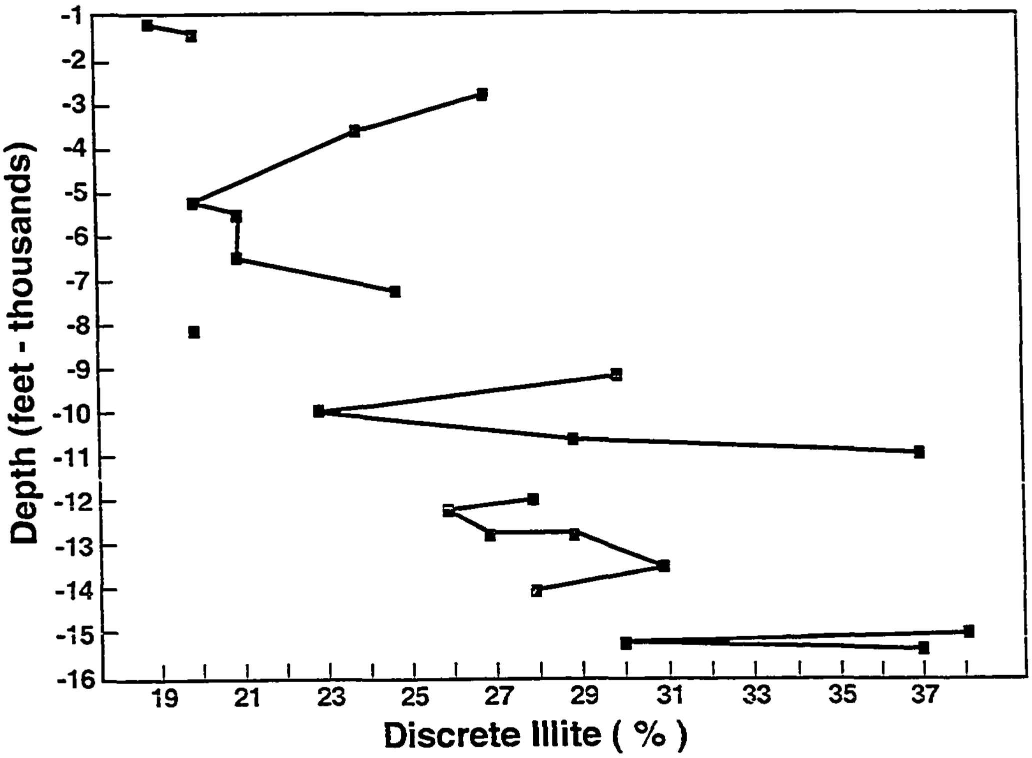


Figure 82. Depth vs Illite Content, West Seg-1.

Kaolinite is a major constituent of the less than two micron fraction contributing 16% to the outcrop and 34% to the subsurface stratigraphic section. A plot of percentage kaolinite against depth in the West SEG-1 well shows no smooth linear relationship; however, a best fit line suggests a decrease in the content of kaolinite with depth (Figure 83). Such high kaolinite content probably reflects a period of deep intense weathering of lateritic horizons, (Biscaye, 1965).

It is interesting to note that the kaolinite content of the West Seg-1 well decreases slightly with depth (Figure 83). This trend may indicate some kaolinite involvement in the smectite to illite transformation. This is predicted within the ideal burial diagenetic reaction of Perry and Hower (1978). As mentioned in the previous paragraph this reacticon is also not the only explanation for a decrease in the kaolinite content. However, to what extent the reactions of Perry and Hower (1976) and Ehrenberg and Nadeau (1989) have occurred, is a matter for further study. Kaolinite, which is generally formed from the erosion ofland surfaces weathered in a semi-humid tropical climate, may also vary according to distance from shoreline. Hansen and Lindgreen (1989) indicate that decreasing kaolinite content probably reflects greater distance from the shoreline. The increase in kaolinite often reflects a higher degree of proximity to deltaic or shoreline facies, eg., during deltaic progradation. This environmental influence upon kaolinite content may be important because the depositional model developed suggest an intimate association between a prograging delta and shelf-fansystem developed as sediment was mobilized and sedimented.

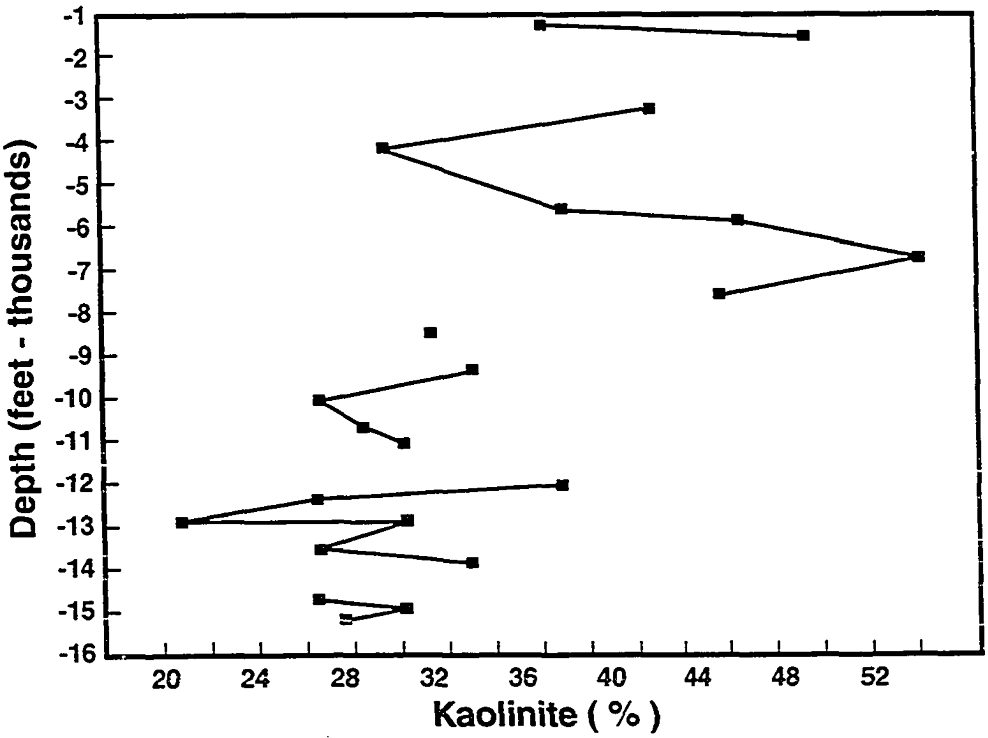


Figure 83. Depth vs Kaolinite Content, West Seg-1.

The percentage of I/S also differs greatly from well to outcrop, with the average I/S content of the well being 39% whereas that of the outcrop is 75%. A plot of depth against percentage illite/smectite (Figure 84) is a scatter of points with no definite trend. There is no marked vertical variability in the amount or type of ordering of illite/smectite in either outcrop or subsurface. During the reaction series of Perry and Hower (1976) this mineralogic phase becomes more illitic with burial or increasing temperature. A plot of depth versus percent illite in I/S was therefore examined to investigate these changes. This Figure 85, at best shows a minor increase in percentage illite layers in I/S with depth in the West Seg-1 well. The high I/S content of the outcrop samples is difficult to evaluate and may be any one or a combinaticon of the following factors: source control, depositional or facies control. It is also possible that the outcrop and well sections experienced different burial conditions or had different sediment sources and the differences in I/S content may be due to these possibilities.

There is a tendency for specific temperatures to be assigned to the smectite to illite transformation (eg. Hower et al., 1976). More recently Freed and Peacor (1989) have criticised this tendency and provided evidence for variability in the temperature of the smectite illite reaction. They have provided several factors as pcossible contributors to this variability. The sediments in the West Seg-1 well were exposed to temperatures of at least 50°-60°C (see discussion of Geothermal Gradients in next section) which is lower than earlier suggested temperatures.

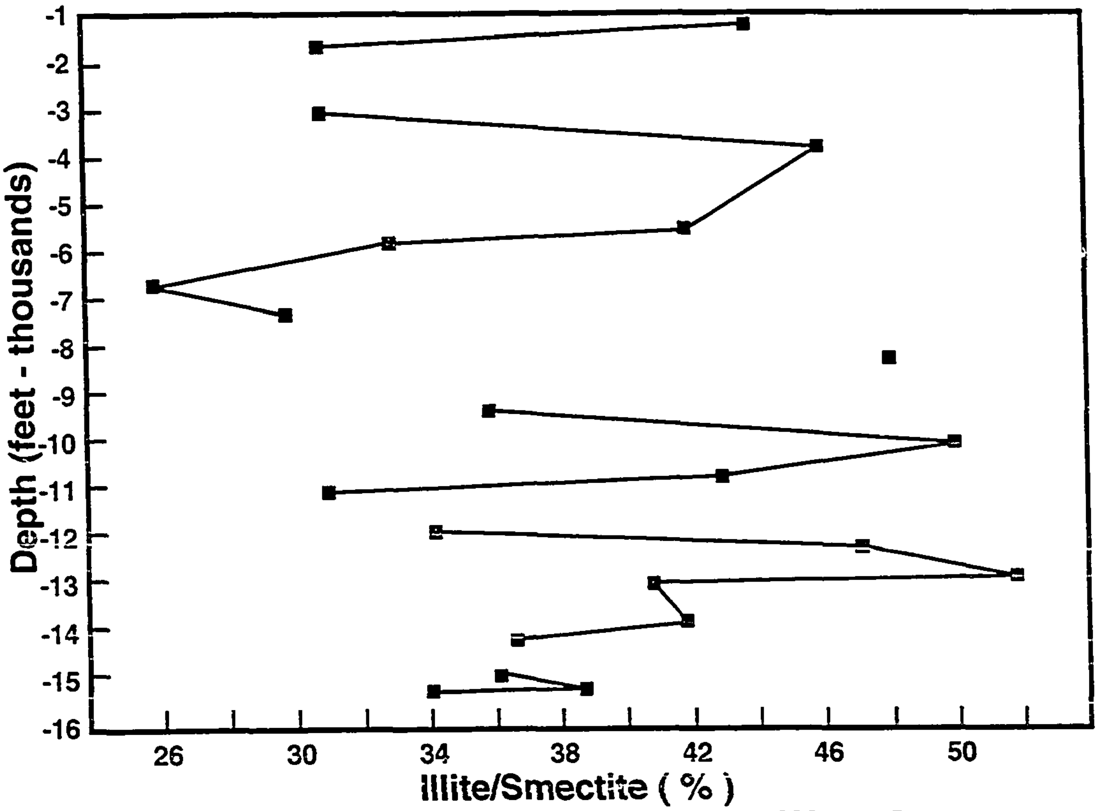


Figure 84. Depth vs I/S Content, West Seg-1.

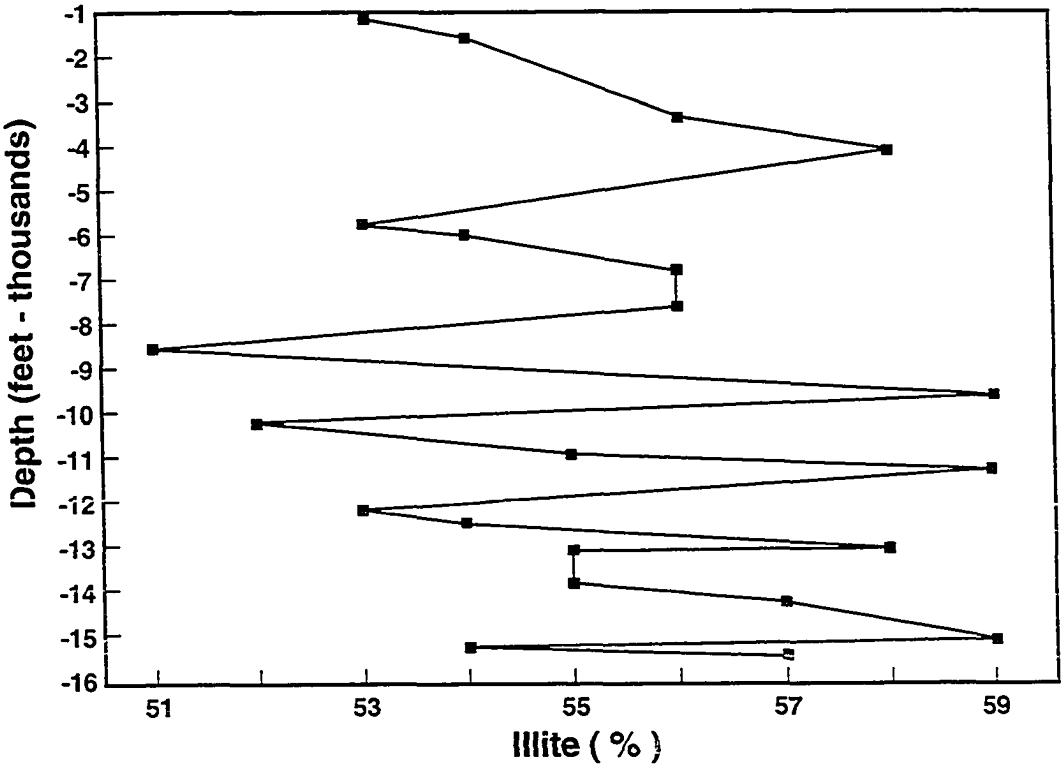


Figure 85. Depth vs % Illite in I/S, West Seg-1

Recent publications have suggested that residence times are more important than absolute temperatures, Ramseyer and Boles (1986), Freed and Peacor (1989) and Hillier and Clayton (1989). Bruce (1984) concluded that the geologic age of the sediments is not important to the contribution of time or temperature in the smectite to illite transformation. Ramseyer and Boles have shown that residence time at a given temperature was the driving force behind the smectite to illite transformation in Miocene sediments of the San Jaoquin Basin.

Given that the evidence suggest that the smectite to illite transformation has begun. Could it be that time and not temperature was the most important factor in producing the assemblage encountered, and; is it possible that the section penetrated in West Seg-1 has been buried for a longer period of time? A reconciliation of the time versus temperature argument is beyond the scope of this study, mainly because there is little evidence and control to constrain these two variables. It is difficult to say if the initial I/S content of the older outcrop section was similar to that encountered in the subsurface. It however appears to be clear that source is a major factor in the apparent clay mineral compositions. Given that these sediments have not been exposed to adequate thermal stress, it is difficult to assess the degree to which the smectite to illite transformation has progressed.

Since south Trinidad emerged in the Late Pliocene it may be expected that the outcrop section has been at surface or near surface temperatures for a longer period of time. It should therefore be expected that some of the rough diagenetic trends observed in the subsurface will not be present in outcrop.

The trends which arise out of these investigations are generally unrelated. There is, however, evidence that clays in the subsurface have experienced the onset of burial metamorphism. There is some difference in the percent illite layers in I/S between outcrop and subsurface. This might be indicative of (a) a diference in the burial history of the outcrop and subsurface sections, (b) a difference in the compositions of the starting materials in both sections (eg. Braide and Huff, 1982) and, (c) factors which have inhibited the smectite to illite transformation (eg. early cementation, Foscolos and Powell, 1980 and Pollastro, 1985).

Kaolinite is twice as abundant in the subsurface than in outcrop. There is a steep decrease in the kaolinite content with depth in the West Seg-1 well. This decrease does not parallel the very minor increase in the percent illite layers with depth in the same well. The much larger variation in kaolinite content with depth must therefore be explained otherwise. It is possible that the kaolinite variation is controlled by depositional or provenance factors. Chlorite is a minor constituent of both outcrop and the subsurface sections. It is unclear what role if any, did chlorite have in any reactions which might have occurred as there is no variation in chlorite content with depth (Figure 86).

The data in this study indicates that the clay mineral assemblage encountered cannot be explained strictly by inferring a series of burial diagenetic reactions. It can be concluded that the observed mineralogy is

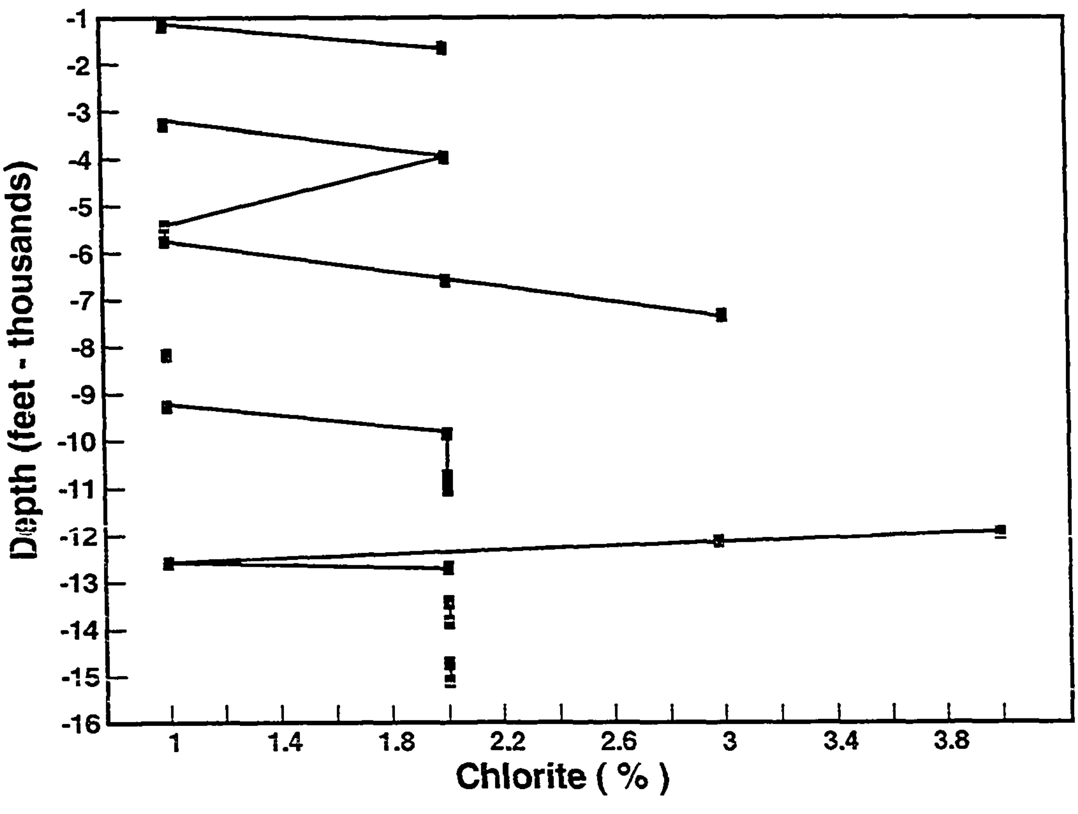


Figure 86. Depth vs Chlorite Content, West Seg-1.

a function of various factors. To what extent each factor has contributed may form the subject of further research. Modal analyses of outcrop samples indicated a very low potassium feldspar content (approximately 3%). Was the lack of potassium a limiting factor; or was the lack of adequate burial for a long enough time more important? To what extent did both contribute? Given the present data, it seems likely that source and depositional controls played a much greater part than burial metamorphism in generating the clay mineral suites encountered. The low thermal gradient did not greatly affect clay mineral transformations in South Trinidad.

Organic Geochemistry: Background to Investigations

The data obtained from Rock Eval pyrolysis are by definition the following:

During burial (diagenesis) transformation of organic matter takes place in response to increased temperature and thermal stress. This transformation is a natural consequence of the organic matter proceeding toward equilibrium (Tissot and Welte, 1978).

Diagenesis involves first the breakdown of biopolymers (by biochemical degradation), then a series of polycondensation reactions before the formation of kerogen (a geopolymer). This process ends at about R_0=0.5.

The next stage in the burial sequence is catagenesis (ending at R_0=2) during which there is thermal degradation of kerogen to form oil and gas often with a carbon residue (Tissot and Welte, 1978).

The final stage during burial evolution of organic matter is metagenesis which proceeds up to and probably above R_0=4. This stage includes carbonization and corresponds to the semi-anthracite and anthracite stages of coal formation.

S1: (Milligrams of hydrocarbons per gram of rock. To convert to ppm x 1000). This is a measure of the free hydrocarbons present in the whole rock sample, and only those hydrocarbons which vaporize up to approximately 330°C are included. The technique used to evaluate S1 values for potential oil staining is to convert to ppm and divide by total organic carbon (TOC). Contamination by oil staining may lead to anomalously high values often greater than 1. S1 measures the fraction of the original genetic potential which has been effectively converted into hydrocarbons, (Tissot and Welte, 1978).

S2: These are the hydrocarbons which result from the cracking of kerogen and high molecular weight free hydrocarbons which do not vaporize in the S1 peak. Generally heavier free hydrocarbons which vaporize or crack at higher temperatures than those reached during the S1 phase. These represent the residual genetic potential which has not yet been used to generate hydrocarbons. The value of S1+S2, expressed in kilogram/ton of rock is an evaluation of the genetic potential of the source rock, (Tissot and Welte, 1978). S2 values are converted to ppm by multiplication by 1000.

S3: The milligrams of organic carbon dioxide per gram of rock. The value also includes oxygen from water generated during the breakdown of organic matter. S3 values may be affected by weathering and mineral matrix interaction. Generally, S3 values greater than 200 are anomalously high and may or may not be valid.

A classification of source rocks based on the genetic potential (sum of S1 and S2) has been suggested (Tissot and Welte, 1978):

- lower than 2000 ppm - no oil source rock but some gas potential;
  2000-6000 ppm - moderate source rock;
- above 6000 ppm - good source rock.

TOC - weight percent of carbon (expressed as mg of carbon per 100 mg of whole rock). The TOC value is composed of two fractions: a pyrolyzable fraction represents the hydrocarbons already generated (S1) and the potential to generate hydrocarbons (S2). The residual fraction (S4) has no potential to generate hydrocarbons. The TOC is therefore the normalized potential plus the normalized residual and is given by:

$$TOC = K\ (S1 + S2)/10 + S4/10;$$

where k = .83 (an average carbon content of hydrocarbons by atomic weight).

HI - The hydrogen index is the normalized hydrogen content of the source rock sample. Kerogen type information is derived from this value as Type I kerogens are hydrogen rich, Type III kerogens are hydrogen poor, and Type II kerogens are intermediate between Type I and Type II. HI decreases as the sample matures.

HI = S2 x 100/TOC

HI < 150 indicates Poor potential

HI=150-300 indicates Type III (gas/oil prone)

HI= 300-600 indicates Type II (oil/gas prone)

HI > 600 indicates Type I (oil prone).

OI - The oxygen index is the normalized oxygen content of a rock sample. In kerogen typing Type III kerogens generally have higher oxygen indices than either Type I or Type II kerogens. HI is however the major discriminating factor in kerogen type.

OI = S3 x 100/TOC

Van Krevelen Diagrams - these are plots of the Hydrogen Index against the Oxygen Index. The plots result in a grouping of the organic matter according to their composition and their evolution paths. Some authors have argued that organic matter derived from similar depositional envirorments follow the same paths. Tissot et al., (1974).

The kerogens are classified as:

Type I with a high initial H/C ratico, mainly lipids and aliphatic chains, low in polyaromatic nuclei and heteroaromatic bonds, these are oil prone. High lipids may be the result of selective accumulation of algal matter or the severe biodegradation of organic matter during deposition, (Tissot and Welte, 1978).

Type II with high H/C ratios and low O/C ratios, carboxylic groups and ester bonds are abundant. Sulphur content is also high. Though these will give a lower yield of coil they may produce commercial oil shales, (Tissot and Welte, 1978).

Type III with a low initial H/C ratio and a high O/C atomic ratio, no ester groups, ketones and carboxylic acid; are common, derived from land plants and has identifiable vegetal debris. This type of kerogen is gas prone, (Tissot and Welte, 1978).

T_{max} (°C) - The maximum evolution of S2 hydrocarbons. T_{max} values are affected by low organic matter content where low broad S2 peaks are encountered. When the S2 value less than 0.50, T_{max} values are not reliable, (Trissot and Welte, 1978). T_{max} values may be affected by the presence of heavy, free hydrocarbons in the S2 peak which may cause the T_{max} value to be anomalously low (>400°C). Also, T_{max} values may be affected by reworked organic matter which may cause them to be anomalously high (>500°C). Reliable T_{max} values may be correlated with R_0 values and may be used to classify source rocks as follows:

430°C Immature (R_0 <0.60)

430-465°C Oil Window (R_0 [0.60-1.40]).

465°C Gas Window (R_0 > 1.40).

The above forms the background against which the data was interpreted.

Results

The results of the Rock Eval Analysis of the organic matter obtained from outcrop and subsurface samples are presented as an appendix. Presented here are van Krevelen plots of the oxygen and hydrogen index data, Figures 87 (subsurface data) and 88 (outcrop data). Due to the very high oxygen index (>200) readings obtained for most samples they were off the scale used in plotting the data. Figure 89 is a plot of TMAX against depth for the West Seg-1 well.

Visual Carbonization Estimates

During the examination of palynologic samples observations on the visual estimates of carbonization were made (Andrew Lamy, 1989, 1990). These data are presented here:

Visual Carbonization estimates (West Seg-1)

Depth (in feet)	Kerogen Type	H/C Generating Potential	Wt % C	H/C Type
860-3765	Struct.	pre-Gen	-	Dry Gas
4040-6830	"	"	-	"
7050-7350	"	"	-	"
8600	"	"	-	"
9200-10700	"	"	-	"
10900	"	"	-	"
11300-11810	"	"	-	"
12300-15230	"	Early Gen.	75	"

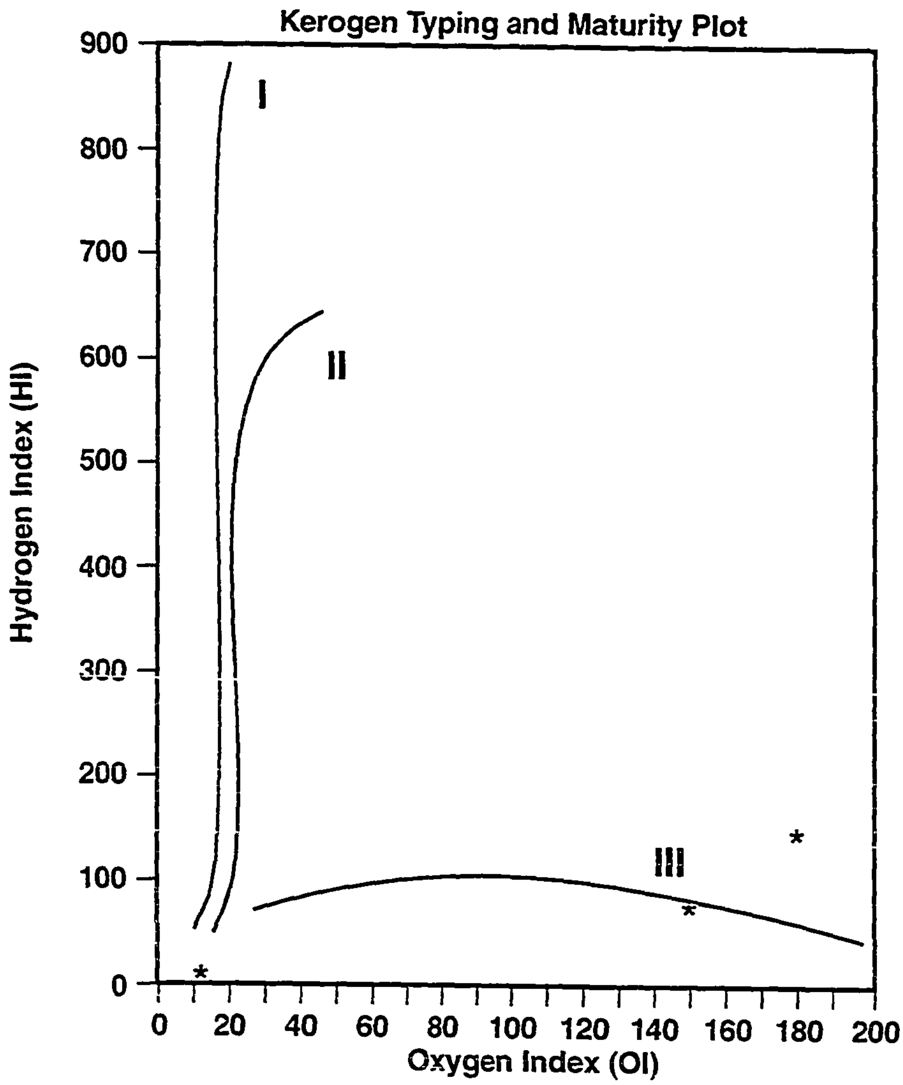


Figure 87. Amoco Production Company: West Seg-1

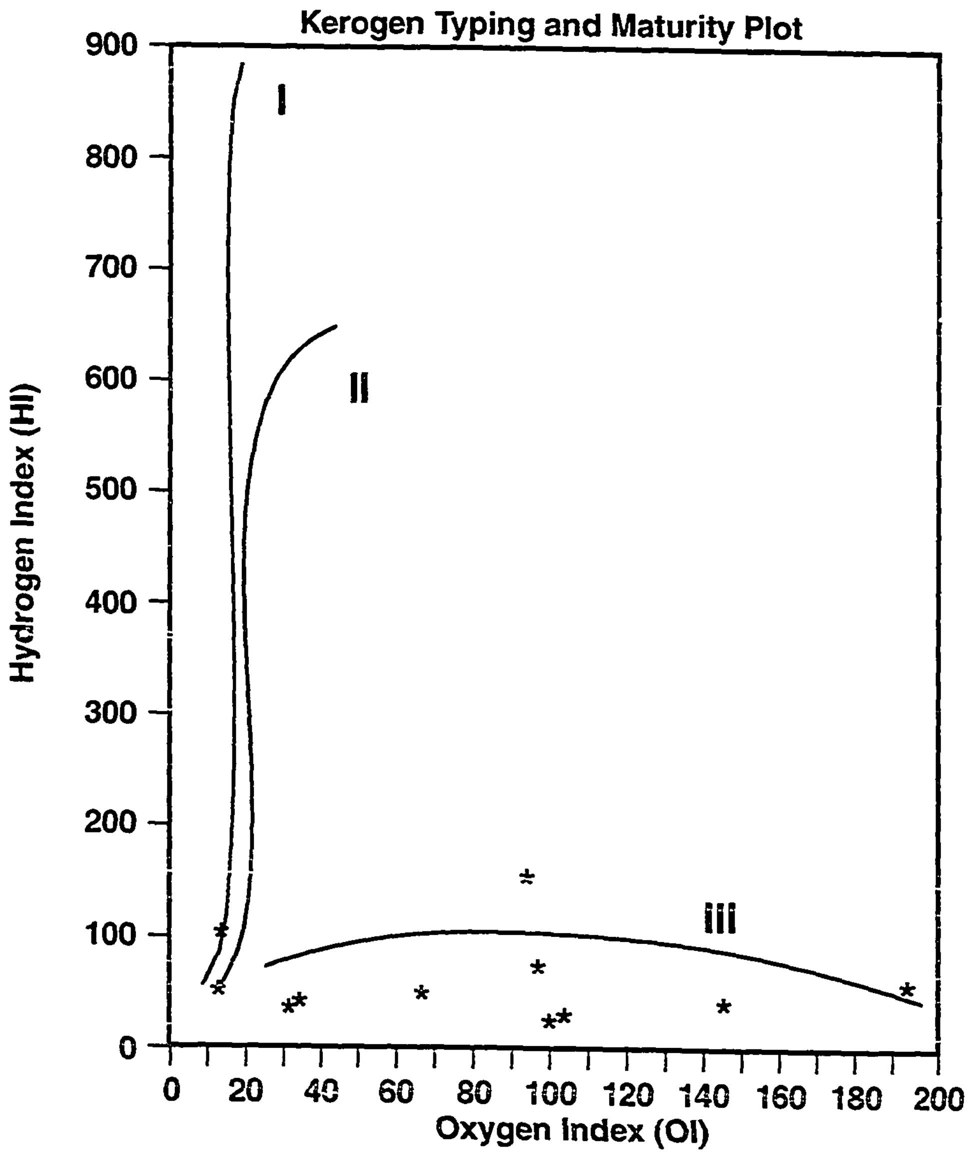


Figure 88. South Coast Stratigraphic Section, Trinidad: Outcrop Data

Visual Carbonization Estimates (Outcrop Samples)

Sample Nos.	Kerogen Type	H/C Generating Potential	Wt. % C	H/C Type
BH 2-50	Struct.	Early Gen.	75 %	Dry Gas
PC 4-8	"	"	"	"
LL 2	"	"	"	"

Basin Modelling Experiment

Data from the West SEG-1 well was subjected to an experiment using the BASINMOD program. BASINMOD's primary function in this study is to construct a burial history model. For the purposes of constructing this model the proportions of the basic lithological components had to be specified. The thermal conductivity parameters of the lithology so created is then averaged and an estimate created for the new lithology. The program is based on a kinetic model which utilizes vitrinite reflectance data and thermal conductivity data to construct a burial history profile. The data used is presented below:

Depth	Log Temp.	Ss/sl/ms	Age
1550-5150'	100-120°F	70/10/20	Pleist.
5150-7800'	165°F	60/20/20	L. Plio.
7800-8800'	177°F	70/10/20	L. Pleist.
8800-12250'	177-200°F	65/10/25	L. Plio.
12250-15230'	210-245°F	70/15/15	L. E. Plio.

An estimation of the sandstone/siltstone/mudstone ratio was made from cuttings and electric log calculations. The ages used were derived through the use of palynology in this study, and the temperatures were obtained from electric well logs. A thermal gradient of 10°F adopted from Leonard (1983) was used in this experiment.

Organic Geochemistry: Discussion

The main observations on the presented data are listed below:

a) The sediments are low in total organic matter content,

b) A very high percentage of the organic matter has been reworked,

c) The Oxygen Index for the outcrop samples indicate less weathering than well samples (!),

d) TMAX values are high, however S1, S2 and TOC values are low.

Total Organic Carbon

These values are again quite low and reflect poor organic matter content of the samples and their poor source potential. As a result of the tremendous amount of reworking present in Trinidad samples, it appears that TOC values reported and based on Rock Eval pyrolysis are unacceptable, as they are based on insufficient measurable material. The sediments classify as inadequate source rocks!

S1 & S2

These indicators also suggest that the studied section is low in organic matter and does not have good or marginal source potential. S1 values greater than 1 are indicative of good source rocks however all values reported are much less than 1. All samples show very poor source potential with respect to S2. These data suggest that there is very little free thermally extractable hydrocarbons within the section, that the genetic potential is poor and that the organic matter content is low thus not affording much kerogen to be cracked during pyrolysis. The data thus suggest that the TMAX values reported are not acceptable and are possibly the result of reworked organic matter. Further, high TMAX values along with low S1, S2 and TOC strongly indicate reworking.

TMAX Values

TMAX values indicate that the sedimentary sequence encountered along the south coast and in the subsurface of southern offshore Trinidad in generally immature or that the sediments are within the gas window. A plot (Figure 89) of these values against depth roughly indicate that TMAX values decrease with depth. This is indeed the opposite to the expected trend if the assumption is that these values increase with depth or with progressive thermal stress. TMAX values obtained from this data set are unacceptable as indicated by the very low S2 values. This, therefore, precludes their use in making more definite statements on levels of maturity and hydrocarbon potential of the studied section.

Geothermal Gradients

In the West Seg-1 well off the south east coast of Trininad a bottom hole temperature of 140°F was reported. Compensation corrections using

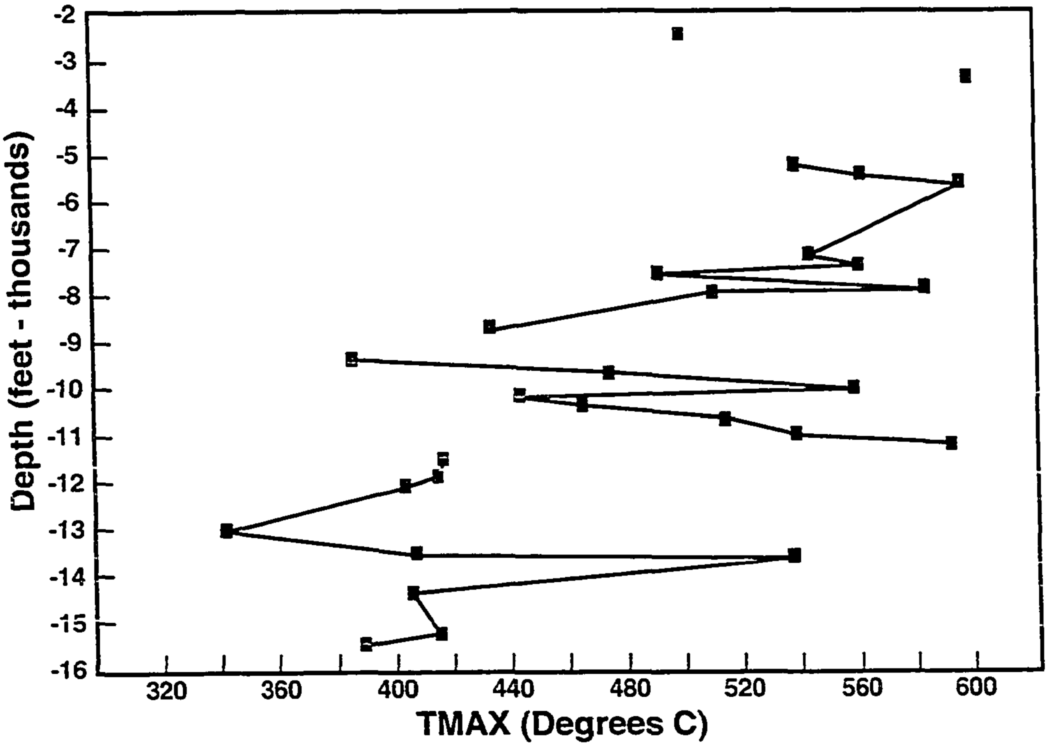


Figure 89. Depth vs TMAX, West Seg-1, Trinidad

the Horner plots corrects the bottom hole temperature to 170°F, (Fertl and Wichmann, 1977). This suggests a very low geothermal gradient of approximately 8°F/1000 ft - a figure which closely approximates the 10°F/1000 ft calculated by Leonard (1983). Other data (vitrinite reflectance measurements of selected horizons in Trinidad) not presented here supports this very low thermal gradient and presents a vitrinite reflectance gradient of .1%R_0/1000 ft. Both these figures suggest a very low thermal stress gradient for southern Trinidad.

Leonard (1983) also noted very low gradients in this part of the basin and suggested that they may be accounted for by the high conductivity of the sand-rich southern Trinidad stratigraphic section and the rapid rate of sedimentation.

Oxygen Index-Hydrogen Index Plot

Van Krevelen diagrams (for both outcrop and subsurface) which plot the hydrogen index against the oxygen index indicate that Type III organic matter is the predominant type. This suggests that if a thick section is encountered (to compensate for low TOCs) at depth such a section will be gas prone. The gas window should be encountered somewhere below 18,000 feet (the suggested end of the oil window in Trinidad). At this depth a bottom hole temperature of approximately 240°F-250°F should be encountered together with approximately 1.8%R_0.

Also very few data points are plotted on the van Krevelen diagram as the scales do not allow for the very high oxygen indices encountered.

This is indeed a manifestation of the intense reworking and/or weathering undergone by these sediments. Reworking and rapid deposition of sediments in the Trinidad region appear to be a major factor in most geologic considerations. The outcrop section showed some horizons with very large amounts of reworked and resedimented organic matter. It may be envisaged that this situation is more widespread than thought. Lamy (pers. comm., 1990) points out that this is indeed the situation at many Tertiary horizons, eg. the Lizard Springs formation where organic rich horizons (thought of as lignite) have been transported over great distances.

BASINMOD

The available maturity and temperature data was matched by a model which used a heat flow value of 0.9 units. The model involved four events with the ages, tops, thicknesses and lithologies illustrated in Figure 90. The model indicates that thrusting began 500,000 years ago. The sediments penetrated in West SEG-I are predicted to be early mature at total depth 15,230 and, peak oil is predicted to occur deeper than the total depth encountered at West SEG-1.

A calculated burial profile (Figure 91) illustrates the burial path and supports the conclusions above.

Isotope Geochemistry: Background and Theory

In using stable isotopes a goal was to offer some preliminary insights into the diagenetic, thermal and maturation histories of Early

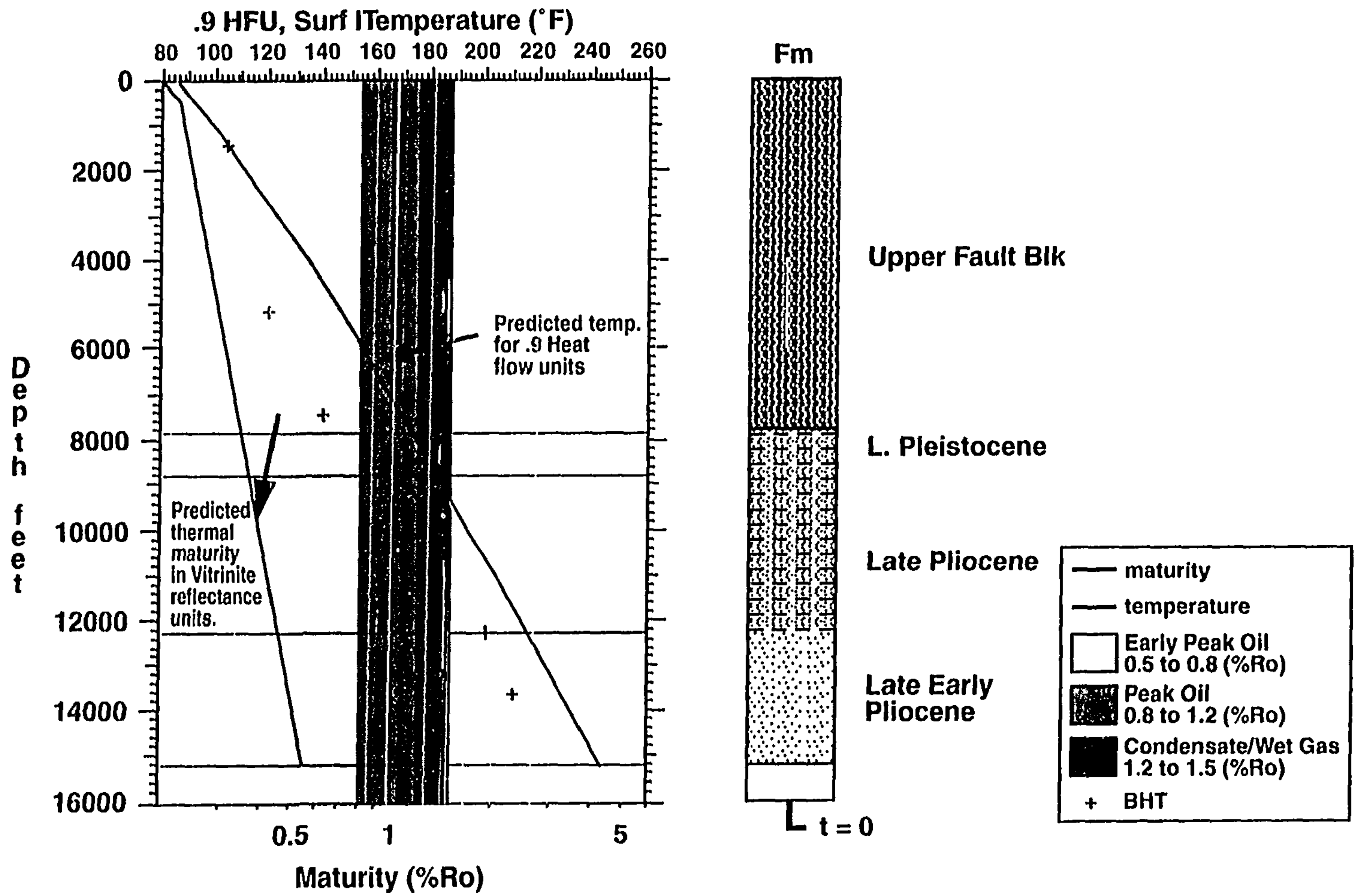


Figure 90. Thermal Maturity Model, West Seg-1

Pliocene sediments on the south coast of Trinidad. These investigations are intended to supplement the data obtained from clay mineralogy and organic geochemistry.

Studying oxygen and carbon isotopes give information on the diagenetic origin of cements and authigenic minerals. Especially in the case of oxygen, systematic trends in $^{18}O/^{16}O$ ratios suggest that significant temperature information can be derived up to and often in excess of 500°C. Oxygen isotopes are as a result good geothermometers. The advantage of oxygen as a geothermometer is that it is not pressure sensitive, (Hoefs, 1980). In contrast to oxygen isotopes, the equilibrium fractionation of carbon isotopes is less temperature sensitive, (Reeder, 1983). Various authors have devised mechanisms whereby these isotopes are incorporated into the chemistry of authigenic minerals, and their models show boundaries, marked by definite isotopic compositions, (eg. Milliman, 1974). Carbon isotopes are of tremendous use in establishing the origins of carbonate cements and deriving information on the paleogeochemistry of the water conditions, (Hoefs, 1980, and Reeder, 1983).

Hudson (1975), Irwin and Curtis (1977), Dickson and Coleman of events occurring within burial profiles. These events are summarized and presented as a series of zones based on Irwin and Curtis, (1977).

Zone I - A zone of bacterial oxidation, where very light carbonates dominate. This zone is also characterized by isotopically light oxygen;

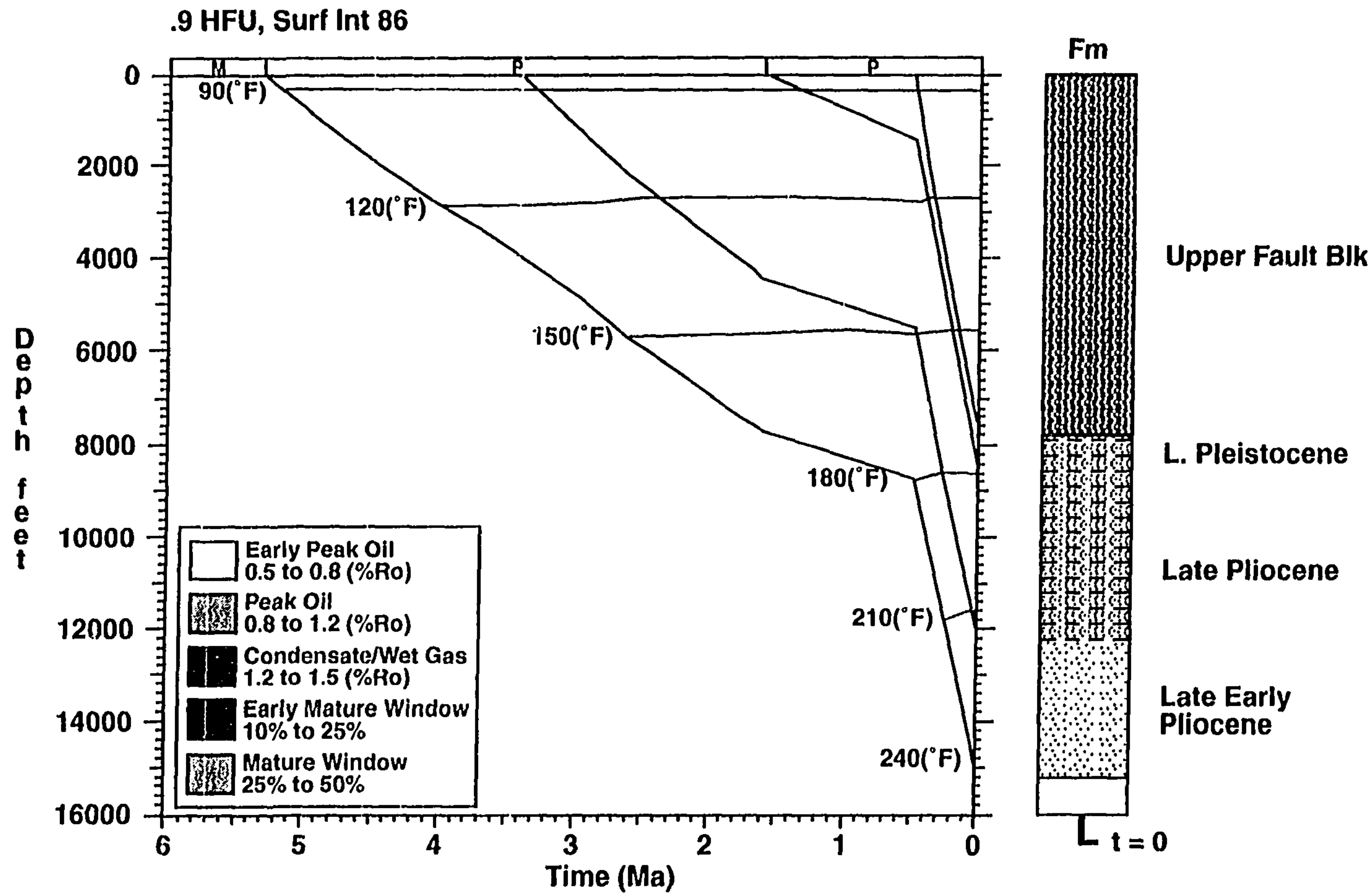


Figure 91. Thermal Maturity Model, West Seg-1

Zone II - where bacterial reduction of sulphate occurs and isotopically light carbon is generated.

Many authors believe that meteoric waters are very important in the formation of volumetrically important calcite cements within Zones I and II. Hudson (1975), however, believes that deep burial diagenesis is the major factor in the formation of such large volumes of cements. Hudson argues (using minor changes in isotopic compositions) that due to the fact that "during diagenesis marine carbonates generally become lighter in carbon isotopic composition". Many authors mistake these cements for cements which have originated in shallow burial conditions. Maynard (1983) believes that marine carbonates, eg. skeletal and inorganic carbonates, range from -2 to 1+ per mil, and that Zones I and II by incorporating this carbonate produce light CO_2 within the uppermost sediment column, with an appreciable proportion of biogenic carbon which is much lighter -20 to -25 per mil in modern sediments.

Zone III - the zone of bacterial fermentation, where there is a change to isotopically heavy carbon, about +15 (Maynard, 1983). The base of this zone marks the onset of the influence of thermal maturation of organic matter. These three zones are therefore influenced by bacterial or biotic processes, and may range from 0 to 1000 meters depth and 0 to 30°C.

Zone IV - is a major zone of abiotic processes and a major zone of organic maturation processes, eg. thermal decarboxylation. Rates of reactions in this zone rise with temperature and then decrease as suitable molecules for cracking are depleted.

Results

This table presents the oxygen and carbcon isotopic compositions of two samples from the West SEG-1 well and twelve samples from the outcrcop section.

Sample ID	^{13}C	^{10}O (PDB)	^{10}O (SMOW)
WSEG-1 2780	-6.6	-1.7	29.11
WSEG-1 8420	-4.0	-1.6	29.21
Outcrop BH5	1.8	-2.7	28.10
" BH9	-15.8	-10.6	19.90
" BH10	2.4	-5.7	24.90
" BH12	7.0	-8.0	22.60
" BH15	-9.2	-2.4	28.39
" BH18	-14.2	-7.2	23.40
" BH25	-14.0	-5.8	24.90
" BH28	-5.8	-9.3	21.30
" BH33	-9.1	.6	26.10
" BH36	-7.7	-7.1	23.50
" BH38	-11.5	-8.3	22.30
" BH58	-14.7	-8.4	22.20

* These samples contained up to 50% siderite and were therefore omitted from the isotopic considerations with regard to oxygen. This is because

the fractionation relationship between siderite and phosphoric acid during sample preparaticon is not well defined, (Maynard, 1983).

Isotope Geochemistry: Discussion

A plot of carbon isotopic composition versus oxygen isotopic composition shows no relation between carbon and oxygen values, suggesting a complex diagenetic history. The data however suggests that early cementation was a very important process. All of the samples are isotopically light in oxygen compared to seawater, but carbon is sometimes heavier and sometimes lighter than primary marine carbonates.

The light samples (negative ^{13}C values) probably derived part of their carbon from oxidation of organic matter during early diagenesis, but prior to the formation of the methane fermentation cements. The set of light carbon samples (negative C values) does define a rough trend on the carbon versus oxygen plot (Figure 92); a plot that suggests primary marine carbonate as one end-member. With increasing diagenetic influence, the composition moves to lighter carbon (more organic influence) and lighter oxygen (more meteoric influence).

Samples BH18, BH25, BH28, BH33, BH36, BH38 and BH58 show isotopic compositions which suggest that carbonates were derived from diagenesis of organic carbon, whereas oxygen was either derived from meteoric (fresh-water) water (Maynard, 1983) or high temperature (deep burial) diagenesis. Another possibility is that such light oxygen isotopic compositions may be the result of re-equilibration with present meteoric water after uplift.

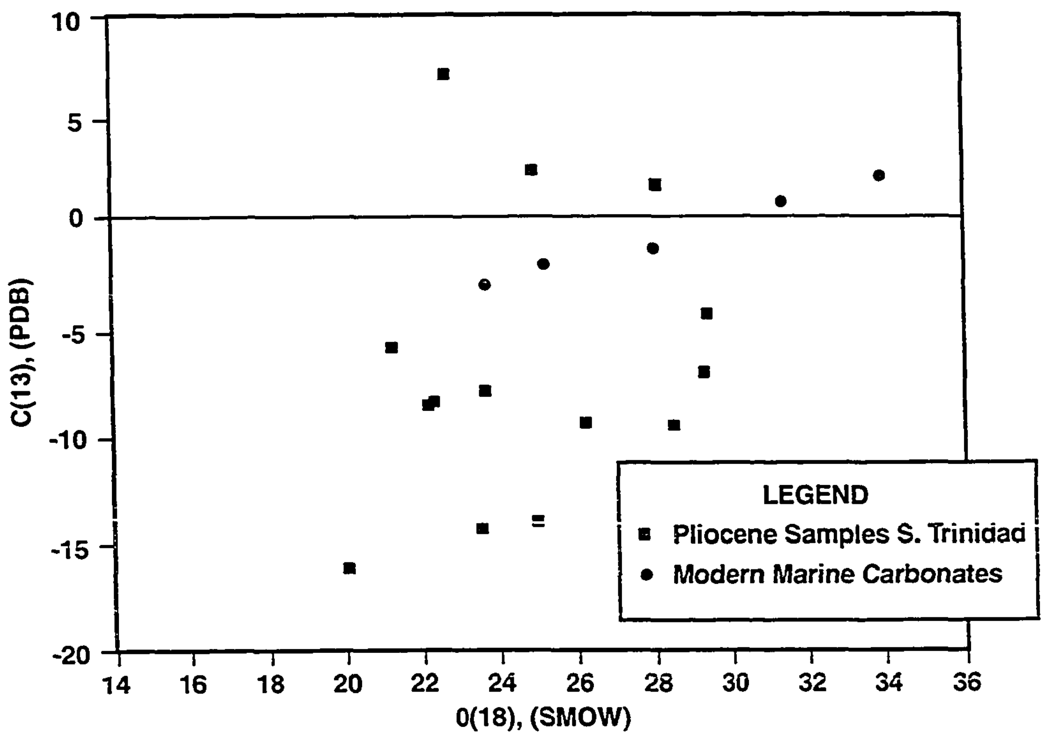


Figure 92. Stable Isotope Data, South Trinidad

Carbon is both heavier and lighter than primary carbonates. The three heavy samples (positive ^{13}C values) probably derived their C during early diagenesis via the methane fermentation reaction. The positive or heavy carbon values are indicative of heavy carbon produced during fermentation. This therefore suggest shallcow cementation conditions in zones less than 1000 meters. Sample BH9 with values of -10.6 and 15.8 for oxygen and carbon respectively span a temperature range from fermentation to burial decarboxylation.

Byers (1977) suggested that the level of oxygenation within the sediment can be deduced from the degree of lamination of organic rich shales. This is, however, not applicable in these samples because the larger proportion of organic matter was reworked and resedimented. The level of preservation does not reflect the primary depositional, biologic and geochemical conditions within the sediment column.

These samples are generally iron rich with the result that siderite is locally developed. It is possible that the source of this iron could be the smectite to illite transformation; however, this process has occurred only to a limited extent in these sediments.

The data presented here suggest that calcite cements encountered in the sandstones from south Trinidad are primarily the result of early cementation and burial, under the influence of meteoric waters and biogenic gases. The light numbers way also indicate some minor influence from late stage cementation which may have occluded secondary porosity and microporosity originated during decarboxylation.

LATE FARY PLIOCENE OFFSHORE - ONSHORE RELATIONSHIPS

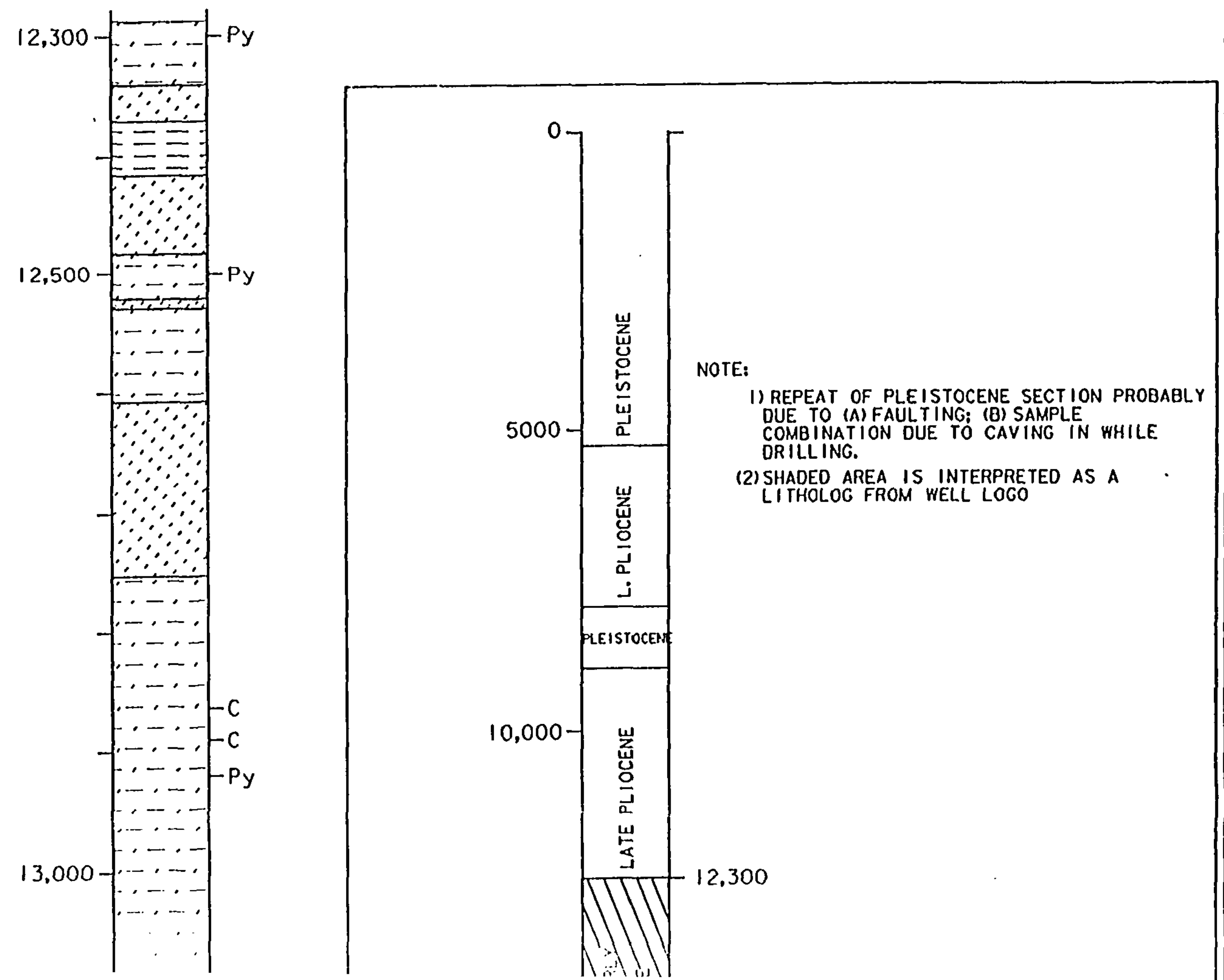
The Late Early Pliocene of the Subsurface Offshcore Trinidad

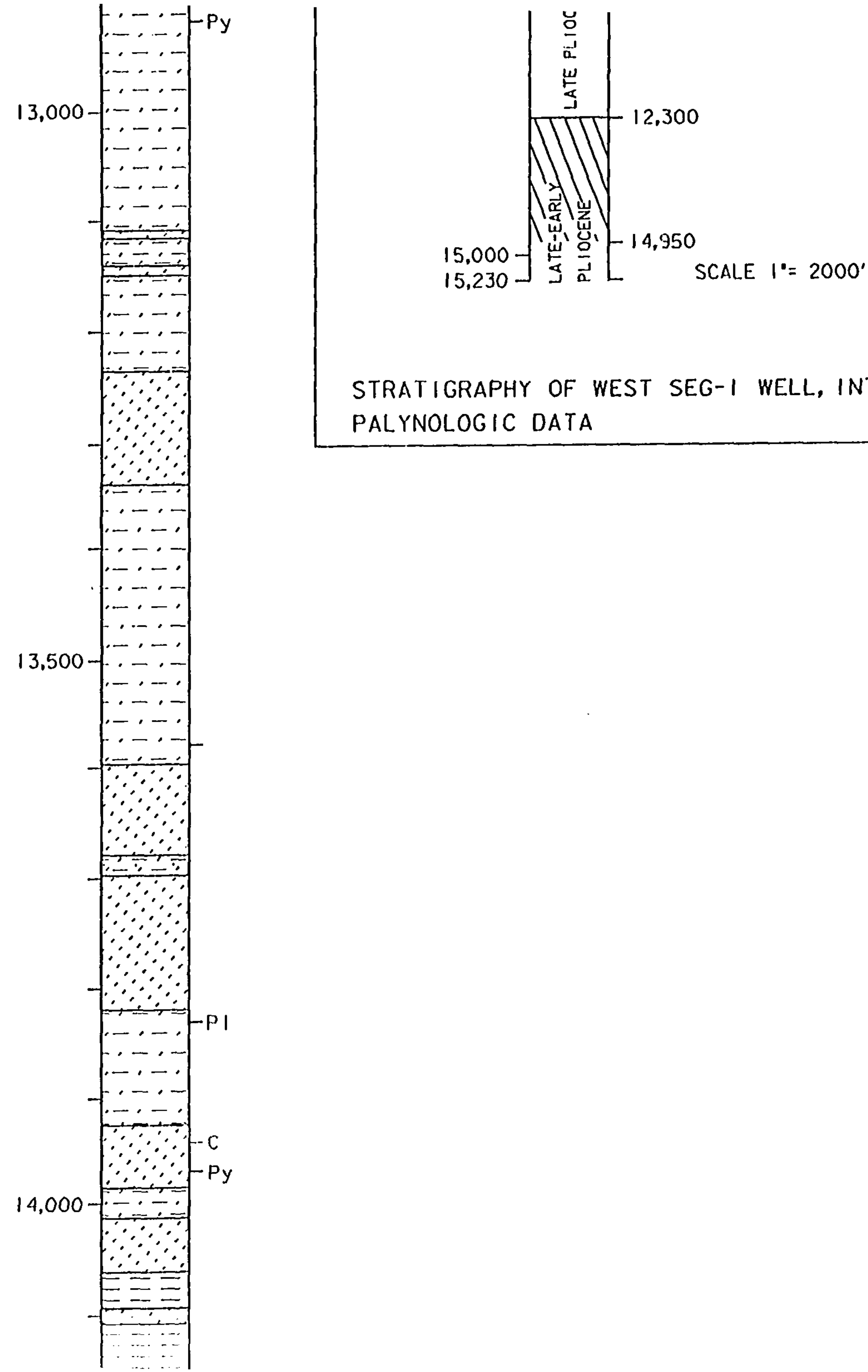
The section described here begins at 12,300 feet and ends at 15,236 feet TD. This section was determined to be the top of the Late Early Pliocene of the subsurface. Though seismic profiles indicate that the rocks of the south coast stratigraphic section are to be encountered deeper than the total depth of the West SEG-1 well this section will be described since it was determined to be Late Early Pliocene in age - similar to the south coast stratigraphic section. The south coast lithologies should in an undeformed sequence be encountered below 12,300 feet, in the subsurface of the Columbus Basin.

The subsurface section (determined from well logs and cuttings) is comprised of thickly bedded silty sandstones and sandy siltstones. Occasionally thickly bedded sandstones occur. These thickly bedded units may be up to 70 feet thick. The section shows very little or no mudstone. Examination of cuttings, geophysical well logs and mud logs indicate that the interval in the subsurface is on the average comprised of approximately 45% siltstone, 20% mudstone and 35% sandstone. See Figure 93, which illustrates the interpreted stratigraphy and lithology encountered in the West SEG 1 well.

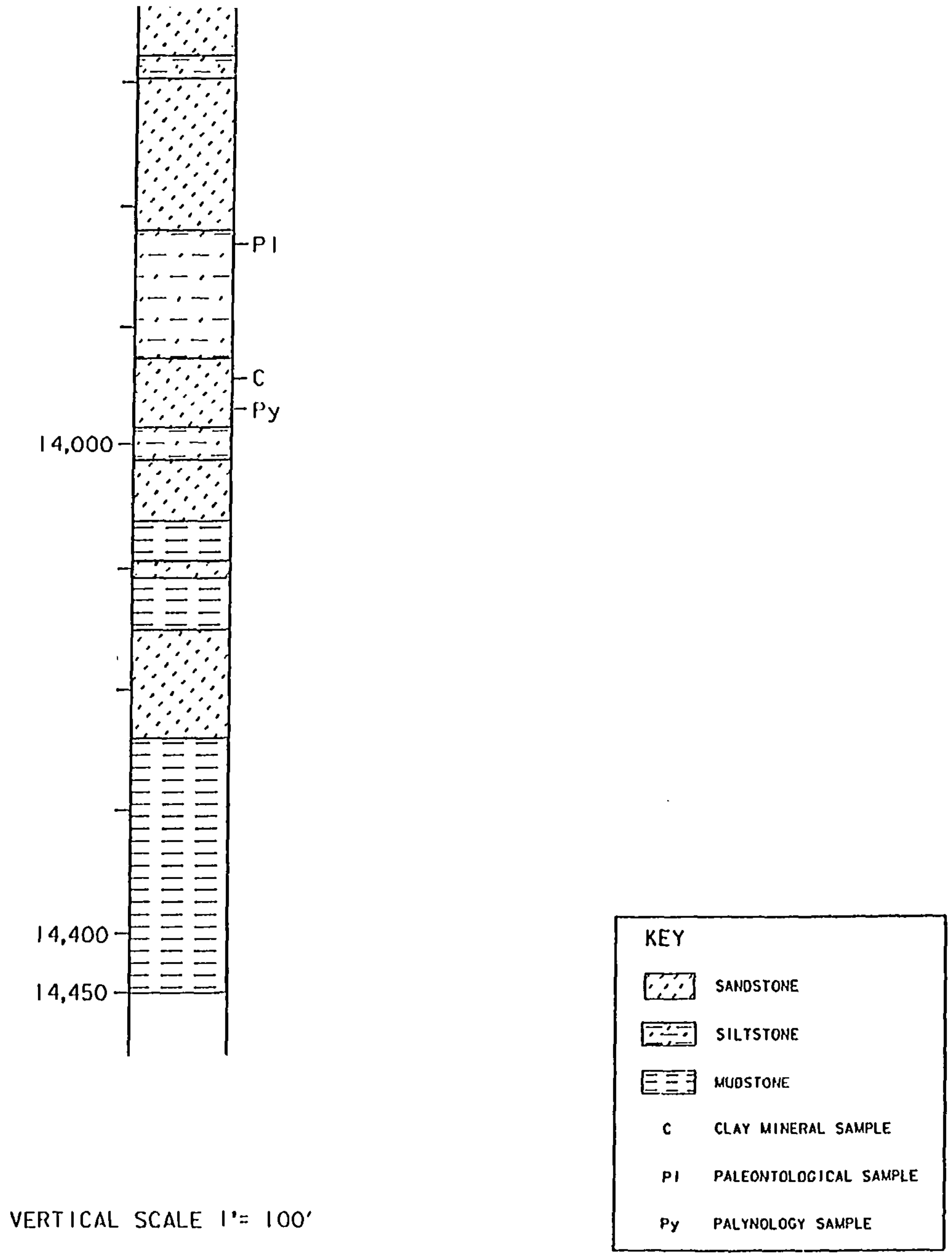
Geophysical well logs indicate that there were some problems completing the hole, probably due to caving in and unconsolidated sediment.

FIGURE 93: GROSS LITHOLOGICAL INTERPRETATION AND SAMPLE LOCATION, WEST SEG-1, TRINIDAD, W.I.





STRATIGRAPHY OF WEST SEG-1 WELL, INTERPRETED FROM PALYNOLOGIC DATA



PI
C
Py
14,000
14,400
14,450
VERTICAL SCALE 1"= 100'
KEY
SANDSTONE
SILTSTONE
MUDSTONE
C CLAY MINERAL SAMPLE
PI PALEONTOLOGICAL SAMPLE
Py PALYNOLOGY SAMPLE

Relationship Between Outcrop and Subsurface: Palynologic and Seismic Evidence and Interpretation.

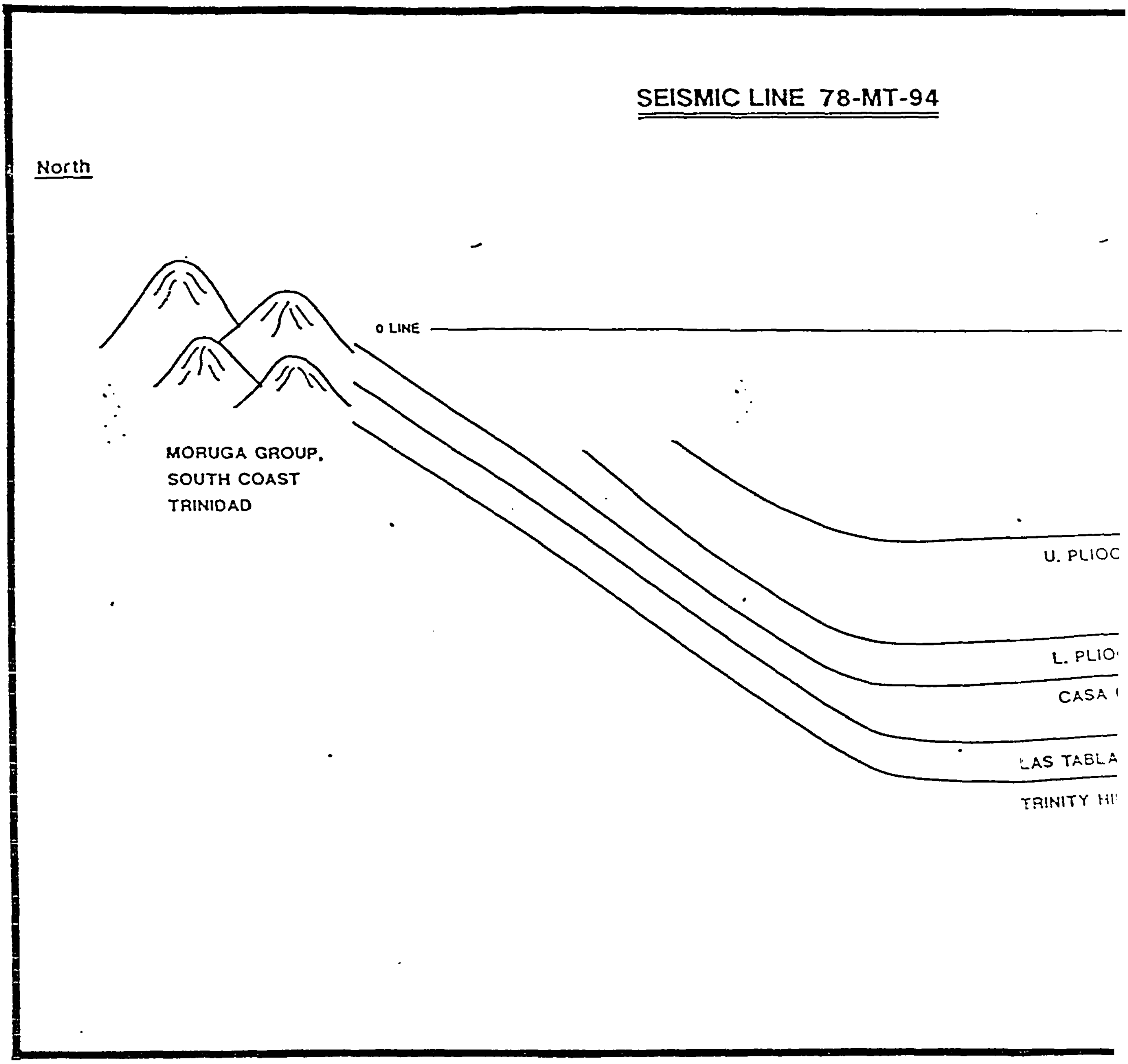
By combining seismic and palynologic evidence the two sequences studied were placed in their correct stratigraphic positions.

Two seismic lines provided an opportunity to construct a correlation (geoseismic cross section) between the two sequences studied (Figure 94). When coupled with palynological data an even more accurate assignment is possible.

Palynologically the outcrop section along the south coast was determined to be of Late Early Pliocene age. In the West SEG-1 well the uppermost late Early Pliocene sediments were encountered at 12,300 feet depth. Sediments of this age persisted to TD 15,236 feet and probably beyond. This data suggest that the outcrop section is equivalent to the section encountered in the West SEG-1 well below 12,300 feet.

Seismic data indicate that the steep dips of the outcrop section persists into the subsurface for some distance offshore before flattening out. These data also suggest that the south coast Moruga Group stratigraphic section if traced on the seismic lines will be encountered at depths greater than the total depth (15,236 feet) of the West SEG-1 well.

The West SEG-1 well was terminated within the Las Tablas Silt which forms the top of the Late Early Pliocene sequence. The seismic profiles also indicate that the rocks of Pliocene and Pleistocene ages off the


SEISMIC LINE 78-MT-94
North
0 LINE
MORUGA GROUP,
SOUTH COAST
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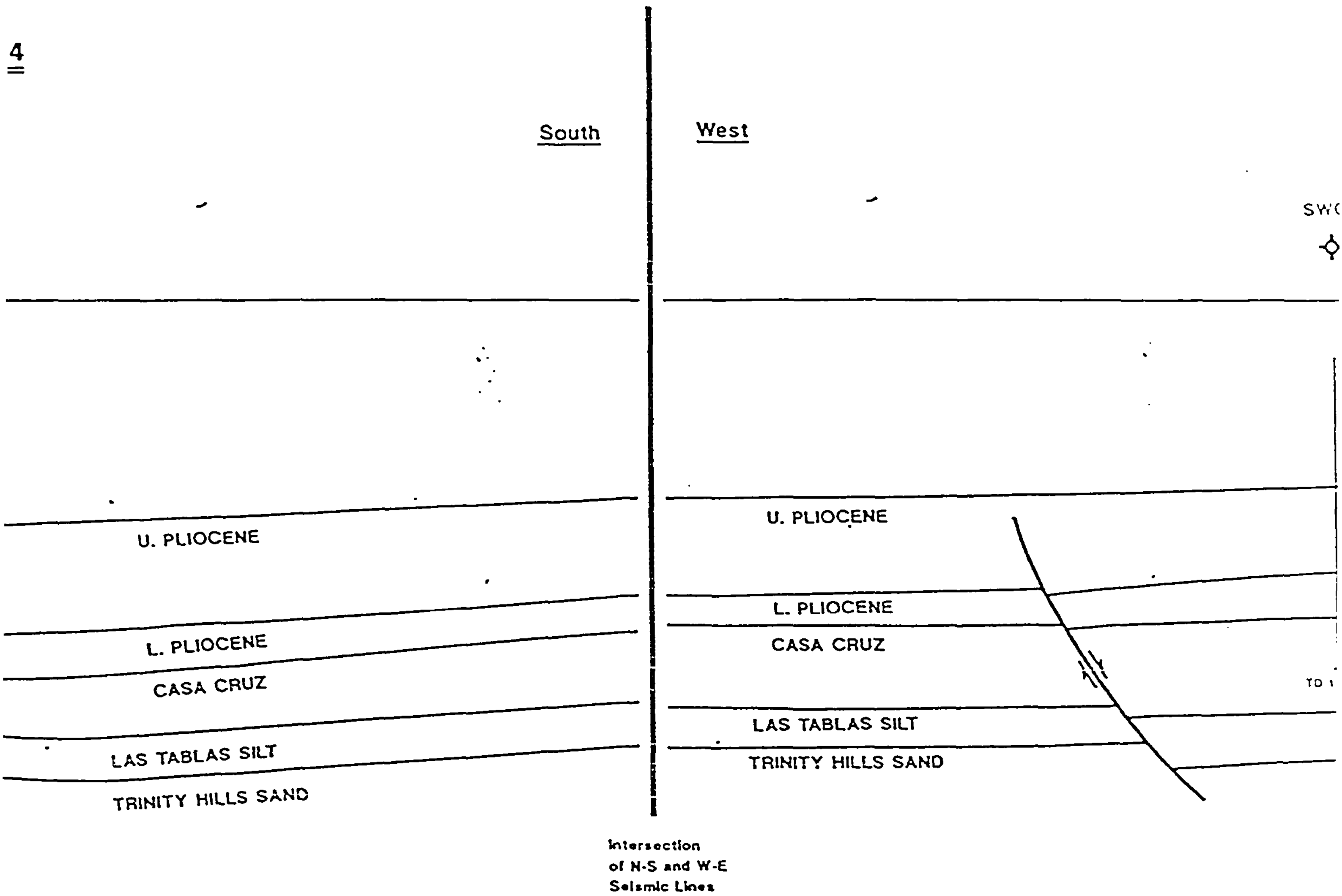
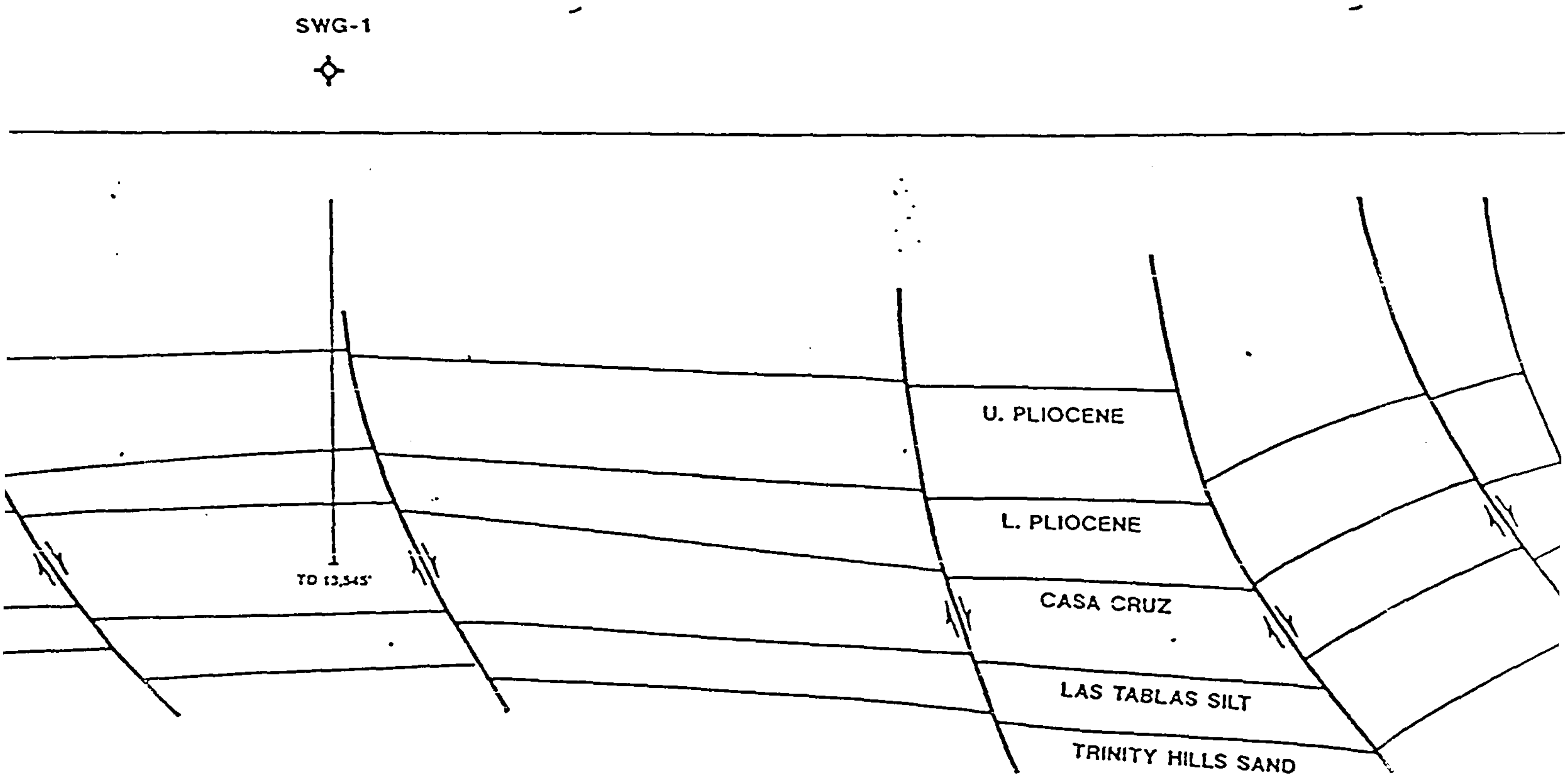
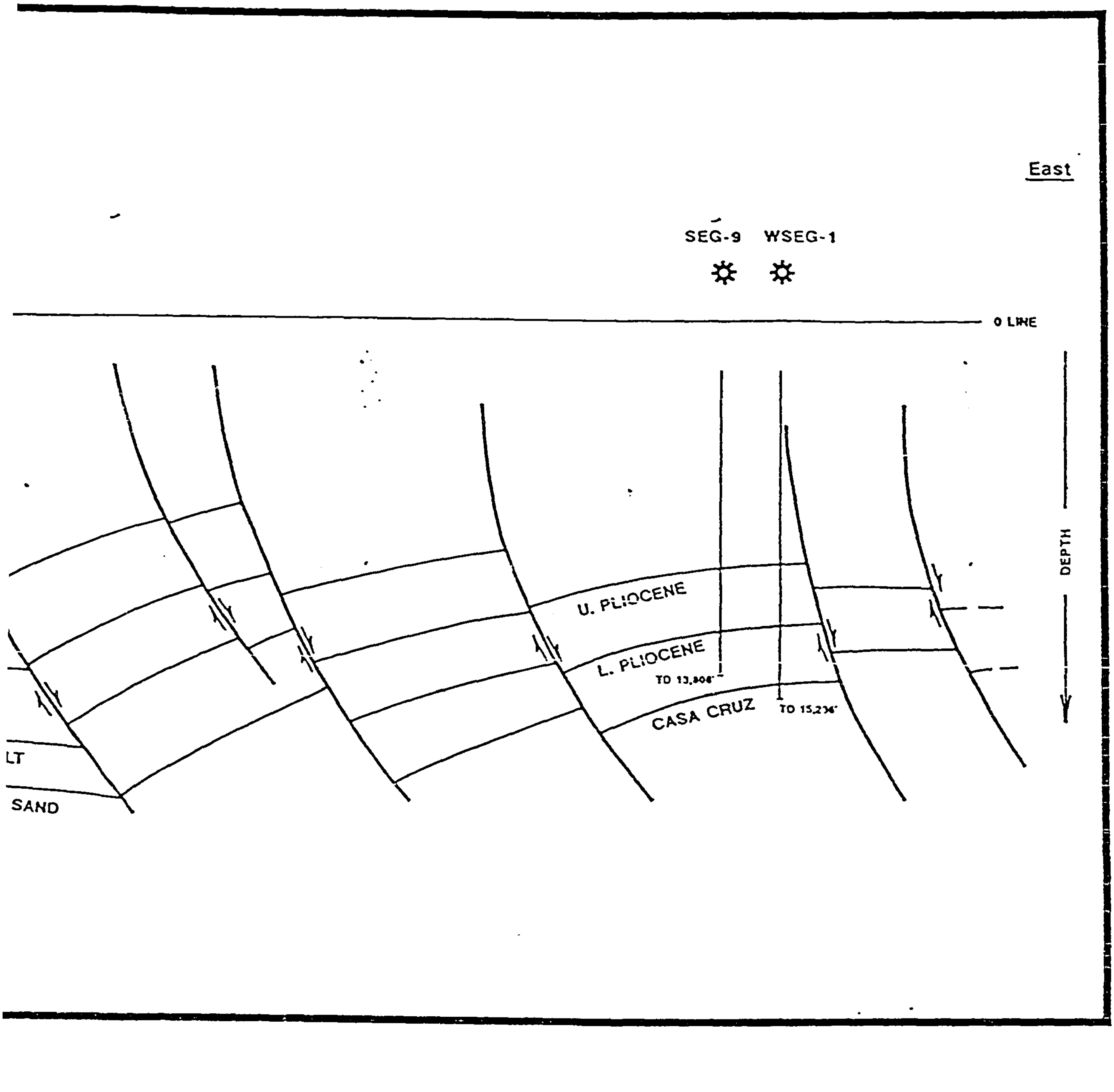


Figure 94 GEOSEISMIC CARTOON SHOWING CORRELATION

SEISMIC LINE D-AM-C



N SHOWING CORRELATION BETWEEN OUTCROP AND WEST SEG-1



East
SEG-9
WSEG-1
0 LINE
DEPTH
U. PLIOCENE
L. PLIOCENE
CASA CRUZ
TD 13,806'
TD 15,236'
LT
SAND

south and south east coast of Trinidad are a series of well bedded, often channelled units. These channels are very broad, low amplitude scours, typical of submarine fans rather than deeply cut and well defined "fluvial type" channels.

The channels or "channel-like" features observed on the seismic traces (Line C parallel to the southern coastline) are observed within the Las Tablas silt. These very broad, low amplitude channels or scours pass laterally into well bedded, laterally continuous clastics which appear as strong reflectors. Line 78MT94 runs normal to Line C and shows a northward progradational sequence toward the southern Trinidad shore. Progradational sequences are the case in both the Las Tablas Silt and the underlying Trinity Hills sandstone. This is further evidence for the northward progradation of the depositional system, during late Early Pliocene time. The northward line ends about two kilometers from the south coast in a series of steeply dipping, well bedded clastic rocks which dip seaward in a southerly direction, and which show up as relatively strong reflectors.

Seismic lines also show a series of normal faults (possibly sediment load related) which become younger eastward and in the process may be responsible for thicker Pleistocene sediment covers moving eastward within the basin.

The present positions of these two sequences are the result of uplift and structural involvement possibly related to the Tertiary evolutionary stage of the southern Caribbean Plate Boundary. These events probably involve the Los Bajos Wrench Fault System and more importantly the northwest-southeast trending normal faults in the offshore area. Clay mineralogy and organic geochemistry (discussed in another section) suggest that though older the onshore lithologies have probably experienced less thermal stress than the West SEG-1 rocks. This is probably the result of differential burial associated with faulting and uplift.

Structural Implications

In this well the presence of a major unconformity is confirmed by palynology. This unconformity occurs at the base of the Pleistocene sequence (5050 feet) as the Late Pleistocene rests directly upon the Late pliocene, indicating absence of the Early Pleistocene and possibly some Late Pliocene strata.

The palynologic data derived from the West SEG-1 well also indicated repetition of Late Pleistocene section suggestive of reverse faulting. Evidence for this thrusted relationship is indicated by the two sidewall cores taken at 8600 feet and one at 10,900 feet. Sidewall core 8600 A shows a reworked flora and indicates some faulting, whereas sidewall core 8600 B contains a flora which indicates some repetition of sequence as a Pleistocene flora is present in a part of the sequence which is apparently of Pliocene age. The sidewall core taken at 10,900 feet also encountered sediments of Late Pleistocene age indicating thrust faulting.

Some evidence of faulting may be indicated by the data. The exact location of these faults is not apparent.

The major importance of this section to the dissertation is that new data is provided on the ages of these sediments. These ages have long been the subject of many debates. Previously the sediments have been ascribed Miocene ages (eg. Michelson, 1976), based on stratigraphic relationships in other parts of the Southern Basin and the subsurface. The new data presented here is therefore an invaluable and new contribution to the stratigraphy and geologic history of Trinidad and the East Venezuela Tertiary Basin.

BASIN ANALYSIS AND CONCLUSIONS

Depositional Model

Thick marine sedimentary and volcanic sequences accumulated in northern Venezuela and Trinidad during Late Jurassic and Cretaceous time (Bell, 1972). A period of regional metamorphism and orogenesis followed along with the associated formation of flysch troughs which recieved large masses of turbidite sands until early Eocene. By Middle Eocene convergent right lateral wrench tectonics associated with the relative motions of the Caribbean and North American plates began along the southern boundary of the Caribbean plate (Bertrand and Bertrand, 1985). This style of tectonics continued and was intensified during the Oligocene. That wrench tectonics might not have been as important as suggested was indicated by Bassinger (1971). Differential motion associated with the above tectonic regime might have led to the formation of several structomorphologic areas (Persad, 1979) of which the southern Trinidad sedimentary basin is an example. This basin provided a tectonically active depocenter for large volumes of sediment to be deposited from the previously uplifted areas of South America. Tectonic factors caused relative sea level falls during which large volumes of detritus were supplied to the basin.

By Early Pliocene time the northerly prograding, ancestral Orinoco Delta deposited large volumes of sediment in the Northern Venezuela/Columbus Basin Area. The South Coast stratigraphic section was deposited in an open marine probably outer shelf envirorment, by turbidity currents which developed on the front of the northward prograding delta system. The presence of plant debris and a terrestrially derived flora support the influx of deltaic/ terrigenous sediments into the depositional basin.

The Late Early Pliocene depositional episodes within this basin occurred during periods of lowstands of sea level, during which the Orinoco Delta prograded onto the shelf area, thus transporting more sediment onto the shelf.

Large areal extent of the sandstone lobe facies associations suggest analogy with elongate high efficiency (Mutti, 1979, 1985), Type 1 turbidite systems. The overall coarsening up patterns observed suggest that the sequence grew essentially as a result of progradation. Development of such large volume turbidite systems (Mutti's high efficiency, Type 1) appears to require prograding mud-rich river delta sources. Such ideas are in congruence with the suggestion that the Orinoco Delta was active along the southern margin of the depositional basin. In view of the large vcolumes of material resedimented on the shelf, the major river system feeding the Orinoco Delta must have drained an extensive area of land.

The turbidite system differs from classic models as there are no indicators of point sources (eg. canyons) which funnelled sediment into basinal settings, but considers a line source along which viscous sheets flows of sand, silt and mud were moved down the delta front. Similar models have been recently described in the literature (Chan and Dott, 1983, and Heller and Dickinson, 1985). The model of Heller and Dickinson (1985) is preferred for the sediments of the Moruga Group along the south coast of Trinidad, as it invokes a delta-fed submarine ramp setting for similar sequences.

Progradation of the Orinoco Delta provided large volumes of failure prone sediment for resedimentation. Sediment pile instability and seismic events associated with an evolving and tectonically active basin remobilized large volumes of sediment derived from the delta top and delta front areas. The associated turbidity currents were highly viscous, dense, gravity driven slurries which moved rapidly down the delta slope and onto the outer shelf and upper slope areas. Widespread occurrence of fluidization structures, contorted bedding and synsedimentary ptygmatic folding, suggest that slumping and sediment pile failure were responsible for the movement cof a large part of the sediment mass (Figure 95).

The widespread presence of HCS (truncated wave ripples) within the sequence, in association with the suite of sedimentary structures encountered and the vertical and lateral variation of facies, suggest that this structure (commonly associated with storm activity) may result from processes other than purely oscillatory flows generated by storms.

It is proposed here that HCS may also result from the remobilization of the upper layers of plane beds, probably by localized oscillatory currents as velocity decreases. Whether oscillatory currents are necessary for the formation of HCS, is a pertinent question which arises. The close relationship between upper flow regime plane beds and truncated

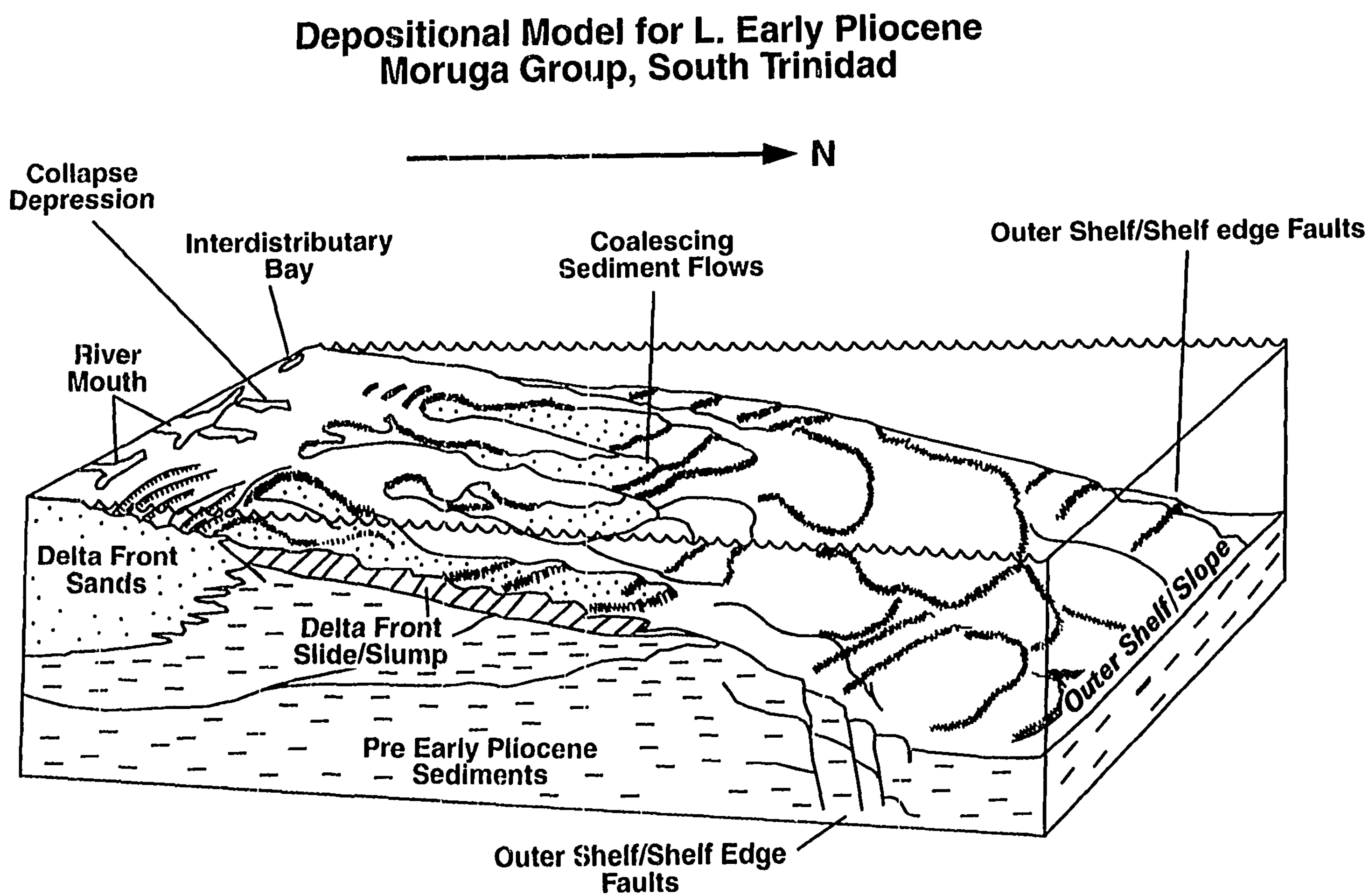

Depositional Model for L. Early Pliocene
Moruga Group, South Trinidad
N
Collapse Depression
Interdistributary Bay
River Mouth
Coalescing Sediment Flows
Outer Shelf/Shelf edge Faults
Delta Front Sands
Delta Front Slide/Slump
Outer Shelf/Slope
Pre Early Pliocene Sediments
Outer Shelf/Shelf Edge Faults

Figure 95

wave ripple lamination (HCS) led to modification of the widely accepted Bouma sequence.

Provenance

The sandstones of the Moruga Group, along the south coast of Trinidad have been classified primarily as subarkoses and sublitharenites in the classification schemes of Pettijohn et al., (1972) and Folk, (1978). When an adjectival prefix is used to describe the cementing material these sediments are appropriately classified as calcareous subarkcoses and calcareous sublitharenites.

The chemical maturity of the Late Early Pliocene sandstones of the south coast of Trinidad is highlighted by modal analyses and provenance studies. The framework modes suggest that the detritus had a recycled orogen provenance and more specifically was derived from a collision orogen source with probably some input from a subduction complex source. High quartz content is generally suggestive of extensive transport and weathering which, overall, produces a more mature sand.

The angularity and freshness of grains present in the south coast Trinidad sandstones however, suggest that transport distances were not very long, or alternatively, that the sands were transported in a fashion which prevented extensive abrasion of grains. Potter (1978) considered the possibility that some rounding may be due to solution in saprolitic soils or even in mature soils developed in alluvium in a river's lower valley and delta. It therefore appears that a long residence time in such environments was not the case for these Early Pliocene sandstones. This described freshness is common to quartz, feldspar and mica grains. As discussed in the earlier section on detrital grains, there are also few grains that show rounding and other signs of reworking, resedimentation and weathering as in the case of feldspar. This may reflect more than one source and the low percentage of reworked grains strongly suggest that there might have been reworking of older sedimentary rocks.

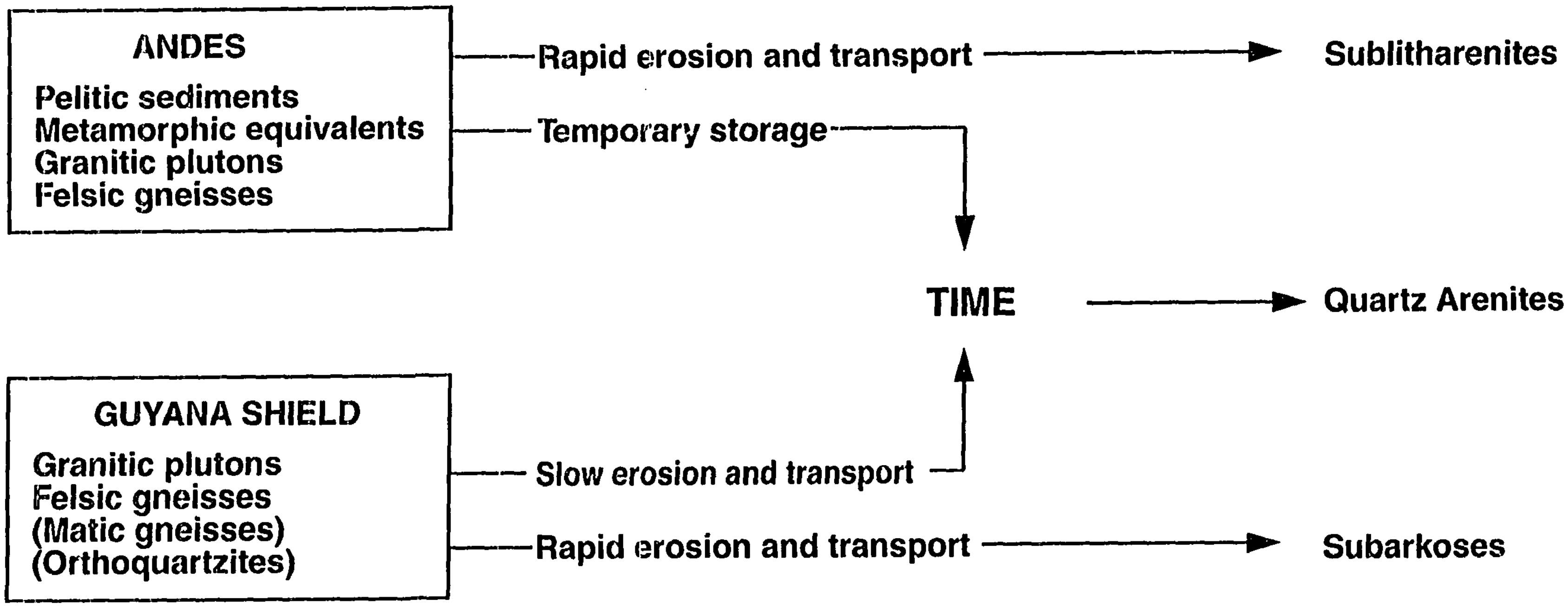
The detritus thus derived was not exposed to extensive weathering and indications are that the framework grains were cemented and deposited relatively soon after erosion. The low feldspar content is probably a reflection of source composition, but is more likely the result of chemical weathering and the effective removal of labile constituents. The only forms of alteration evident in the feldspars are mild sericitization due to weathering and, diagenetic alteration due to replacement by calcite.

An alternative interpretation however is that these sands are multi-cycle sands which have undergone multiple cycles of a transporting agent and depositional environment. This interpretation must however ignore the relative angularity of the grains discussed above. Johnsson et al., (1988) suggest that relative degrees of roundness and angularity are not necessarily good criteria to distinguish between first- and multi-cycle sands. The presence of rounded quartz grains with and without overgrowths therefore becomes potentially important in a discussion of multi-cyclicity. In these rocks however, the finer quartz grains were generally more angular and less likely to be interpreted as multi-cycle grains.

It is important to consider the following scheme (Figure 96) of Johnsson et al., (1988) while arriving at a possible source for the rocks found on Trinidad's south coast. As suggested by this scheme South American sublitharenites are the result of rapid transport and erosion of Andean source rocks which are typically pelitic sediments, metamorphic equivalents, granitic plutons and felsic gneisses. The South Anerican subarkoses on the other hand are the result of rapid erosion and transport of granitic plutons, felsic gneisses (mafic gneisses) and orthoquartzites found on the Guyana Shield.

The heavy mineral suite indicates that the sandstones were derived from a mixed igneous and metamorphic source terrain. Zircon, tourmaline, hornblende, staurolite and chloritoid indicate a high rank metamorphic terrain. Zircon, tourmaline, rutile and hornblende may also be found in acidic and intermediate igneous rocks. Garnets may be derived from igneous and metamorphic rocks and titanite is indicative of acid and intermediate plutonic igneous rocks. Staurolite and chloritoid are however the most diagnostic metamorphic minerals found. Chloritoid occurs in micaceous schists and phyllites, while staurolite and garnet may be common minerals in phyllites, schists and gneisses.

The heavy mineral assemblage is therefore indicative of a mixed source terrain which consisted of two rock types (a) a low to medium grade metamorphic rock and, (b) an intermediate to acidic igneous rock.



(Johnsson, Stallard, and Meade, 1988)

Figure 96. Model for the Production of First-Cycle Quartz Arenites in the Orinoco Drainage Basin

Additionally, the determined ZTR index of 48-53% indicates moderate mineralogic maturity of the sediments.

Compositional and paleocurrent studies of sandstone in southern Trinidad suggest that these sediments were derived from source rocks of the Pre-Pliocene Andes and Guyana Shield. Further analysis of these compositions suggest that the discrimination of first- and multi-cycle quartz-rich sands is an exceedingly difficult task. Johnsson et al., (1988) have shown that previous criteria, eg. that of Pettijohn et al., (1972), are invalid in making these distinctions. At least one component of the sandstones from southern Trinidad is multi-cycle as suggested by rounded quartz overgrowths and sedimentary lithic fragments.

Paleontology

The sequence encountered in both wells West SEG-1 and GBM-1 appear to be of similar age. In the GBM-1 well limiting fauna includes the following planktonics:

Globorotalia limbata
Globorotalia dutertrei
Globorotalia conglobatus
Sphaeroidinella dehiscins (?)

Considered together these planktonic foraminifera indicate an age range within the Neogene Planktonic Foraminifera Biozones N19-N21, with *Globorotalia limbata* being the limiting species. The age range indicated by these forams is therefore Pliocene. Be (1977) and Bolli et al., (1987) assigned a similar age to these foraminifera.

Using benthonic foraminifera a better refinement of the biostratigraphy is possible. Buliminella 1/2 is indicative of zone N19 in the Gulf of Mexico. This zone (N19) is of Early Pliocene age.

The foraminiferal assemblage in the West SEG-1 well also suggest an Early Pliocene age. The common foraminiferal link between the two wells is Buliminella indicative of zone N19 in the Gulf of Mexico (Flugeman pers. comm., 1990).

Palynostratigraphy

Twenty-four sidewall core samples (1550-12500 feet) and twelve cutting samples (860-15230 feet) from the Amoco West SEG-1 well, offshore South Trinidad, and nineteen outcrop samples from the South coast stratigraphic section were analyzed for palynologic content. Palynomorph occurrence indicated ages of Late Early Pliocene, Late Pliocene and Late Pleistocene through the studied interval in the West SEG-1 well, and Late Early Pliocene through the studied outcrop stratigraphic section. Both sections were similar in that they contained numerous reworked fossils ranging in age from Early Cretaceous to Early Pliocene. Reworking of fossil matter is an important factor affecting interpretations of Trinidad's biostratigraphy. This is clearly documented in the literature. That this is so dictates that persons studying Trinidad's stratigraphy should draw upon information from multiple sources in support of their findings.

Palynologic data was only available for the West SEG-1 well and the outcrop along the south coast from Galeota Point to Pt. Curao. The palynologic analysis presented here is only relevant to these two sections.

(i) West SEG-1

860-5050 Feet: Late Pleistocene

The presence of Alnipollenites verus and Retitricolporites sp. (Avicennia Type) in association with Compositae sp., Echitriporites sp., Psilatriporites sp. indicate a Late Pleistocene age (Lamy, 1985). These sediments apparently lie unconformably upon the underlying Late Pliocene sediments (the Early Pleistocene missing).

5250-7350), 9200-10700, 11300-11810 Feet: Late Pliocene

The presence of Bivesiculate sp., and the absence of Alnipoilenites verus, in association with Grimsdalea magnaclavata, Pachydermites diederixi, Echiperiporites estelae, Cyantheacidites annulata, Compositae sp., Bombacacidites ciriloensis, indicate a Late Pliocene age (Lamy, 1985 and Muller et al., 1987).

12300-15230 Feet: Late Early Pliocene

The presence of Compositae, Ambrosia type and the absence of Bivesiculate sp. in associaticon with Echitricolporites mcneillyi, Clavamonocolpites sp., Fenestrites sp., Polvadopollenites mariae, Chenopodipollis multiplex, Compositae sp. Psilatricolporites caribbiensis, Magnastriatites grandiosus, Fenestrites spinosus, Striasyncolpites zwaardi, Multiareolites formosus indicate a Late Early Plicocene age (Lamy, 1985 and Muller et al., 1987).

(i) South Coast Stratigraphic Section

This section outcrops from Galeota Point west along the south coast to Pt. Curao.

The presence of Compositae, Ambrosia Type and the absence of Bivesiculate sp., in association with Echitricolpites mcneillyi, Magnastriatites grandiosus, Clavamonocolpites sp. (Polyadopoliinites maria), Striasyncolpites sp., Compositae sp., Fenestrites spinosus, Striasyncolpites zwaardi, Multiareolites formosus, Fenestrites sp., Chenopolipollis multiplex indicates a Late Early Pliocene age (Lamy, 1985 and Muller et al., 1987).

Close examination of the data provided suggest that the oldest strata penetrated in the West SEG-1 well is approximately Middle Gros Morne (Middle to Late Pliocene) in age. This suggests that the thick, laterally continuous sands exposed along the south coast will be encountered with deeper penetration. It is therefore, reasonable to suggest that the possibility of deeper pay zones in this well might exist. That this outcrop sequence is present deeper in this well is supported by seismic data and a possible target of deeper exploration will be the very thickly bedded, laterally extensive sands observed in outcrop.

Acceptable levels of porosity are low in these outcrop sediments. It can be expected that secondary (and remaining primary) porosity may be preserved at depth, if migration of oil and/or gas (generated in deeper Early Tertiary to Cretaceous sources) coincided with the formation of such porosity. Visual carbonization studies also suggest that the West SEG-1 has only marginally penetrated rocks of an age similar to those encountered in outcrop. All the outcrop samples examined suggest some early generation of gas.

Paleoecology

An examination of benthonic forams can provide estimates of the water mass conditions at the time of deposition of sediments. Palynology also uses the relative abundances of various characteristic spores, pollen, cyst; and algae to deduce water mass conditions.

In the paleontologic reports the Amphistegina assemblage which includes some miliolids is indicative of a reef envirorment, Hag and Boersma (1978). Hag and Boersma (ibid) also indicate that Uvigerina is indicative of outershelf and high oxygen environment. The association with Uvigerina and Buliminella suggest that this was a fore-reef envirorment, (Flugeman, pers. comm., 1990). Though the exact taxonomic positions of the Buliminella (probably Brizalina of the Gulf of Mexico) reported is unknown the assemblage is associated with the oxygen minimum layer in the Gulf of Mexico (200-250 meters water depth), (Flugeman, pers. comm., 1990 and Murray, 1973). Another key assemblage is dominated by Cyclammina a common constituent of the Glomospira assemblage of the Gulf of Mexico, where it is associated with areas of reduced sedimentation.

The Bolivina, Textularia, Buliminella 1/2 assemblage is indicative of an outer shelf to deep inner shelf environment, (Hag and Boersma, 1978 and Murray, 1973).

Palynologically the two sections studied yielded similar organic constituents all of which indicate a marginal to open marine environment of deposition, based on the common to abundant dinoflagellate cysts, and few to common microforams. Terrestrially derived pteridophyte spores, abundant angiosperm pollen, fungal spores, wood fragments, plant tissue, fresh water algae referable to Pediastrum sp. and Botryococcus sp. suggest a continental assemblage deposited in marginal marine to open marine environment.

Burial History

The methods of Moore and Reynolds (1989) were used to determine the degree of ordering and indicates that all samples in West SEG-1 below 8390 feet have Reichweite numbers of .5 to 1 indicating minor ordering with 50% to 60% illite layers.

The outcrop samples showed little or no shoulder attributable to chlorite and investigation was thus possible using both methods - the peaks in the 5.5 to 6.5 two-theta range and the two-theta difference between the 002 and 003 peaks. This investigation suggests that the outcrop samples were all randomly interstratified with 35% to 50% illite layers.

Hansen and Lindgreen (1989) suggested that discrete illite may be formed by erosion of lightly weathered source rocks and secondly, from an environmental viewpoint, that illite and I/S becomes more abundant with increasing distance from shore.

High kaolinite content may indicate a period of deep intense weathering of lateritic horizons, (Biscaye, 1965). It is also possible that the kaolinite variation is controlled by depositional or provenance factors. Hansen and Lindgreen (1989) indicate that decreasing kaolinite content probably reflects greater distance from the shoreline. The increase in kaolinite often reflects a higher degree of proximity to deltaic or shoreline facies, for example - during deltaic progradation. This environmental influence upon kaolinite content way be important because the depositional model developed suggest an intimate association between a prograging delta and and shelf-fan system developed as sediment was mobilized and sedimented.

The difference in the percent illite layers in I/S between outcrcop and subsurface might be indicative of (a) a diference in the burial history of the outcrop and subsurface sections, (b) a difference in the compositions of the starting materials in both sections (eg. Braide and Huff, 1982) and, (c) factors which have inhibited the smectite to illite transformation (eg. early cementation, Foscolos and Powell, 1980 and Pollastro, 1985).

Despite being deeply buried at least since Middle Pliocene these sediments do not show any clear evidence of clay mineral transformation. There is however some evidence that other factors - source and depositional environment might be more important in explaining the mineral assemblages encountered. To what extent is burial diagenesis responsible for many assemblages encountered in other basins requires further investigation, and this study suggest that burial diagenesis may not be as important a factor as emphasized in the literature.

The West SEG-1 well had a total depth of 15,236 feet. At this depth the sediments though gas prone are immature with respect to gas production, and must be pursued to greater depths in order to encounter more mature source rocks. Also at greater depths thicker sands with less mud (similar to the outcrop section along the south coast of Trinidad) should be encountered which may provide reservoirs for generated hydrocarbons. The presence of porosity will be a higher risk at greater depths. However, given the low TOC's the possibility of generating commercial quantities of hydrocarbons is doubtful and any significant quantities of hydrocarbons would have been derived from vertical migration of Cretaceous sourced oil and gas. Low TOC's coupled with low geothermal gradients suggested that source rocks younger than Upper Cretaceous are very unlikely, (B. Claxton, pers. comm., 1990).

Interpretation of calcite cements was difficult and stable isotope data suggest that calcite precipitation spanned the range from early, shallow cementation influenced by meteoric waters to deep burial. There was no relationship between carbon and oxygen isotopic compositions which is indicative of a complex diagenetic history.

Light samples (those with negative ^{13}C values) derived their carbon from oxidation of organic matter during early diagenesis, and the heavier carbon was derived from the process of methane fermentation.

Light oxygen isotopic compositions were probably derived from one or a combination of the following factors:

(a) meteoric water;

(b) high temperatures during deeper burial; or,

(c) re-equilibration with meteoric water after uplift.

The data in this study indicates a very complex diagenetic history which might involve some early diagenesis with subsequent overprinting. The stable isotope data presented is very limited, however indicates that this might be an area for further research.

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APPENDIX 1

Measured Stratigraphic Section

Moruga Group, South Coast, Trinidad

Key to Symbols and Abbreviations

Sorting

Extremely well	XW
Very well	VW
Well	W
Moderately	M
Poorly	P
Very poor	VP

Bedding Thickness

tcb - thickly bedded (> 75 cm)

mb - medium bedded (35 - 75 cm)

thb - thinly bedded (< 30 cm)

Lithologies

mudstone

siltstone

sandstone

Grain Size

vcU	=	1410 - 2000 microns
vcL	=	1000 - 1410 microns
cU	=	710 - 1000 microns
cL	=	500 - 710 microns
mU	=	350 - 500 microns
fU	=	250 - 350 microns
fL	=	177 - 250 microns
vfU	=	125 - 177 microns
vfL	=	88 - 125 microns
vfL	=	62 - 88 microns

BH 1 Samples

f.25 Photograph and figure numbers used in text.

Sedimentary Structures

Plane parallel lamination

Very low angle cross beds

Graded bedding

Ripple marks

Flute casts

Striations

Wavy lamination

Slump structures and contorted beds

Convolute bedding

Load casts

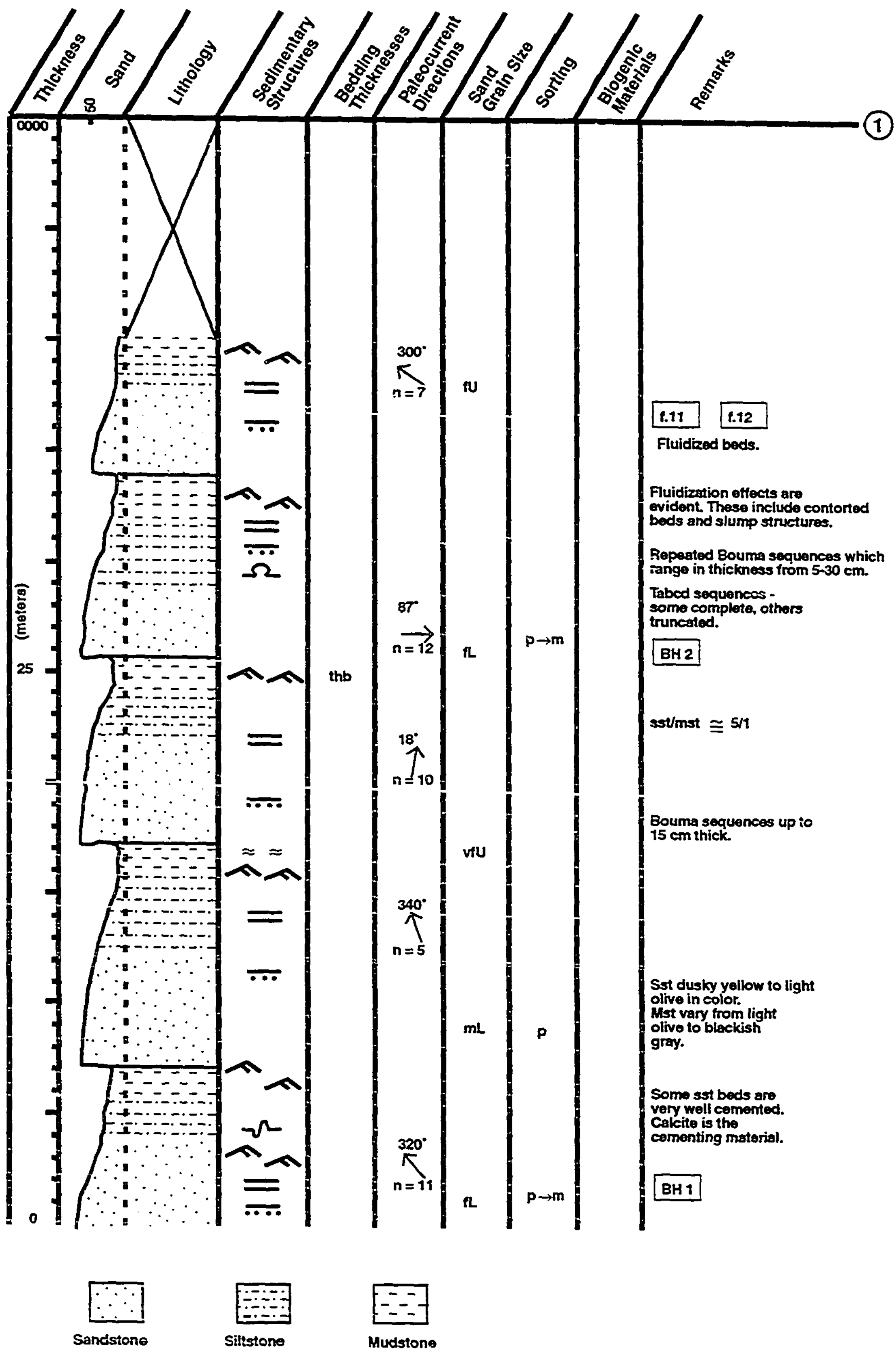
Thin graded bed

Chaotic beds

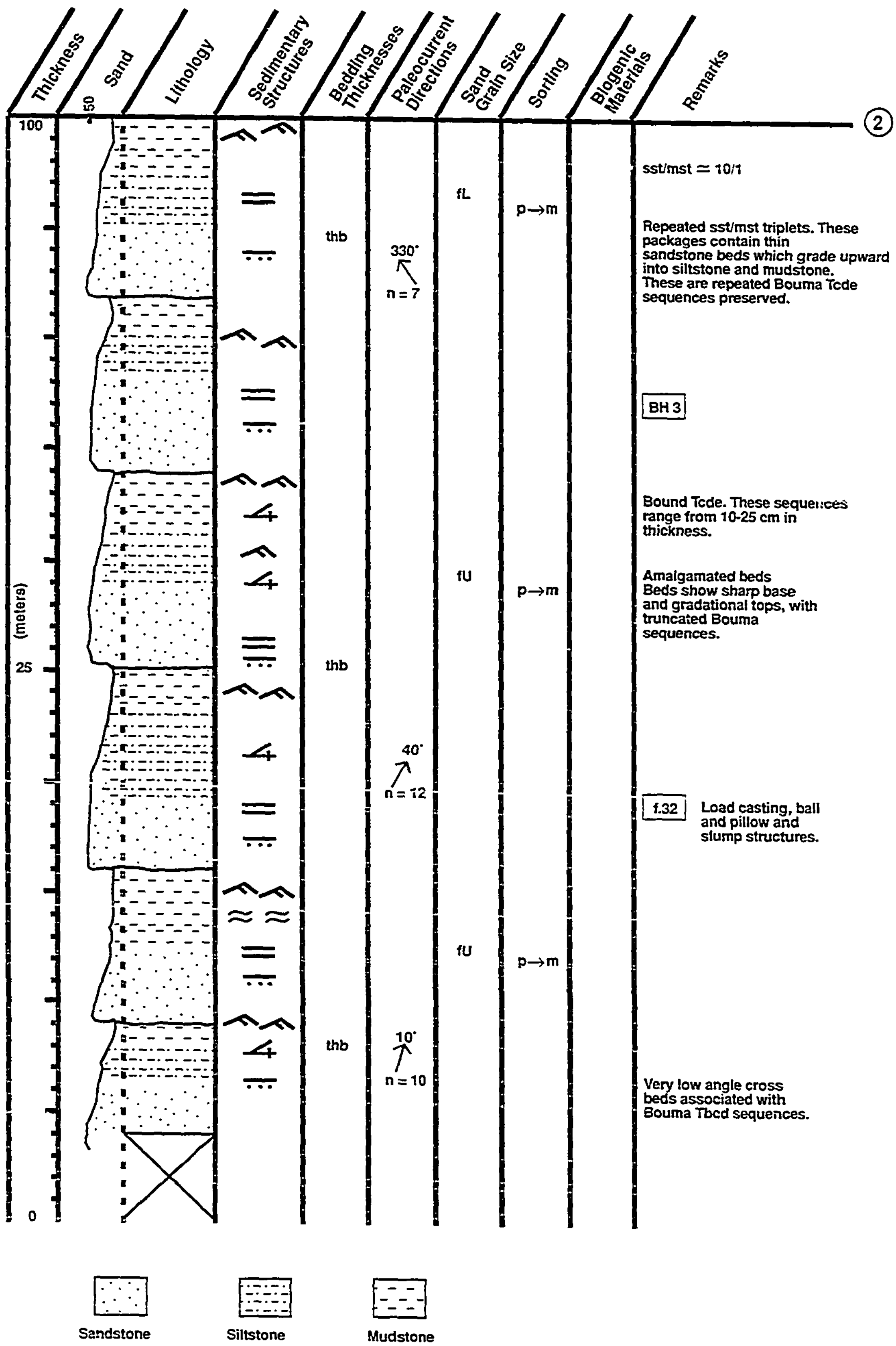
Thin parallel laminae

Floral/fauna remains

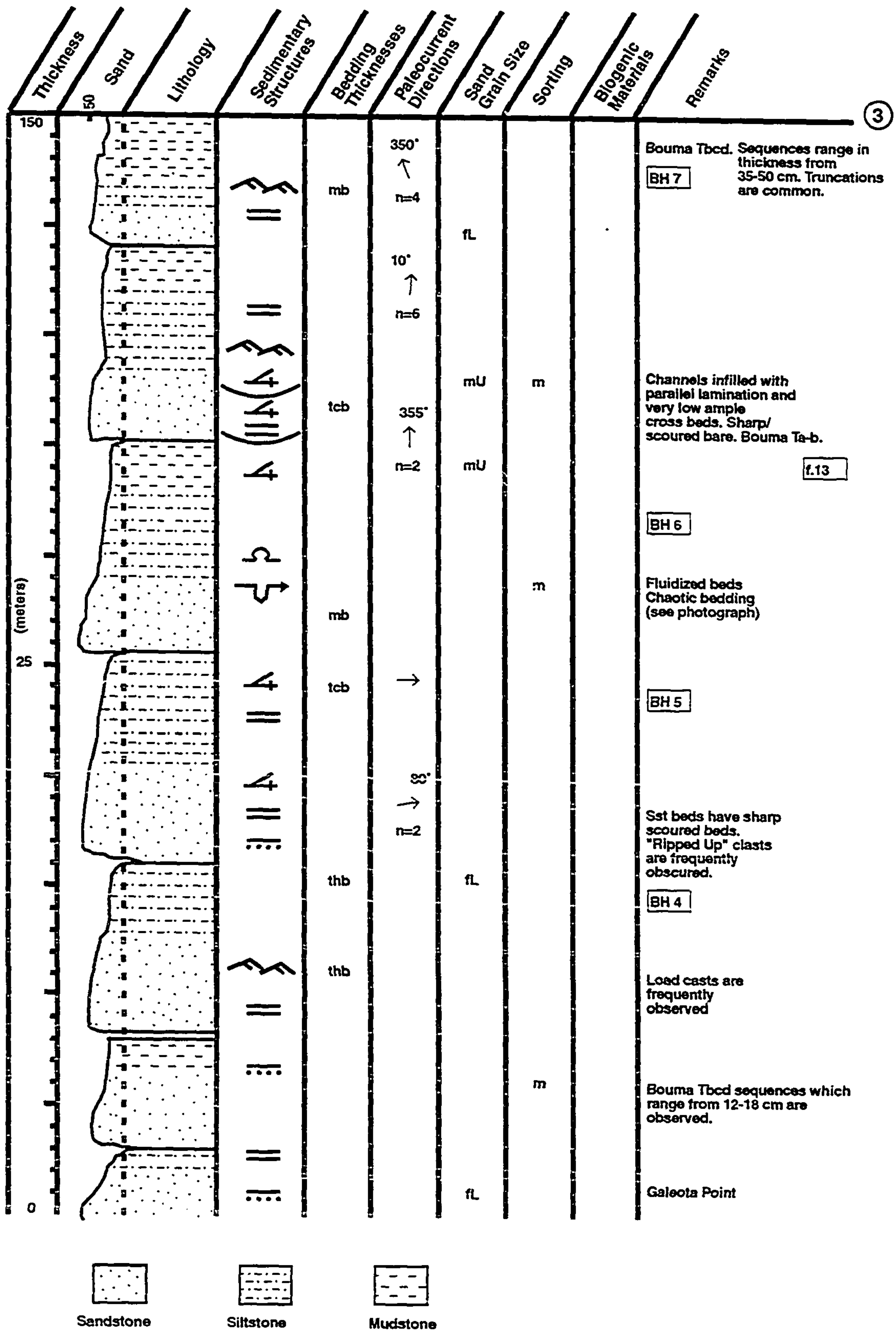
Bed and Pillow Structures



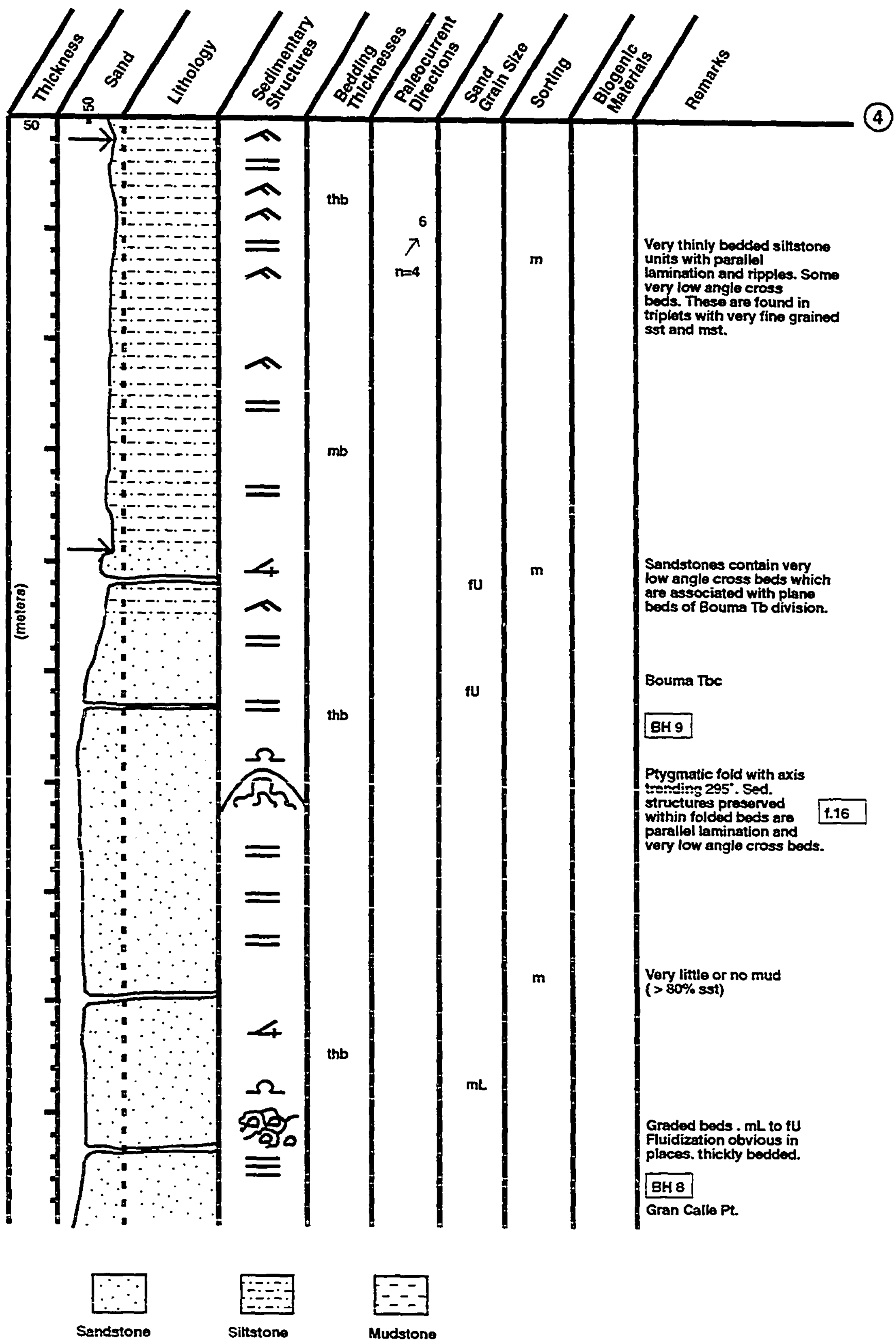
Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
1
0000
50
(meters)
25
0
300°
n = 7
fU
f.11
f.12
Fluidized beds.
Fluidization effects are evident. These include contorted beds and slump structures.
Repeated Bouma sequences which range in thickness from 5-30 cm.
Tabcd sequences - some complete, others truncated.
87°
n = 12
fL
p→m
BH 2
thb
sst/mst ≅ 5/1
18°
n = 10
Bouma sequences up to 15 cm thick.
vfU
340°
n = 5
Sst dusky yellow to light olive in color.
Mst vary from light olive to blackish gray.
mL
p
Some sst beds are very well cemented. Calcite is the cementing material.
320°
n = 11
fL
p→m
BH 1
Sandstone
Siltstone
Mudstone



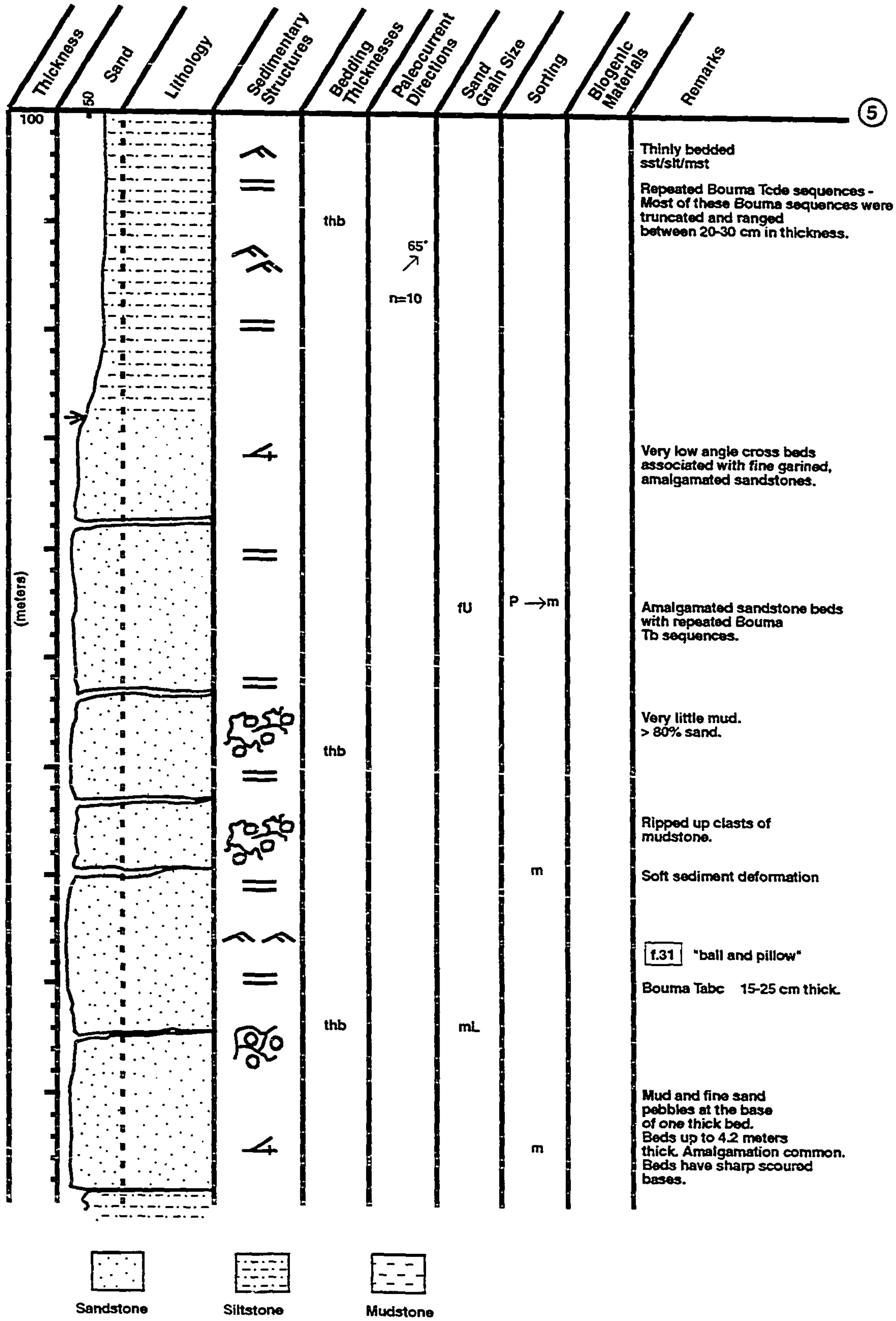
Thickness
Sand
50
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
2
100
(meters)
25
0
thb
thb
thb
330°
n = 7
40°
n = 12
10°
n = 10
fL
fU
fU
p→m
p→m
p→m
sst/mst ≃ 10/1
Repeated sst/mst triplets. These packages contain thin sandstone beds which grade upward into siltstone and mudstone. These are repeated Bouma Tcde sequences preserved.
BH 3
Bound Tcde. These sequences range from 10-25 cm in thickness.
Amalgamated beds
Beds show sharp base and gradational tops, with truncated Bouma sequences.
f.32
Load casting, ball and pillow and slump structures.
Very low angle cross beds associated with Bouma Tbcd sequences.
Sandstone
Siltstone
Mudstone



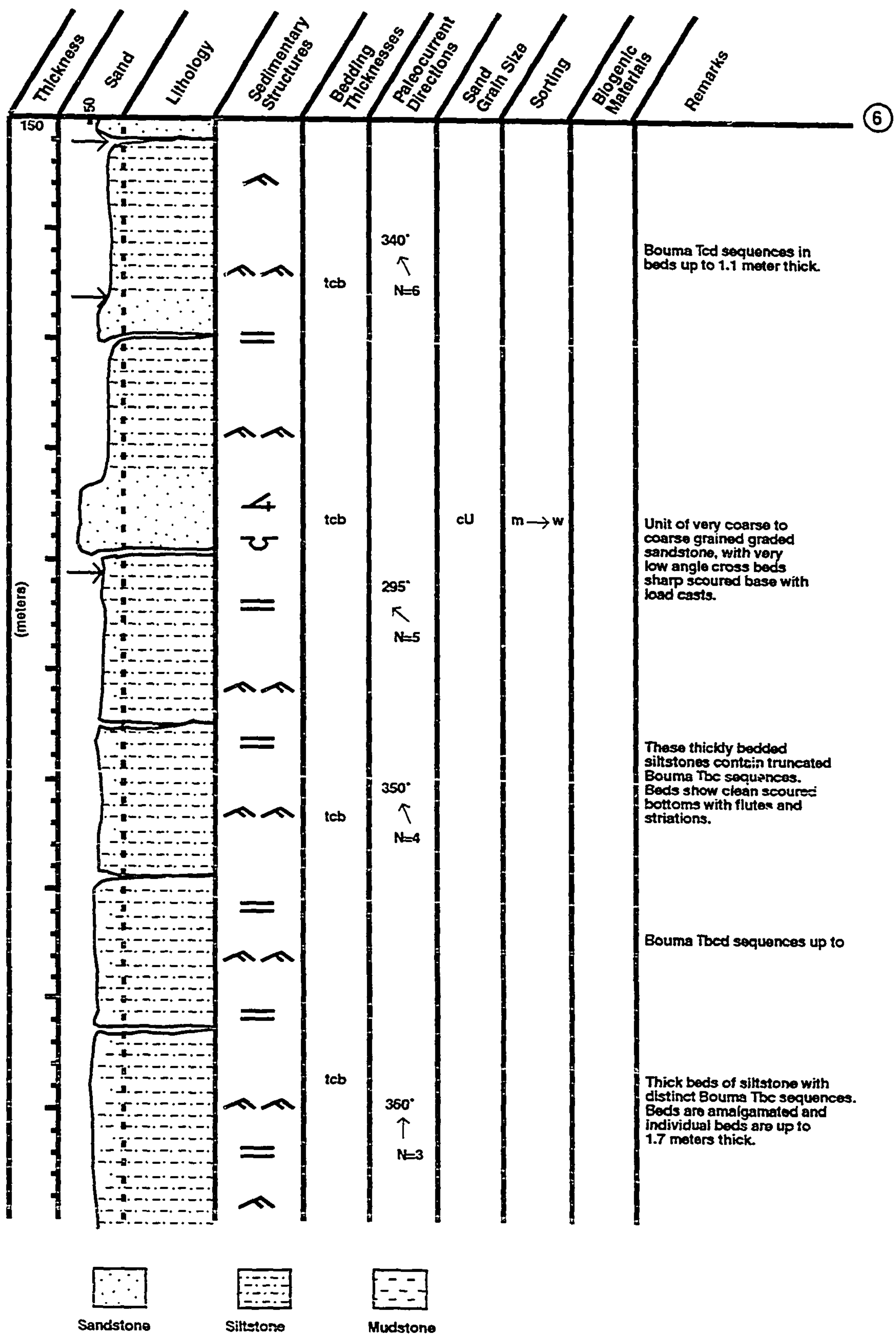
Thickness
Sand
50
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
3
150
25
0
(meters)
350°
n=4
10°
n=6
355°
n=2
80°
n=2
mb
tcb
mb
tcb
thb
thb
fL
mU
mU
fL
fL
m
m
m
Bouma Tbcd. Sequences range in thickness from 35-50 cm. Truncations are common.
BH 7
Channels infilled with parallel lamination and very low ample cross beds. Sharp/ scoured bare. Bouma Ta-b.
f.13
BH 6
Fluidized beds Chaotic bedding (see photograph)
BH 5
Sst beds have sharp scoured beds. "Ripped Up" clasts are frequently obscured.
BH 4
Load casts are frequently observed
Bouma Tbcd sequences which range from 12-18 cm are observed.
Galeota Point
Sandstone
Siltstone
Mudstone



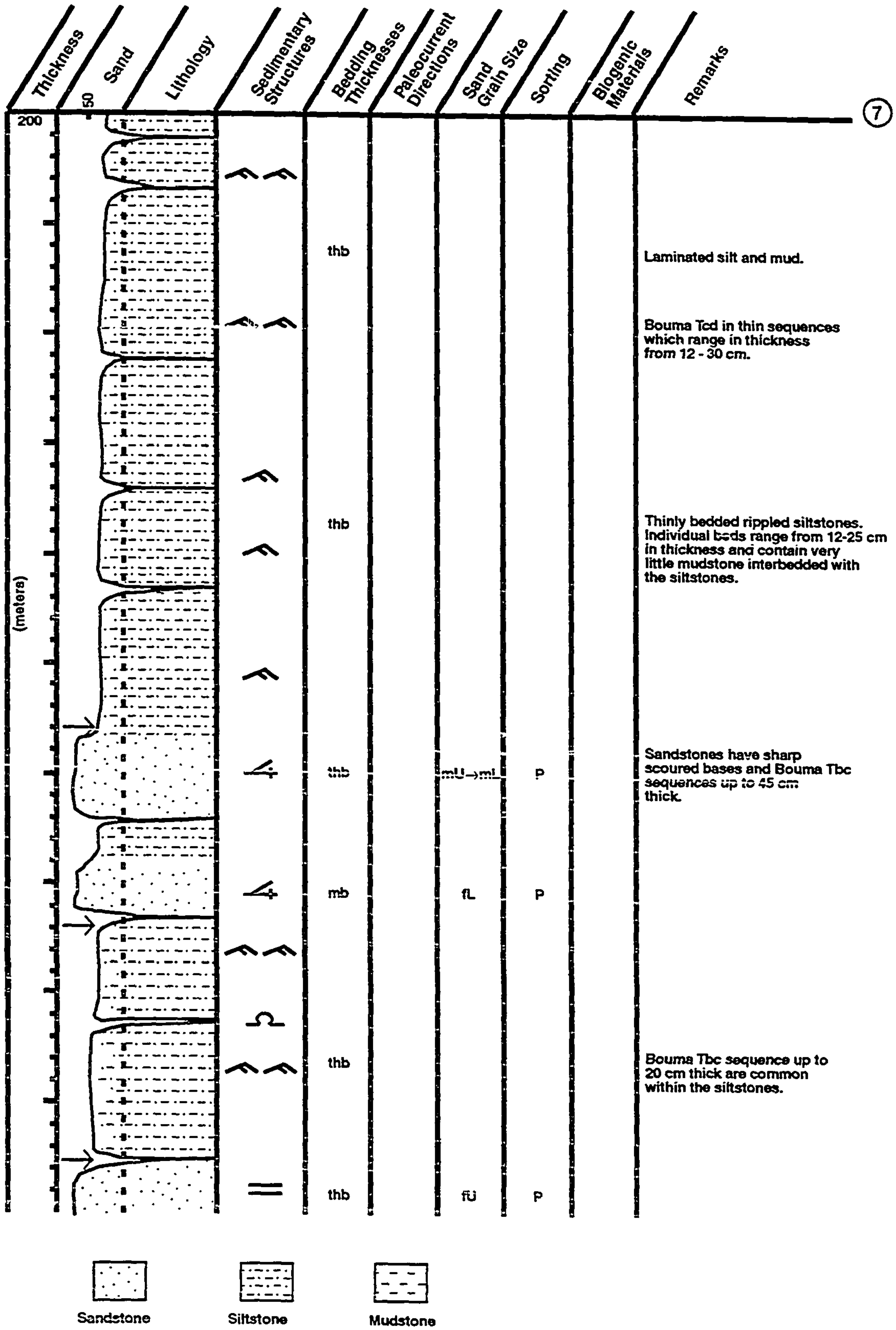
Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
4
50
(meters)
thb
6
n=4
m
Very thinly bedded siltstone units with parallel lamination and ripples. Some very low angle cross beds. These are found in triplets with very fine grained sst and mst.
mb
fU
m
Sandstones contain very low angle cross beds which are associated with plane beds of Bouma Tb division.
fU
Bouma Tbc
thb
BH 9
Ptygmatic fold with axis trending 295°. Sed. structures preserved within folded beds are parallel lamination and very low angle cross beds.
f.16
m
Very little or no mud (> 80% sst)
thb
mL
Graded beds. mL to fU Fluidization obvious in places. thickly bedded.
BH 8
Gran Calle Pt.
Sandstone
Siltstone
Mudstone



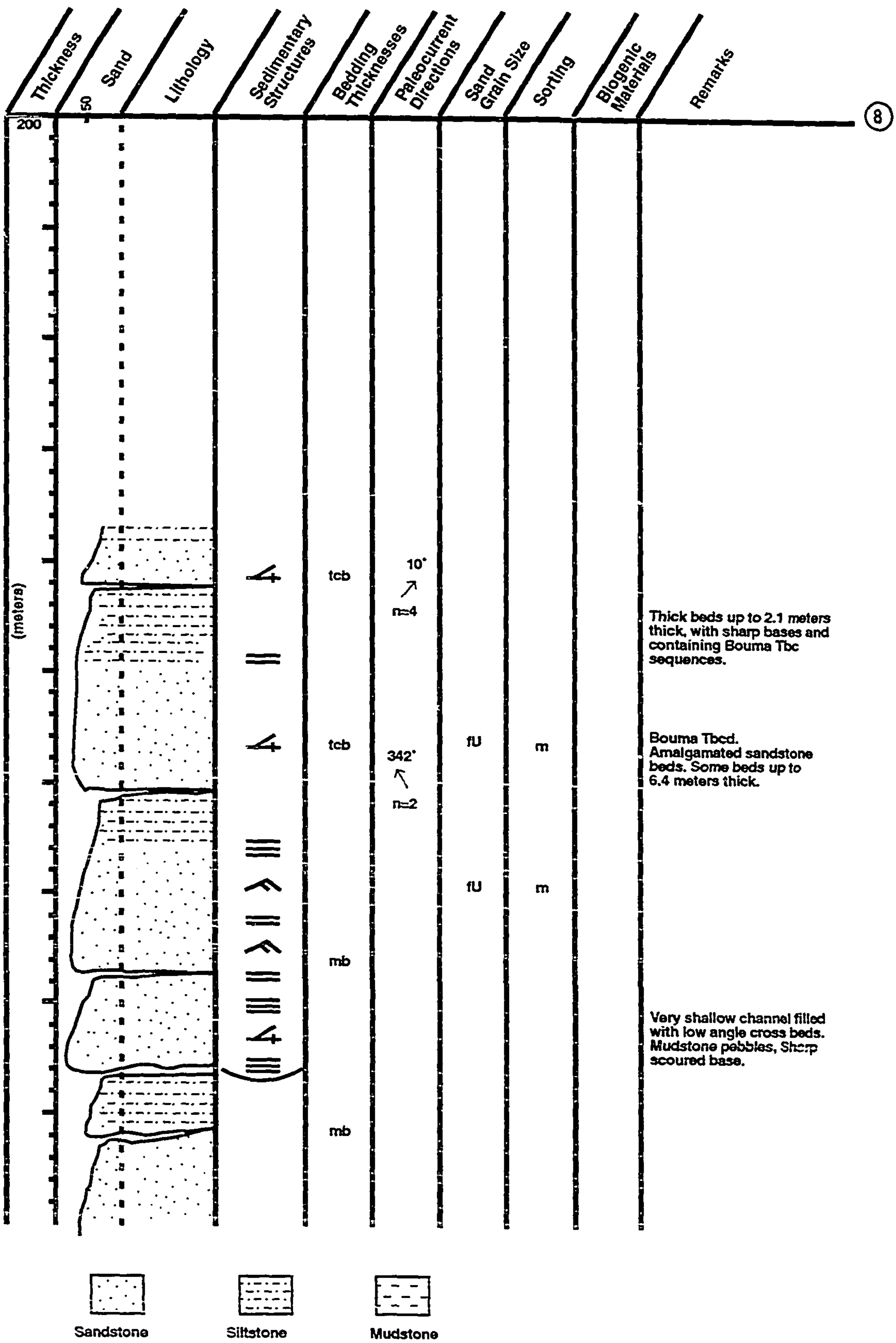
Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
5
100
50
(meters)
thb
65°
n=10
thb
thb
fU
mL
P →m
m
m
Thinly bedded sst/slt/mst
Repeated Bouma Tcde sequences - Most of these Bouma sequences were truncated and ranged between 20-30 cm in thickness.
Very low angle cross beds associated with fine garined, amalgamated sandstones.
Amalgamated sandstone beds with repeated Bouma Tb sequences.
Very little mud. > 80% sand.
Ripped up clasts of mudstone.
Soft sediment deformation
f.31 "ball and pillow"
Bouma Tabc 15-25 cm thick.
Mud and fine sand pebbles at the base of one thick bed. Beds up to 4.2 meters thick. Amalgamation common. Beds have sharp scoured bases.
Sandstone
Siltstone
Mudstone



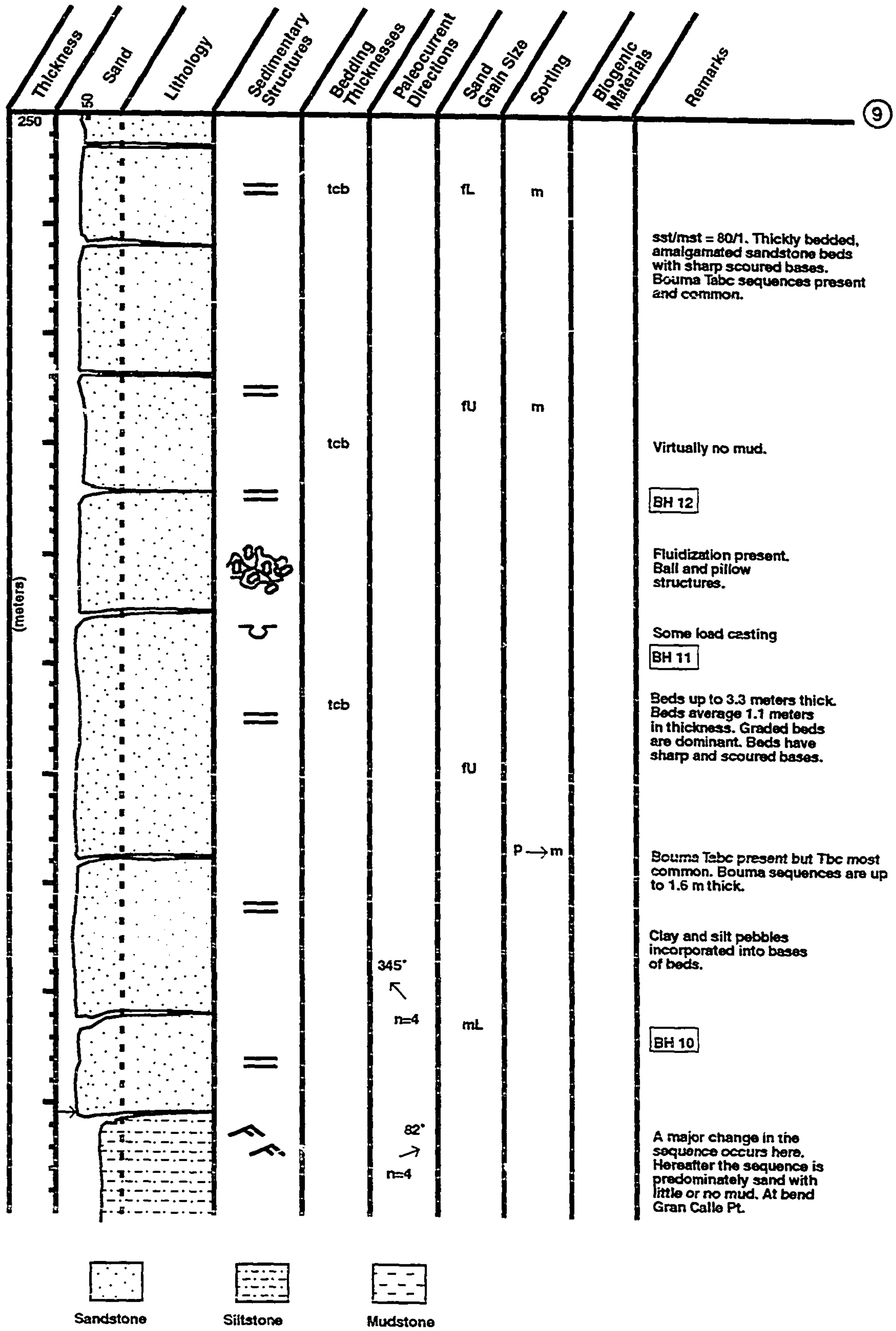
Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
6
150
50
(meters)
tcb
340°
N=6
Bouma Tcd sequences in beds up to 1.1 meter thick.
tcb
cU
m —> w
Unit of very coarse to coarse grained graded sandstone, with very low angle cross beds sharp scoured base with load casts.
295°
N=5
These thickly bedded siltstones contain truncated Bouma Tbc sequences. Beds show clean scoured bottoms with flutes and striations.
350°
tcb
N=4
Bouma Tbcd sequences up to
tcb
360°
N=3
Thick beds of siltstone with distinct Bouma Tbc sequences. Beds are amalgamated and individual beds are up to 1.7 meters thick.
Sandstone
Siltstone
Mudstone



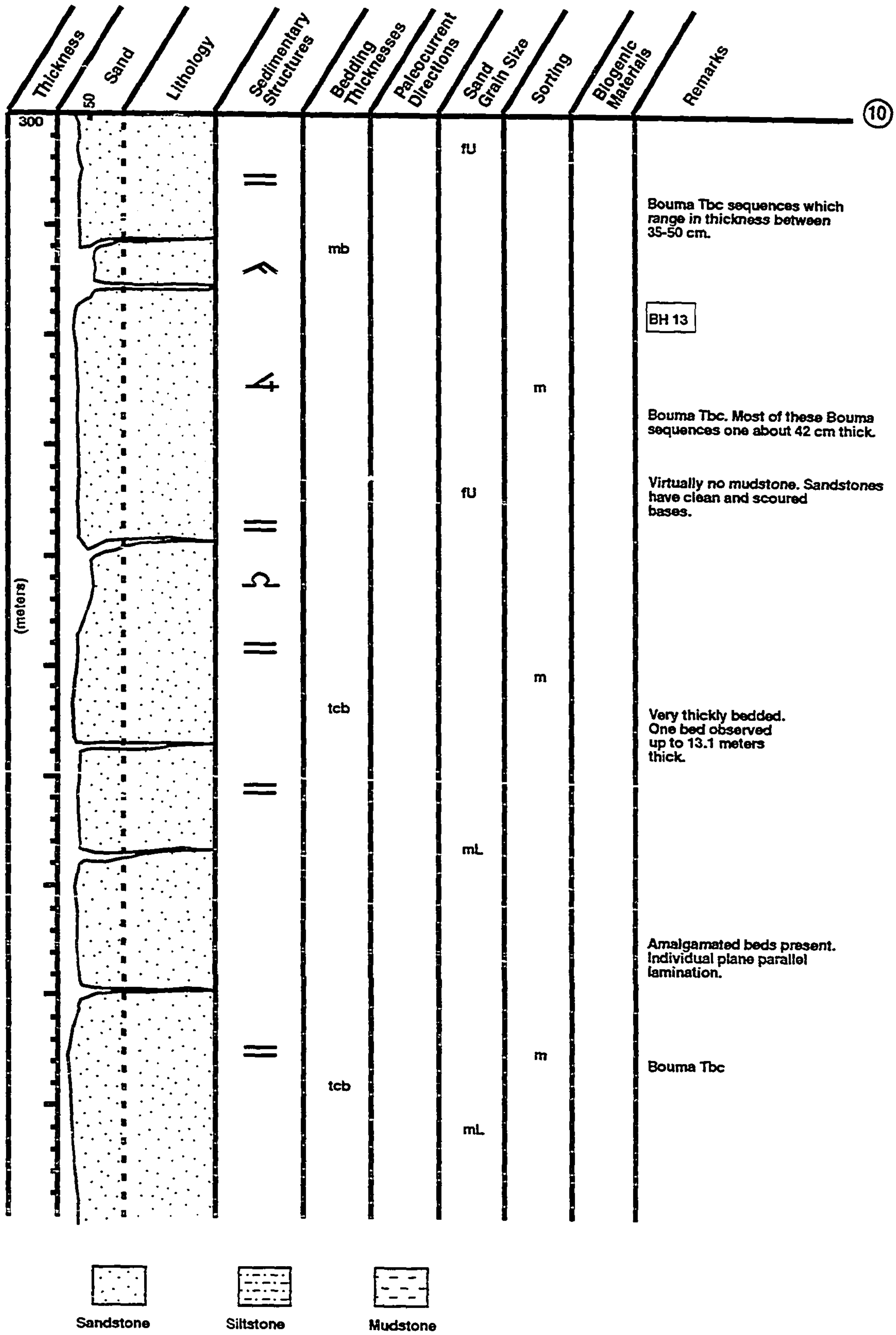
Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
7
200
50
(meters)
thb
thb
thb
mb
thb
thb
mU→mL
fL
fU
P
P
P
Laminated silt and mud.
Bouma Tcd in thin sequences which range in thickness from 12 - 30 cm.
Thinly bedded rippled siltstones. Individual beds range from 12-25 cm in thickness and contain very little mudstone interbedded with the siltstones.
Sandstones have sharp scoured bases and Bouma Tbc sequences up to 45 cm thick.
Bouma Tbc sequence up to 20 cm thick are common within the siltstones.
Sandstone
Siltstone
Mudstone



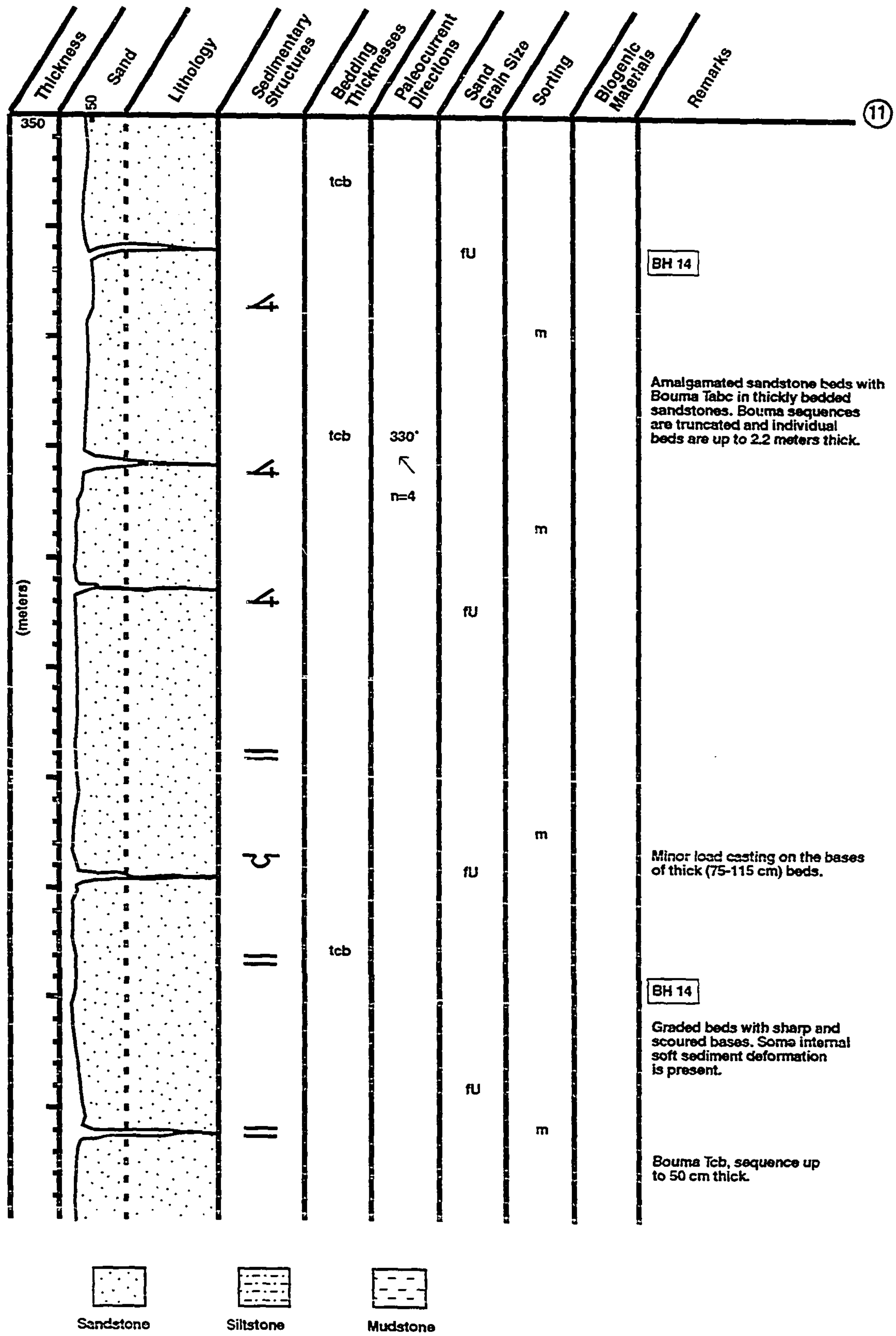
Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
8
200
50
(meters)
tcb
10°
n=4
tcb
342°
n=2
mb
mb
fU
fU
m
m
Thick beds up to 2.1 meters thick, with sharp bases and containing Bouma Tbc sequences.
Bouma Tbcd. Amalgamated sandstone beds. Some beds up to 6.4 meters thick.
Very shallow channel filled with low angle cross beds. Mudstone pebbles, Sharp scoured base.
Sandstone
Siltstone
Mudstone

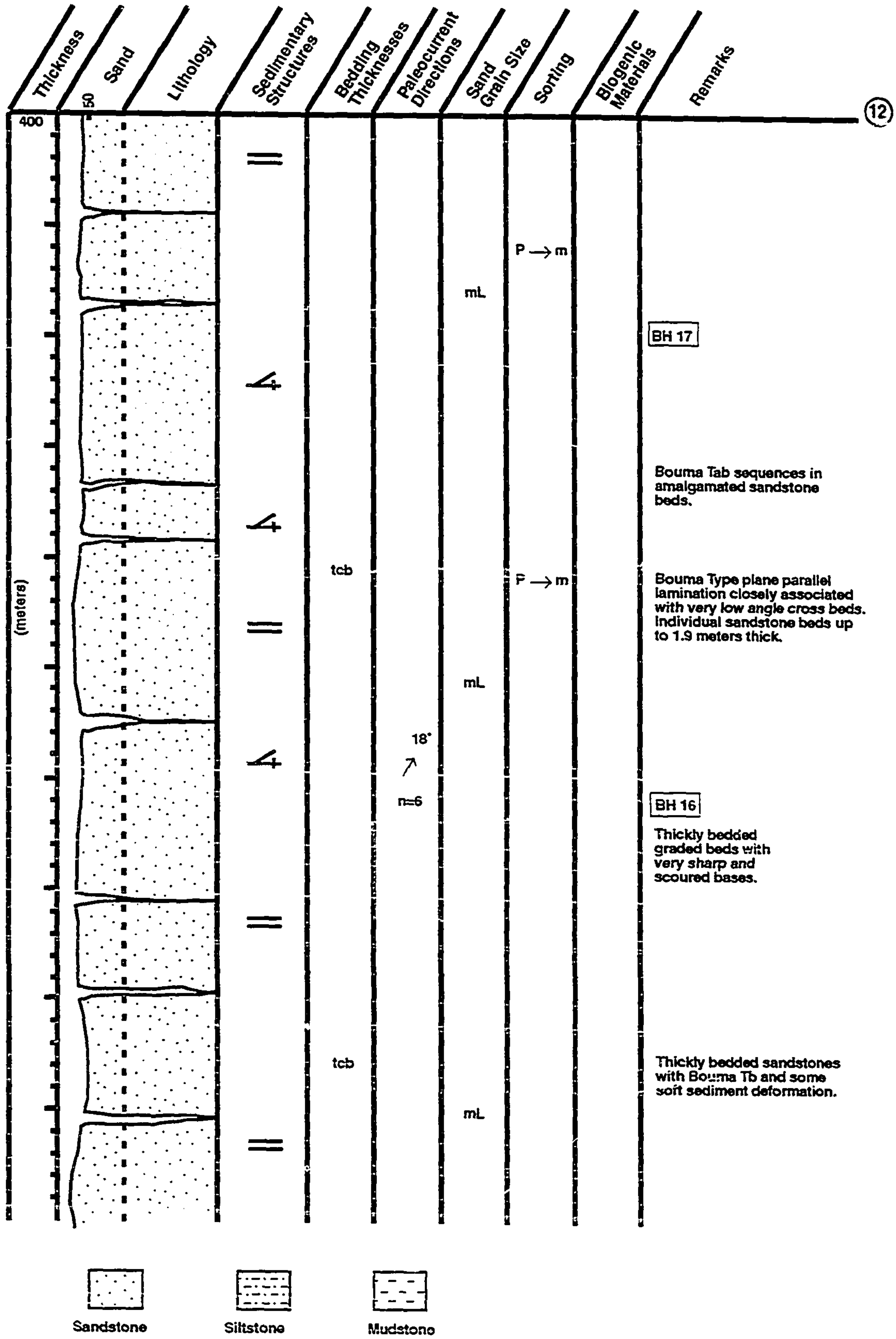


Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
9
250
50
(meters)
tcb
fL
m
sst/mst = 80/1. Thickly bedded, amalgamated sandstone beds with sharp scoured bases. Bouma Tabc sequences present and common.
fU
m
tcb
Virtually no mud.
BH 12
Fluidization present. Ball and pillow structures.
Some load casting
BH 11
tcb
Beds up to 3.3 meters thick. Beds average 1.1 meters in thickness. Graded beds are dominant. Beds have sharp and scoured bases.
fU
P ⟶ m
Bouma Tabc present but Tbc most common. Bouma sequences are up to 1.6 m thick.
Clay and silt pebbles incorporated into bases of beds.
345°
n=4
mL
BH 10
82°
n=4
A major change in the sequence occurs here. Hereafter the sequence is predominately sand with little or no mud. At bend Gran Calle Pt.
Sandstone
Siltstone
Mudstone

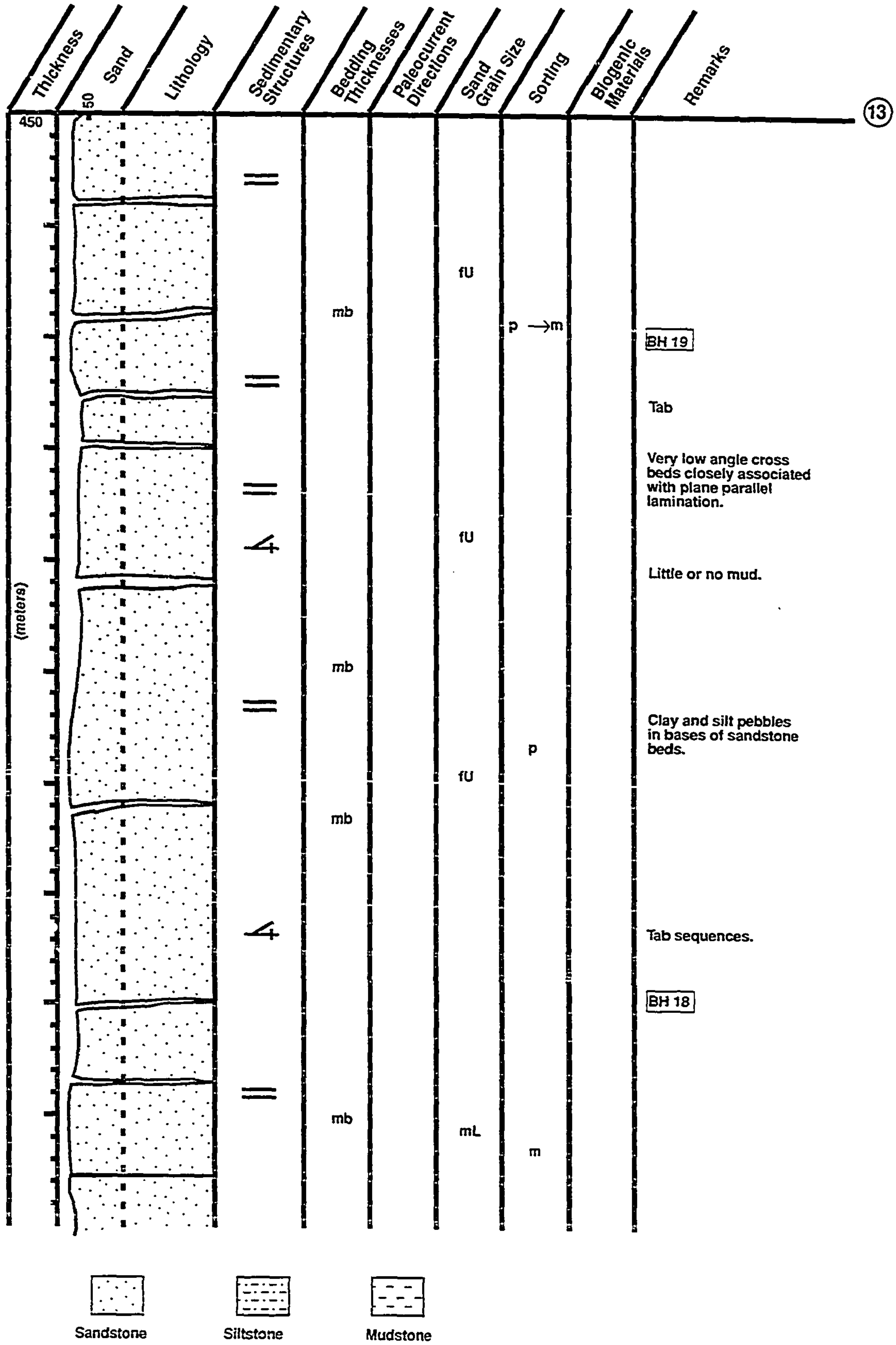


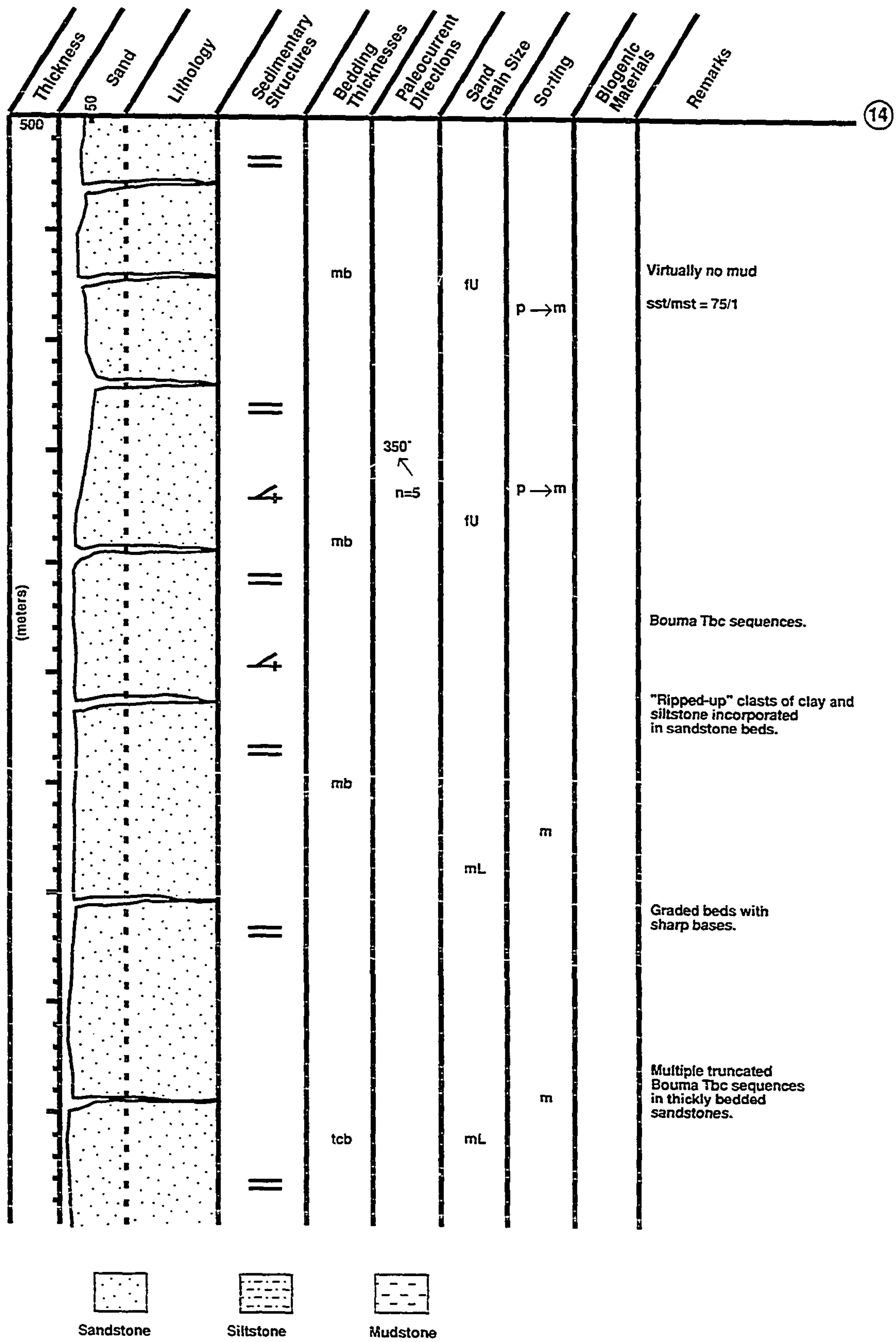
Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
10
300
50
(meters)
fU
mb
Bouma Tbc sequences which range in thickness between 35-50 cm.
BH 13
m
Bouma Tbc. Most of these Bouma sequences one about 42 cm thick.
fU
Virtually no mudstone. Sandstones have clean and scoured bases.
m
tcb
Very thickly bedded. One bed observed up to 13.1 meters thick.
mL
Amalgamated beds present. Individual plane parallel lamination.
m
Bouma Tbc
tcb
mL
Sandstone
Siltstone
Mudstone

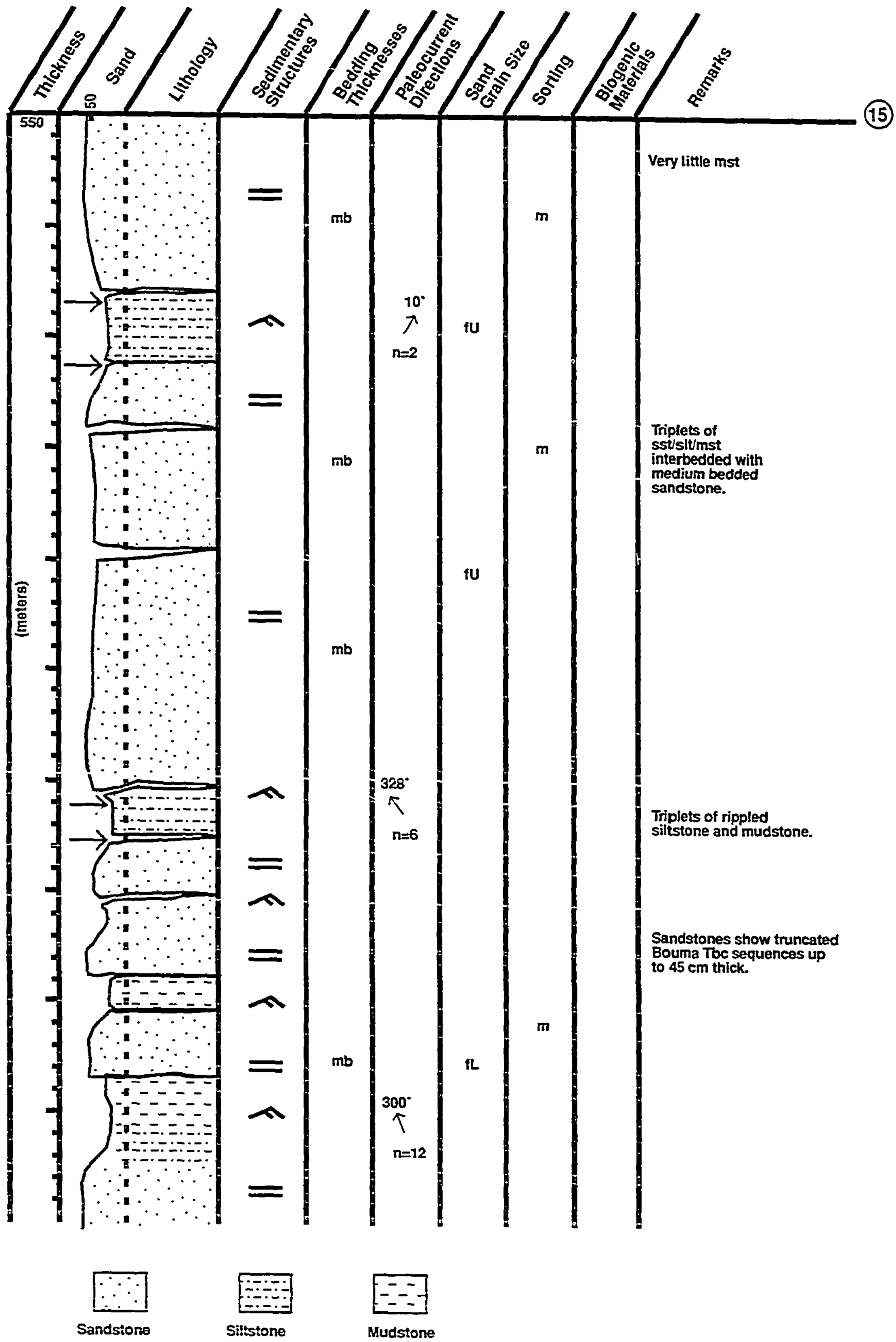

Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
11
350
50
(meters)
tcb
fU
BH 14
m
Amalgamated sandstone beds with Bouma Tabc in thickly bedded sandstones. Bouma sequences are truncated and individual beds are up to 2.2 meters thick.
tcb
330°
n=4
m
fU
m
Minor load casting on the bases of thick (75-115 cm) beds.
fU
tcb
BH 14
Graded beds with sharp and scoured bases. Some internal soft sediment deformation is present.
fU
m
Bouma Tcb, sequence up to 50 cm thick.
Sandstone
Siltstone
Mudstone



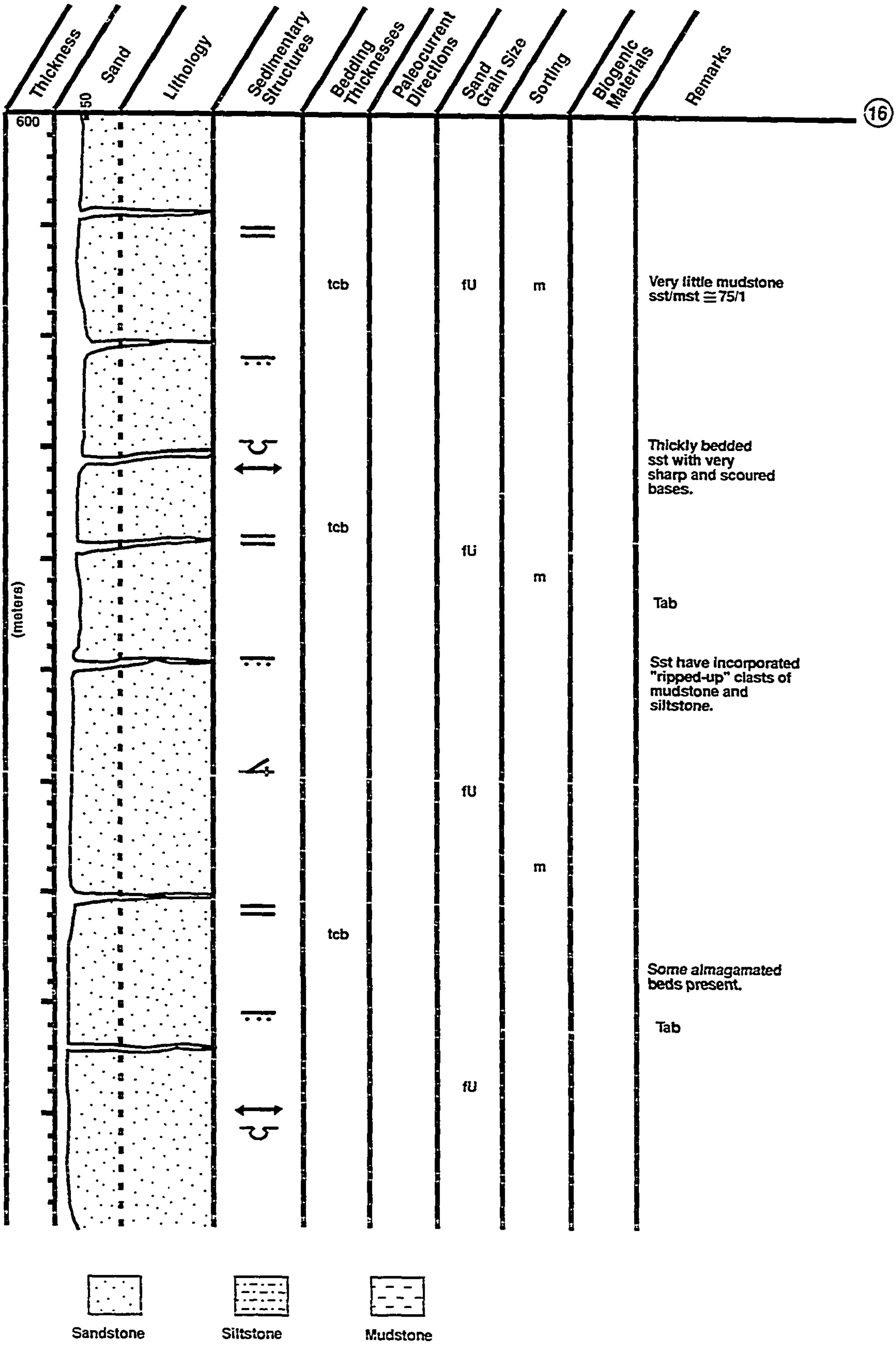
Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
12
400
50
(meters)
P → m
mL
BH 17
Bouma Tab sequences in amalgamated sandstone beds.
tcb
P → m
Bouma Type plane parallel lamination closely associated with very low angle cross beds. Individual sandstone beds up to 1.9 meters thick.
mL
18°
n=6
BH 16
Thickly bedded graded beds with very sharp and scoured bases.
tcb
Thickly bedded sandstones with Bouma Tb and some soft sediment deformation.
mL
Sandstone
Siltstone
Mudstone

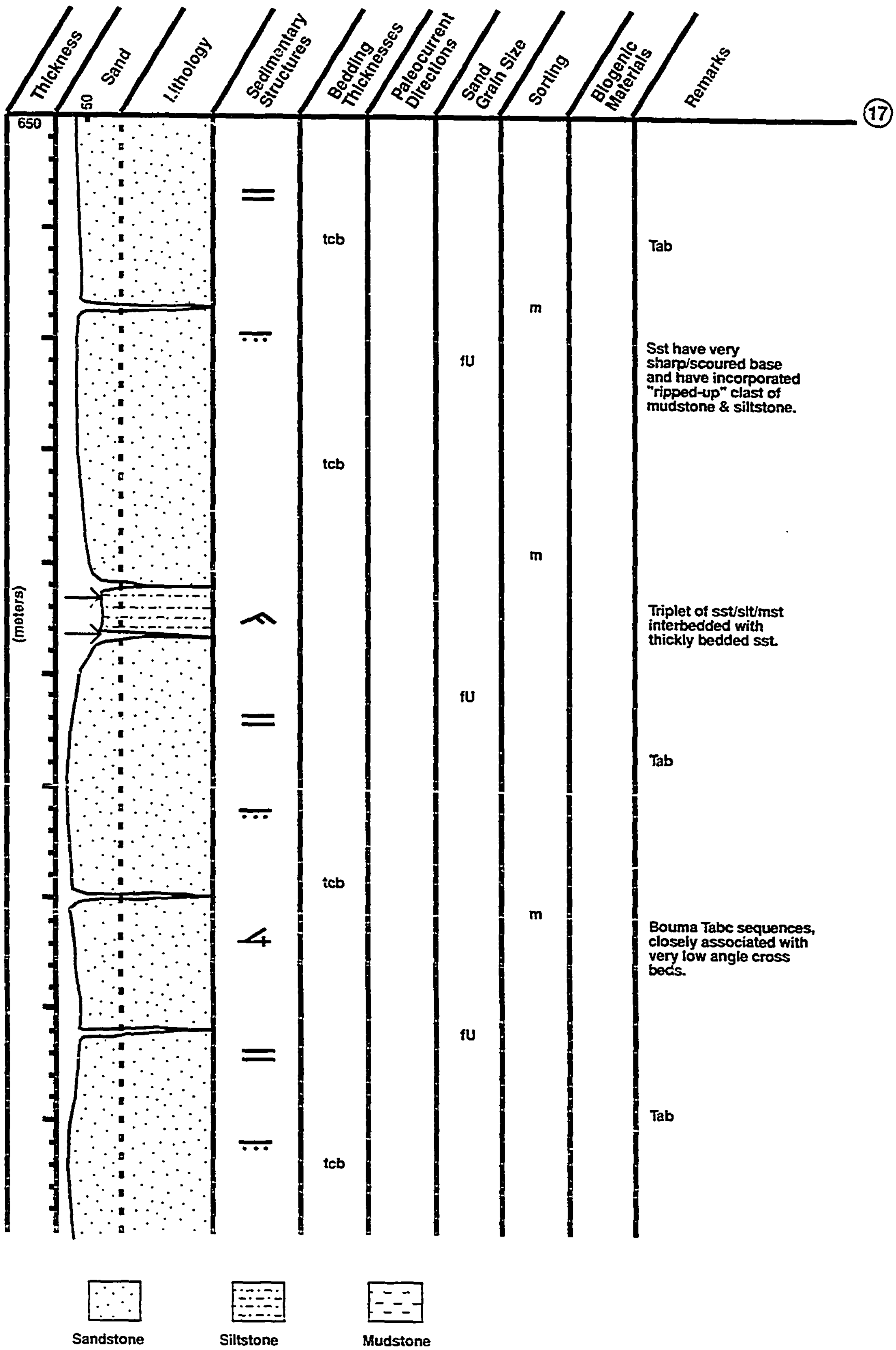

Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
13
450
50
(meters)
fU
mb
p →m
BH 19
Tab
Very low angle cross beds closely associated with plane parallel lamination.
fU
Little or no mud.
mb
Clay and silt pebbles in bases of sandstone beds.
p
fU
mb
Tab sequences.
BH 18
mb
mL
m
Sandstone
Siltstone
Mudstone

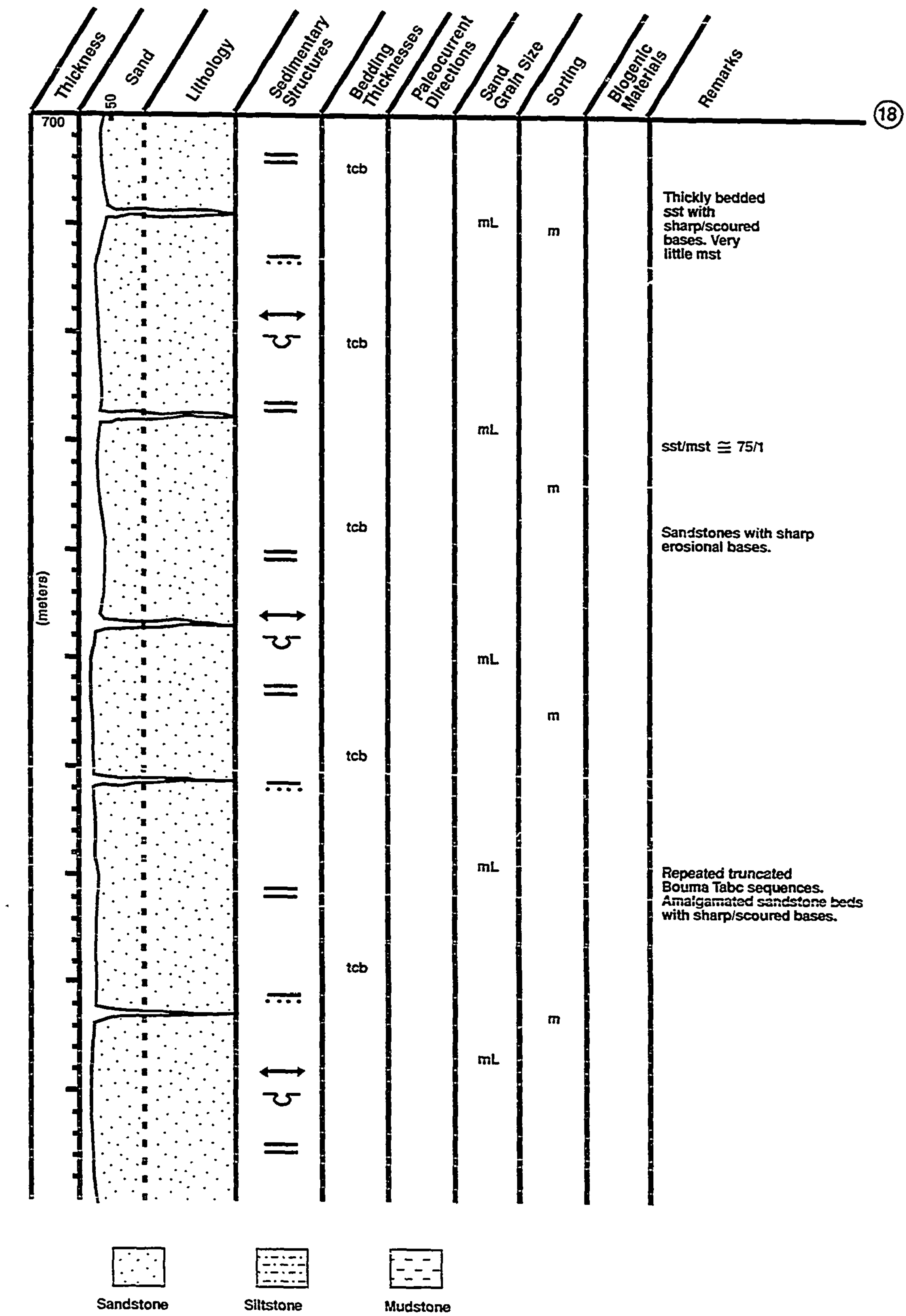

Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
14
500
50
(meters)
mb
fU
p → m
Virtually no mud
sst/mst = 75/1
350°
n=5
p → m
fU
mb
Bouma Tbc sequences.
"Ripped-up" clasts of clay and siltstone incorporated in sandstone beds.
mb
m
mL
Graded beds with sharp bases.
Multiple truncated Bouma Tbc sequences in thickly bedded sandstones.
m
tcb
mL
Sandstone
Siltstone
Mudstone


Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
15
550
50
(meters)
Very little mst
mb
m
10°
n=2
fU
Triplets of sst/slt/mst interbedded with medium bedded sandstone.
mb
m
fU
mb
328°
n=6
Triplets of rippled siltstone and mudstone.
Sandstones show truncated Bouma Tbc sequences up to 45 cm thick.
m
mb
fL
300°
n=12
Sandstone
Siltstone
Mudstone

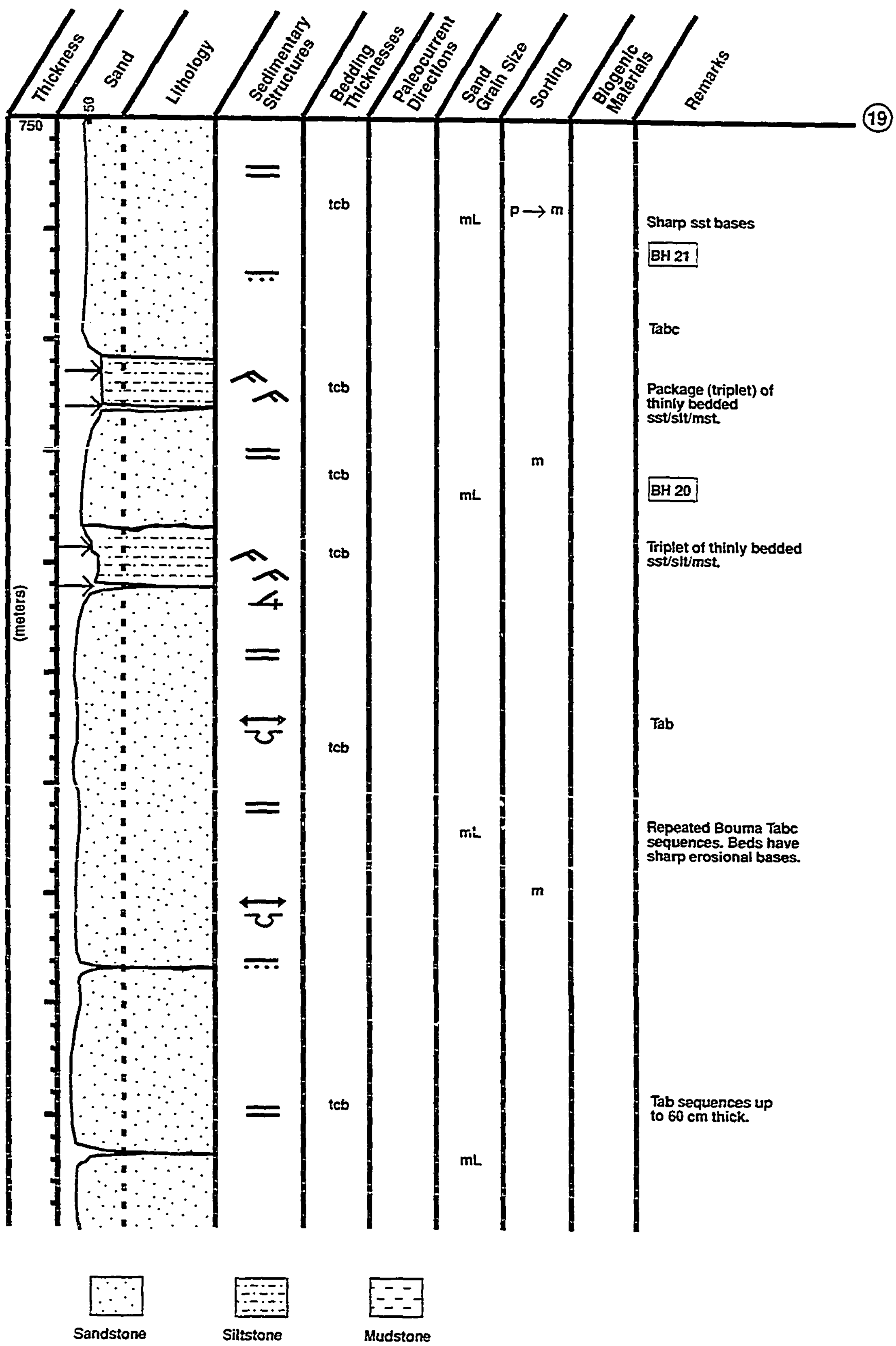
16

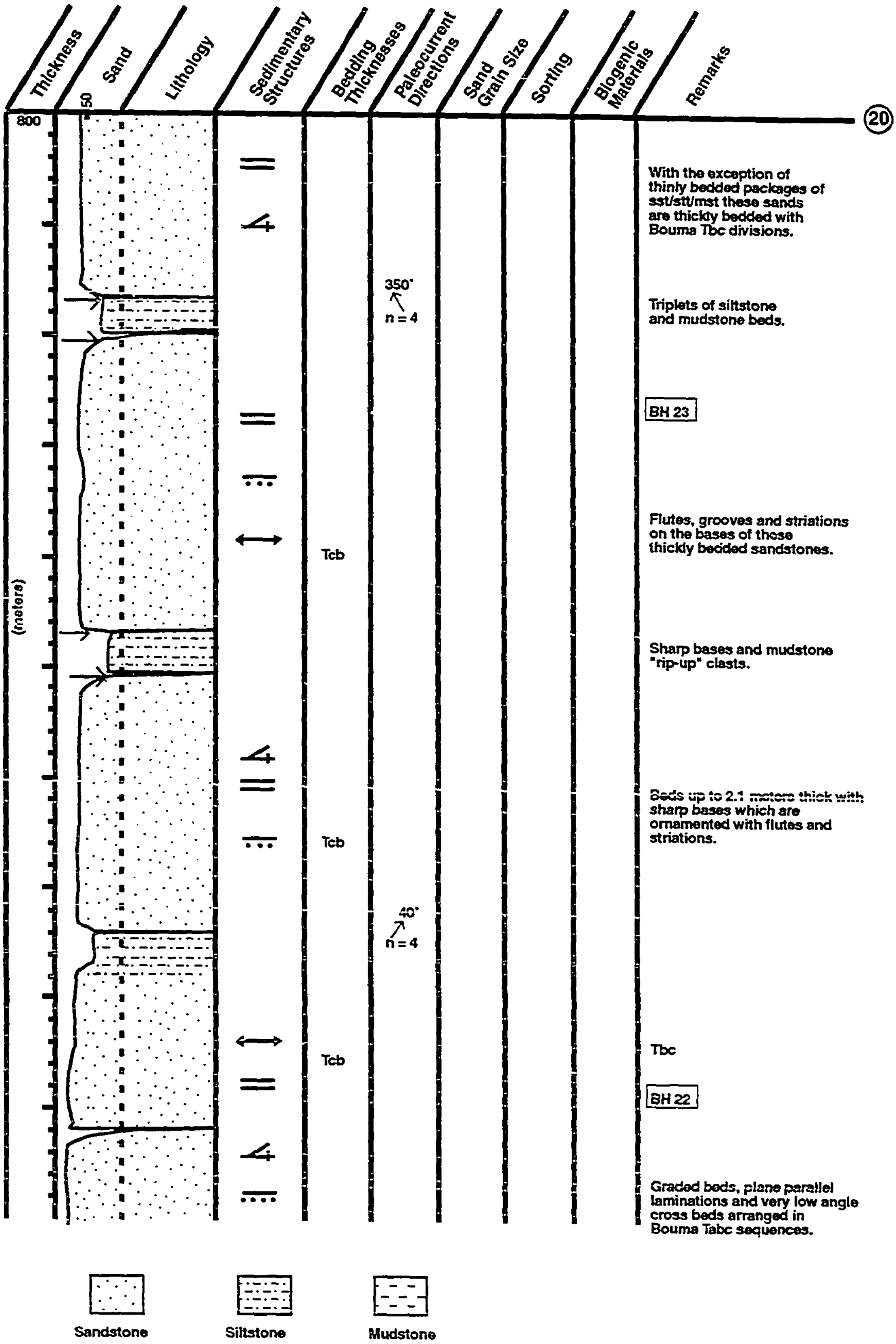

Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
600
50
(meters)
tcb
fU
m
Very little mudstone sst/mst ≅ 75/1
Thickly bedded sst with very sharp and scoured bases.
tcb
fU
m
Tab
Sst have incorporated "ripped-up" clasts of mudstone and siltstone.
fU
m
tcb
Some almagamated beds present.
Tab
fU
Sandstone
Siltstone
Mudstone


Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
17
650
50
(meters)
tcb
Tab
m
fU
Sst have very sharp/scoured base and have incorporated "ripped-up" clast of mudstone & siltstone.
tcb
m
Triplet of sst/slt/mst interbedded with thickly bedded sst.
fU
Tab
tcb
m
Bouma Tabc sequences, closely associated with very low angle cross beds.
fU
Tab
tcb
Sandstone
Siltstone
Mudstone

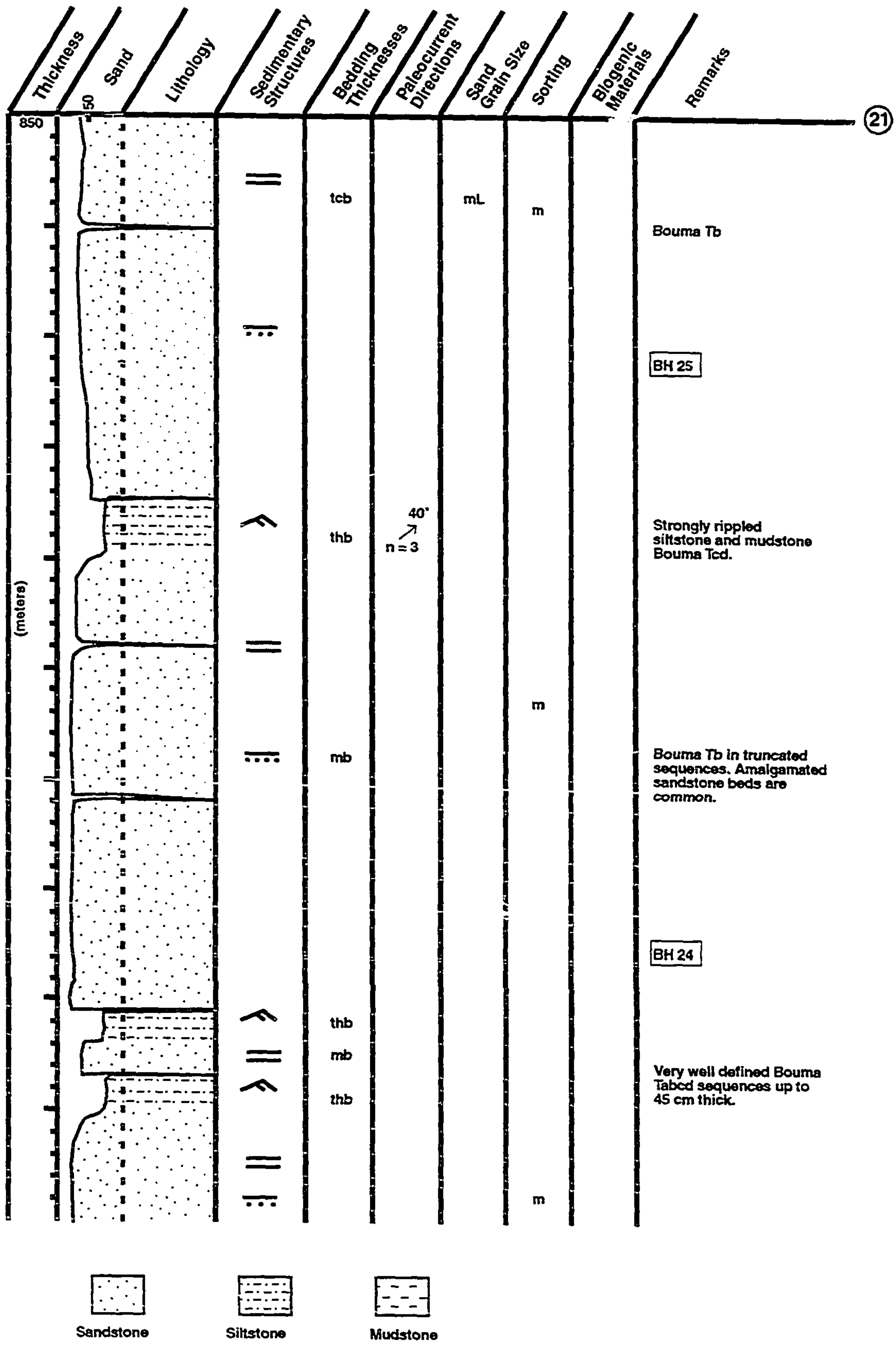


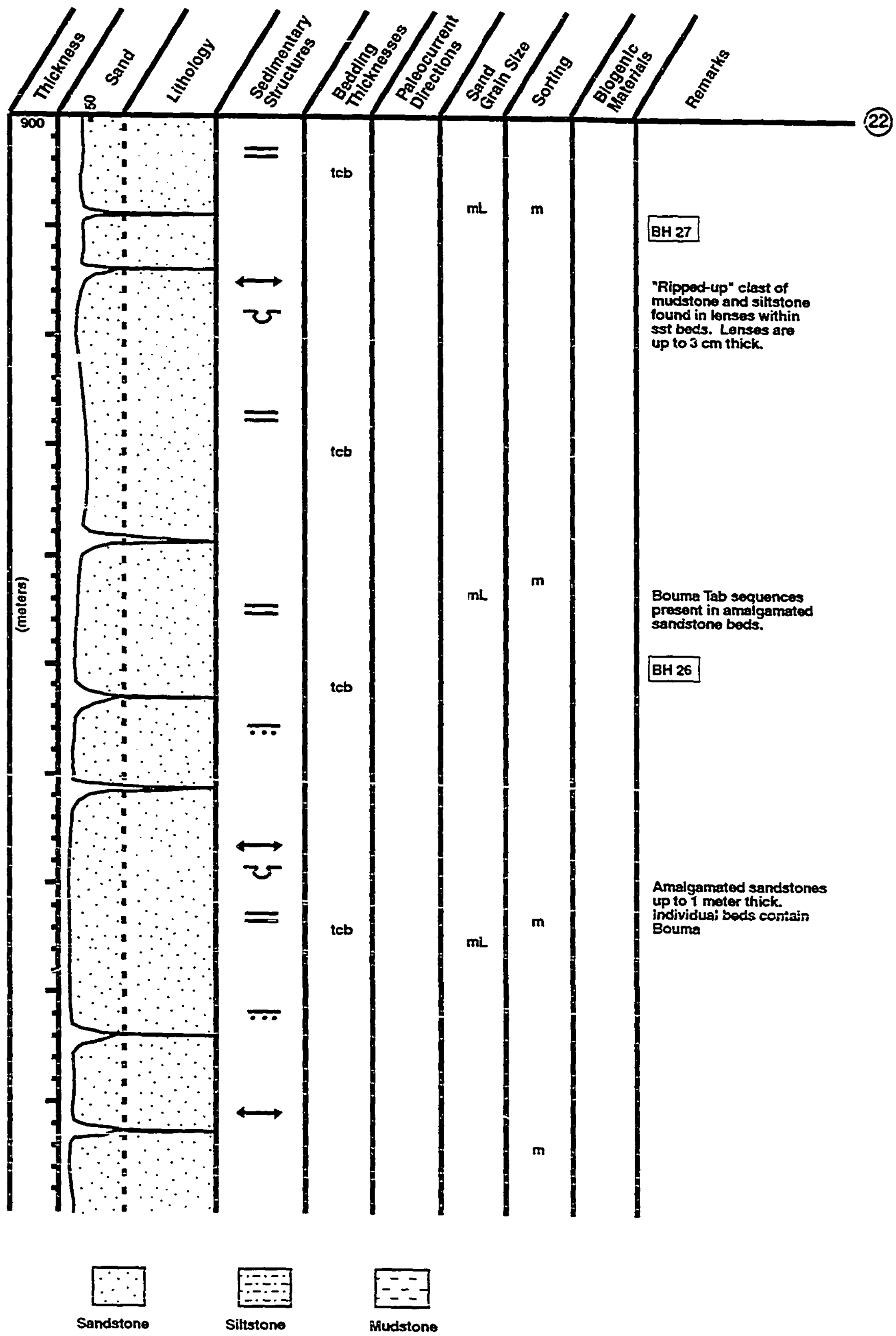
Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
18
700
50
(meters)
tcb
tcb
tcb
tcb
tcb
mL
mL
mL
mL
mL
m
m
m
m
Thickly bedded sst with sharp/scoured bases. Very little mst
sst/mst ≅ 75/1
Sandstones with sharp erosional bases.
Repeated truncated Bouma Tabc sequences. Amalgamated sandstone beds with sharp/scoured bases.
Sandstone
Siltstone
Mudstone

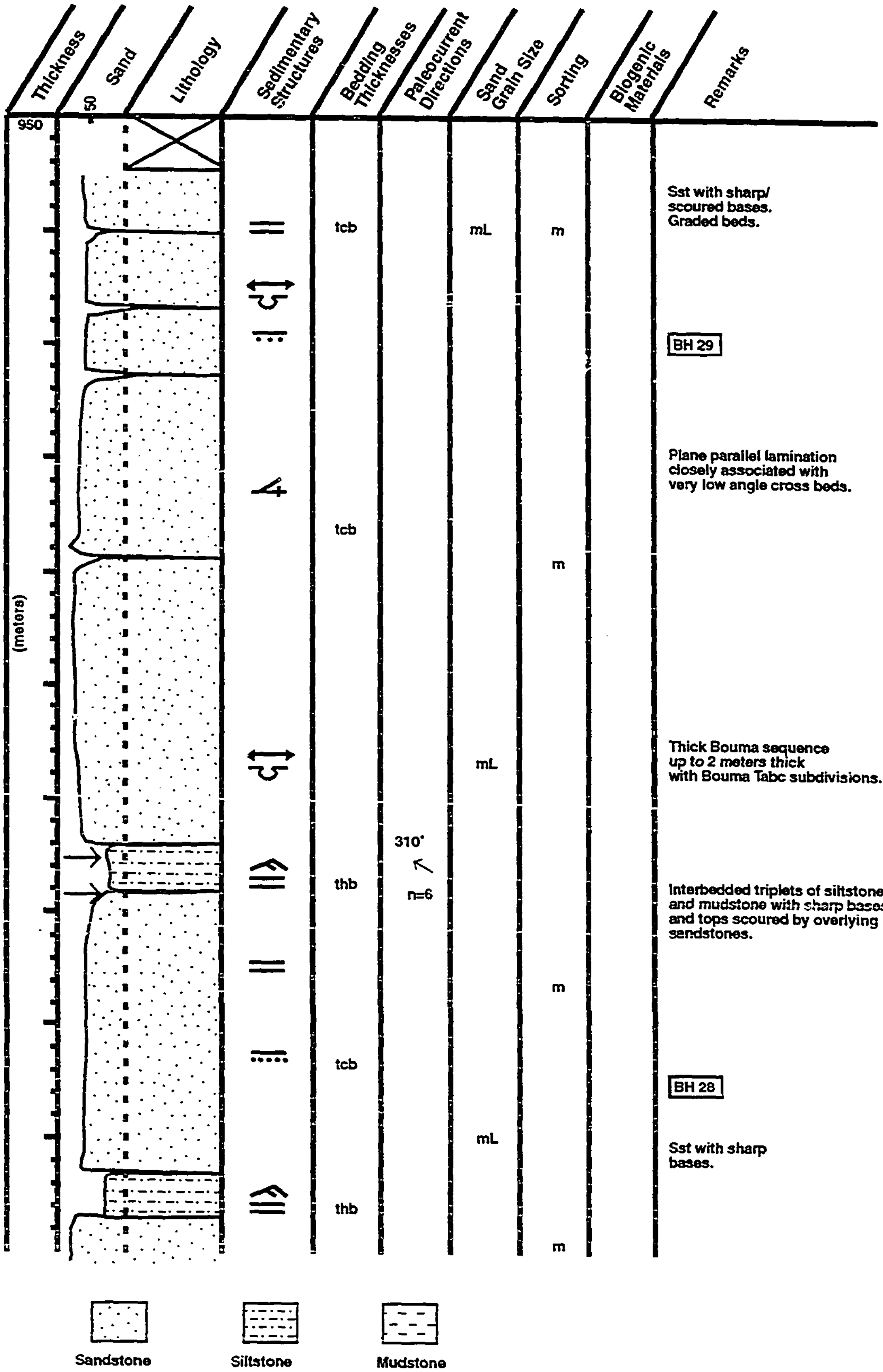

Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
19
750
50
(meters)
tcb
mL
p → m
Sharp sst bases
BH 21
Tabc
tcb
Package (triplet) of thinly bedded sst/slt/mst.
m
tcb
mL
BH 20
tcb
Triplet of thinly bedded sst/slt/mst.
Tab
tcb
mL
Repeated Bouma Tabc sequences. Beds have sharp erosional bases.
m
tcb
Tab sequences up to 60 cm thick.
mL
Sandstone
Siltstone
Mudstone

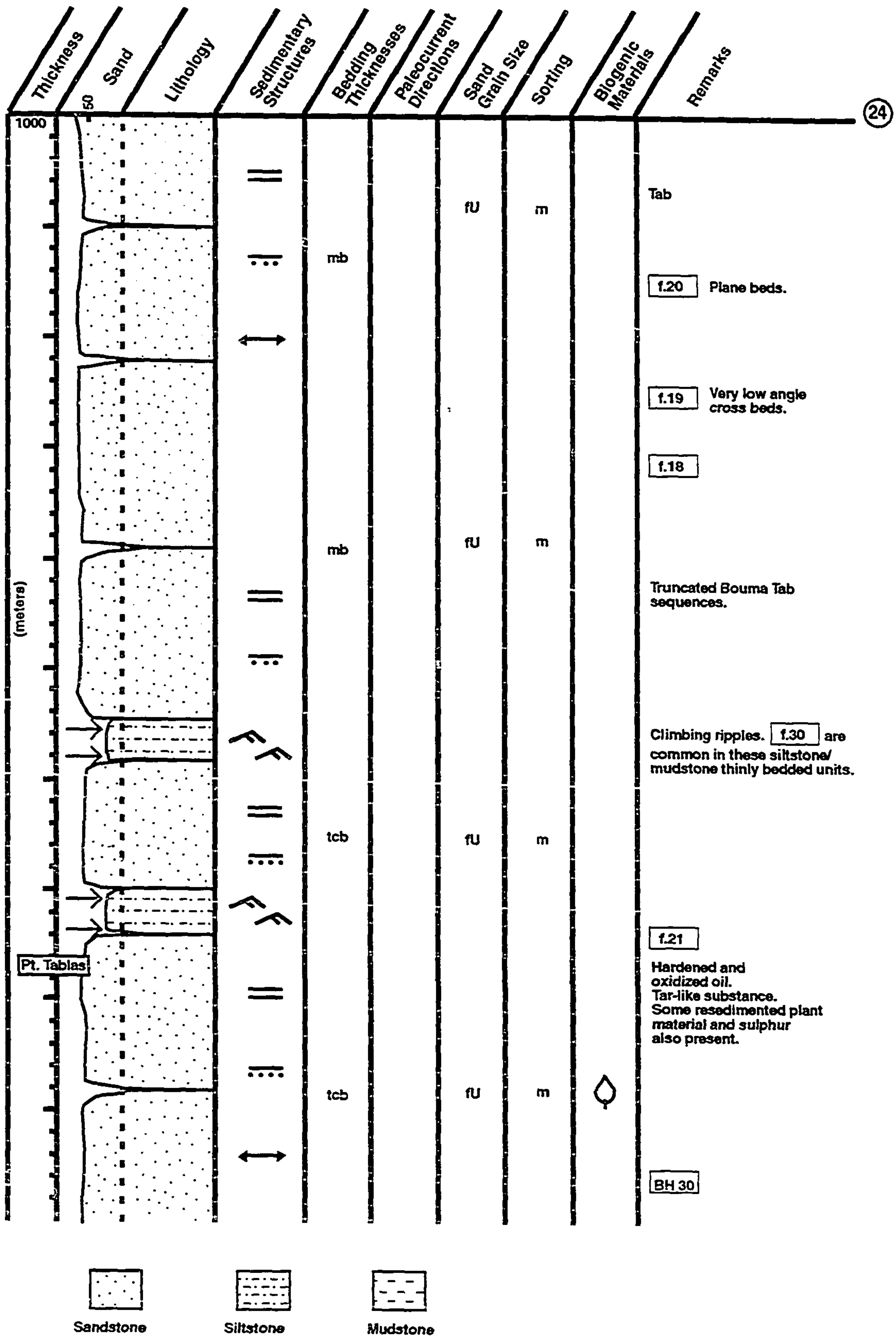


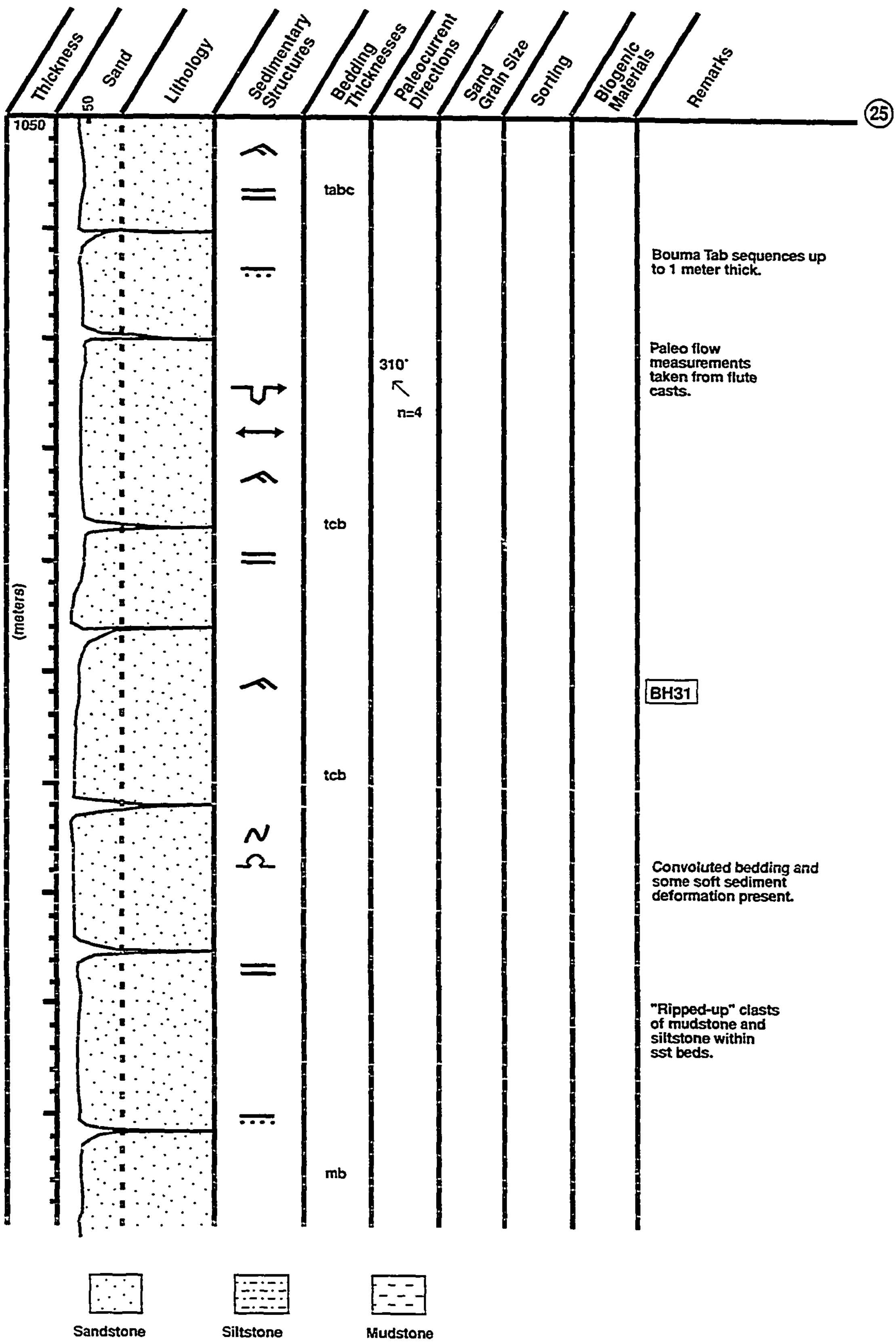
Thickness
Sand
50
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
20
800
(meters)
350°
n = 4
40°
n = 4
Tcb
Tcb
Tcb
With the exception of thinly bedded packages of sst/stt/mst these sands are thickly bedded with Bouma Tbc divisions.
Triplets of siltstone and mudstone beds.
BH 23
Flutes, grooves and striations on the bases of these thickly bedded sandstones.
Sharp bases and mudstone "rip-up" clasts.
Beds up to 2.1 meters thick with sharp bases which are ornamented with flutes and striations.
Tbc
BH 22
Graded beds, plane parallel laminations and very low angle cross beds arranged in Bouma Tabc sequences.
Sandstone
Siltstone
Mudstone


Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
21
850
50
(meters)
tcb
mL
m
Bouma Tb
BH 25
40°
n = 3
thb
Strongly rippled siltstone and mudstone Bouma Tcd.
m
mb
Bouma Tb in truncated sequences. Amalgamated sandstone beds are common.
BH 24
thb
mb
thb
Very well defined Bouma Tabcd sequences up to 45 cm thick.
m
Sandstone
Siltstone
Mudstone

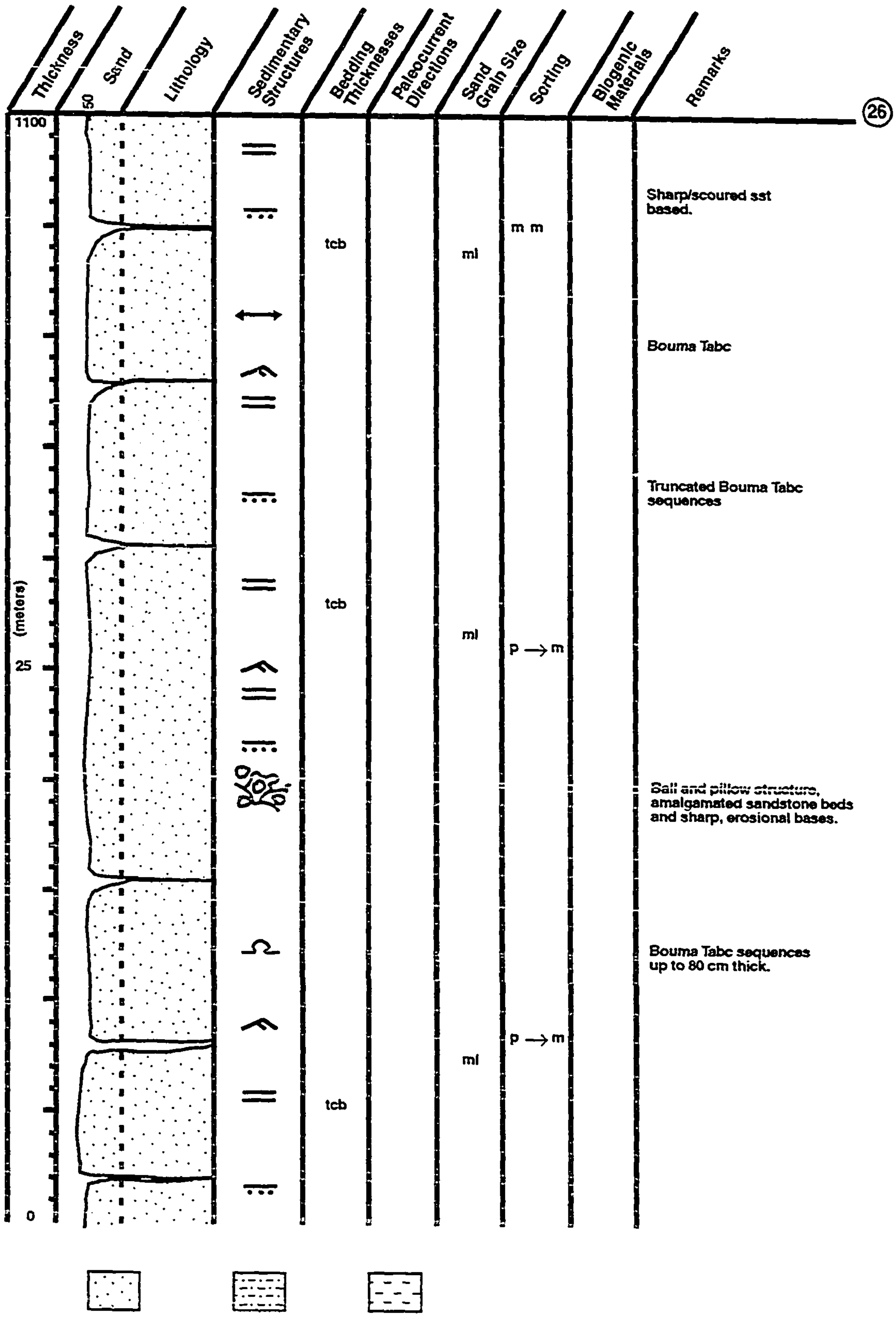

Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
22
900
50
(meters)
tcb
mL
m
BH 27
"Ripped-up" clast of mudstone and siltstone found in lenses within sst beds. Lenses are up to 3 cm thick.
tcb
mL
m
Bouma Tab sequences present in amalgamated sandstone beds.
BH 26
tcb
Amalgamated sandstones up to 1 meter thick. Individual beds contain Bouma
tcb
m
mL
m
Sandstone
Siltstone
Mudstone

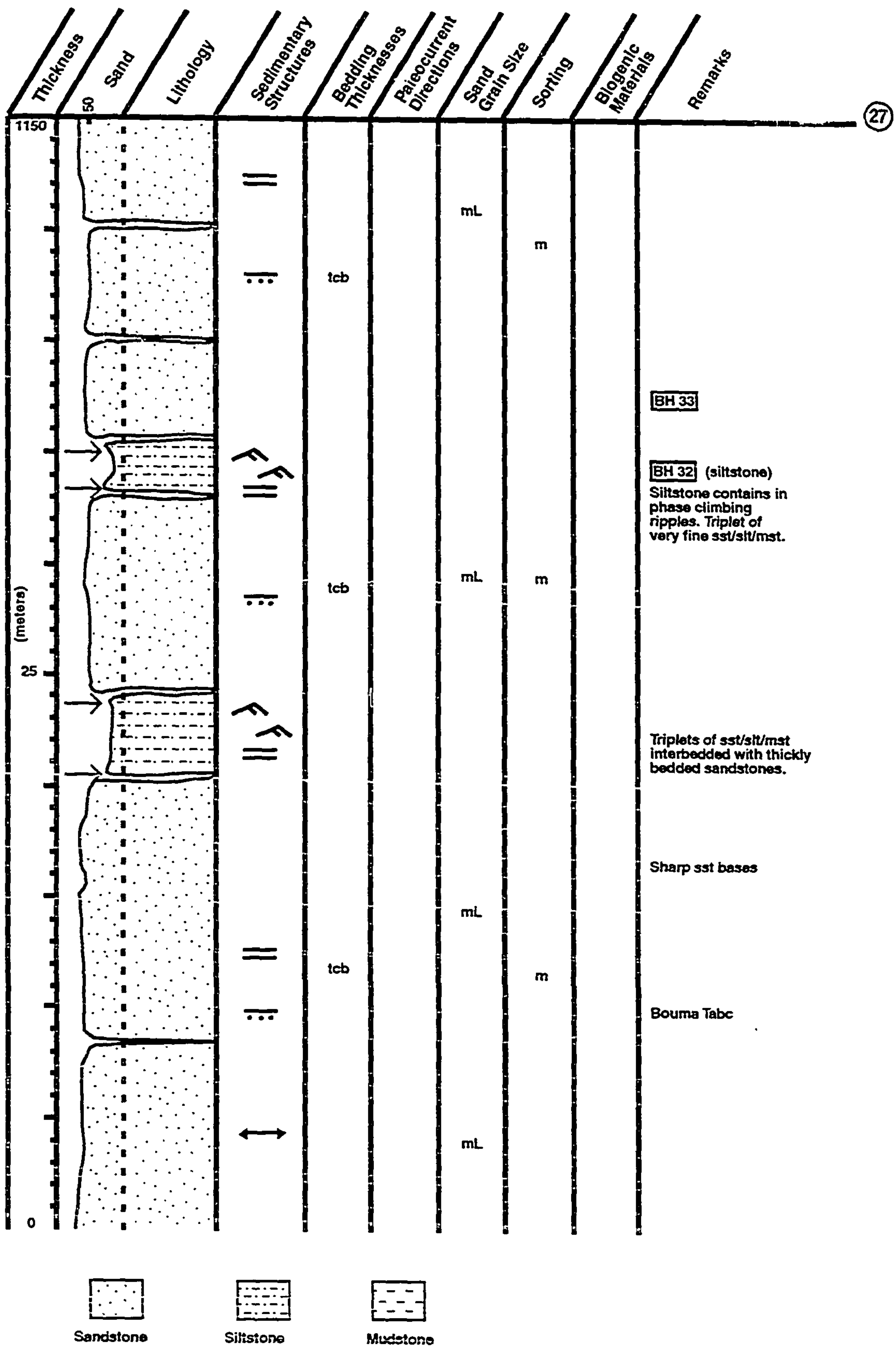

Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
950
50
(meters)
tcb
mL
m
Sst with sharp/ scoured bases. Graded beds.
BH 29
Plane parallel lamination closely associated with very low angle cross beds.
tcb
m
mL
Thick Bouma sequence up to 2 meters thick with Bouma Tabc subdivisions.
310°
thb
n=6
Interbedded triplets of siltstone and mudstone with sharp bases and tops scoured by overlying sandstones.
m
tcb
BH 28
mL
Sst with sharp bases.
thb
m
Sandstone
Siltstone
Mudstone


Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
24
50
1000
(meters)
Pt. Tablas
Tab
fU
m
mb
f.20 Plane beds.
f.19 Very low angle cross beds.
f.18
mb
fU
m
Truncated Bouma Tab sequences.
Climbing ripples. f.30 are common in these siltstone/ mudstone thinly bedded units.
tcb
fU
m
f.21
Hardened and oxidized oil.
Tar-like substance.
Some resedimented plant material and sulphur also present.
tcb
fU
m
BH 30
Sandstone
Siltstone
Mudstone

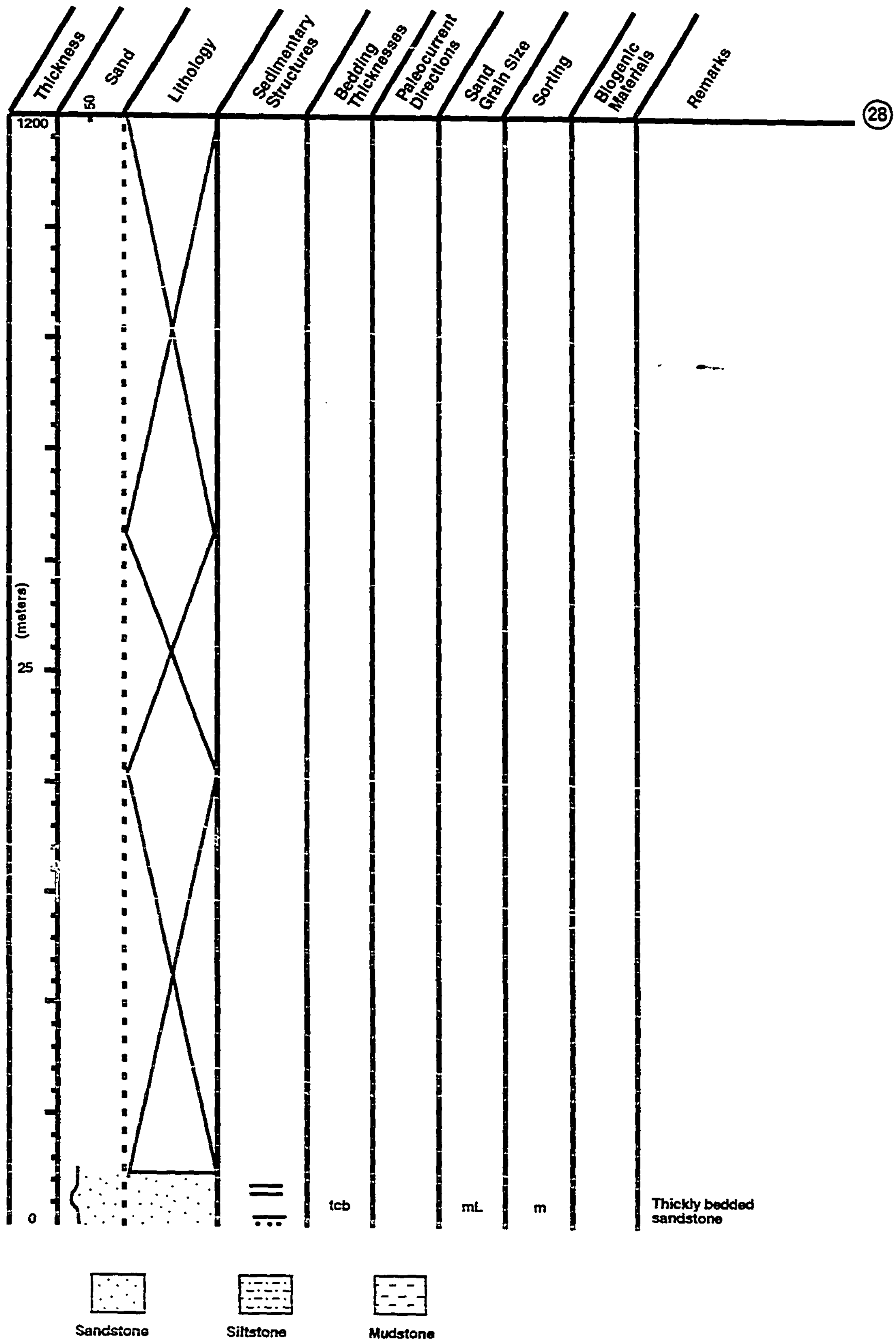


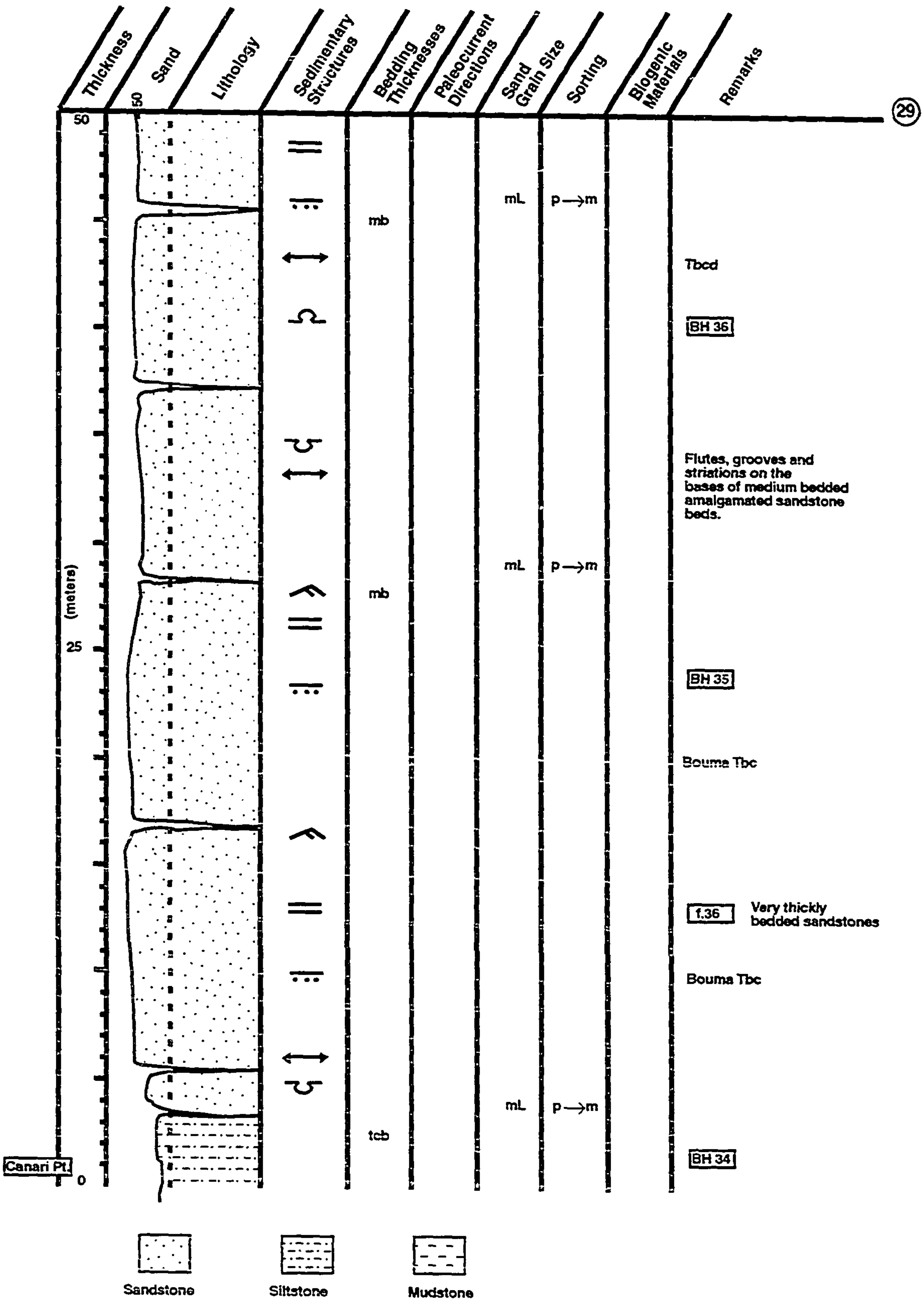
Thickness
Sand
50
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
25
1050
(meters)
tabc
tcb
tcb
mb
310°
n=4
Bouma Tab sequences up to 1 meter thick.
Paleo flow measurements taken from flute casts.
BH31
Convoluted bedding and some soft sediment deformation present.
"Ripped-up" clasts of mudstone and siltstone within sst beds.
Sandstone
Siltstone
Mudstone


Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
26
1100
50
(meters)
25
0
tcb
ml
m m
Sharp/scoured sst based.
Bouma Tabc
Truncated Bouma Tabc sequences
tcb
ml
p → m
amalgamated sandstone beds and sharp, erosional bases.
Bouma Tabc sequences up to 80 cm thick.
p → m
ml
tcb
Sandstone
Siltstone
Mudstone

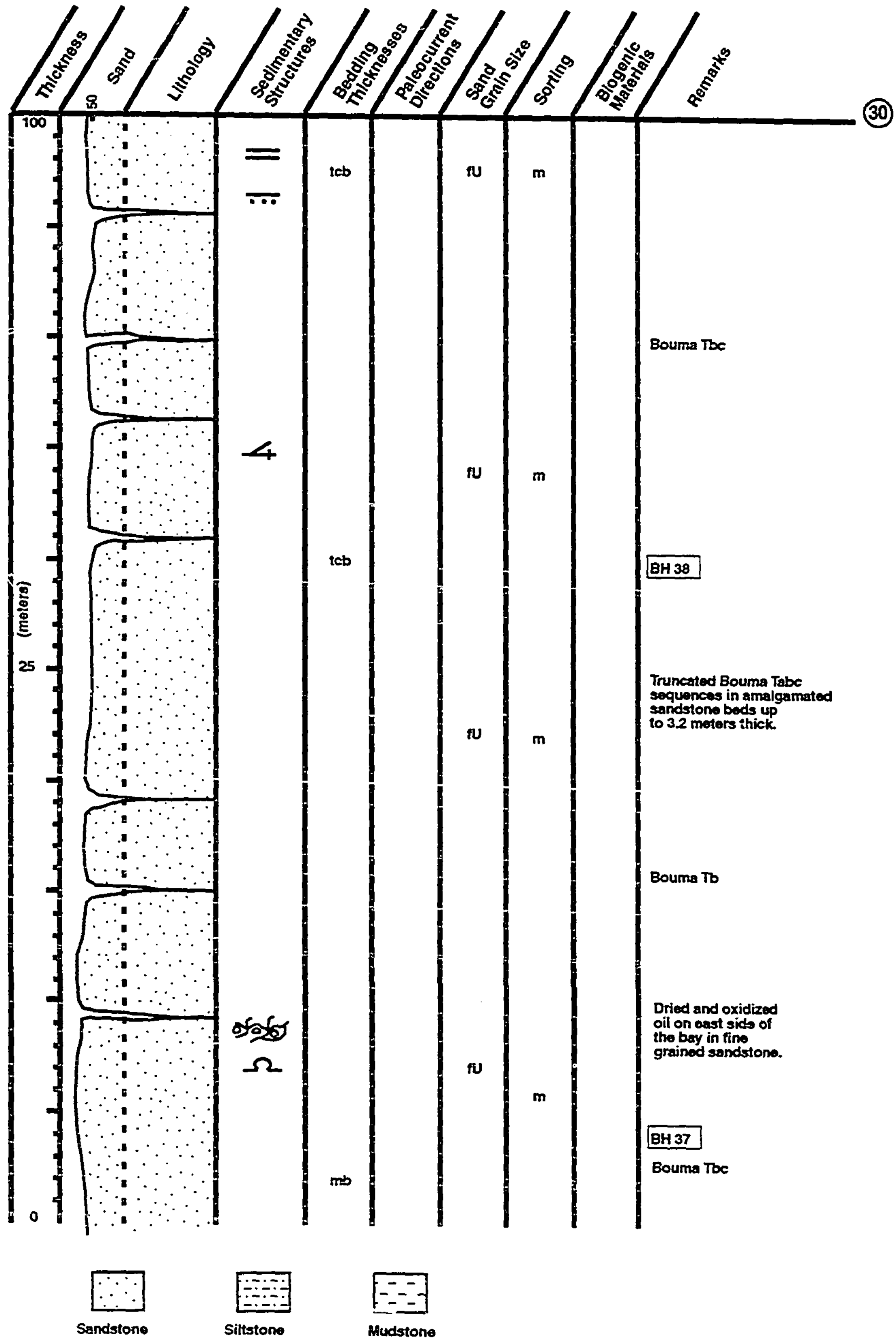


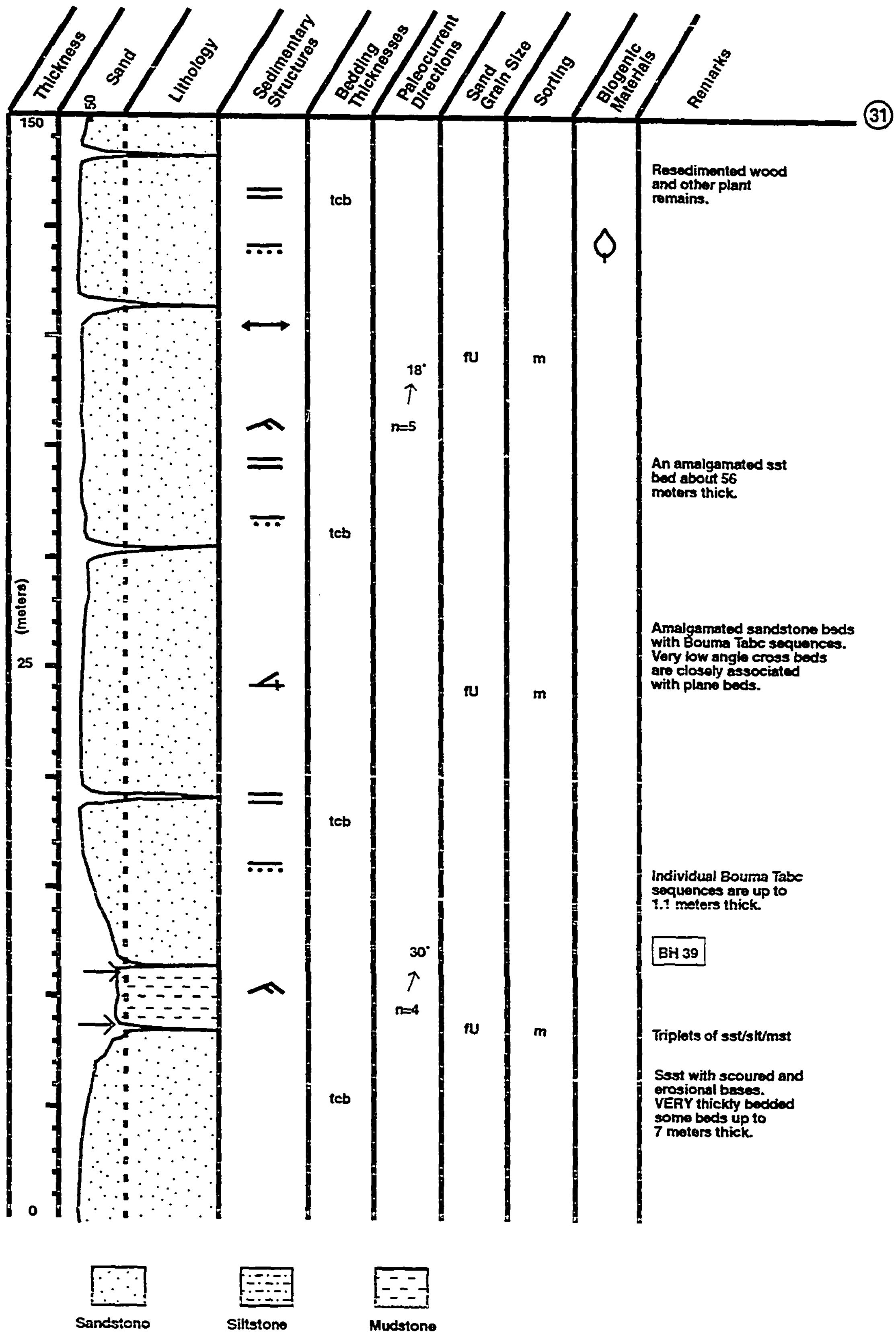
27
Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
1150
50
(meters)
25
0
mL
m
tcb
BH 33
BH 32 (siltstone)
Siltstone contains in phase climbing ripples. Triplet of very fine sst/slt/mst.
Triplets of sst/slt/mst interbedded with thickly bedded sandstones.
Sharp sst bases
Bouma Tabc
Sandstone
Siltstone
Mudstone


Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
28
1200
50
(meters)
25
0
tcb
mL
m
Thickly bedded sandstone
Sandstone
Siltstone
Mudstone

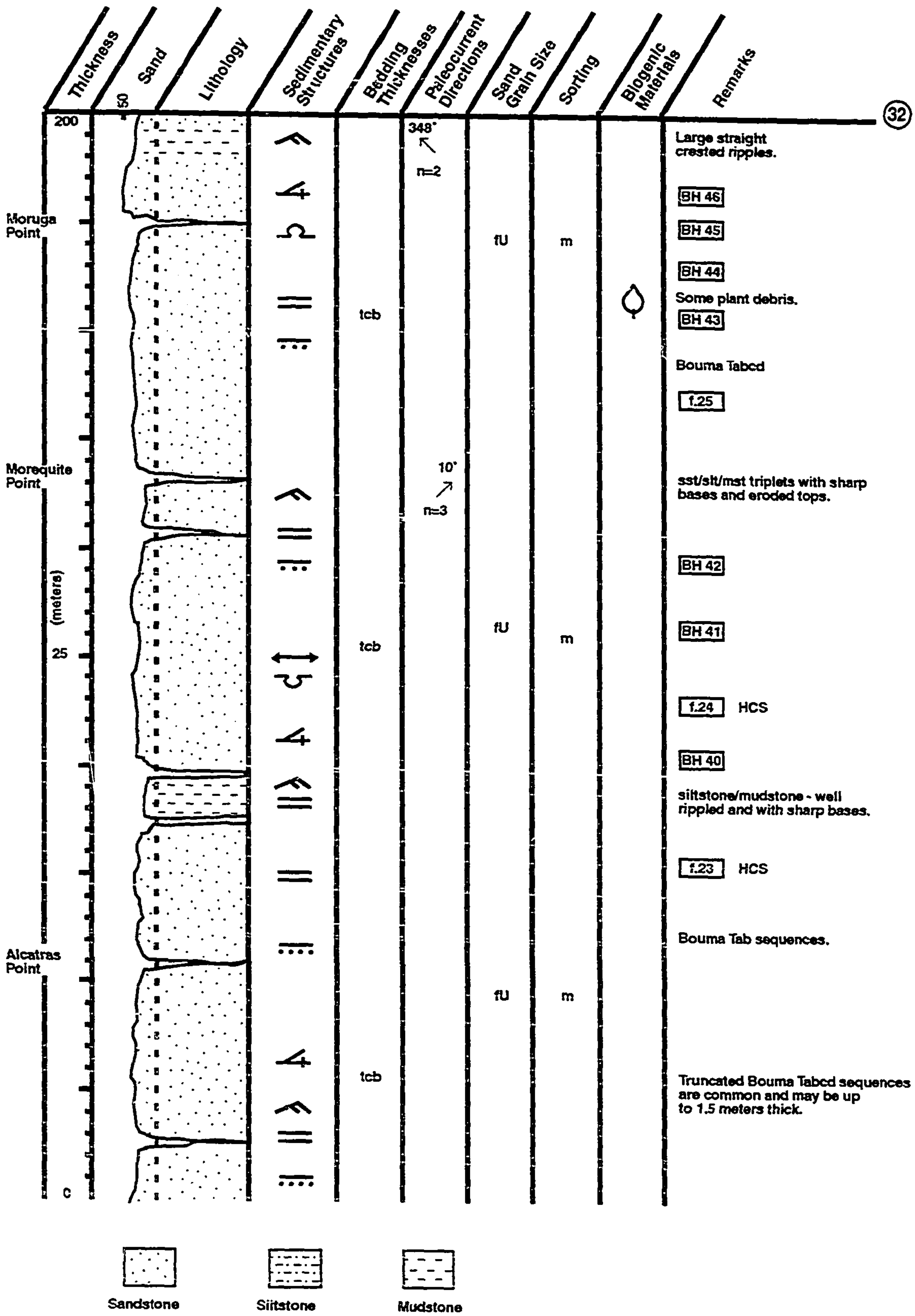


Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
29
50
25
0
(meters)
Canari Pt.
mb
mb
tcb
mL
mL
mL
p→m
p→m
p→m
Tbcd
BH 36
Flutes, grooves and striations on the bases of medium bedded amalgamated sandstone beds.
BH 35
Bouma Tbc
f.36
Very thickly bedded sandstones
Bouma Tbc
BH 34
Sandstone
Siltstone
Mudstone

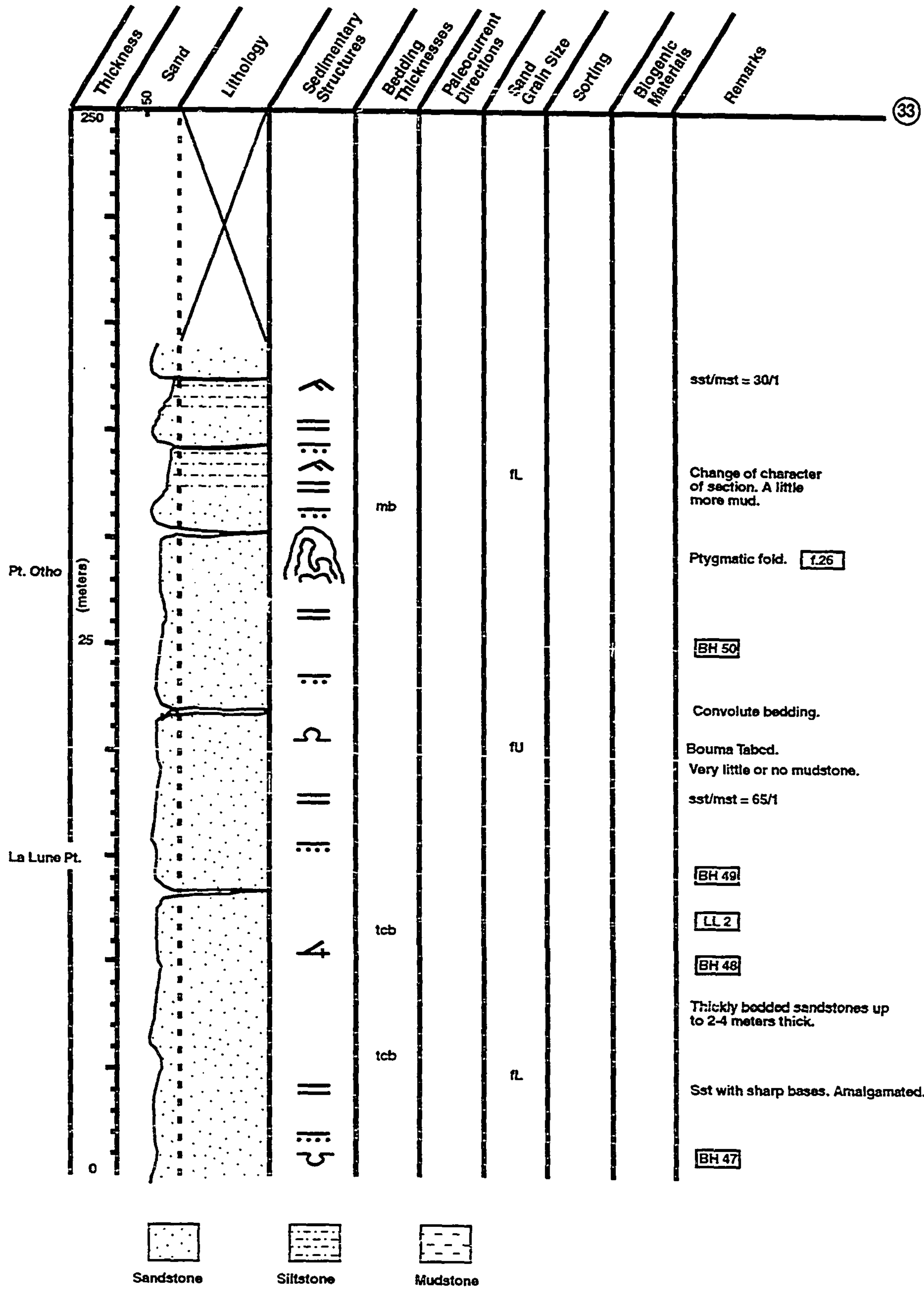

Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
30
50
100
25
0
(meters)
tcb
tcb
mb
fU
fU
fU
fU
m
m
m
m
Bouma Tbc
BH 38
Truncated Bouma Tabc sequences in amalgamated sandstone beds up to 3.2 meters thick.
Bouma Tb
Dried and oxidized oil on east side of the bay in fine grained sandstone.
BH 37
Bouma Tbc
Sandstone
Siltstone
Mudstone

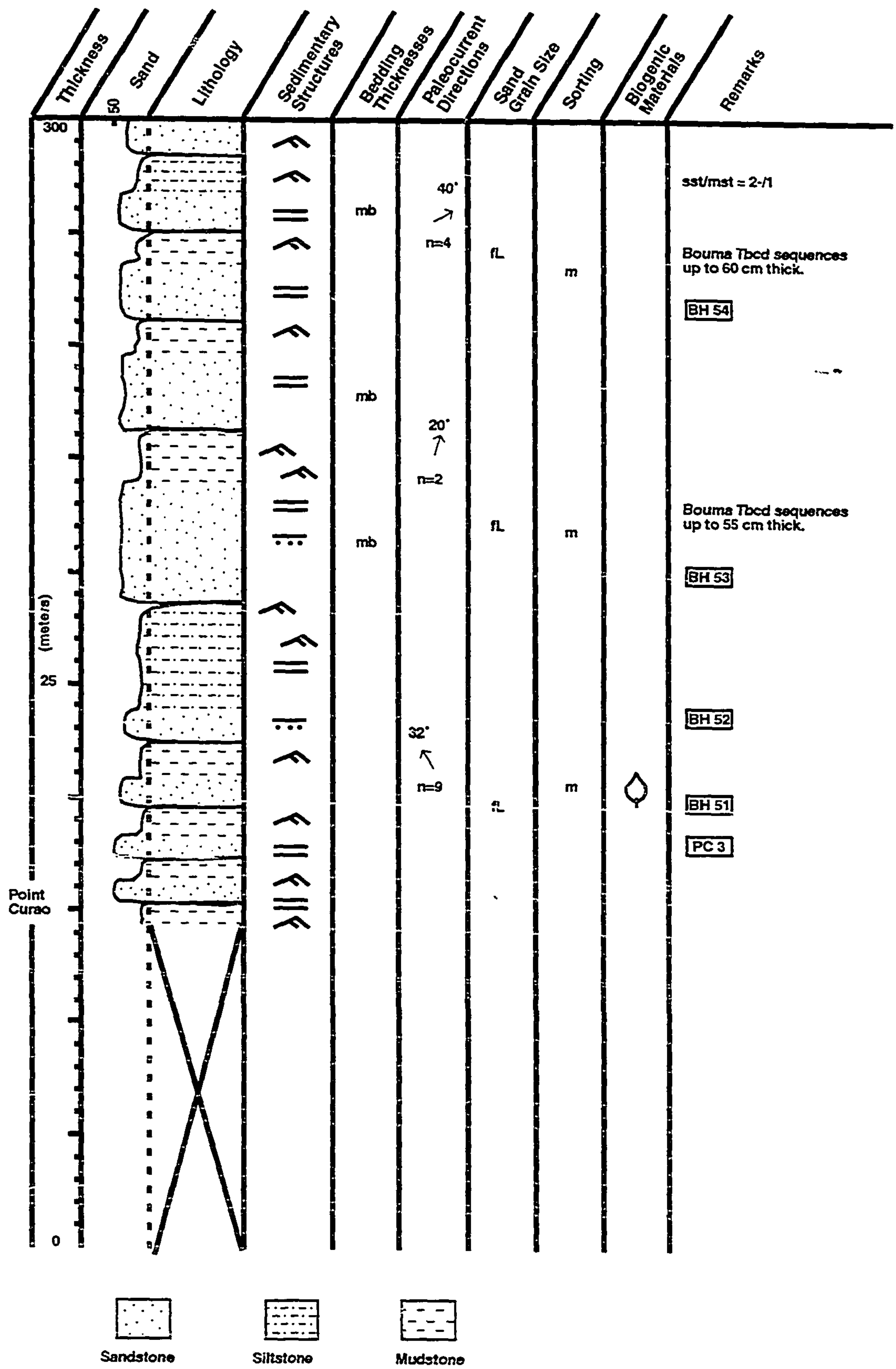


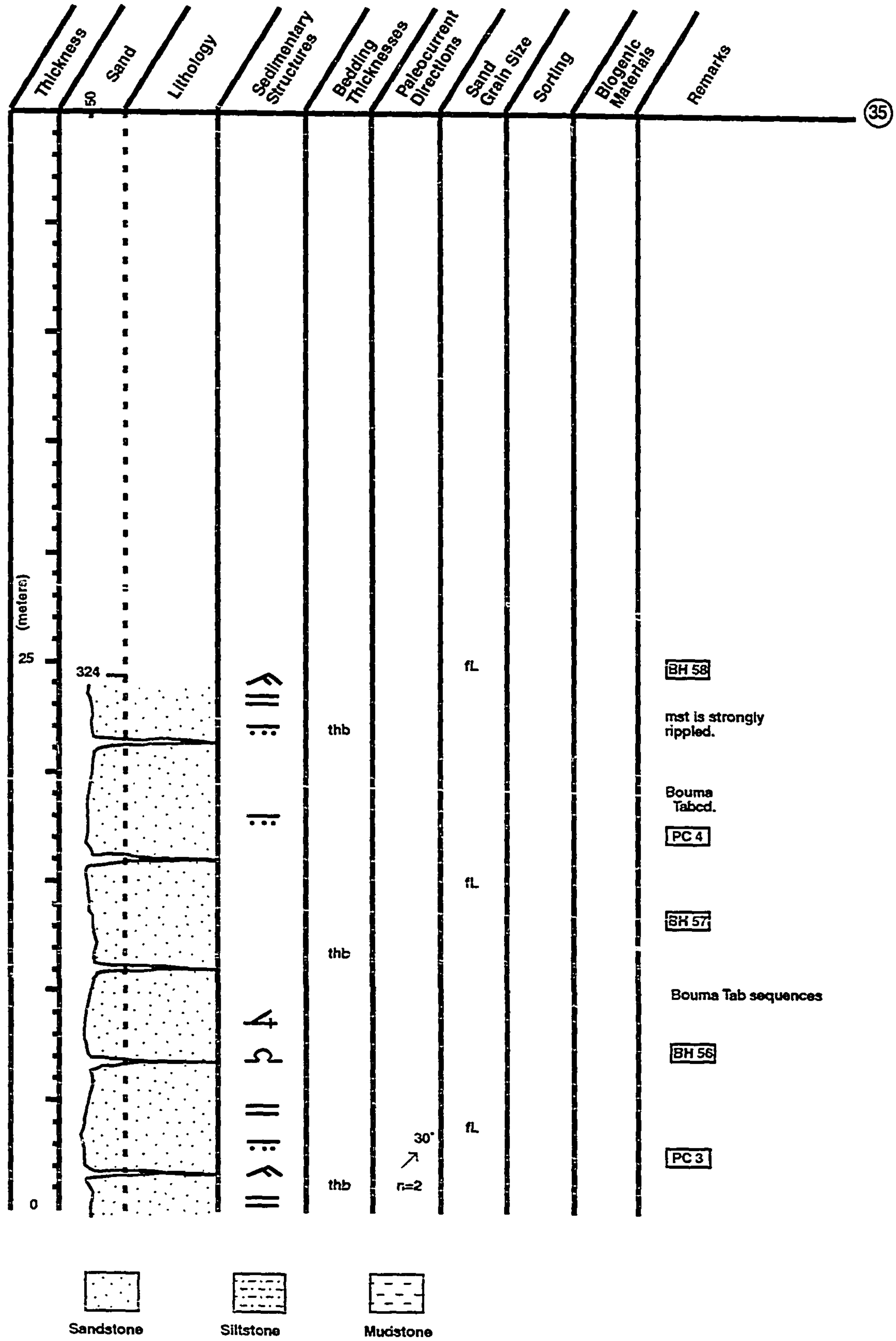
Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
31
150
50
(meters)
25
0
tcb
tcb
tcb
tcb
18°
n=5
30°
n=4
fU
fU
fU
m
m
m
Resedimented wood and other plant remains.
An amalgamated sst bed about 56 meters thick.
Amalgamated sandstone beds with Bouma Tabc sequences. Very low angle cross beds are closely associated with plane beds.
Individual Bouma Tabc sequences are up to 1.1 meters thick.
BH 39
Triplets of sst/slt/mst
Ssst with scoured and erosional bases. VERY thickly bedded some beds up to 7 meters thick.
Sandstone
Siltstone
Mudstone



Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
32
200
50
Moruga Point
Morequite Point
(meters)
25
Alcatras Point
0
348°
n=2
10°
n=3
tcb
tcb
tcb
fU
fU
fU
m
m
m
Large straight crested ripples.
BH 46
BH 45
BH 44
Some plant debris.
BH 43
Bouma Tabcd
f.25
sst/slt/mst triplets with sharp bases and eroded tops.
BH 42
BH 41
f.24 HCS
BH 40
siltstone/mudstone - well rippled and with sharp bases.
f.23 HCS
Bouma Tab sequences.
Truncated Bouma Tabcd sequences are common and may be up to 1.5 meters thick.
Sandstone
Siltstone
Mudstone


Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
250
50
(meters)
25
0
Pt. Otho
La Lune Pt.
mb
tcb
tcb
fL
fU
fL
sst/mst = 30/1
Change of character of section. A little more mud.
Ptygmatic fold. f.26
BH 50
Convolute bedding.
Bouma Tabcd.
Very little or no mudstone.
sst/mst = 65/1
BH 49
LL 2
BH 48
Thickly bedded sandstones up to 2-4 meters thick.
Sst with sharp bases. Amalgamated.
BH 47
Sandstone
Siltstone
Mudstone


Thickness
Sand
50
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
300
25
0
(meters)
Point Curao
mb
mb
mb
40°
n=4
20°
n=2
32°
n=9
fL
fL
m
m
m
sst/mst = 2-/1
Bouma Tbcd sequences up to 60 cm thick.
BH 54
Bouma Tbcd sequences up to 55 cm thick.
BH 53
BH 52
BH 51
PC 3
Sandstone
Siltstone
Mudstone


Thickness
Sand
Lithology
Sedimentary Structures
Bedding Thicknesses
Paleocurrent Directions
Sand Grain Size
Sorting
Biogenic Materials
Remarks
35
50
(meters)
25
0
324
thb
thb
thb
30°
n=2
fL
fL
fL
BH 58
mst is strongly rippled.
Bouma Tabcd.
PC 4
BH 57
Bouma Tab sequences
BH 56
PC 3
Sandstone
Siltstone
Mudstone

APPENDIX 2

Paleontology and Palynology Data

APPENDIX 2

PALYNOLOGIC AND PALAEONTOLOGIC DATA, MORUGA GROUP, SOUTH COAST, TRINIDAD.

Paleontology Summary

Below is a list of key foraminifera encountered within the West Seg-1 well (data supplied by Amoco Trinidad Oil Company).

Depth in Well	Foram
2450-2480	*Buliminella*
3740-3770	*Miliammina*
4640-4670	*Buliminella*
5300-5330	*Lenticulina*
5570-5600	*Amphistegina*
7490-7520	*Saccamina sp.*
8810-8840	*Haplophragmoides*
9440-9470	*Haplostiche*
10040-10070	*Haplostiche*
11000-11030	*Haplostiche*
11330-11360	*Bolivina*
11930-11960	*Textularia*
13820-13850	*Reticulophragmium*
14840-14870	*Alveovalvulina*

The following is a list of foraminifera encountered in the GBM-1 well (data supplied by the Ministry of Energy, Trinidad and Tobago).

Depth in Well	Foram
630	Reworked fragments, Amphistegina sp.
840	Reworked reefal types, Amphistegina
1320	Amphistegina sp., Rotalia choctawensis
1470	Uvigerina, Buliminella 1/2
1560	Globorotalia limbata, Uvigerina
1590	Globorotalia dutertrel
1800	Globigerinoides conglobatus
2430	Reworked fauna with Amphistegina sp.
2760	Bolivina sp., Hormosina sp.
2910	Bolivina sp., Amphistegina sp.
3450	Haplostiche, Bolivina sp.
3510	Textularia, Valvulilna, Buliminella 1/2
3720	Sphaeroidinella sp.
4170	Haplophragmoides, Bolivina
7290	Haplostiche, Cyclammina
7380	Bolivina, Textularia, Buliminella 1/2
9120	" " "
9270	" " "
9420	" " "
9540	" " "
9630	Textulaaria, Amphistegina, Buliminella 1/2

9840	Bolivina, Amphistegina, Buliminella 1/2
9960	Textularia, Buliminella 1/2
10004	Textularia, Buliminella 1/2

Palynlogy Summary

Outcrop Samples

Sample #	Age	Palynomorphs
BH 2, 10, 11, 13, 20, 29, 31, 32, 41 & 42	L. Early Plio.	Badly corroded and sparse palynomorphs with reworked early and late Cretaceous
BH 43 & 44	L. Early Plio.	Reworked early and late Cretaceous and heavily reworked Oligocene
BH 48 & 50	L. Early Plio.	Heavily reworked Barremian, Cenomanian, Senonian, middle and late Miocene
PC 4, 5 & 8	L. Early Plio.	Reworked early and late Cretaceous and

		Oligocene
LL2	L. Early Plio.	Reworked early and late Createaceous.

<u>West Seq-1</u> (Cuttings)

(Depth in feet)

860-3380	L. Pleist.	Reworked late Cretaceous and Oligocene
5330-5360	L. Plio.	Reworked early Cretaceous
5990-6020	L. Plio.	Reworked early Cretaceous and Oligocene
6980-7010	L. Plio.	Reworked early Cretaceous and Eocene
7940-7970	L. Plio.	Reworked Cenomanian
9140-9170	L. Plio.	Reworked Paleocene and Senonian
9620-9650	L. Plio.	Reworked Senonian
10790-10820	L. Plio.	Reworked Senonian

11780-11810	L. Plio. (?) L. Early Plio.	Reworked Senonian and Cenomanian
12920-12950	Indeterminate	Reworked Senonian and Cenomanian
13970-15230	L. Early Plio.	Reworked early and late Cretaceous

West Seq-1 (SWC)

(Depth in Feet)

1550	L. Pleist.	Heavily reworked late Cretaceous
1850-29950	L. Pleist.	Reworked late Cretaceous
3140	Indeterminate	Reworked early Cretaceous
3765	Indeterminate	
4040-4600	L. Pleist.	Reworked early and late Cretaceous
5050	L. Pleist.	Heavily reworked early and late Cretaceous and early Miocene

5250	L. Plio.	Reworked early and late Cretaceous
5670	L. Plio.	
6830	L. Plio.	Reworked late Cretaceous and early Miocene
7050	L. Plio.	Reworked early and late Cretaceous
7350	L. Plio.	Heavily reworked early and late Cretaceous
8600A	L. Pleist.	Heavily reworked early and late Cretaceous, Oligocene, Middle and late Miocene
8600B	L. Pleist.	
9200	L. Plio.	Reworked late Cretaceous and late Miocene
9600	L. Plio.	Reworked early and late Cretaceous
9800	L. Plio.	Reworked early and late

		Cretaceous, Middle and Late Miocene
10700	Indeterminate	Reworked late Miocene
10900	L. Pleist.	Reworked early Cretaceaous, late Miocene and early Pliocene
11300	L. Plio.	Heavily reworked early Cretaceous
12300	L. Early Plio.	
12500	L. Early Plio.	Reworked late Miocene

APPENDIX 3

Modal Analyses

RAW SANDSTONE PETROGRAPHIC DATA; TRINIDAD, WEST INDIES

Sample	Q_m	Q_p	F_k	F_p	CHERT	L_m	L_s	L_v	MIC	CHL	GLAU	OPAQ	CEM	POR	MAT.	UNID	P/F	N
BH 1	253	46	30	48	40	4	16	5	38	9	21	38	84	26	65	3	.62	726
BH 3	239	60	33	22	31	6	14	2	36	12	29	38	91	5	75	0	.40	693
BH 5	271	51	27	29	21	11	26	9	21	5	20	21	89	13	101	1	.52	716
BH 8	244	32	32	31	19	2	20	1	26	8	29	38	108	9	91	0	.49	690
BH 9	222	41	34	27	21	8	19	3	32	2	18	30	77	11	103	0	.44	648
BH 10	280	39	40	42	27	10	20	4	19	1	32	35	96	21	93	0	.51	759
BH 11	209	55	20	23	22	7	18	8	21	5	20	19	100	31	89	2	.54	649
BH 12	291	50	50	43	29	2	19	2	42	14	26	31	60	20	76	0	.46	755
BH 15	222	41	31	32	27	0	10	0	13	16	21	22	93	4	63	5	.51	590
BH 16	251	67	14	20	30	4	7	3	9	2	8	28	101	0	119	0	.59	663
BH 18	215	34	22	26	19	6	19	9	21	0	9	16	62	8	91	0	.54	557
BH 19	240	32	19	22	21	1	9	2	19	0	22	41	65	14	97	0	.54	604
BH 21	209	23	16	19	20	3	13	7	18	4	12	39	93	12	89	1	.54	578
BH 25	230	19	8	13	18	0	21	5	25	0	9	20	60	1	96	3	.62	528
BH 26	261	64	20	24	15	2	26	8	20	0	10	19	61	9	110	2	.55	651
BH 27	271	40	30	33	21	4	4	6	36	1	18	32	68	7	71	0	.52	642
BH 28	290	51	21	37	28	0	15	2	17	5	13	41	74	12	79	4	.64	689
BH 33	276	39	19	29	18	3	11	4	11	13	12	23	99	19	93	0	.60	669
BH 36	290	49	31	29	14	6	14	2	12	11	17	21	90	21	106	0	.48	713
BH 38	241	28	31	34	32	4	17	0	30	8	13	19	97	0	100	0	.52	654
BH 39	256	31	28	29	10	0	20	3	26	2	17	22	83	3	99	0	.51	629
BH 49	263	24	29	38	18	2	19	8	21	0	19	31	81	2	73	0	.57	628
BH 58	202	18	33	36	15	4	19	5	17	3	7	28	72	09	81	0	.52	549

RECALCULATED SANDSTONE PETROGRAPHIC DATA: TRINIDAD, WEST INDIES

	Q-F-L	$Q_mF_k-F_p$	$Q_m-F_t-L_t$	$Q_p-L_s-L_v$
BH 1	68-18-14	76-9-15	64-20-16	43-52-5
BH 3	73-14-13	81-11-8	69-16-15	56-42-2
BH 5	72-13-15	83-8-9	69-14-17	48-44-8
BH 8	72-17-11	79-10-11	70-18-12	60-38-2
BH 9	70-16-14	78-12-10	66-18-16	49-48-3
BH 10	69-18-13	77-11-12	66-19-15	43-52-5
BH 11	73-12-15	83-8-9	68-14-18	68-22-10
BH 12	70-19-11	76-13-11	67-21-12	50-48-2
BH 15	72-17-11	78-7-15	69-20-11	53-47-0
BH 16	80-8-12	88-5-7	76-10-14	62-35-3
BH 18	71-14-15	82-8-10	68-15-17	42-47-11
BH 19	72-12-9	85-7-8	76-13-11	50-47-3
BH 21	75-11-14	86-6-8	73-12-15	36-52-12
BH 25	79-7-14	92-3-5	78-7-15	30-62-8
BH 26	77-11-12	86-7-7	73-12-15	57-36-7
BH 27	76-15-9	81-9-10	73-17-10	56-35-9
BH 28	77-13-10	83-6-11	74-15-11	53-45-2
BH 33	79-12-9	88-3-9	77-13-10	54-40-6
BH 36	78-14-8	83-9-8	75-16-9	62-35-3
BH 38	69-17-14	79-10-11	67-18-15	36-64-0
BH 39	76-15-9	82-9-9	74-16-10	48-47-5
BH 49	72-17-11	80-9-11	70-18-12	35-54-11
BH 58	66-21-13	74-12-14	64-22-14	32-60-8

APPENDIX 4

Geochemistry Data

SUBSURFACE DATA SOUTH EAST, TRINIDAD, W.I.

DEPTH	TMAX		S1	S2	S3	TOC Ch	HI	OI
590 -	332	*	0.11	0.09	1.82	0.31	29	587
800	392		0.45	0.76	9.40	2.06	37	456
920	363		0.34	1.29	1.68	0.94	137	179
1520	427	*	0.17	0.38	3.25	0.53	72	613
2030	377	*	0.05	0.09	5.47	0.13	69	4208
2450	501	*	0.13	0.35	1.96	0.57	61	344
2660	---		0.16	0.82	2.19	0.77	106	284
3140	---		0.09	0.53	2.62	0.74	72	354
3380 - 3410	600		0.13	0.51	1.37	0.53	96	258
3560 - 3590	---		0.12	0.51	1.80	0.74	69	243
3740 - 3770 R	---		0.17	0.68	2.49	1.14	60	218
3940 - 3970 R	---		0.16	0.46	1.89	0.79	58	239
4970 - 5000	---		0.09	0.39	1.67	0.52	75	321
5300 - 5330	539	*	0.09	0.32	2.38	0.51	63	467
5450 - 5480	562	*	0.11	0.38	1.88	0.55	69	342
5600 - 5630	598	*	0.10	0.40	1.19	0.34	118	350
7220 - 7250	544		0.12	0.70	1.36	0.45	156	302
7490 - 7520	560	*	0.14	0.47	1.68	0.37	127	454
7670 - 7700	492	*	0.13	0.44	1.36	0.51	86	267
7970 - 8000	585	*	0.10	0.48	1.56	0.47	102	332
8000 - 8030	512		0.18	0.58	1.33	0.51	114	261
8660 - 8690	436	*	0.12	0.20	1.43	0.37	54	386
8870 - 8900	---		0.08	0.58	0.90	0.26	223	346
9230 - 9260	387	*	0.10	0.16	1.09	0.53	30	206
9500 - 9530	476	*	0.06	0.23	1.05	0.30	77	350
9830 - 9860	559	*	0.06	0.24	1.02	0.30	80	340
9920 - 9950	448	*	0.09	0.19	1.37	0.26	73	527
10130 - 10160	468	*	0.12	0.38	1.05	0.44	86	239
10430 - 10460	516	*	0.16	0.33	0.79	0.36	92	219
10730 - 10760	540		0.24	0.54	1.58	0.46	117	343
11030 - 11060 R	593	*	0.17	0.48	1.24	0.37	130	335
11200 - 11230 R	---		0.19	0.39	1.16	0.41	95	283
11390 - 11420	417	*	0.08	0.22	1.01	0.31	71	326
11720 - 11750	416	*	0.12	0.26	0.92	0.39	67	236
11870 - 11900	405	*	0.21	0.22	1.03	0.41	54	251
12620 - 12650	343	*	0.13	0.13	0.88	0.30	43	293
13100 - 13130	408	*	0.48	0.47	1.79	0.59	80	303
13370 - 13400	538	*	0.15	0.46	1.13	0.49	94	231
14030 - 14060	407	*	0.46	0.28	1.33	0.49	57	271
14870 - 14900	417		0.88	0.74	1.33	0.90	82	148
15230 - 15260 std	390	*	0.04	0.05	0.08	0.68	7	12

OUTCROP DATA SOUTH EAST, TRINIDAD, W.I.

SAMPLE	TMAX		S1	S2	S3	TOC Ch	HI	OI
BH - 2 R	431	*	0.03	0.19	1.22	0.48	40	254
BH - 10	431	*	0.05	0.40	0.52	0.54	74	96
BH - 13	367	*	0.00	0.07	0.35	0.35	20	100
BH - 22	402	*	0.02	0.21	0.18	0.57	37	32
BH - 29	383	*	0.00	0.14	0.54	0.52	27	104
BH - 32	309	*	0.03	0.16	0.52	0.27	59	193
BH - 40	410		1.09	14.46	1.86	13.63	106	14
BH - 41 R	435		0.04	0.50	0.64	0.96	52	67
BH - 42	415		0.60	4.81	1.12	8.63	56	13
BH - 43	413	*	0.08	0.24	0.19	0.55	44	35
BH - 44std	412		2.64	14.93	9.14	9.76	153	94
BH - 48	461	*	0.05	0.32	1.10	0.76	42	145
PC - 8	424	*	0.03	0.33	2.74	0.59	56	464
W - 14 R	427	*	0.05	0.24	2.04	0.55	44	371

KEY

* TMAX data not reliable due to low S2 value

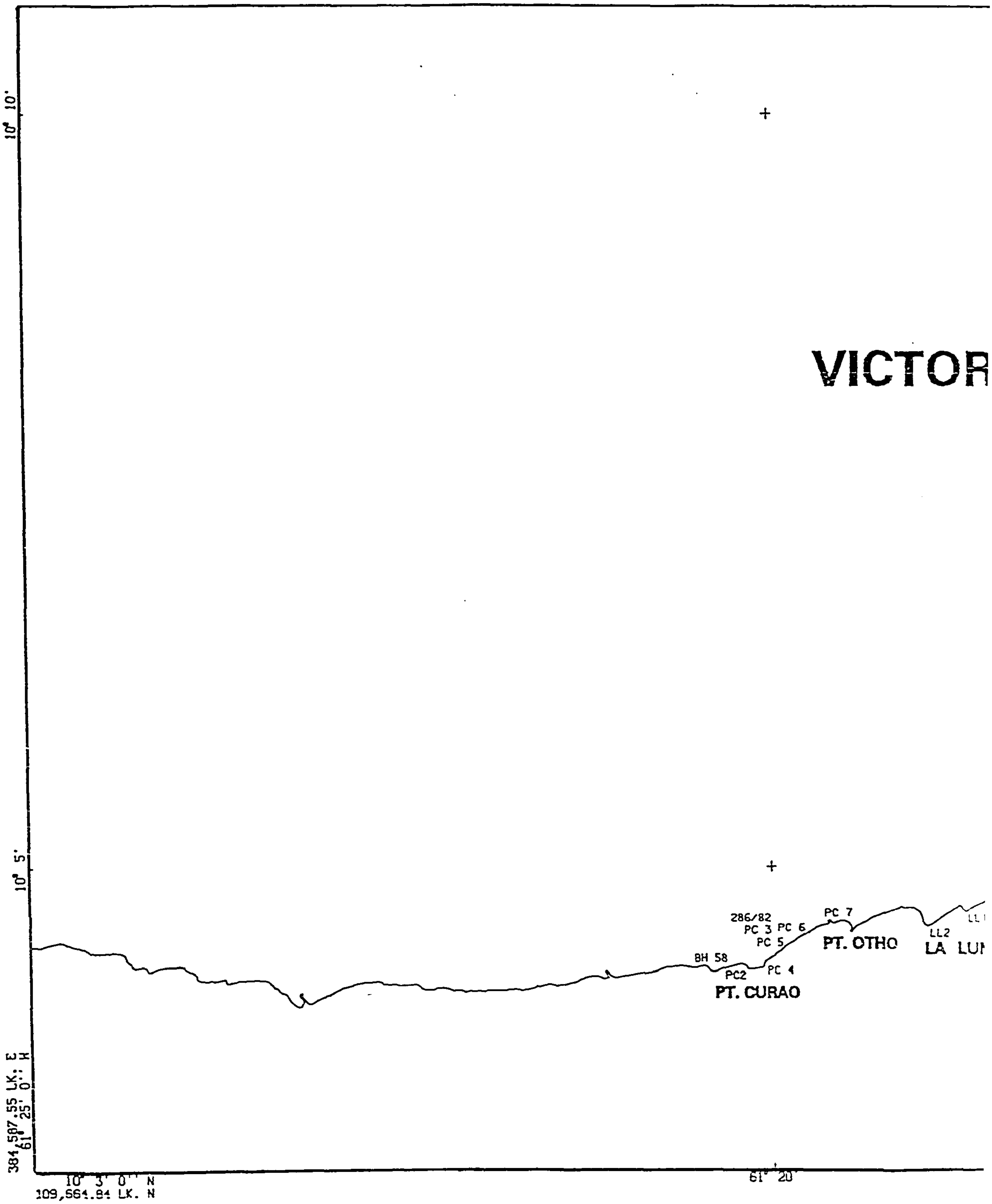
Ch Sample analysis checked

R Replicate analysis conducted

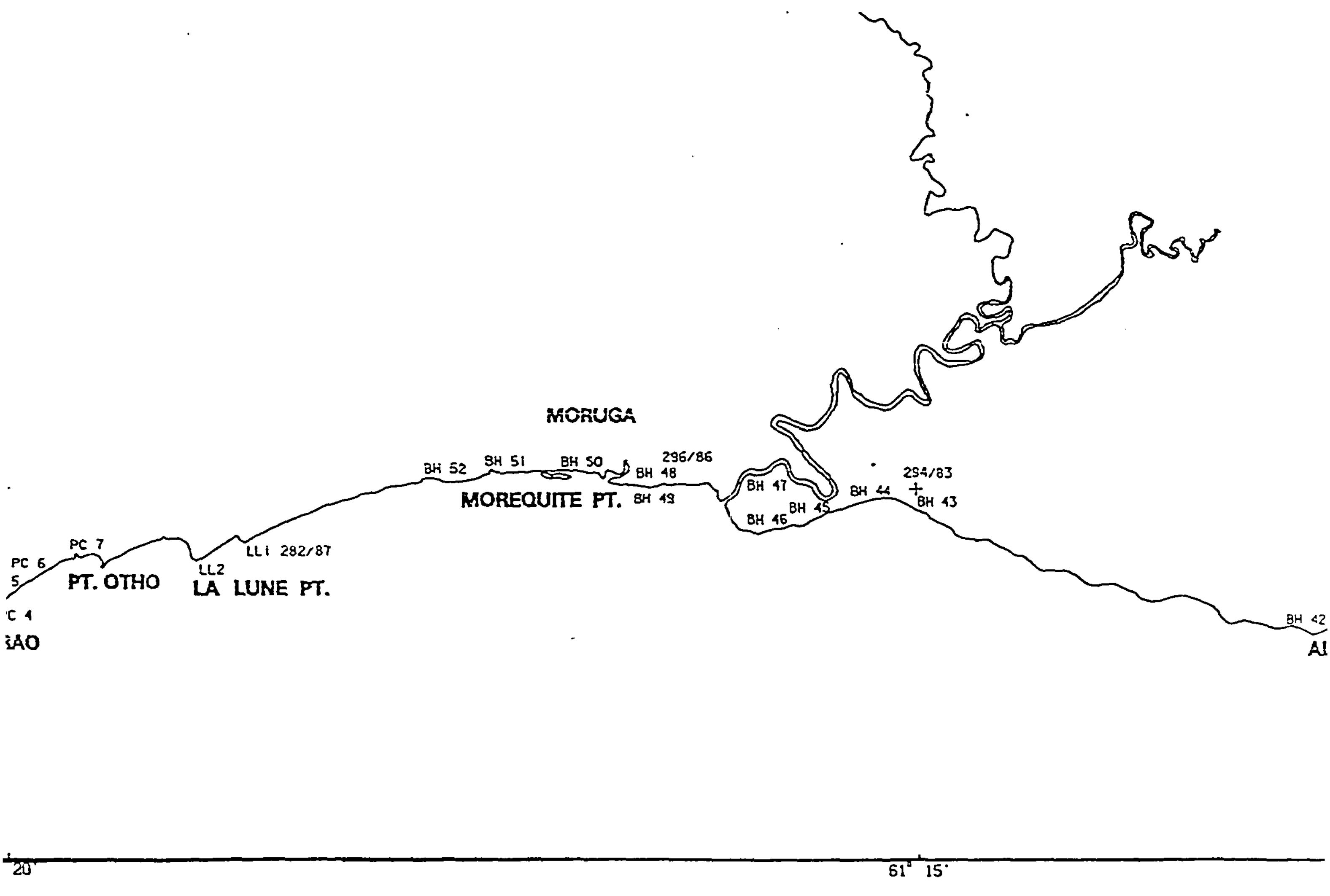
std Standard

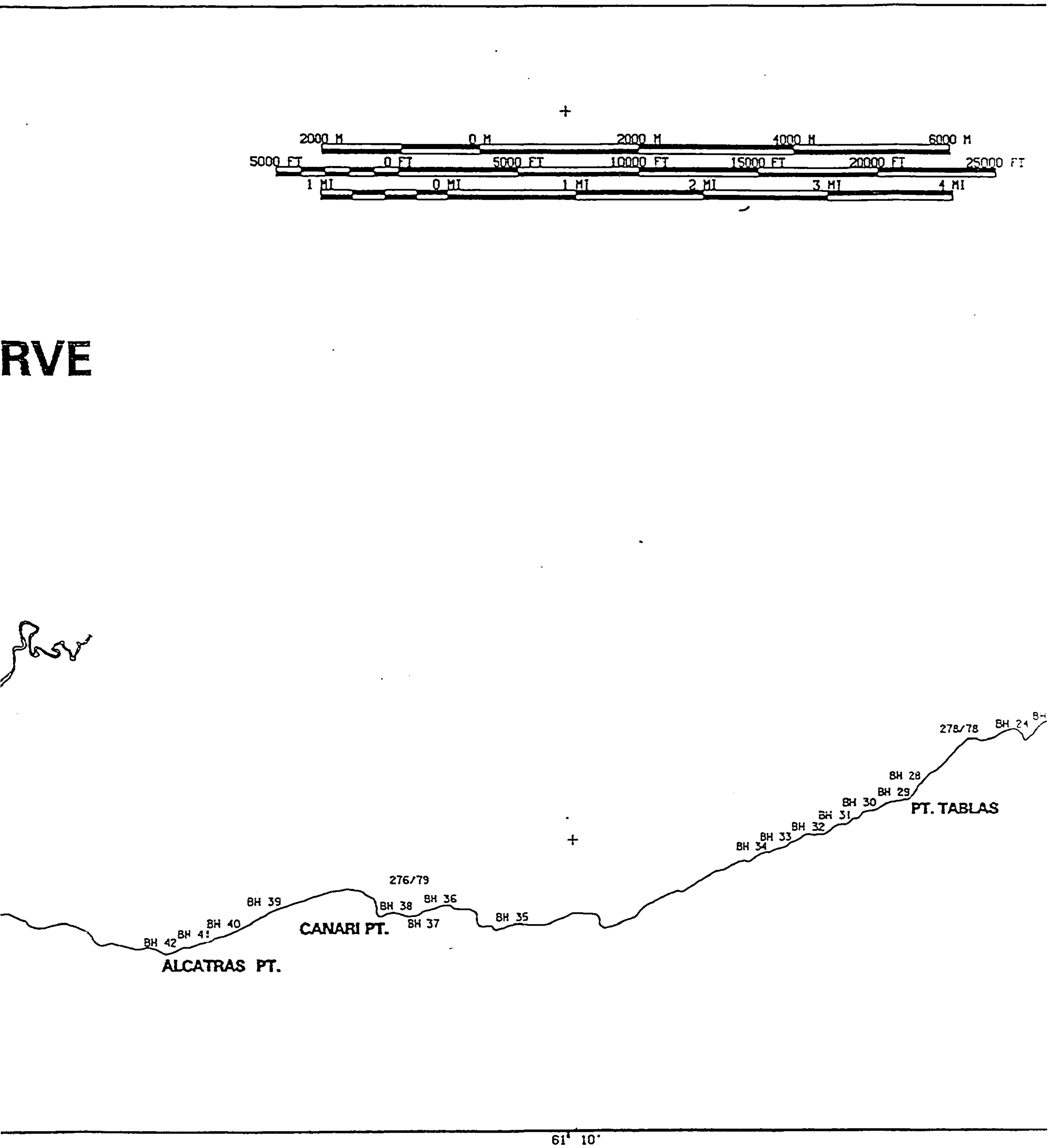
APPENDIX 5

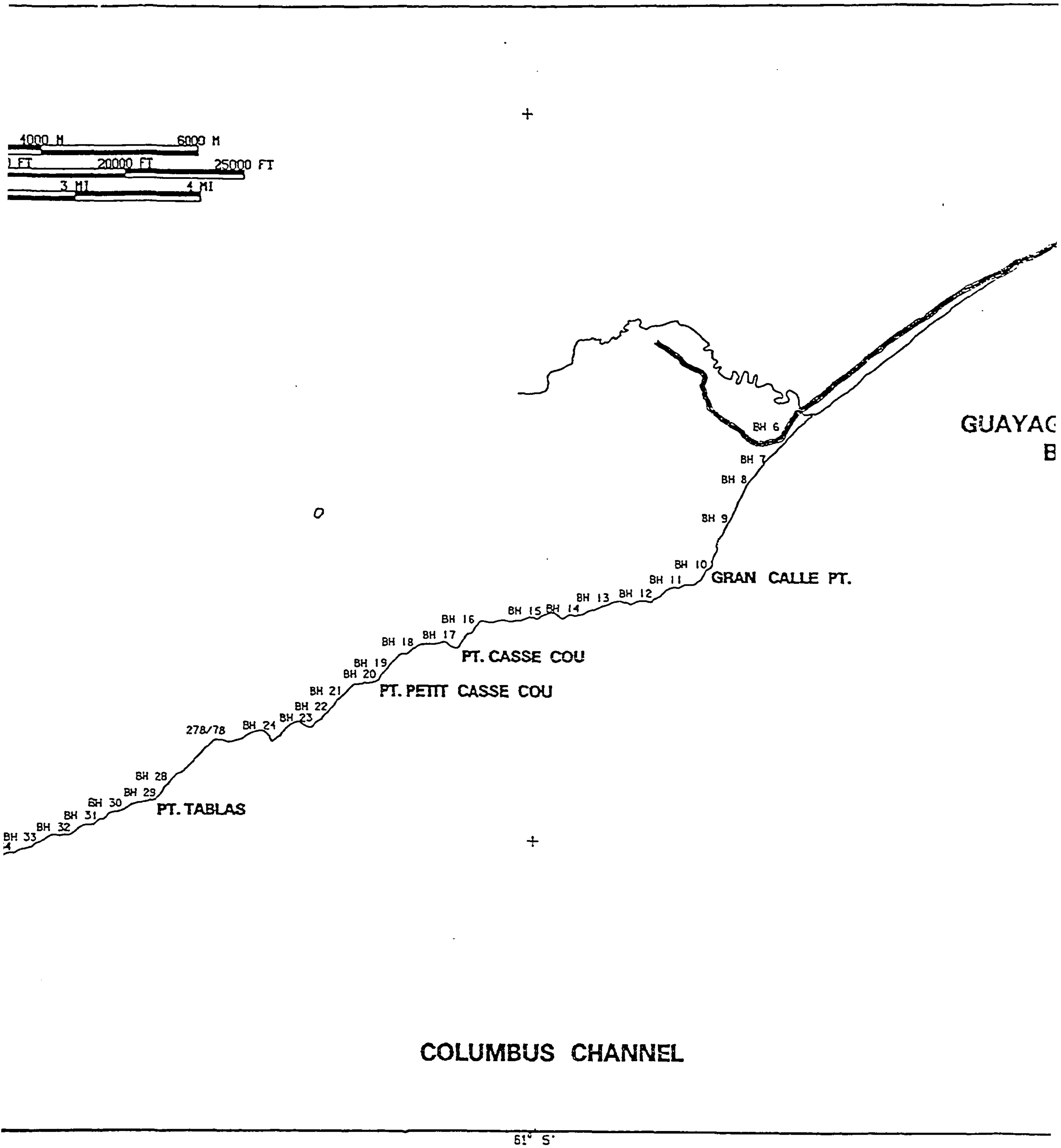
Sample Location Map

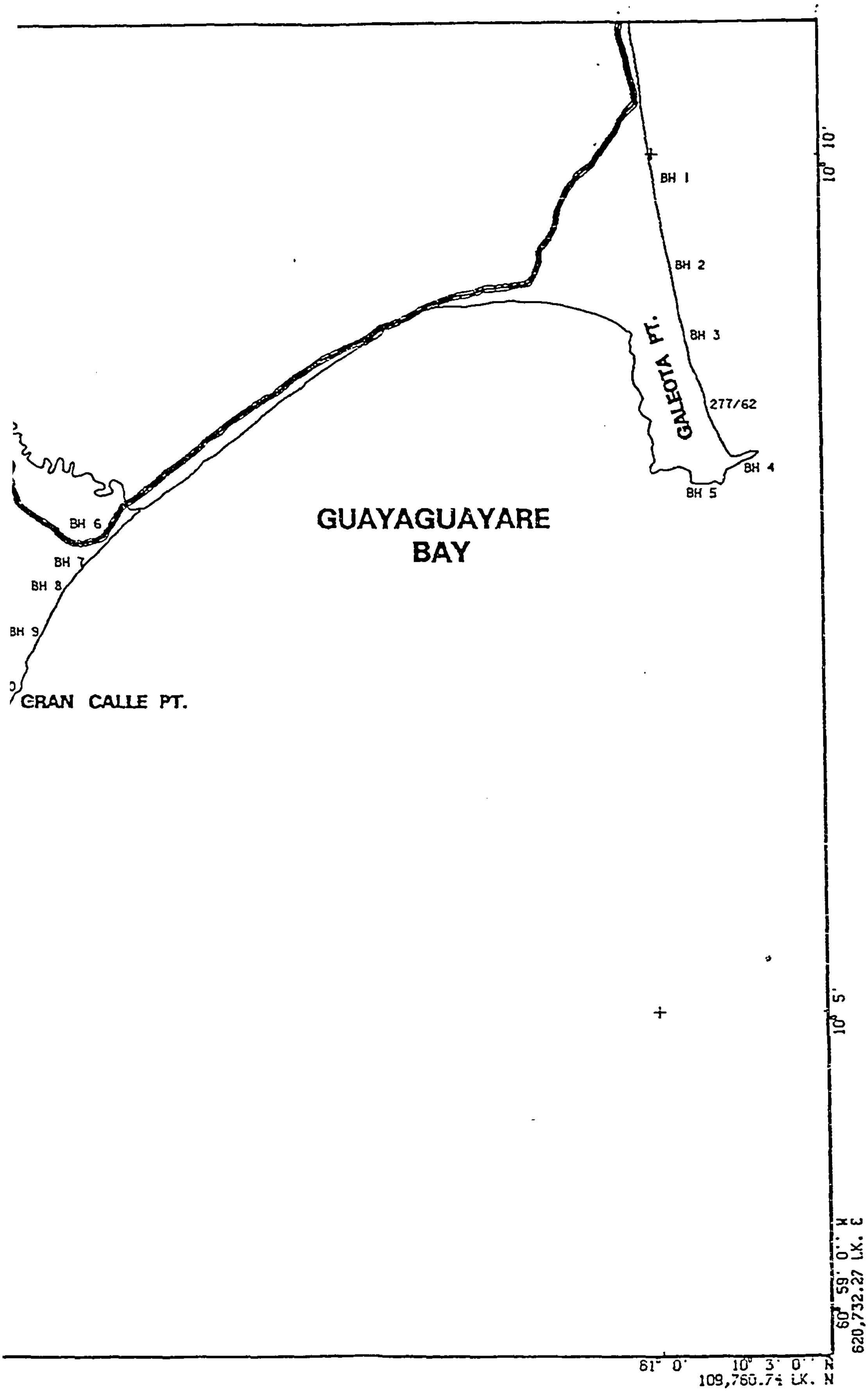

10° 10'
VICTOR
10° 5'
286/82
PC 3 PC 6
PC 5
PC 7
PT. OTHO
LL2
BH 58
PC2
PC 4
PT. CURAO
384,587.55 LK. E
61° 25' 0'' W
10° 3' 0'' N
109,564.84 LK. N
61° 20'

VICTORIA MAYARO FOREST RESERVE




2000 M 0 M 2000 M 4000 M 6000 M
5000 FT 0 FT 5000 FT 10000 FT 15000 FT 20000 FT 25000 FT
1 MI 0 MI 1 MI 2 MI 3 MI 4 MI
RVE
278/78
BH 24
BH 28
BH 29
BH 30
BH 31
BH 32
BH 33
BH 34
PT. TABLAS
276/79
BH 39
BH 38
BH 36
BH 37
BH 35
BH 40
BH 41
BH 42
CANARI PT.
ALCATRAS PT.
61° 10'


4000 M
6000 M
20000 FT
25000 FT
3 MI
4 MI
GUAYAC
BH 6
BH 7
BH 8
BH 9
BH 10
BH 11
GRAN CALLE PT.
BH 12
BH 13
BH 14
BH 15
BH 16
BH 17
BH 18
PT. CASSE COU
BH 19
BH 20
PT. PETIT CASSE COU
BH 21
BH 22
BH 23
BH 24
278/78
BH 28
BH 29
BH 30
BH 31
BH 32
BH 33
PT. TABLAS
COLUMBUS CHANNEL


GUAYAGUAYARE
BAY
GALEOTA PT.
GRAN CALLE PT.
BH 1
BH 2
BH 3
277/62
BH 4
BH 5
BH 6
BH 7
BH 8
BH 9
10° 10'
10° 5'
60° 59' 0" W
620,732.27 LK. E
61° 0'
10° 3' 0" N
109,760.74 LK. N