STRATIGRAPHY AND SEDIMENTOLOGY OF THE LATE MIOCENE TO QUATERNARY DEPOSITS OF TIMOR

CHRISTOPHER STUART KENYON

THESIS SUBMITTED FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY OF THE
UNIVERSITY OF LONDON

MAY, 1974

BIBL.
LONDIN.
UNIV.

ABSTRACT

The entire succession lying above the Bobonaro Scaly Clay olistostrome in Indonesian Timor is included in a new group, named the Viqueque Group. This group is subdivided into the Batu Putih Limestone, Sabaoe Limestone, Noele Marl, Noil Lakoe Marl, Soe Limestone and Noilbesi Conglomerate Formations. Twenty six members are recognised within these formations. The detailed stratigraphy and sedimentary history of these units are described. The Viqueque Group is shown to range in age from the Late Middle Miocene (N15) to Quaternary (N23).

The overall Soro Uplift of Timor is shown to have consisted of phases of uplift lasting from Late Middle Miocene (N15) to Late Pliocene (N21); from uppermost Late Pliocene (N21) to Early Pleistocene (N22); and from the Late Pleistocene (N23) to the present. Evidence is also presented for a stable phase in Late Pliocene (Early N21) times and phases of subsidence during the Late Pliocene (N21) and during the Pleistocene (at approximately the N22/N23 boundary).

The Mataian Orogeny is shown to be Pleistocene (N22) in age rather than Late Pliocene as previously supposed. A further phase of folding named the Bidjeli Phase, is shown to have taken place during the Late Pliocene (N21) in Timor and to have been preceded by a less important phase of folding in Middle to Late Pliocene (Early N21) times.

The Central Basin of Timor is shown to comprise three structural sub-basins, the Kupang Bay, Bokong and Noele Sub-basins, each of which

is bounded by a number of major fractures. These sub-basins were formed in the Late Pliocene (N21), at a time probably coincident with subsidence along the Timor Trough. The implications of Viqueque Group history for the Late Miocene to Pleistocene development of the Wetar Strait-Sahul Shelf region are discussed.

Finally, similarities are shown to exist between modern sedimentation in Kupang Bay, Timor, and the sedimentation of certain units of the Viqueque Group.

CONTENTS PAGE

Introduction. (xiii)

Acknowledgments. (xiv)

Chapter 1. General Stratigraphy of the Viqueque Group 1

A. Lithostratigraphy. 1

B. Chrono-and Biostratigraphy. 6

Chapter 2. Distribution of the Viqueque Group: 8

A. Indonesian Timor. 8

B. Portuguese Timor. 9

Chapter 3. The Batu Putih Limestone Formation: 11

A. Introduction. 11

B. Distribution. 11

C. Stratigraphy: 13

(i) The type section. 13

(ii) The Tanah Runtu Member. 15

(iii) The calcilutite unit. 20

(iv) The Fatu Laob Member. 24

D. Microfauna. 26

E. Age. 27

F. Nature of the Batu Putih Limestone/ Bobonaro Scaly Clay interface. 28

Chapter 4. The Sabaoe Limestone Formation: 29

A. Introduction and Summary. 29

B. Previous work. 30

C. Distribution. 30

D. Stratigraphy: 30

(i) The Sabaoe Limestone Formation of the Noele Sub-basin. 30

(ii) The Sabaoe Limestone Formation of the Bokong Sub-basin. 42

(iii) The Sabaoe Limestone Formation of the Panite High. 48

(iv) The Sabaoe Limestone Formation of the Kolbano Region. 48

(v) The Sabaoe Limestone Formation of Portuguese Timor. 50

E. Microfauna. 51

F. Age. 52

G. Palaeogeographic development of the Central Basin during Sabaoe Limestone deposition. 52

Chapter 5. Noele Marl Formation: 57

A. Summary. 57

B. Stratigraphy of the Noele Marl Formation of the Noele Sub-basin: 58

(i) The Noele Marl Formation type section: Noele Sub-basin southern margin. 58

(a) The Ofua Sandstone Member. 63

(b) The Oemenu Sandstone Member. 71

(c) The Nuanain Sandstone Member. 79

(d) The Nanfua Sandstone Member. 93

(ii) The Noele Marl Formation of the Noele Sub-basin northern margin: the Kali Sabaoe section. 96

(a) The Nekana Sandstone Member. 99

(b) Palaeogeography of the northern basin margin during Noele Marl deposition. 110

(iii) Palaeogeography of the Noele Sub-basin during Noele Marl deposition 112

D. Stratigraphy of the Noele Marl Formation of the Bokong Sub-basin. 118

(i) The Noele Marl Formation of the southern basin margin: 118

(a) The Nuanain Sandstone Member. 118

(b) The Tanah Putih Marl Member. 123

(ii) The Noele Marl Formation of the centre of the Bokong Sub-basin. 132

(iii) The Noele Marl Formation of the northern basin margin: The Obernaik Member. 135

(iv) Summary: Palaeogeographic development of the Bokong Sub-basin during Noele Marl deposition. 139

E. The Noele Marl Formation of the Portuguese Timor south coast basins: 143

(i) General 143

(ii) The Samé Member 143

F. Factors influencing sedimentation of the Noele Marl Formation. 149

Chapter 6. The Noil Lakoe Marl Formation: 154

A. Introduction. 154

B. Distribution. 154

C. Stratigraphy:

(i) The Noil Lakoe Marl Formation of the central part of the Noele Sub-basin: the type section. 154

(ii) The Noil Lakoe Marl Formation of the Bokong Sub-basin: the Fatu Kona Member. 154

(iii) Palaeogeography of Indonesian Timor during Noil Lakoe Marl deposition. 165

(iv) The Noil Lakoe Marl Formation of the Colitie syncline (Portuguese Timor). 167

D. Microfauna. 168

E. Age of the Noil Lakoe Marl Formation 169

Chapter 7. The Soe Limestone Formation: 170

A. Summary. 170

B. Introduction and distribution. 170

C. Stratigraphy: 175

(i) The Soe Limestone Formation of the Noele Sub-basin. 175

(a) The succession of the south flank of the Noetufi syncline:

The Oesena Member. 175

(b) The succession of the central part of the Noetufi syncline. 181

The Noetufi Marl Member. 181

The Noelenat Marl Member. 185

The Toi. O Lignite Member. 188

The Noe Ko. U Member. 192

(c) The type section of the Soe Limestone Formation. 195

(d) History of deposition of the Soe Limestone Formation in the Noetufi Syncline. 198

(e) Other Soe Limestone deposits of the Noele Sub-basin: 202

The Kapan Limestone Member 202

The Noebunu Marl Member 202

(ii) The Soe Limestone succession of the Bokong Sub-basin and Panite high 205

(a) The Tjamplong Limestone Member. 205

(b) The Oemolo Member. 209

D. Microfauna. 209

E. The age of the Soe Limestone Formation 211

F. Origin of the Soe Limestone Formation reef terraces. 214

Chapter 8. The Noilbesi Conglomerate Formation. 217

A. Introduction. 217

B. Stratigraphy: 217

(i) The Noilbesi Conglomerate Formation of the Bokong Sub-basin. 217

(a) The succession of the Noilbesi River: the type section 219

(b) Conglomerate-silt facies. 221

(c) Alluvial fan facies. 222

(d) The Tacari Limestone Member. 222

(ii) The Noilbesi Conglomerate Formation of the Noele Sub-basin. 224

(a) The Pene Member. 224

(b) The Oeajo Clay Member. 226

C. Age of the Noilbesi Conglomerate Formation. 229

D. History of uplift of the Noilbesi Conglomerate Formation. 229

Chapter 9. Summary of the tectonic history of the Viqueque Group of Indonesian Timor. 231

Chapter 10. The structure of the Viqueque Basins of Timor. 234

A. Summary 234

B. The Kupang Sub-basin. 234

C. The Bokong Sub-basin. 239

D. The Noele Sub-basin. 241

E. Portuguese Timor. 243

F. Age of major faulting 244

(i) The Bokong-Batu Putih fault zone. 244

(ii) The Napsanuna fault zone. 244

(iii) The Mollo, Wini, Halilulik, Noil Leke - Tandjung Naifallo and Noil Moeki - Netenaro faults. 245

Chapter 11. Middle Miocene to Recent structural development of the Timor-Sahul Shelf region. 249

Chapter 12. The Nature of the Timor Trough and classification of the Viqueque Basins of Timor. 252

Chapter 13.	Recent and Modern sedimentation in Kupang Bay, Timor.	260
	A. Introduction.	260
	B. Summary and conclusions.	260
	C. Geographic setting.	263
	D. Climate.	264
	E. Sediment distribution in Kupang Bay	265
	(i) The carbonate regime.	266
	(ii) The terrigenous regime.	268
	(iii) Summary of factors affecting Recent and Modern sedimentation in Kupang Bay.	272
	F. A comparison of modern and ancient environments.	277
References		pp 279-290
Legend for stratigraphic sections		291

Full-page illustrations and plates:

20 Plates

78 Figures

4 Tables

Enclosures (3):

Enclosure 1. Geology of the Viqueque Group of Indonesian Timor (1:100,000 scale geological map)

Enclosure 2. Total Viqueque Group isopachyte map (1:200,000 scale)

Enclosure 3. Location map of type sections and geographic place-names

Total number of bound pages: 407

(xiv pp, 291 pp, 20 Plates, 78 Figures, 4 Tables).

INTRODUCTION

This thesis is the result of geological field and laboratory work carried out between June 1966 and June 1969 on the Late Miocene to Quaternary deposits of Indonesian Timor.

The main object of the research was to establish the stratigraphic succession and nature of the equivalent in Indonesian Timor of Audley-Charles' Viqueque Formation of Portuguese Timor, and to determine the nature and extent of the Late Tertiary basins within which the formation was known to have been deposited. To this end a total of eleven months was spent in the field, in Indonesian Timor, during which time many detailed and general stratigraphic sections were measured, and a large number of samples collected. Microforaminiferal analysis was conducted by Mr. D. J. Carter of Imperial College, London, on samples from the most important type sections.

The initial stratigraphic work was preceded by field geological mapping on a 1:50,000 scale, of selected parts of the Late Tertiary basins. This, the first detailed mapping of this portion of Indonesian Timor, was necessary in order to plan and meaningfully interpret the subsequent stratigraphy, and was supplemented by reconnaissance mapping and photogeological work.

Finally, a semi-detailed sedimentological study of the modern day embayment of Kupang Bay was conducted in order to determine the similarities, if any, which might exist between this embayment and certain stages in the Tertiary evolution of the structurally related onshore Tertiary sub-basins.

ACKNOWLEDGMENTS

The writer is indebted to Dr. M. G. Audley-Charles, who initiated this research, and who gave unstintingly of his time both in the laboratory and field, and without whose enthusiasm and keen interest this thesis would never have reached its final form.

The manuscript has been read and improved by the constructive criticism of Dr. M. G. Audley-Charles and by Mr. J. F. Keith, Jr. Their help is gratefully acknowledged.

The writer would also like to thank Mr. D. J. Carter for microfaunal analysis of the samples collected in Timor and Drs. G. Evans and P. Wallace of Imperial College for their helpful discussions during the earlier stages of this research.

The writer is also indebted to the late Loren M. Hart and to Mr. Jack D. Montgomery of Cities Service International for their help and encouragement during the compilation of this thesis, to Mrs. M. L. McNair for assistance in typing, and to Mr. George Jordan and his staff for help in the production.

The receipt of a bursary from International Oils Exploration N.L. of Melbourne, Australia to support the research and field work from 1966 to 1969 is gratefully acknowledged.

Chapter 1. General stratigraphy of the Viqueque Group

(A) Lithostratigraphy

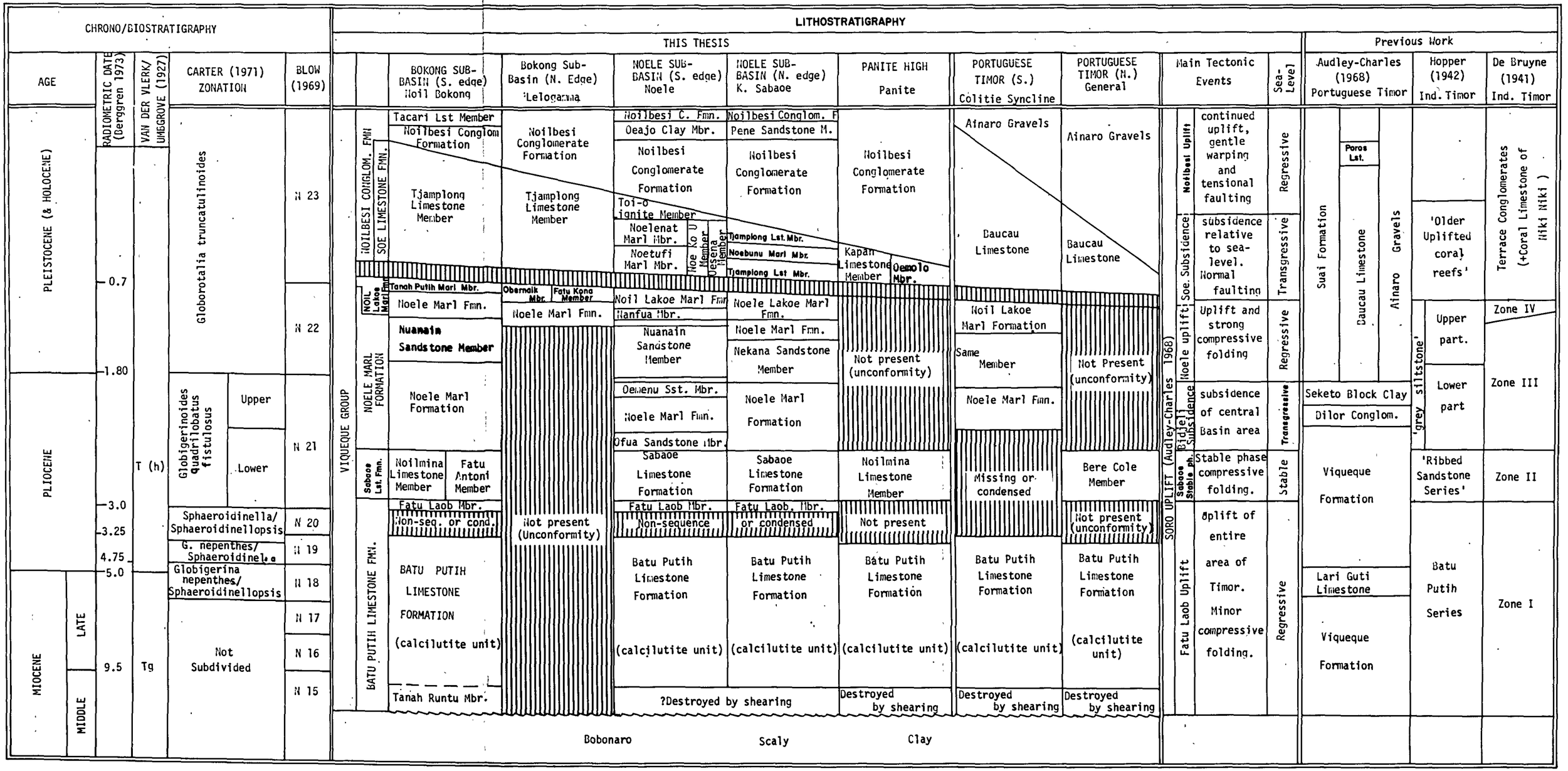
The earliest detailed stratigraphic subdivision of the Plio-Pleistocene rocks of Indonesian Timor can be attributed to De Bruyne (1941), who distinguished five major lithostratigraphic units comprising, from the base upwards, 'Globigerina limestones and marls' (Zone I), 'Limestones and calcareous conglomeratic sandstone' (Zone II), 'Soft clays, marls and sandstones' (Zone III), 'Marls, sands, foraminiferal limestones and oyster beds' (Zone IV), and finally an uppermost unit of 'Terrace conglomerates' and 'Coral limestones'.

These five units were correlated by Van Bemmelen (1949) directly with the later ones of Hopper (1942), who recognised a 'Batuputih' unit, a 'ribbed sandstone' unit, upper and lower 'grey siltstone' units and an 'uplifted coral reef' unit. It would appear from Hopper's description however, that at least part of his upper grey siltstone unit is equivalent to part of De Bruyne's Zone III (Table 1).

Although both of these workers recognised the gross lithostratigraphic divisions of the Plio-Pleistocene succession of Indonesian Timor, both were restricted in their areas of study and neither attempted formal definition or subdivision of the lithostratigraphic units, one of the major obstacles presumably being the widespread lateral and vertical facies changes which characterise the succession.

Although prior mention of the Neogene succession of Portuguese Timor had been made by Weber (1911, in Wanner, 1956), the first recognition of these rocks as a stratigraphic unit was made by Grunau (1953) who named them the 'Plio-Pleistocene Series', but

Table 1. Stratigraphic subdivision of the Viqueque Group


CHRONO/BIOSTRATIGRAPHY
LITHOSTRATIGRAPHY
THIS THESIS
Previous Work
AGE
RADIOMETRIC DATE (Berggren 1973)
VAN DER VLERK/ UMBGROVE (1927)
CARTER (1971) ZONATION
BLOW (1969)
BOKONG SUB-BASIN (S. edge) Noil Bokong
Bokong Sub-Basin (N. Edge) Lelogama
NOELE SUB-BASIN (S. edge) Noele
NOELE SUB-BASIN (N. edge) K. Sabaoe
PANITE HIGH Panite
PORTUGUESE TIMOR (S.) Colitie Syncline
PORTUGUESE TIMOR (N.) General
Main Tectonic Events
Sea-Level
Audley-Charles (1968) Portuguese Timor
Hopper (1942) Ind. Timor
De Bruyne (1941) Ind. Timor
PLEISTOCENE (& HOLOCENE)
PLIOCENE
MIOCENE
LATE
MIDDLE
0.7
1.80
3.0
3.25
4.75
5.0
9.5
T (h)
Tg
Globorotalia truncatulinoides
Globigerinoides quadrilobatus fistulosus
Upper
Lower
Sphaeroidinella/ Sphaeroidinellopsis
G. nepenthes/ Sphaeroidinella
Globigerina nepenthes/ Sphaeroidinellopsis
Not Subdivided
N 23
N 22
N 21
N 20
N 19
N 18
N 17
N 16
N 15
VIQUEQUE GROUP
NOILBESI CONGLOM. FMN.
SOE LIMESTONE FMN.
NOELE MARL FORMATION
Sabaoe Lst. Fmn.
BATU PUTIH LIMESTONE FMN.
Tacari Lst Member
Noilbesi Conglom Formation
Tjamplong Limestone Member
Tanah Putih Marl Mbr.
NOIL Lakoe Marl Fmn.
Noele Marl Fmn.
Nuanain Sandstone Member
Noele Marl Formation
Noilmina Limestone Member
Fatu Antoni Member
Fatu Laob Mbr.
Non-seq. or cond.
BATU PUTIH LIMESTONE FORMATION
(calcilutite unit)
Tanah Runtu Mbr.
Noilbesi Conglomerate Formation
Tjamplong Limestone Member
Obernaik Mbr.
Fatu Kona Member
Noele Marl Fmn.
Not present (Unconformity)
Noilbesi C. Fmn.
Oeajo Clay Mbr.
Noilbesi Conglomerate Formation
Toi-o ignite Member
Noelenat Marl Mbr.
Noe Ko U Member
Oesena Member
Noetufi Marl Mbr.
Tjamplong Lst. Mbr.
Noebunu Marl Mbr.
Tjamplong Lst. Mbr.
Noil Lakoe Marl Fmn.
Nanfua Mbr.
Nuanain Sandstone Member
Oemenu Sst. Mbr.
Noele Marl Fmn.
Ofua Sandstone Mbr.
Sabaoe Limestone Formation
Fatu Laob Mbr.
Non-sequence
Batu Putih Limestone Formation
(calcilutite unit)
?Destroyed by shearing
Noilbesi Conglom. F
Pene Sandstone M.
Noilbesi Conglomerate Formation
Noele Lakoe Marl Fmn.
Noele Marl Fmn.
Nekana Sandstone Member
Noele Marl Formation
Sabaoe Limestone Formation
Fatu Laob. Mbr. or condensed
Batu Putih Limestone Formation
(calcilutite unit)
Destroyed by shearing
Noilbesi Conglomerate Formation
Kapan Limestone Member
Oemolo Mbr.
Noil Lakoe Marl Fmn.
Noilmina Limestone Member
Not present
Batu Putih Limestone Formation
(calcilutite unit)
Destroyed by shearing
Ainaro Gravels
Baucau Limestone
Noil Lakoe Marl Formation
Same Member
Noele Marl Fmn.
Missing or condensed
Batu Putih Limestone Formation
(calcilutite unit)
Destroyed by shearing
Ainaro Gravels
Baucau Limestone
Not Present (unconformity)
Bere Cole Member
Not present (unconformity)
Batu Putih Limestone Formation
(calcilutite unit)
Destroyed by shearing
SORO UPLIFT (Audley-Charles 1968)
Noilbesi Uplift
Soe. Subsidence
Noele uplift
Bidjeli Subsidence
Sabaoe Stable ph.
Fatu Laob Uplift
continued uplift, gentle warping and tensional faulting
subsidence relative to sea-level. Normal faulting
Uplift and strong compressive folding
subsidence of central Basin area
Stable phase compressive folding.
Uplift of entire area of Timor. Minor compressive folding.
Regressive
Transgressive
Regressive
Transgressive
Stable
Regressive
Suai Formation
Poros Lst.
Baucau Limestone
Ainaro Gravels
Seketo Block Clay
Dilor Conglom.
Viqueque Formation
Lari Guti Limestone
Viqueque Formation
'Older Uplifted coral reefs'
'grey siltstone'
Upper part.
Lower part
'Ribbed Sandstone Series'
Batu Putih Series
Terrace Conglomerates (+Coral Limestone of Niki Niki)
Zone IV
Zone III
Zone II
Zone I
Bobonaro
Scaly
Clay

later amended this to 'Viqueque Series' after the town of Viqueque on the southern coast of Portuguese Timor, where the rocks are well exposed.

Formal definition of the Viqueque Series of Grunau and its recognition as a lithostratigraphic unit in Portuguese Timor was first achieved by Audley-Charles (1965), who amended the name to Viqueque Formation and distinguished as members of this formation the Lari Guti Limestone, the Dilor Conglomerate and the Seketo Block Clay. These members were each later given formation status by Audley-Charles (1968).

Because of the much greater extent, complexity and thickness of the Plio-Pleistocene succession of Indonesian Timor, the whole of the post-Bobonaro Scaly Clay succession, ranging in age from Late Middle Miocene to Recent is here included in a group, named the VIQUEQUE GROUP. This group is taken to include:

(a) the Indonesian Timor equivalent of Audley-Charles' Viqueque Formation of Portuguese Timor (comprising, in Indonesian Timor, the BATU PUTIH LIMESTONE FORMATION and the NOELE MARL FORMATION)

(b) a new formation, missing over most of Portuguese Timor, named the SABAOE LIMESTONE FORMATION

(c) the NOIL LAKOE MARL FORMATION, possibly equivalent in part to the Dilor Conglomerate of Audley-Charles (1968)

(d) the lithostratigraphic equivalents in Indonesian Timor of Audley-Charles' Baucau Limestone and Ainaro Gravels of Portuguese Timor, defined in this thesis as the SOE LIMESTONE FORMATION AND THE NOILBESI CONGLOMERATE FORMATION.

The Viqueque Group so established is fundamentally different lithologically from the entire pre-Middle Miocene succession, thus satisfying one of the prime stratigraphic characteristics of a group according to the British code of stratigraphic nomenclature (Harland et al. 1972).

These formations and their relationship to the stratigraphy of Hopper, De Bruyne, and Audley-Charles are tabulated in Table 1.

The complexity of the vertical and lateral changes in lithology within the Viqueque Group of Indonesian Timor has necessitated the recognition within these formations of twenty six members, each of which is defined in this thesis in accordance with the rules of the British code of stratigraphic nomenclature (Harland et al. 1972). The increasing tectonic instability under which the Viqueque Group accumulated and its overall regressive nature is reflected by the fact that twelve of these members occur within the uppermost two formations, the Soe Limestone and Noilbesi Conglomerate Formations respectively, which together represent a time span of only 0.7 million years, compared with approximately 10 m.y. for the remaining four formations of the Viqueque Group. Most of the following detailed stratigraphic account is therefore concerned with the development of the Batu Putih Limestone Formation, the Sabaoe Limestone Formation, the Noele Marl Formation, and the Noil Lakoe Marl Formation, during which time most of the Late Neogene and Quaternary development of Timor took place.

This detailed stratigraphic subdivision has revealed that the Late Tertiary history of Timor took place not by means of a single uplift (the 'Soro Uplift', Audley-Charles, 1968) but by way

of a series of movements which may be regarded as phases of the Soro Uplift.

These movements are:

(a) a Late Middle Miocene (N15) to Late Pliocene (N21) phase of uplift, here named the FATU LAOB UPLIFT

(b) a phase of tectonic stability in Late Pliocene times (Early N21), here named the SABAOE STABLE PHASE

(c) a Late Pliocene (Late N21) phase of subsidence, here named the BIDJELI SUBSIDENCE

(d) a Late Pliocene (Late N21) to Early Pleistocene (N22) phase of uplift, here named the NOELE UPLIFT.

(e) an Early Pleistocene (N22) to Middle Pleistocene (N23) phase of relative subsidence, here called the SOE SUBSIDENCE

(f) a Middle Pleistocene (N23) to Recent uplift, here called the NOILBESI UPLIFT.

Furthermore, in addition to the Mataian phase of folding of Audley-Charles (1968), evidence is presented in this thesis for phases of movement (a) at the end of Batu Putih Limestone deposition (N20 to Early N21) and (b) at the end of Sabaoe Limestone deposition (Early N21) in addition to minor local movements in the Late Miocene to Early Pliocene (N18-N19) and in the Late Pliocene (Late N21).

Reference should be made to Table 1, in which these events are tabulated.

(B) Chrono- and Biostratigraphy

According to Felix (1915) the coral limestones of Niki Niki (equivalent to the Soe Limestone Formation of this thesis) contain a ratio of 65.5/34.5 of living to extinct coral species, and are therefore of Upper Pliocene age.

De Bruyne (1941) however, regarded the entire sequence (comprising his five stratigraphic units) as Plio-Pleistocene on the basis of its molluscan fauna. Later, Brouwer (1942) assigned an Upper Miocene to Lower Pliocene age to the 'Batu Putih Series' (equivalent to the Batu Putih Limestone of this thesis) on the basis of its similarity to the Globigerina marls of this age in Java. The age of the Viqueque Series in Portuguese Timor was attributed by Grunau (1953) to the Plio-Pleistocene on the basis of molluscan evidence. This was later amended by Gageonnet and Lemoine (1958) to Upper Miocene (T f2) to Lower Pleistocene. Audley-Charles (1968) later used various lines of evidence to date his Viqueque Formation as Upper Miocene to Upper Pliocene, and included within the latter the Dilor Conglomerate and the Seketo Block Clay, attributing only the Baucau Limestone to the Pleistocene.

Analysis of samples from the writer's type sections of the Viqueque Group in Indonesian Timor by Carter (unpublished report dated 1970a) resulted in a detailed foraminiferal zonation of the Viqueque Group. This helped both to confirm the succession and assisted in the correlation of widely separated Viqueque sections throughout the island.

By means of these dated type sections it will be shown in this thesis that the lower part of the Viqueque Group, comprising

the Batu Putih Limestone, Sabaoe Limestone and Noele Marl Formations ranges in age from Late Middle Miocene (N15) to Early Pleistocene (N22) in both Indonesian and Portuguese Timor. Audley - Charles' original Viqueque Formation (equivalent to the Batu Putih Limestone, Sabaoe Limestone and Noele Marl of Indonesian Timor) is therefore somewhat younger than he stated. An indication that the lower part of the Viqueque Group ranges up into the Pleistocene is obtained from the placing of the Pliocene/Pleistocene boundary at the base of a thick series of turbidites in the Noele Marl type section (Carter, unpublished report dated 1970a). From this it can be concluded that the deposition, subsequent strong (Mataian) compressive folding, uplift and erosion of these turbidites, all took place within the Pleistocene, although the latest of these events can be shown to have taken place in Indonesian Timor not later than the N22/N23 boundary.

Dating of the lowermost member of the Batu Putih Limestone has similarly shown that the Viqueque Group extends downwards as far as the Late Middle Miocene (N15) and that the Miocene/Pliocene boundary (N18/N19) falls in the middle of the Batu Putih Limestone succession.

Accordingly, although the Viqueque Formation, Dilor Conglomerate, Ainaro Gravels and Suai Formation of Portuguese Timor are positioned in Table 1 as originally dated by Audley - Charles (1968), the Viqueque Formation actually extends upwards to the N22/N23 boundary of the Pleistocene.

Chapter 2. Distribution of the Viqueque Group

(A) Indonesian Timor

The SW-NE trending Late Tertiary basin of central Indonesian Timor which Van Bemmelen (1949) called the Central Basin is divided in this thesis into three structural sub-basins (Fig. 1), comprising, from west to east: (i) the Kupang Bay Sub-basin of probable Quaternary origin, containing sediments of Pleistocene (Soe Limestone Formation) and Recent age, together with isolated outliers of the Late Middle Miocene to Late Pliocene Batu Putih Limestone Formation; (ii) the Bokong Sub-basin, containing 1400 metres of Viqueque sediments; and (iii) the Noele Sub-basin, containing 1300 metres of Viqueque sediments. In both the Bokong and Noele Sub-basins all six constituent formations of the Viqueque Group are represented.

Separating the Kupang Bay and Bokong Sub-basins, and the Bokong and Noele Sub-basins are the Tjamplong-Naifallo and Soe-Kapan Highs respectively, consisting mostly of Bobonaro Scaly Clay with thin cappings of the Soe Limestone Formation.

To the south of the three sub-basins are the Oekabiti, Panite and Kolbano Highs, consisting mostly of Bobonaro Scaly Clay and older rocks with cappings of Soe Limestone Formation and occasional outcrops of the Batu Putih and Sabaoe Limestone Formations.

Lying to the north of the three sub-basins is the Northern Mountains High, from which most of the Viqueque Group has been removed. Sediments belonging to the Batu Putih Limestone, Sabaoe Limestone and Soe Limestone Formations have, however, been recorded in part of this region (Fig. 1).

(B) Portuguese Timor

Sediments belonging to Audley-Charles' Viqueque Formation occur mainly in a number of south coast basins in the region of Matai , Beco, Colitie, and Viqueque (Fig. 1). Some of these are known to extend offshore. Field reconnaissance and sampling of parts of the Colitie and Viqueque Basins by the writer has revealed that the Sabaoe Limestone Formation of Indonesian Timor is not represented, most of the succession belonging to the Noele Marl and Batu Putih Limestone Formations.

North of the south coast basins, Audley-Charles' Viqueque Formation outcrops consist only of Batu Putih Limestone, with a thin, unimportant development of Sabaoe Limestone Formation in an outcrop near Bere Cole on the north coast.

An important fact apparent from this distribution is that the deep water Noele Marl Formation, which comprises most of the succession in the Bokong, Noele, Matai , Beco, Colitie and Viqueque Sub-basins, is absent from the entire region to the north, the Soe Limestone or Baucau Limestone resting unconformably upon the Batu Putih and Sabaoe Limestone Formations.

Also apparent is the approximate alignment of the depoaxes of the Indonesian Timor and Portuguese Timor Viqueque Basins. The Viqueque Group/Formation outcrops occurring in central Indonesian/ Portuguese Timor north of Matai appear to belong either to the Batu Putih Limestone Formation or Soe Limestone and Noilbesi Conglomerate Formations, and do not lie in an easterly structural continuation of the Central Basin of Indonesian Timor, as was formerly thought (Audley-Charles, 1968).

Fig. 1: Viqueque Group distribution in Indonesian and Portuguese Timor

Major structural sub - basins include:

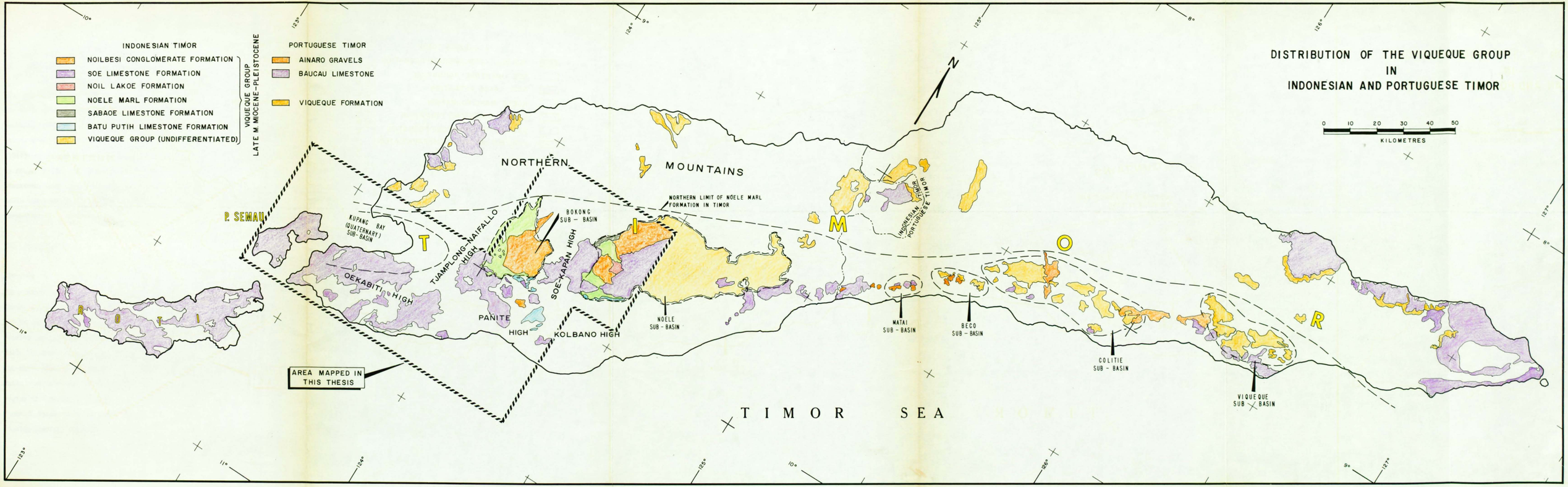
(a) The Kupang Bay Sub - basin, containing the Batu Putih Limestone and Soe Limestone Formations, in addition to Recent deposits;

(b) The Noele and Bokong Sub - basins, containing the Batu Putih Limestone, Sabaoe Limestone, Noele Marl, Noil Lakoe Marl, Soe Limestone and Noilbesi Conglomerate Formations;

(c) The Matai, Beco, Colitie and Viqueque Sub - basins of Portuguese Timor, containing (i) the equivalent of the Noele Marl and Batu Putih Limestone Formations, (ii) the Dilor Conglomerate Formation of Portuguese Timor and (iii) the approximate equivalent of the Soe Limestone and Noilbesi Conglomerate Formations of Indonesian Timor, comprising, in Portuguese Timor, the Baucau Limestone, Ainaro Gravels and Suai Formations.

Note the apparent alignment of the depoaxis joining the depocentres of the Indonesian Timor sub - basins with that joining those of the Portuguese Timor sub - basins.

Outcrop distribution in Portuguese Timor from Audley - Charles (1968). Data from Indonesian Timor outside mapped area from Audley - Charles (personal communication) and reconnaissance mapping.


DISTRIBUTION OF THE VIQUEQUE GROUP
IN
INDONESIAN AND PORTUGUESE TIMOR
INDONESIAN TIMOR
NOILBESI CONGLOMERATE FORMATION
SOE LIMESTONE FORMATION
NOIL LAKOE FORMATION
NOELE MARL FORMATION
SABAOE LIMESTONE FORMATION
BATU PUTIH LIMESTONE FORMATION
VIQUEQUE GROUP (UNDIFFERENTIATED)
VIQUEQUE GROUP
LATE M. MIOCENE-PLEISTOCENE
PORTUGUESE TIMOR
AINARO GRAVELS
BAUCAU LIMESTONE
VIQUEQUE FORMATION
0 10 20 30 40 50
KILOMETRES
N
NORTHERN MOUNTAINS
NORTHERN LIMIT OF NOELE MARL FORMATION IN TIMOR
INDONESIAN PORTUGUESE BORDER
P. SEMAU
KUPANG BAY (QUATERNARY) SUB-BASIN
OEKABITI HIGH
TJAMPLONG-NAIFALLO HIGH
BOKONG SUB-BASIN
SOE-KAPAN HIGH
PANITE HIGH
KOLBANO HIGH
NOELE SUB-BASIN
MATAI SUB-BASIN
BECO SUB-BASIN
COLITIE SUB-BASIN
VIQUEQUE SUB-BASIN
AREA MAPPED IN THIS THESIS
TIMOR SEA
ROTI
TIMOR

Chapter 3. The Batu Putih Limestone Formation

(A) Introduction

The Batu Putih Limestone is the lowermost formation of the Viqueque Group and comprises a series of distinctive white calcilutites and tuffs with subordinate marls, which unconformably overlies the Bobonaro Scaly Clay in Indonesian and Portuguese Timor. The white limestones which constitute most of the succession were noted by De Bruyne (1941) who placed them in Zone I of his Central Basin stratigraphy and by Hopper (1942) who named them the 'Batu Putih Series'. Similar limestones were also described by Audley-Charles (1968) from the south-coast basins of Portuguese Timor, and included in his Viqueque Formation.

(B) Distribution

Due to the extensive cover of younger deposits, the formation does not crop out over most of the Noele and Bokong Sub-basins. The most extensive outcrops are present (a) along the southern edge of the Bokong Sub-basin, mostly along the Noil Bokong and Noilmina Rivers; (b) in the region south of the Bokong Sub-basin, where scattered outcrops overlie the Bobonaro Scaly Clay; (c) along the southern edge of the Noele Sub-basin and (d) along the north-western edge of the Noele Sub-basin (Fig. 2). Lithologies corresponding to those of the Batu Putih Limestone have also been described from the northern mountain region (J.S.Noakes, personal communication) from eastern Indonesian Timor (L.Giani, personal communication) and from Roti and Sabu (Audley-Charles, unpublished report dated 1970). Samples from the last

Fig. 2: Distribution of the Batu Putih Limestone Formation

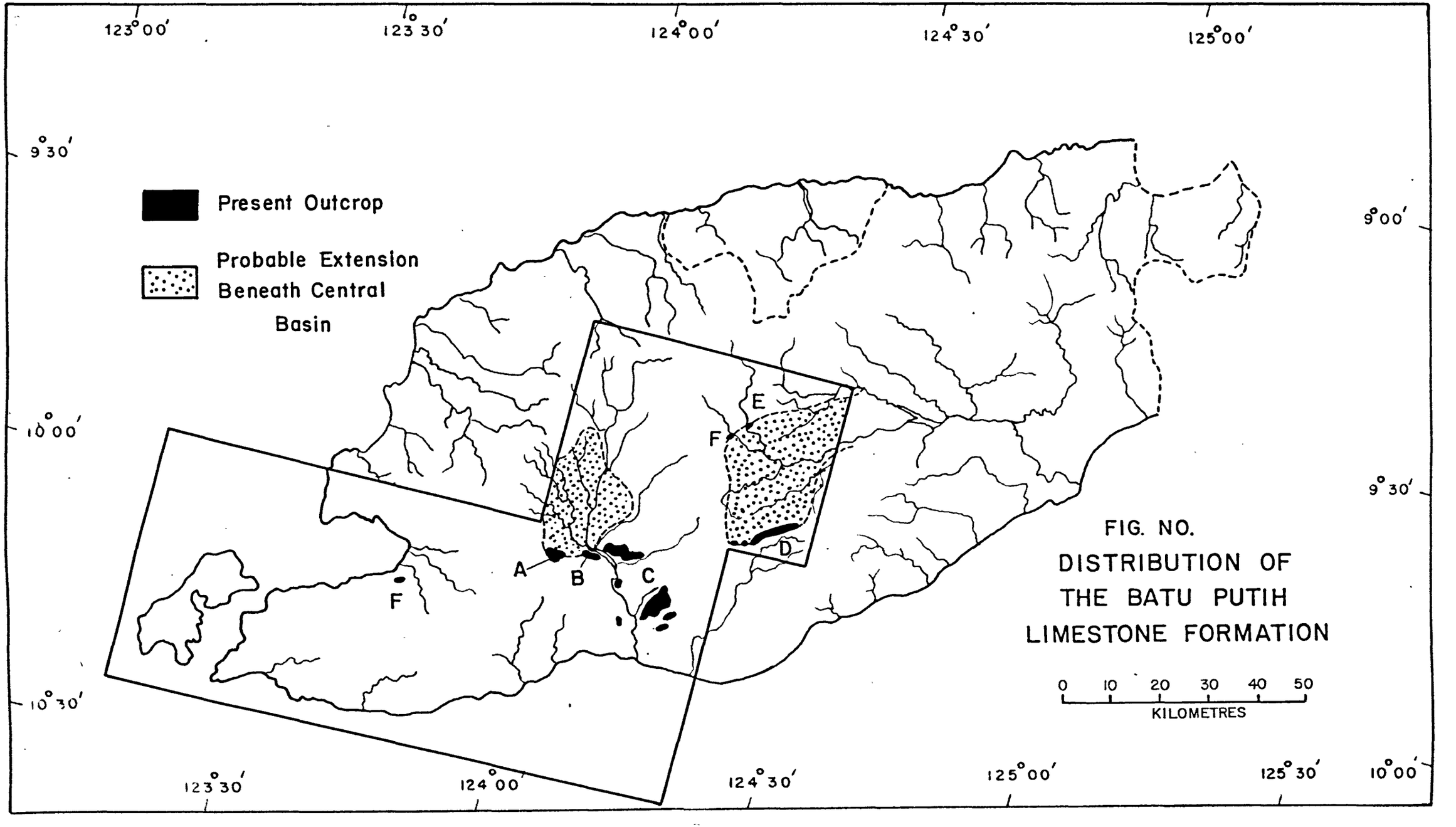
A,B: Outcrops of the Bokong - Batu Putih fault zone. 'B' includes the type sections of the Batu Putih Limestone Formation and of the Tanah Runtu Member.

C: Outcrops of the Panite High

D: Outcrops of the Noele Sub - basin southern margin

E, F: Outcrops of the Noele Sub - basin northern margin. Outcrop 'F' includes the type section of the Fatu Laob Member in the Kali Sabaoe.

Evidence for the extension of the formation beneath the Bokong and Noele Sub - basins comes in part from the presence of Batu Putih Limestone clasts in diapiric extrusions of Bobonaro Scaly Clay occurring within the sub - basins.


123°00′
123°30′
124°00′
124°30′
125°00′
9°30′
9°00′
10°00′
10°30′
Present Outcrop
Probable Extension Beneath Central Basin
A
B
C
D
E
F
F
FIG. NO.
DISTRIBUTION OF THE BATU PUTIH LIMESTONE FORMATION
0 10 20 30 40 50
KILOMETRES

three localities were confirmed as being of Batu Putih Limestone age by Carter (unpublished report dated 1970a). A small outlier of the formation is also present on the south side of Kupang Bay (Fig. 2).

(C) Stratigraphy

(i) The type section

The type section of the formation in this thesis (Fig. 3) was measured on the south side of the River Noilmina, at the village of Batu Putih ('white rocks') on the south side of the Bokong Sub-basin, where the formation crops out as a series of white cliffs.

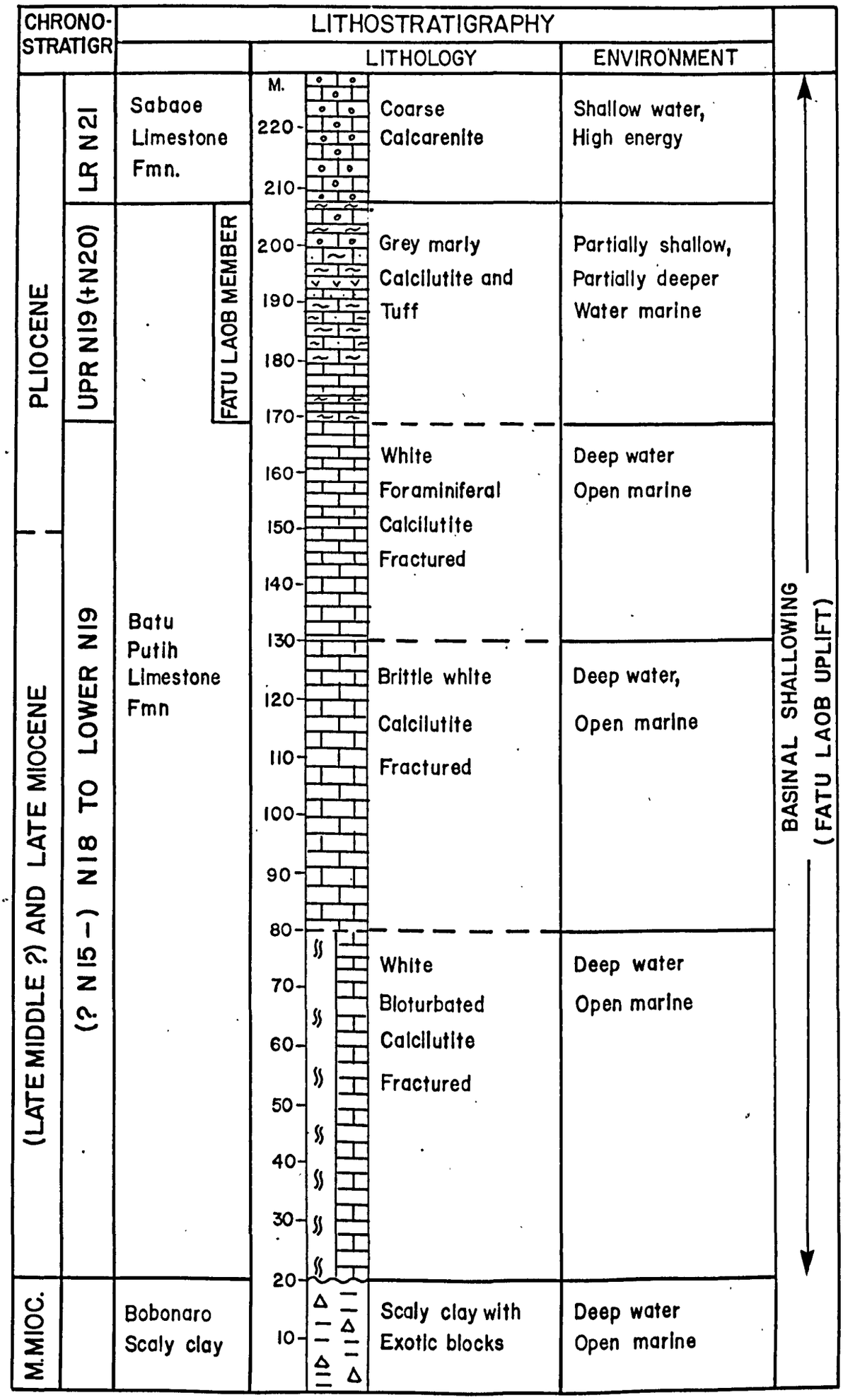
In the outcrop, as in most others in Timor, two major units can be recognised, consisting of (a) a lowermost series of calcilutites and white vitric tuffs (the 'calcilutite unit') and (b) an uppermost series of grey foraminiferal marls with rare tuff interbeds and occasional, fine grained, graded arenites (the Fatu Laob Member). In the type section these units attain an aggregate thickness of 187 metres.

Underlying the calcilutites of the lowermost part of the type section in outcrops between Tacari and Bokong, west of Batu Putih, is a thin succession of olive-green, shiny clays, white limestones, tuffs and thin, graded arenites here named the Tanah Runtu Member. Foraminiferal analysis of this succession by D. J. Carter (personal communication) showed it to belong to zone N15 of (Blow, 1969) or to the Late Middle Miocene, suggesting a considerably older age than Batu Putih Limestone samples from the type

Fig. 3: Batu Putih Limestone Formation

Type section, measured 200 metres southeast of the village of Batu Putih, Bokong Sub - basin. Note the presence of the two principal units of the formation, the Fatu Laob Member and the calcilutite unit. The third unit of the Batu Putih Limestone, the Tanah Runtu Member, is not present in the type section, but precedes the latter in age. The contact of the calcilutite unit of the type section with the Bobonaro Scaly Clay is therefore probably a tectonic one, as in most other localities in Timor.

For location of section see Fig. 2


CHRONO-STRATIGR
LITHOSTRATIGRAPHY
LITHOLOGY
ENVIRONMENT
M.
PLIOCENE
(LATE MIDDLE ?) AND LATE MIOCENE
M.MIOC.
LR N21
UPR N19 (+N20)
(? N15 –) N18 TO LOWER N19
Sabaoe Limestone Fmn.
FATU LAOB MEMBER
Batu Putih Limestone Fmn
Bobonaro Scaly clay
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
Coarse Calcarenite
Shallow water, High energy
Grey marly Calcilutite and Tuff
Partially shallow, Partially deeper Water marine
White Foraminiferal Calcilutite Fractured
Deep water Open marine
Brittle white Calcilutite Fractured
Deep water, Open marine
White Bioturbated Calcilutite Fractured
Deep water Open marine
Scaly clay with Exotic blocks
Deep water Open marine
BASINAL SHALLOWING (FATU LAOB UPLIFT)

section and elsewhere in Timor. The resulting age range extension of the Viqueque Group also suggested a Late Middle Miocene date as the youngest date of emplacement of the Bobonaro Scaly Clay olistostrome (Audley-Charles and Carter, 1972).

In the type section, the boundary between the Batu Putih Limestone and the overlying Sabaoe Limestone Formation is a transitional one, and is taken as the uppermost occurrence of a marl interbed within the transitional marl-calcarenite sequence between the two formations. In the type section this boundary also corresponds to the first appearance of the coarse conglomeratic calcarenite which constitutes most of the overlying Sabaoe Limestone succession. Elsewhere in Timor the formations are locally unconformable.

The boundary between the Batu Putih Limestone Formation and the underlying Bobonaro Scaly Clay is taken as the first occurrence of a white calcilutite or white vitric tuff bed. In most parts of Timor, this boundary is a tectonic one, due to the widespread shearing between the competent limestone of the Batu Putih Limestone Formation and the underlying, highly plastic Bobonaro Scaly Clay.

(ii) The Tanah Runtu Member

The Tanah Runtu Member consists of a series of interbedded white calcilutites, white vitric tuffs with small calcilutite clasts, sheared olive-green porcellaneous clay and thin-bedded, graded, lithic arenites (Plate 1, A and B). In the only exposure of this member so far discovered, on the south side of the Bokong Sub-basin, east of Batu Putih (Fig. 2), only 3m. of succession are exposed, and neither

Plate 1: Batu Putih Limestone Formation, Tanah Runtu Member

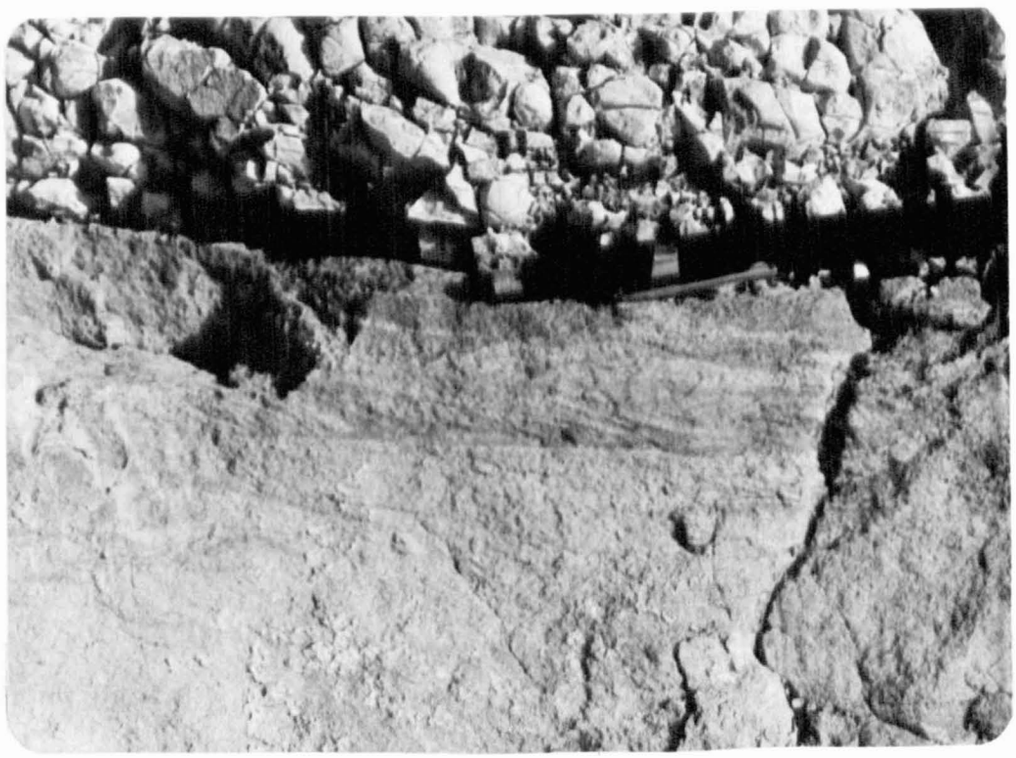
A: Rhythmically interbedded, white calcilutites and sheared brown clay, near Tacari, Bokong Sub - basin. Note the 'boudinage' structure of the calcilutites, suggesting plastic deformation.

B: Part of a thin arenite unit within the Tanah Runtu Member. Note the extreme fineness of the bed and the presence of ripple bedding at the top.

A



B



the lowermost contact with the Bobonaro Scaly Clay, or uppermost contact with the Batu Putih Limestone Formation calcilutite unit is seen (Fig. 4,A). The similarity of the interbedded clays to those of the underlying Bobonaro Scaly Clay suggests that the succession be placed below that of the Batu Putih Limestone type section at Batu Putih. This has been confirmed by D. J. Carter (personal communication) whose foraminiferal analysis suggested an N15 (Late Middle Miocene) age for the Tanah Runtu Member.

Depositional Environment of the Tanah Runtu Member

The similarity of the olive-green clay to the underlying Bobonaro Scaly Clay suggests either (a) reworking and resedimentation of sea floor outcropping Bobonaro Scaly Clay or (b) sea-floor deposition of an original volcanic tuff and subsequent in-situ alteration by shearing. Evidence suggesting the latter is provided by an observed transition in outcrop from a light olive-green, compact, unsheared sediment which exists near to the contact with massive calcilutite beds, to a dark-brown, much sheared, soapy, scaly clay which exists near the central part of individual clay units.

Abundant evidence of current reworking exists, however, within the Tanah Runtu Member, such as reworked calcilutite pellets within the vitric tuff beds, and the presence of small clasts of rocks of Pre-Bobonaro Scaly Clay age within the porcellaneous clay. A derivation from existing Bobonaro Scaly Clay outcrops by current distribution, and later modification by shearing therefore seems the most likely explanation for the similarity of the Tanah Runtu Member to the apparently allochthonous Bobonaro Scaly Clay.

No reliable indications exist as to the depth of deposition of the Tanah Runtu Member. The derivation of the Bobonaro Scaly Clay by sliding from 'uplifted sea floor' to the north of Timor (Audley-Charles and Carter 1972) however, clearly implies a considerable north-south gradient towards Timor at the time of emplacement of that formation (Fig. 5, A). It is thus likely that a considerable depth of water was present over the south coast of Timor at that time. It will be shown in this thesis that the first stage in the depositional history of the Viqueque Group included an uplift (the Fatu Laob Uplift) from Late Miocene (N18) to Late Pliocene times (N21). During this uplift from unknown, but probably bathyal depths, calcium carbonate deposition would be expected to begin at, or around the local calcite compensation depth (Van Andel and Moore, 1974). One of the factors affecting this might have been the influence of bottom-hugging ocean currents, known to have a significant effect on present day Pacific Ocean sedimentation (Horn et al. 1970). The influx of these bottom-hugging (and therefore cold) currents into an environment which was only just at the calcite compensation depth would be enough to cause cessation of calcium carbonate deposition and allow a layer of reworked Bobonaro Scaly Clay to be deposited. The shifting of the ocean currents on a seasonal or longer basis might thus produce an alternating clay-calcilutite sequence.

The graded arenites which exist within the Tanah Runtu sequence are interpreted as turbidity current deposits. All consist of very fine, lithic sands, displaying abundant ripple and parallel lamination indicating a derivation from the north (Fig. 5,B).

Fig. 4: Batu Putih Limestone Formation

A: Tanah Runtu Member, type section, showing rhythmic intercalation of limestone and clay, with subordinate tuff and arenite beds. The upper and lower contacts of the member with the calcilutite unit of the Batu Putih Limestone Formation, and the Bobonaro Scaly Clay respectively are not exposed.

A: White calcilutites

B: Lithic arenite

C: Olive green clay

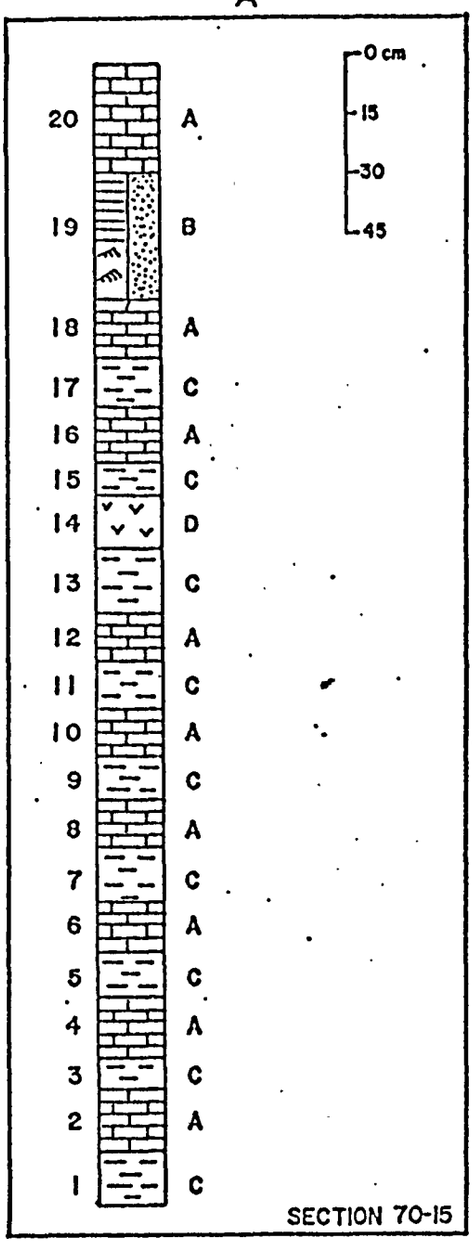
D: White vitric tuff

B: Fatu Laob Member, type section. Note increasing proportion of higher energy, sandy marl towards top of succession, reflecting shallowing during final stages of Fatu Laob Uplift.

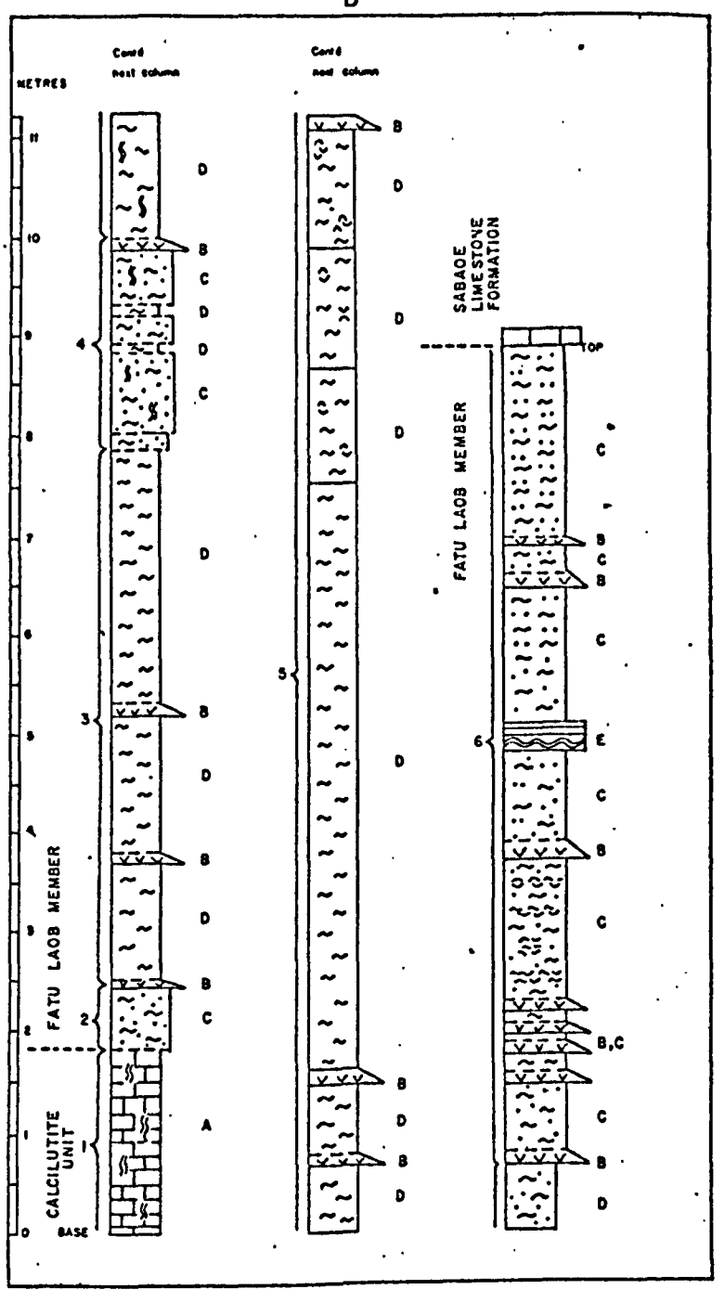
Numbers correspond to sedimentary units, letters to facies mentioned in the text.

C: Fatu Laob Member: Summary of lithology and depositional history of the type section.

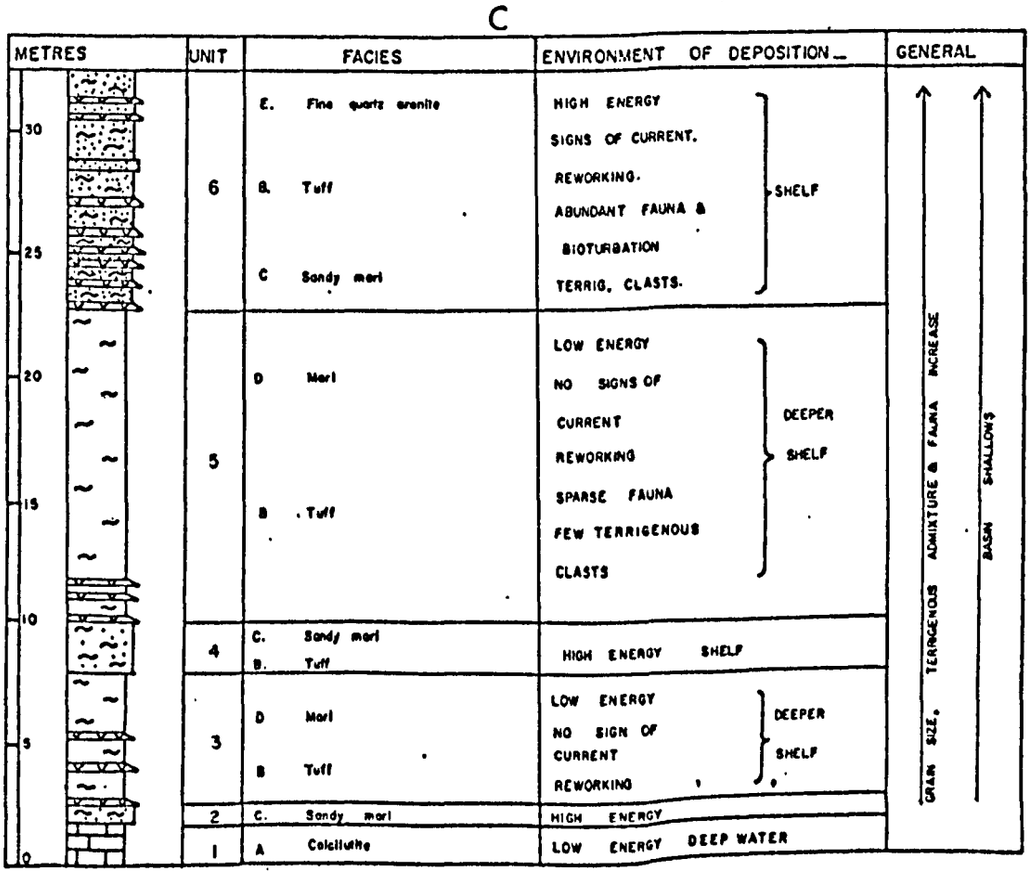
A


0 cm
15
30
45
SECTION 70-15

B


METRES
Contd next column
Contd next column
SABAOE LIMESTONE FORMATION
FATU LAOB MEMBER
CALCILUTITE UNIT
TOP
BASE

C


METRES
UNIT
FACIES
ENVIRONMENT OF DEPOSITION
GENERAL
E. Fine quartz arenite
B. Tuff
C Sandy marl
HIGH ENERGY
SIGNS OF CURRENT REWORKING.
ABUNDANT FAUNA & BIOTURBATION
TERRIG. CLASTS.
SHELF
D Marl
B . Tuff
LOW ENERGY
NO SIGNS OF CURRENT REWORKING
SPARSE FAUNA
FEW TERRIGENOUS CLASTS
DEEPER SHELF
C. Sandy marl
B. Tuff
HIGH ENERGY SHELF
D Marl
B Tuff
LOW ENERGY
NO SIGN OF CURRENT REWORKING
DEEPER SHELF
C. Sandy marl
HIGH ENERGY
A Calcilutite
LOW ENERGY DEEP WATER
GRAIN SIZE, TERRIGENOUS ADMIXTURE & FAUNA INCREASE
BASIN SHALLOWS

Grading is well-developed, most beds grading into clay through silt at the bed tops. Beds possessing such features are usually of distal derivation (Walker, 1967).

In addition to the very distal aspect of these turbidites the absence of clay or terrigenous material in the calcilutites of the northern part of the Noele Sub-basin suggests that as late as N18 times during the Fatu Laob Uplift, deep, open water conditions existed in the northern part of Timor. The land area from which these turbidites were derived must therefore have been situated outside the limits of the present day island (Fig. 5, B) and may have been the Middle Miocene volcanic island arc suggested by Audley-Charles et al.,(1972) to have been present north of Timor at that time. Persistence of the north-south gradient present during Bobonaro Scaly Clay emplacement would have facilitated southwards flow of these arenites toward the present day Central Basin of Timor.

The presence of well-developed tuff horizons within the member does, however, suggest that the figure of 1800 kilometres suggested by Audley-Charles et al., (1972) for the separation of the volcanic arc and Timor may be too great. It would seem necessary to postulate a considerably nearer source than this for both arenites and tuff.

(iii) The calcilutite unit

Succeeding the Tanah Runtu Member in the Batu Putih region, and forming most of the Batu Putih Limestone Formation elsewhere in Timor are a series of white, compact, foraminiferal calcilutites, white vitric tuffs and occasional, thin-bedded lithic arenites.

Fig. 5: Palaeogeography of Batu Putih Limestone deposition

A. Middle Miocene palaeogeography of Indonesian Timor (after Audley - Charles and Carter, 1972).

Double arrows indicate direction of emplacement of Bobonaro Scaly Clay. Single arrows show presumed direction of palaeoslope across Timor.

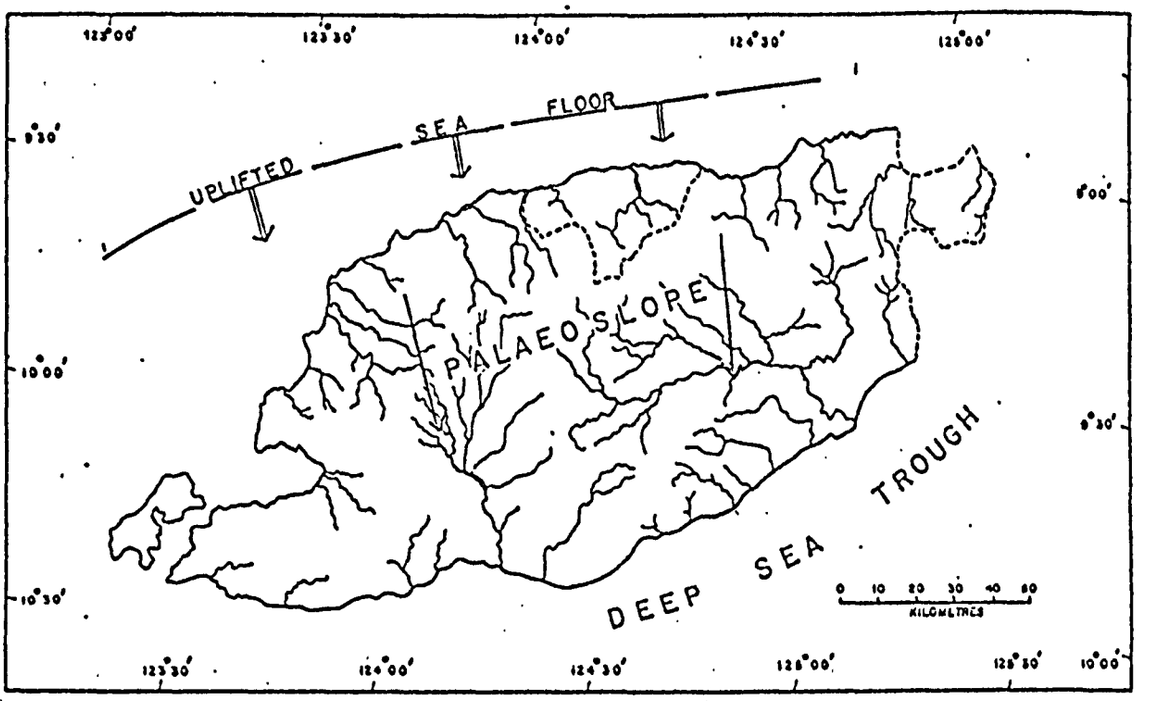
B. Suggested palaeogeography of Tanah Runtu deposition in the Late Middle Miocene.

A: Location of Tanah Runtu Member type section

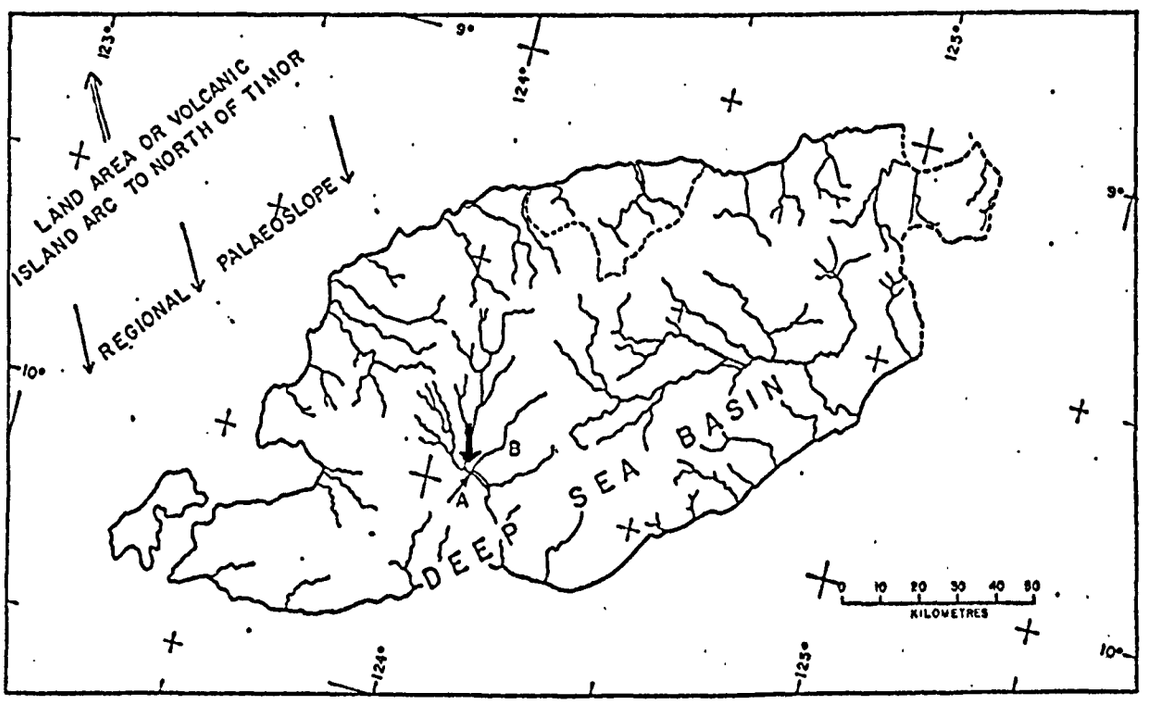
B: Direction of derivation of Tanah Runtu arenites, inferred from ripple cross - lamination direction.

C: Suggested palaeogeography of calcilutite unit and Fatu Laob Member deposition

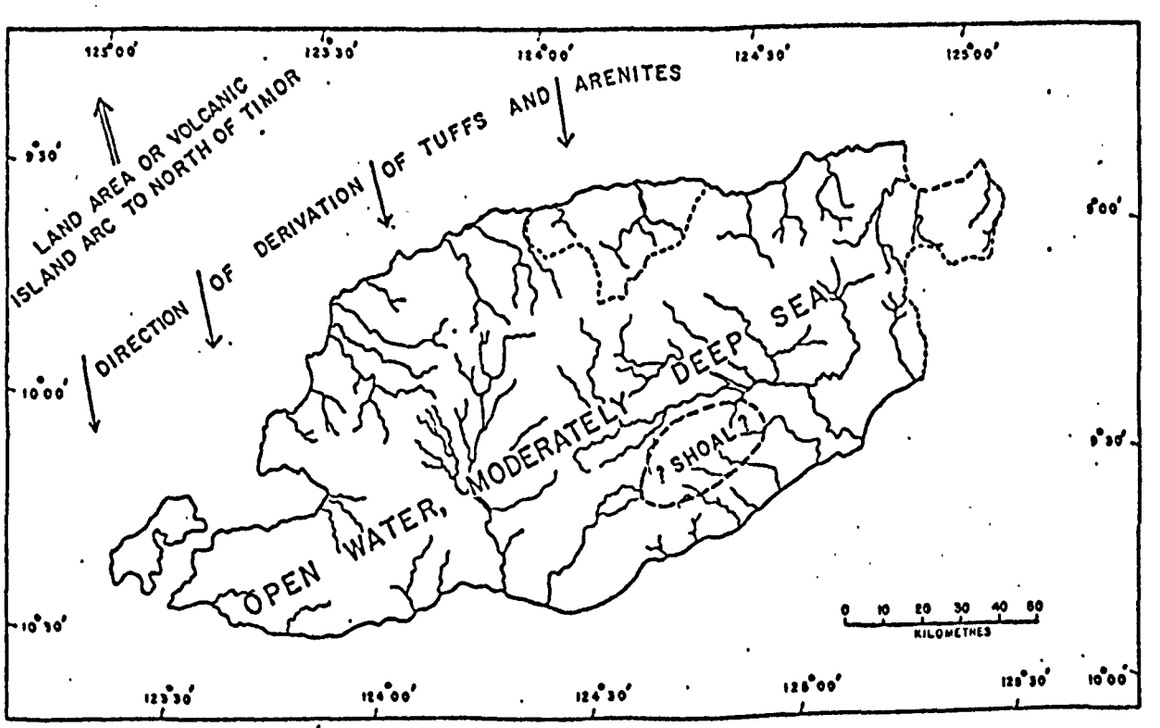
A


UPLIFTED
SEA FLOOR
PALAEOSLOPE
DEEP SEA TROUGH
0 10 20 30 40 50
KILOMETRES

B


LAND AREA OR VOLCANIC ISLAND ARC TO NORTH OF TIMOR
REGIONAL PALAEOSLOPE
DEEP SEA BASIN
A
B
0 10 20 30 40 50
KILOMETRES

C


LAND AREA OR VOLCANIC ISLAND ARC TO NORTH OF TIMOR
DIRECTION OF DERIVATION OF TUFFS AND ARENITES
DEEP SEA
MODERATELY
? SHOAL ?
OPEN WATER,
0 10 20 30 40 50
KILOMETRES

The calcilutites are characterised by abundant, visible, pelagic foraminifera and rare, usually broken, valves of thin-shelled, pelagic lamellibranchs. Indistinct burrows occur in parts of the sequence, and well-preserved feeding traces of Zoophycos were noted in the calcilutites of the Colitie syncline in Portuguese Timor (Plate 2, B). Interbedded tuffs within this calcilutite sequence achieve a maximum thickness of 12 metres with individual particles extending in diameter to medium sand size. Beds are often graded and some possess parallel or convolute lamination (Plate 2, A). Rare tests of pelagic foraminifera are found within the tuffs.

Convolute and wavy bedding are also seen within the interbedded, fine-grained lithic arenites, which range from 15 to 100 cm. in thickness.

Environment of deposition

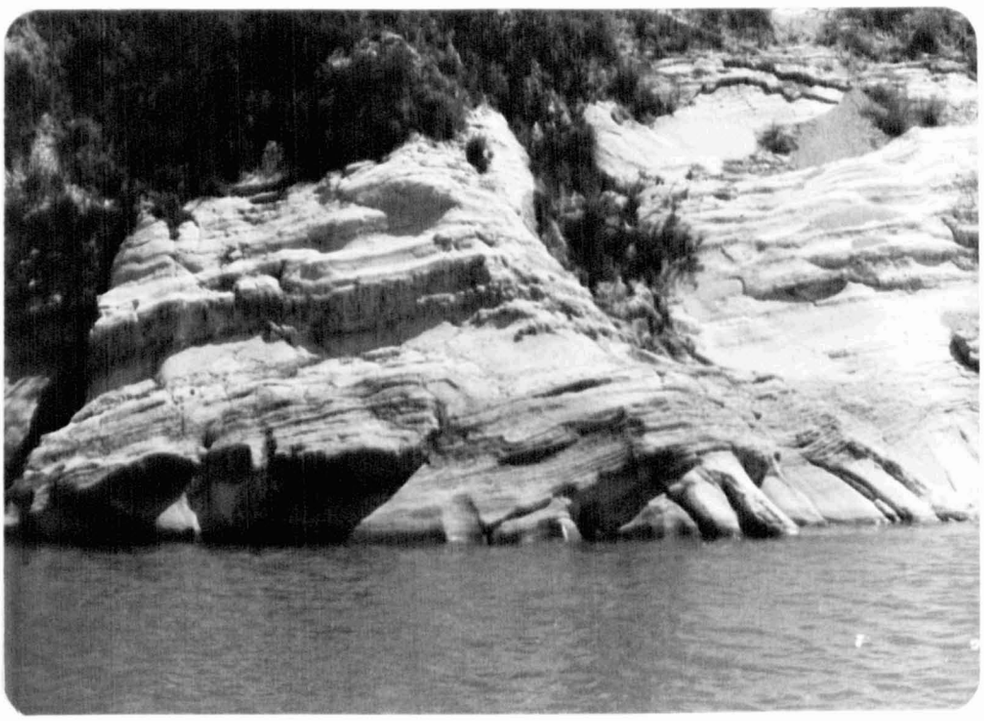
The depositional environment of the calcilutite unit appears to have been one of consistently low energy, above the calcite compensation depth (3900 metres in the Miocene equatorial Pacific (Van Andel and Moore, 1974)) but below the level at which abundant benthonic life was supported. The abundance of pelagic foraminifera and lamellibranchs, and the very low percentage of clay material in the calcilutites suggests an open marine environment with insignificant land influence. At the same time the environment was evidently subject to the incursion of turbidity currents carrying terrigenous debris, and to large amounts of volcanic ash settling from the water. By analogy with the preceding member, the source of both volcanic ash and terrigenous debris is assumed to have been the uplifted sea floor

Plate 2: Batu Putih Limestone Formation, calcilutite unit

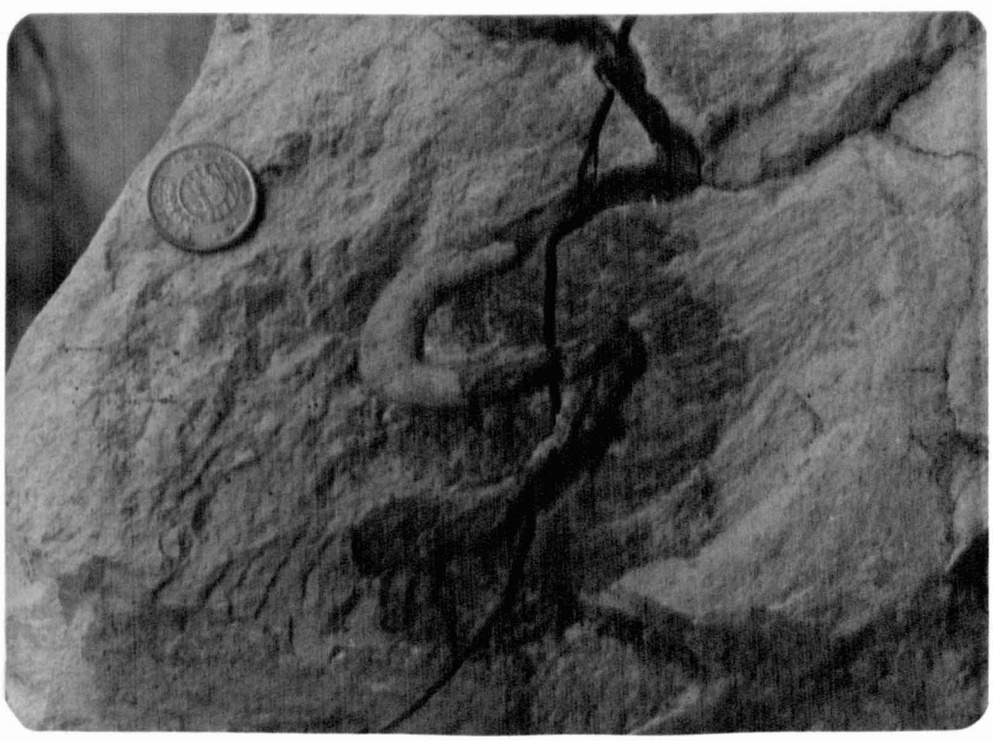
A: Interbedded white calcilutites and vitric tuffs, south of Noilmina. Note the fine lamination of the tuff horizons. In the uppermost part of the lower tuff horizon this lamination assumes a semi - convolute form.

B: Traces of Zoophycos burrows in the Batu Putih Limestone calcilutite of the Colitie syncline, Portuguese Timor.

A



B



north of Timor (Fig. 5, C).

The occurrence of reworked belemnites in the Batu Putih Limestone of the Kolbano district (M.G. Audley-Charles, personal communication) suggests possible high energy reworking in that region during deposition of the calcilutite unit.

(iv) The Fatu Laob Member

The Fatu Laob Member (Fig. 4, B and C) comprises a series of grey, foraminiferal marls, thin arenites, vitric tuffs and thin, muddy calcarenites, which forms the uppermost stratigraphic unit of the Batu Putih Limestone Formation. The member is widespread in occurrence, being present in both Bokong and Noele Sub-basins, in the region south of the Bokong Sub-basin, and in Portuguese Timor.

The type section of the member (Fig. 4, B) was measured in the Kali Sabaoe east of Kapan, where the succession is 29 metres thick. The following sedimentary facies are recognised within, and immediately preceding, the type section:

Facies A

Consists of white to grey, structureless calcilutite, with abundant tests of Globigerina and some white, comminuted, thin-shelled molluscan material. This facies represents the uppermost part of the preceding calcilutite unit of the Batu Putih Limestone Formation and is assumed to have been deposited in a low energy, open marine environment.

Facies B:

Comprises white tuff beds, some of which display ripple, and/or parallel lamination. The beds are usually graded, and display abrupt bases and transitional tops.

Facies C:

Consists of friable grey marl, with an abundant admixture of terrigenous clasts. Tests of foraminifera and comminuted molluscan debris are frequent. The occurrence of large terrigenous clasts and comminuted shell debris suggests periodic introduction of the former, and reworking of both, by high energy currents, and the environment is interpreted as shallow water marine, above wave base.

Facies D:

Comprises fine, compact grey marl with Globigerina tests. This facies shows little evidence of reworking and is assumed to have accumulated in an open marine environment, below wave base.

Facies E:

Consists of fine quartz arenite displaying parallel and wavy lamination. The beds are parallel-sided and are assumed to have been deposited by subaqueous currents, possibly turbidity currents.

Interpretation

Study of the vertical distribution of the above lithofacies in the Kali Sabaoe section suggests that the facies with the deepest aspect, that is facies A, occurs at the base of the section, and that with the shallowest (facies C), although being interbedded throughout with the deeper water facies D, becomes gradually predominant, until at the top of the section it passes transitionally into the base of

the shallow water Sabaoe Limestone Formation (Fig. 4, C). This shallowing of the succession, marking the end of the Fatu Laob Uplift, is recorded in Timor wherever the complete section (Bobonaro Scaly Clay to Sabaoe Limestone) is present.

The occurrence of clasts of older rocks within the Fatu Laob Member in the northern part of the basin indicates erosion of land in the vicinity. In spite of this, however, thick beds of arenite or conglomerate do not occur in this generally regressive sequence, terrigenous material being limited to isolated clasts and sandy admixtures within the marls. This is in direct contrast to the succession in the northern part of the area, during the later Noele Uplift, which includes thick turbidite deposits and strongly implies that the area now occupied by the Northern Mountains was one of relatively low relief throughout the Fatu Laob Uplift and until well into Sabaoe Limestone times. The very well-sorted, fairly mature turbidites of facies 'E' above, which occur in the marl member, would support this hypothesis, and suggest that only later did the relief of the northern area become positive enough for widespread subaerial erosion.

D. Microfauna

The following foraminifera have been identified from the type section of the Batu Putih Limestone Formation by Mr D.J. Carter (Unpublished report, dated 1970a):

(a) Planktonics

Globorotalia cultrata menardii

G. tumida tumida (sinistral)

G. subcretacea

G. acostaensis pseudopima

G. cultrata cultrata

Globigerina nepenthes

Pulleniatina spp.

Sphaeroidinella dehiscens

Globigerinoides gomitulus

G. ruber

Globigerinoides conglobatus

G. quadrilobatus gp.

G. obliquus obliquus

(b) Benthonics

Textularia spp.

Spiroplectammina spp.

Miliolacea

Nodosariacea

Cibicides spp.

Uvigerina spp.

Bulimina spp.

Planulina spp.

Orissodorsalis spp.

Carter's analysis confirmed the depositional environment and general history of deposition of the Batu Putih Limestone as set out earlier and in Kenyon (unpublished report, dated 1970). Carter suggested that deep, tranquil, open sea conditions were indicated by the benthonic fauna present from the base of the Batu Putih Limestone Formation up into the basal portion of the Globigerinoides quadrilobatus fistulosus zone (the upper part of the Fatu Laob Marl Member). At the top of the Fatu Laob Member, Carter found increased percentages of Uvigerina, Nodosariacea, Cibicides spp. and particularly Miliolids, suggesting some degree of shallowing.

E. Age of the Batu Putih Limestone Formation.

Samples from the three principal units of the Batu Putih Limestone Formation as defined in this thesis range in age from N15 (Late Middle Miocene) to N21 (Late Pliocene). Specifically, the exposed part of the Tanah Runtu Member appears to be N15 (Late Middle Miocene) in age, the calcilutite unit, N18 to Lower N19 and the Fatu Laob Member Upper N19, N20 and lowermost N21. The apparent absence of samples covering the gap from N16 to N17 may be a result of the extensive shearing which has occurred between the Batu Putih

Limestone Formation and the Bobonaro Scaly Clay and the absence of a continuous section of the formation in Timor. The calcilutite composition of the formation as a whole, and the high proportion of drifted planktonic foraminifera tests to sediment is indicative of a slow depositional rate; thus the apparent absence of two planktonic zones in a tectonically complex succession may be easily explained. Carter (unpublished report, dated 1970a) has also suggested from foraminiferal analysis that zone N20 may be strongly condensed or even completely missing in Timor.

F. Nature of the Batu Putih Limestone/Bobonaro Scaly Clay interface.

Owing to the widespread presence of large exotic blocks in the immediately preceding Bobonaro Scaly Clay (Audley-Charles 1968), the initial depositional surface of the Batu Putih Limestone Formation, and therefore of the Viqueque Group, must have been highly uneven. Evidence of this, and possibly early diapiric behaviour of the Bobonaro Scaly Clay is seen in outcrop south of the Central Basin, three miles south of Batu Putih along the River Noilmina, where an initially thick Batu Putih Limestone succession can be seen to thin rapidly northwards against a present day high of Bobonaro Scaly Clay. This thinning is accompanied by the development of a slight angular unconformity in the middle of the Batu Putih Limestone succession, which increases in intensity towards the old high. The thinning is also accompanied by a steepening of dip and faulting. Many such highs must have been present on this original surface.

Chapter 4. The Sabaoe Limestone Formation

A. Introduction and Summary

The Sabaoe Limestone Formation is defined as a series of shallow water and marginal marine skeletal calcarenites and marls of maximum thickness 228 metres, which succeeds the Batu Putih Limestone Formation in Indonesian Timor. In the type section, the contacts with the Batu Putih Limestone below and Noele Marl above are transitional. Elsewhere they are locally unconformable. In addition to the Sabaoe Limestone of the type section, two locally occurring members, the Noilmina Limestone Member and Fatu Antoni Member are defined.

Evidence is presented for the existence of intertidal, barrier bar, lagoonal, beach; shallow shelf, deep shelf and shelf edge environments during Sabaoe Limestone deposition. Three distinct physiographic provinces are shown to have existed in Timor during the Late Pliocene, comprising a northern positive area, a central subsiding negative area and a southern shelf area. A hinge zone is shown to have existed between the southern shelf and central negative areas and to have been situated in the region of the Bokong - Batu Putih fault zone.

The depoaxis of the central negative area is shown to have lain on the south side of a postulated major east - west fault zone present between the northern positive and central negative areas. The depositional history of Portuguese Timor during Sabaoe Limestone times is also discussed.

Finally, the age of the Sabaoe Limestone Formation is shown to be earliest Late Pliocene (N21).

B. Previous work

The Sabaoe Limestone of this thesis appears to be equivalent to the 'ribbed sandstone' of Hopper (I942) and to the 'Zone II' of De Bruyne (I94I). Neither of these authors attempted formal definition of the unit. The Sabaoe Limestone Formation was not recognised by Audley - Charles (I968) in Portuguese Timor. The present investigation in that part of the island suggests it is confined to an unimportant single bed in a north coast Viqueque Formation outcrop.

C. Distribution of the Sabaoe Limestone Formation

The Sabaoe Limestone Formation crops out within the Central Basin of Indonesian Timor in the following three major regions (Fig. 6):

(i) the Noele Sub - basin

(ii) the Bokong Sub - basin

(iii) the Panite High.

Limestones of equivalent age to the Sabaoe Limestone have also been identified by Carter (unpublished report, dated I97Ib) from the Kolbano region.

D. Stratigraphy

(i) The Sabaoe Limestone Formation of the Noele Sub --basin

Outcrops of Sabaoe Limestone Formation are found in four principal areas in the Noele Sub - basin(3, 4, and 5 in Fig. 6). From north to south these are (a) the northern margin, in the rivers Sabaoe and Bidjeli (5); (b) the Noele anticline (3); and (c) the southern margin in the Oemenu river (4).

(a) Northern basin margin outcrops: the type section of the Sabaoe Limestone Formation

The Sabaoe Limestone Formation crops out along the north - west

Fig. 6: Distribution of the Sabaoe Limestone Formation in Indonesian Timor.

1; Outcrops of the Bokong Sub -basin southern margin

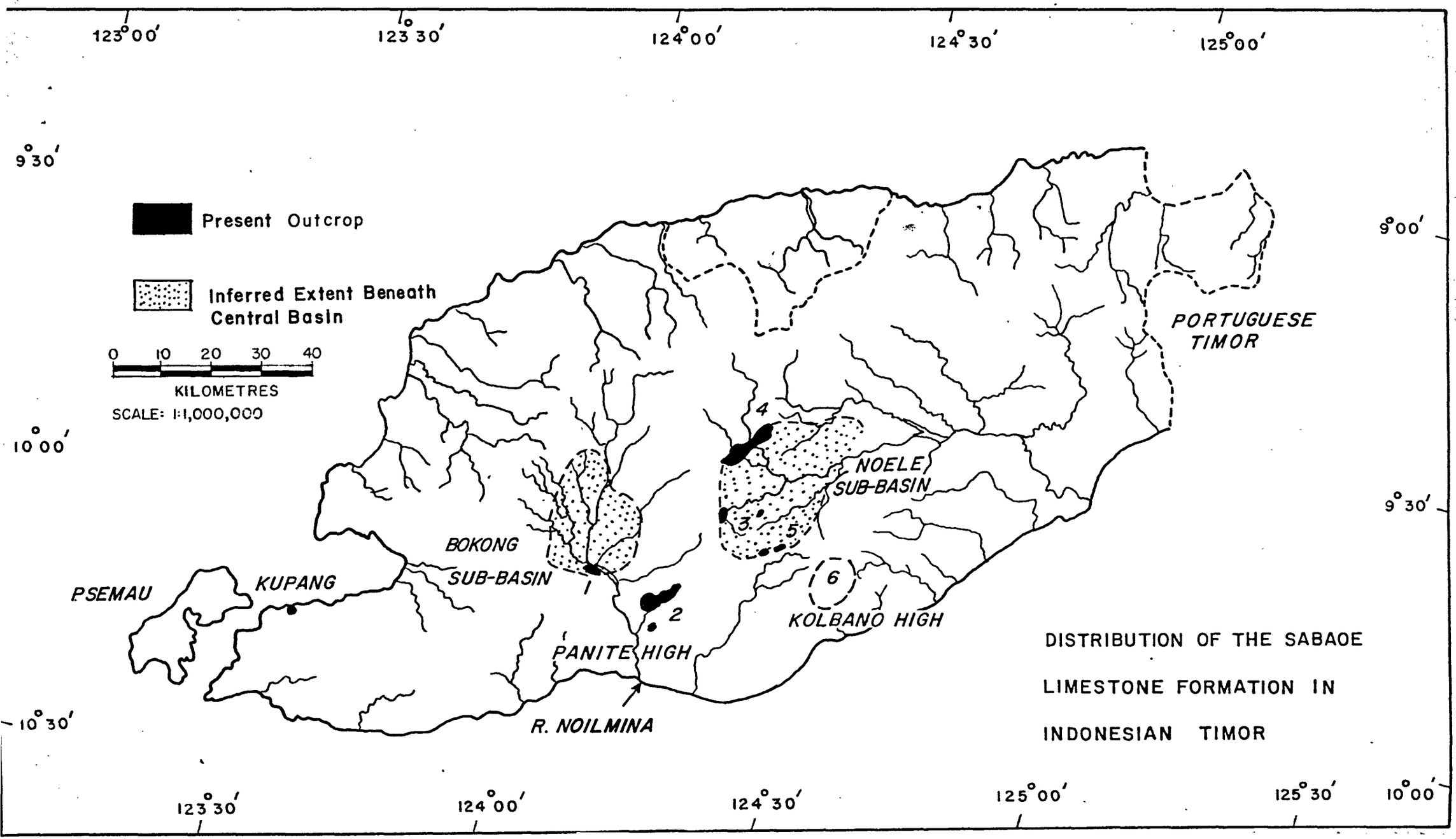
2: Outcrops of the Panite High

3: Outcrops of the Noele Sub - basin centre

4: Outcrops of the Noele Sub - basin northern margin (including the Sabaoe Limestone Formation type section)

5: Outcrops of the Noele Sub -basin southern margin (including the Kali Oemenu section

6: Approximate position of the Kolbano High.


123°00′
123°30′
124°00′
124°30′
125°00′
9°30′
9°00′
10°00′
10°30′
Present Outcrop
Inferred Extent Beneath Central Basin
0 10 20 30 40
KILOMETRES
SCALE: 1:1,000,000
PORTUGUESE TIMOR
NOELE SUB-BASIN
BOKONG SUB-BASIN
PSEMAU
KUPANG
PANITE HIGH
KOLBANO HIGH
R. NOILMINA
1
2
3
4
5
6
DISTRIBUTION OF THE SABAOE LIMESTONE FORMATION IN INDONESIAN TIMOR

margin of the Noele Sub - basin in a prominent, thickly forested escarpment south of Kampong Sabaoe. This escarpment is crossed by the Bidjeli and Sabaoe Rivers, along each of which the formation and its upper and lower contacts with the Noele Marl and Batu Putih Limestone Formations respectively are clearly exposed.

The type section of the formation (Figs. 7 and 8) was measured in the River Sabaoe, beginning at the first occurrence of a cemented calcarenite bed, in the transitional zone with the Batu Putih Limestone Formation and extending upwards to the Noele Marl Formation contact, distinguished as the uppermost occurrence of a cemented calcarenite bed.

Lithofacies development

The type section (Fig. 7) consists of an overall upwards - fining sequence, beginning above the Fatu Laob Member of the Batu Putih Limestone with coarse calcarenites, clay pellet conglomerates, clays and sands, and passing upwards into a sequence of cross - bedded calcarenites and marls. The succession ends with a predominantly marly sequence before passing transitionally into the Noele Marl Formation. The following major subdivisions are recognised:

(A) The marly calcarenite facies

(B) The calcarenite - conglomerate facies association

(C) The calcarenite - marl facies association

(D) The marl facies

Unit (A): The marly calcarenite facies

The base of the Sabaoe Limestone is marked by a number of parallel - bedded, grey, bioturbated, marly skeletal calcarenites,

Fig. 7: Sabaoe Limestone Formation, type section, Kali Sabaoe, Noele Sub -basin. Detailed stratigraphic section, showing upwards gradation from a shallow water calcarenite and conglomerate sequence to a predominantly deeper water marl sequence.

Note also the arrangement of the sequence into a number of upwards - fining sedimentary cycles, those in the lower part of the sequence consisting of conglomerate, calcarenite and marl elements in ascending order and those in the upper part comprising calcarenite and marl elements.

The transitional passage from the Batu Putih Limestone Formation and that into the overlying Noele Marl Formation are also shown.

For location of this section see Fig. 6.

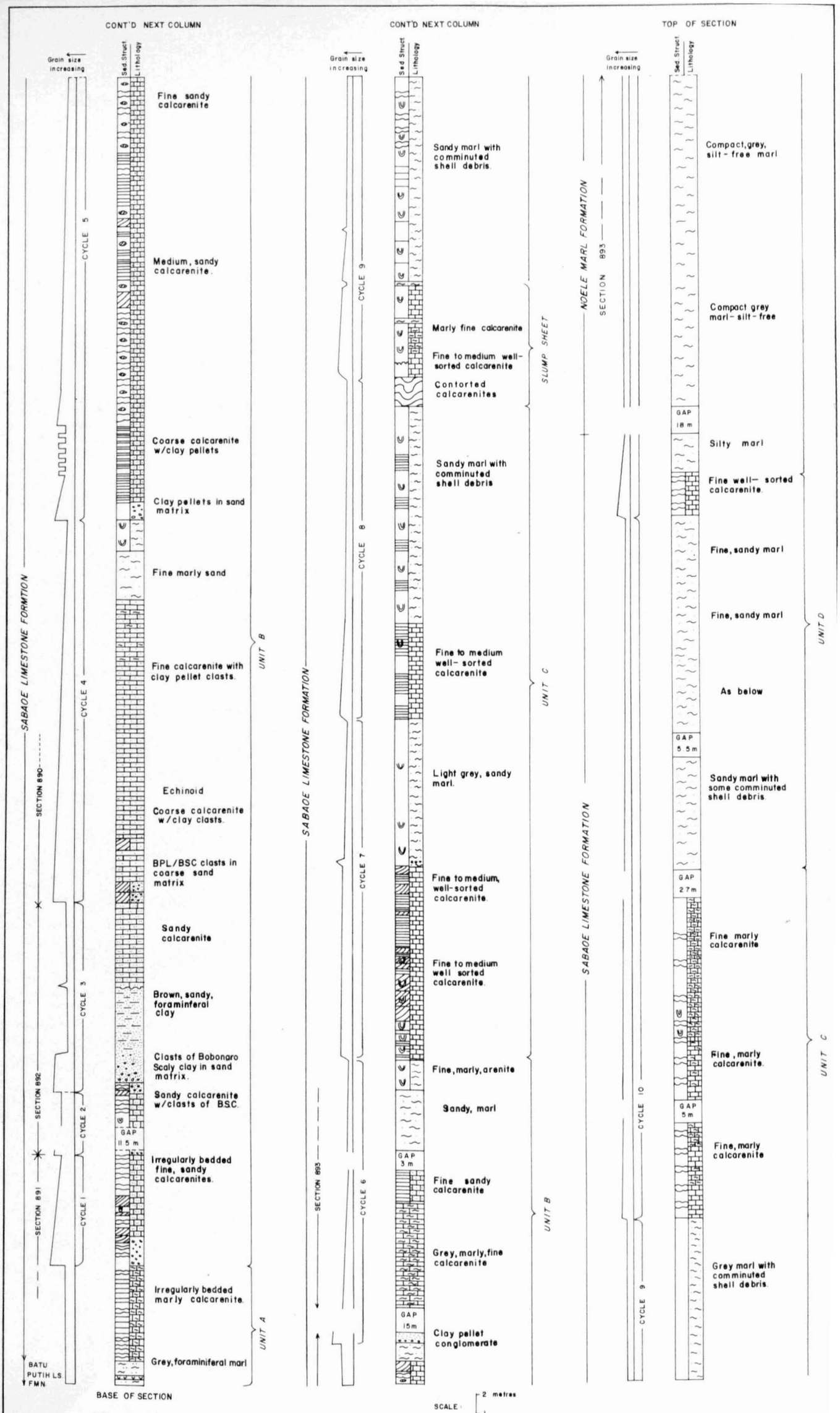
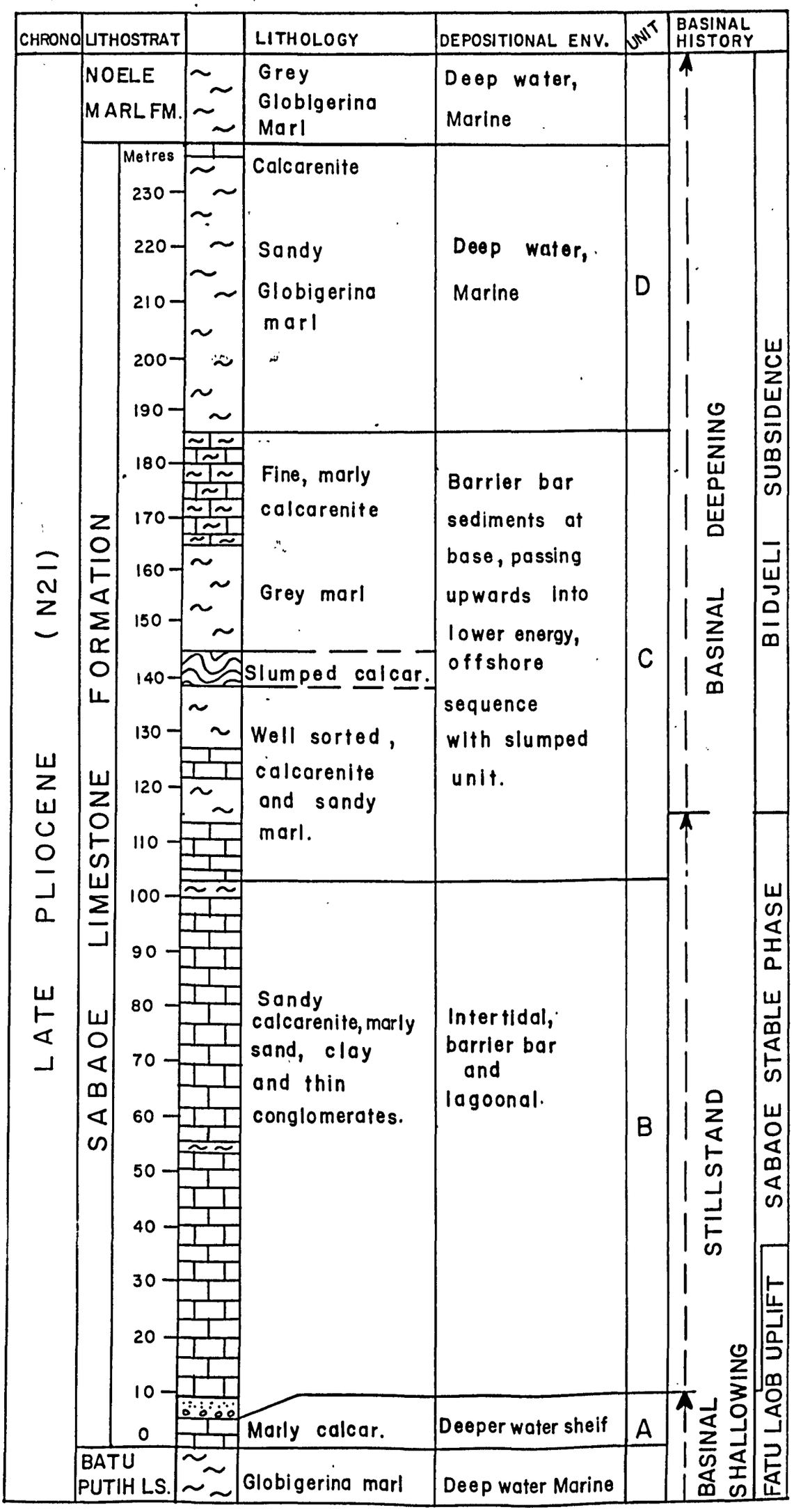


FIG SABAOE LIMESTONE FORMATION : TYPE SECTION, KALI SABAOE

Fig. 8: Summary of Sabaoe Limestone Formation stratigraphy, lithology and depositional history as shown by the type section, Kali Sabaoe, Noele Sub - basin. Note the phases of basinal shallowing, stillstand and deepening accompanying the deposition of the unit and responsible for the marked range in depositional environments under which the sediments accumulated. For precise location of this section see Fig. 6.


CHRONO
LITHOSTRAT
LITHOLOGY
DEPOSITIONAL ENV.
UNIT
BASINAL HISTORY
LATE PLIOCENE (N21)
NOELE MARL FM.
Grey Globigerina Marl
Deep water, Marine
SABAOE LIMESTONE FORMATION
Metres
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Calcarenite
Sandy Globigerina marl
Deep water, Marine
D
Fine, marly calcarenite
Grey marl
Barrier bar sediments at base, passing upwards into lower energy, offshore sequence with slumped unit.
Slumped calcar.
C
Well sorted, calcarenite and sandy marl.
Sandy calcarenite, marly sand, clay and thin conglomerates.
Intertidal, barrier bar and lagoonal.
B
Marly calcar.
Deeper water sheif
A
BATU PUTIH LS.
Globigerina marl
Deep water Marine
BASINAL DEEPENING
BIDJELI SUBSIDENCE
STILLSTAND
SABAOE STABLE PHASE
BASINAL SHALLOWING
FATU LAOB UPLIFT

which follow transitionally from the grey Globigerina marl of the Batu Putih Limestone Formation. Cementation is confined to certain intervals, the resulting differential erosion giving the beds a 'ribbed' appearance (Plate 4, C).

Environment of deposition

The relatively high energy sediments of unit (A) mark the beginning of the emergence of Timor during the closing stages of the Fatu Laob Uplift in Late Pliocene times. Similar muddy calcarenites have been described by Houbolt (1957) from the Persian Gulf, where they are accumulating in water depths generally greater than three fathoms. Marly skeletal calcarenites are also present in Kupang Bay, at depths of between 5 and 17 fathoms.

A form of cementation similar to that of the unit (A) beds was described from the Persian Gulf by Shinn (1969), who demonstrated its formation in offshore environments in water depths less than 30 metres.

A shallow water marine depositional environment of the order of 6 to 33 metres deep is therefore postulated for unit (A) sediments.

Unit (B): The calcarenite - conglomerate facies association

Succeeding the parallel - bedded calcarenites of unit (A) are a series of upwards - fining, terrigenous - carbonate cycles averaging 20 metres in thickness. Each cycle begins, sometimes via a minor erosional surface, with a coarse conglomerate (Plate 3, B), which is followed by a coarse, sandy, bioturbated, skeletal calcarenite and finally by a marl or clay sequence (Plate 3, C).

Depositional environment

The pronounced upwards - fining of the lowermost cycle of

Plate 3: Sabaoe Limestone Formation, Kali Sabaoe and Bidjeli sections.

A: Slumped, shallow water marly calcarenites in the upper part of the Sabaoe Limestone Formation type section, Kali Sabaoe.

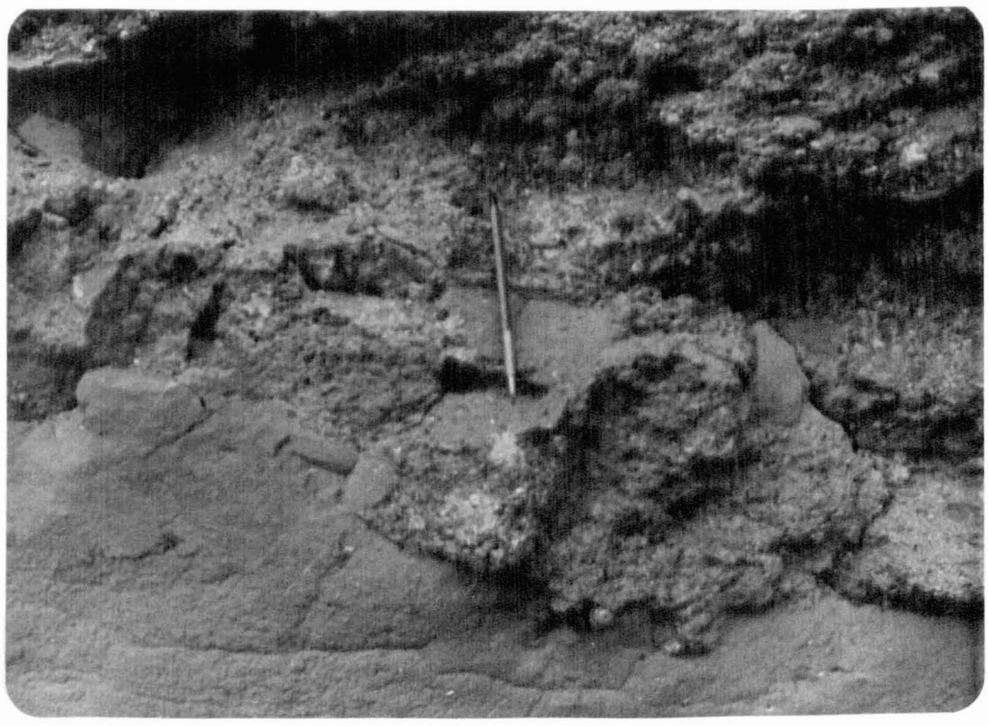
B: Coarse lag conglomerate at the base of a conglomerate - calcarenite marl cycle, Sabaoe Limestone Formation, Kali Bidjeli.

C: Lower and middle parts of a calcarenite - marl cycle, Sabaoe Limestone Formation, Kali Sabaoe.

A



B



C

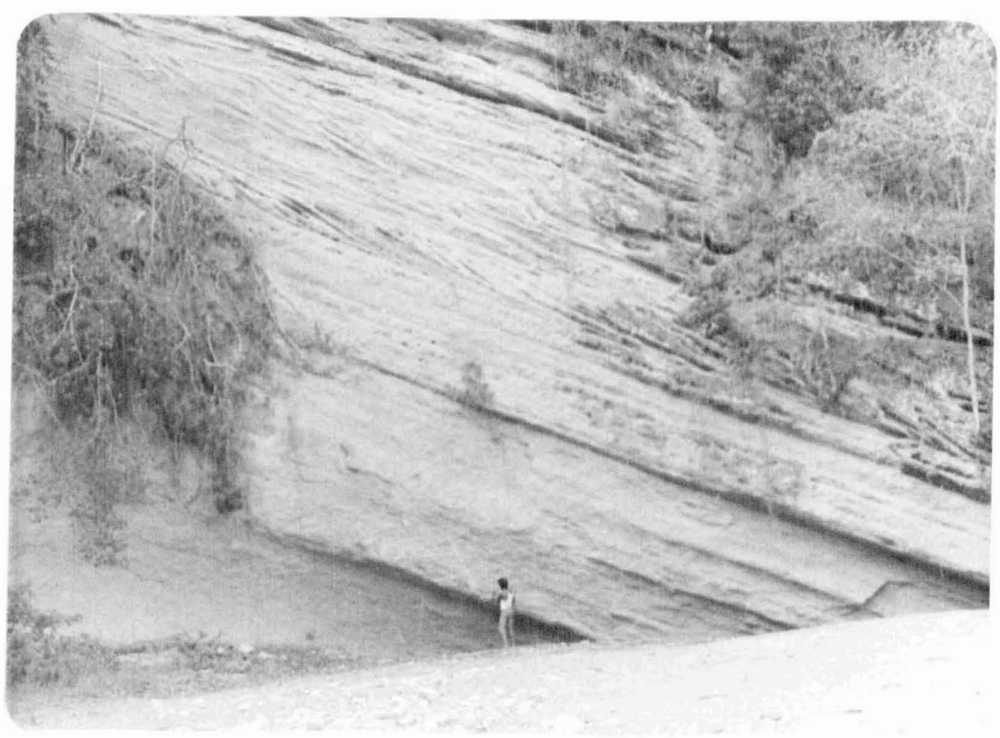


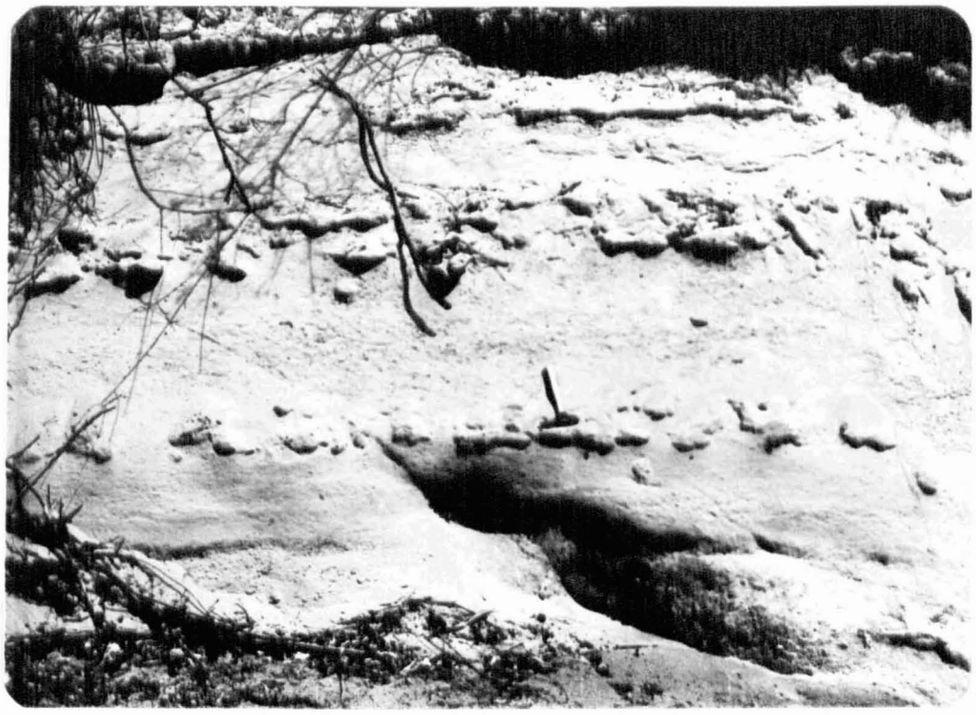
Plate 4: Sabaoe Limestone Formation

A: Widely spaced beds of marly calcarenite with Globigerina marl interbeds, Noele anticline section. Note the irregular cementation of the calcarenite beds.

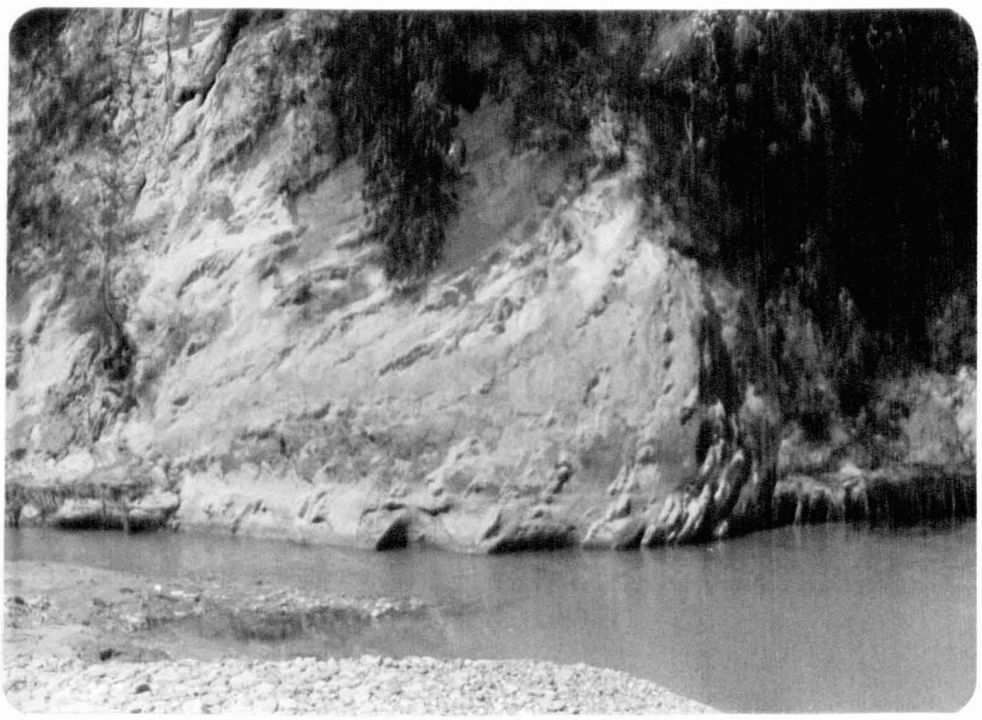
B: Part of the type section of the Noilmina Limestone Member, west of Noilmina, Bokong Sub - basin. Note the disconformity near to the base of the section, the apparent deformation of beds above and below this disconformity being due to downward throw on the Bokong - Batu Putih fault zone to the south (right) of the type section. Alternating hard and soft beds similar to those seen in (A) can also be seen.

C: Parallel bedded skeletal calcarenites of the Kali Bidjeli section. Note the projecting cylindrical tubes (bioturbation) accentuated by differential cementation.

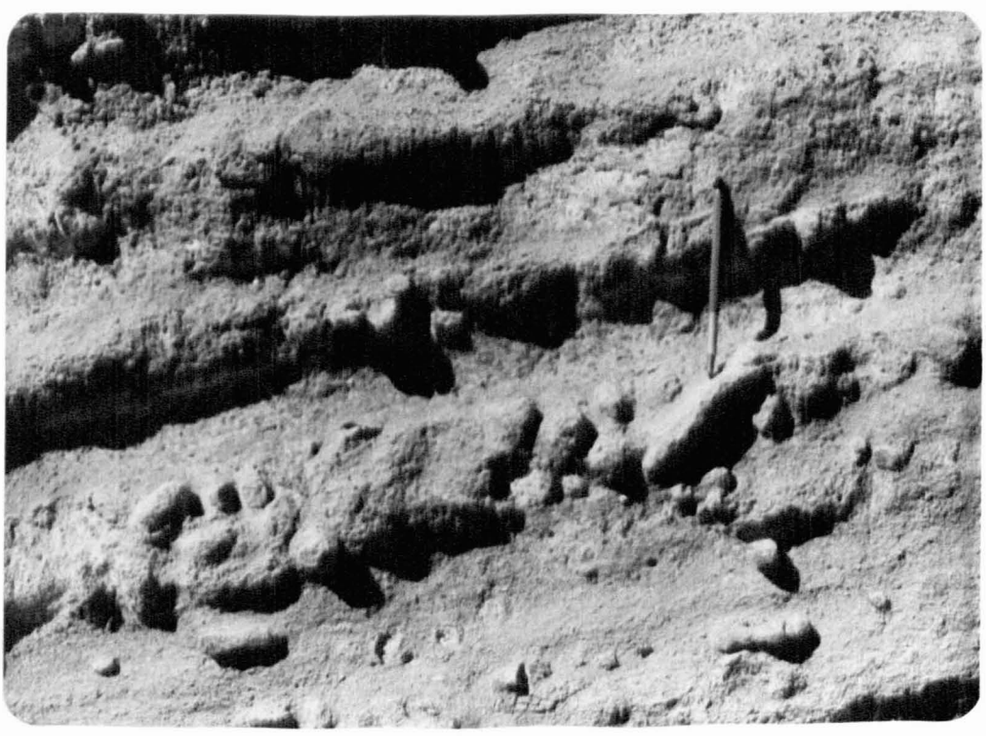
A



B



C



unit (B) and the lag conglomerate at its base are reminiscent of the features produced by present day lateral migration of intertidal distributary channels along the Dutch Wadden Sea (Van Straaten, 1950 and Klein, 1964) and the Wash (Evans, 1965). The diminished importance of lag conglomerates in cycles 4 to 6 of unit (B) however, the predominance of calcarenites, and the presence of marl interbeds, suggest the interaction of high and low energy processes such as those associated with barrier beaches or bars migrating over lagoonal sediments (McKee and Sterrett, 1961). A similar explanation was advanced by Burri et al (1971) for the cycles in the Barrhemian Orgon Limestone of south Provence. Other cyclic near - shore carbonate sequences have been described from the Lower Carboniferous of South Wales (Dixon and Vaughan, 1911), from the Upper Viséan of Belgium (Pirlet, 1963) and from the Pennsylvanian of East Nevada (Dott, 1968).

The accumulation of a thick sequence of cyclic sediments such as those of the Sabaoe Limestone Formation does not necessarily imply rapid vertical movements of sea level such as those postulated by Dixon and Vaughan (1911). Such a sequence can be produced by simple lateral migration of high and low energy environments, coupled with regional tectonic subsidence and a relatively rapid rate of deposition. It is suggested that this process operated during Sabaoe Limestone deposition.

Unit (C): The calcarenite - marl facies association

Unit (C) is characterised by cyclic calcarenite and marl sequences with rare conglomerates. Cross - bedding is present only in the calcarenites of the lowermost cycle (Fig. 7, cycle 7). A thick, slumped unit of calcarenite is present in the upper part of this

sequence (Plate 3, A).

Environment of deposition

The much reduced occurrence of cross - bedding, the absence of intertidal lag conglomerates, the overall fineness of the sequence compared to unit (B) and the presence of the thick, slumped sediment mass are evidence of a deeper environment of deposition than that concluded for the previous unit. The deepening appears to have become more pronounced in cycles 9 and 10.

Unit (D): The marl facies

The uppermost unit of the Sabaoe Limestone Formation is characterised by a succession of grey, silty, Globigerina marl containing abundant, comminuted, thin - shelled molluscan debris. A thin sequence of cemented calcarenite occurs at the top of this unit.

Unit (D) sediments represent the beginning of the deep water sedimentation which later led to the deposition of the overlying Globigerina marls of the Noele Marl Formation.

The phase of subsidence responsible for the deepening depositional environment of the Sabaoe Limestone Formation in Timor is here named the Bidjeli Subsidence, after the village of Bidjeli in the north-western part of the Noele Sub - basin.

Derivation of the terrigenous material within the deeper water parts of the Sabaoe Limestone Formation

Apart from the silt component of the marls of unit (D), very little terrigenous material, either interspersed, or in the form of turbidite sandstones, has been noted in the deeper water parts of the

Sabaoe Limestone of the northern basin margin. The area north of the present Bokong and Noele Sub - basins was probably therefore not of sufficient relief during Sabaoe Limestone deposition to supply great quantities of terrigenous material and is assumed to have consisted either of a number of individual islands or of a low - lying shelf area, perhaps with a number of isolated, low emergent areas.

Summary: Depositional history of the Sabaoe Limestone Formation of the northern margin of the Noele Sub - basin

The following stages are proposed:

Stage 1: The Fatu Laob Uplift

Uplift of the northern margin of the sub - basin from deeper water to shallow shelf environment. Deposition of unit (A) towards the end of this uplift.

Stage 2: The Sabaoe Stable Phase

Further uplift to point of maximum regression. Deposition of intertidal, mixed calcareous - terrigenous sediments in the northern part of the sub - basin.

Stage 3: Bidjeli Subsidence

Deepening of depositional environment. Deposition of offshore barrier bar calcarenites and marls.

Stage 4: Acceleration of the Bidjeli Subsidence

Rapid offshore deepening leading to slumping. Deposition of low energy marls.

(b) The Sabaoe Limestone Formation of the central and southern parts of the Noele Sub - basin.

The Sabaoe Limestone Formation crops out in the central part

Fig. 9: Sabaoe Limestone Formation, Noele anticline section, Noele Sub - basin.

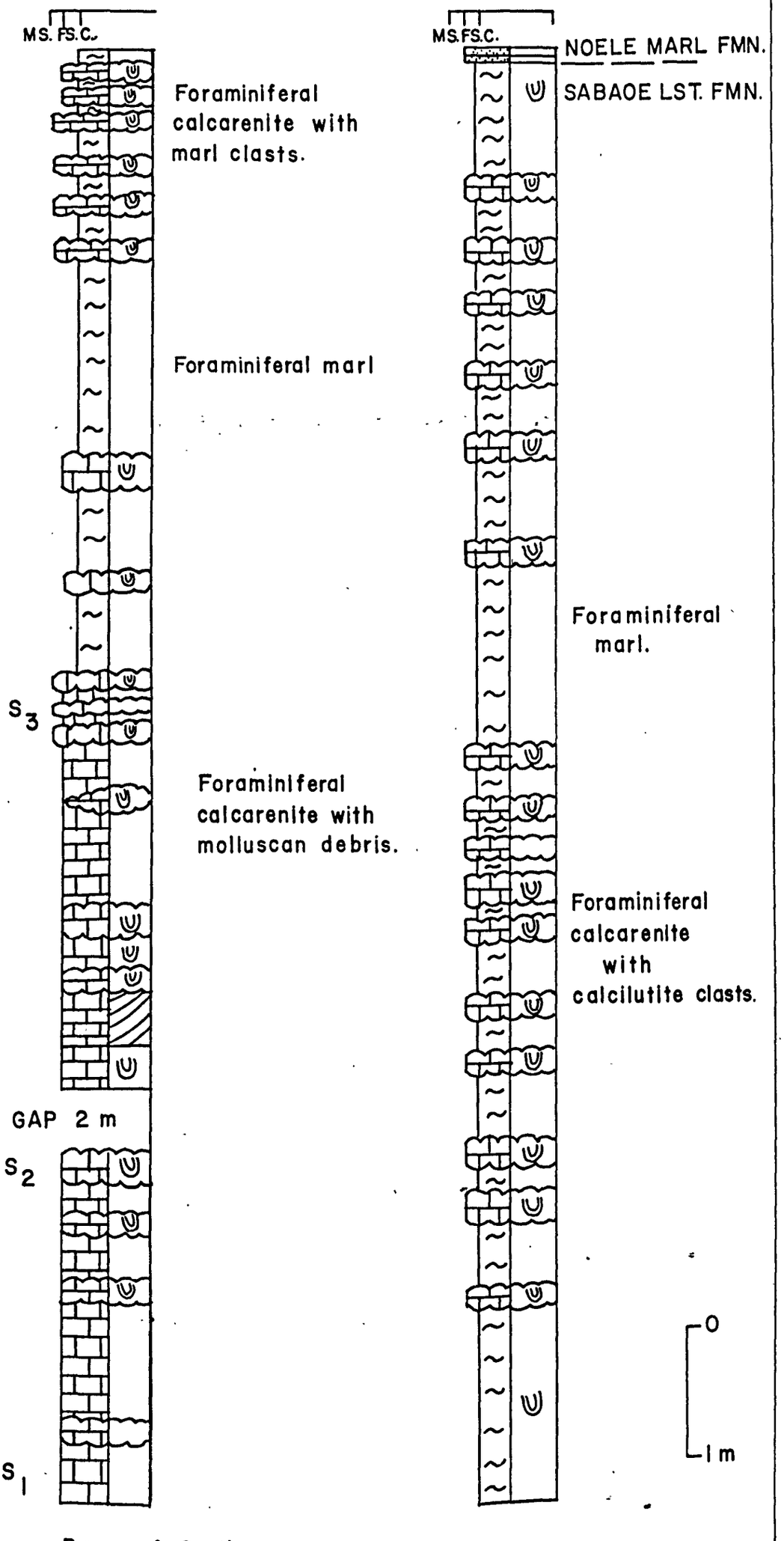
Exposed section showing good development of foraminiferal and molluscan calcarenites with foraminiferal marl interbeds. Note the high proportion of the latter and the poor development of cross - bedding.

For location of section see Fig. 6.

S_1, S_2 etc. refer to sample numbers

SECTION 620

cont'd next col.



Base of Section

of the sub - basin in the Noele anticline (Fig. 9), and in the southern part in the Oemenu river. The succession at these localities consists of 22 and 11 metres respectively of grey, marly, foraminiferal and shelly calcarenite with interbeds of grey, foraminiferal marl (Plate 4, A). Cross - bedding is rare and bioturbation abundant. In both sections the contact with the overlying Noele Marl Formation is unconformable. The base of the Sabaoe Limestone Formation is not seen in the Noele anticline, but is strongly unconformable where exposed in the Oemenu section.

Depositional environment

Both sequences correspond to unit (A) of the type section and are similarly interpreted as offshore, shallow water carbonates of deeper shelf origin. The reduced percentage of marl in the southernmost outcrop compared to that in the basin centre suggests a shallower environment of deposition.

(ii) The Sabaoe Limestone Formation of the Bokong Sub - basin

The Sabaoe Limestone Formation crops out in the Bokong Sub - basin only at the extreme southern margin (Fig. 10) adjacent to the Bokong - Batu Putih fault zone, where the following subdivisions are recognised;

(a) The Kali Bokong section

(b) The Noilmina section (containing the Noilmina Limestone Member)

(c) The Fatu Antoni section (comprising the Fatu Antoni Member)

Fig. 10: Sabaoe Limestone Formation: Location map of outcrops in the Bokong - Batu Putih fault zone at the southern edge of the Bokong Sub - basin.

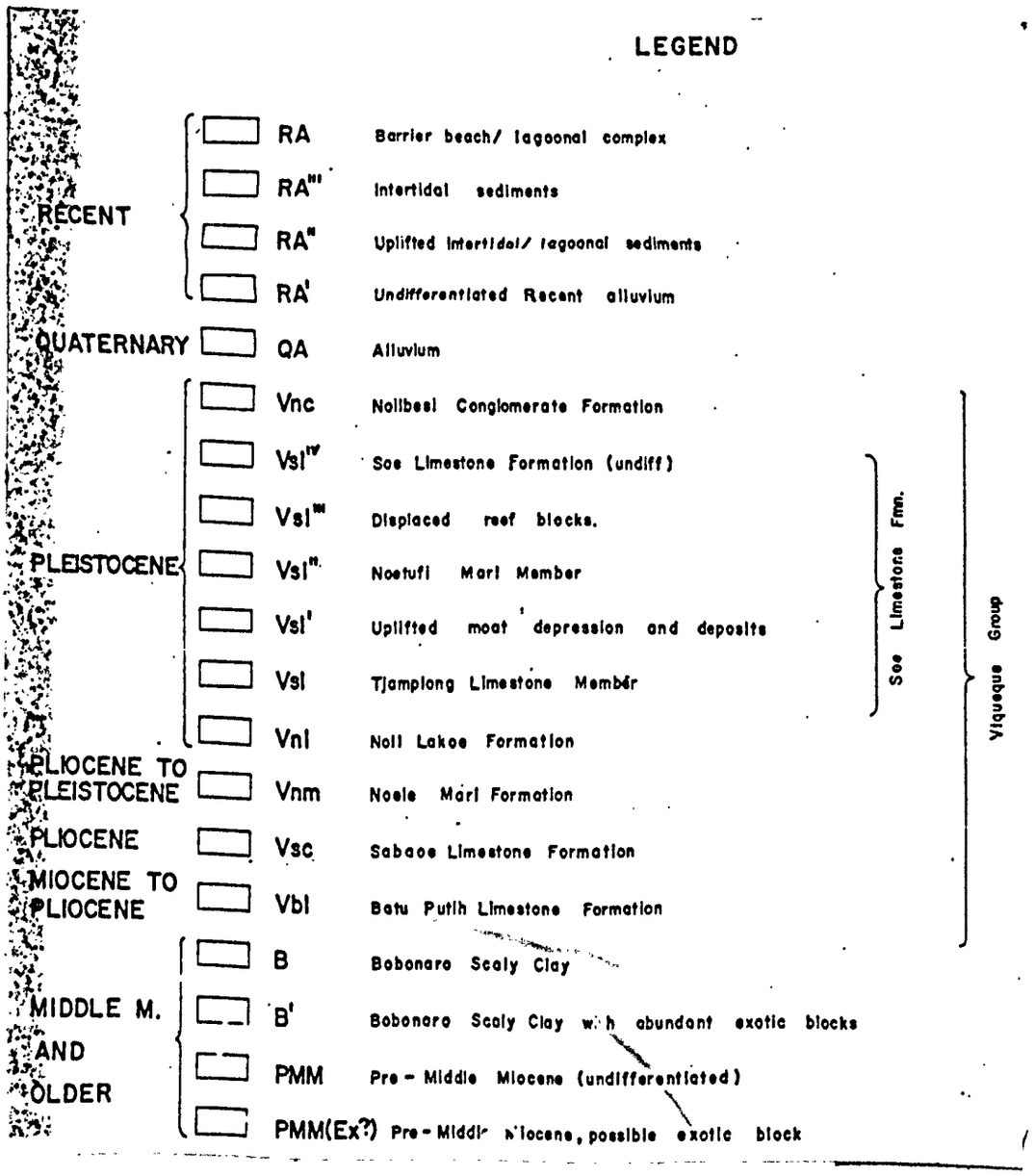
1: Kali Bokong section.

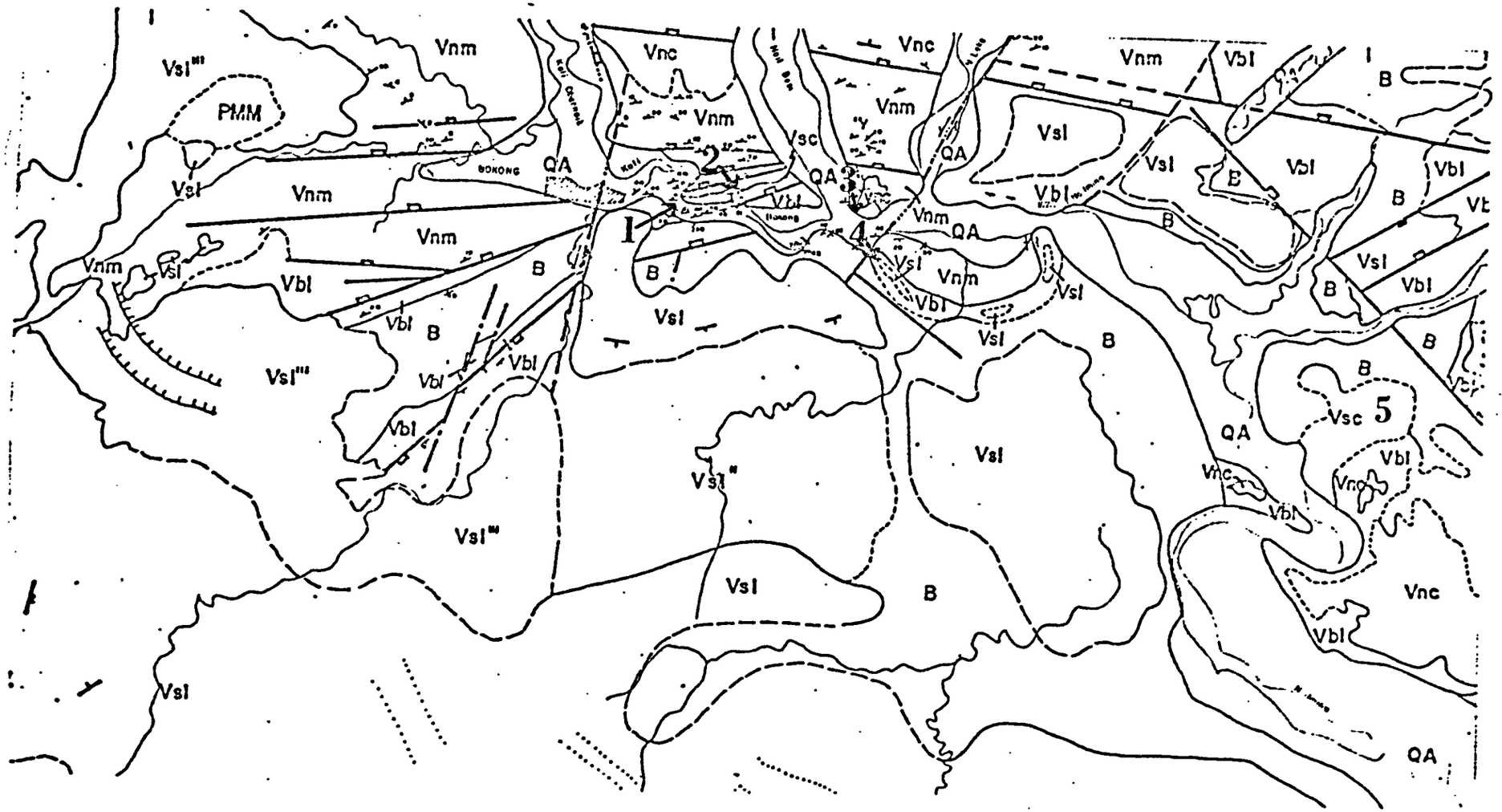
2: Fatu Antoni Member, type section.

3: Section 401, Noilmina Limestone Member, type section.

4: Section 407, Noilmina Limestone Member.

5: Outcrop of Noilmina Limestone Member on the Panite High.




Vsl'''
PMM
Vnm
Vnc
Vsc
Vbl
Vsl
QA
B
Vsl''
Vsl'
1
2
3
4
5
Km. 1 0 1 2 3 4 5 6 7 8 Km
MILES 1 0 1 2 3 4 5 MILES

(a) The Kali Bokong section

About twelve metres of marly calcarenite similar to unit (A) of the type section is exposed in the strongly faulted, northward dipping succession immediately north of the Obernaik - Kupang road intersection east of Bokong.

(b) The Noilmina sections

The Sabaoe Limestone Formation crops out in the Bokong - Batu Putih fault zone between Tacari and Noilmina as a series of bright yellow, well - sorted, foraminiferal calcarenites, of maximum thickness 27 metres, defined as the Noilmina Limestone Member. In addition to the high proportion of foraminifera, heavy mineral grains occur in laminae or along ripple surfaces in flaser bedding. Unidirectional, planar and trough cross - lamination is abundant in sets averaging 75 cm. in thickness. Inferred current directions throughout the sequence are from south to north. An angular discordance is present within the sequence (Fig. 11, section 401 and Plate 4, B). Oversteepening and slumping of cross - bedding also occurs.

The member is succeeded transitionally by a thin succession of grey, marly, shelly calcarenites (Fig. 11), which passes transitionally upwards into the Globigerina marls of the Noele Marl Formation.

Environment of deposition

The high degree of sorting, abundance of cross - bedding and the occurrence of abundant heavy minerals suggest deposition in a very high energy, shallow water environment. Similar foraminiferal calcarenites have been described by Van Andel and Veevers (1967) from positions on the edge of the Sahul Shelf opposite Timor; from the edge

Fig. 11: Sabaoe Limestone Formation: Noilmina sections, Bokong Sub - basin. Stratigraphic sections showing sequences fining upwards from foraminiferal calcarenites of shallow shelf origin to marly calcarenites of deeper shelf origin to deeper water, offshore Globigerina marls of the Noele Marl Formation.

Section 401 includes the type section of the Noilmina Limestone Member.

For location of sections see Fig. 10.

SABAOE LIMESTONE FORMATION

STRATIGRAPHIC SECTIONS 401 & 407

LOCATION : NOILMINA, BOKONG SUB-BASIN

401

407

EARLY PLEISTOCENE (N22)

MIDDLE AND LATE PLIOCENE - (N.21)

E.PLIOC(N20)

NOELE UPLIFT

BIDJELI SUBSIDENCE

SABAOE STABLE PHASE

FATU LAOB UPLIFT

Grey Globigerina marl with graded arenites.

S_{21}

S_{20}

S_{17-19}

S_{16}

S_{15}

GAP 67m

Sandy Globigerina marl with thin arenite intercalations.

Globigerina marl with fine arenite intercalations

S_{15}

DEEP WATER

Globigerina marls with turbidites.

NUANAIN SANDSTONE MEMBER

Grey Globigerina marl with molluscan debris

S_{14}

Sandy Globigerina marl with molluscan debris.

OFFSHORE, DEEPER WATER

Globigerina marls

S_{13}

S_{14}

NOELE MARL FORMATION

SABAOE LIMESTONE FORMATION

S_{11}

Finer, grey foraminiferal calcarenites with marl admixture.

Irregular bedding.

Grey foraminiferal Calcarenite

DEEPER WATER SHELF

Marly Calcarenites

S_{10}

S_6

S_9

NOILMINA LIMESTONE MEMBER

S_8

As below. with flaser-bedding

S_7

S_6

S_5

S_{13}

Yellow foraminiferal calcarenite with abundant terrigenous clasts and heavy minerals

Bioturbated

S_4

S_{11}

S_{12}

S_3

Yellow foraminiferal calcarenites with heavy mineral laminae

SHALLOW WATER SHELF

Foraminiferal Calcarenites

S_4

Display cross-bedding and parallel lamination.

S_2

S_1

F

F

S_3

DISCONFORMITY

As above

S_2

SABAOE LIMESTONE FORMATION / BATU PUTIH LIMESTONE FORMATION

DEEPER WATER

LIME MUDSTONES

S_1

F

F

0 Metres

2

4

of the Gulf of Mexico (Curray, 1960) and from the Guyana Shelf (Nota, 1958).

The transitional passage of the member into deeper water, marly calcarenite of the upper part of the section (Fig. 11) marks the beginning of the Bidjeli Subsidence in the Bokong Sub - basin.

(c) The Fatu Antoni section

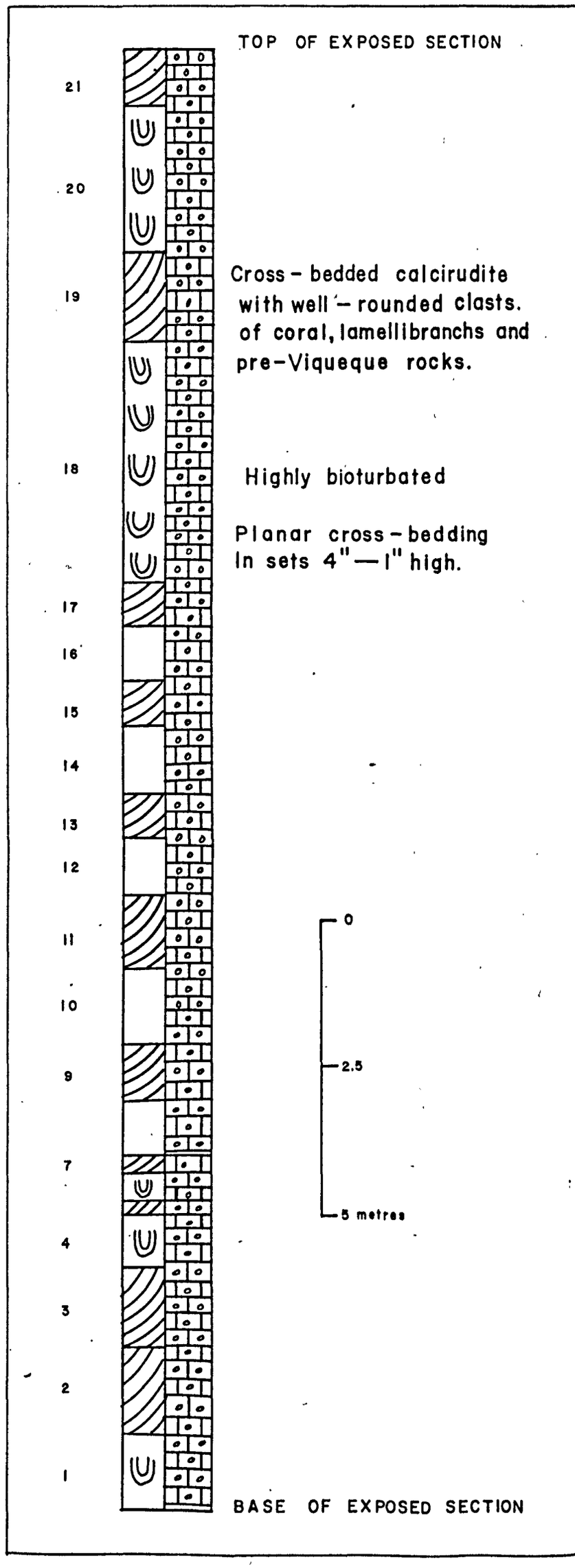
The Fatu Antoni Member consists of a series of structurally inverted, coarse conglomerates, of maximum exposed thickness 26 metres, which form the hogback hill of Fatu Antoni, directly north of Tacari. The succession (Fig. 12) consists of a mixed carbonate/terrigenous conglomerate containing a wide variety of coral, molluscan, calcilutite, clay, sandstone and echinoid debris. The terrigenous debris is derived from the Batu Putih Limestone and Bobonaro Scaly Clay Formations. Rounded clasts of chert and flint are also common. The sequence is well bioturbated, cross - bedded and possesses a calcite cement. The upper and lower contacts of the sequence are not exposed, but are probably transitional, as in other Sabaoe Limestone units of the region. The member appears to be a lateral equivalent of the Noilmina Limestone Member to the east and the marly calcarenites of the Kali Bokong section to the west, both of which crop out along the same present - day structural strike (Fig. 10).

Environment of deposition

The very coarse nature of the deposit, abundance of marine invertebrate remains, and absence of features of fluviatile deposition strongly suggest that the Fatu Antoni Member is a beach conglomerate.

Fig. 12: Sabaoe Limestone Formation: Fatu Antoni Member, Bokong Sub-basin. Type section illustrating uniform development of cross - bedded, coarse calcirudite of predominantly beach origin.

For location of section see Fig. 10.



FATU ANTONI CONGLOMERATE MEMBER: TYPE SECTION.

(iii) The Sabaoe Limestone Formation of the Panite High

Outcrops of Sabaoe Limestone Formation south of the Bokong - Batu Putih fault zone consist exclusively of yellow, foraminiferal calcarenites of the Noilmina Limestone Member. These outcrops vary from 1 to 30 metres in thickness. An angular unconformity between the Sabaoe Limestone Formation and underlying Batu Putih Limestone is present north-west of Panite(Plate 5, A).

Environment of deposition

The depositional environment of the region south of the Bokong Sub - basin is likely to have been very shallow water marine, of much higher energy than that which existed within the sub - basin to the north.

(iv) The Sabaoe Limestone Formation of the Kolbano region

Outcrops of Sabaoe Limestone Formation appear to be generally absent due to erosion in the greater part of the region south of the Noele Sub - basin. Carter (unpublished report, dated 1971,b) however, reports a possible N21 age for certain samples collected by Audley - Charles from within imbricate thrust slices amongst the Cretaceous of the Kolbano mountains. Although Carter's determination states only a general N18 to N21 age range for some of these samples, his description of them as 'pale buff, sandy, glauconitic limestone' identifies them as lithologically, if not chronologically equivalent to the Sabaoe Limestone Formation of the Central Basin to the north.

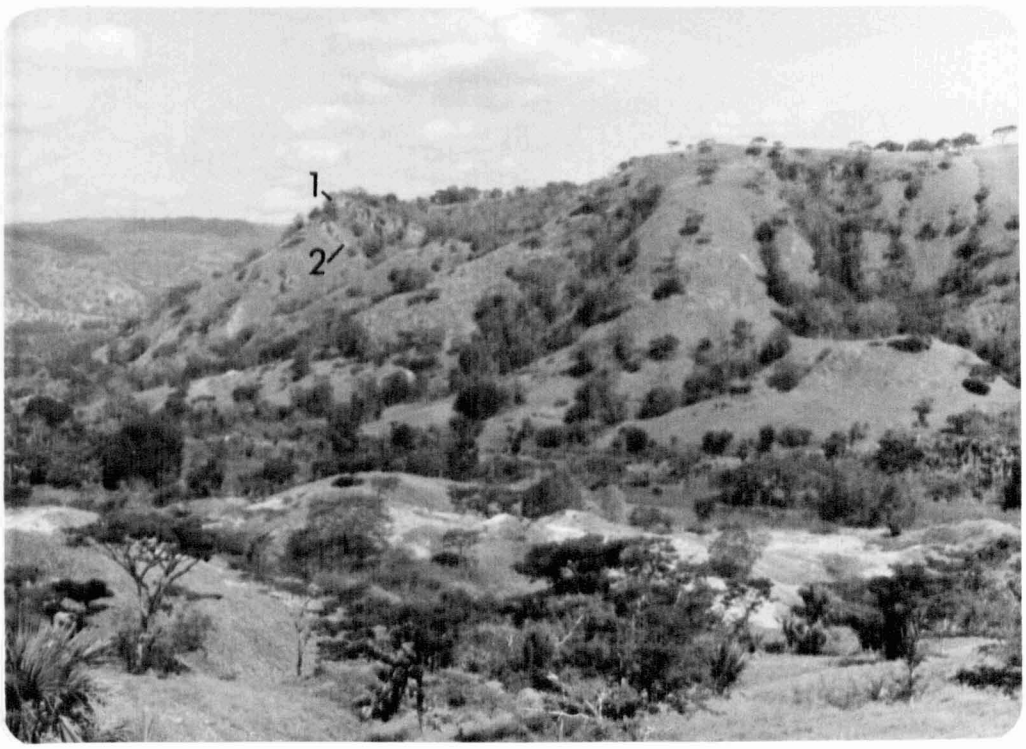
Assuming that the Sabaoe Limestone Formation samples are indeed from the imbricate thrust slices themselves, the latest age of this thrusting must obviously be post - Sabaoe Limestone. As the major period of compressive movement in the history of the Viqueque Group took place

Plate 5: Sabaoe Limestone Formation, southern platform region:

A: Gently dipping Sabaoe Limestone beds (1) unconformably overlying steeply dipping Batu Putih Limestone Formation (2). Bobonaro Scaly Clay crops out in the valley area below the Batu Putih Limestone.

Location: three miles north - west of Panite.

A



during deposition of the upper part of the Noele Marl Formation, it might be assumed that compression in the Kolbano region, and incorporation of the Sabaoe Limestone also took place during that time. Evidence against this is the apparent absence of sediments of Noele Marl Formation age within the imbricate thrust slices. There is evidence furthermore, in the form of unconformities within the Sabaoe Limestone Formation of the Oemenu section in the southern part of the Noele Sub - basin (to the north of the Kolbano mountains) that some compressive movements did take place at the end of Sabaoe Limestone deposition. These compressive movements may have been of sufficient strength to cause reactivation of previously existing imbricate zones in the Cretaceous Kolbano structure.

(v) The Sabaoe Limestone Formation of Portuguese Timor

Beds in equivalent stratigraphic position to the Sabaoe Limestone Formation of Indonesian Timor have not been described from Portuguese Timor. Examination by the writer of Audley - Charles' (1968) original type section of the Viqueque Formation in the Viqueque anticline revealed an apparent transitional passage from the marls of the Batu Putih Limestone Formation into the Globigerina marls and turbidites of the succeeding Noele Marl Formation. No outcrops of the Sabaoe Limestone Formation were found in either the Colitie or Viqueque basins. An age determination by Carter (unpublished report, dated 1971a) of samples collected from these successions suggested the presence of a considerable hiatus between the Batu Putih Limestone and Noele Marl of these successions. This hiatus appears to have lasted from uppermost Early Pliocene to lowermost Late Pliocene. The Sabaoe Limestone Formation does outcrop, however, in the northern part of Portuguese Timor as a

series of calcarenites and calcirudites achieving a maximum thickness of 4 metres. This unit is here named the Bere Cole Member, from the village of Bere Cole near the type section. In the latter, the member follows transitionally from the Batu Putih Limestone calcilutite unit, and is overlain unconformably by the reef limestone of the Baucau Limestone Formation (Soe Limestone equivalent).

The Lari Guti Limestone

Audley - Charles (1968) described a series of foraminiferal calcarenites and reefs, which he named the Lari Guti Limestone, from the mountains directly north of the south coast Portuguese Timor basins. Although the Early Pliocene age of these suggests slightly earlier deposition than the Sabaoe Limestone Formation of Indonesian Timor, it is probable that the beds were deposited in the shallow water environment that must have existed as the Portuguese Timor peaks emerged during the Fatu Laob Uplift.

E Microfauna

The following foraminifera have been identified by Mr. D. J. Carter (unpublished report, dated 1970a) from the Sabaoe Limestone Formation:

(a) Planktonics

Orbulina universa

Globorotalia cultrata menardii

G. subcretacea

G. acostaensis pseudopima

G. borealis

G. cultrata cultrata

Pulleniatina spp.

Sphaeroidinella dehiscens

Globigerinoides gomitulus

G. conglobatus gp.

G. quadrilobatus gp.

(b) Benthonics

Textularia spp.	Globocassidulina spp.
Spiroplectammina spp.	Planulina spp.
Miliolacea	Orissodorsalis spp
Nodosariacea	Peneroplidae
Uvigerina spp.	
Cibicides spp.	

F. Age

Samples from the Oemenu and Noele anticline sections of the Sabaoe Limestone Formation were assigned a lowermost Late Pliocene age by Carter (unpublished report, dated 1970a), who placed them in the lowermost part of his Globigerinoides quadrilobatus fistulosus zone, equivalent to the lower part of the N21 zone of Blow (1969).

G. Palaeogeographic development of the Central Basin during Sabaoe Limestone deposition

The following palaeogeography is postulated for Sabaoe Limestone times (Fig. 13, A and B):

(i) A northern positive area; coinciding with the present day Northern Mountains, and consisting of a low lying land area, a shelf region or an archipelago of small islands of low relief. Although the Sabaoe Limestone does not outcrop north of the Central Basin, the existence of a more positive region to the north is inferred from (a) the shoreline facies in the Kali Sabaoe section of the Noele Sub - basin; (b) the northwards derived slump sheet in the uppermost part of the same section (Fig. 14) and (c) the dominance of the region to the north of the Central Basin as a positive area throughout most of Viqueque deposition and at the present day.

Fig. 13: Sabaoe Limestone Formation

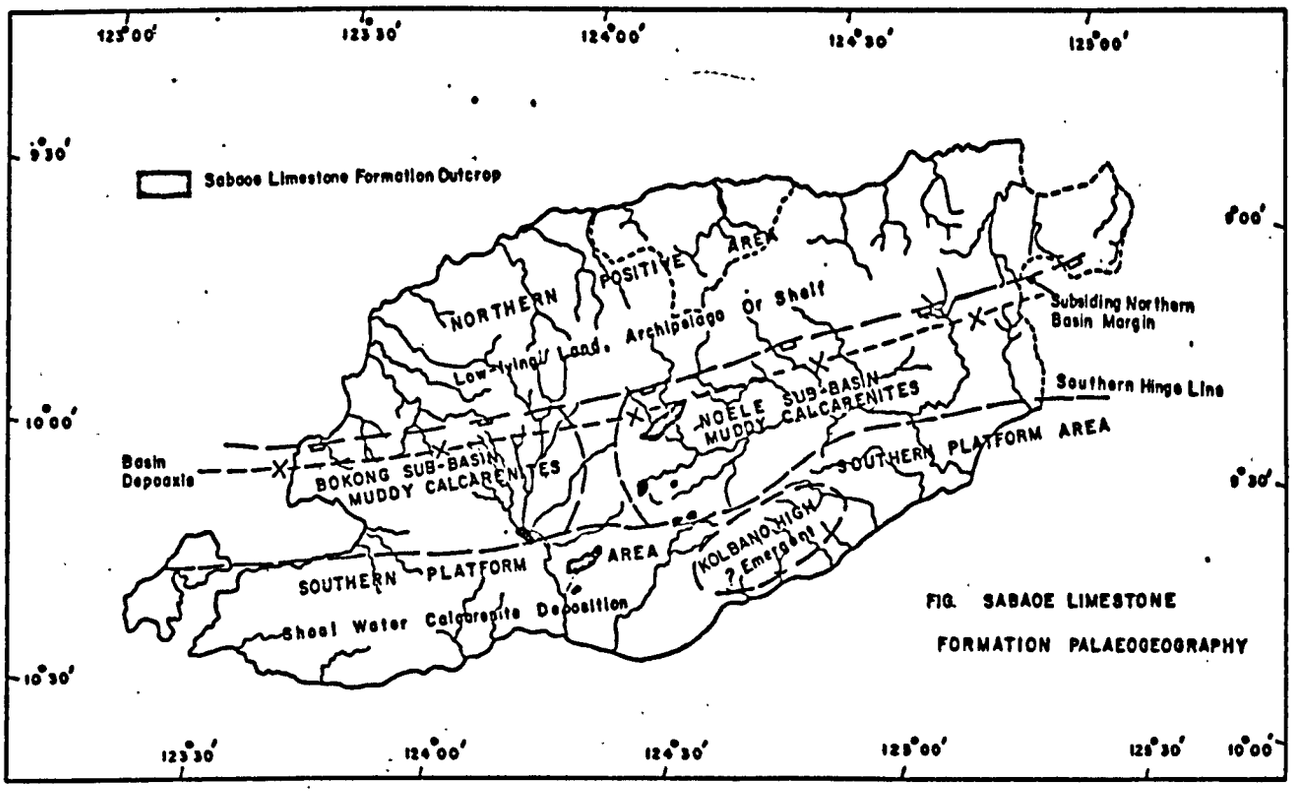
A. Sabaoe Limestone Formation palaeogeography, illustrating three - fold physiographic subdivision of Indonesian Timor into (i) a northern positive area; (ii) a central basinal area (comprising Bokong and Noele Sub - basins) and (iii) a southern platform area.

B. Diagrammatic north - south cross section across Central Basin near close of Sabaoe Limestone deposition, illustrating rapid deepening of the sub - Sabaoe Limestone depositional surface (cross - hatched) towards active northern fault zone.

Note the resulting transition from high energy, shelf calcarenites in the south to lower energy, marly calcarenites in the basinal area to the north. The beach conglomerates of the Fatu Antoni Member occur in the region of the southern hinge zone between the above regions.

Diagram is a composite one, using evidence from both Bokong and Noele Sub - basins.

A


123°00'
123°30'
124°00'
124°30'
125°00'
9°30'
10°00'
10°30'
Sabaoe Limestone Formation Outcrop
NORTHERN POSITIVE AREA
Low-lying Land, Archipelago Or Shelf
Subsiding Northern Basin Margin
Southern Hinge Line
NOELE SUB-BASIN MUDDY CALCARENITES
BOKONG SUB-BASIN MUDDY CALCARENITES
Basin Depoaxis
SOUTHERN PLATFORM AREA
KOLBANO HIGH ? Emergent
SOUTHERN PLATFORM AREA
Shoal Water Calcarenite Deposition
FIG. SABAOE LIMESTONE FORMATION PALAEOGEOGRAPHY

B

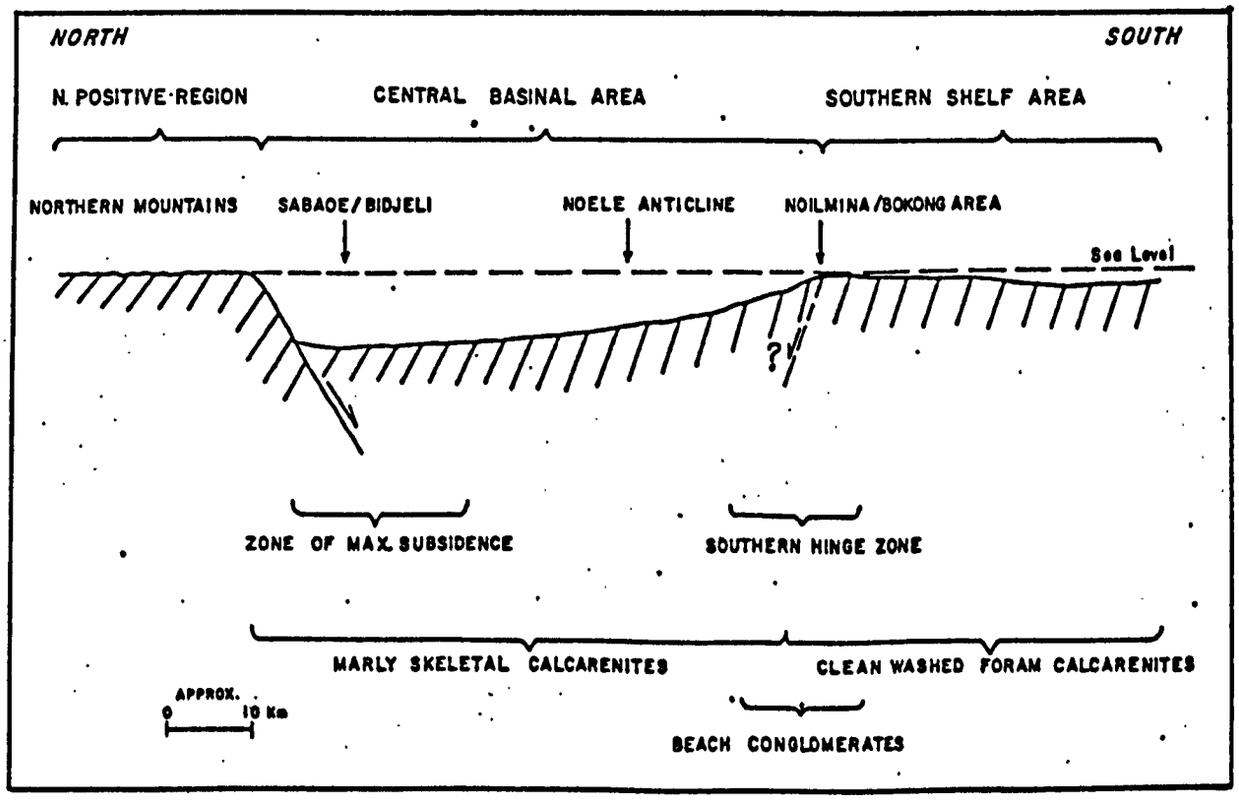

NORTH
SOUTH
N. POSITIVE REGION
CENTRAL BASINAL AREA
SOUTHERN SHELF AREA
NORTHERN MOUNTAINS
SABAOE/BIDJELI
NOELE ANTICLINE
NOILMINA/BOKONG AREA
Sea Level
?
ZONE OF MAX. SUBSIDENCE
SOUTHERN HINGE ZONE
MARLY SKELETAL CALCARENITES
CLEAN WASHED FORAM CALCARENITES
APPROX.
0 10 Km
BEACH CONGLOMERATES

Fig. 14: Sabaoe Limestone Formation: Correlation of stratigraphic sections from the Bokong and Noele Sub - basins and Panite High.

Note the rapid northwards thickening of section in the Noele Sub - basin and the marked difference in depositional environment between sediments deposited in the sub - basins (deeper shelf marly calcarenites) and those deposited to the south of the basinal areas (shallow water shelf calcarenites).

Inset: A. Bokong Sub - basin.

B. Noele Sub - basin.

C. Panite High.

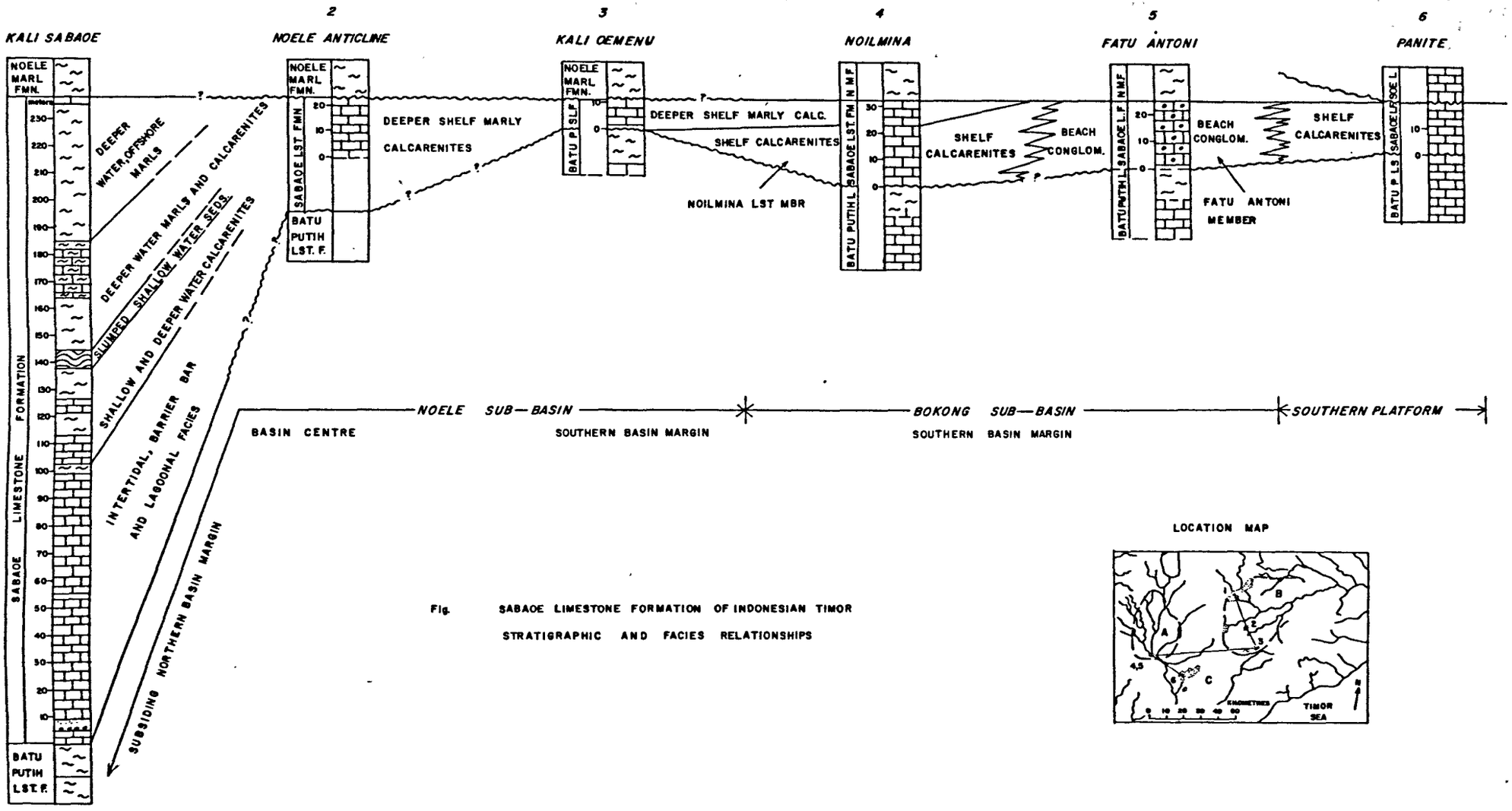


Fig. SABAOE LIMESTONE FORMATION OF INDONESIAN TIMOR
STRATIGRAPHIC AND FACIES RELATIONSHIPS

That this region possessed only moderate to low relief is suggested by the general lack of clastic detritus in the Sabaoe Limestone Formation of the northern part of the Noele Sub - basin.

(ii) A central basinal area, the extent of which coincided approximately with that of the present Bokong and Noele Sub - basins. Throughout this generally negative area, deposition took place mostly under conditions of deeper shelf sedimentation, so that the resulting calcarenites are marly and contain interbeds of deeper water Globigerina marl.

Evidence from the northern basin margin sections of the Noele Sub - basin suggests that the northern part of this negative area formed the depoaxis of the Central Basin area. This depoaxis, situated just to the south of the boundary between the northern positive and central negative areas is evidenced by (a) the rapid thickening of the Sabaoe Limestone succession northwards across the Noele Sub - basin and (b) by the disappearance of the upper and lower unconformities of the Sabaoe Limestone in the same direction (Fig. 14). Deposition in this region apparently did not keep pace with subsidence, producing an at first gradually, then rapidly deepening succession present in the Kali Sabaoe and Bidjeli sections. The'half graben' shape of the Central Basin at the end of Sabaoe Limestone deposition and the rapid subsidence of the northern part of the basin suggests the existence of a major east - west fault zone between the Central Basin and northern positive areas. Rapid subsidence along this fault zone, and production of a rapidly increasing south - sloping gradient between the two regions presumably led to the southwards slumping of the calcarenites found in the deeper water, upper part of the Sabaoe Limestone succession of the

type section.

Although outcrops are not present in the central and northern parts of the Bokong Sub - basin, the existence of marly calcarenites in the Kali Bokong section at the extreme southern edge of the basin suggests similar conditions.

(iii) A southern shelf area

The region south of the Noele and Bokong Sub - basins appears to have been one of very shallow water deposition, producing the well - sorted calcarenites of the Noilmina Limestone Member, which occur throughout this region.

Between regions (ii) and (iii) a southern hinge zone must have been present. Along this hinge zone were deposited either at isolated, or at numerous, now unexposed locations, beach conglomerates of Fatu Antoni type and well - sorted, yellow, foraminiferal calcarenites.

With the possible exception of the northern positive region, subsidence appears to have affected most regions of Timor at the close of Sabaoe Limestone times, so that even the calcarenites of the Noilmina Limestone Member occurring along the southern hinge line pass transitionally upwards into deeper water, marly calcarenites before giving way to the Globigerina marls of the Noele Marl Formation.

Chapter 5. The Noele Marl Formation.

(A) Summary

The Noele Marl Formation is defined as a series of grey Globigerina marls and subordinate sandstones of maximum measured thickness 710 metres, which occurs in the Noele and Bokong Sub-basins of Indonesian Timor and in the south coast basins of Portuguese Timor. The following formal stratigraphic units of the formation are defined: (a) the Ofua Sandstone Member of Early N21 (Late Pliocene) age, shown to be a fan-valley deposit; (b) the Oemenu Sandstone Member of Late N21 (Late Pliocene) age, interpreted as a deep water density flow deposit from a shelf source; (c) the Nuanain Sandstone Member of N22 (Early Pleistocene) age, comprising turbidites deposited in the suprafan area of a submarine fan complex, with a fan-valley distributary channel (the Fautao Conglomerate Bed); (d) the Nanfua Sandstone Member of N22 (Early to Middle Pleistocene) age, of proximal fan-valley or submarine canyon origin; (e) the Tanah Putih Marl Member, of Late N22 (Early to Middle Pleistocene) age, of brackish lagoonal origin; (f) the Obernaik Member, also of Late N22 age, of shoreline/shallow marine origin and (g) the Samé Conglomerate Member of N22 (Early Pleistocene) age, interpreted as a base of slope proximal turbidite deposit.

The Noele Marl Formation is shown to be of Late Pliocene (N21) to Early Pleistocene (N22) age, the Plio-Pleistocene boundary being placed at the base of the Nuanain Sandstone Member.

The age of the important Mataian folding of Audley-Charles (1968) is shown to be Pleistocene, rather than Pliocene as previously

supposed, and is shown on tentative evidence to have begun at the Pleistocene/Pliocene boundary, and to have continued until the close of Tanah Putih Marl deposition (Early to Middle Pleistocene, N22) in the Bokong Sub-basin and Nuanain Sandstone deposition (N22) in the Noele Sub-basin.

In addition to the widespread production of clastic material which followed the onset of the Mataian Orogeny, a brief period of clastic deposition is shown to have been associated with the close of the Bidjelian folding phase earlier defined. A period of relative tectonic quiescence is shown to have existed between these two phases and to have been associated with the buildup of well-sorted shelf and/or beach clastic sediments on the distant (northern) shoreline.

B. Stratigraphy of the Noele Marl Formation of the Noele Sub-basin.

(i) The Noele Marl Formation type section: Noele Sub-basin southern margin.

The thickest, best exposed and least tectonised development of the Noele Marl in Timor is that cropping out in the vicinity of Noele in the Noele Sub-basin (Fig. 15). This succession, where exposed along the rivers Oemenu and Fekufatu (Fig. 16) is chosen as the type section of the formation. It extends from the contact with the Sabaoe Limestone Formation to the base of the Nuanain Sandstone Member (see below) in the Oemenu River, resumes at the base of that member on the southern limb of the Noele anticline, two miles to the north, and is completed on the northern limb of the Noele anticline in the Fekufatu River. The type section ends at the contact with the

Fig. 15: Noele Marl Formation, type section, rivers Oemenu and Fekufatu, Noele Sub - basin.

For exact locality see Fig. 16.

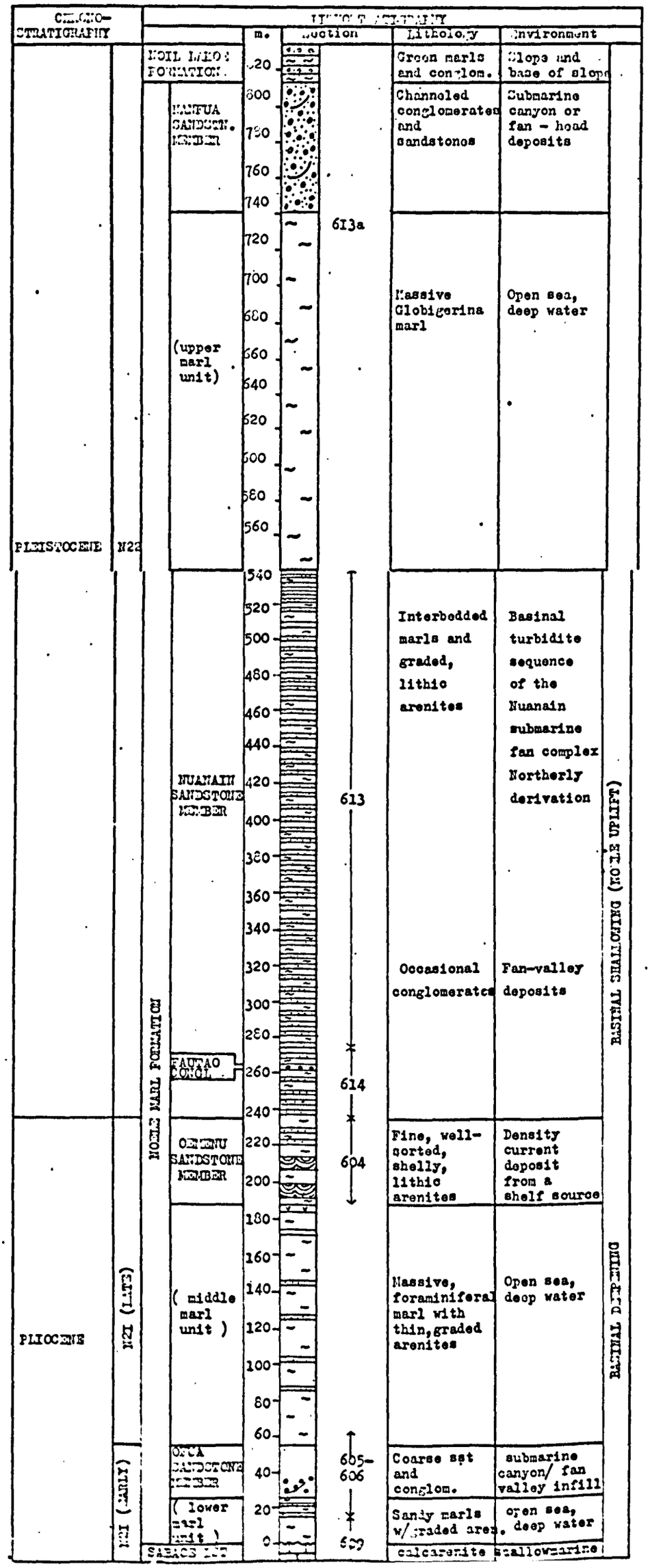
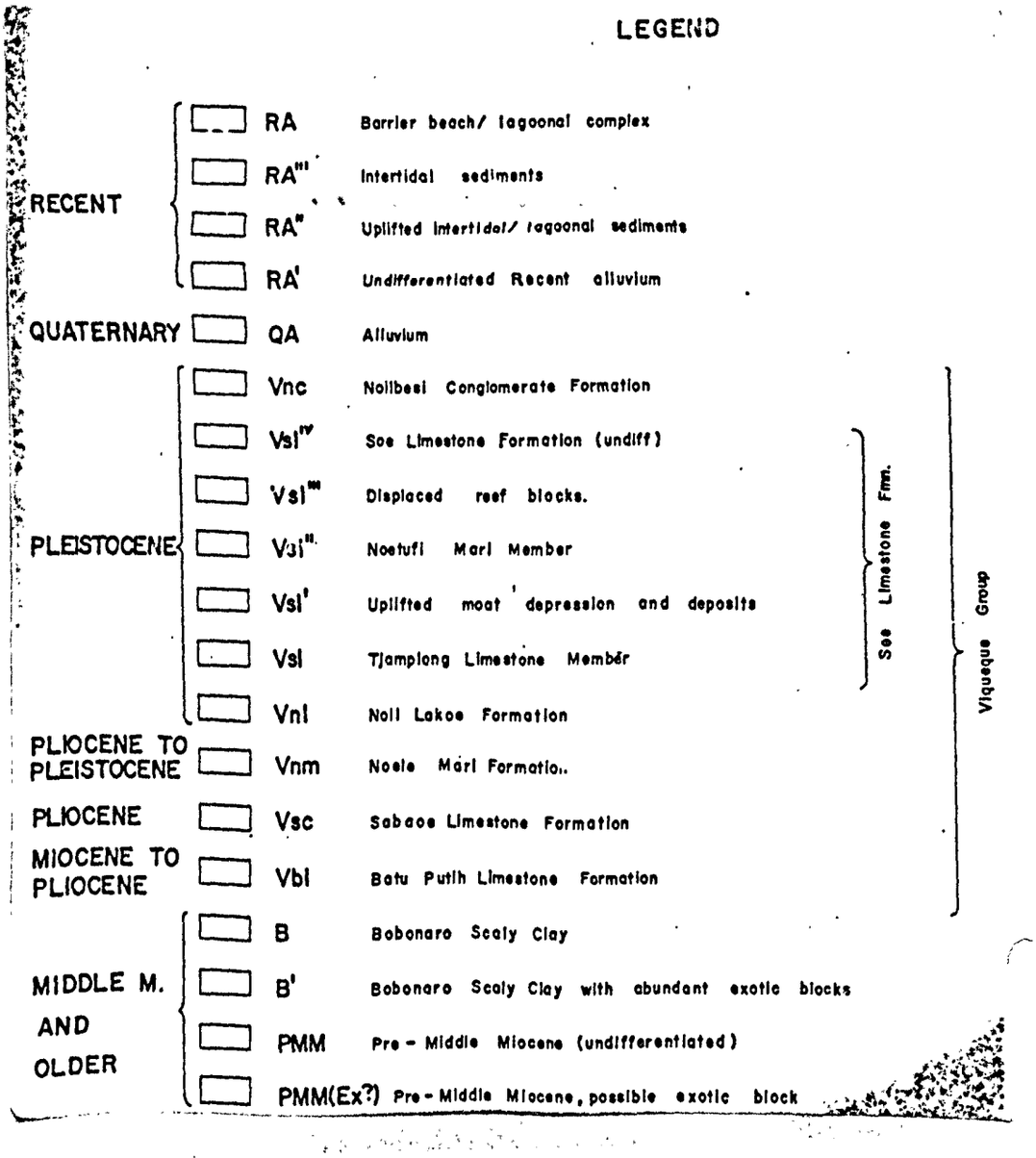
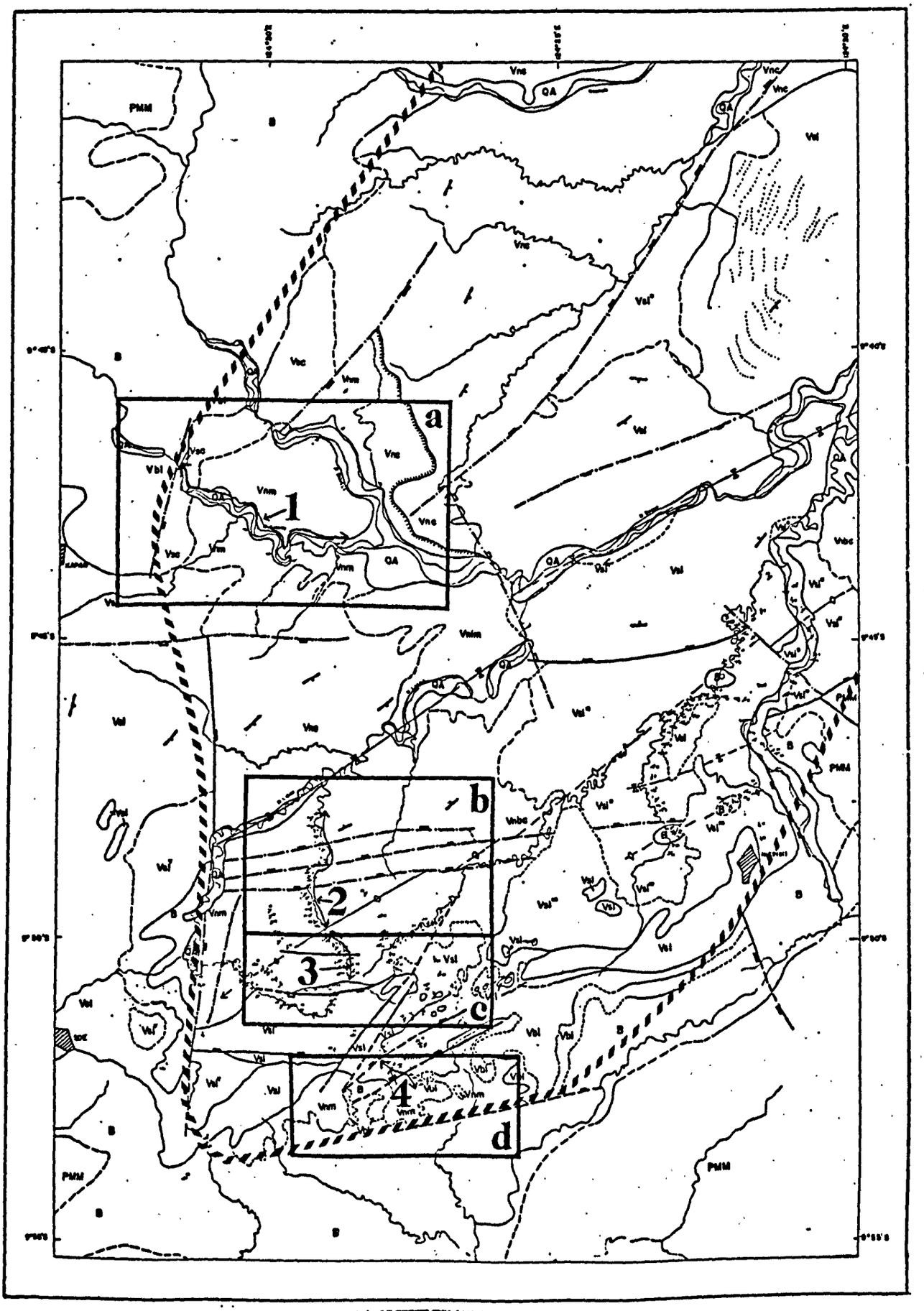

CHRONO-STRATIGRAPHY
LITHOSTRATIGRAPHY
m.
Section
Lithology
Environment
NOIL LIKOI FORMATION
Green marls and conglom.
Slope and base of slope
MANFUA SANDSTN. MEMBER
Channeled conglomerates and sandstones
Submarine canyon or fan - head deposits
(upper marl unit)
Massive Globigerina marl
Open sea, deep water
PLEISTOCENE
N22
NUANAIN SANDSTONE MEMBER
Interbedded marls and graded, lithic arenites
Basinal turbidite sequence of the Nuanain submarine fan complex Northerly derivation
Occasional conglomerates
Fan-valley deposits
FAUTAO CONGL.
NOEL KARL FORMATION
OEMENU SANDSTONE MEMBER
Fine, well-sorted, shelly, lithic arenites
Density current deposit from a shelf source
PLIOCENE
N21 (LATE)
(middle marl unit)
Massive, foraminiferal marl with thin, graded arenites
Open sea, deep water
OPCA SANDSTONE MEMBER
Coarse sst and conglom.
submarine canyon/ fan valley infill
N21 (EARLY)
(lower marl unit)
Sandy marls w/ graded area.
open sea, deep water
SABAOS LST
calcarenite
shallow marine
613a
613
614
604
605-606
609
BASINAL SHALLOWING (NOLE UPLIFT)
BASINAL DEEPENING

Fig. 16: Noele Sub - basin location map, outlining major areas of Noele Marl Formation outcrop referred to in text. These are, from north to south: (a) northern basin margin outcrops, including the Kali Sabaoe section (1); (b) the succession of the Noele anticline northern limb, with the principal section along the River Fekufatu (2); (c) the Noele anticline southern limb succession, with measured sections along the River Fekufatu (3); and (d) the southern basin margin outcrops, including measured section along the River Oemenu (4). The type section of the Noele Marl Formation comprises sections (2), (3) and (4).

The dashed line corresponds to the approximate present day limits of outcrop of the pre - Soe Limestone Formation portion of the Viqueque Group in the Noele Sub - basin.




a
1
b
2
3
c
4
d

dark green marls of the Noil Lakoe Formation.

The type section comprises seven major stratigraphic units: four arenite units, distinguished as members of the Noele Marl Formation and three intervening units of Globigerina Marl (Fig. 15).

At the base of the section, lying unconformably above the calcarenites of the Sabaoe Limestone Formation is a series of bioturbated sandy marls containing abundant, comminuted molluscan material. This lower marl unit is succeeded by a thick arenite and conglomerate unit, the Ofua Sandstone Member. Lying above this is a thick sequence of grey Globigerina marl (the middle marl unit) containing occasional, thin-bedded, graded arenites. Another sandstone member, the Oemenu Sandstone Member succeeds these marls and comprises four thick, fine-grained, convolute-bedded arenite units, the highest one of which is succeeded directly by the Nuanain Sandstone Member, consisting of rhythmically bedded sandstones and marls with minor conglomerate development. Another thick marl development (the upper marl unit) succeeds the Nuanain Sandstone Member, and the type section ends with the Nanfua Sandstone Member, which is overlain conformably by the dark green marls of the Noil Lakoe Formation.

Age.

Foraminiferal analysis of samples from this type section by Carter (unpublished report, dated 1970a) has revealed that the Noele Marl Formation ranges in age from Late Pliocene (N21) to Early Pleistocene (N22). The Plio-Pleistocene boundary, characterised by the first appearance of Globorotalia truncatulinoides, is placed

by Carter at the base of the Nuanain Sandstone Member. A Microfaunal distinction is also made between Early and Late N21 zones, this boundary being placed at the top of the Ofua Sandstone Member.

(a) The Ofua Sandstone Member.

The Ofua Sandstone Member (Fig. 17) forms the basal sandstone unit of the Noele Marl type section. The member is 29 metres thick in the type section, which extends from the base of the first massive sandstone in the Noele Marl Formation, to the junction with the overlying Globigerina marl.

Five facies can be recognised within the member and the immediately preceding marl section.

Facies A

Consists of a massive, grey marl with abundant comminuted shell debris and tests of Globigerina and other planktonic foraminifera. This marl represents the 'standard' deep water marine marl occurring throughout the Noele Marl Formation.

Facies B

Consists of white, friable, sometimes graded, tuff beds, displaying parallel and/or convolute lamination.

The absence of reworked terrigenous material within the beds, the graded bedding and the presence of occasional Globigerina tests suggests deposition of originally subaerial material by vertical settling in a marine environment.

Facies C

Interbedded within the marl sequence are numerous, graded lithic arenites, mostly less than 30 cm in thickness. These display the 'A', 'B' and 'ABD' intervals of Bouma (1962) and are therefore interpreted as the products of turbidity currents.

Facies D

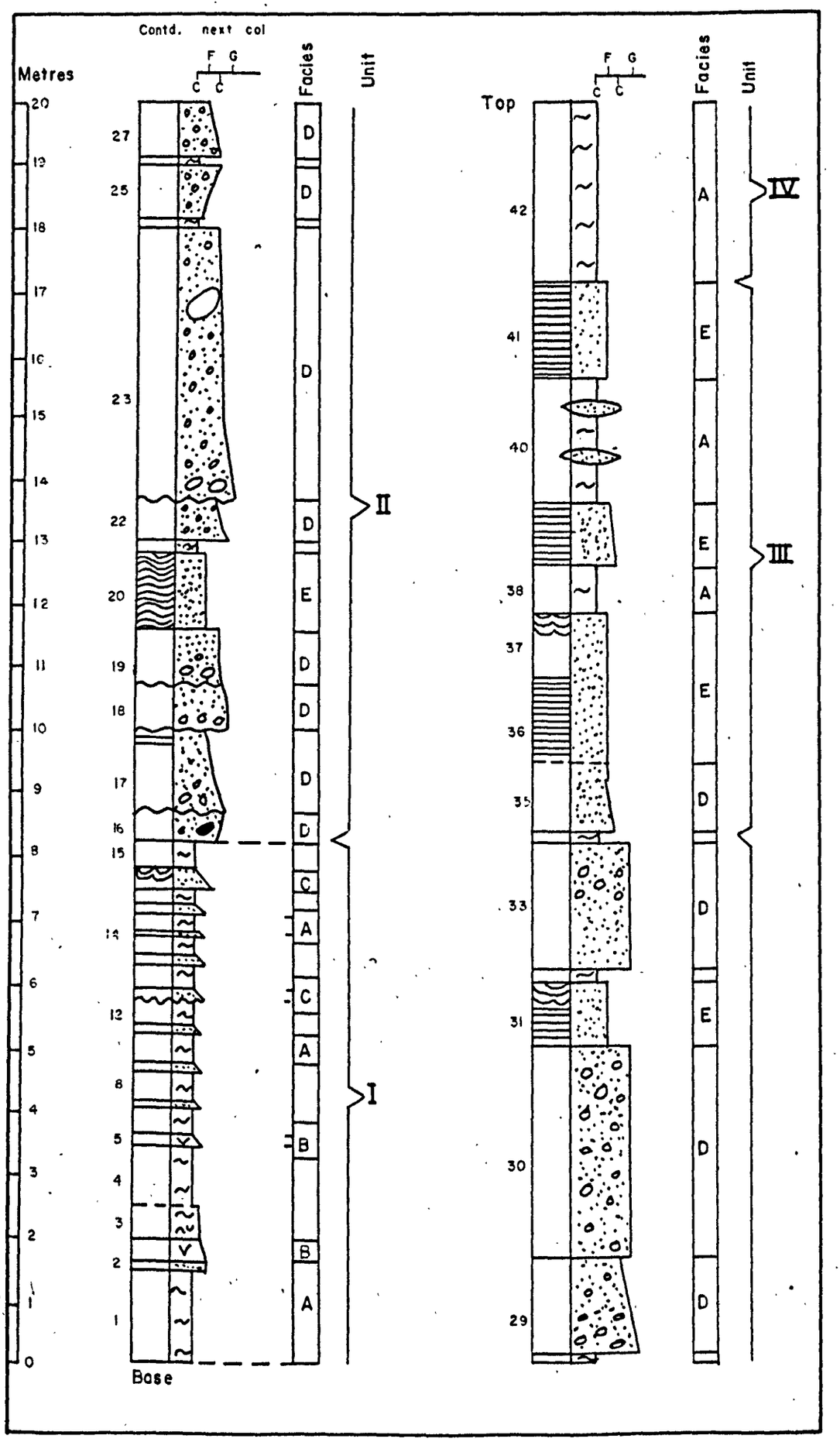
Most of the Ofua Sandstone Member comprises beds of coarse,

Fig. 17: Ofua Sandstone Member, type section, River Oemenu.

Letters refer to facies types (see text); Roman numerals to major environmental units: I: pre - channel marls/turbidites (facies A and C); II: main channel sequence (D and E); III: channel abandonment sequence (E and A) and IV: post - channel basinal marls. Section also shows wide range of grading types amongst conglomerate units (facies D), from 'normal' (e.g. bed 29); reverse (25) to non - graded (30).

The Ofua Sandstone Member extends from the base of unit II to the top of unit III.

For exact position of this section within the Noele Marl Formation type section see Fig. 15.



SECTION 605/606

OFUA SANDSTONE MBR,
NOELE MARL FMN.

TYPE SECTION

lithic arenite and conglomerate. The beds range in thickness from 1 - 5 metres. Graded bedding, clay pellet inclusions, erosive bases and rapid lateral thickness changes are common throughout the section. Large (up to 1m. diameter), isolated, rounded and angular boulders occur in the thicker beds (Plate 6). The grading of some of the beds of facies 'D' and their intercalation with deep water marl of facies 'A' suggests deposition by some form of turbidity current. The coarseness, thickness, lateral impersistence, absence of grading and erosive bases which characterise the coarse conglomerate beds are difficult to explain by turbidity current deposition alone, and the advocation of traction currents and/or sliding (perhaps initiated by the passage of turbidity currents) is necessary to explain their deposition. Traction currents have been advocated for the deposition of similar deposits by Stanley and Unrug (1972).

Facies E

Comprises thick-bedded, convolute and parallel-bedded, medium grained lithic arenites which are interbedded with and succeed the conglomerate units of facies 'D'.

These beds appear to be the result of deposition by turbidity currents of much lower density than those responsible for facies 'D' arenites and conglomerates.

Environment of deposition of the Ofua Sandstone Member.

Conglomerate and coarse arenite sequences similar to the above, which occur in deep-water successions usually mark the positions of former distributary channels on the surface of submarine fans, or of the submarine canyons which feed these channels (Horn et al 1971).

Plate 6: Ofua Sandstone Member, River Oemenu, Noele Sub - basin.

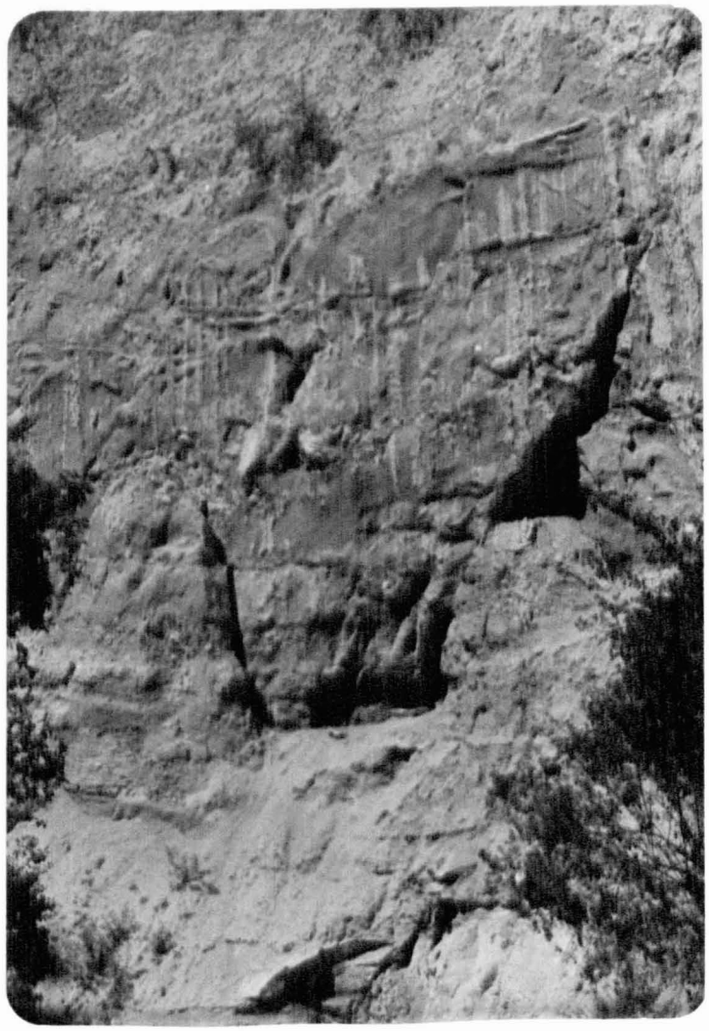
Basal part, showing mostly unit 11 conglomerates and sandstones. A lens of large boulders can be seen within the latter.

About 25 metres of section are present in the lower photograph.

A



B



Most published accounts of cores obtained from the surfaces of modern submarine fans report the apparent confinement of the gravel and coarse sand fraction to the most proximal part of the fan. Consequently, the Ofua Sandstone is likely to have been deposited in the region of Normark's 'upper fan' (Normark 1970) or possibly within a submarine canyon to the shoreward of this zone. This interpretation is reinforced by the presence of boulders within the arenites of facies 'D', suggesting derivation from the canyon walls. Similar boulders in submarine canyons have been reported by Shepard and Dill (1966), Piper (1970) and McKerrow and Campbell (1960).

Interpretation of the Ofua Sandstone Member as a fan-valley infilling is suggested also by the arrangement of facies in the type section (Fig. 17). At the base of the sequence is a series of interbedded arenites and marls of facies A and C (unit I). This is succeeded by the erosive base of a thick succession of facies D arenites and conglomerates (unit II). A sequence of finer and more thinly bedded facies A and D conglomerates, together with facies E sandstones succeeds these (unit III), and this unit is followed at the top of the section by a thick marl sequence (unit IV).

This essentially upwards-fining sequence suggests (a) deposition of Globigerina marls and turbidites (unit I) in a deep water, basinal environment; (b) incision of coarse, submarine canyon or fan-valley deposits into this low energy sequence; (c) filling of this channel by conglomerates and arenites of facies D and E (unit II); (d) gradual abandonment of the channel, possibly by lateral migration, and the reception of finer, 'channel overflow' deposits (unit III) from the main channel, now some distance away and (e) final

abandonment of the channel and a return to deposition of facies 'A' Globigerina marls (unit IV).

Provenance.

The sandstone units of the Ofua Sandstone Member contain 15% of green schist clasts similar to those comprising most of the Lolotoi metamorphic complex of Timor. Audley-Charles (1974) has shown that the present day outcrop of the Lolotoi Complex is confined to the mountains north of the Central Basin.

Although rare exotic blocks of Lolotoi are also present in the Bobonaro Scaly Clay of the regions north and south of the Central Basin, it does not seem conceivable, except under conditions of exceptional sorting and deposition, that the erosion products from those to the south could have been concentrated so much as to form 15% of the coarser units of the Ofua Sandstone Member.

The northwards thinning and eventual disappearance of the member (Fig. 18) away from its type section can be explained in part by postulating the existence of a high on the site of the present Noele anticline during Ofua Sandstone deposition (see later). The avoidance of this positive high by the southwards-flowing submarine channels would account for the much thinner Ofua Sandstone section present on the southern limb of the anticline and for the absence of the member on the northern limb.

The depositing channels must have followed a course to the east or west of the Kali Sabaoe section in the northern part of the Sub-basin, in which the Ofua Sandstone Member is absent. The sinuous nature of most present-day submarine channels is well-known (Shepard and Dill 1966).

Fig. 18: North - south regional correlation of the Viqueque Group of the Noele Sub - basin, showing lateral changes of thickness and facies of the Noele Marl Formation. Note: (i) the lateral transition from Nekana Sandstone Member in north to Nuanain Sandstone Member in south; (ii) the southwards appearance and thickening of the Ofua and Oemenu Sandstone Members and (iii) the half - graben shape of the Noele Sub - basin at the end of Noele Marl deposition.

For location of sections see Fig. 16.

KALI SABAOE

NOELE A/C NORTH LIMB

NOELE A/C SOUTH LIMB

OEMENU

PLEISTOCENE

PLIOCENE

MIOCENE

N23

N22

N21 (LATE)

N21 (EARLY)

N15

N21

N23

N22

N21 (LATE)

N21 (EARLY)

N15
N20

N15?

PLEISTOCENE

PLIOCENE

MIOCENE

NOILBESI C

NOILBESI CONGLOM FMN

NOETUFI MARL

NOIL LAK. FM.

NANFUA CONGL MBR

NOELE MARL FORMATION

NEKANA SANDSTONE MEMBER

NUANAIN SST MBR

OEMENU SST MBR

OFUA SST MEMBER

SOE LST FMN

SABAOE LIMESTONE FMN

B.P. LST FMN

BOB. S. CLAY

SL. FMN

TJAMP. MBR

OESENA MBR

NUANAIN SANDSTN MBR

OEMENU SST MBR

OFUA SST. MBR

SABAOE LST FM

BPL. FMN

BOBONARO SCALY CLAY

M

960 920 880 840 800 760 720 680 640 600 560 520 480 440 400 360 320 280 240 200 160 120 80 40 0

840 900 760 720 680 640 600 560 520 480 440 400 360 320 280 240 200 160 120 80 40 0

440 400 360 320 280 240 200 160 120 80 40 0

490 440 400 360 320 280 240 200 160 120 80 40 0

NEKANA No. 4 UNIT

NEKANA No. 3 UNIT

NEKANA No. 2 UNIT

NEKANA No. 1 UNIT

NUANAIN SANDSTONE MEMBER

NUANAIN SANDSTONE MBR.

OEMENU SANDSTONE MEMBER

OFUA SANDSTONE MEMBER

F LAOB MBR

BP LST FM.

Viqueque Group. North— South regional correlation,

Noele sub— basin.

Datum: Base Soe Limestone/Noilbesi Conglomerate Formations

CSK

The deposition of the Ofua Sandstone Member represents a brief incursion into the Central Basin of clastic material probably associated with the closing stages of the Late Pliocene tectonism (the Bidjeli Folding)

(b) The Oemenu Sandstone Member.

The Oemenu Sandstone Member succeeds the middle marl unit of the Noele Marl type section and is itself overlain conformably by the Nuanain Sandstone Member (Fig. 15). In the type section (Fig. 19) the member is 36 metres thick and comprises four beds of well-sorted, mixed lithic and quartz arenites, varying in thickness from 3 to 10 metres. Grey Globigerina marl is present between each arenite unit. The type section extends from the base of the first arenite bed to the top of the fourth. Beds resembling those from the type section are also found in the Noele anticline section (southern limb), where the member consists of two arenite units, each about 5m thick.

The following four major facies are recognised in the type section:

Facies A.

This facies comprises thick-bedded, fine to medium-grained, well- sorted, lithic arenites with abundant comminuted molluscan and other skeletal debris. Parallel, ripple drift and convolute bedding are present throughout the beds but show no preferred vertical sequence. (Fig. 20 and Plate 7).

Size grading within facies 'A' sequences is generally confined to thin, isolated beds which precede the main arenite units (Fig. 19). The latter are not graded. Other sedimentary structures include water expulsion structures and horizons of well-rounded, plastically deformed clay pellets (Plate 7). In one bed post depositional flowage of such a layer has occurred. Layers of carbonaceous plant debris, up to 2 cm thick are found throughout each bed (Plate 7).

Fig. 19: Oemenu Sandstone Member, type section, River Oemenu, Noele Sub - basin.

Numbers 1 to 4 refer to the main sandstone units, comprising facies A. Preceding, and interbedded with these are Globigerina marls (facies B); thick bedded, graded arenites (facies D) and thin bedded, graded arenites (facies C).

The type section of the member extends from the base of sandstone unit 1 to the top of unit 4.

For stratigraphic position and geographic location see Figs. 15 and 16 respectively.

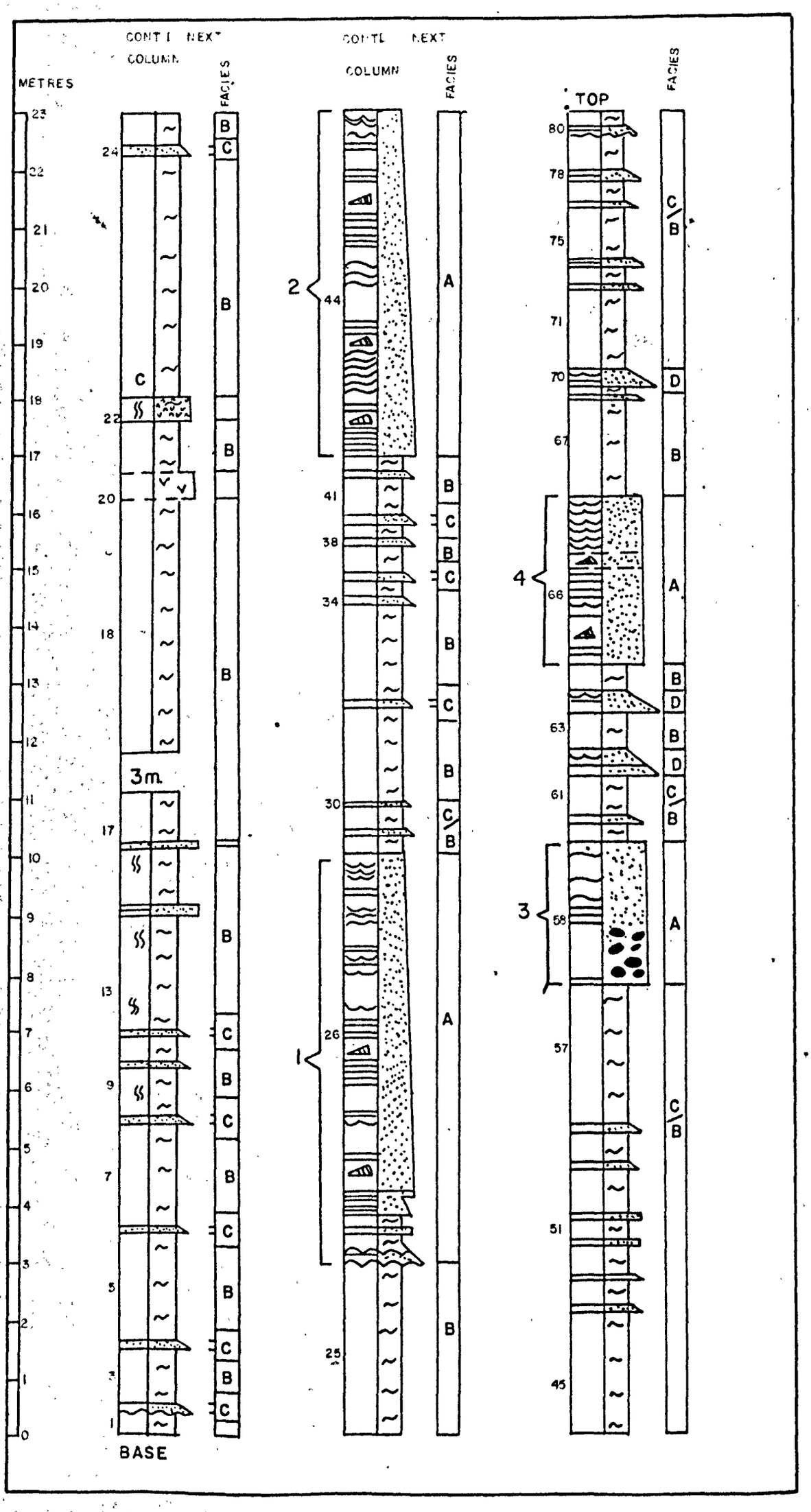

METRES
CONT'D NEXT COLUMN
FACIES
CONT'D NEXT COLUMN
FACIES
TOP
FACIES
BASE
3m.
1
2
3
4

Fig. 20: Detailed section of arenite units 1 and 2 (see Fig 19), showing convolute lamination (A); ripple cross - lamination (B); graded units (~~with Bouma A, B and C intervals~~); (C); parallel laminated units (D) and massive units (E). Note also the relatively constant grain size of both units.

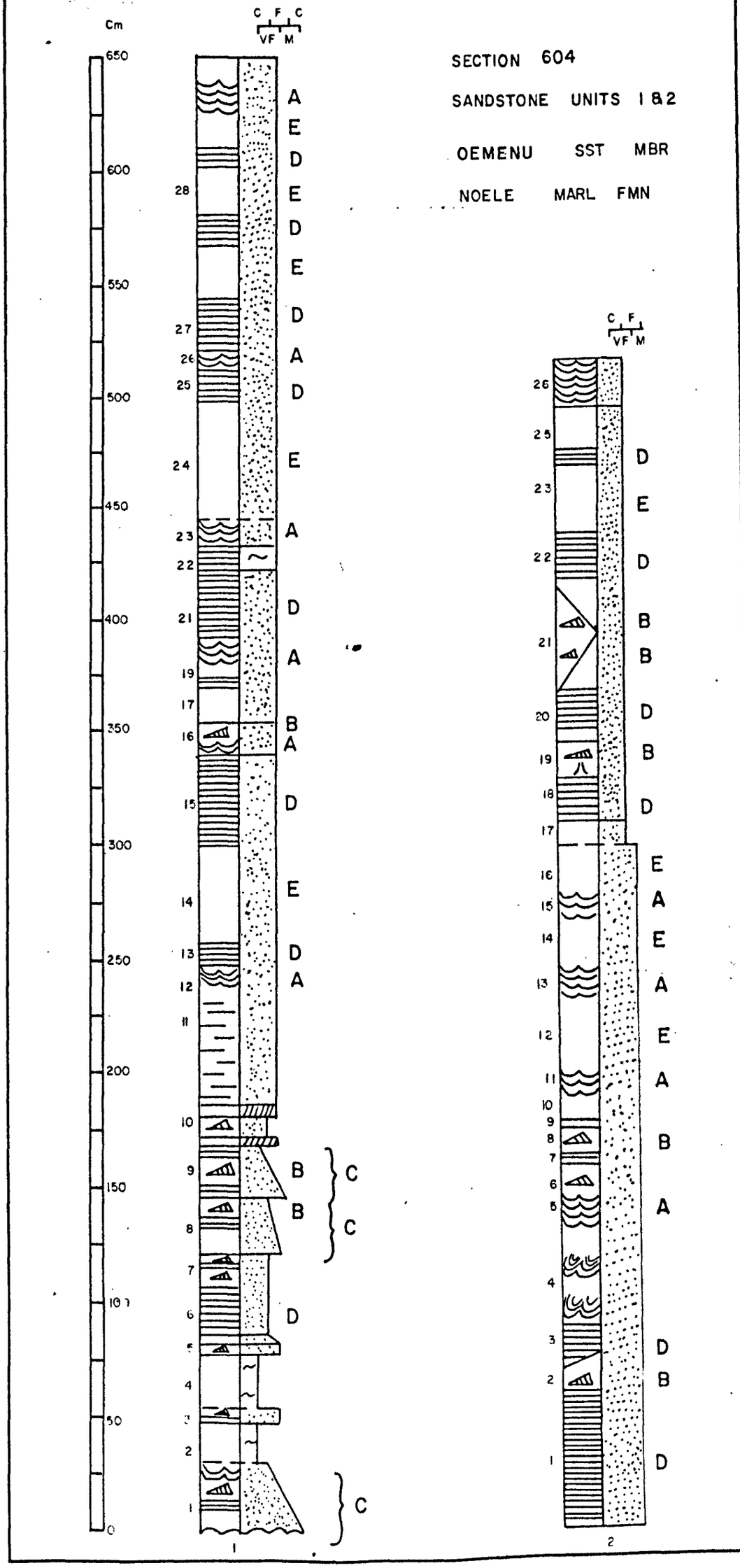

SECTION 604
SANDSTONE UNITS 1 & 2
OEMENU SST MBR
NOELE MARL FMN
Cm
650
600
550
500
450
400
350
300
250
200
150
100
50
0
C F C
VF M
28
27
26
25
24
23
22
21
19
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
A E D E D E D A D D E A D A B A D E D A
B C
B C
D
C
1
C F
VF M
26
25
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
D E D B B D B D E A E A E A B A D B D
2

Plate 7: Oemenu Sandstone Member, River Oemenu, Noele Sub - basin

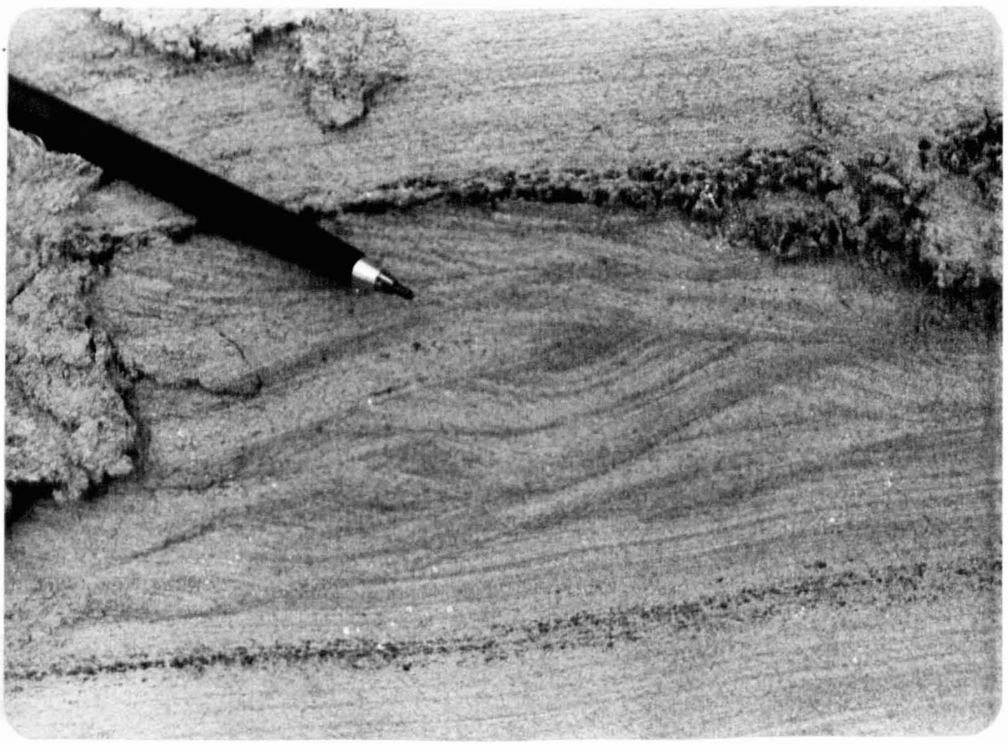
Detail of part of sandstone unit 4 (Plate A) and sandstone unit 1 (Plate B). Visible in 'A' are a number of well rounded marl clasts in a fine sand matrix. Plate 'B' shows ripple cross - lamination, parallel lamination and layers of carbonised plant debris.

Note the fineness and high degree of sorting of both units.

A



B



Interpretation.

Although the thick arenite units themselves do not display size grading, the small scale convolute lamination of the kind occurring in facies 'A' sandstones is often taken as indicative of turbidity current deposition (Sanders 1960) although there are abundant examples of convolute lamination not produced by turbidity currents (Dott and Howard 1962). Although diagnostic turbidite characteristics are absent from the Oemenu sandstone units, it is suggested that their thickness, rapid deposition (inferred from the abundance of convolute lamination and water expulsion structures), lateral sedimentation (indicated by ripple-drift bedding, parallel lamination etc.) and lack of erosion surfaces or breaks in sedimentation must have been effected by some form of density current.

Density flows of sediment from shallow-water areas usually contain an admixture of many grain sizes, producing in the resulting deposit some form of size grading (Kuenen 1964). The source material of facies 'A' sandstones was either (a) originally well sorted, suggesting that the sediment originated from a shallow, shelf or beach environment, or (b) it was originally poorly sorted, but lost most of the coarser fraction during the initial stages of deposition. The thickness of the beds and consistency of grain size strongly suggest the first alternative as most likely. Shepard and Dill (1966) have shown that reworked, nearshore and beach deposits in California are intercepted by the heads of submarine canyons, which become filled with prograding fine sands and matted organic debris. The latter is thought to have caused the slumping of the sediment in large masses. A mechanism such as this would explain (a) the considerable thickness

and lateral extent of facies 'A' sandstones; (b) the abundance of carbonised plant debris; (c) the excellent sorting and (d) the abundance of comminuted shell debris of apparently nearshore origin.

The environment of deposition of facies 'A' sandstones can therefore be interpreted as moderately deep water marine, into which well-sorted sediment derived from a shallow water source was introduced by a high velocity current displaying rapid and frequent fluctuations of velocity. This current is thought to have been some form of density current and to have originated in a canyon head.

Facies B.

Consists of grey, slightly silty marl with tests of Globigerina and some comminuted, thin-shelled lamellibranch debris.

Interpretation.

The predominantly muddy nature of the beds and the occurrence of pelagic foraminifera suggest a deep water, low energy environment of deposition.

Facies C.

Comprises thin bedded (less than 50cm), fine to medium grained, lithic arenites. The majority of beds are graded, display parallel lamination, and are similar to those occurring elsewhere in the Noele Marl of the Central Basin, with the difference that a wider range of 'Bouma units' (e.g. ABC, ABCD, AD etc.) is present. This fact may suggest a more distal environment of deposition, and agrees with the observation that these are the most southern (i.e. furthest from inferred source) of any of the turbidites in the Noele Sub-basin.

Facies D.

Comprises very thin-bedded (less than 5cm), very fine grained, graded lithic arenites, interpreted as having been deposited from the distal parts of the major density flows.

The arenite units of the Oemenu Sandstone Member contain approximately 20% of clasts of metamorphic green schist, assumed to have been derived from the Lolotoi Complex. For this reason a northerly derivation is suggested.

Fauna.

The following foraminifera have been identified by Mr D.J. Carter (unpublished report, dated 1970a):

(a) Planktonics

Orbulina universa

Globorotalia cultrata menardii

G. tumida tumida (sinistral)

G. subcretacea

G. borealis

G. acostaensis pseudopima

Pulleniatena spp.

Sphaeroidinella dehiscens

Globigerinoides gomitulus

G. ruber

G. quadrilobatus gp.

G. conglobatus gp.

Globigerina bulloides

G. parabulloides

G. rubescens

G. juvensis

G. calida praecalida

(b) Benthonics

Ammobaculites spp.

Textularia spp.

Spiroplectammina spp.

Miliolacea

Nodosariacea

Uvigerina spp.

Bulimina spp.

Hoeglundina spp

Cibicides spp

Bolivinita quadrilatera

Planulina spp

Orissodorsalis spp.

Globocassidulina spp

Age of the Oemenu Sandstone Member.

A young N21 age (i.e. Late Pliocene) has been assigned to the Oemenu Sandstone Member by Carter, who considered the N21/N22 boundary to fall at the base of the immediately overlying Nuanain Sandstone Member.

(c) The Nuanain Sandstone Member.

Summary

The Nuanain Sandstone Member is defined as a series of interbedded arenites and marls which was deposited in the centre of the Noele Sub-basin during Early Pleistocene (N22) times. The member is shown to have been deposited by turbidity currents in the suprafan area of a submarine fan complex. Evidence is presented for a northerly derivation, from a shoreline situated in the centre of the present northern mountain complex.

A thick conglomerate (the Fautao Conglomerate Bed) occurring near the base of the succession is described and interpreted as the infilling of a former fan-valley distributary channel on the fan surface. Reconstruction of the palaeogeography of Timor during Nuanain Sandstone deposition strongly supports a post Nuanain Sandstone (i.e. post Early Pleistocene) origin for the Wetar Strait (Audley-Charles and Hooijer, 1973).

Introduction.

The Nuanain Sandstone Member comprises a thick series of rhythmically bedded lithic arenites and foraminiferal marls which succeeds the Oemenu Sandstone Member in the type section of the Noele Marl Formation.

The type section of the member (Fig. 15) was measured along the upper reaches of the River Fekufatu (Fig. 16) on the southern limb of the Noele anticline, beginning at the contact with the Oemenu Sandstone Member and extending upwards as far as the conformable contact

with the upper marl unit. The latter boundary is taken at the top of the uppermost arenite bed of the Nuanain Sandstone Member. The member is 310 metres thick in the type section.

Four major facies are distinguished:

Facies A: Globigerina marl

Consists of a greyish-white to olive green, sandy, structureless marl containing abundant Globigerina and other pelagic foraminifera. No skeletal remains were observed.

Interpretation

The fine nature of facies 'A' beds, the lack of benthonic invertebrate remains and the abundance of pelagic foraminifera suggest an open sea, moderately deep water environment of deposition. The coarser particles are assumed to have been derived from the interbedded, unconsolidated sandstone either by current disturbance or bioturbational inmixing.

Facies B: Graded arenites; thick bedded.

Comprises graded lithic arenites, varying in thickness from 15cm to 1½m (Fig. 21). Most beds display (a) constant lateral thickness; (b) some form of grading; (c) sedimentary structures corresponding to units A and B of Bouma (1962), and are interpreted as turbidites.

Types of grading

Most beds consist of a non-graded, coarse, lower portion and a thicker, upper, graded unit (Fig. 21 and Plate 8). The junction between the two units is usually sharp. A second sharp break in grading is present in the upper unit of some beds.

Fig. 21: Nuanain Sandstone Member: Section 613. Detail of part of the type section, illustrating sedimentary structures, grading types and bed thicknesses of the exposed section. Note (a) the predominance of delayed grading (e.g. beds 24, 66, 96); (b) beds displaying normal grading (83, 87); (c) ungraded beds (2, 125); (d) beds displaying Bouma unit A only (60, 83, 121); unit B only (139, 125, 145) and unit AB only (18, 43, 66, 90).

For stratigraphic location of this section see Fig. 15.

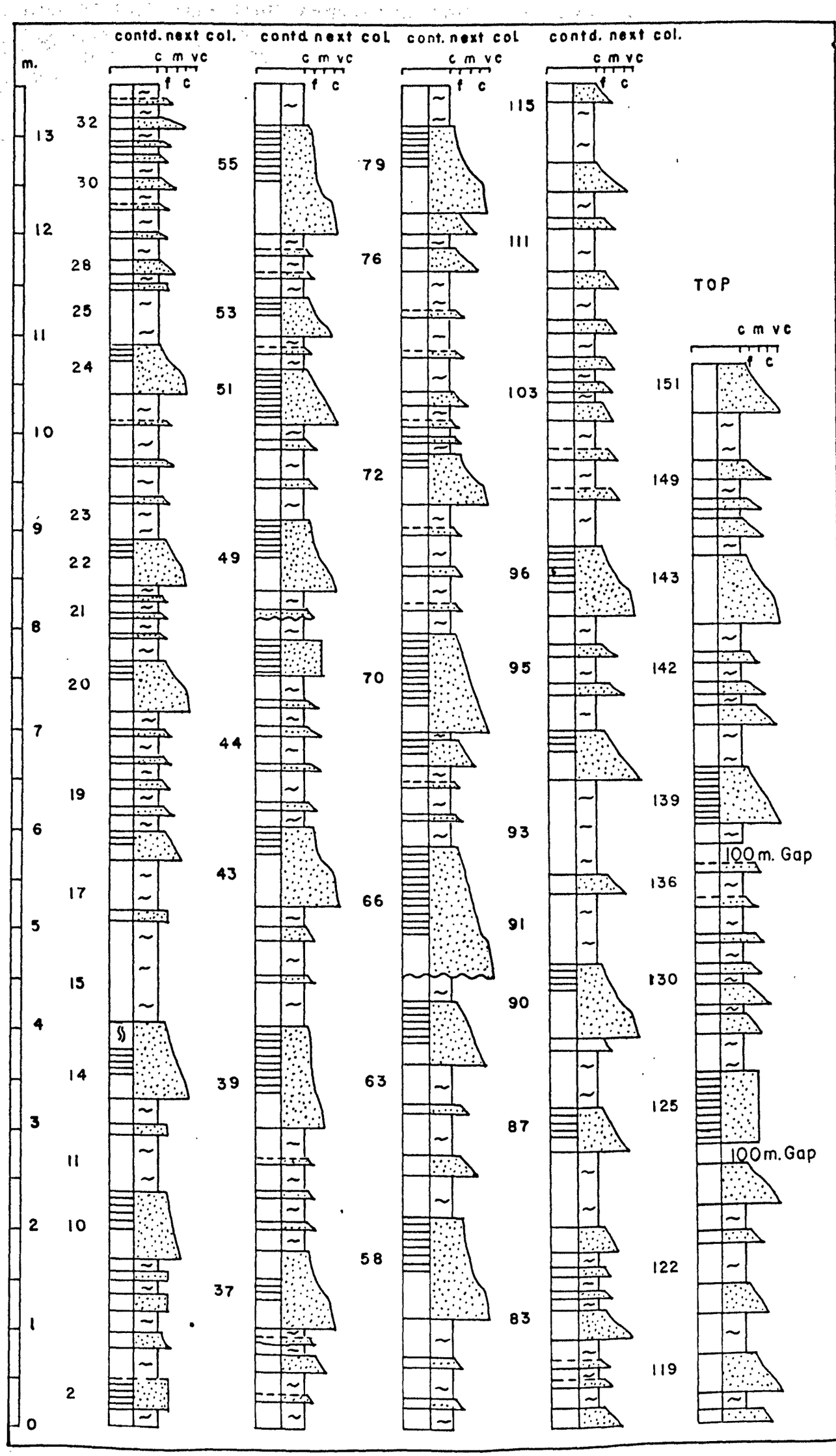

m.
contd. next col.
c m vc
f c
32
30
28
25
24
23
22
21
20
19
17
15
14
11
10
2
55
53
51
49
44
43
39
37
79
76
72
70
66
63
58
115
111
103
96
95
93
91
90
87
83
TOP
151
149
143
142
139
136
130
125
122
119
100m. Gap
100m. Gap
0
1
2
3
4
5
6
7
8
9
10
11
12
13

Plate 8: Nuanain Sandstone Member, type section, River Fekufatu, north of Noele, Noele Sub - basin.

A: Facies 'B' bed displaying delayed grading. Note poorly sorted, non - or poorly graded coarse basal unit and irregular, slightly erosive bed base. Lying above this basal unit is a poorly graded unit of medium sand, and above the lamination near the centre of the bed (at pencil tip) the bed consists of fine sand.

B: Thick, facies 'B' turbidite bed displaying parallel lamination (Bouma 'B' interval) throughout.

Pencil is 24 cm. in length.

A



B



In many beds the basal coarse layer is laterally impersistent, and may be present only in scours at the bases of the beds.

This type of grading was described by Migliorini (in Kuenen and Menard 1952) from the Macigno Sandstones of Italy and later named 'delayed grading' by Birkenmjaer (1959). It was reproduced in early experiments by Kuenen (1952) by prolonged feeding of a turbulent suspension from its source. An earlier experiment by Kuenen (1951b) in which a very dense suspension was used, produced a lower, ungraded portion from a turbulent wedge of dense sediment and an upper, graded portion from settling of suspended materials.

Concentration of coarse grains of up to 50% by volume form at the base of a turbidity current, under certain conditions, as the 'traction carpet' of Bagnold (1956). As the flow regime decreases, 'freezing' of this carpet is known to produce a bed of poorly or non-graded coarse grains with a sharp top. Of the suggested mechanisms that of Kuenen (1951) does not satisfactorily account for the much greater thickness of the upper graded portion of facies 'A' sandstone beds compared to the lower, ungraded portion. The later mechanism of Kuenen (1952) and that of Bagnold are both likely to result in the observed graded sequence, and may be interrelated, in that constant feeding of a suspension would be likely to result in a greater concentration of grains and hence in the development of a traction carpet.

Although this type of grading has been described before, it appears to be both rare in occurrence and much more poorly and erratically developed in other turbidite sequences. It is however

a remarkable characteristic of turbidites throughout the Viqueque Group, being well developed in (a) the Samé Member of Portuguese Timor and (b) the Nekana Sandstone Member, in addition to the Nuanain Sandstone Member. Moreover the grading bears little relation to bed thickness, being equally common in both thin beds (15cm) and very thick beds (2 metres). It can therefore be concluded that conditions conducive to the development of this grading were widespread in the Central Basin and in Portuguese Timor south coast basins during Early Pleistocene (N22) times. There is considerable evidence that the final form of a turbidite bed is largely a function of the basin profile over which the depositing turbidity current flowed (Walker 1967). Not only is the basin profile likely to have been remarkably similar in the basins of both central Indonesian Timor and the present south coast region of Portuguese Timor during this time, but also somewhat unusual among turbidite sequences in that the initiation of turbidity currents may have taken place only 15 kilometres to the north, at the top of the relatively steep northern basin slope. There is also some evidence to suggest that the basin floor palaeoslope may have been slightly reversed (i.e. south to north) during the beginning of Nuanain Sandstone deposition. The development of an 'overcharged' condition, with a well developed traction carpet at the base of each flow and its subsequent 'freezing' on encountering the rapid decrease in gradient at the foot of the slope could be easily accounted for under these conditions.

Other types of grading

Another form of grading present in the turbidites of the

Nuanain Sandstone Member is the 'normal' type of Birkenmjaer (1959), in which the grain size of a particular bed decreases gradually and regularly from the base to the top of the bed. The sequence also contains rare examples of multiple grading.

Development of the Bouma sequence

The following combinations of Bouma units occur in facies 'B' sandstones: (a) 'A' sequence only, in which beds consist only of a structureless graded or non-graded division (Plate 8 A); (b) 'B' sequence (graded or non-graded) with parallel lamination present throughout the bed (Plate 8 B) and (c) 'AB' sequences, with parallel lamination appearing only towards the tops of individual units.

Facies C: Graded arenites; thin bedded

Comprises very thin-bedded (less than 15cm thick) fine, lithic arenites containing abundant comminuted shell debris. The latter is often concentrated near the base of each bed.

Interpretation

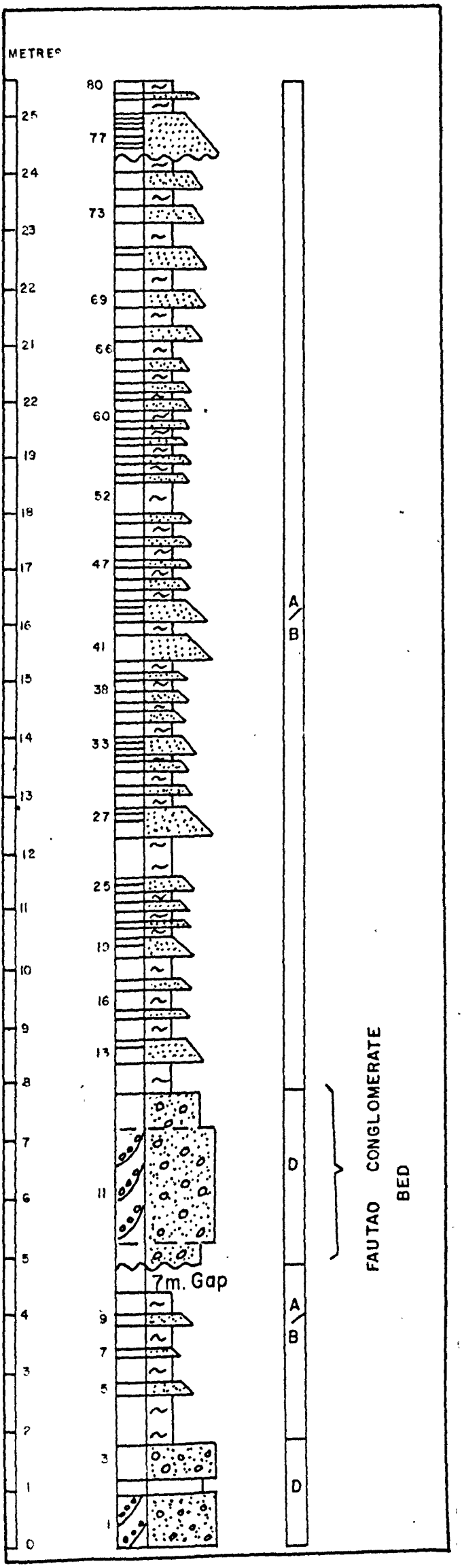
The fineness and grading of these beds suggests that they may have been deposited from the lateral or distal extremities of the major turbidity current flows. Similar beds have been described by Horn et al. (1971) from cores taken at various distances from the main avenues of flow of the Atlantic turbidity currents.

Facies D: The Fautao Conglomerate Bed

A single conglomerate unit, 3m in thickness is present near to the base of the Nuanain Sandstone Member of the type section (Figs. 15,22). The bed itself persists laterally for 100m.

Fig. 22: Nuanain Sandstone Member, section 614: Section of the lower part of the unit, showing the development of thin, fan - valley conglomerate units, the uppermost one of which is named the Fautao Conglomerate Bed.

For stratigraphic location of this section, see Fig. 15.


METRES
25
24
23
22
21
22
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
80
77
73
69
66
60
52
47
41
38
33
27
25
19
16
13
11
9
7
5
3
1
7m. Gap
A
B
D
A
B
D
FAUTAO CONGLOMERATE
BED

Measurement of the exposed profile (Fig. 23) reveals marked lateral thinning, accompanied by a decrease in coarseness, clasts in the thickest part of the unit attaining a maximum diameter of 30cm, decreasing at the extreme edge to 5cm. This decrease in coarseness is accompanied by an increase in perfection of grading, the extreme southern (lateral) edge of the channel displaying grading of 'normal' type, in contrast to the delayed type of the channel core.

The thickness and coarseness of the unit, together with its wedge-shaped (presumably originally lens-shaped before erosion) geometry and erosive base suggest its origin as a fan-valley distributary (Normark and Piper 1969) on the surface of the Nuanain Sandstone submarine fan in Upper Noele Marl times.

Sections measured in the succeeding turbidite sequence (Fig. 23) show that the thickness of the latter increases markedly over the thickest part of the conglomerate, suggesting that after cessation of deposition in the channel, a depression coinciding with the channel axis was preferentially filled by turbidity current deposits.

Interpretation

Normark (1970) subdivided the surfaces of modern submarine fans into three areas: an upper fan, characterised by large, leveed fan valleys, a mid - fan (or suprafan) with many smaller distributary channels, and some channel remnants or depressions, and a lower fan, characterised by an absence of channels (Fig. 24). Because the facies 'D' conglomerate lens has been shown to be a small, abandoned distributary channel, and because few other channel remnants are present in over 300 metres of succession, it is concluded that the conglomerate lens

Fig. 23: Nuanain Sandstone Member, Fautao Conglomerate Bed.

Transverse profile, measured by Abney level and tape, showing main channel sequence (D); pre - channel turbidites and marls (A); post - channel turbidites and marls (B) and erosive channel base (C).

For stratigraphic position and geographic location of the channel see Figs. 15 and 16 respectively.

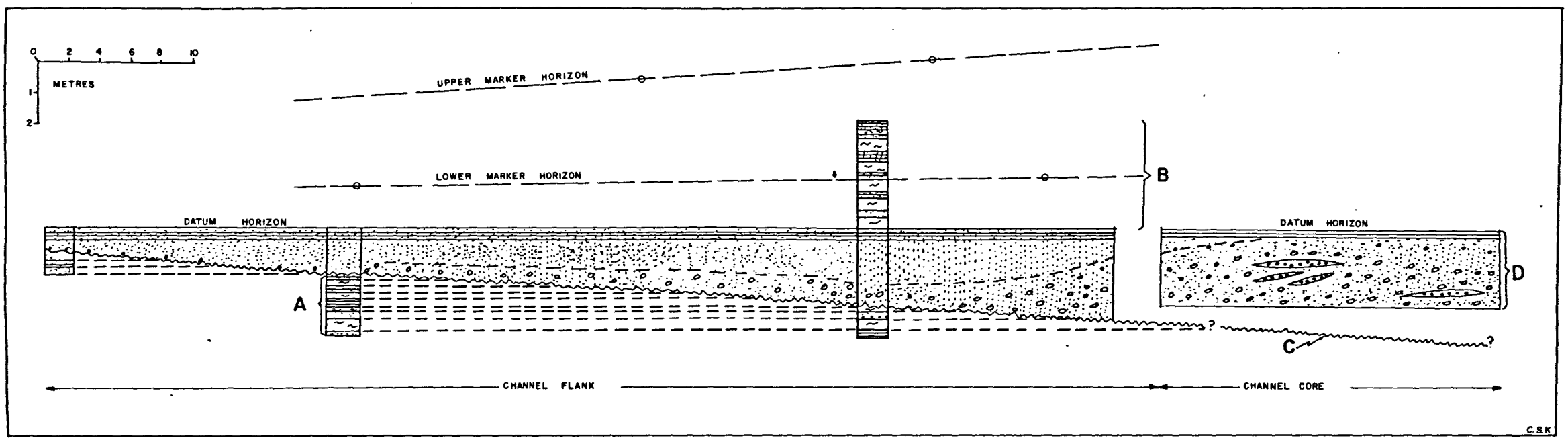

0 2 4 6 8 10
METRES
1
2
UPPER MARKER HORIZON
LOWER MARKER HORIZON
B
DATUM HORIZON
DATUM HORIZON
A
D
C
CHANNEL FLANK
CHANNEL CORE
C.S.K

Fig. 24: Nuanain Sandstone Member

A. Model for deep sea fan growth, from Normark, (1970). The regularity of bedding, and other features, and the presence of only 3 minor distributary channels in over 300 metres of succession suggests deposition of the Nuanain Sandstone Member in the suprafan area of this model (B).

B. Indonesian Timor, showing distribution of the Bobonaro Scaly Clay (stippled). From Audley - Charles, (1973). The Nuanain Sandstone shoreline is likely to have been on the site of, or north of, the thick dashed line in the figure. The position of the Nuanain Sandstone Member type section is also shown (A).

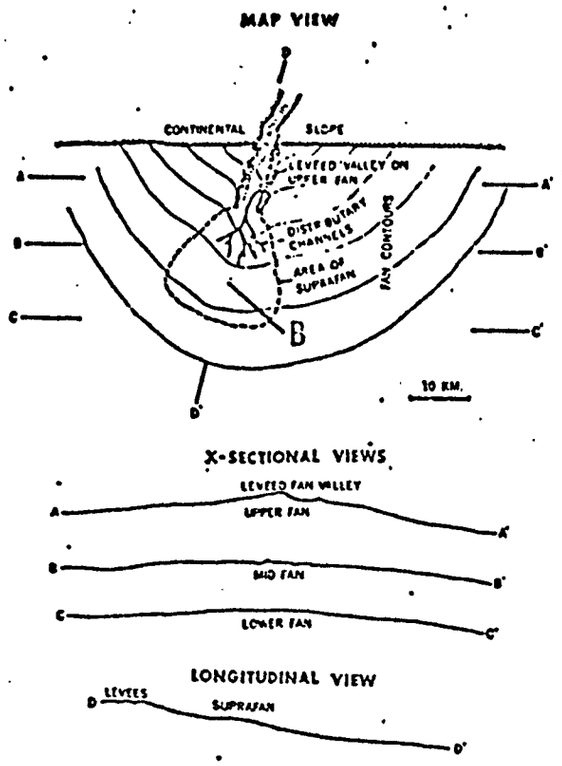
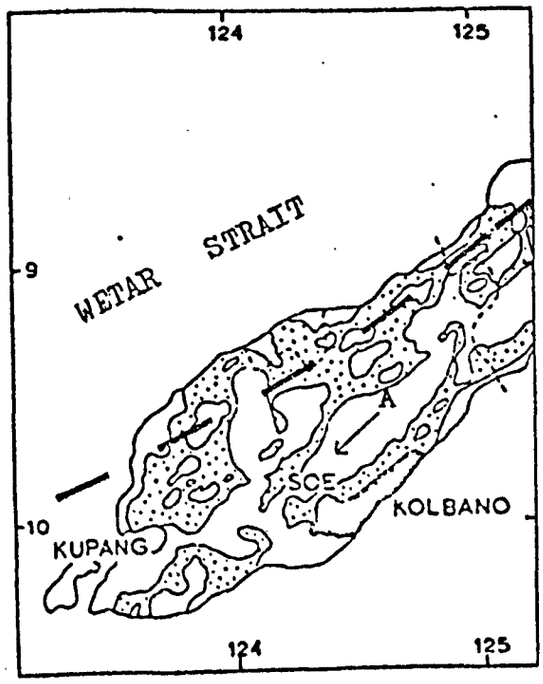


FIG. 22.—Model for deep-sea fan growth showing suprafan and simple morphology of fan related to growth area. Upper fan is characterized by large leveed fan-valley (*A-A'*), whereas midfan (or suprafan) shows many smaller distributary channels and some channel remnants or depressions (*B-B'*). Channels are absent from lower fan (*C-C'*). Suprafan appears as convex-upward bulge on longitudinal profile.



and the Nuanain Sandstone Member in which it occurs was deposited in the area of Normark's (lower) suprafan.

Provenance of the Nuanain Sandstone Member

Although no sole marks were observed on the base of any bed, a northerly derivation for the turbidity currents of Nuanain Sandstone times is strongly suggested by the abundance of metamorphic (Lolotoi Complex) fragments throughout the succession.

Palaeogeography of Nuanain Sandstone times

Evidence has been presented which suggests the deposition of the Nuanain Sandstone Member on a flat basin floor, immediately to the south of the northern basin margin, down which flowed turbidity currents carrying detritus from exposed regions of Lolotoi Complex rocks. That this northern basin margin was still relatively distant during Nuanain Sandstone times is suggested however by the absence of any slump structures suggestive of a nearby gradient, and by the parallel sided and undisturbed nature of the facies 'B' beds, which suggest deposition on a relatively horizontal surface. Evidence from the overlying succession elsewhere in the Noele Sub-basin however suggests that coarse conglomerates and sandstones displaying channeling and slumping were being deposited to the north and later prograded southwards over the surface of the Nuanain Sandstone Member as the succeeding Noil Lakoe Formation. This fact, together with the present day distribution of Lolotoi rocks, appearing through the Bobonaro Scaly Clay cover, strongly suggests that the site of the northern shoreline was in the region of the middle of the present-day Northern Mountains (Fig. 24). That it could not have been further

south than this is suggested by the need to accommodate the Noil Lakoe Marl Formation facies belt between the shoreline and the Nuanain Sandstone Member, and the fact that the Lolotoi is still to some extent mantled by the Bobonaro Scaly Clay south of the suggested shoreline (Fig. 24).

Any attempt to interpret Early Pleistocene palaeogeography must consider the age and origin of the Wetar Strait which separates Timor from the Inner Banda arcs by a sea 3,000 metres deep. The excellent rounding of the clasts within the Nuanain Sandstone is suggestive of prolonged river transport such as that afforded to the gravels of the present day River Noilbesi during their passage from the Northern Mountains to the south coast. Such prolonged transport would not be possible if the northern positive area extended only as far as the present north coast of Timor in Nuanain Sandstone times. It seems likely therefore that the Wetar Strait developed after the deposition of the Nuanain Sandstone Member. This conclusion accords with the Pleistocene land connection between Timor and Alor postulated by Audley-Charles and Hooijer (1973) on the basis of quite different evidence.

Fauna

The following foraminifera have been identified by Mr D.J. Carter (unpublished report, dated 1970a):

(a) Planktonics:

Orbulina universa

Globorotalia cultrata menardii

G. subcretacea

G. acostaensis pseudopima

Globorotalia borealis gp.

G. tumida tumida (sinistral)

G. tosaensis tenuitheka

Pulleniatina spp.

Globigerinoides gomitulus

G. ruber

G. conglobatus gp.

G. quadrilobatus gp.

Globigerina bulloides

G. parabulloides

G. rubescens

G. juvensis

G. calida praecalida

(b) Benthonics:

Textularia spp.

Spiroplectammina sp.

Miliolacea

Nodosariacea

Uvigerina spp.

Protoglobulimina sp.

Bulimina sp.

Hoeglundina sp.

Cibicides sp.

Bolivinita quadrilatera

Globocassidulina spp.

Orissodorsalis spp.

Planulina spp.

Age

On the basis of the above foraminifera Carter (unpublished report, dated 1970a) has determined the age of the Nuanain Sandstone Member to be Early Pleistocene (N22), the N22/N21 boundary being placed at the base of the member.

(d) The Nanfua Sandstone Member

The Nanfua Sandstone is the uppermost member of the Noele Marl Formation type section and comprises a series of thick bedded, coarse clastic units each similar to that of the younger Ofua Sandstone Member. These clastic units are interbedded with subordinate marls.

The base of the member (see Fig. 15) is taken at the abrupt junction of the massive sandstones with the underlying upper marl unit and extends upwards as far as the junction with the green marls of the Noil Lakoe Formation, which succeed it. The member is 42 metres thick.

Each clastic unit begins with a series of thick-bedded, coarse, poorly-sorted lithic arenites with thin, interbedded conglomerate units. The latter possess transitional upper and lower surfaces and show no internal size grading. The clasts are composed largely of Lolotoi metamorphic rocks.

Succeeding these are fine-grained, thick-bedded arenites with convolute bedding. These pass transitionally upwards into grey Globigerina marls.

Each of these main clastic sequences rests with a strongly erosive base on a series of foraminiferal, sandy or tuffaceous marls with thin, interbedded, graded arenites.

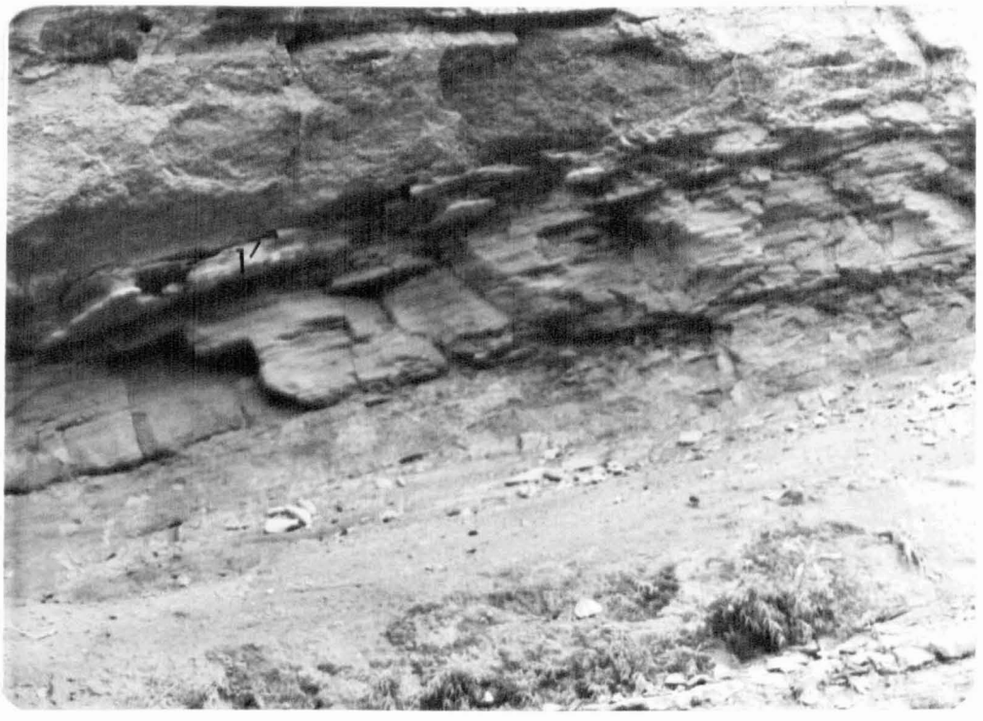
The arenites of the basal part of each main clastic unit are characterised by layers of plastically deformed pellets of grey marl. These pellet layers appear to be more abundant in beds with highly penetrative and lobed bases, suggesting either (a) scouring and erosion of the marl substratum by a high density current or (b) post depositional flowage and loading of a sandstone bed into

Plate 9: Nanfua Sandstone Member, River Fekufatu, Noele Sub - basin

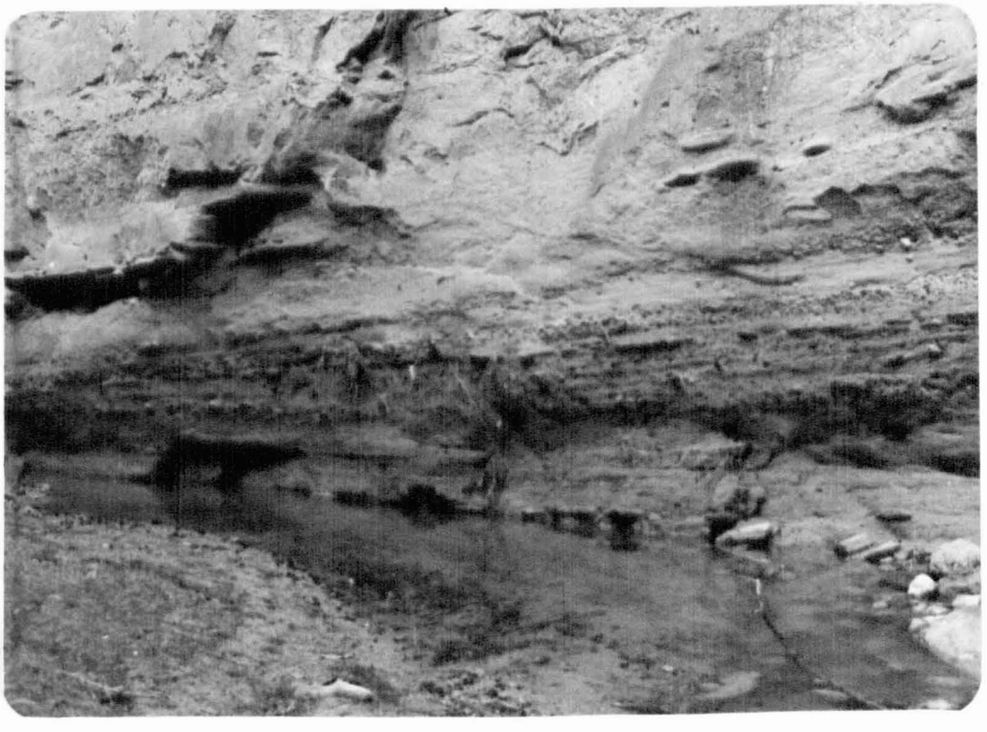
Lowermost parts of two upwards-fining sequences, showing (A): erosive base of main unit (1) cutting into pre - channel, laminated marls; (B): thin, non - graded conglomerate units at the base of an upwards - fining sequence; (C): detail of part of the lower portion of the unit depicted in (B) showing (i) coarseness of clasts; (ii) rounding; (iii) possible imbrication and (iv) non-graded, transitional nature of each conglomerate unit.

For location of member type section see Fig. 16.

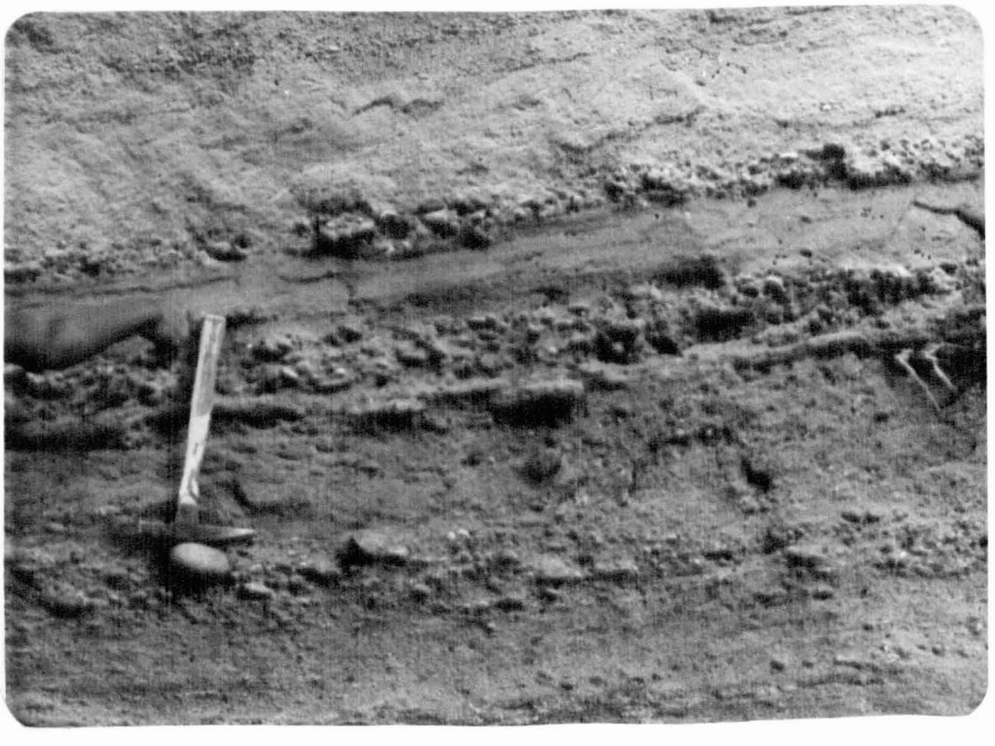
A



B



C



the underlying, still unconsolidated marl, and incorporation of the lobes into the underlying bed as clay pellets.

The four sedimentary divisions of each main clastic unit are directly comparable with those described from the younger Ofua Sandstone Member of the Noele Marl type section and the Nanfua Member is similarly interpreted as a high energy, submarine channel deposit. This is in accordance with the situation of the member between the submarine fan deposits of the Nuanain Sandstone Member and the slope deposits of the Noil Lakoe Marl Formation (see later) and suggests deposition in a submarine canyon or very proximal fan valley, present in the northern part of the Sub-basin during upper Noele Marl times.

Age

Samples from the Nanfua Sandstone Member have not been analysed for microfaunal content. However, the member is clearly younger than the Nuanain Sandstone Member (Early Pleistocene, N22), and older than the post Noil Lakoe Marl Formation unconformity, which corresponds approximately to the N22/N23 boundary. The member is therefore Late N22 (Early to Middle Pleistocene) in age.

(ii) The Noele Marl of the Noele Sub - basin northern margin: The Kali Sabaoe section

A thick and almost continuously exposed sequence of Noele Marl exists along the Kali Sabaoe in the northern part of the Noele Sub - basin (Fig. 25). The succession extends from the top of the Sabaoe Limestone Formation as far as the unconformable contact with the Noilbesi Conglomerate in the region of Oenasse.

The section is divided into nine units, beginning with a thick sequence of silty, Globigerina marl with molluscan debris (unit 1), which passes upwards into a silt - free Globigerina marl (unit 11). The upper part of the succession consists of a series of four units of interbedded sandstones and marls (units 111, V, V11 and 1X) separated by thick marl sequences (units 1V, V1 and V111). Units 111 to 1X are collectively grouped as the Nekana Sandstone Member of the Noele Marl Formation.

Units 1 and 11: Silty Globigerina marl and Globigerina marl

Units 1 and 11 form the uppermost part of a continuous, upwards-fining regressive sequence, which begins with the shallow water calcarenites of the Sabaoe Limestone Formation type section, and ends with the silt - free Globigerina marls of unit 11. Apart from (a) the silty admixture and comminuted shell debris of unit 1 and (b) the complete absence of any turbidite beds both units resemble the 'normal' marl of the Noele Marl Formation.

Fig. 25: Stratigraphic section of the Noele Marl of the Kali Sabaoe, Noele Sub - basin northern margin.

For location of this section see Fig. 16.

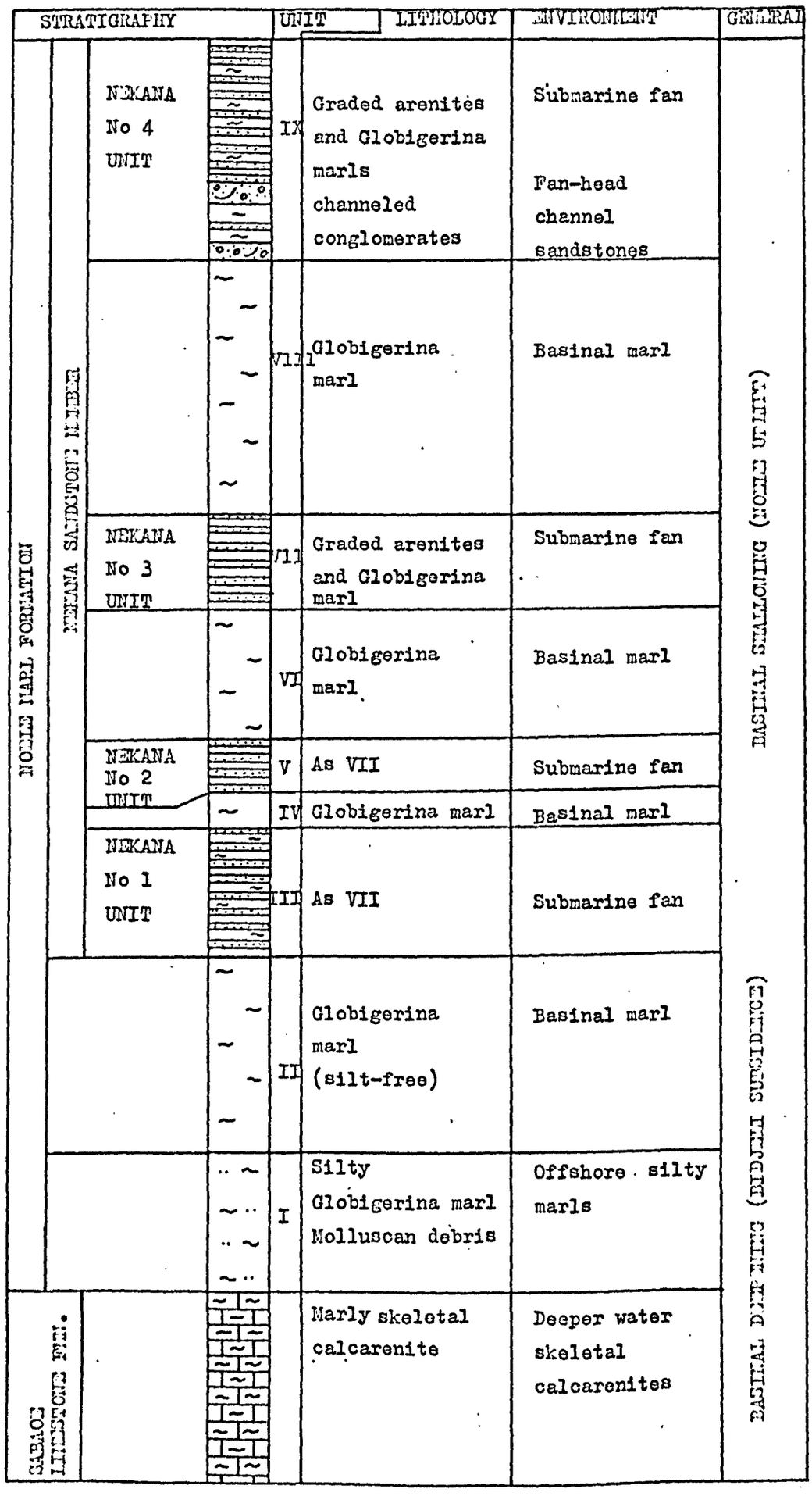
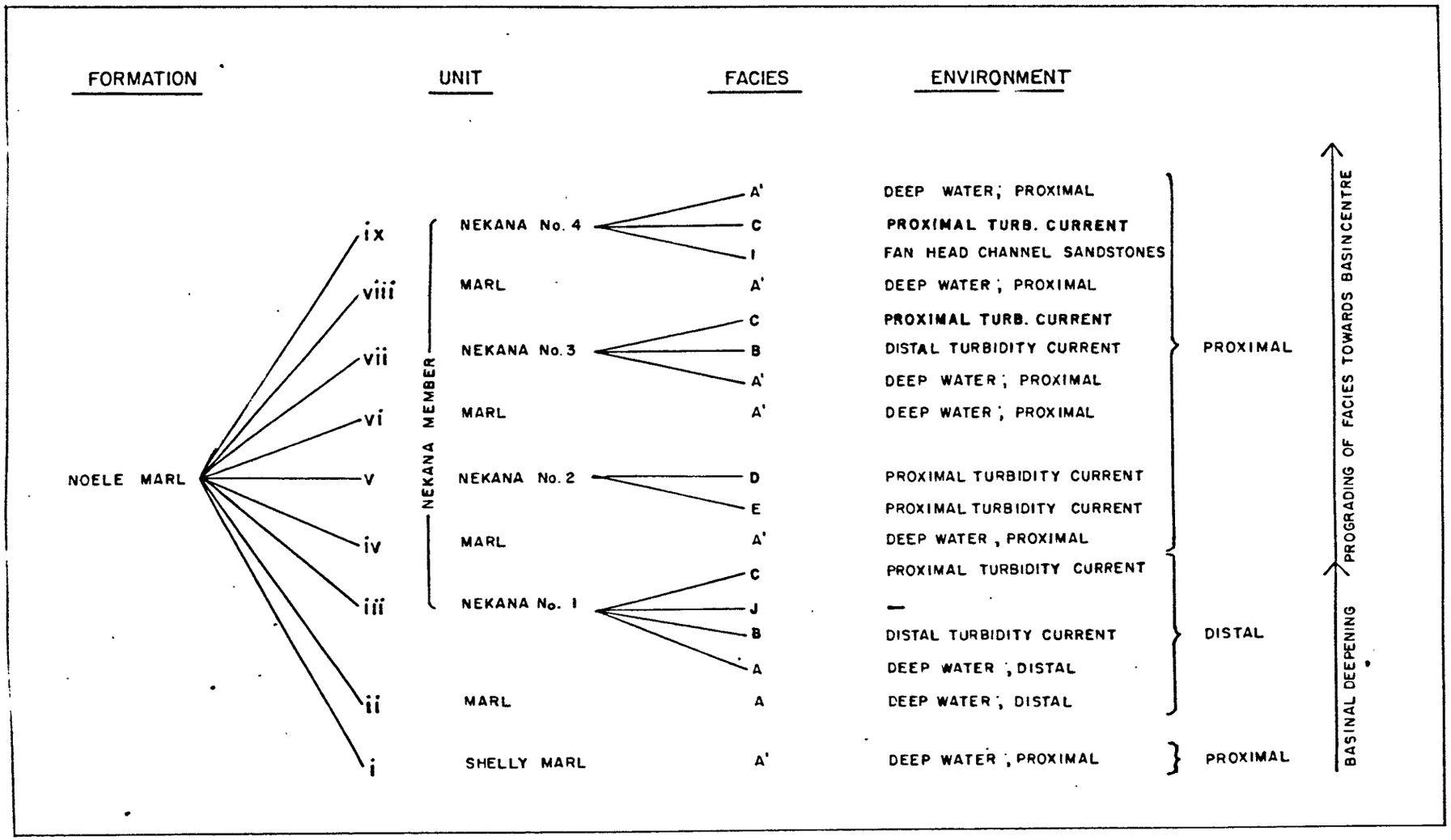

STRATIGRAPHY
UNIT
LITHOLOGY
ENVIRONMENT
GENERAL
NOBLE MARL FORMATION
NEKANA SANDSTONE MEMBER
NEKANA No 4 UNIT
NEKANA No 3 UNIT
NEKANA No 2 UNIT
NEKANA No 1 UNIT
GIBAOI LIMESTONE FM.
IX
VIII
VII
VI
V
IV
III
II
I
Graded arenites and Globigerina marls channeled conglomerates
Globigerina marl
Graded arenites and Globigerina marl
As VII
Globigerina marl
As VII
Globigerina marl (silt-free)
Silty Globigerina marl Molluscan debris
Marly skeletal calcarenite
Submarine fan
Fan-head channel sandstones
Basinal marl
Submarine fan
Basinal marl
Submarine fan
Basinal marl
Offshore silty marls
Deeper water skeletal calcarenites
BASINAL STALLOWING (NOBLE UNIT)
BASINAL DEPOSITS (MIDDLE SUBSIDENCE)
BASINAL DEPOSITS (EARLY SUBSIDENCE)
0m
25
50
75
100

Fig. 26: Summary of stratigraphic units, facies and environmental history of the Noele Marl Formation of the Noele Sub - basin northern margin.


FORMATION
UNIT
FACIES
ENVIRONMENT
NOELE MARL
ix
viii
vii
vi
v
iv
iii
ii
i
NEKANA MEMBER
NEKANA No. 4
MARL
NEKANA No. 3
MARL
NEKANA No. 2
MARL
NEKANA No. 1
MARL
SHELLY MARL
A'
C
I
A'
C
B
A'
A'
D
E
A'
C
J
B
A
A
A'
DEEP WATER; PROXIMAL
PROXIMAL TURB. CURRENT
FAN HEAD CHANNEL SANDSTONES
DEEP WATER; PROXIMAL
PROXIMAL TURB. CURRENT
DISTAL TURBIDITY CURRENT
DEEP WATER; PROXIMAL
DEEP WATER; PROXIMAL
PROXIMAL TURBIDITY CURRENT
PROXIMAL TURBIDITY CURRENT
DEEP WATER, PROXIMAL
PROXIMAL TURBIDITY CURRENT
—
DISTAL TURBIDITY CURRENT
DEEP WATER; DISTAL
DEEP WATER; DISTAL
DEEP WATER; PROXIMAL
PROXIMAL
DISTAL
PROXIMAL
BASINAL DEEPENING
PROGRADING OF FACIES TOWARDS BASIN CENTRE

(a) The Nekana Sandstone Member

Summary

The Nekana Sandstone Member is defined as a series of interbedded lithic arenites and marls forming the uppermost exposed part of the Noele Marl succession of the Noele Sub - basin northern margin. The member is shown to have been deposited towards the north - western proximal edge of the main submarine fan complex of Early Pleistocene (N22) times. Four major incursions of this submarine fan into the Kali Sabaoe region can be demonstrated, each being accompanied by progradation of facies belts from the northern margin, producing an upwards increase in proximality. The member is tentatively correlated with the Nuanain Sandstone Member of the southern and central parts of the basin, the relative position of each member on the submarine fan complex being indicated by an analysis of turbidite structures.

Introduction

The type section of the Nekana Sandstone Member (Fig. 25) is 450 metres thick and extends from the appearance of the first arenite bed at the base of the member to the unconformable contact with the massive conglomerates of the overlying Noilbesi Conglomerate Formation. Nine facies are recognised (Figs. 26 and 27):

Facies A

This consists of structureless, light grey marl containing the tests of Globigerina and other pelagic foraminifera. Numerous small gastropods and occasional, thin shelled lamellibranchs are also present. The latter, together with the pelagic foraminifera, suggest a low energy, open sea environment of deposition. The absence of wave and current

Fig. 27: Nekana Sandstone Member, Noele Marl Formation, Kali Sabaoe section: Detailed section of each of the four major sandstone/shale units (Nekana sandstone units 1 to 4), illustrating facies development. Note (a) the gradual increase and decrease at the base and top respectively of each unit of the proportion of turbidite sandstone beds, representing gradual incursion and final waning stage of each fan unit; (b) the interval of maximum sandstone development in the central part of each unit, deposited during the time of maximum incursion of the submarine fan; (c) the general increase in the proportion of proximal facies types from Nekana unit 1 to unit 4, and (d) the general increase in bed thickness from units 1 to 4.

For stratigraphic and geographic location of these units see Figs. 25 and 29 respectively.

NEKANA SANDSTONE MEMBER

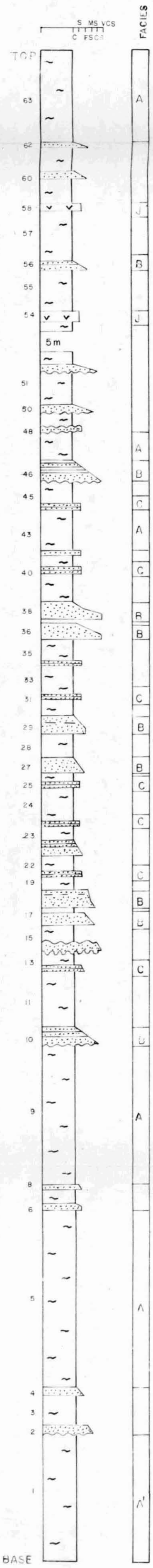
NOELE MARL FORMATION

NEKANA UNITS 1-4

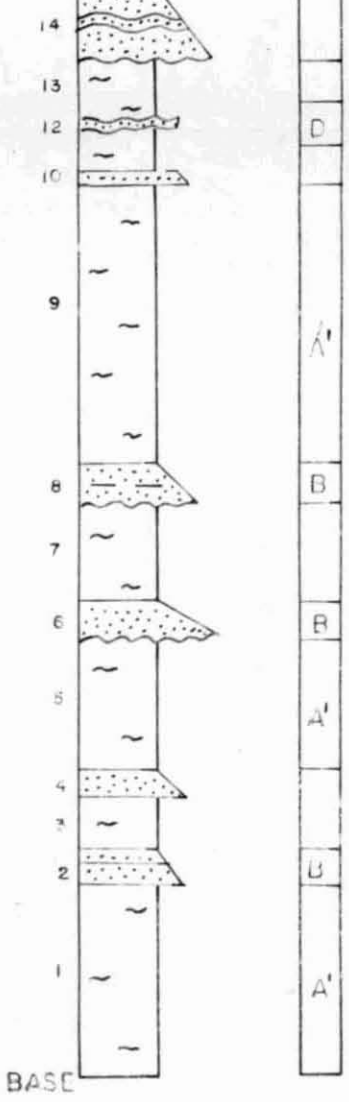
KALI SABAOE SECTION.



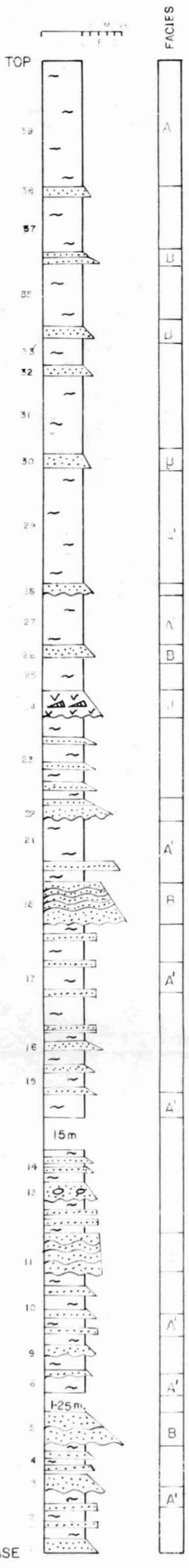
NEKANA 1



NEKANA 2



NEKANA 3



NEKANA 4

produced structures suggests that this environment was reasonably deep.

Facies A'

This facies comprises structureless, silty marls containing an abundant admixture of comminuted molluscan debris. Most of this appears transported, and may be related to the increased current activity associated with the deposition of the turbidites (facies B to E) which accompany this facies.

Facies B

Consists of thick bedded, graded, lithic arenites containing intermixed molluscan debris (Plates 10 and 11). Most beds are greater than 20 cm. in thickness and display Bouma units A, B and AB. The upper portion of most beds grades up into clay.

The well developed grading and regularity of thickness of these beds suggests deposition by turbidity currents of relatively distal aspect (when compared to other turbidites in the same sequence). The absence of slump or similar structures suggests deposition on a surface possessing negligible slope.

Facies C

This comprises non - graded, fine lithic arenites with molluscan debris. Pulses of coarser material occur at intervals throughout these beds, which range in thickness from 10 to 150 cm.. One ofthese beds was observed to pass laterally into a regularly graded facies 'B' arenite, suggesting an origin by local flow variations of an individual turbidity current.

Facies D

Comprises interbedded yellow clays and thin bedded, lensed, lithic arenites. Loading, sedimentary penetration and disruption of the latter within the clay are extremely common. These sedimentary features suggest extreme fluidity of the clay and therefore rapid deposition, and

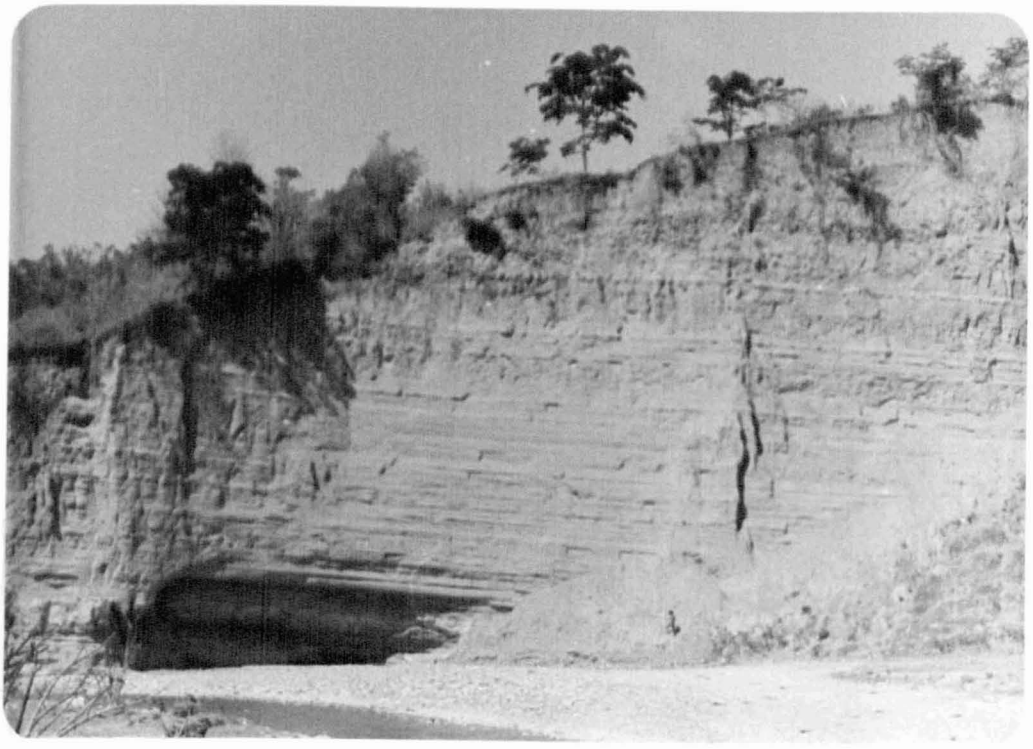
Plate 10: Nekana Sandstone Member, Kali Sabaoe section

A: Middle and upper portions of Nekana no. 3 unit. Note increasing marl intercalation towards the top of the section.

B: Detail of the lowermost part of a facies 'B' sandstone bed showing graded shell lag layer of scaphopod, gastropod, lamellibranch and coral debris and penetration of this shell lag into the underlying marl.

For location see Fig. 29 (inset).

A



B

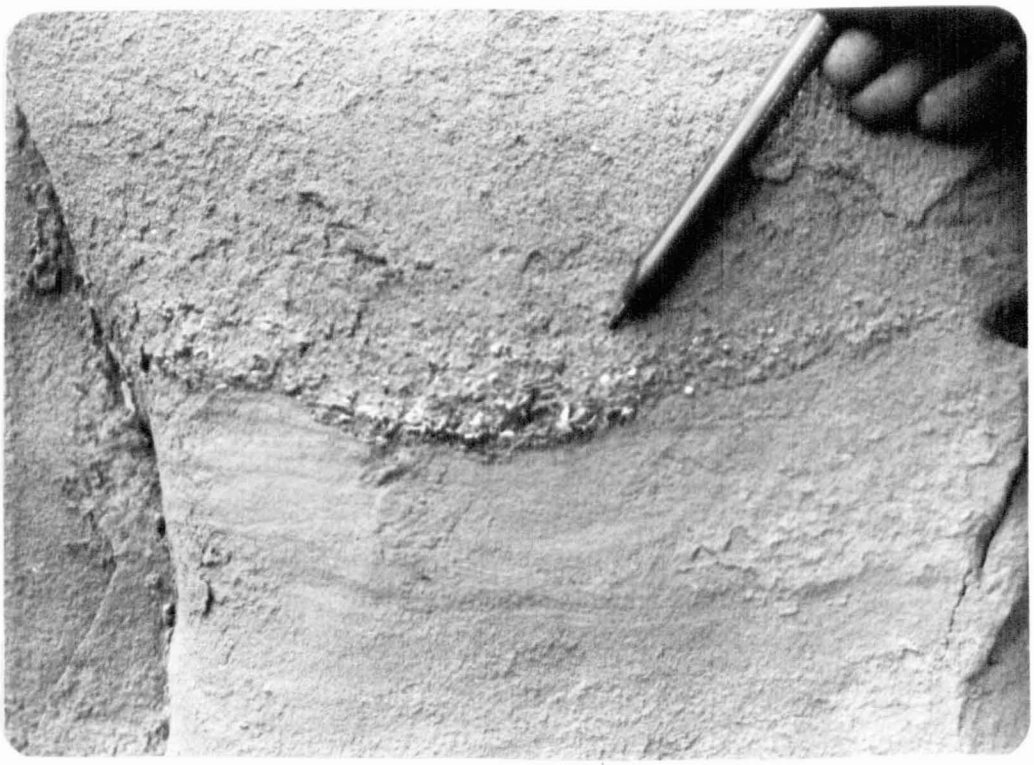


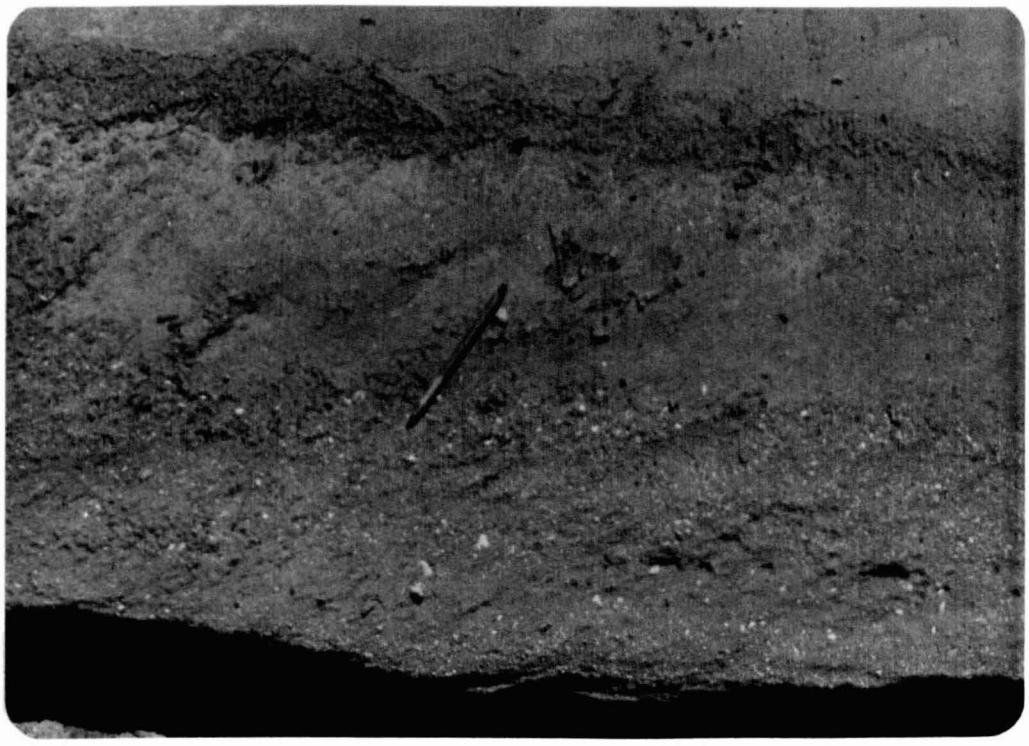
Plate 11: Nekana Sandstone Member, Kali Sabaoe:

A: Basal and middle portions of a facies 'B' sandstone unit, displaying grading of delayed type and coarse, basal unit with abundant, comminuted molluscan debris;

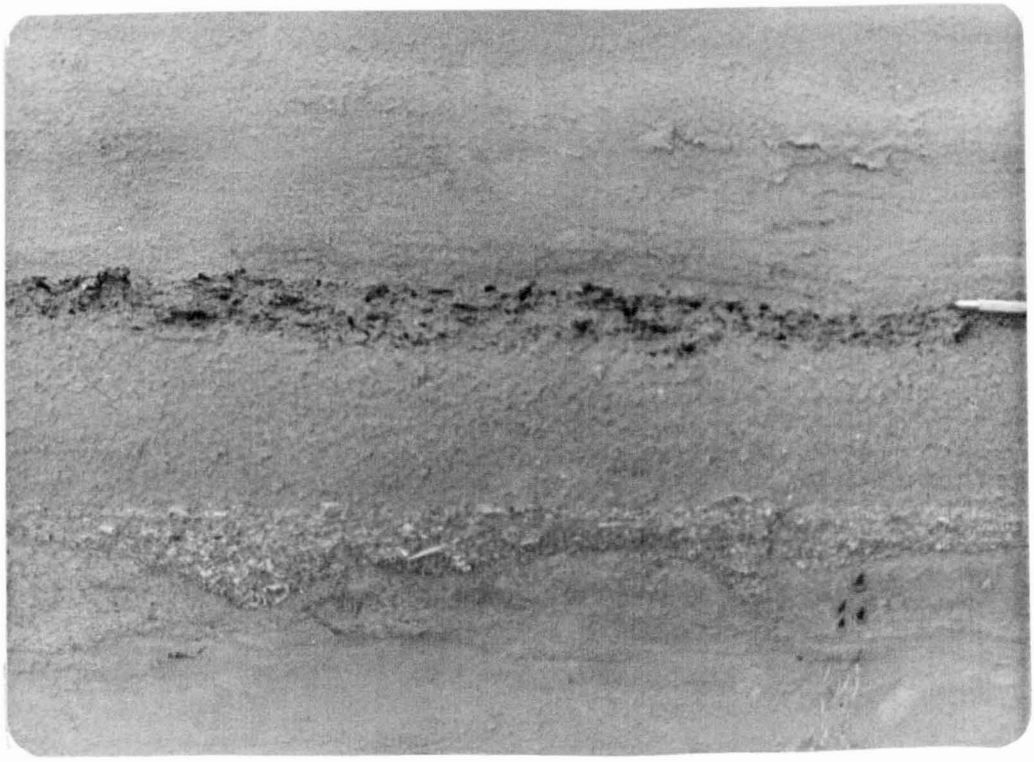
B: Basal shell lag layer of a facies 'B' turbidite unit, showing abundant scaphopod debris and upper layer of plant debris.

For location see Fig. 29 (inset).

A



B



all are features of proximal turbidite deposition. Lateral disruption (i.e. extension) of the layers may also suggest deposition on a slope.

Facies E

Comprises thick bedded (up to 115 cm.) graded arenites, some of which display multiple and delayed grading. The tops of most beds end abruptly in the fine sand fraction. Clay pellet layers are frequently seen at the tops of beds. Sedimentary penetration of the bases of the beds into the underlying mud occurs.

The thickness, and complex type of grading displayed by this facies suggests deposition by turbidity currents of relatively high energy; sedimentary injection, clay pellet inclusions and multiple and delayed grading being features of deposits of very proximal turbidity currents.

Facies I

The thickest and coarsest arenites are found within the uppermost Nekana unit (unit IX) where they consist of very coarse lithic arenite with numerous shell lag and clay pellet conglomerates. Two units, each about 10 metres thick are present. Each possesses a highly erosive base.

Facies J

Comprises beds of white tuff, which display parallel and ripple cross lamination. These tuff beds occur at intervals within the marl sequences. The presence of ripple cross lamination suggests that deep water bottom currents may have played a part in their deposition or redistribution.

Carbonaceous debris

Occurring both within the various sandstone facies and as isolated laminae in the marls are layers of carbonised plant and wood

material (Plate 11). These are often found towards the top of individual units, indicating deposition from the less dense 'tail' of the turbidity currents. Distribution by ocean currents or possible settling directly from floating material are thought to be responsible for the isolated layers found within the marl facies. Uchupi et al (1967) noted that most of the woody debris beyond the continental shelf appears to be associated with turbidites and suggested transport by this mechanism.

Depositional environment of the Nekana Sandstone Member

Comparison of detailed stratigraphic sections (Fig. 27) of each of the main sandstone/marl units (designated Nekana sandstone units 1 - 4) reveals (a) a general upward increase (from Nekana sandstone unit 1 to unit 4) of the sandstone/marl ratio and (b) a general increase up the succession of the proportion of proximal facies types present in the main sandstone section of each unit. Thus sandstone unit 1 consists principally of 'distal' C/B turbidites, unit 2 of C/B turbidites with a number of 'proximal' E and D units, and unit 4 of two thick sandstone units of facies 1. In unit 3, a temporary reversal of this trend towards proximality is suggested, although it is significant that both the sandstone/marl ratio and the general bed thickness of the facies 'B' sandstones in this unit are significantly greater than in Nekana sandstone unit 1.

Most sandstone successions within basinal sequences are now known to have been deposited as submarine fan complexes at the base of the continental slope. The relative thinness of each of the Nekana sandstone units, the low dip of the succession and the almost complete exposure has permitted the measurement of a north - south cross section across one of these units (Fig. 28). The length of the exposed unit

Fig. 28: Controlled cross - section along the exposed part of Nekana sandstone unit no. 2, showing marked wedge - shape, the unit thickening towards the basin centre (south). Note also the increasing proportion of marl in this direction.

The increasing basinward proportion of marl visible between the vitric tuff and the base of the submarine fan unit suggests either depositional thickening towards the basin centre or marked erosion of part of the marl sequence by the base of the submarine fan unit.

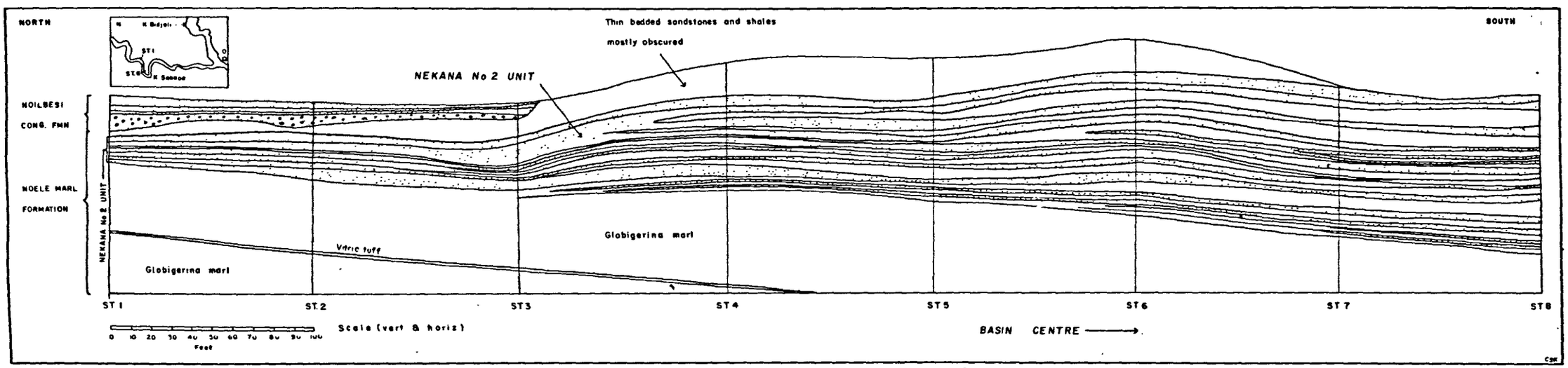
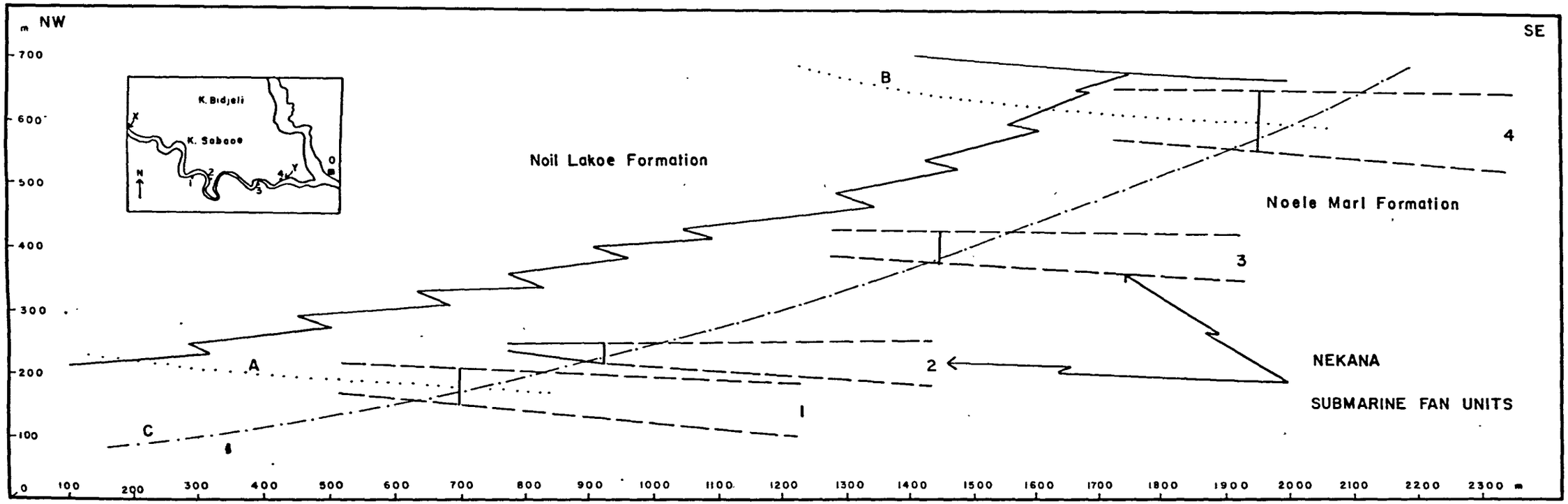

NORTH
SOUTH
Thin bedded sandstones and shales
mostly obscured
NEKANA No 2 UNIT
NOILBESI
CONG. FMN
NOELE MARL
FORMATION
NEKANA No 2 UNIT
Globigerina marl
Vitric tuff
Globigerina marl
ST 1
ST 2
ST 3
ST 4
ST 5
ST 6
ST 7
ST 8
Scale (vert & horiz)
0 10 20 30 40 50 60 70 80 90 100
Feet
BASIN CENTRE

Fig. 29: N.W. - S.E. profile across the Noele Sub - basin northern margin. Reconstructed from a continuous section along the Kali Sabaoe between points X and Y (inset) and restored to pre - tilted condition. Diagram shows actual present - day relationship between measured sections in Nekana submarine fan units 1, 2, 3 and 4. Position of the Noil Lakoe Marl Formation above is diagrammatic, but inferred from evidence elsewhere in the Noele Sub - basin. Approximate field locations of individual submarine fan sections shown in inset (points 1 to 4). For general location of Rivers Sabaoe and Bidjeli see Fig. 16.
O (inset): village of Oenasse.
Lines A and B are postulated time lines, line C plane of present day erosion.


m
NW
SE
700
600
500
400
300
200
100
0
K. Bidjeli
K. Sabaoe
N
X
Y
1
2
3
4
5
6
Noil Lakoe Formation
B
A
C
1
2
3
4
Noele Marl Formation
NEKANA
SUBMARINE FAN UNITS
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
m

(700 feet), maximum exposed thickness (100 feet), wedge shaped profile, orientation perpendicular to the basin margin, turbidite composition and basinward intercalation of marl leave no doubt that the unit represents a single submarine fan complex, deposited during a time when turbidity current activity was focussed in this part of the basin.

It was earlier concluded by facies analysis that the Nekana sandstone units showed a progressive increase in proximality towards the top of the succession. By restoration of the Kali Sabaoe section to its pre - tilted condition, the position of each of the Nekana sandstone unit sections relative to one another at the end of Nekana deposition can be demonstrated (Fig. 29).

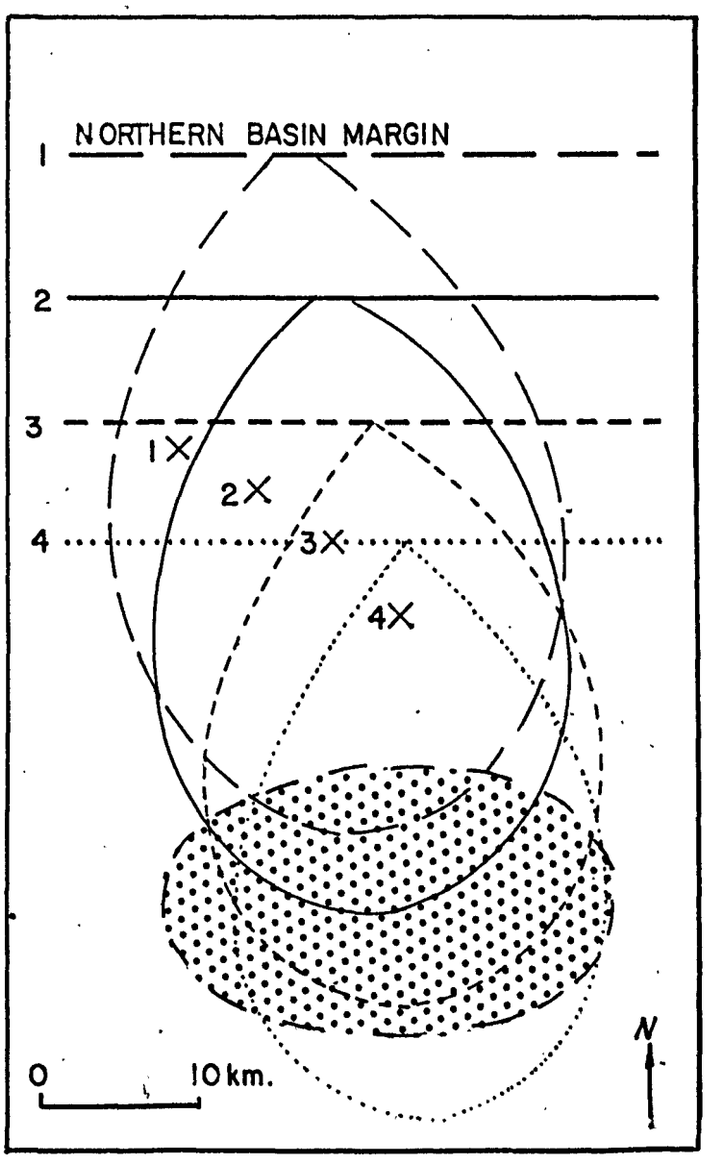
Present day submarine fans are known to alter their position as the locus of supply (often in turn due to migrating delta lobes) alters. Two interpretations of the resulting profile are therefore possible. The first involves the progressive progradation of the fans southwards from the basin edge (Fig. 30) so that the lower part of the resulting succession at any one point consists of turbidites deposited in the distal fan area, and the upper of deposits from the proximal area. Occasional lateral migration of the fan complex allows the deposition of a low energy marl unit between successive fan lobes. However, the same succession could result simply from lateral migration of the fan complex along the basin margin with no accompanying facies progradation, the proximality index of turbidites being a function also of the distance from the main avenues of flow (Horn et al, 1971). Of these explanations, the first is favoured because of (a) the regular upwards increase in proximality of the units and (b) the relatively long period of time represented by the thick Nekana succession, during which some basinward progradation of facies belts is almost certain to have occurred.

Fig. 30: Northern basin margin palaeogeography during deposition of the Nekana Sandstone Member. Diagram attempts to account for the observed upwards increase in proximality of units 1 to 4 by progradation of individual submarine fan units.

Lines 1 to 4 mark supposed successive stages in the progradation of the northern basin margin. Points 1 to 4 mark the approximate present day positions of the type sections of each unit. Note the supposed position of each of the first three units towards the edge of the prograding submarine fans.

The shaded area represents diagrammatically the approximate area of deposition of the equivalent Nuanain Sandstone Member of the southern part of the basin.

Scale is approximate only.


NORTHERN BASIN MARGIN
1
2
3
4
1X
2X
3X
4X
0
10 km.
N

That the Nekana sequence itself was situated throughout its deposition on, or near the edge of the area of influence of the prograding submarine fan complex is suggested, however, by the overall fineness of the deposit and by the abundance of comminuted shell debris of the kind which might be expected to be widely transported by turbidity currents and easily carried to flow extremities. It is therefore concluded that deposition of the Nekana units in the Noele Sub - basin took place toward the edge of a prograding submarine fan complex (Fig. 30).

Relationship to the Nuanain Sandstone Member of the central part of the basin

Although no microfaunal dating of the Nekana Sandstone Member has been attempted, its occurrence in a similar stratigraphic position to that of the Nuanain Sandstone Member of the central part of the basin suggests an Early Pleistocene (N22) age. The differences in lithology and sedimentary structures of the Nekana beds, in particular the eroded base of most beds, wide range of grain size, erratic bed thicknesses and occurrence of clay pellets are indicative of a much more proximal environment than that in which deposition of the Nuanain Sandstone Member took place. This accords well with the more northerly occurrence of the Nekana Sandstone.

(b) Palaeogeography of the northern basin margin during Noele Marl deposition

It was concluded earlier that the absence of turbidites or other arenites within the Batu Putih and Sabaoe Limestone Formations of the Kali Sabaoe section was an indication of the probable low relief during Late Miocene to Late Pliocene times of the region to the north of the basin. Evidence for the persistence of this northern palaeogeography

during all but a brief period (the Ofua Sandstone Member) of Noele Marl deposition is provided by the continued absence of turbidites, the first appearing and marking the base of the Nekana Sandstone. It is significant that the basal part of this arenite sequence and the sandstone portion of the slightly earlier Oemenu Sandstone Member of the southern part of the basin consist of sediment with a high proportion of fine, well sorted sand and comminuted shell material of the kind associated with shallow shelf or stable beach environments. Later, the accelerating uplift of the northern mountains led to an abundance of coarse, river produced detritus, which therefore becomes increasingly coarser and more abundant up the succession.

(iii) Palaeogeography of the Noele Sub - basin during Noele Marl deposition

The following history of deposition is proposed for the Noele Marl Formation in the Noele Sub - basin:

A marked transgressive phase (the result of the Bidjeli Subsidence) lasted from Middle N21 to Early N22, during which time gradual deepening of the whole of the Noele Sub - basin led to a replacement of the shelf carbonate deposition of Sabaoe Limestone times (Fig. 31,A) by deep water Globigerina marls (Fig. 31, B).

The relatively rapid subsidence of the northern part of the Sub - basin, which began in Sabaoe Limestone times, appears to have continued throughout deposition of the lower marl unit of the Noele Marl Formation, which therefore shows an overall thinning to the south (Fig. 32). In the southern part of the basin (Oemenu and Noele anticline (south) sections) slight folding of the Sabaoe Limestone rocks occurred prior to the beginning of the transgression, producing an angular unconformity with the overlying Noele Marl Formation. This unconformity is not present further north (Fig. 32).

The widespread marl sequence (lower marl unit) deposited during the early stages of the Bidjeli Subsidence is remarkable for its lack of associated sandstones, suggesting that the low relief of the region to the north of the Central Basin which existed in Batu Putih Limestone and Sabaoe Limestone times persisted into the Noele Marl Formation, with perhaps a brief period of elevation produced during the Bidjelian phase of folding, and the resulting incursion of the southwards flowing submarine channels of the Ofua Sandstone Member into the sub - basin (Fig. 31, C). This first Noele Marl clastic phase was however, of short duration, and was followed by another extensive period of marl dposition, represented by the middle marl unit (Fig. 31, D).

Fig. 31: Noele Marl palaeogeography; Noele Sub-basin

A. Final phase of Sabaoe Limestone deposition, showing northern land area of low relief (A); subsiding, shallow water shelf area with calcarenite deposition (B) and the emergent Kolbano High (C). Also shown are the Sabaoe Limestone depoaxis (D) and the northern boundary fault (E).

B. Palaeogeography of lower marl unit deposition, showing widespread deep water, open marine conditions (A) represented by marl stipple; probable direction of derivation of the clay mineral fraction of the marls (B) and the depoaxis of lower marl unit deposition (C).

C. Ofua Sandstone Member deposition, depicting southwards flowing submarine channels (C); open marine Globigerina marl deposition (B) depicted by marl stipple; and the postulated position of the northern land area (A).

D. Palaeogeography during middle marl unit deposition, showing widespread, open marine conditions (B); direction of derivation of clay mineral fraction (A) and submerged Kolbano High (C). The northern land - mass at this time was either completely submerged or existed relatively far to the north of the present northern positive area.

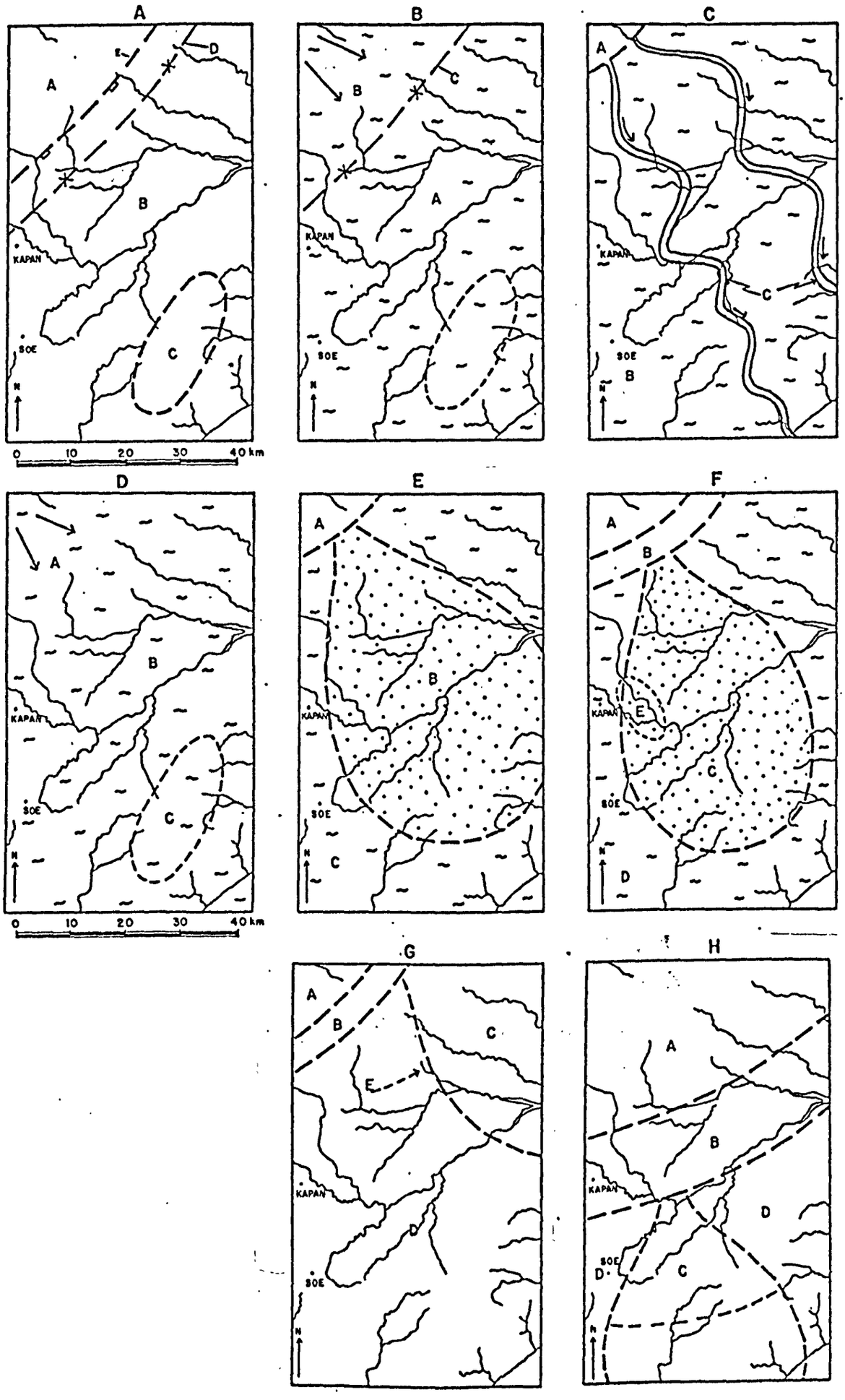
E. Oemenu Sandstone and lowermost Nekana Sandstone Member deposition, depicting extent of sandstone deposition (B); open sea, deeper water Globigerina marl deposition (C) and the northern shelf area from which most of the clastic material was probably derived (A).

F. Palaeogeography during Nuanain Sandstone Member deposition, showing Nuanain Sandstone submarine fan complex (C) and its postulated northwards transition into Noil Lakoe Marl Formation slope deposits (B). Also shown are the northern land area (A); Globigerina marl deposition away from the fan complex (D) and the present day outcrop and assumed position on the submarine fan of the Nekana Sandstone Member (E).

Fig. 31 (contd.)

G. Palaeogeography of upper marl unit deposition, showing open marine Globigerina marl deposition (D) possibly caused by lateral migration (E) of the Nuanain Sandstone submarine fan complex (C). Also shown are the postulated Noil Lakoe Marl Formation slope deposits to the north of the submarine fan complex (B) and the postulated northern land area (A).

H. Deposition of the Nanfua Sandstone Member in the Noele area during southwards progradation of the northern basin margin facies belts: (A) northern land area; (B) Noil Lakoe Marl Formation slope deposits; (C) Nanfua Sandstone deposits; (D) open sea Globigerina marl deposition.


A
B
C
D
E
F
G
H
KAPAN
SOE
N
0 10 20 30 40 km

The cessation of coarse clastic deposition at this time suggests lateral migration of the submarine channels away from the western part of the Noele Sub - basin or temporary subsidence below sea level of the source area to the north. Lateral channel migration is considered unlikely by itself to produce an almost totally arenite - free sequence, deposition at large distances from the main avenues of flow of submarine channels being characteristic of modern turbidite sequences (Horn et al, 1971). Temporary cessation of uplift, or subsidence of the source area is therefore implied.

Both stratigraphic (appearance of the first arenites) and foraminiferal (Carter, unpublished report, dated 1970,a) evidence suggests that towards the end of the middle marl unit deposition, a widespread regression began to take place. This regression, the result of what is here called the Noele Uplift, corresponded to the initiation of the Mataian Orogeny, and had as its first effect the transport of erosional products from the rapidly rising northern mountain region into the basin to the south, resulting in deposition of the Oemenu Sandstone Member (Fig. 31,E). The lithology of these sands suggests that a shelf region of greater or lesser extent was present to the north of the Noele Sub - basin during at least the latter part of the middle marl unit deposition.

Deposition of the Nuanain and Nekana Sandstone Members followed, as an increasing quantity of fluviatile detritus was delivered to the basin by southwards flowing turbidity currents, producing a prograding series of submarine fans (Fig. 31,F).

Cessation of turbidity current deposition in the Noele Sub - basin, possibly caused by lateral migration of the fan complex, permitted the deposition in late Noele Marl times of a thick sequence of Noele Marl, represented by the upper marl unit (Fig. 31,G). A return of

clastic deposition followed towards the end of Noele Marl deposition, with the appearance of a proximal series of submarine canyon infillings (the Nanfua Sandstone Member) which prograded over, and incised themselves into, the preceding marl sequence (Fig. 31, H).

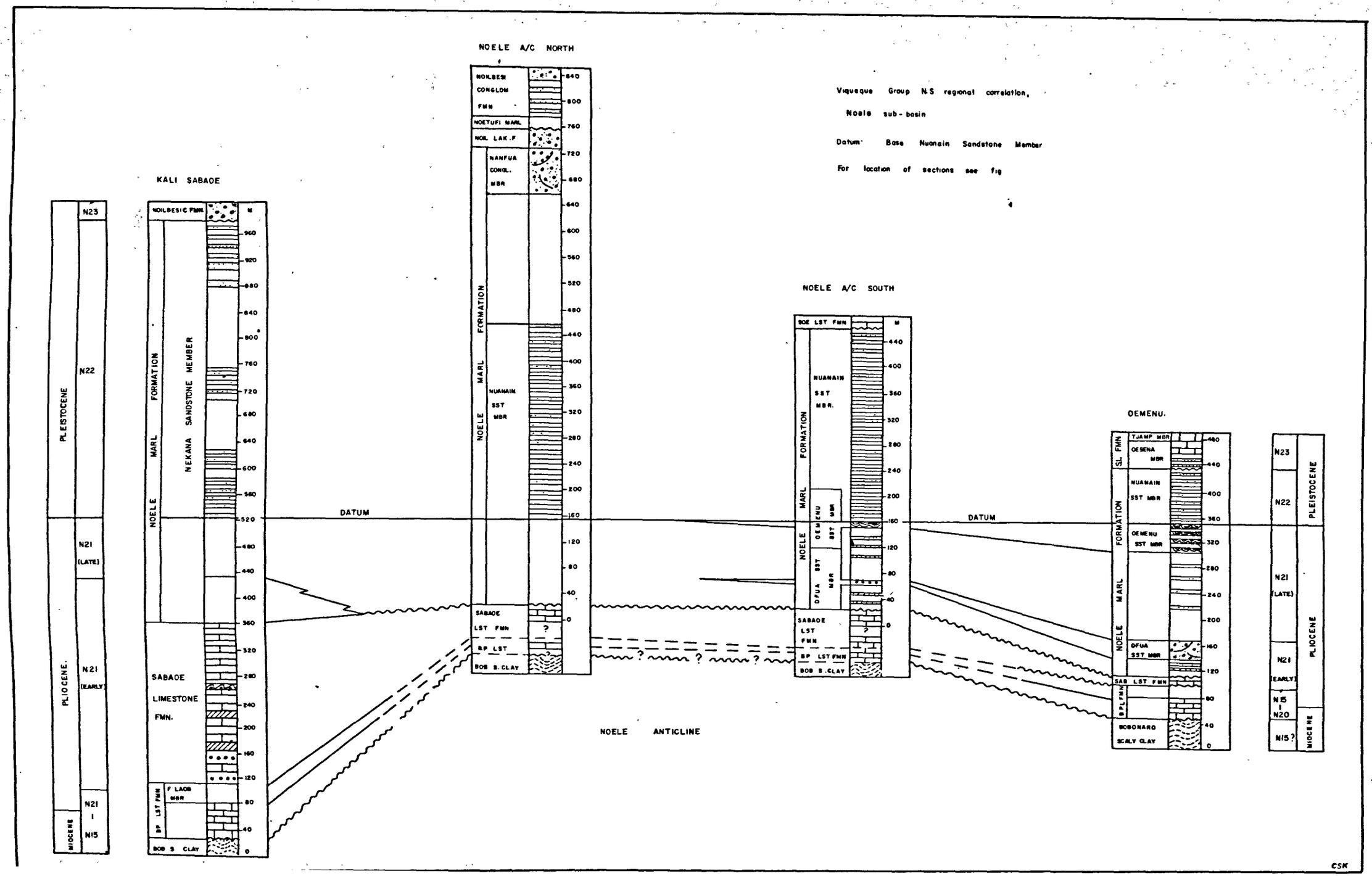
Noele Marl deposition was brought to a close in the Noele Sub-basin by the southwards progradation over the Central Basin deposits, of the slope marls and conglomerates of the overlying Noil Lakoe Marl Formation (Fig. 31, H).

Uplift to sea level of the Noele Sub-basin and the closing stages of the Noele Uplift were approximately coincident with the climax of the Mataian Orogeny, during which extensive folding of the deposits of the Noele Sub-basin occurred.

Age of the first Mataian compressive movements

Correlation of stratigraphic sections across the Noele Sub-basin, using the base of the Nuanain Sandstone Member as datum (Fig. 32) provides some evidence for the existence of a high on the site of the present Noele anticline at least as early as the beginning of Nuanain Sandstone deposition. That it probably was not in existence substantially earlier than Ofua/Oemenu Sandstone times is suggested by the absence of apprciable thickening of the lower marl unit southwards from the Noele anticline (Fig. 32). Initiation of growth on the Noele anticline may, however, have begun during, or immediately before the shedding of clastic debris into the Central Basin during Ofua and Oemenu Sandstone deposition.

Fig. 32: North - south regional correlation of the Viqueque Group of the Noele Sub - basin, using base of the Nuanain - Nekana Sandstone Members as datum. This correlation clearly shows the probable existence at the beginning of Nuanain Sandstone deposition of a high on the site of the present Noele anticline. The existence of this high at an even earlier date may be the reason for the thickening of the northwards derived Oemenu and Ofua Sandstone Members southwards from the Noele anticline south limb section.


NOELE A/C NORTH
KALI SABAOE
NOELE A/C SOUTH
OEMENU.
Viqueque Group N-S regional correlation,
Noele sub-basin
Datum- Base Nuanain Sandstone Member
For location of sections see fig
PLEISTOCENE
PLIOCENE.
MIOCENE
N23
N22
N21 (LATE)
N21 (EARLY)
N21 I N15
NOILBESIC FMN
NOELE MARL FORMATION
NEKANA SANDSTONE MEMBER
SABAOE LIMESTONE FMN.
F LAOB MBR
BP LST FMN
BOB S CLAY
NOILBESIC CONGLOM FMN
NOETUFI MARL
NOIL LAK.F
NANFUA CONGL. MBR
NUANAIN SST MBR
SABAOE LST FMN
BP LST
BOB S.CLAY
DATUM
BOE LST FMN
OEMENU SST MBR
OFUA SST MBR
SAB LST FMN
BP LST FMN
TJAMP MBR
OESENA MBR
SL FMN
BOBONARO SCALY CLAY
N15 - N20
N15?
PLIOCENE
MIOCENE
NOELE ANTICLINE
CSK

D. Stratigraphy of the Noele Marl Formation of the Bokong Sub - basin

The Noele Marl of the Bokong Sub - basin can be divided for the purpose of description into the following three areas(Fig. 33):

(i) The Noele Marl of the southern basin margin, exposed on the northern side of the Bokong - Batu Putih fault zone.

(ii) The Noele Marl of the basin centre, exposed beneath the cover of Noilbesi Conglomerate and Soe Limestone.

(iii) The Noele Marl of the northern basin margin, overlying the southern edge of the older autochthon.

(i) The Noele Marl Formation of the southern basin margin

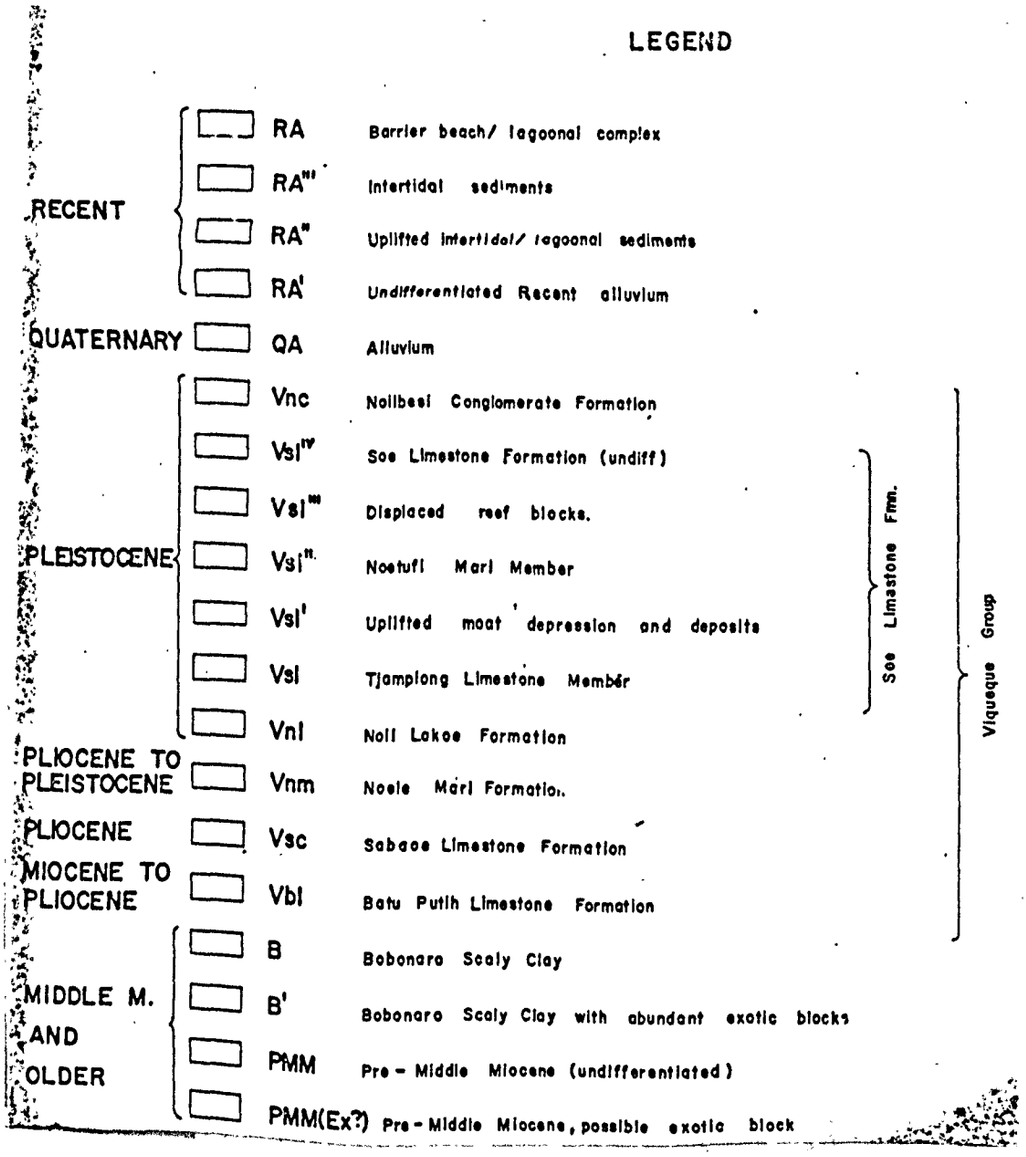
The Noele Marl outcrop of the Bokong Sub - basin southern margin is confined to a relatively narrow zone immediately to the north of the Bokong - Batu Putih fault zone, where the strong northerly dip associated with the downthrow has exposed some 720 metres of succession. Although somewhat complicated by minor faulting, the most continuous section is that of the Kali Bokong (Figs. 34 and 35), in which a thin development of Globigerina marl is succeeded conformably by an interbedded series of graded arenites and marls belonging to the Nuanain Sandstone Member. The succession is completed above a faulted contact, by a thick sequence of fissile marls, 'varved' silts and thin, graded sandstones comprising the Tanah Putih Marl Member.

(a) The Nuanain Sandstone Member of the Bokong Sub - basin

In the Bokong Sub - basin, the Nuanain Sandstone Member consists of a series of thin bedded (7 to 50cm.), lithic arenites with interbeds of massive, grey, foraminiferal marl. Most of the arenite units (98%) display the 'normal' grading type of Birkenmjaer (1959), the remainder

Fig. 33: Bokong Sub - basin location map, showing the three principal regions of outcrop referred to in the text. These are: (a) the southern basin margin, comprising mostly outcrops within, and on the northern side of the Bokong - Batu Putih fault zone, and including the main section along the River Kali Bokong (comprising the Kali Bokong section (1) and the Tanah Putih Marl section (2)); (b) outcrops of the basin centre, showing the approximate position of the slump sheets referred to in the text (3) and (c) the northern basin margin outcrops, including the Obernaik Member (4).

The entire width of the present day Bokong structural sub - basin is shown in this location map. The sub - basin extends from Bobonaro Scaly Clay outcrops in the extreme northwestern corner to those south of the Bokong - Batu Putih fault zone.



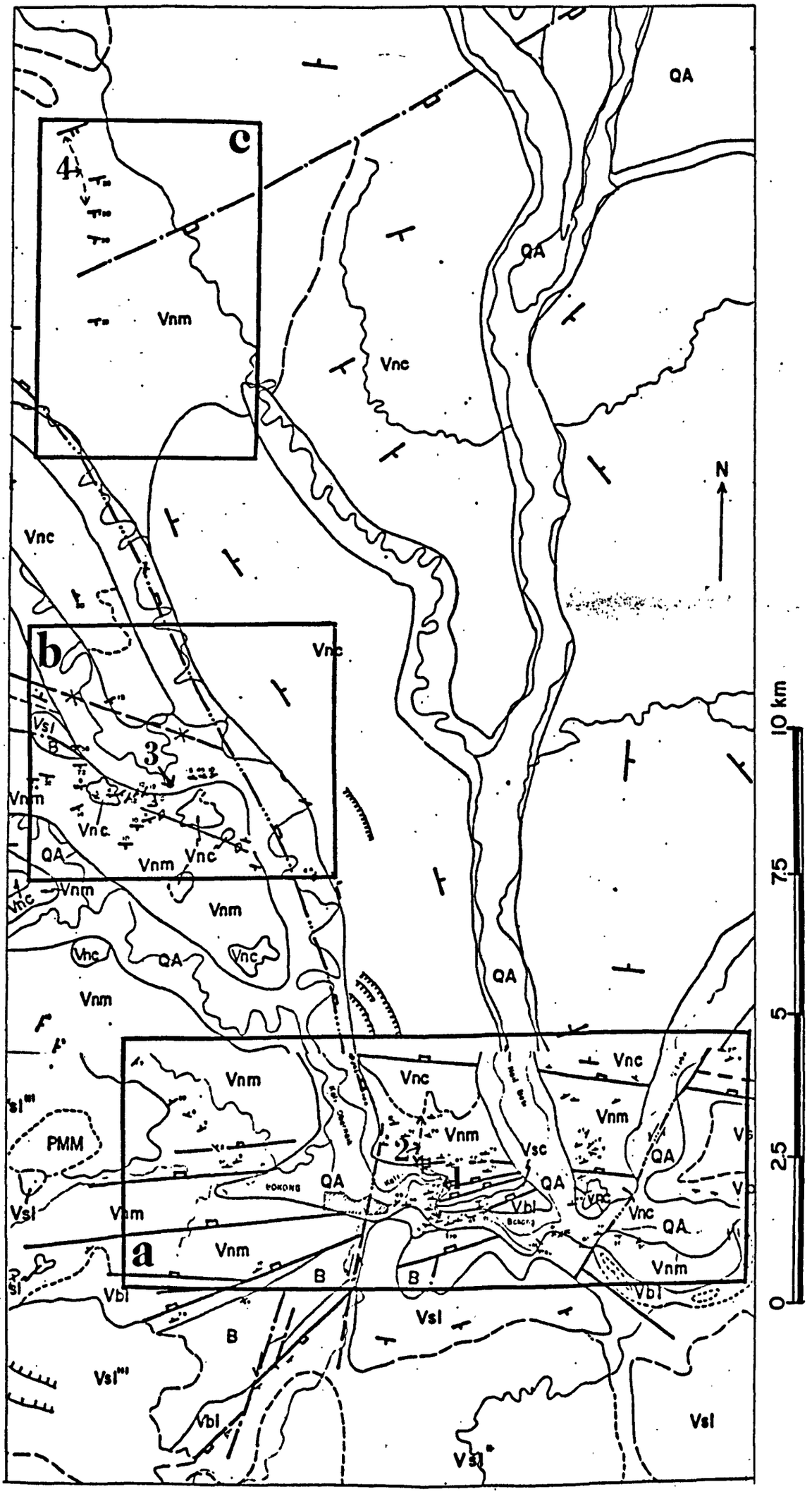

c
4
Vnm
QA
Vnc
N
Vnc
b
Vnc
Vsl
B
3
Vnm
Vnc
QA
Vnm
Vnc
Vnc
Vnm
Vnm
Vnc
QA
Vnc
Vnm
QA
Vnm
Vnc
Vnm
Vnc
Vnm
2
1
Vsc
QA
QA
Vnc
Vnm
QA
PMM
Vsl
Vnm
Vnm
a
Vnm
B
B
Vbl
Vbl
Vsl
B
Vsl
Vbl
Vsl
Vsl
10 km
7.5
5
2.5
0

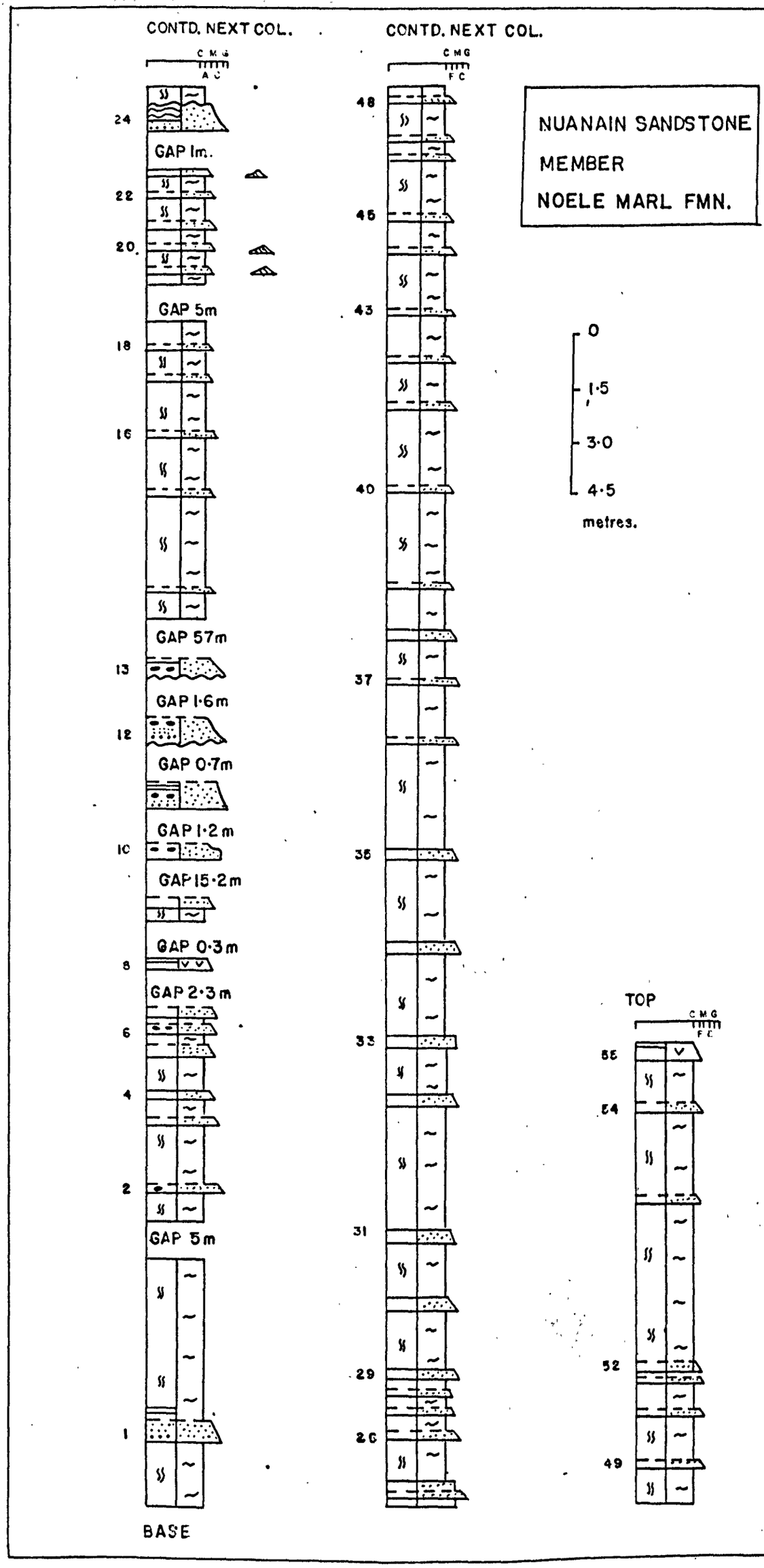
Fig. 34: Stratigraphic section of the Noele Marl Formation of the Bokong Sub - basin, measured along the Kali Bokong.

For location of section see Fig. 33.

CHRONO-STRATIG.
LITHO-STRATIG.
SECTION
LITHOLOGY
ENVIR-ONMENT
TECT-ONICS
PLEISTOCENE
PLIOCENE
N23
N22
N21
NOILBESI CONGLOM. FORMN.
NOILE MARL FORMATION
TANAH PUTIH MARL MEMBER
KUANAIN SST. MBR.
SABAOR LST FORMN.
m
720
690
660
630
600
570
540
510
480
450
420
390
360
330
300
270
240
210
180
150
120
90
60
30
0
Conglomerate, sand and gravel
Laminated grey marl and silty marl with graded sandstones. Intercalations of massive, silt-free marl.
FAULT CONTACT
Grey marl with thick-bedded graded arenites.
Grey foraminiferal marl
Muddy calcarenite.
Fluviatile
Slightly subsaline to brackish water lagoonal. Regressive sequence
Deep water marine
Shallow Deep water neritic marine
Warping, faulting
Compressional folding during and after deposition
Pre main Natalian folding
Regional subsidence

Fig. 35: The Nuanain Sandstone Member of the Kali Bokong section, Bokong Sub - basin.

Note (a) predominance of Bouma A units (e.g. bed 1) or AB units amongst the graded sandstones; (b) thinness of bedding displayed by the latter; (c) general abundance of clay pellet inclusions (beds 6, 10, 13) and (d) occurrence of vitric tuff beds near top and bottom of succession.


CONTD. NEXT COL.
CONTD. NEXT COL.
C M G
A C
F C
NUANAIN SANDSTONE
MEMBER
NOELE MARL FMN.
0
1·5
3·0
4·5
metres.
GAP 1m.
GAP 5m
GAP 57m
GAP 1·6m
GAP 0·7m
GAP 1·2m
GAP 15·2m
GAP 0·3m
GAP 2·3m
GAP 5m
TOP
BASE

being ungraded. The thicker arenite units (greater than 20 cm.)aare characterised by 'Bouma' intervals A, B, or ABC and the thinner units by 'Bouma' interval A only.

Lithologically, the beds are similar to those of the Noele Sub - basin, with clasts derived from the Lolotoi, Cribas, Bobonaro Scaly Clay and other pre - Viqueque formations. Some matrix is present, although most of the intergranular space is filled by calcite cement. The coarsest fraction of some beds consists of comminuted molluscan and coral debris.

The marls are grey, massive, silt - free and break with a conchoidal fracture.

(b) The Tanah Putih Marl Member

Summary

The Tanah Putih Marl Member is defined as a series of interbedded marls, silty mudstones, silts and arenites forming the uppermost part of the Noele Marl Formation in the Bokong Sub - basin.

The environment of deposition is determined as a shallow water, brackish lagoon, which is shown to have existed in the Sub - basin during Early Pleistocene (N22) times. The succession appears to have been strongly affected both by the final stages of the Noele Uplift, which produced a markedly regressive sequence, and by movement on the adjacent Bokong - Batu Putih fault zone, which produced contemporaneous deformation within the Tanah Putih Marl succession.

Introduction

The Tanah Putih Marl Member forms the uppermost part of the Noele Marl succession of the Bokong Sub - basin southern margin, succeeding the underlying marls and arenites of the Nuanain Sandstone Member above a faulted contact and being itself succeeded unconformably by the Noilbesi Conglomerate Formation or the Noetufi Marl Member of the Soe Limestone Formation.

The type section begins at the first appearance of grey, fissile marls and shales above the massive marls of the Noele Marl Formation and continues upwards to the unconformity with the overlying massive conglomerates of the Noilbesi Conglomerate Formation.

The member is confined in distribution to a broad zone on the northern side of the Bokong - Batu Putih fault scarp (Fig. 33), where a total of 500 metres of succession was measured.

The succession (Figs. 36 and 37) consists of a series of interbedded marls, mudstones and silty mudstones with thin silt laminae

Fig. 36: Tanah Putih Marl Member: Type section, measured north of Tacari, Bokong Sub - basin.

For location, see Fig. 33.

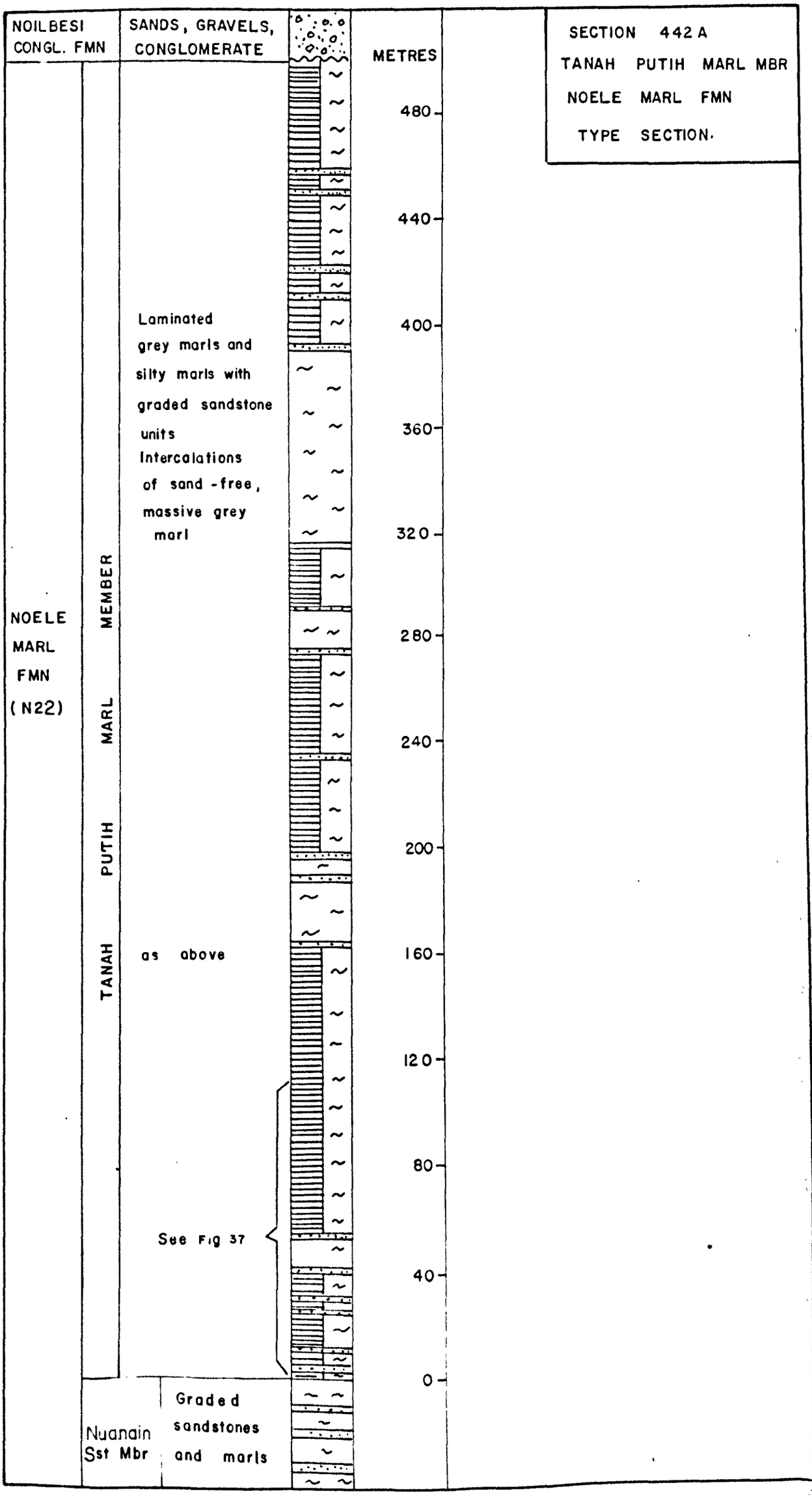
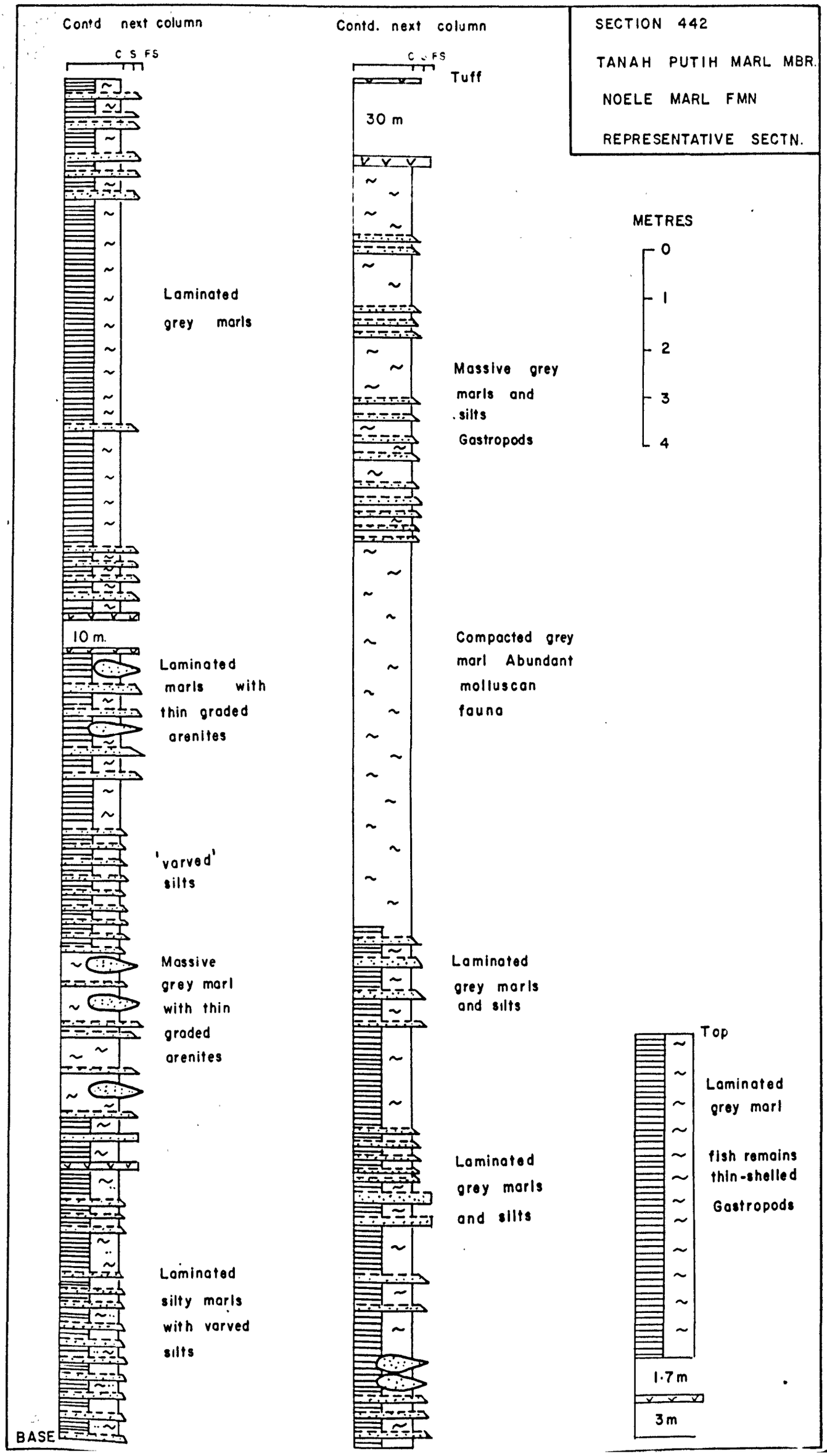

SECTION 442 A
TANAH PUTIH MARL MBR
NOELE MARL FMN
TYPE SECTION.
NOILBESI CONGL. FMN
SANDS, GRAVELS, CONGLOMERATE
METRES
480
440
400
360
320
280
240
200
160
120
80
40
0
Laminated grey marls and silty marls with graded sandstone units
Intercalations of sand-free, massive grey marl
as above
See Fig 37
NOELE MARL FMN (N22)
TANAH PUTIH MARL MEMBER
Nuanain Sst Mbr
Graded sandstones and marls

Fig. 37: Tanah Putih Marl Member: Detail of part of the lower portion of the type section (see Fig. 36), showing alternation of grey, silt - free marls (facies A, unlaminated), laminated silty marls (facies B), graded arenites and boudin - like graded arenites. Note the restriction of the abundant molluscan fauna to the silt free parts of the succession (facies A).


Contd next column
C S FS
Laminated grey marls
10 m.
Laminated marls with thin graded arenites
'varved' silts
Massive grey marl with thin graded arenites
Laminated silty marls with varved silts
BASE
Contd. next column
C S FS
Tuff
30 m
Massive grey marls and silts
Gastropods
Compacted grey marl Abundant molluscan fauna
Laminated grey marls and silts
Laminated grey marls and silts
SECTION 442
TANAH PUTIH MARL MBR.
NOELE MARL FMN
REPRESENTATIVE SECTN.
METRES
0
1
2
3
4
Top
Laminated grey marl
fish remains thin-shelled Gastropods
1·7m
3m

and thin - bedded, graded arenites. The marls are distinguished from those of the remainder of the Noele Marl Formation in being visibly well - bedded and in possessing a slight fissility. The thin - shelled lamellibranchs and visible planktonic foraminifera of the Noele Marl Globigerina marl are noticeably absent.

Lithology

The section comprises the following three major facies (Fig.37):

Facies A

Consists of silt - free grey mudstone or marl, within which interbedded arenites or silt 'varves' are rare or absent. Except for the restriction of the megafauna to one species of gastropod and the absence of visible Foraminifera or comminuted shell remains, this facies resembles marl occurring elsewhere in the Noele Marl Formation.

Facies B

Consists of thinly bedded, grey, silty mudstone, usually with many 5 mm. thick, graded silt laminae, all of which display an abrupt base (sometimes loaded) and transitional top. This facies contains no visible fauna. The absence of original soft - shelled fauna is suggested by the undisturbed condition of the silt laminae and general absence of bioturbation.

Facies C

Within the mudstones of facies 'B' are occasional, thin (20 cm.) beds of graded, lithic arenite (facies C), varying in grain size from fine to medium. Most beds display 'Bouma' A interval only. Sedimentary pinch and swell features are common within deformed marl masses, particularly in the steeply dipping beds near to the Bokong - Batu Putih fault zone.

Microfauna

The following foraminifera have been identified by Mr. D. J. Carter (unpublished report, dated 1970b):

Benthonics

Facies A

Brizalina sp.
Bolivina sp.
Fursenkoina schreibersiana
Hyalina baltica
Siphonoperta sp.
Quinqueloculina lamarckiana
Ammonia beccarii

Facies B

Ammonia beccarii
Bolivina sp.
Cibicides lobatulus
Fursenkoina schreibersiana
Cassidulina laevigata

Planktonics

Globigerina bradyi
G. juvensis
G. bulloides
G. cf. bulloides
Globigerinoides quadrilobatus gp.
G. gomitulus
G. ruber gp.
Globorotaloides variabilis hexagona
Globigerinita ambitacrena
Globorotalia scitula scitula
G. subcretacea
G. cultrata exilis
G. crassaformis crassaformis

Derived materials

According to Carter, (op. cit.) planktonics from the lower levels of the Viqueque Group (Batu Putih Limestone and Sabaoe Limestone Formations) are common in the coarser arenite beds.

Age of the Tanah Putih Marl

Carter (op. cit.) argued that the Tanah Putih Marl is a younger part of the Noele Marl Formation and suggested its equivalence to the upper part of the Nuanain Sandstone in the type section of the Noele Marl Formation.. This accords well with the observed position of the Tanah Putih Marl in the field.

Environment of deposition

The combination of (a) a restricted molluscan fauna, (b) a paucity of indigenous planktonic foraminifera and (c) a low energy environment dominated by gastropods and fish is strongly indicative of lagoonal deposition. This interpretation is supported by the occurrence of the Tanah Putih Marl Member between the open marine Nuanain Sandstone below and the overlying, fluviatile Noilbesi Conglomerate Formation in a generally regressive sequence.

The graded lithic arenite and silt layers suggest the distribution and deposition of land - derived terrigenous material within this lagoon by turbidity currents. In the case of the silt laminae this may have been by direct outflow of fine suspended material from the river mouths as the'courants turbides de surface' of Duff et al (1967,p.35). Surface hugging clouds of suspended material can be seen offshore from the south coast rivers of Timor during the flood season, and a similar mechanism was invoked by Horn (1969) to explain thin, graded, silt varves occurring in the mudstones of the Lower Cretaceous of S. E. Alexander Island in the Antarctic.

The restriction of the megafauna to the silt - free marl and clay (facies A) rather than to facies B mudstones and turbidites suggests that the environment was particularly unfavourable during the introduction of the latter (i.e. during the introduction of sediment - charged river water), suggesting that the lagoon was brackish rather than hypersaline.

Palaeogeography of the Bokong Sub - basin during Tanah Putih Marl deposition

The following factors suggest that the Tanah Putih Marl lagoon was widespread over most of the Bokong Sub - basin during Early Pleistocene (N22) times:

(i) The thickness (500 metres) and wide lateral extent of the deposit in the southern part of the basin and its dip beneath younger rocks to the north;

(ii) The diagnosis on the basis of the microfauna by Carter (op. cit.) of a shallow water, brackish environment of deposition for the lowermost part of the Tanah Putih Marl sequence and the description of the remainder of the sequence as 'strongly regressive'. Clearly, a considerable subsidence is implied by the deposition of 500 metres of shallow water sediment, and although some of this was probably due to movement on the local Bokong - Batu Putih fault zone, the behaviour of the Central Basin as a tectonic unit throughout much of Viqueque deposition suggests that the basin as a whole may have been subsiding at this time.

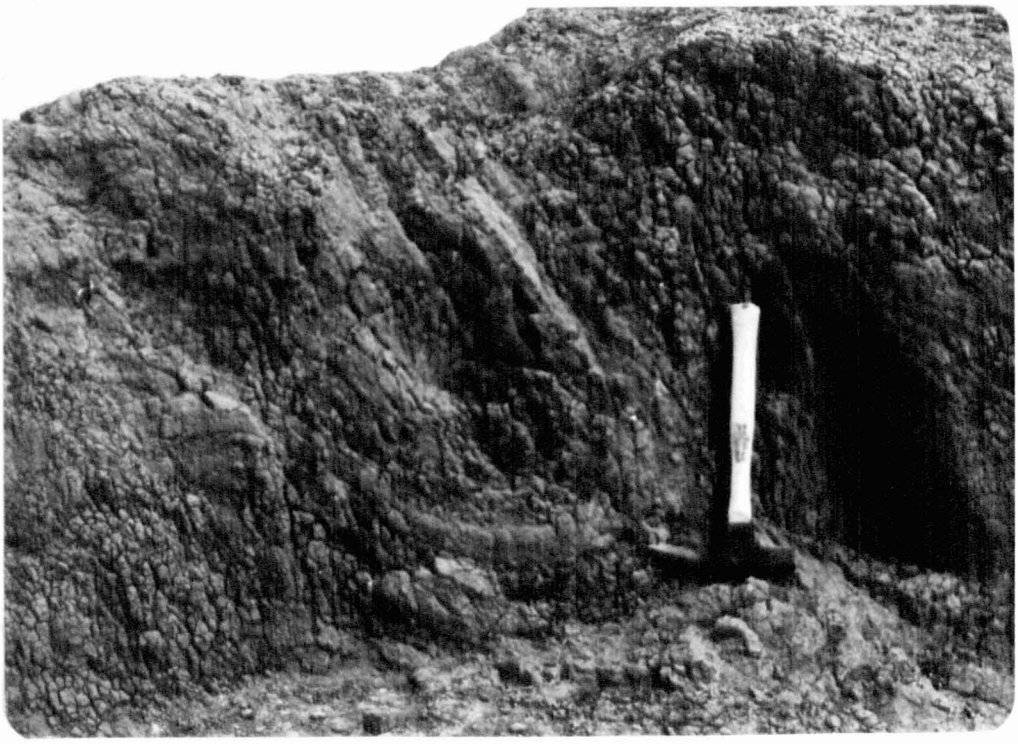
(iii) Carter (unpublished report, dated 1970b) noted the presence of derived foraminiferal material within the Tanah Putih Marl from the Batu Putih Limestone and Sabaoe Limestone Formations only. This clearly implies that the Central Basin, with its widespread younger deposits was still submerged and suggests the southern Panite High, the Tjamplong - Naifallo High, the Soe - Kapan High or the northern mountains as the main source of the derived material (Fig. 41,C). The similar present - day height of the sub - Soe Limestone unconformity on each of these highs suggests the possible emergence of all of them, although development of extensive drainage systems on either the Tjamplong - Naifallo or Soe - Kapan Highs at that time seems unlikely because of their probably

restricted extent. Similarly, the fineness and maturity of grading of many of the Tanah Putih Marl arenites suggest a source more distant than that of the adjacent Panite High, although this was probably emergent and of low relief at that time.

The palaeogeography of the Bokong Sub - basin during Tanah Putih Marl deposition therefore appears to have been that of a shallow water, brackish lagoon, which extended southwards from the northern mountain area as far as the discontinuous, emergent islands of the Panite High, through gaps in which a connection with the open sea was maintained. The lagoon was probably confined to the west by the Tjamplong - Naifallo High and to the east by the Kapan - Soe High. Clastic material was introduced at intervals into the lagoon by rivers draining the northern mountain area and distributed by surface suspension and turbidity currents.

Plate 12: Drag folding in the Tanah Putih Marls, 400 metres north of the Bokong - Batu Putih fault zone, Bokong Sub - basin.

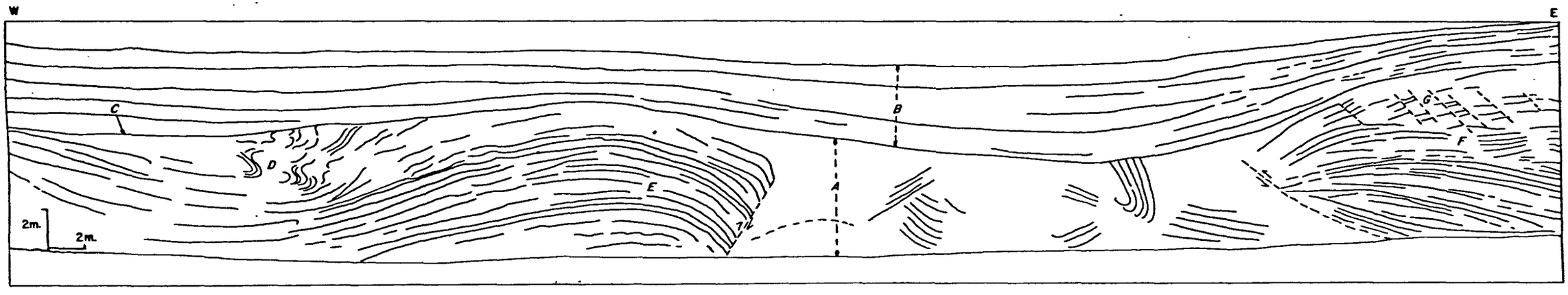
A



(ii) The Noele Marl Formation of the centre of the Bokong Sub-basin.

The Noele Marl of the central part of the basin is largely obscured by the overlying Noilbesi Conglomerate Formation, but is present in a few isolated outcrops along the rivers Kali Cacu and Noil Noni in the western part of the basin. The most continuous exposure is that along the banks of the Kali Cacu at localities 52/53 (Fig. 33), where the Noele Marl Formation consists of a remarkable series of slumped and folded beds (Fig. 38) of massive Globigerina marl, overlain unconformably by a thick series of interbedded, graded, lithic arenites and foraminiferal marl, tentatively correlated with the Nuanain Sandstone succession of the southern basin margin. That these folds are due to local slumping, rather than to a major pre- or intra-Nuanain Sandstone Member phase of movement is suggested by (a) the apparent lack of a similar phase of movement at this time elsewhere in the basinal succession and (b) the lateral passage of the slumped beds (although the actual transition is not exposed) into an unconformity of very small angular discordance. Although this slumping could be related to either (a) local basin floor faulting or (b) the northern or southern basin margins, a much more likely source would appear to be the Naimona diapir to the west (Chapter 10). This is suggested by (a) the easterly transition into normal, although slightly disturbed strata, (b) the time of growth of the diapir, which can be shown to have been at least as early as intra- Tanah Putih Marl (i.e. immediately post- Nuanain Sandstone deposition) and (c) the apparently consolidated nature of the marl at the time of its slumping, giving rise to the imbrication and faulting seen in Fig. 38. It might be argued that a considerable angle of repose, such as that on the flanks of an actively growing diapir, would be required to dislodge such sediments.

Fig. 38: Locality 52, Kali Cacu, Bokong Sub - basin, illustrating penecontemporaneous sediment disturbance in the lower marl unit below the Nuanain Sandstone Member. Sequence comprises: (i) lower, sand free marl unit (A), showing probable slump folding (E and F); imbrication (G) and small 'parasitic slumps' (D); (ii) upper, graded arenite and marl sequence of the Nuanain Sandstone Member (B).



NOELE MARL FORMATION

LOCALITY 52, CALI CACU

Elsewhere in the central part of the basin, outcrops consist mainly of similar interbedded graded arenites and marls and massive, grey, foraminiferal marls. These exposures correspond respectively to the Nuanain Sandstone Member and lower marl unit sections of the Bokong Sub - basin southern margin, and indicate a similar, open sea, moderately deep water environment of deposition, into which clastic material was introduced from the north.

(iii) The Noele Marl Formation of the northern basin margin:

The Obernaik Member

Introduction

The Noele Marl reappears to the north west of the downwarped Noilbesi Conglomerate Formation as a complex series of conglomerates, arenites and marls, 142 metres thick, which laps onto the Bobonaro Scaly Clay and Cribas Formations between Obernaik and Lelogamma (see Fig. 33). The exact relationship of this Obernaik Member to the Noele Marl of the southern and central areas is therefore difficult to determine on field evidence alone. Lithologically, the member appears to be the northern basin margin equivalent of the Tanah Putih Marl, deposited as a shoreline/shallow water marine complex during Early Pleistocene (N22) times.

The type section extends from the contact of the basal conglomerates (Fig. 39) with the underlying Globigerina marl, to the unconformity with the reef limestone of the Soe Limestone Formation.

The following facies are distinguished:

Facies A:

Comprises an extensively bioturbated, structureless, fine arenite with oysters and other molluscs. The oysters are very thin shelled, flat, unbroken and in apparent life position. Facies A occurs throughout the lower and middle parts of the succession, but becomes gradually finer with increasing admixture of lutite. The molluscan fauna persists throughout.

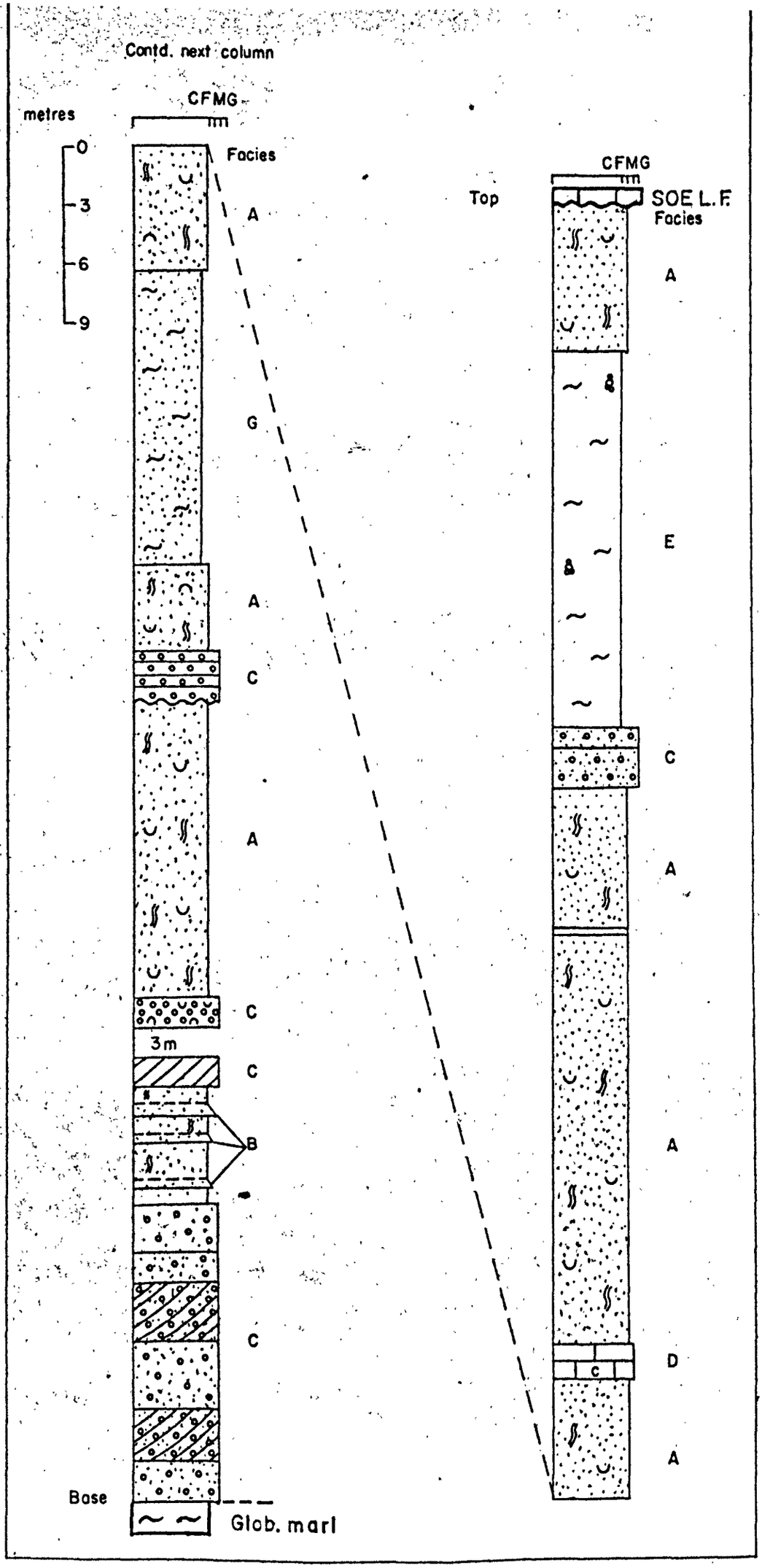
The arenitic composition and fineness of the deposit suggest a low to moderately high energy, somewhat turbid, shallow water marine environment of deposition.

Facies B:

Consists of lensed and parallel - sided, sometimes graded,

Fig. 39: Obernaik Member, type section, Bokong Sub - basin northern margin. Letters refer to facies types (see text). For location of section see Fig. 33.

The base of the section is taken at the base of the first conglomerate unit in the exposed Noele Marl Formation of the northern basin margin. The top is taken at the unconformable contact with the overlying Soe Limestone Formation.



SECTION 70/142
OBERNAIK MEMBER
TYPE SECTION
NOELE MARL FMN

arenites found interbedded with the lowest occurrence of facies A. These arenites are highly bioturbated.

The grading and lateral continuity of the arenites suggest deposition by turbidity currents. The presence of in situ oysters suggests a shallow water environment of deposition and emphasises the fact that caution should be exercised when attaching depth significance to turbidity current deposits. Similar shallow water turbidites have already been described from the Tanah Putih Marl Member and evidence has been presented by Kuenen (1964) for turbidite deposition in 20 metres of water.

Facies C:

Consists of poorly sorted conglomerates, some of which display low - angle cross stratification. One example of graded bedding was noted. The clasts, which attain a maximum diameter of 8 cm. are mostly derived from the Lolotoi Complex.

Facies D:

Represented by a single bed of fine calcarenite, within facies A, containing in situ gastropods.

Facies E:

Consists of grey clays with plant remains and abundant, large (10 to 15 cm. in length) gastropods.

Lying below the Obernaik Member are grey, massive, sand free marls containing occasional, thin shelled lamellibranch debris. These sediments belong to the Globigerina marl of the Noele Marl Formation.

Depositional environment of the Obernaik Member

The abundance of shallow water molluscs (e.g. Ostrea), bioturbation and cross - bedding throughout the succession suggests deposition in a moderately to very shallow water marine environment.

Age

The member is included in the Noele Marl Formation because of (a) its occurrence below the pre - Soe Limestone Formation unconformity and (b) the presence below it of marl of 'normal' Noele type. The relatively deep water aspect of both lower marl and Nuanain Sandstone Member sequences of the southern basin edge almost certainly implies shorelines during the deposition of these members some distance to the north of Obernaik and at a somewhat higher elevation, particularly as these members in the southern part of the basin appear to have since subsided relative to the Obernaik Member. It is therefore concluded that the latter was deposited along the northern basin margin of the Tanah Putih Marl lagoon during Early Pleistocene times, the conglomerates and sands being the basin edge, coarser clastic equivalent of the fine arenites of the Tanah Putih Marl. This suggested relationship is illustrated in Fig. 40.

(iv) Summary: Palaeogeographic development of the Bokong Sub-basin during Noele Marl deposition

Deposition of the Noele marl in the Bokong Sub-basin was similar to that in the Noele Sub-basin from Late Pliocene (N21) to Early Pleistocene (N22) times, producing a deep water marl/turbidite succession (Fig. 41, A and B), the latter marking the first signs of the Mataian orogenic phase and Noele Uplift. Apart from minor slumping, there is no evidence either before or during deposition of this deep water succession, to suggest that the compression associated with this uplift had begun to affect the basinal succession. The earliest movements which can be dated in the Bokong Sub-basin are those which affected the succeeding Tanah Putih Marl Member, probably during its deposition, which on foraminiferal evidence appears to be Late N22.

The resulting compression produced (a) a steepening of dip on the Bokong- Batu Putih normal fault zone, causing penecontemporaneous or immediately post-depositional rupturing of the Tanah Putih Marl arenite beds and (b) a post- Tanah Putih Marl series of NNE-SSW wrench faults with combined left-lateral displacement of 5 kilometres in the Bokong- Batu Putih region. This wrench faulting was accompanied by E-W, gentle folding and is discussed later.

The deposition of the Tanah Putih Marl Member itself evidently took place in a shallow water, brackish lagoon (Fig. 41 C), which extended over much of the Bokong Sub-basin in upper Noele Marl times and was bounded to the north by a land area of moderate relief and by an intervening belt of shoreline clastics and marls (the Obernaik Member). To the south of the lagoon and

Fig. 40: Diagrammatical cross - section of the Bokong Sub - basin during early stages of Noilbesi Conglomerate deposition, illustrating supposed relationship of Obernaik (6) and Tanah Putih Marl (5) members of the Noele Marl Formation. Also shown are pre - Viqueque formations (1); pre - Noele Marl Formations of the Viqueque Group (2); lower marl unit of the Noele Marl Formation (3); the Nuanain Sandstone Member (4) and the Noilbesi Conglomerate Formation (7).

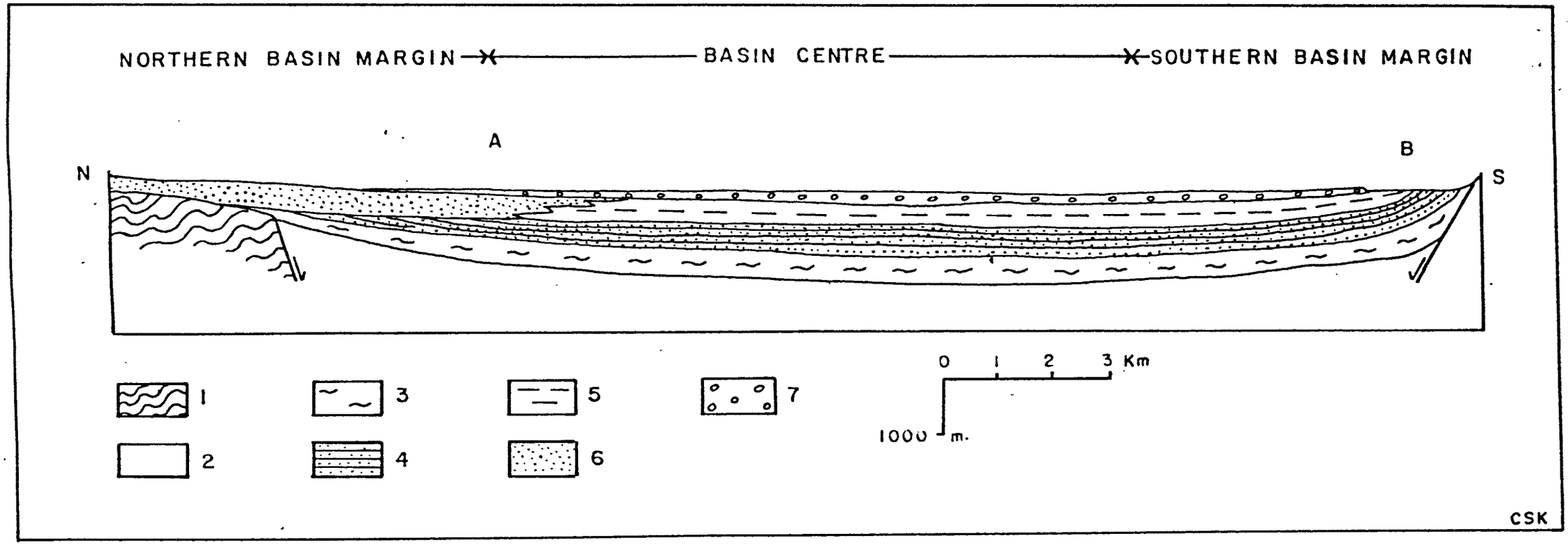
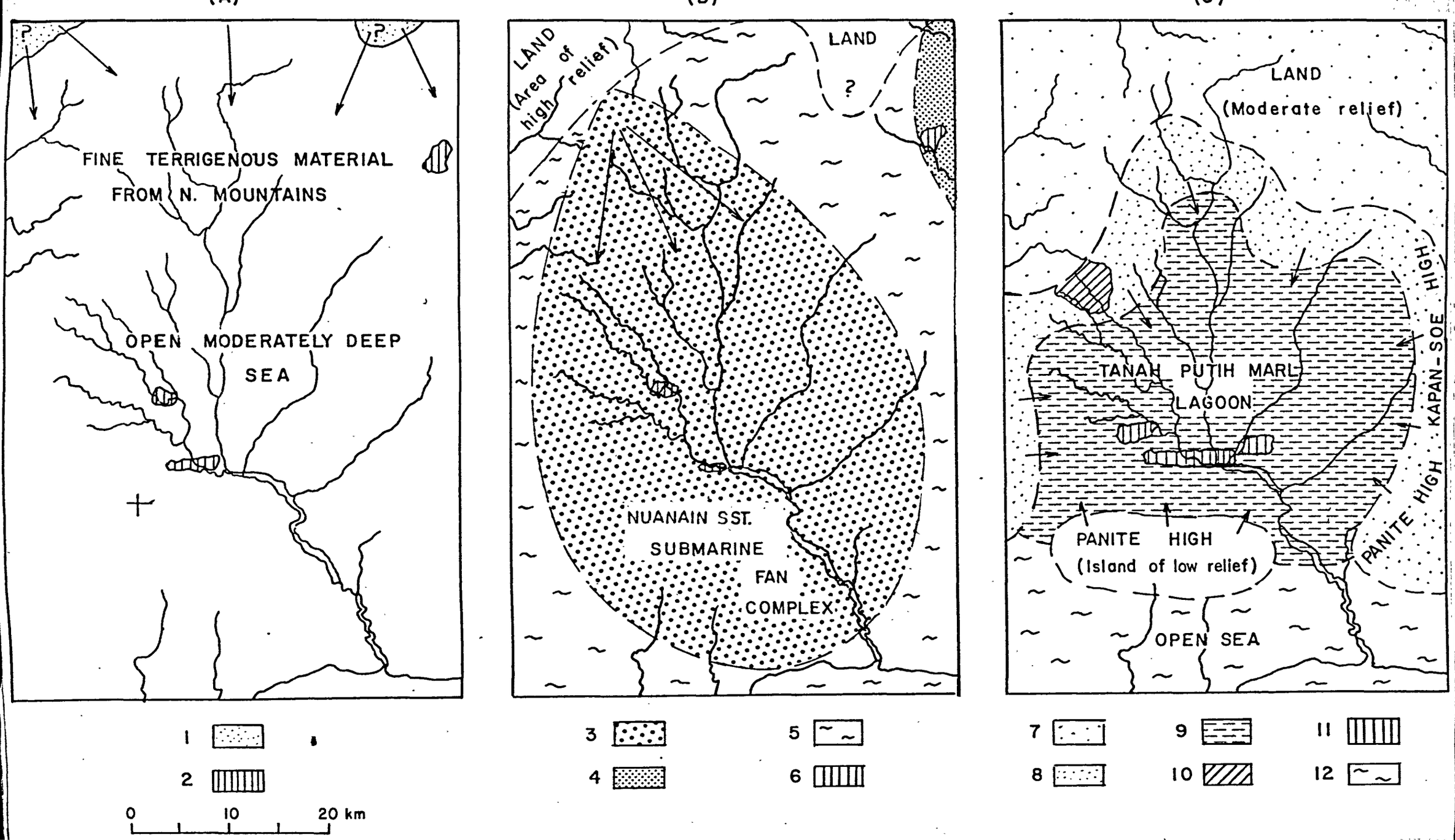

NORTHERN BASIN MARGIN
BASIN CENTRE
SOUTHERN BASIN MARGIN
A
B
N
S
1
2
3
4
5
6
7
0 1 2 3 Km
1000 m.
CSK

Fig. 41: Noele Marl palaeogeography, Bokong Sub - basin: Depicting (A) lower marl unit deposition (Early N21); (B) Nuanain Sandstone deposition (N22) and (C) deposition of the Tanah Putih Marl and Obernaik Members (Late N22).

1: Postulated land area of northern Indonesian Timor; 2: Present day distribution of deep water Globigerina marl; 3: Turbidites and marls of the Nuanain Sandstone submarine fan complex of the Bokong Sub-basin; 4: Turbidites and marls of the Nuanain submarine fan complex of the Noele Sub - basin; 5: Open sea Globigerina marls; 6: Present day outcrop of the Nuanain Sandstone Member; 7: Postulated land area; 8: Shoreline marls and arenites of the Obernaik Member; 9: Tanah Putih Marl Member marls and arenites; 10: Present day outcrop of the Obernaik Member; 11: Present day outcrop of the Tanah Putih Marl Member; 12: Possible open sea marl deposition to the south of the Panite High.

Positions of (a) the submarine fan complexes (b) the margins of the Tanah Putih Marl lagoon and (c) the northern land area are tentative only, and based on evidence from the outcrops shown in the diagrams.


(A)
(B)
(C)
?
?
FINE TERRIGENOUS MATERIAL
FROM N. MOUNTAINS
OPEN MODERATELY DEEP
SEA
LAND
(Area of high relief)
LAND
?
NUANAIN SST.
SUBMARINE
FAN
COMPLEX
LAND
(Moderate relief)
TANAH PUTIH MARL
LAGOON
PANITE HIGH
(Island of low relief)
PANITE HIGH
KAPAN-SOE HIGH
OPEN SEA
1
2
3
4
5
6
7
8
9
10
11
12
0
10
20 km

separating the latter from the sea lay an island, or series of islands, on the site of the present Panite High.

Considerable subsidence of the Bokong Sub-basin appears to have taken place during deposition of the Tanah Putih Marl Member, probably by means of downwarping of the basin centre in response to the Mataian compressive forces.

Finally, in Late N22/Early N23 times the Noele Marl of the Bokong Sub-basin was uplifted above sea level, resulting in the production of the widespread unconformity which now separates the formation from the succeeding Soe Limestone and Noilbesi Conglomerate Formations.

E. The Noele Marl succession of the Portuguese Timor south coast basins.

(i) General

The Noele Marl Formation is represented in the two south coast basins investigated by the writer (the Colitie and Viqueque Basins), by interbedded Globigerina marls and silty marls with arenite and conglomerate beds. The succession in these basins and those in the similar Matai' Basin were first described by Audley-Charles (1968), who chose as his type section of the Viqueque Formation the succession on the southern limb of the Viqueque syncline in the basin of the same name. In all of these localities the arenite and conglomerate beds are much thicker and coarser and the main marl development much thinner than in the corresponding succession of Indonesian Timor.

(ii) The Samé Member

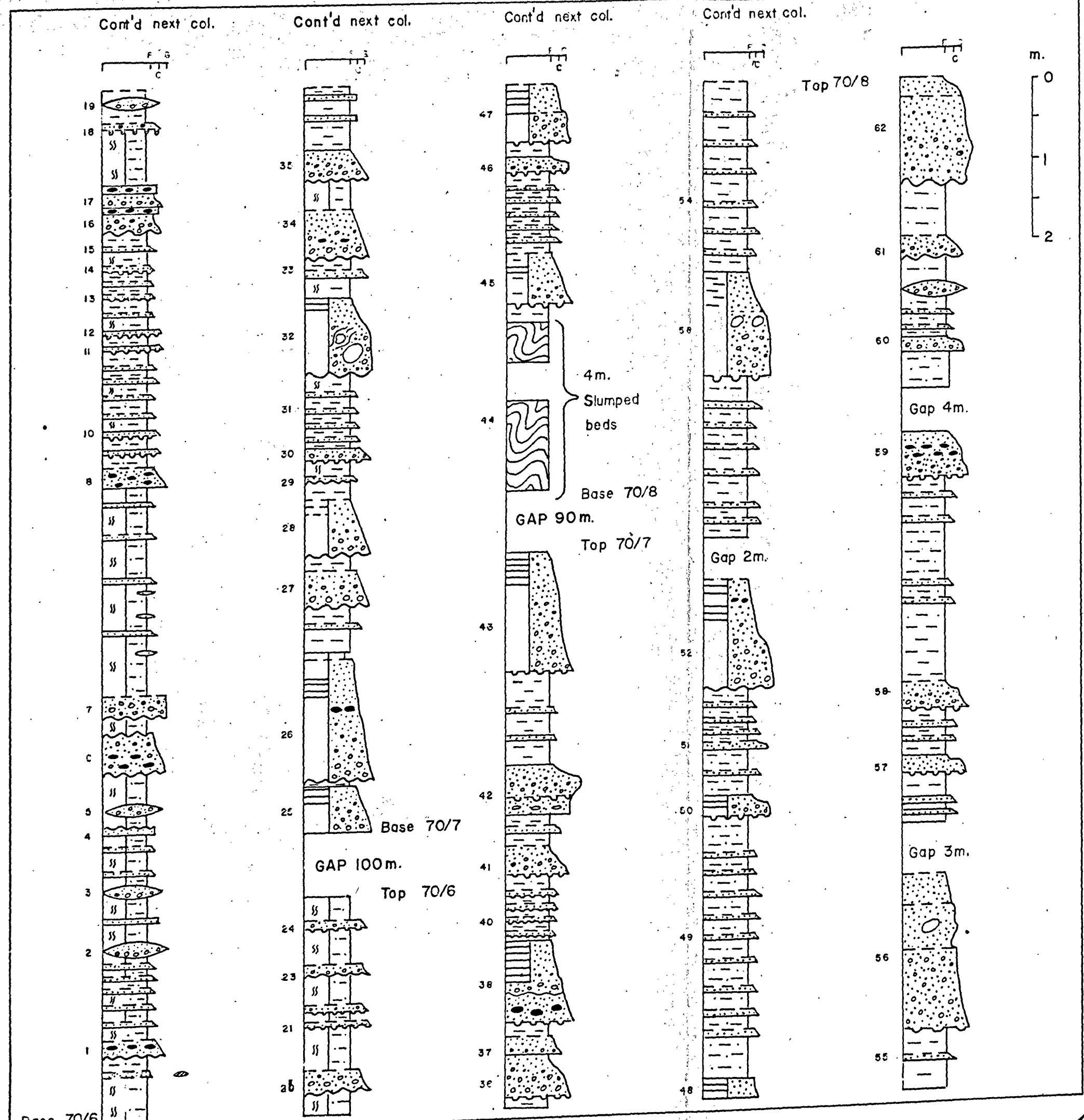
The upper part of the Viqueque succession in the Colitie syncline of southern Portuguese Timor consists of grey foraminiferal marls and silty marls with interbeds of lithic arenite and conglomerate (Fig. 42). Although the succession bears a superficial resemblance to the Nuanain Sandstone Member of Indonesian Timor the many important differences of detail which exist lead to the conclusion that palaeogeographic conditions within the two basins were very different. The type section, 262 metres thick, was measured along the Samé-Betano road, and extends from the appearance of the first arenite in the Noele Marl succession to the top of the last.

Description

Most of the coarse beds in the Colitie syncline possess some form of grading, and all are interbedded with a Globigerina,

Fig. 42: Same Member: Type section, measured along the Same - Betano road.

Note the thickness (up to 1.5 metres, e.g. bed 43), coarseness (bed 32), irregularity of bed bases (beds 9 to 16), presence of abundant marl clasts (beds 6, 26, 38) and thick slumped unit (bed 44), all of which are features of extremely proximal turbidite successions. Compare this section with the type section of the Nuanain Sandstone Member (Fig. 21).


Cont'd next col.
Cont'd next col.
Cont'd next col.
Cont'd next col.
m.
0
1
2
Base 70/6
Base 70/7
GAP 100m.
Top 70/6
4m.
Slumped
beds
Base 70/8
GAP 90m.
Top 70/7
Top 70/8
Gap 4m.
Gap 2m.
Gap 3m.

apparently deep water,marl. For this reason, and because of the presence of other features such as parallel lamination these beds are interpreted as the deposits of various forms of turbidity current.

The following sedimentary features testify to the nature of the environment:

(i) The majority of beds display the 'delayed grading' described from the Nuanain Sandstone Member. In the Samé Member this grading type is seen in beds less than 10cm thick, the non-graded lower part of these beds often being well developed and of wide lateral extent. This observation suggests the possession of a great degree of mobility by the depositing medium and provides further support for a 'traction carpet' origin.

(ii) Large (up to 60cm diameter), well-rounded boulders occur in some of the thicker beds.

(iii) Marked lateral changes of thickness and lenticularity of the sandstone beds are common.

(iv) Sandstone bed bases often penetrate the marl on which they rest. Isolated terrigenous clasts are often present in this marl beneath the sandstone beds. These features suggest that the mud was in an unconsolidated state before the deposition of the turbidites.

(v) Most beds consist of Bouma units A or AE. Parallel lamination is generally rare, only one example of an AB sequence being noted.

(vi) Marl pellet clasts derived from the finer interbeds occur within the coarser units.

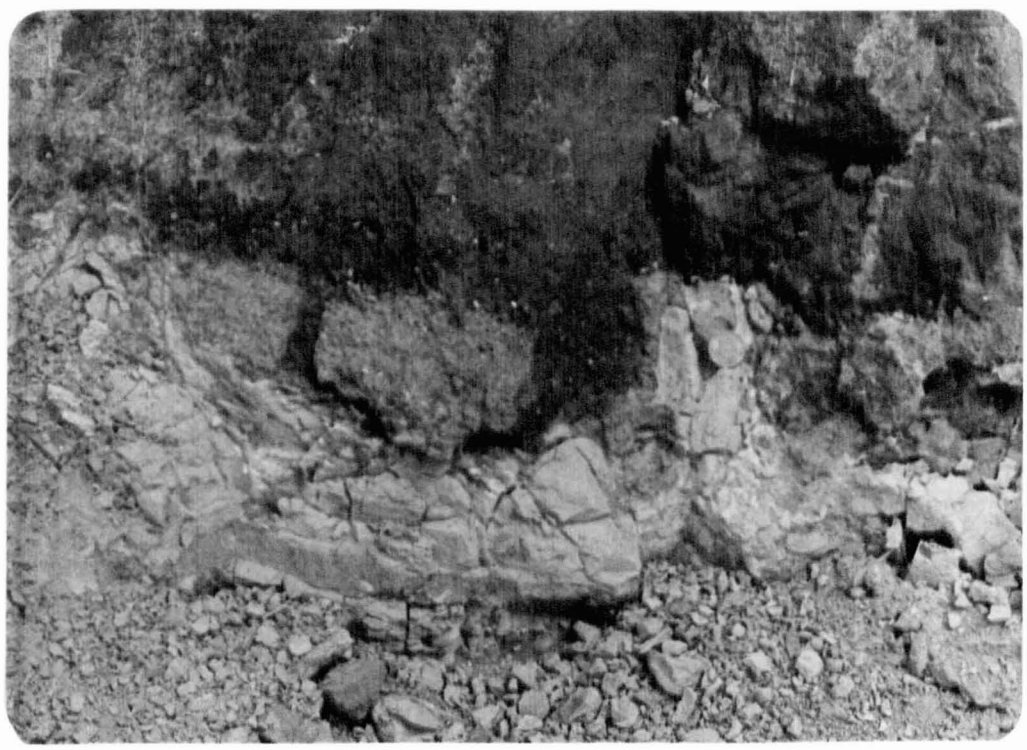
(vii) Some small scale slump structures involving several metres of succession occur.

(viii) No palaeocurrent indicators were observed within the Noele Marl sequence of the Colitie syncline. Four determinations of

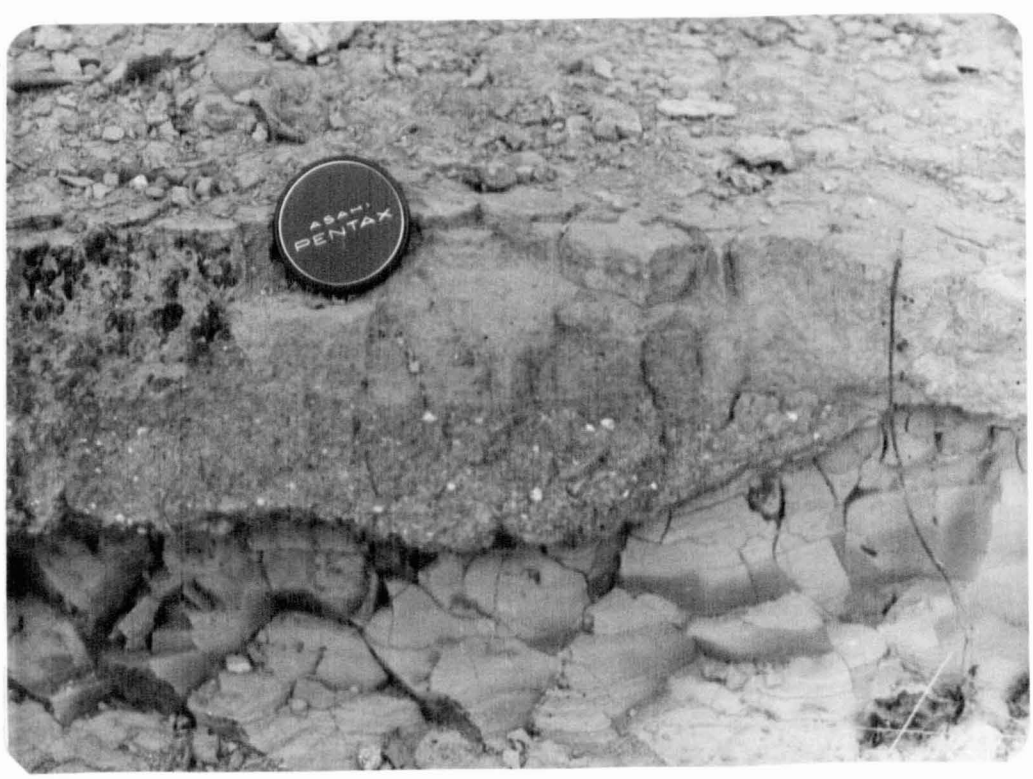
Plate 13: Proximal turbidite beds of the Same Member type section.

Note variations in bed thickness, erosive bed bases and delayed grading in thin beds (B) and thick beds (A).

A



B



ripple cross lamination direction within the succeeding Noil Lakoe Marl Formation showed current directions implying movement from SE to NW.

Environment of deposition

In addition to the very much coarser nature of the Samé succession compared to the Nuanain Sandstone succession,the presence of slump structures, boulders within graded beds and lenticularity of the units suggests a much more proximal environment of deposition than that ascribed to the Indonesian Timor equivalent. In such an environment the high rate of deposition of both coarse and fine units results in extreme instability of the succession and the presence of even a slight slope is enough to cause slumping (Lewis 1971; Shepard 1955). Similarly, the high rate of deposition of the mud or marl leaves little time between incursion of turbidity currents or slumps for pore water to be expelled by compaction, thus facilitating penetration of sediment-charged currents and subsequent settling of the deposited clasts into the mud. This feature is not found in the turbidites of the Nuanain Sandstone.

The interpretation of the environment of deposition of the Same succession as more proximal in aspect than that of the Nuanain Sandstone is in agreement with the relative positions of the two units with regard to the areas of older rocks from which they appear to have been derived. The Same type section lies only 5km south of the southern edge of a Lolotoi thrust sheet, whereas the nearest similar outcrop in the Central Basin is 15km north of the Nuanain Sandstone Member type section.

Fauna

The following foraminifera have been identified by Mr D.J. Carter (unpublished report, dated 1971a):

(a) Planktonics

Orbulina universa

Globorotalia cultrata menardii

G. tumida tumida (sinistral)

G. subcretacea

G. acostaensis pseudopima

G. borealis gp.

Pulleniatina spp.

Sphaeroidinella dehiscens

Globigerinoides gomitulus

G. ruber

G. conglobatus gp.

Globigerina bulloides

G. parabulloides

G. juvensis

G. rubescens

(b) Benthonics

Ammobaculites spp.

Textularia spp.

Spiroplectammina spp

Miliolacea

Peneroplidae

Nodosariacea

Uvigerina spp.

Protoglobulimina spp

Bulimina spp.

Hoeglundina spp.

Cibicides spp.

Bolivinita quadrilatera

Globocassidulina spp

Oridorsalis spp.

Elphidium spp.

Pseudorotalia sp.

Amphistegina sp.

Calcarina spp.

Ceratobulimina pacifica

Age

Carter (op. cit.) assigned an N22 (Early Pleistocene) age to samples from the Samé Member type section of this thesis.

F. Factors affecting sedimentation of the Noele Marl Formation

Most members of the Noele Marl Formation consist of two basic lithologic elements; an endogenetic or basin derived element, represented by the normal marls and clays, and an exogenetic element, consisting of the gravity displaced, resedimented arenites and conglomerates which are interbedded within these.

1. The endogenetic lithologies

(a) Source

The term 'marl' has been adopted in this work to describe fine grained sediments consisting of admixtures of between 30 to 40% carbonate mud and 60 to 70% terrigenous material, mostly clay mineral particles. Much of the terrigenous component probably originated by vertical settling of clouds of suspended matter similar to those which today travel long distances from the mouths of rivers on the south coast of Timor. The Bobonaro Scaly Clay which must have mantled large areas of the northern mountains at the time of Noele Marl deposition would have provided a widespread and readily eroded source of clay minerals.

A large proportion of the carbonate fraction of the marl consists of the tests of pelagic foraminifera such as Globigerina, which presumably settled to the floor of the basin after death. Much of the finer carbonate material is likely to have been derived from a comminution of carbonate benthonic remains on the shelves fringing the Central Basin, and also from onshore erosion of the two preceding carbonate units of the Viqueque Group, the Batu Putih Limestone and the Sabaoe Limestone Formations.

(b) Depth and distance from land

In the previous account of the Noele Marl, the abundance of carbonate material and the absence of structures indicating current disturbance have been used as evidence of a fairly deep water environment, above the calcite compensation depth (minimum 3,500m) but below general wave base. Examination of the various Noele Marl successions, at least in Indonesian Timor, reveals that nowhere in the now exposed succession were these limits exceeded, although it is likely that the upper part of the Noele Marl, deposited towards the end of the Mataian uplift and subsequently eroded was of a relatively shallow water aspect.

(c) In situ fauna

A proportion of the carbonate fraction in some parts of the Noele Marl succession consists of comminuted molluscan debris, mostly derived from in situ destruction of lamellibranch shells. A portion of the shelly debris in the marls interbedded with the Oemenu and Nekana Sandstones appears to have originated from the sandstone units and to have been redistributed by bottom currents.

Sedimentation of the finer beds of the Noele Marl is therefore chiefly a function of depth of water (the sediment - water interface being below wave base), the distance from land (far enough to allow the settling of pelagic organisms, but near enough to allow a large contribution by river - derived suspended material), the abundance of readily erodable terrigenous and carbonate onshore deposits, and finally the local presence or absence of benthonic molluscan debris.

(ii) The exogenetic lithologies

In the accompanying diagram (Fig. 43), the various types of exogenetic assemblage which occur in the Noele Marl are tabulated. An immediate difference is apparent between those sediments deposited during the main Viqueque folding phases and those deposited during the intervening period of quiescence.

The Bidjelian exogenetic assemblage comprises the Ofua Sandstone Member. The pre - Mataian exogenetic assemblage comprises the Oemenu Sandstone Member. This is of much finer grain size than the later sandstones and contains a very large proportion of comminuted, shallow water molluscan debris and occurs within a thick, otherwise sand - free marl sequence. It was concluded in an earlier section that the emerged land at that time was tectonically stable and of relatively low relief.

The main Viqueque uplift and compression was marked within the Noele Marl, however, by the appearance of thick arenite and conglomerate sequences of a much coarser nature than the earlier members. This Mataian exogenetic assemblage comprises the thick turbidites of the Nuanain Sandstone, which consist of much coarser, poorly sorted, well rounded material, presumably derived from delta fronts fringing the then growing northern mountains. These sandstones were not allowed to remain for long in a shallow water environment and consequently do not contain as much shell material as the Oemenu Sandstone Member. Some of the shell material which is present was probably derived from the erosion of the earlier Sabaoe Limestone.

Also forming part of the Mataian exogenetic assemblage are the coarse submarine fan deposits of the Nanfua Sandstone and most of the Noele Marl of Portuguese Timor.

It is clear therefore, that the relative development of the coarser units within the Noele Marl is closely related to the occurrence

Fig. 43: Relationship of the main clastic units of the Noele Marl Formation to periods of onshore tectonic activity.

DERIVATION	STRATIGRAPHICAL UNITS	ASSEMBLAGE	TECTONIC ACTIVITY	LITHOLOGY	FACTORS CONTROLLING DEPOSITION
ENDOGENETIC (Basin Derived material)	MARL SEQUENCES	(Present throughout Noele Marl Formation)	INCREASING →	GRAIN SIZE INCREASING →	Depth of water. Distance from shore. Source.
EXOGENETIC (Extraneous material)	Nuanain Sandstone Member Nanfua Sandstone Member Nekana Sandstone Member	MATAIAN			Primarily tectonic uplift of northern mountains. Distance from source.
	Oemonu Sandstone Member	PRE-MATAIAN			Tectonic quiescence allowing shallow-water accumulation of well-sorted sediments and subsequent transportation into basinal areas.
	Ofua Sandstone Member	BIDJELIAN			Tectonic: transgression and earth movements at beginning of Noele Marl times.

of the main tectonic episodes. Within each of the assemblages however, marked differences exist between individual members. Because most of the beds can be attributed directly or indirectly to deposition by turbidity currents, and because the latter change in character away from source, many of these differences are a direct function of distance from source. For example, the thinner bedding and finer grain size of the Nuanain Sandstone compared to the Nanfua Sandstone is a direct consequence of the position of the former in the central part of the submarine fan complex, compared to the slope or base of slope position of the latter.

Chapter 6. The Noil Lakoe Marl Formation

A. Introduction

The Noil Lakoe Marl Formation consists of a series of blue - green marls and clays with interbeds of conglomerate, arenite and occasional coral debris. The formation succeeds the Noele Marl Formation conformably and is itself succeeded unconformably by both the Soe Limestone Formation and the Noilbesi Conglomerate Formation. It achieves a maximum thickness of 450 metres in the Noil Lakoe syncline north of Noele.

B. Distribution

Present day distribution of the Noil Lakoe Marl Formation (Fig. 44) is confined to (a) the north - western part of the Bokong Sub - basin in the region of Kampong Fatu Kona; (b) the central and north - central part of the Noele Sub - basin, mostly in the Noil Lakoe syncline, and (c) the Colitie syncline of Portuguese Timor.

The formation was formerly distributed more widely than the present - day outcrop would suggest, pre - Soe Limestone Formation erosion in the southern part of both the Noele and Bokong Sub - basins having removed most of the Noil Lakoe Marl Formation and the upper part of the Noele Marl Formation.

C. Stratigraphy

(i) The Noil Lakoe Marl Formation of the central part of the Noele Sub - basin: the type section

The Noil Lakoe Marl Formation crops out along the Noil Lakoe in the Noele Sub - basin, from Noil Noni village to the junction with the Noe Ko. U River, a distance of approximately 10 kilometres (see Enclosure 1). Over most of this outcrop, the formation is horizontal or gently dipping. Three major facies can be recognised in the type section (Fig. 45):

Fig. 44: Noil Lakoe Marl Formation distribution:

A. Bokong Sub - basin (containing the Fatu Kona Member type section).

B. Noele Sub - basin (containing the Noil Lakoe Marl Formation type section).

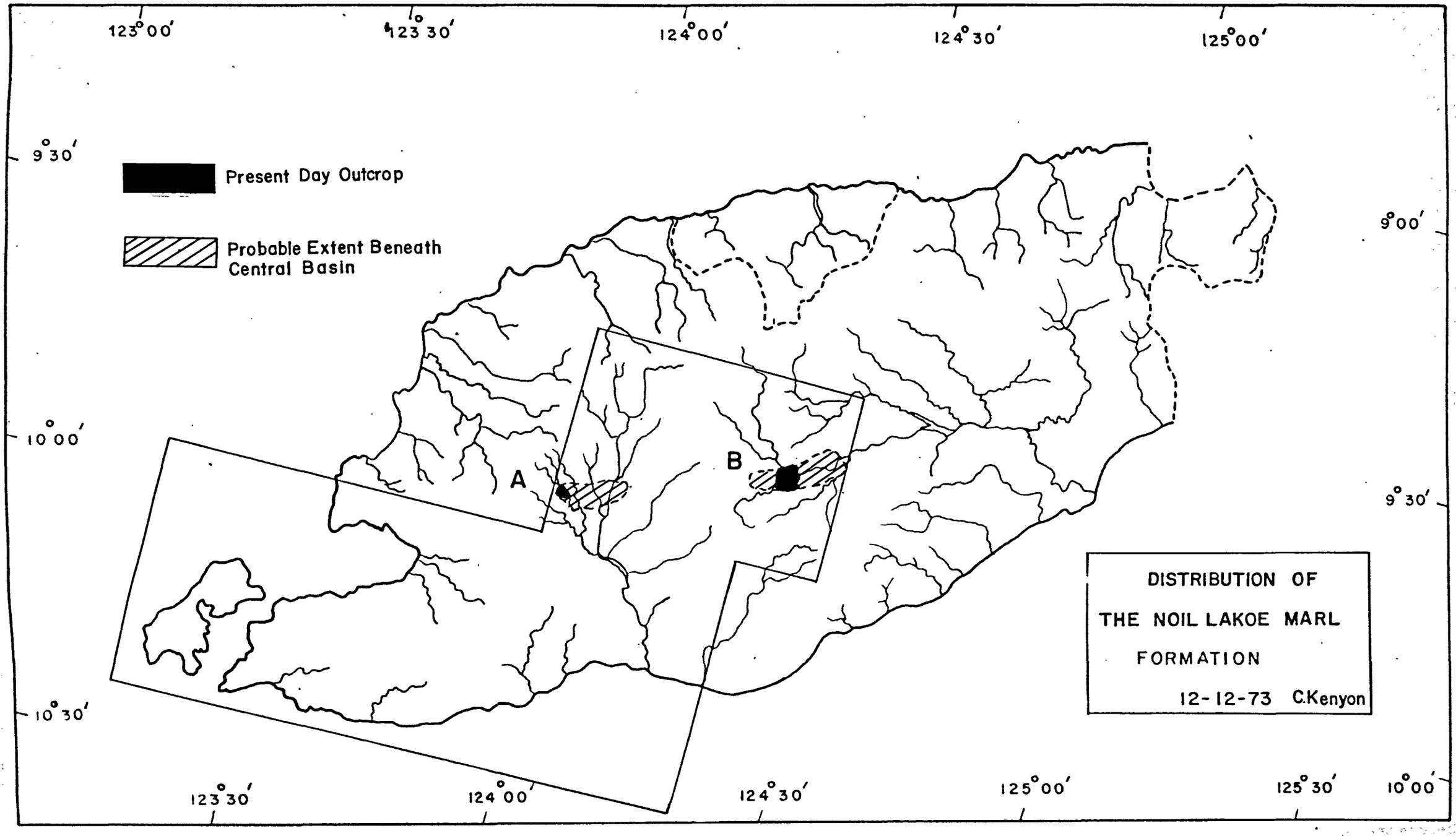
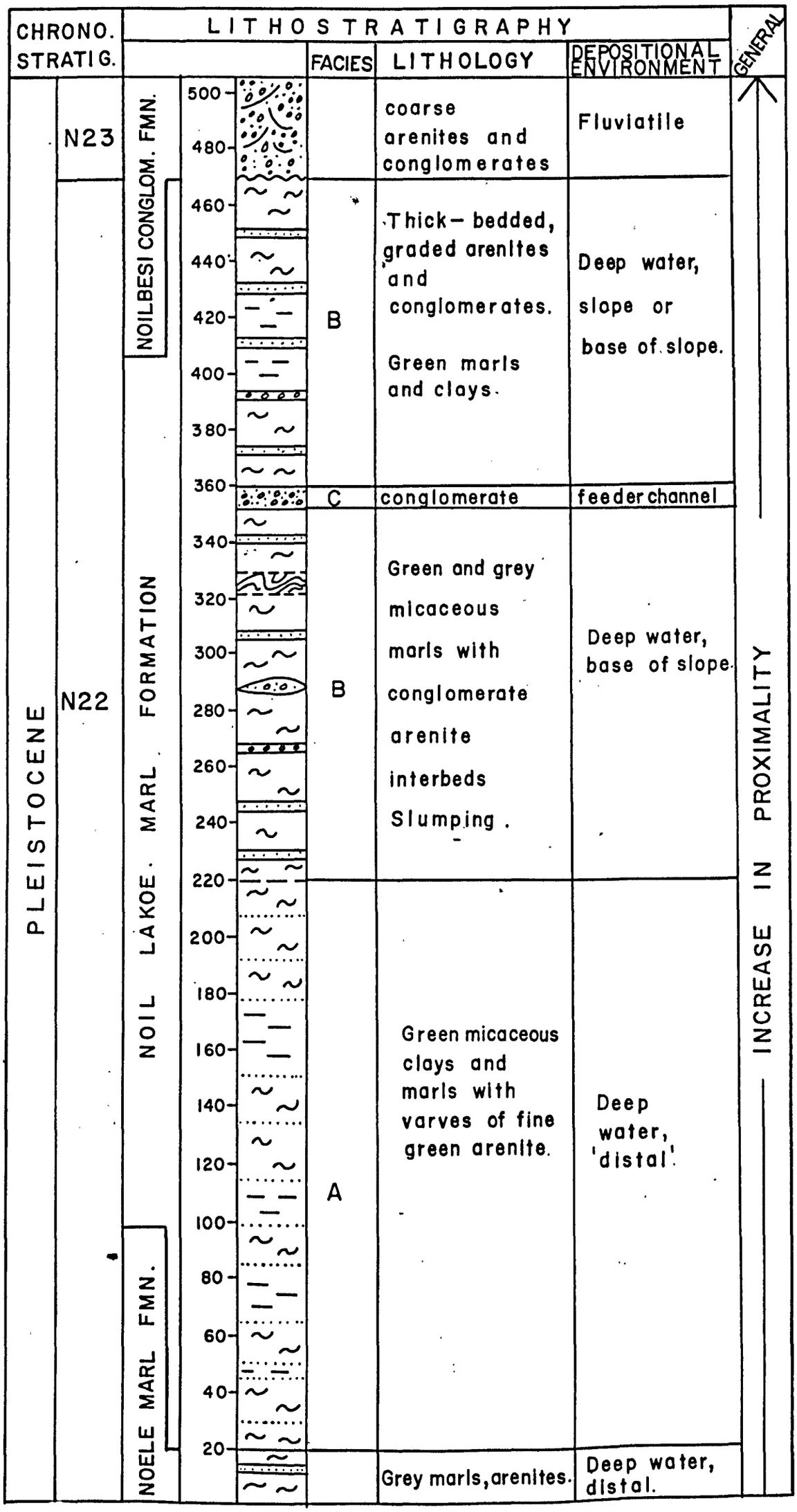

123°00'
123°30'
124°00'
124°30'
125°00'
9°30'
9°00'
10°00'
10°30'
Present Day Outcrop
Probable Extent Beneath Central Basin
A
B
DISTRIBUTION OF
THE NOIL LAKOE MARL
FORMATION
12-12-73 C.Kenyon

Fig. 45:- Noil Lakoe Marl Formation, type section, Noil Lakoe, Noele Sub - basin.

Note the presence of conglomerates and slumped beds within the middle and upper parts of the succession, reflecting the increasing influence of the northern basin slope.

For location of section see Fig. 44.


CHRONO. STRATIG.
LITHOSTRATIGRAPHY
FACIES
LITHOLOGY
DEPOSITIONAL ENVIRONMENT
GENERAL
PLEISTOCENE
N23
N22
NOILBESI CONGLOM. FMN.
NOIL LAKOE. MARL FORMATION
NOELE MARL FMN.
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
coarse arenites and conglomerates
Fluviatile
Thick-bedded, graded arenites and conglomerates.
Green marls and clays.
B
Deep water, slope or base of slope.
C
conglomerate
feeder channel
Green and grey micaceous marls with conglomerate arenite interbeds
Slumping.
B
Deep water, base of slope.
Green micaceous clays and marls with varves of fine green arenite.
A
Deep water, 'distal'.
Grey marls, arenites.
Deep water, distal.
INCREASE IN PROXIMALITY

Facies A:

Consists of green, shell free, marls and clays with occasional, thin arenite interbeds, or varves of graded, fine green arenite. Underlying this lowermost facies, via a transitional contact, is a series of grey marls containing a thin shelled molluscan fauna and a number of interbedded, thin bedded, graded arenites. This latter sequence appears to belong to the upper part of the Noele Marl Formation. The contact between the two formations is taken at the base of the green marls of the Noil Lakoe Marl Formation.

Facies B:

Facies 'A' is succeeded transitionally by a succession of green and grey micaceous, sandy marls containing thick beds of non-graded, coarse cobble beds and coarse arenites. Many have transitional upper and lower surfaces. The marl of this sequence is sandy and is characterised by the presence of isolated, larger terrigenous clasts.

Succeeding facies 'B' is the strongly erosive base of the conglomerates of the Noilbesi Conglomerate Formation.

Several small, angular discordances, probably related to slumping are present within the facies 'B' succession.

Facies C:

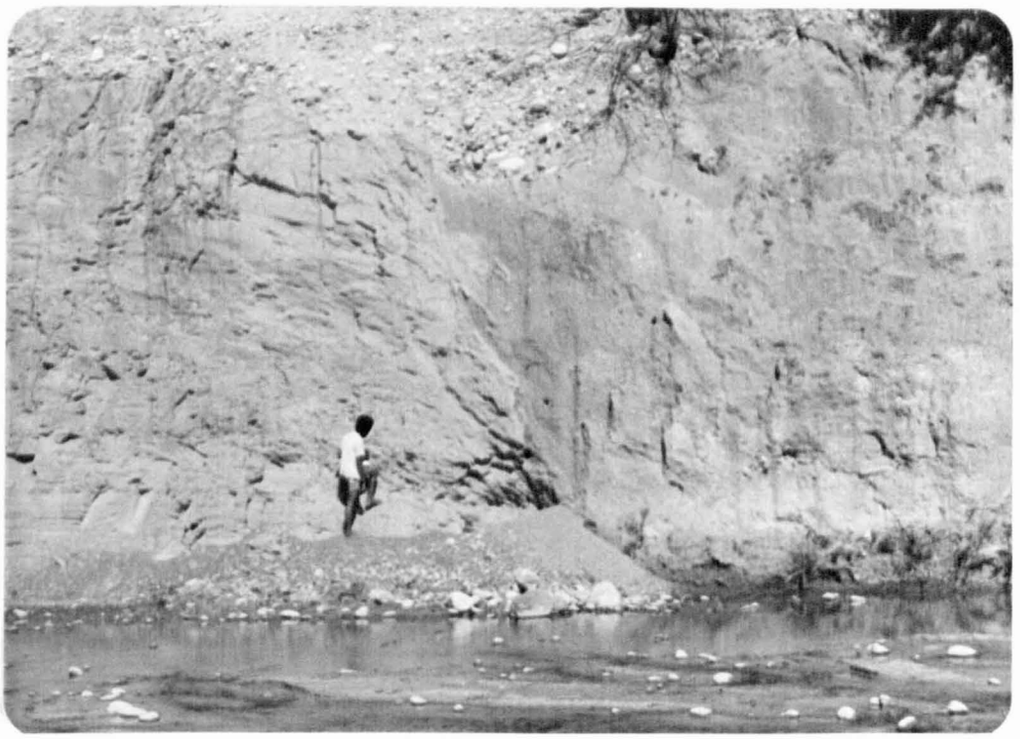
Occurring within the above facies 'B' succession is a thick conglomerate unit with a maximum exposed thickness of 7 metres. The conglomerate consists of a variety of very poorly sorted, well-rounded clasts of green Lolotoi metamorphic debris, which become finer towards the top of the unit. Also present are a number of large, (60 cm. diameter) contorted clasts of green-grey marl (Plate 14) similar to that occurring above and below facies 'C'.

Plate 14: Noil Lakoe Marl Formation, type section, Noil Lakoe River, Noele Sub-basin.

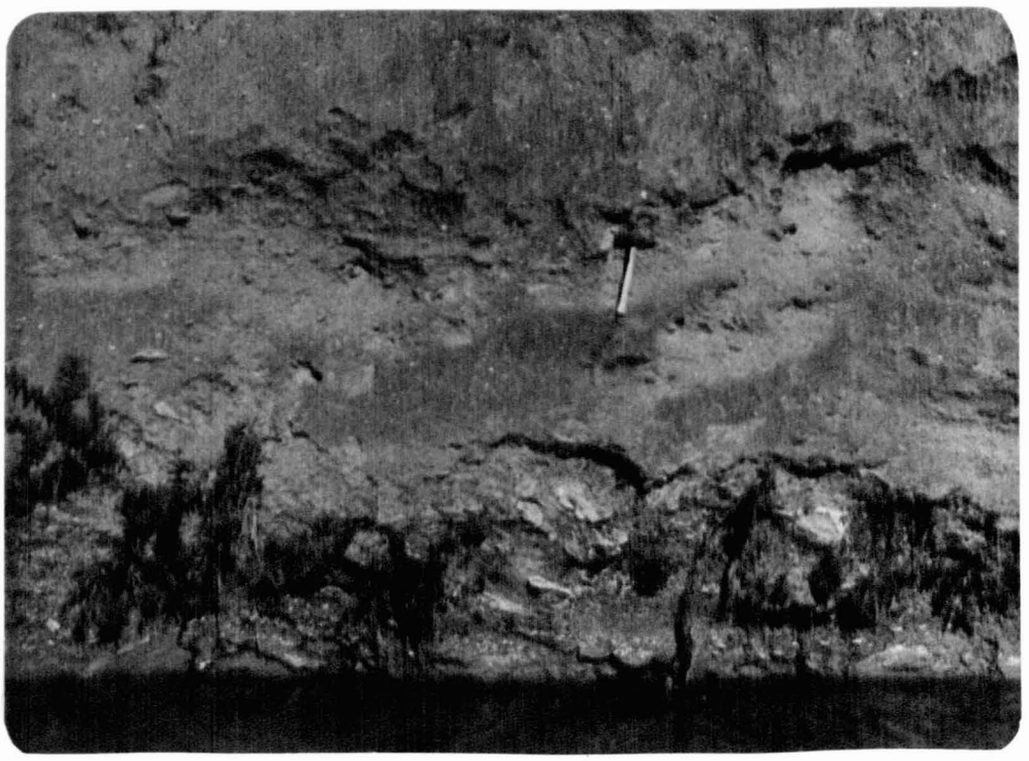
A: Photograph showing eastern contact of facies 'C' conglomerate lens (on right) with interbedded grey-green marls of the facies 'B' sequence (on left). Fluviatile conglomerates of the Noilbesi Conglomerate Formation can be seen cutting into both facies in the upper part of the photograph.

B: Photograph of the lowermost exposed part of the facies 'C' conglomerate lens showing large light-coloured clasts of marl at the base. Note the poorly sorted nature of the deposit.

A



B



The conglomerate passes laterally into interbedded marl, eastwards via an abrupt channel wall (Plate 14) and westwards via increasing intercalation of marl.

Environment of deposition of the Noil Lakoe Marl of the type section

The increased proportion of coarser clastic debris, non - graded nature and lensing of arenite and conglomerate beds, and the occurrence of structures related to slumping all suggest a considerably more proximal environment of deposition than that deduced for the underlying Noele Marl Formation. This interpretation is supported by the occurrence of the facies 'C' conglomerate unit within the sequence. The lens shaped geometry of this unit, upwards - fining, poor sorting and occurrence of large marl clasts all suggest the infilling of a large submarine channel by a high energy, erosive process. The deposit is therefore interpreted as a fan valley or submarine canyon conglomerate. That it is of a more proximal type than that encountered in the Nuanain Sandstone Member of the underlying Noele Marl Formation is indicated by its much steeper walls, coarser infilling and larger clast size.

(ii) The Noil Lakoe Marl Formation of the Bokong Sub - basin: The Fatu Kona Member.

The Noil Lakoe Marl Formation of the northern part of the Bokong Sub - basin crops out in the vicinity of the village of Fatu Kona as a series of grey - green, sandy marls with beds of coarse clastic detritus of (a) terrigenous (Lolotoi Complex) or (b) shallow water carbonate origin. Sequences of predominantly carbonate debris pass laterally over the scale of several hundred metres into sequences of predominantly terrigenous origin. These sediments are named the

Fatu Kona Member. The member has an estimated maximum thickness of 80 metres, and is overlain unconformably by reef limestones of the Soe Limestone Formation. The base of the member is not seen, but the unit is assumed to pass transitionally into the underlying Noele Marl Formation. Detail of part of the type section is depicted in Figure 46.

(a) Beds of terrigenous (Lolotoi) derivation

Facies A:

Consists of thin bedded, poorly graded conglomerate beds, of mainly Lolotoi clasts. Most beds possess abrupt, undulating bases and transitional or abrupt tops. Many beds end abruptly in the gravel size grade and most consist only of Bouma unit 'A'.

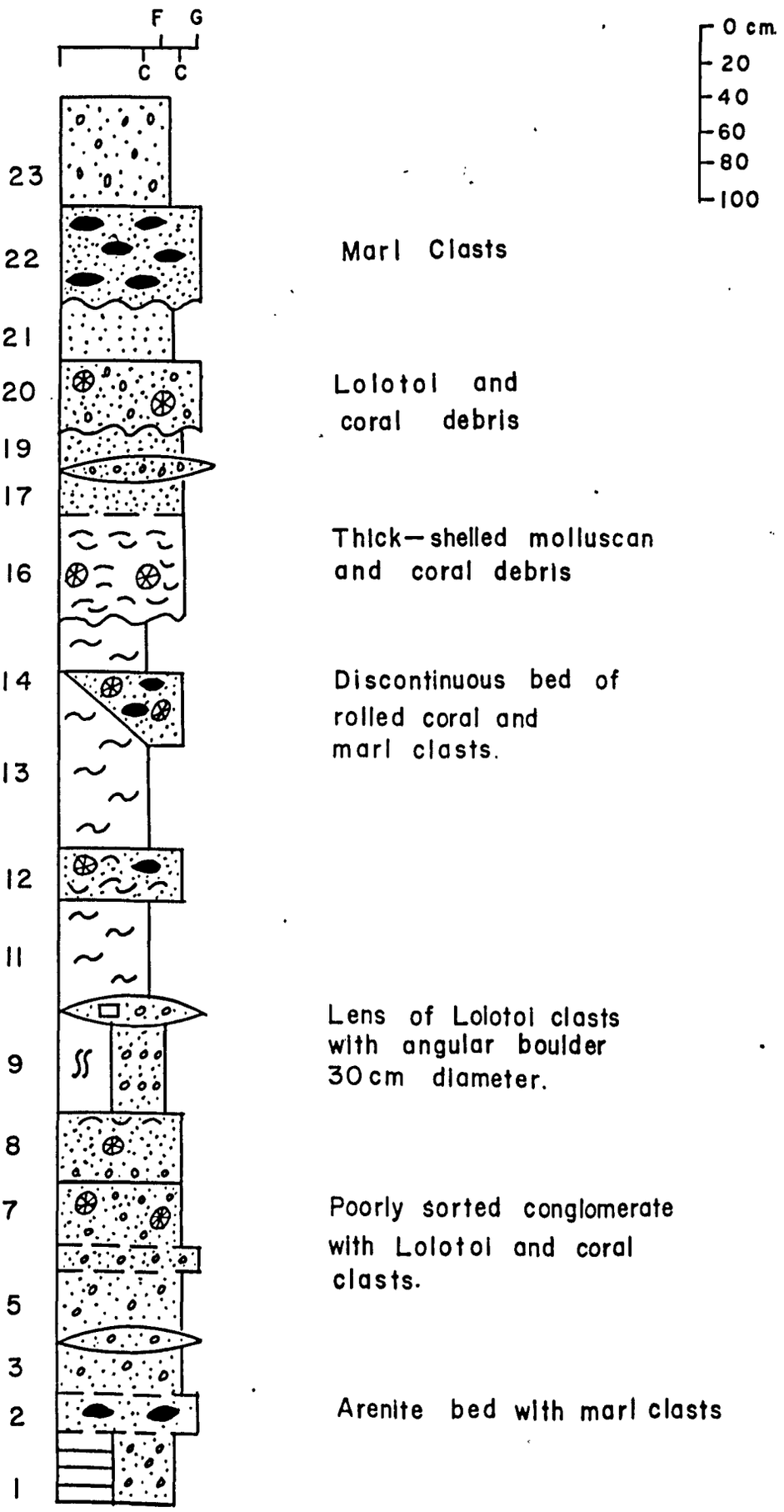
Some facies 'A' beds consist of large, angular Lolotoi clasts (up to 12 cm. diameter) throughout and show an abrupt change in grain size near to the top of the bed, where a very rapid grading down to coarse sand occurs. The coarse fragments appear to float in a matrix of coarse sand or gravel. This type of grading is similar to that observed in the turbidites of the Nuanain Sandstone and in the Same Member of Portuguese Timor.

Interpretation of facies 'A' beds

The coarseness of the beds and their occurrence within a marl sequence containing marine fauna suggests deposition by a high energy submarine current. The grading suggests that this submarine current was a turbidity current, but the occurrence of large, floating clasts throughout suggests that it was one within which adequate size grading and differentiation of clasts towards the nose and base had not yet taken place. Other evidence of a proximal environment of deposition

Fig. 46: Detailed section of part of the Fatu Kona Member of the Noil Lakoe Marl Formation, showing abundance of coarse arenites and conglomerates of facies 'B', containing coral and other carbonate debris. Note the wedging and lensing of individual beds, reflecting the proximality of the environment.

For approximate location of section, see Fig. 44.


F G
C C
0 cm
20
40
60
80
100
23
22
21
20
19
17
16
14
13
12
11
9
8
7
5
3
2
1
Marl Clasts
Lolotoi and coral debris
Thick-shelled molluscan and coral debris
Discontinuous bed of rolled coral and marl clasts.
Lens of Lolotoi clasts with angular boulder 30 cm diameter.
Poorly sorted conglomerate with Lolotoi and coral clasts.
Arenite bed with marl clasts

SECTION 514

Plate 15: Noil Lakoe Marl Formation, Fatu Kona Member, Bokong Sub - basin.

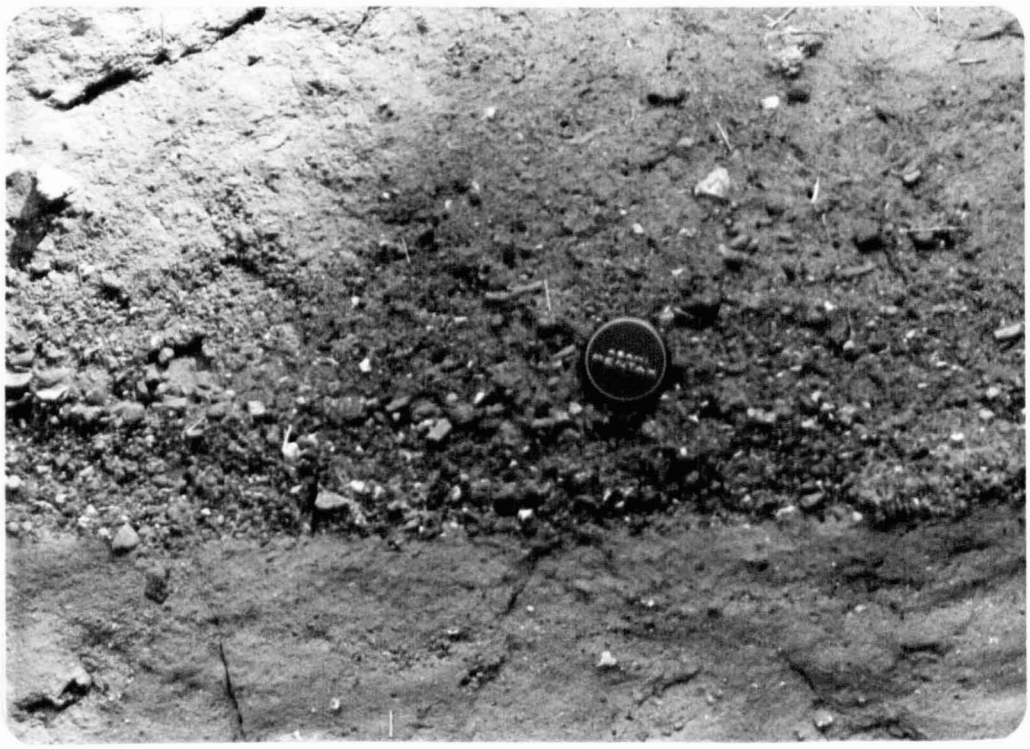
A: Thick facies 'A' (Lolotoi derived) conglomerate unit preceded and surrounded by green marl. Note the coarseness of the deposit, crude grading and angularity of the clasts.

B: Lower part of a non - or poorly graded facies 'E' unit of mostly carbonate derivation. Note the abundance of gastropod and coral and molluscan debris, and the lack of a well defined bed base. Underlying the bed is a unit of grey marl.

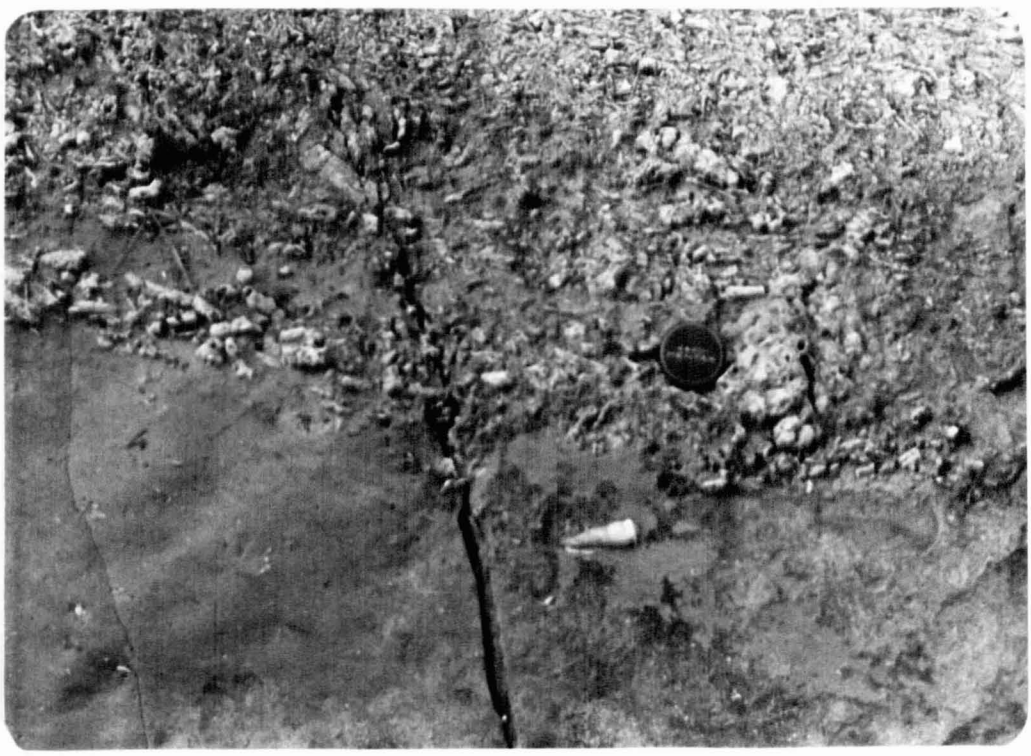
C: Photograph showing a well graded, facies 'D', predominantly carbonate unit. Note well defined bed base and top, coarseness of deposit and darker, scattered terrigenous (Lolotoi) clasts.

Location of beds: River Noil Noni, near Kampong Fatu Kona, Bokong Sub - basin.

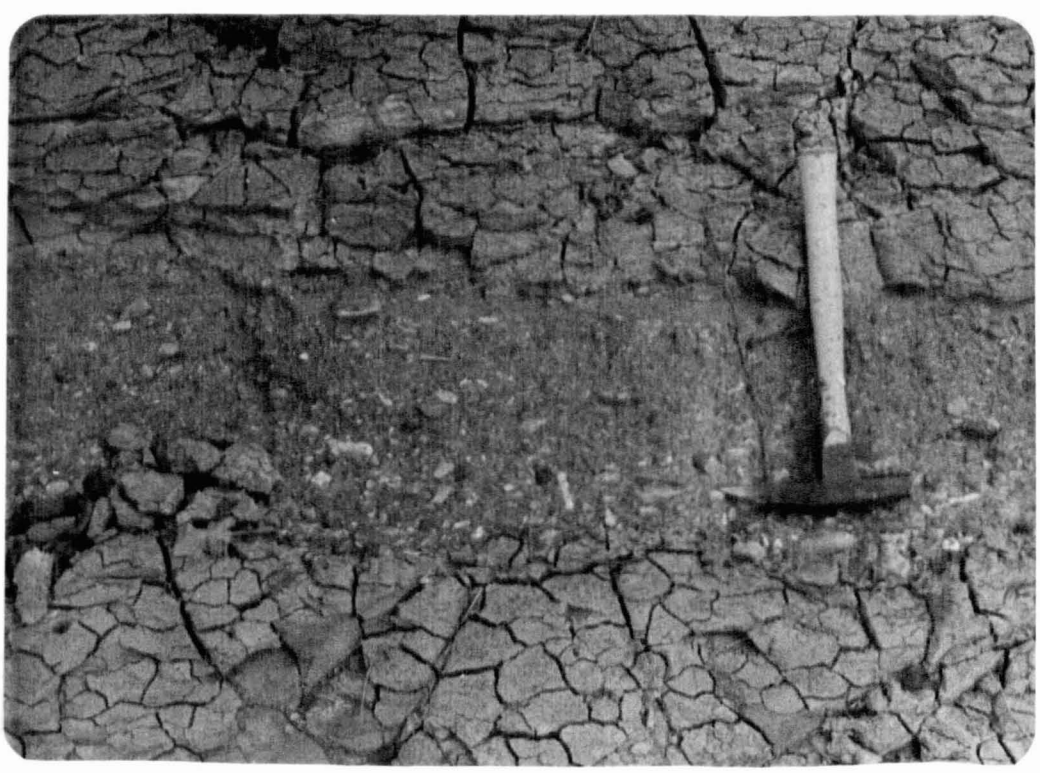
A



B



C



is provided by the occurrence of 'delayed grading' discussed in connection with the Samé and Nuanain Sandstone Members of the previous chapter.

Facies B:

Comprises thick beds of ungraded conglomerate or coarse arenite. The clasts, which are predominantly of Lolotoi derivation, are angular, vary in size from 2 to 20 cm. in diameter, and possess a sandy mud matrix. Lateral thickness changes on the scale of several metres are common within the coarse beds. In places, the arenite and conglomerate beds succeed one another directly. In others, thin, usually discontinuous beds of green marl, often highly charged with fine, terrigenous debris, intervene.

Interpretation

The absence of grading and extreme coarseness of the deposit, together with the suspension of clasts within the sandy mud suggest a form of subaqueous mudflow as the depositional agent. The proximality of the deposits as a whole and the association of slump structures suggest that the northern basin slope was relatively close. Submarine mudflows, originating on delta slopes building out from the northern mountains, must have been relatively frequent during this time.

Facies C:

Terrigenous debris in a variety of sizes also occurs isolated or in thin layers within the marl sequence. Isolated boulders, some angular, and varying in size up to 30 cm. diameter are sometimes found on bedding planes, occasionally with evidence of distortion of the marl on which they rest. These boulders could have been emplaced by downhill sliding on the mud surface of the submarine slope. Alternatively,

they could have been transported by Kelp hold - fasts (Shepard and Dill, 1966) or by entanglement in floating tree roots.

(b) Beds of carbonate derivation

Facies D:

Comprises thick, (30 cm.) well graded beds of rounded coral and molluscan debris with abrupt bases and transitional tops, interbedded with grey marls containing a shelly gastropod fauna. The sedimentary structures of these beds thus compare directly with facies 'A' of the terrigenous beds, and a similar depositional mechanism can be invoked-namely very proximal, poorly developed turbidity currents. The abundant coral and molluscan debris of facies 'D' beds suggests derivation from a reef front or reef related environment.

Other beds included in this facies possess a structureless lower part and a graded upper portion, suggesting a depositional mechanism similar to that invoked for the corresponding beds in the terrigenous sequences.

Facies E:

Consists of thick beds of coral and molluscan debris with abundant marl matrix. These beds are not graded and display no well - defined base, the underlying marl passing transitionally into the marl matrix of the bed (Plate 15). These beds correspond to facies 'B' of the terrigenous beds. The abundant Turritella gastropods which they contain, however, possess a preferred orientation. This feature has been reported from many mudflow deposits (Bull, 1972) and in conjunction with the lack of abrasion shown by the gastropods and coral debris further suggests transportation from the fronts of coral reefs into deep water by mudflows.

Facies F:

Consists of grey marls containing lensed layers of coral and molluscan debris, interstratified with, and passing transitionally upwards into boulders of coral and coral limestone up to 1.25 metres in diameter. This facies occurs in an isolated outcrop east of the village of Noil Noni and is assumed to belong to the uppermost part of the Fatu Kona Member succession.

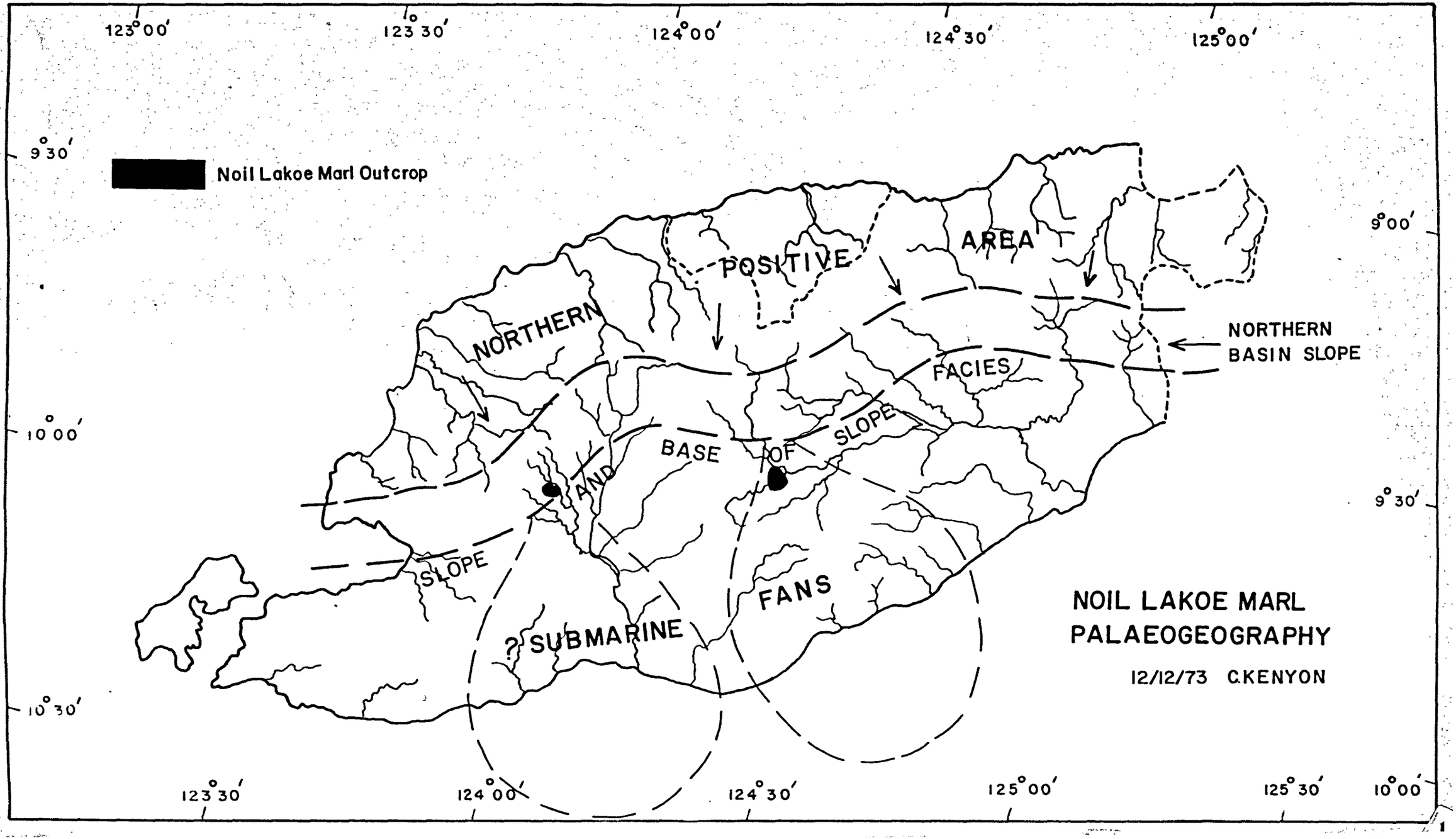
(iii) Palaeogeography of Indonesian Timor during Noil Lakoe Marl deposition (Fig. 47).

During Noil Lakoe Marl deposition, the Noele (Mataian) Uplift, combined with the progressive prograding of facies belts southwards from the northern positive area resulted in generally shallower water, much more proximal environments of deposition in the northern part of Timor. Thus, Noil Lakoe Marl environments range from deeper water, offshore (e.g. facies 'A' of the Noil Lakoe Marl type section) to reef front transition (Fatu Kona Member, facies 'F') of probably much shallower water origin. During this time much terrigenous debris was introduced into the basin from the northern positive area via deltas, positioned between growing shoreline fringing reefs. This situation is closely paralleled by the present day configuration of the southern coast of the island, where rivers carrying terrigenous debris cut through a discontinuous fringe of coral reefs. The resulting succession is therefore one in which sequences of predominantly carbonate derivation pass laterally into sequences of terrigenous derivation.

Fig. 47: Palaeogeography during Noil Lakoe Marl deposition.

Diagram showing probable relationship of the present Noil Lakoe Marl outcrop to inferred Noil Lakoe Marl palaeogeography.

The submarine fans shown to the south of the northern basin slope are conjectural, but probably existed as a southwards progradation of the fans of Noele Marl times.


123°00′
123°30′
124°00′
124°30′
125°00′
9°30′
9°00′
10°00′
10°30′
Noil Lakoe Marl Outcrop
POSITIVE AREA
NORTHERN
NORTHERN BASIN SLOPE
FACIES
BASE OF SLOPE AND
SLOPE
? SUBMARINE FANS
NOIL LAKOE MARL
PALAEOGEOGRAPHY
12/12/73 C.KENYON

general, and the association of graded beds and the abundance of planktonic foraminifera suggests a slightly deeper, more open water environment of deposition than that implied by tidal or subtidal environments.

D. Microfauna

The following microfauna have been identified by Mr. D. J. Carter (op. cit.) in samples taken from the writer's sections in the Noil Lakoe Marl Formation of the Colitie syncline, Portuguese Timor.

Planktonics

Orbulina universa
Globorotalia cultrata menardii
G. subcretacea
G. acostaensis pseudopima
G. borealis gp.
G. truncatulinoides
Globorotalia tosaensis tenuitheka
Pulleniatina sp.
Sphaeroidinella dehiscens
Globigerinoides gomitulus
G. conglobatus gp.
G. quadrilobatus gp.

Benthonics

Ammobaculites spp.
Textularia spp.
Spiroplectammina spp.
Miliolacea
Peneroplidae
Nodosariacea
Uvigerina spp.
Protoglobobulimina spp.
Bulimina spp.
Hoeglundina spp.
Bolivinita quadrilatera
Planulina spp.
Orissodorsalis spp.
Elphidium spp.
Amphistegina spp.
Calcarina spp
Baculogypsina sp.
Schlumbergerella sp.

E. Age of the Noil Lakoe Marl Formation

No direct age determination has been attempted on samples from the Noil Lakoe Marl Formation of the type section. However, microfaunal analysis by Carter (op. cit.) of samples from the southern limb of the Noele anticline section of the Viqueque Group (in which the Noil Lakoe Marl Formation is missing) suggests a Late N22 (Pleistocene) age for the underlying Nuanain Sandstone Member of the Noele Marl, whilst a Late N22 age determination is also given by Carter for the Noetufi Marl Member of the succeeding Soe Limestone Formation. On this evidence the age of the Noil Lakoe Marl Formation must be Late N22.

Samples from the Colitie syncline Noil Lakoe Marl Formation have been examined by Carter (op. cit.) and suggest an equivalence to the upper part of the Nuanain Sandstone Member of Indonesian Timor (planktonics) or to the Noetufi Marl (benthonics), again suggesting a Late N22 age for the succession.

Chapter 7. The Soe Limestone Formation

A. Summary

The Soe Limestone Formation is defined as a series of reef limestones, sandstones, marls and calcarenites, of maximum thickness 117 metres, which overlies the Noele Marl/Noil Lakoe Marl Formation unconformity in Indonesian Timor. Nine members of the formation are recognised and interpreted as the deposits of reef, open lagoonal, restricted lagoonal, fresh water lake, reef platform and fore-reef environments. The vertical and lateral relationships of five of these members, present in a small trough in the southern part of the Noele Sub-basin are demonstrated and the depositional history shown to have been primarily regressive, from a deep water environment at the base of the succession, through open and restricted lagoonal, to a fresh water lake environment at the top of the succession.

The age of the Soe Limestone Formation in the Central Basin is shown to be Pleistocene, Late N22 to Early N23, with parts of the formation outside the basin ranging from Late N23 to the very recent deposits of the modern beach.

A phase of relative subsidence, hitherto unrecognised in Timor, and here called the Soe Subsidence, is shown to have taken place immediately prior to the deposition of the Soe Limestone Formation.

B. Introduction and distribution

The Soe Limestone Formation consists of a series of crystalline limestones, breccias, sandstones and marls deposited in reef and associated environments during the latest emergence of the island in Pleistocene times. Similar deposits, included in the Baucau

Table 2: Summary of characteristics of the major stratigraphic subdivisions of the Soe Limestone Formation.

MEMBER	THICKNESS	LITHOLOGY	ENVIRONMENT OF DEPOSITION	EXTENT	REMARKS
NOEBUNU MARL MEMBER	30m	Blue-green, sandy marl and conglomerates.	Shallow water marine.	LOCAL. Succeeds reef limestone in Noebunu area.	
TOI-O LIGNITE MEMBER	10m	Black carbonaceous earth with gastropods.	Fresh water lakes in former lagoonal depressions.	LOCAL. Occurs in Noetufi syncline only.	Present day equivalent in nearby lakes.
NOELENAT MARL MEMBER	40m	Olive-green marl and calcarenite.	Hypersaline (?) lagoon.	LOCAL. Occurs in Noetufi syncline.	Contains no visible fauna.
NOETUFI MARL MEMBER	70m	Grey marl with thick-shelled molluscan fauna.	Restricted lagoon.	REGIONAL. Occupies old lagoonal depressions between reefs.	Distinguished from Noele Marl by absence of graded arenites and by abundant thick-shelled fauna.
KAPAN LIMESTONE MEMBER	10m	Yellow foraminiferal calcarenite.	Reef platform deposits.	LOCAL. Overlies reef on Kapan-Soe high.	Similar to earlier Sabaoe Limestone Formation calcarenites.
NOE KO-U MEMBER	15m	Calcareous silt and clay with oysters.	Reef platform bioherm.	LOCAL. Occurs in centre of Noetufi syncline only.	
TJAMPLONG LIMESTONE MEMBER	70m	Massive, crystalline limestone.	Fringing and table reefs.	REGIONAL. Most areas of Indonesian and Portuguese Timor.	Most important member of Soe Limestone Formation.
OESENA MEMBER	70m	Aronites, calcarenite and calcilutite.	Shallow water marine.	LOCAL. Occurs to south of Noetufi syncline.	Formed on topographic highs upon emergence of Soe-Niki-Niki region.
OEMOLO MEMBER	23m	Red foraminiferal calcarenites and calcirudites.	Fore-reef deposit.	LOCAL. Occurs in Oemolo area of Tanite High.	

Limestone of Audley-Charles (1968) are also present over a large part of Portuguese Timor.

The Soe Limestone Formation of Indonesian Timor is subdivided in this thesis into nine members (Table 2), of which seven (the Oesena Member, Noe Ko.U Member, Kapan Limestone Member, Noelenat Marl Member, Noebunu Marl Member, Toi. O Lignite Member and Oemolo Member) are local and two (the Tjamplong Limestone Member and Noetufi Marl Member) regional in occurrence.

By far the most important member of the Soe Limestone Formation is the reef limestone itself, the Tjamplong Limestone Member, which occupies large plateau areas in most regions of Timor (Fig. 48), being absent only from areas of irregular or high relief, such as parts of the northern mountains.

In the Central Basin, the Tjamplong Limestone occurs mostly as tabular reef masses, which cover the Tjamplong-Naifallo High on the western margin of the Bokong Sub-basin and the Niki Niki-Soe and Soe-Kapan Highs on the southern and western flanks of the Noele Sub-basin. Reef limestones of approximately equivalent age also cover older rocks to the south of the Central Basin and around the area of Kupang Bay.

Also of wide extent is the fine grained Noetufi Marl, which occupies the depressions between the reef masses in various parts of the Central Basin and the region to the south.

Of the more restricted members of the Soe Limestone, the Oesena Member, Noelenat Marl, Toi. O Lignite and Noe Ko. U Member form a complex series of laterally and vertically interfingering lithologies associated with the depression and flanks of the Noetufi syncline in the Noele Sub-basin (Figs. 48, 49). Twelve kilometres to

Fig. 48: Distribution of the Soe Limestone Formation within the mapped area (outlined): Note the Tjamplong Limestone Member of (A) The Tjamplong-Naifallo High; (B) the Tjamplong-Panite High; (C) the Soe-Kapan High; (D) the Soe-Niki Niki High and (F) the Noil Benain outcrops. Also shown are the Noetufi Marl Member distribution and the location of the Noetufi syncline deposits (E), containing the type sections of the Oesena Member, the Noe Ko. U Member, the Noetufi Marl Member, the Noelenat Marl Member and the Toi O. Lignite Member. The location of the Noebunu Marl Member type section (H) and the location of the Oemolo Member type section (G) are also shown.

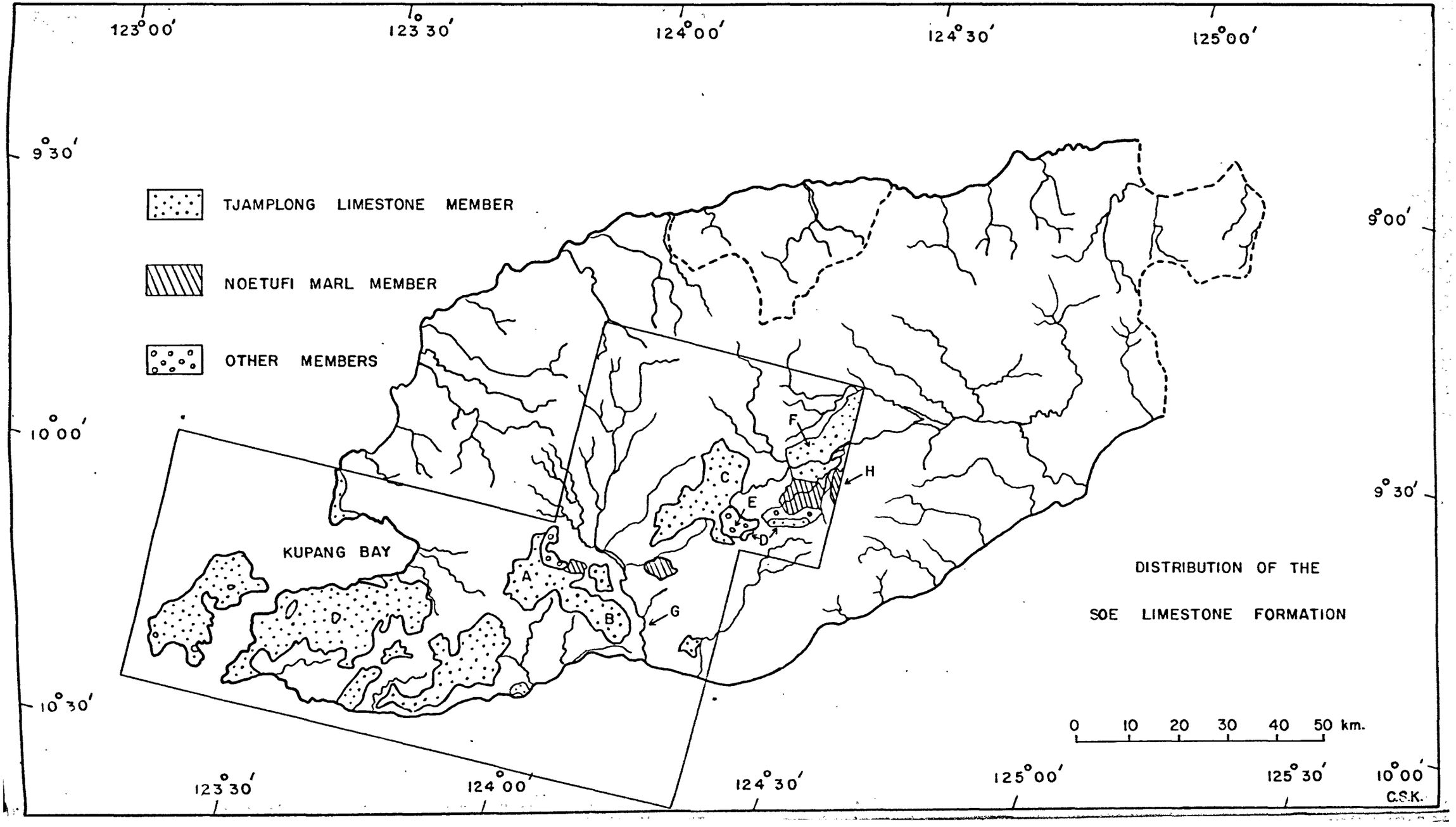
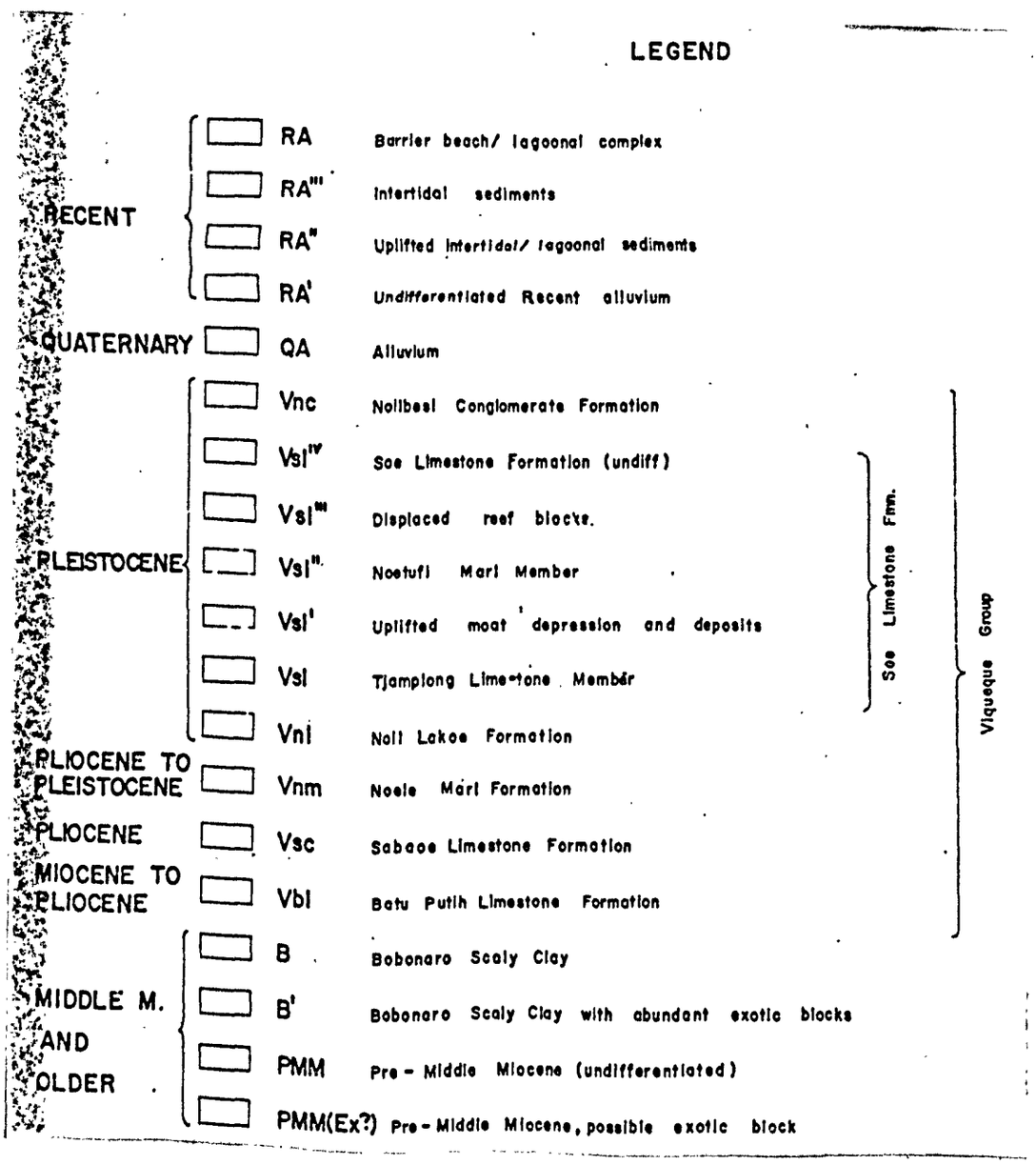
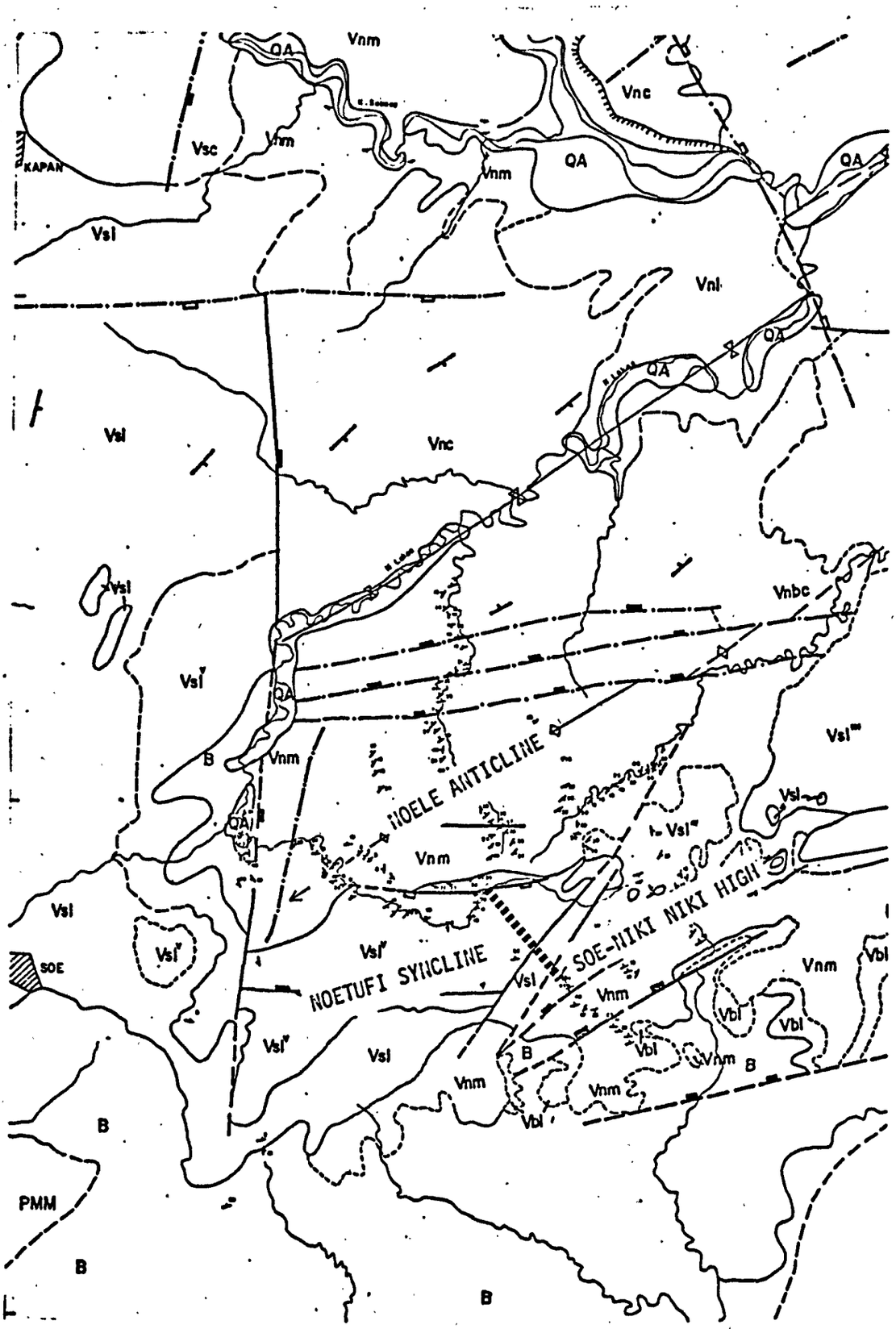

123°00'
123°30'
124°00'
124°30'
125°00'
9°30'
9°00'
10°00'
10°30'
TJAMPLONG LIMESTONE MEMBER
NOETUFI MARL MEMBER
OTHER MEMBERS
KUPANG BAY
A
B
C
D
E
F
G
H
DISTRIBUTION OF THE
SOE LIMESTONE FORMATION
0 10 20 30 40 50 km.
C.S.K.

Fig. 49: Diagram showing location of the Noetufi syncline in the south-western part of the Noele Sub-basin, and the presence of the Noele anticline and Soe-Niki Niki Highs to the north and south. Also shown is the location of the line of stratigraphic section in Fig. 50 (thick, dashed line).

The Oesena Member type section is located at the extreme southern end of the line of cross-section.




QA
Vnm
Vnc
Vsc
KAPAN
Vsl
Vnl
Vsl'
Vsl''
Vsl'''
Vnbc
B
NOELE ANTICLINE
NOETUFI SYNCLINE
SOE-NIKI NIKI HIGH
SOE
Vbl
PMM

the north-west, the Kapan Limestone Member is present as a thin covering over the Kapan-Soe High, and completing the Soe Limestone succession is the Oemolo Member of the area to the south of the Bokong Sub-basin.

These members are summarised in Table 2.

C. Stratigraphy

(i) The Soe Limestone Formation of the Noele Sub-basin

The most complex Soe Limestone succession in Timor is that which occurs in the Noetufi syncline and its bordering present-day highs, the Soe-Niki Niki High to the south and the Noele anticline to the north (Fig. 49). Five members are distinguished within this region.

The succession in the centre of the syncline (Fig. 50) begins with a series of grey, molluscan marls (the Noetufi Marl Member) which pass upwards into the green marls and calcarenites of the Noelenat Marl Member. Completing the succession is a series of black carbonaceous earths with calcareous concretions, the Toi. O Lignite Member. Also occurring in the centre of the syncline, and laterally equivalent to part of the above succession, is the Noe Ko. U Member, a series of oyster-bearing clays, sandstones and calcarenites present on an isolated high in the basin centre. On the southern margin of the Noetufi syncline is a fifth member, the Oesena Member.

(a) The Soe Limestone succession on the southern flank of the Noetufi syncline: the Oesena Member.

The Oesena Member outcrop is confined to various localities on the Soe-Niki Niki High to the south of the Noetufi syncline, where it occurs beneath the Tjamplong Limestone Member of the Soe Limestone. In the type section (Fig. 51), at the village of Oesena near Noele,

Fig. 50: Correlation of stratigraphic sections across the Noetufi syncline, showing restriction of the high energy facies (Oesena Member and Tjamplong Limestone Member) to the Oesena High and Noele anticline High respectively. The sections show the apparent lateral transition of the above facies into the lower energy Noetufi and Noelenat Marls of the basin centre. Note the overall upwards - regressive sequence shown by these sections, passing from the deep water Noele Marl, via the open lagoonal Noetufi Marl and restricted lagoonal Noelenat Marl to the fresh water deposits of the Toi O. Lignite.

1: Toi O. Lignite Member.

2: Tjamplong Limestone Member.

3: Oesena Member.

4: Noelenat Marl Member.

5: Noetufi Marl Member.

6. Noele Marl Formation.

For location of line of section see Fig. 49.

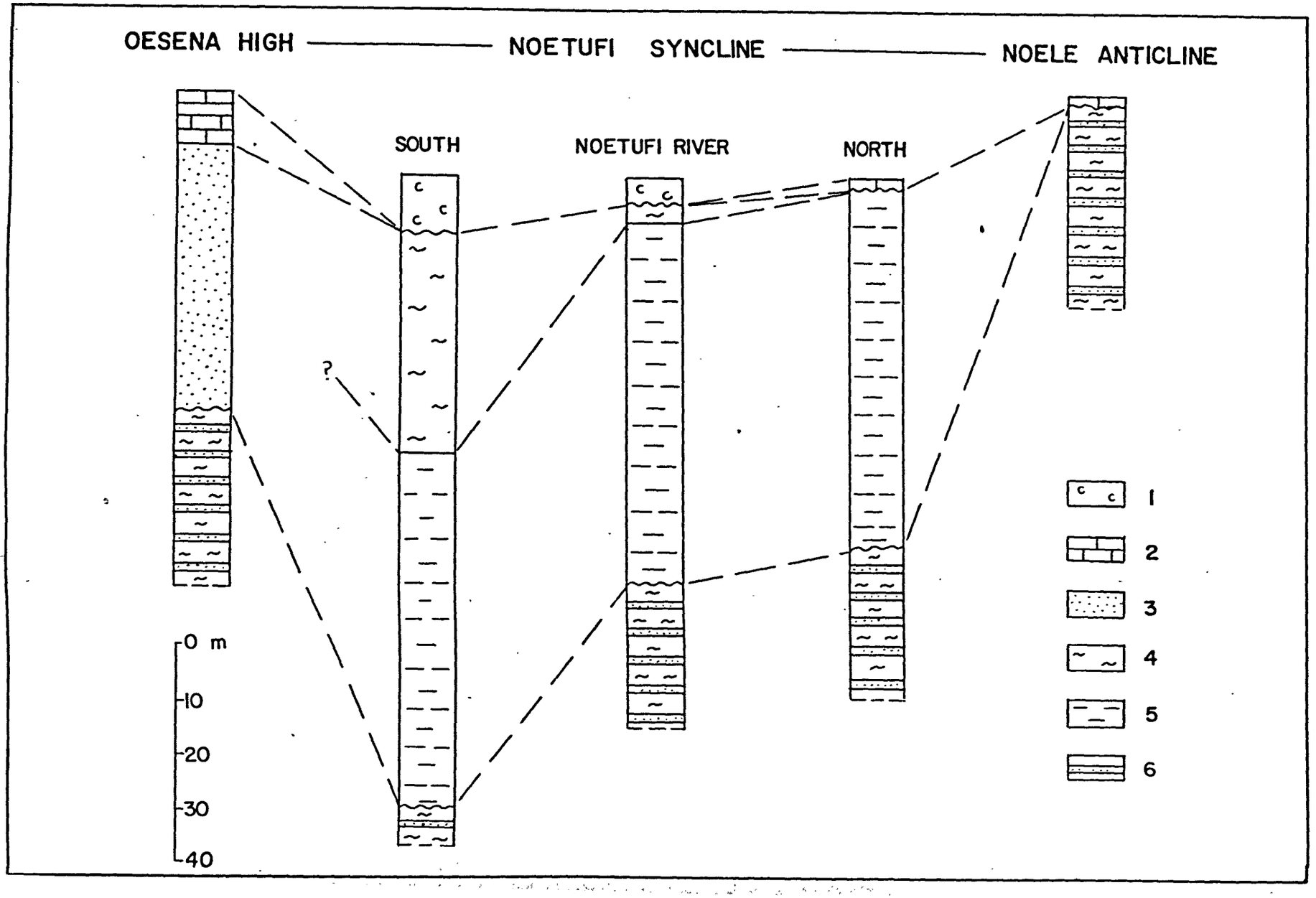
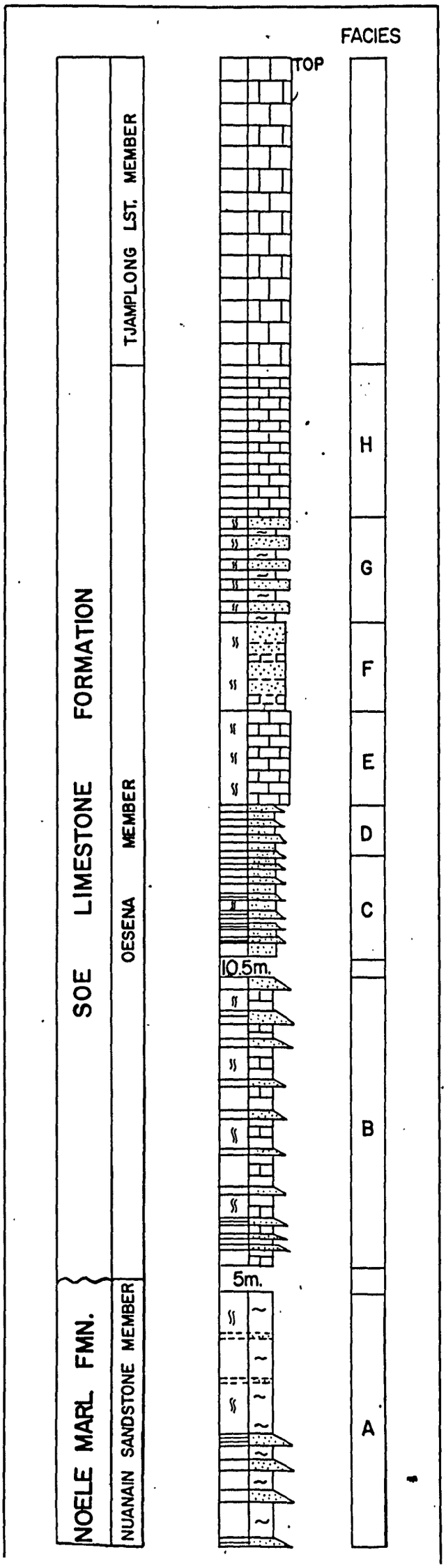

OESENA HIGH
NOETUFI SYNCLINE
NOELE ANTICLINE
SOUTH
NOETUFI RIVER
NORTH
?
0 m
10
20
30
40
1
2
3
4
5
6

Fig. 51: Oesena Member, type section: Note complex intercalation of limestone, sandstone and marl, occurrence of graded arenites near to the base of the section, and overall upwards - transition from the basinal Noele Marl Formation through the regressive Oesena Member to the reef facies of the Soe Limestone Formation (Tjamplong Limestone Member).

For location of section see Fig. 49.

For description of facies A to H see text.



SECTION 614
OESENA MEMBER
SOE LIMESTONE FMN.
TYPE SECTION

METRES
0
2
4
6

the member lies unconformably on the Nuanain Sandstone Member of the Noele Marl (facies 'A'), the section as a whole consisting of a complex intercalation of the facies described below.

Facies A

Consists of graded lithic arenites of maximum bed thickness 75cm, with interbedded grey marls. The latter contain lenses and laminae of fine sand and display frequent bioturbation.

Interpretation

The relationship between beds of facies 'A' and those of the remainder of the sequence is difficult to determine in the field. The Globigerina content of the marl, however, and its lithological similarity to the Nuanain Sandstone Member of the basin centre, together with the radical change in the nature of the section directly above facies 'A' beds suggests that the latter belong to the upper part of the Noele Marl sequence.

Facies B

Consists of graded, lithic arenites similar to those above, but interbedded with a fine, shelly calcilutite.

Interpretation

The presence of shelly calcilutites in facies 'B' and the absence of a similar facies anywhere in the underlying Noele Marl Formation suggests that the base of the Oesena Member lies in the unexposed gap of 5m between facies 'A' and facies 'B'. Although the dips in the two units appear to be broadly similar, the abrupt change from the deep water, basinal marls and turbidites of facies 'A' to the apparently shallower facies 'B' suggests the presence of a Soe Limestone/ Noele Marl Formation unconformity.

Facies C

Consists of thin-bedded, graded, lithic arenites displaying parallel lamination. These graded arenites are interbedded with massive, ungraded, highly bioturbated arenites of the same composition.

Facies D

Consists of thin-bedded, graded arenites similar to those above, but containing abundant, comminuted shell debris.

Facies E

Consists of irregularly bedded, white calcarenite, with abundant, comminuted molluscan debris and widespread evidence of bioturbation.

Facies F

Comprises thick beds of yellow, highly bioturbated lithic arenite with lenses of white calcarenite.

Facies G

Consists of bedded, lithic arenite with occasional marl interbeds. Both show abundant evidence of bioturbation.

Facies H

Consists of poorly bedded, white, foraminiferal and molluscan calcarenites.

Interpretation of facies C to H

The generally coarse nature of facies C to H, the abundance of comminuted, thick shelled molluscan material, widespread bioturbation and diversity of sediment types suggests the accumulation of the Oesena Member under shallow water (above wave base) conditions. The similarity of the lithic material to that of the underlying Nuanain Sandstone Member suggests derivation from that unit, and redeposition of at least some of the sediment in the lower part of

the section (facies 'B' and 'C') by turbidity currents.

The absence of the Oesena Member in the Noetufi syncline to the north, and its occurrence along the Soe-Niki Niki High suggest its accumulation on the emerging high during pre-Soe Limestone times, this emergence being reflected in the regressive sequence which begins with deep water turbidites and passes upwards into calcarenites and finally into reef limestones. It is probable that much of the lithic material was derived from the more positive parts of this high and redistributed into the lows by turbidity currents.

(b) The succession of the central part of the Noetufi syncline

The Noetufi Marl Member

The Noetufi Marl is the second most widespread of the Soe Limestone Members. It occurs mainly in present day topographic lows between reef masses, and consists in general of a sand-free, structureless grey marl containing abundant thick-shelled gastropods and other molluscs. In the type section in the Noetufi syncline (Fig. 52) the member consists of the following five facies:

Facies A

Consists of a slightly tuffaceous, structureless grey marl containing some comminuted thin shelled molluscan debris. No larger fauna is present.

The facies resembles the Noele Marl, into which it may grade in the Noetufi syncline. The environment of deposition was evidently a low energy one, that is below wave base, and the lack of fauna suggests that it was restricted.

Facies B

Comprises a fine arenite with a high lutite content and randomly arranged, both comminuted and in place,large, thick shelled lamellibranchs. This arenite, which averages 75cm in thickness, appears to be a wave or current-winnowed layer which may have been formed during a temporary lowering of sea level.

Facies C

Consists of a structureless grey marl with a comminuted thin shelled fauna and containing a number of small, thick shelled gastropods.

Facies D

Consists of a grey marl with a high proportion of comminuted

Fig. 52: Noetufi Marl Member, type section, Noele Sub - basin, showing subdivision of the Noetufi Marl Member into five major facies, A to E. This section was measured from the centre of the Noetufi syncline to its flanks, thereby reflecting both the horizontal and vertical distribution of facies. See also Fig. 53.

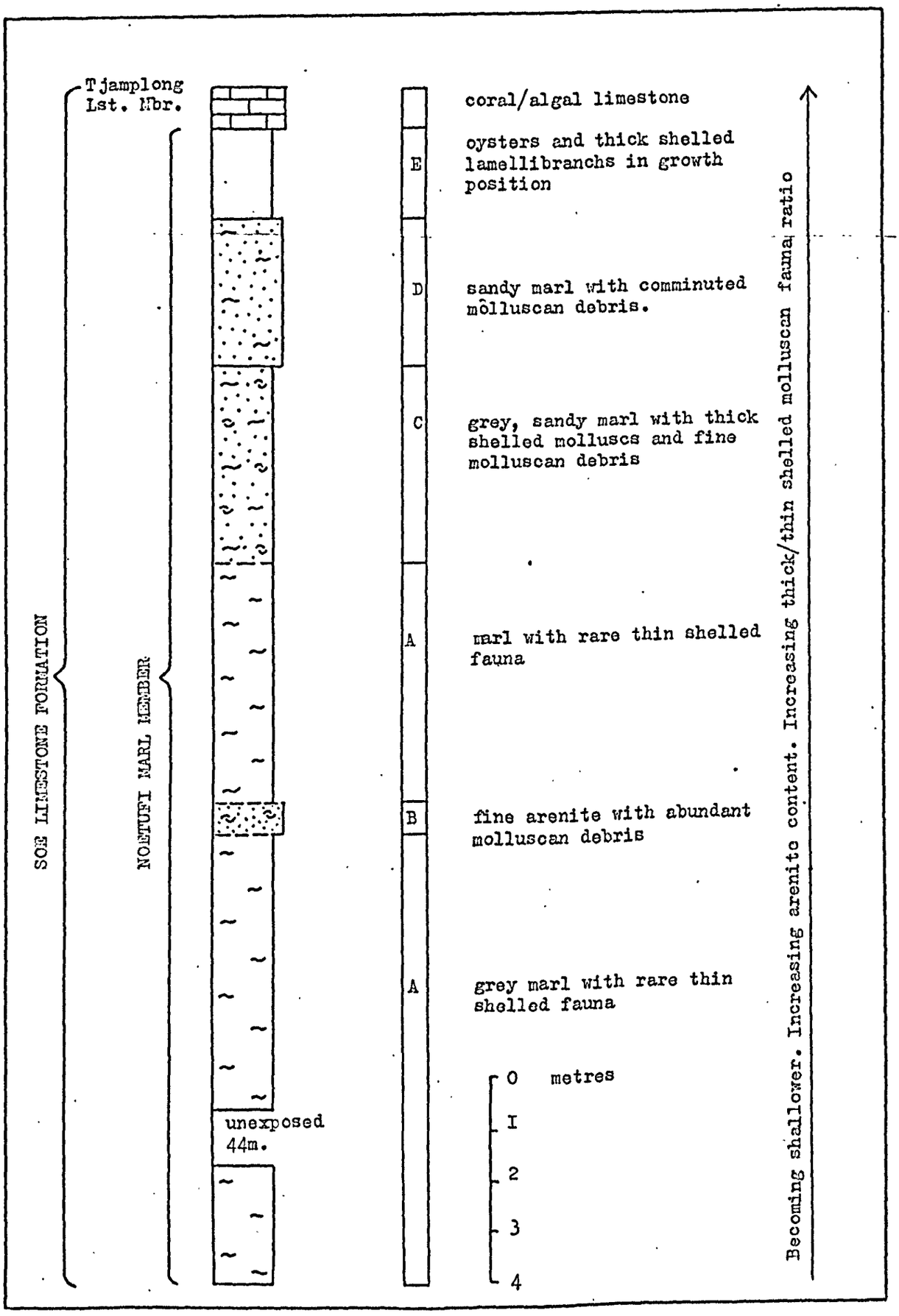
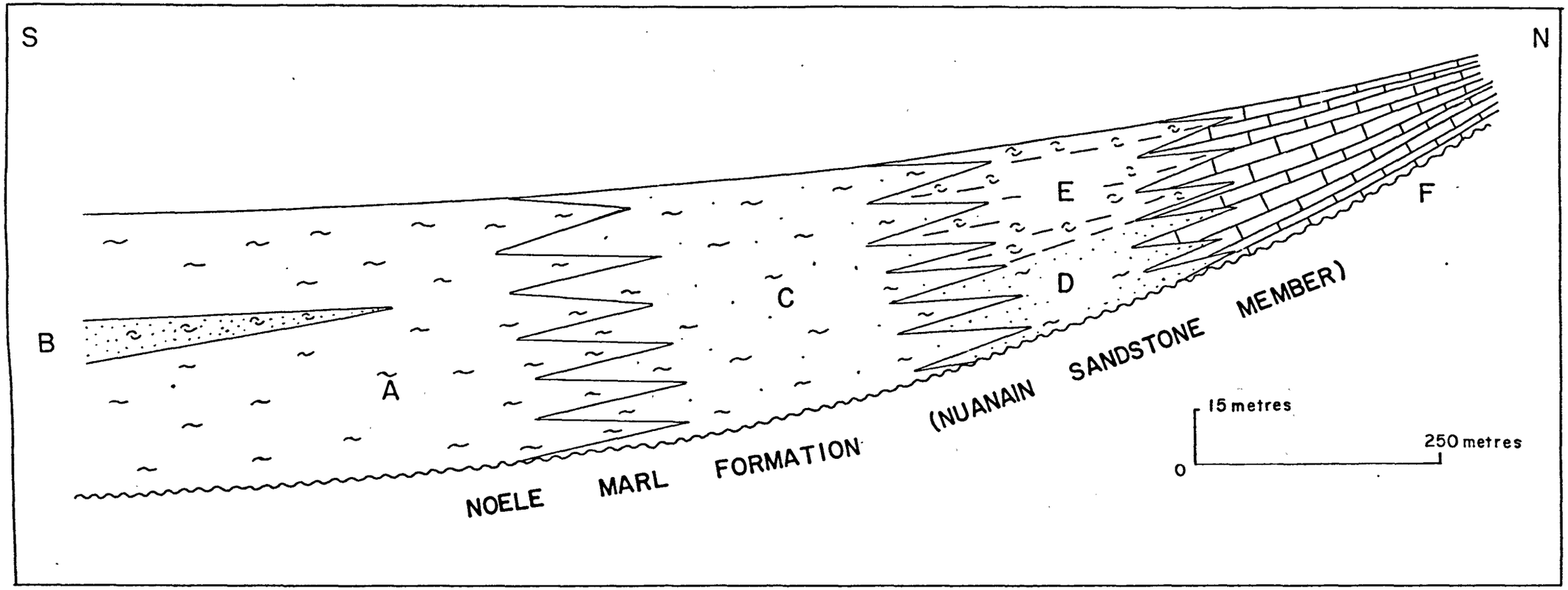

Tjamplong Lst. Mbr.
SOE LIMESTONE FORMATION
NOETUTI MARL MEMBER
unexposed 44m.
E
D
C
A
B
A
coral/algal limestone
oysters and thick shelled lamellibranchs in growth position
sandy marl with comminuted molluscan debris.
grey, sandy marl with thick shelled molluscs and fine molluscan debris
marl with rare thin shelled fauna
fine arenite with abundant molluscan debris
grey marl with rare thin shelled fauna
0 metres
I
2
3
4
Becoming shallower. Increasing arenite content. Increasing thick/thin shelled molluscan fauna ratio

Fig. 53: Noetufi Marl Member: Diagrammatic cross - section of the Noetufi Marl Member from the centre of the Noetufi syncline to the northern flank on the Noele anticline southern limb. Note north - south facies changes, from the Tjamplong Limestone Member (F) to the bioherm (E) and marly sand facies (D) to sandy marl with molluscan fauna (C) to sand free marl with thin shelled molluscan fauna (A). Facies (B) consists of sand with comminuted shell debris. The member lies on the eroded surface of the Nuanain Sandstone Member of the Noele Marl Formation.


S
N
A
B
C
D
E
F
NOELE MARL FORMATION
(NUANAIN SANDSTONE MEMBER)
15 metres
0
250 metres

shell and arenite debris, and many large, thick shelled, in situ molluscs and solitary corals.

Facies E

Consists of thick shelled molluscs in a growth position in a clay matrix, and appears to have been formed as a bioherm in very shallow water. The bioherm passes laterally into a very thin reef limestone.

Figure 53 illustrates the distribution of the above facies in the Noetufi Marl of the Noetufi syncline. The following relationships are evident from this profile:

(i) The proportion of thick shelled molluscs to thin shelled decreases in a basinward and down the succession direction (i.e. from facies 'D' to facies 'A').

(ii) The proportion of arenite, very high in the region of the bioherm, decreases in the same direction, until the pure marls of facies 'A' are reached in the basin centre.

(iii) There is a basinward decrease in the proportion of comminuted thin shelled molluscan debris.

(iv) There is a decrease in the number of species of mollusc in a basinward direction. In facies 'C' for example, these are limited to a single species of gastropod.

The history of the Noetufi syncline during Noetufi Marl times is therefore one in which the original east-west depression was gradually uplifted and filled, in the basin centre by low energy marls below wave base (facies 'A'), and towards the basin margins by deposits showing a higher energy level (facies 'D' and 'E') and supporting a more abundant molluscan fauna. The increased wave and current activity apparently caused winnowing of much of the finer material

to give the resulting deposit a high arenite content (facies 'D'). At the very edge of the syncline, bioherms acted as sedimentary traps for the suspended clays, which now form a high percentage of the matrix. The Noetufi syncline was later uplifted to form a more restricted lagoon, in which was deposited the Noelenat Marl.

The Noelenat Marl Member

The Noelenat Marl Member (Fig. 54) consists generally of an olive green marl or fine calcarenite with no visible megafauna. It occurs solely in the Noetufi syncline north of Noele, where it overlies the Noetufi Marl and is itself overlain disconformably by the Toi. O Lignite. The contact with the Noetufi Marl is gradational, the base of the Noelenat Marl Member being taken at the first occurrence of green marl. The member achieves a maximum thickness of 30m. Three facies, comprising marls (facies 'A'), conglomerates (facies ' B') and calcarenites (facies 'C') are recognised.

Facies A

The lowermost facies consists of an olive green, structureless marl with a high proportion of small foraminifera and rare pieces of thin shelled molluscan debris.

Facies B

Consists of a series of conglomerate lenses (Plate 16) with well rounded calcareous clasts, many of which consist of coral debris.

Facies C

Succeeds facies 'B' and consists of fine, olive green, foraminiferal calcarenite with no other fauna or structure.

In general the Noelenat Marl Member shows evidence of low energy deposition in an environment not favourable for the support of

Fig. 54: Noelenat Marl Member, type section, Noetufi syncline: Note subdivision into three major facies: calcarenite (facies C); conglomerate (facies B) and marl (facies A). The contact with the underlying Noetufi Marl Member is not seen.

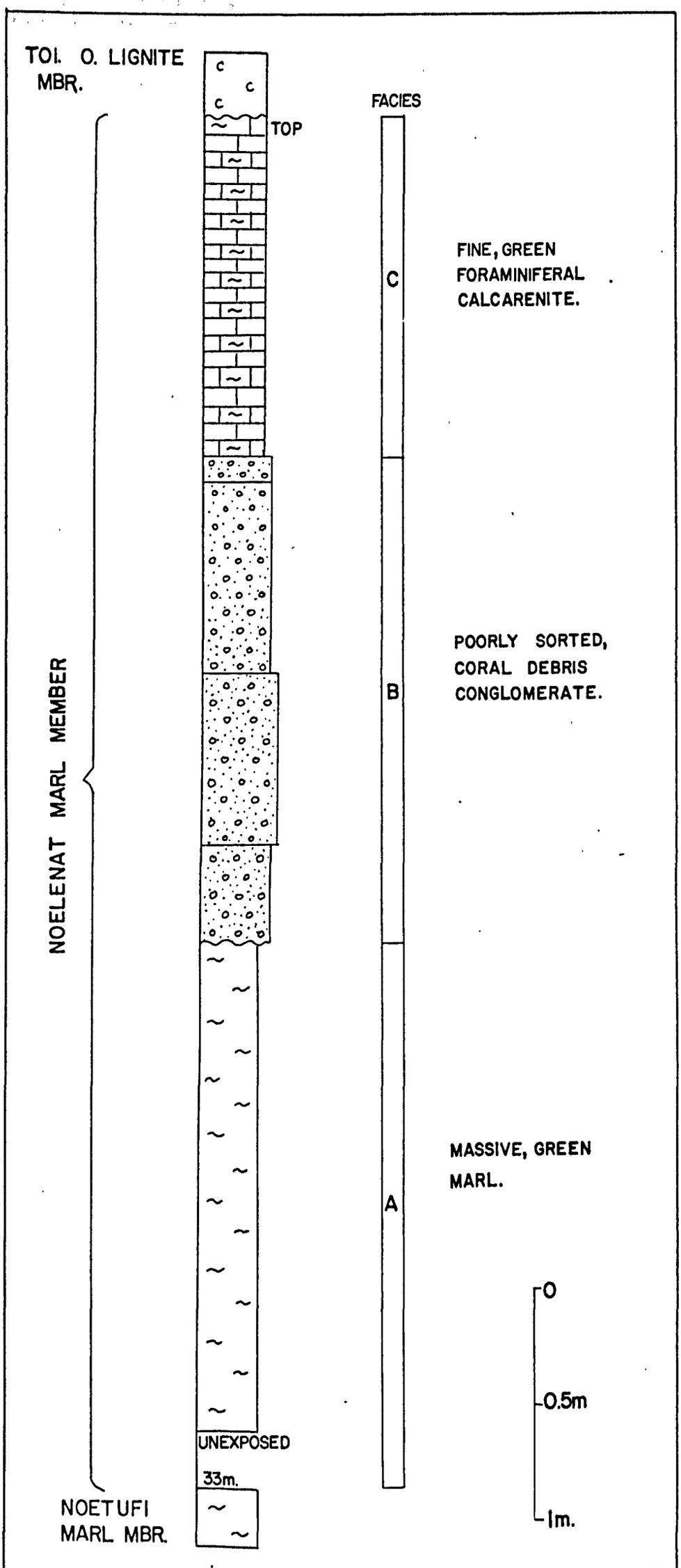

TOI. O. LIGNITE MBR.
C
C
C
TOP
FACIES
C
B
A
FINE, GREEN FORAMINIFERAL CALCARENITE.
POORLY SORTED, CORAL DEBRIS CONGLOMERATE.
MASSIVE, GREEN MARL.
NOELENAT MARL MEMBER
UNEXPOSED
33m.
NOETUFI MARL MBR.
0
0.5m
1m.

Plate 16: Noelenat Marl Member, Noetufi syncline, Noele Sub - basin.

Conglomerate lens of facies 'B' showing abundance of reef derived clasts, lateral pinch - out of lens into marls of facies 'A' (lower photograph) and marly calcarenites of facies 'C' succeeding the conglomerate (upper photograph).

A



B



shelly organisms, such as a hypersaline or brackish lagoon. In contrast to the earlier Tanah Putih Marl, however, (interpreted as a brackish lagoonal deposit) the Noelenat Marl contains no visible terrigenous debris, suggesting the absence of surface run-off and hence possibly hypersaline conditions. This interpretation is supported by the occurrence of the Noelenat Marl between the Noetufi Marl below (shallow water open lagoon) and the Toi. O Lignite (fresh water lake) above, and its restriction to the Noetufi syncline between the present day reef masses of the Noele anticline to the north and the Oesena High to the south. The predominance of reef-derived material in the conglomerate (facies 'B') suggests derivation from either a reef front or a back reef beach, either by some form of turbidity current or slumping. The general shallowing of the lagoon, leading eventually to emergence of the Noetufi syncline and to later deposition of the Toi. O Lignite is evidenced by the generally coarser facies 'C' calcarenite, probably formed by winnowing of the finer marl material when the floor of the lagoon came within wave base.

The Toi. O Lignite Member

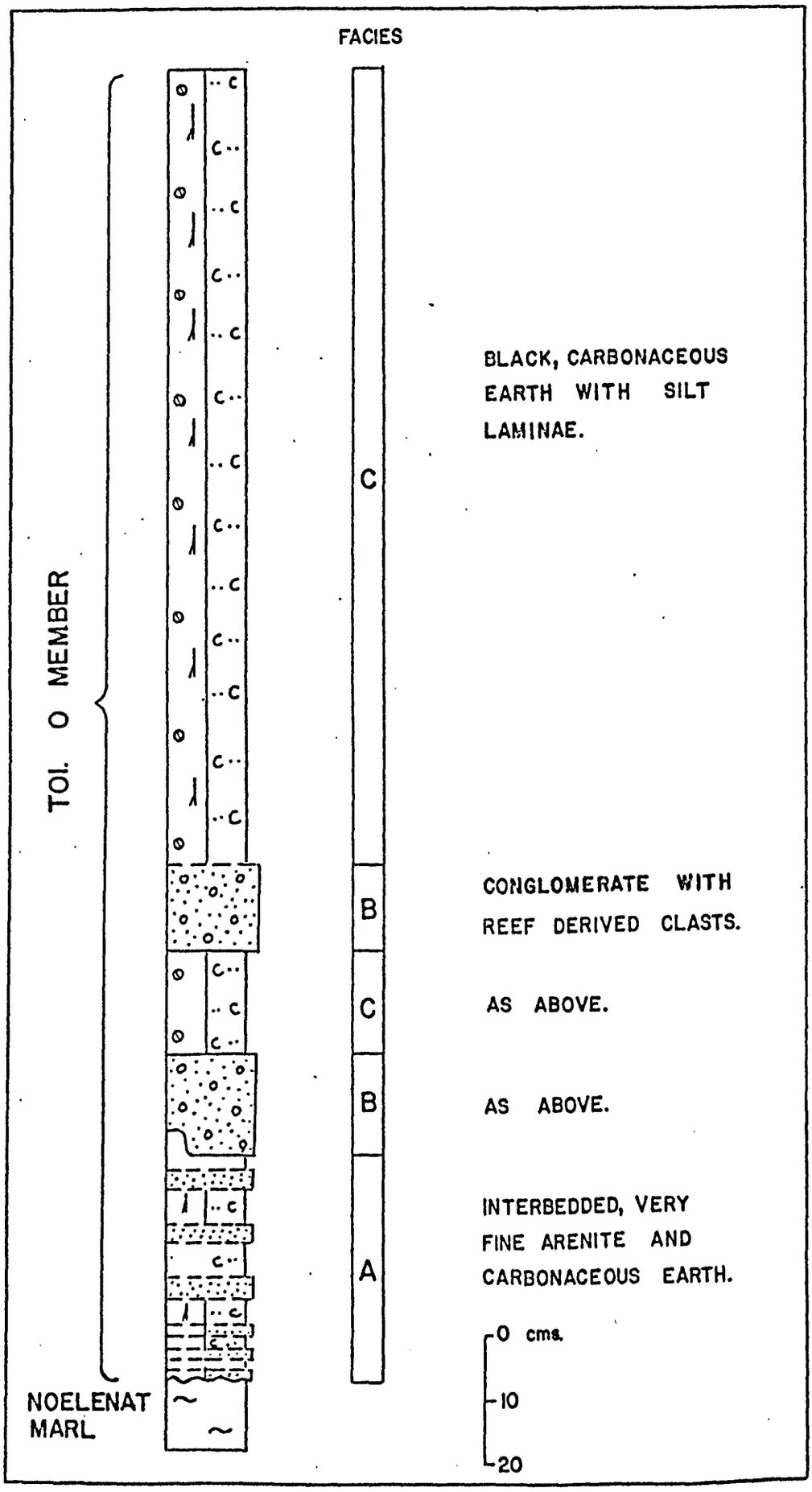
The uppermost unit of the Soe Limestone in the Noetufi syncline north of Noele consists of a black carbonaceous earth containing many calcareous concretions and plant root structures (Fig. 55). This deposit attains a maximum thickness of 10 metres, and follows disconformably from the underlying green marls of the Noelenat Marl Member (Plate 17). The following lithological elements are recognised:

Facies A

Consists of thick, irregularly bedded arenites of very fine sand, with transitional upper and lower surfaces.

Fig. 55: Toi O. Lignite Member, Noetufi syncline: Detail of the lowermost part of the section, illustrating fine arenites (facies A); conglomerates (facies B) and carbonaceous earths with plant root structures (facies C).

For approximate location of this section see Fig. 49.


FACIES
TOI. O MEMBER
NOELENAT MARL
C
B
C
B
A
BLACK, CARBONACEOUS EARTH WITH SILT LAMINAE.
CONGLOMERATE WITH REEF DERIVED CLASTS.
AS ABOVE.
AS ABOVE.
INTERBEDDED, VERY FINE ARENITE AND CARBONACEOUS EARTH.
0 cms.
10
20

Facies B

Consists of thick lenses of gravel size calcareous pellets, terrigenous material and abundant, rounded, reef derived clasts. These beds are generally unaffected by plant root structures.

Facies C

Consists of black, carbonaceous earth with many thin, diffuse lenses and laminae of white silt. Thin shelled gastropods of 'Planorbis' type occur within this unit. Most beds show vertical, straight or branching cylindrical cavities which are interpreted as plant root structures.

The 'Planorbis' type gastropods, plant root structures and plant debris suggest that the environment was a shallow, freshwater lake with abundant vegetation. The reef clasts in facies 'B' suggest that these lenses of coarser material are the result of incursion of small streams bringing debris from the surrounding reef areas. The latter were presumably also responsible for the introduction of the fine silt and sand which are found interbedded with the carbonaceous earth.

The possible present day equivalent of the Toi. O Lignite environment can be seen near Niki Niki, where a large lake now occupies an old lagoonal depression surrounded by elevated reef areas (Plate 17). Sediment along the edges of this lake consists of a highly carbonaceous black soil with numerous calcareous concretions. This black soil also contains 'Planorbis' gastropods of a similar type to those in the Toi. O Lignite. The layered calcareous horizons of the latter could not be discerned in the small depth investigated, but it is possible that they will be found to exist in a drier deposit, and may be due to later diagenetic breakdown and redistribution of the calcareous concretions encountered in the modern sediment.

Plate 17: Soe Limestone Formation

A: Tjamplong Limestone Member, Meo area, Noele Sub - basin. Note (i) the great thickness of reef limestone (from cliff top level to below river level); (ii) the general height of the reef limestone in the Noele Sub - basin (corresponding to cliff top level) and (iii) the difference between the latter height and that of the distant Tjamplong Limestone capping of the Soe-Kapan High (background), reflecting the amount of subsidence undergone by this part of the Central Basin during, and after Soe Limestone times.

B: Photograph showing disconformity between the Noelenat Marl (below) and the Toi. O Lignite (above). Note the apparent absence of appreciable angular discordance, suggesting that the contact between the two members is an erosional one only, produced during the period between the emergence of the Noelenat Marl lagoon and establishment of the Toi. O Lignite lake.

C: Present day lake in a lagoonal dpression near Niki Niki, showing probable Toi. O Lignite environment of deposition.

A



B



C



The Niki Niki lake appears to be the only remnant of the lake which, judging from the present day extent of the Toi. O Lignite, once covered a much larger area.

The Noe Ko. U Member

In the centre of the Noetufi syncline, east of Noele, the characteristic Soe Limestone succession described above is missing, the eroded ~~base~~ top of the Nuanain Sandstone being succeeded by a thin development of reef limestone, capped by a series of light coloured silts and clays (Figs. 56, 57). Three facies can be recognised:

Facies A

Consists of a very fine, cream coloured, calcareous silt and calcilutite with abundant calcareous concretions. Large, thick shelled lamellibranchs of 'Pecten' and Modiola type are also present. A single solitary coral was noted.

Facies B

Consists of a fine, calcareous silt with very many large, thick shelled oysters and many solitary corals.

Facies C

Consists of a buff-coloured, fine clay with some comminuted molluscan debris.

Because of their occurrence directly above reef proper in a generally emergent sequence the above facies are interpreted as reef platform deposits. The succession shows a certain similarity to the Oesena Member of the high to the south, and was developed on a local basin-centre high of Nuanain Sandstone during the emergence of the area.

A similar deposit occurs near Tjamplong in the Bokong Sub-basin.

Fig. 56: Correlation of stratigraphic sections across the Noetufi syncline, showing the effect of an isolated mid - basinal high on the facies distribution. Capping this high and replacing the Noetufi and Noelenat Marls of the basin centre (sections 2, 4 and 5) are the Tjamplong Limestone and Noe Ko. U Members. Line of section is approximately the same as Fig. 50.

1: Toi O. Lignite Member.

2: Noe Ko. U Member.

3: Tjamplong Limestone Member.

4: Noelenat Marl Member.

5: Noetufi Marl Member.

6: Oesena Member.

7: Noele Marl Formation

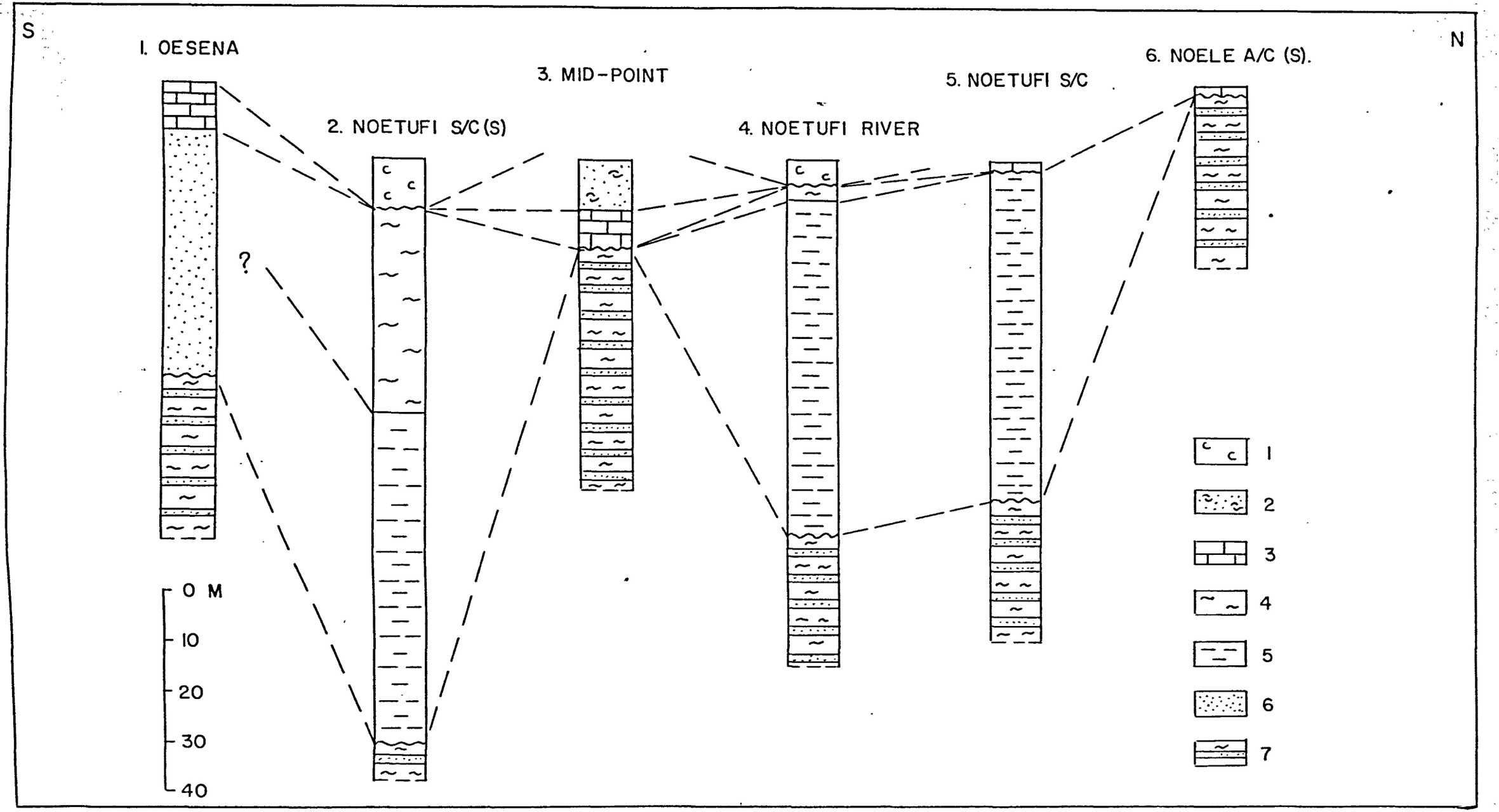
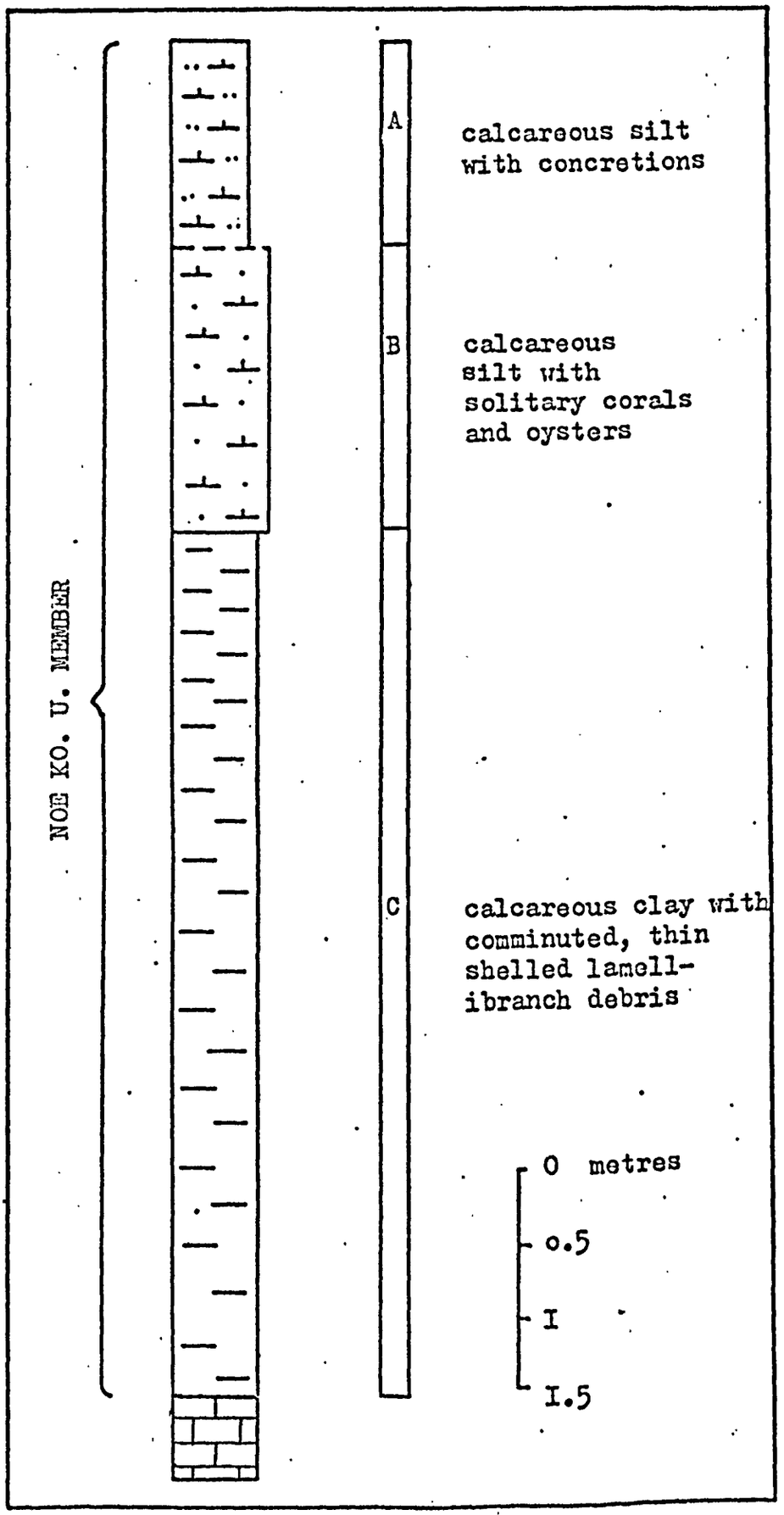

S
N
1. OESENA
2. NOETUFI S/C (S)
3. MID-POINT
4. NOETUFI RIVER
5. NOETUFI S/C
6. NOELE A/C (S).
?
0 M
10
20
30
40
1
2
3
4
5
6
7

Fig. 57: Noe Ko. U Member, type section, Noetufi syncline.
For approximate location of section see Fig. 49.


NOE KO. U. MEMBER
A
B
C
calcareous silt with concretions
calcareous silt with solitary corals and oysters
calcareous clay with comminuted, thin shelled lamell-ibranch debris
0 metres
0.5
I
I.5

(c) The type section of the Soe Limestone Formation

Designation of a truly representative type section for the Soe Limestone Formation is rendered difficult due to the widespread lateral facies variations which characterise the succession. The type section is therefore a composite section which includes most of the members of the Soe Limestone Formation present in the Noetufi syncline east of Soe. This type section (Fig. 58) includes the two most important and widespread members of the Soe Limestone Formation, namely the Noetufi Marl Member and the Tjamplong Limestone Member. It should however be noted that the actual type section of the latter is taken from the Bokong Sub-basin near Tjamplong.

The boundary between the Soe Limestone and Noele Marl Formations in the type section is taken at the uppermost occurrence of an arenite unit, the Noele Marl Formation being represented by the Nuanain Sandstone Member at the type locality.

Fig. 58: Soe Limestone Formation, type section, from the Noetufi syncline in the Noele Sub - basin. The section is a composite one, derived from the succession of the centre and flanks of the Noetufi syncline.

NMF: Noele Marl Formation.

PLEISTOCENE (N22 TO N23)
N22
NOETUFI MARL MEMBER
NMF
NOELENAT MARL MEMBER
TJAMP L.MBR
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
MASSIVE REEF LIMESTONE.
GREEN MARL, CALCARENITE AND REEF DERIVED CONGLOMERATE.
GREY MARL WITH THICK SHELLED MOLLUSCAN FAUNA.

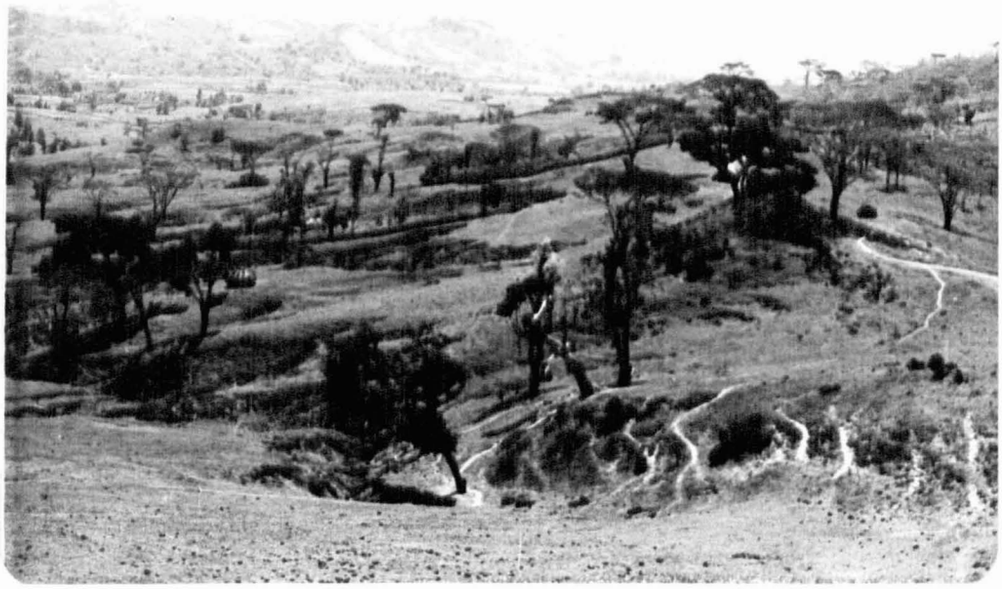
Plate 18: Soe Limestone Formation

A: Panoramic view of the Noetufi syncline, looking west away from the southern flank of the Noele anticline. The hills in the background are capped by sandstones of the Oesena Member and by reef limestones. In the foreground can be seen remnants of the Tjamplong Limestone Member directly overlying the Nuanain Sandstone Member of the Noele Marl Formation. The intervening syncline (middle distance) contains deposits of the Noelenat and Noetufi Marl Members, the Toi. O Lignite Member and the Noe Ko. U Member.

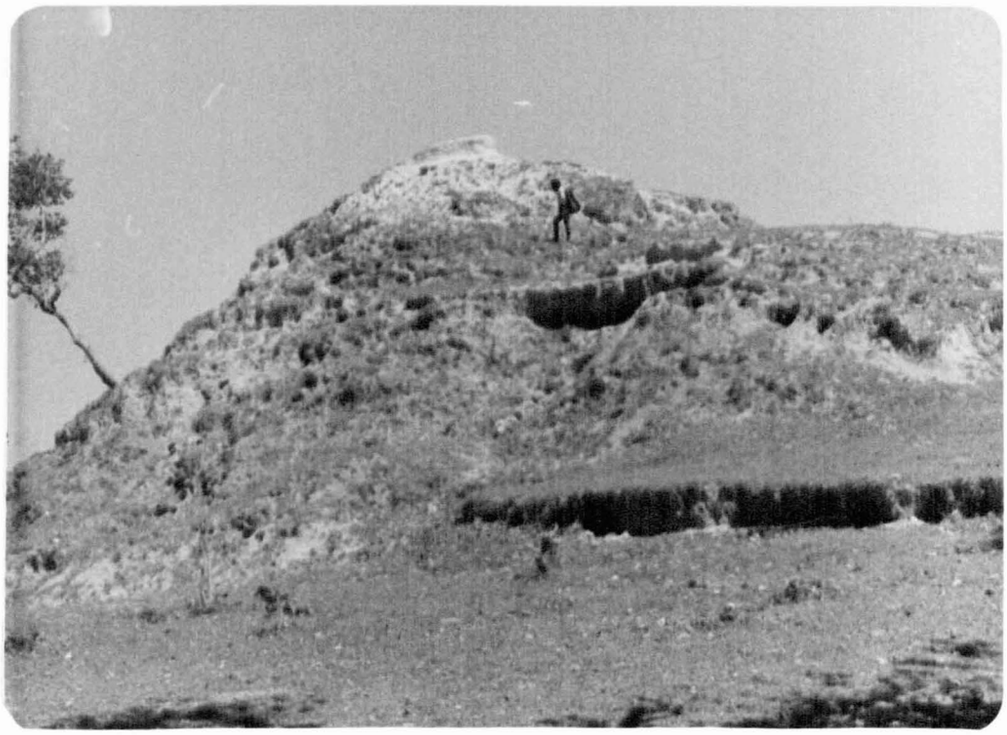
B: Present day capping of Noe Ko. U Sandstone Member on an isolated high in the centre of the Noetufi syncline.

C: Noebunu Marl Member, Noele Sub - basin, showing a cross - bedded, channelled conglomerate lens enclosed by marl.

A



B



C



(d) History of deposition of the Soe Limestone Formation in the Noetufi syncline

The completeness and diversity of the Soe Limestone succession of the Noetufi syncline facilitate a reconstruction of the palaeogeography of this portion of the Noele Sub-basin during Soe Limestone times. The following account however, also provides much evidence as to the evolution of the entire island of Timor during this time, over much of which the Soe Limestone succession deposited was neither as thick nor as complete as that of the Noetufi area.

Pre-Soe Limestone times

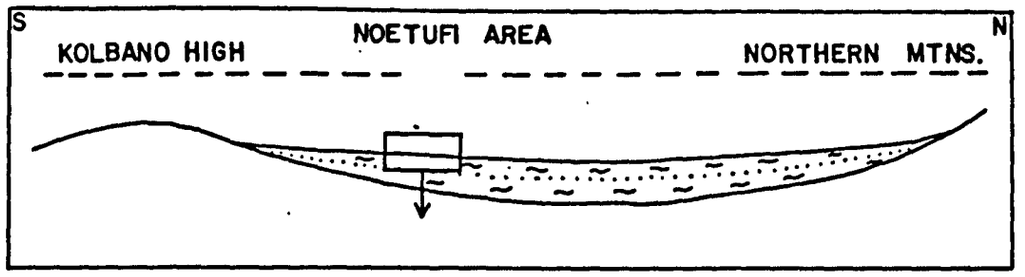
The Nuanain Sandstone Member of the Noele Marl Formation, which underlies the Soe Limestone of the Noele Sub-basin was interpreted in a previous section as a turbidite submarine fan deposit, of deep water origin (Fig. 59,1). During the uplift of this deposit, folding of the Central Basin took place (Fig. 59,2), resulting in the formation in the southern part of the Noele Sub-basin of the Noele anticlinal axis, with complementary synclines to the north (Noil Lakoe syncline) and south (Noetufi syncline). Following uplift and erosion, a phase of relative subsidence must have taken place, as the lowermost Soe Limestone deposits in the region are of marine origin. Contemporaneously with, or shortly after this subsidence, a phase of normal faulting resulted in the formation of an east-west trending graben on the site of the former Noetufi syncline (Fig. 59,3).

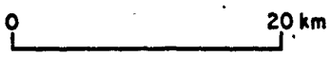
The relative rarity of coarse deposits within the Noetufi syncline and the persistence of the latter as a negative area of deposition from the beginning of Nuanain Sandstone times until the

Fig. 59: Diagram illustrating successive stages in the development of the Noetufi syncline and its associated Soe Limestone Formation deposits:

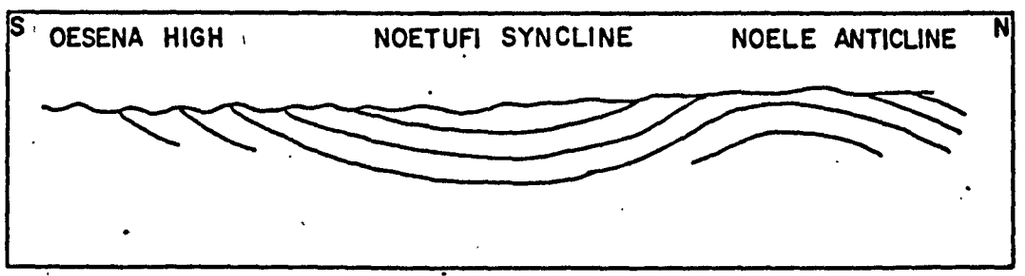
1: Deposition of the turbidites and marls of the Noele Marl Formation in the Central Basin; 2: Uplift, folding and erosion of the basinal deposits; 3: Subsidence of the Noele Sub - basin, accompanied by normal faulting along the north and south flanks of the Noetufi syncline and subsidence of the latter. Deposition of the Oesena Member (stippled) and the Noetufi Marl Member (dashed) on the highs and in the basin respectively; 4: Renewed uplift and establishment of reef growth on the Oesena and Noele anticline Highs. Continuation of Noetufi Marl deposition in the syncline; 5: Further uplift, slight tilting and virtual isolation of the Noetufi syncline, resulting in deposition of the Noelenat Marl (wavy lines); 6: Uplift, with possible erosion and establishment of the Toi. O fresh water lake in the Noetufi syncline.

1.


S
NOETUFI AREA
N
KOLBANO HIGH
NORTHERN MTNS.

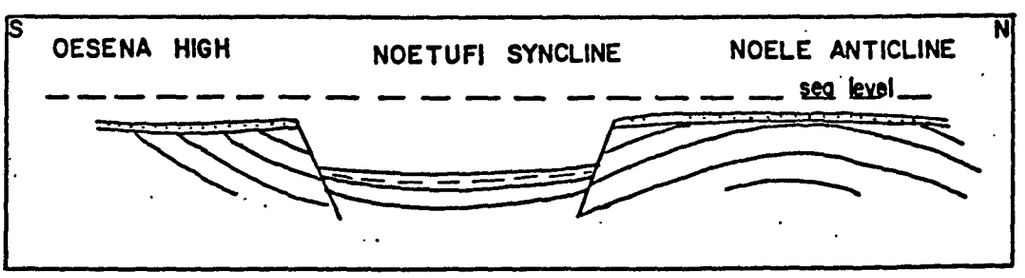

0
20 km
HORIZONTAL SCALE

2.

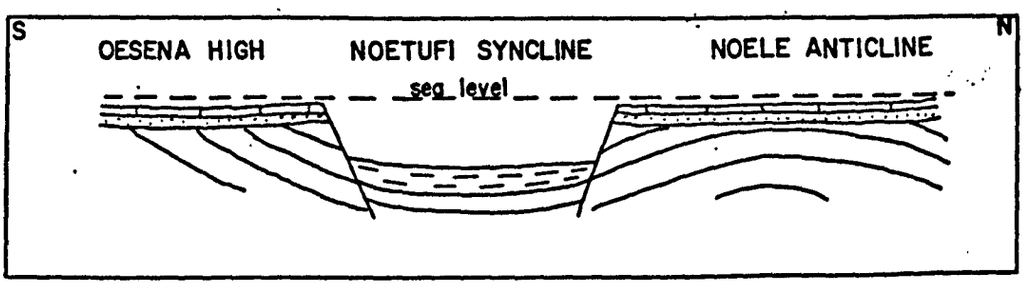

S
OESENA HIGH
NOETUFI SYNCLINE
NOELE ANTICLINE
N


0
5 km
HORIZONTAL SCALE (DIAGRAMS 2-6)

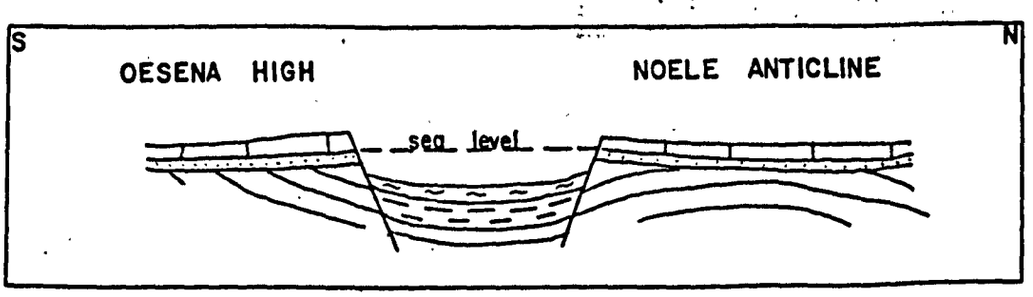
3.


S
OESENA HIGH
NOETUFI SYNCLINE
NOELE ANTICLINE
N
sea level

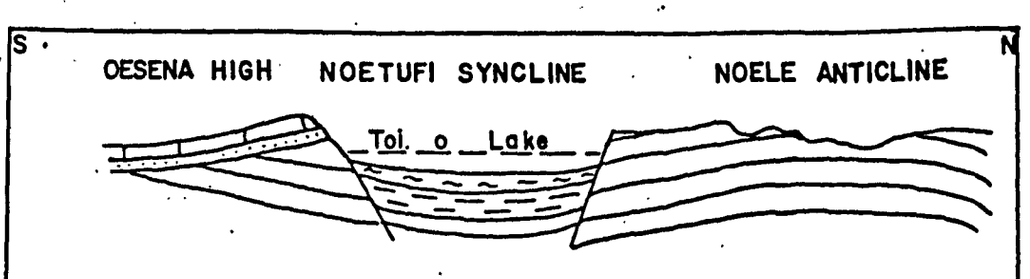
4.


S
OESENA HIGH
NOETUFI SYNCLINE
NOELE ANTICLINE
N
sea level

5.


S
N
OESENA HIGH
NOELE ANTICLINE
sea level

6.


S
N
OESENA HIGH
NOETUFI SYNCLINE
NOELE ANTICLINE
Toi. o Lake

present day strongly suggest that the erosion of the folded Nuanain Sandstone Member preceded the normal faulting and the formation of the graben and that the erosional products were probably carried southwards to the coastline at that time. Only subsequent to this erosion did the formation of the graben occur, this being accompanied by a phase of relative rise of sea level. How deep the Noetufi area actually sank is not known. What is recorded however, is the following sequence of events during the subsequent gradual emergence of the region.

(i) Deposition of the Soe Limestone Formation began, on the Oesena High to the south of the Noetufi syncline, with the Oesena Member (Fig. 59,3), consisting of a thin succession of reworked arenites, derived from the continued erosion of the Nuanain Sandstone Member. At this time, the centre of the Noetufi syncline, which was below wave base, was subject to slow deposition of fine, grey marl. The varied nature of the associated molluscan fauna, at least in the lower part of the succession, suggests that the Noetufi syncline was not at this stage completely enclosed by reef masses.

(ii) Deposition of the reef and Noelenat Marl facies

Further uplift of the area (Fig. 59,4) permitted the initiation of reef growth on the Oesena and Noele anticline Highs. The effect of this was to gradually cut off the Noetufi syncline from the open sea to the south by the formation of a linear reef area. For this reason, and possibly because of the resulting hypersalinity the deposits of the Noelenat Marl which succeed the Noetufi Marl,

contain very little megafauna. Debris from the reef fronts fringing the Noetufi syncline at this time found its way into the synclinal deposits, either as slumps or by way of subaqueous currents.

(iii) Noe Ko. U Member and mid-synclinal reef deposits

The emergence of the deposits of the centre of the syncline was responsible for the deposition of a thin capping of reef which now exists on a high of Noele Marl in the centre of the syncline. The reef platform biostrome deposits of the Noe Ko. U Member succeed this facies. This mid-basinal high is not depicted on the cross-sections.

(iv) Deposition of the Toi. O Lignite and final uplift

As a result of the final stage of uplift and retreat of the sea southwards towards the present coast, the uplifted Noetufi syncline would have formed an ideal depression for the drainage of surface waters (Fig. 59,6). The present-day distribution of the carbonaceous earths of the Toi. O Lignite Member suggests that the fresh water lake so formed was of fairly wide extent.

(e) Other Soe Limestone deposits of the Noele Sub-basin

Outside the Noetufi syncline and adjacent areas the Soe Limestone Formation is represented mostly by extensive plateau areas of the Tjamplong Limestone Member (see Enclosure 1), with occasional deposits of the Noetufi Marl Member in the intervening lows and of the Oesena Sandstone Member on the highs. Two other distinctive members of the Soe Limestone Formation, the Kapan Limestone and Noebunu Marl (Fig. 60) are present at the north- western and south-eastern margins of the basin respectively.

(i) The Kapan Limestone Member

The Kapan Limestone is present over much of the northern part of the Kapan-Soe High as a series of yellow foraminiferal calcarenites and arenites which succeeds the Tjamplong Limestone Member. The member attains a maximum thickness of 10 metres (Fig. 60) and is interpreted as a reef platform deposit.

(ii) The Noebunu Marl Member

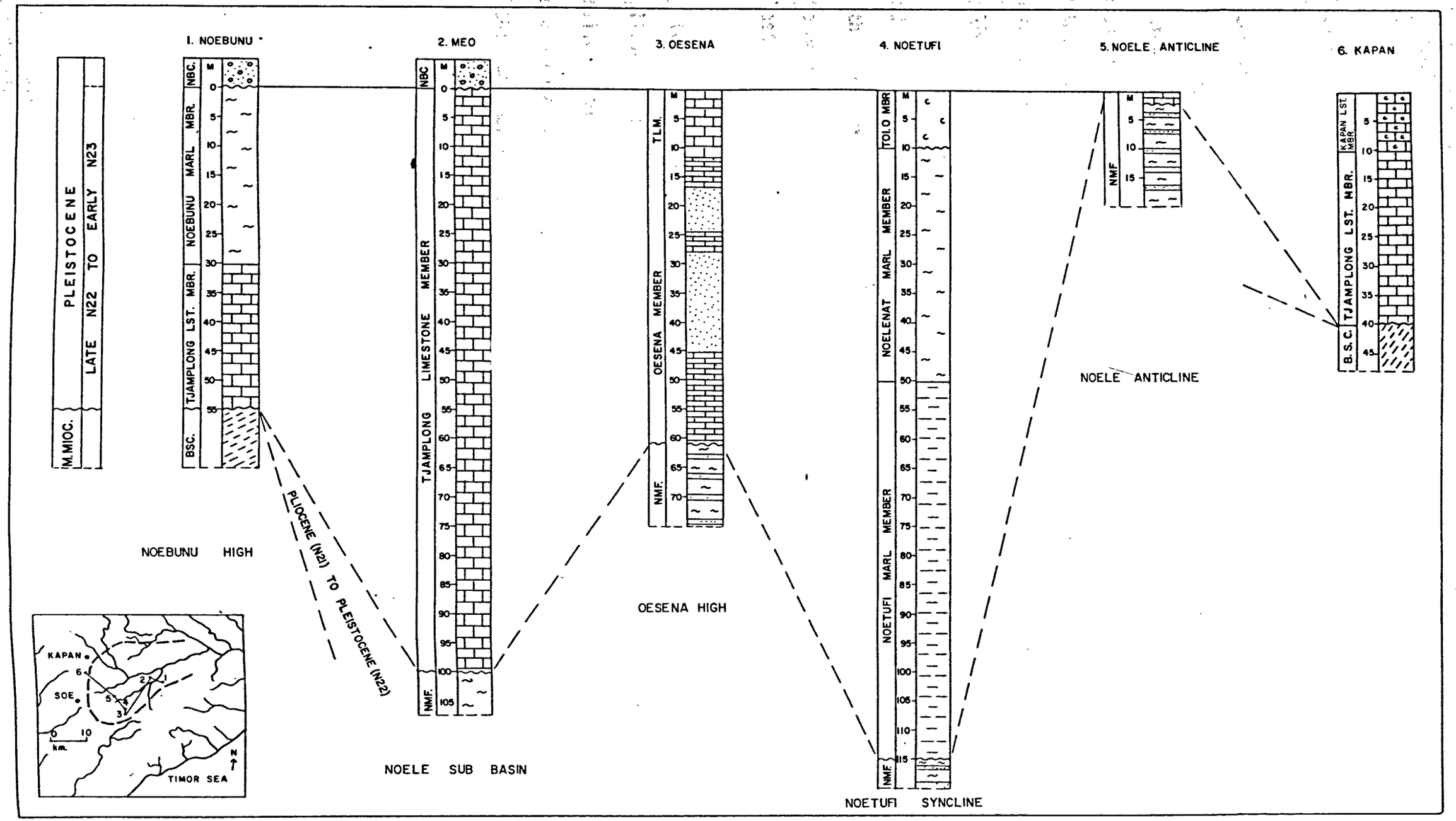
The Noebunu Marl is a blue-green marl of maximum thickness 30 metres (Fig. 60), exposed along the banks of the Noebunu River, east of Niki Niki. It directly overlies the reef facies (Tjamplong Limestone Member) of the Soe Limestone (via a sharp contact) and is itself overlain abruptly by the Noilbesi Conglomerate Formation. Three facies can be recognised:

Facies A

Green to blue marls with many, isolated, well rounded Lolotoi clasts of coarse sand size. The marls also contain much isolated, comminuted thin shelled molluscan debris. Bioturbation is common.

Fig. 60: Correlation of stratigraphic sections of the Soe Limestone Formation throughout the Noele Sub - basin: Of particular interest are (a) the very thick section of Tjamplong Limestone in the Meo section, probably caused by contemporaneous subsidence of this part of the Central Basin during Soe Limestone deposition and (b) the Noebunu section, which is the only known section in Timor in which a marine marl (the Noebunu Marl Member) overlies the Tjamplong Limestone Member. The resulting sequence contains channels which appear to be distal equivalents of the coarse conglomerates of the Noilbesi Conglomerate Formation, which later prograded over the area.

For location of sections see inset.


1. NOEBUNU
2. MEO
3. OESENA
4. NOETUFI
5. NOELE ANTICLINE
6. KAPAN
PLEISTOCENE
LATE N22 TO EARLY N23
M.MIOC.
BSC.
TJAMPLONG LST. MBR.
NOEBUNU MARL MBR.
NBC.
TJAMPLONG LIMESTONE MEMBER
NMF.
OESENA MEMBER
TLM.
NOETUFI MARL MEMBER
NOELENAT MARL MEMBER
TOLO MBR
B.S.C.
TJAMPLONG LST. MBR.
KAPAN LST. MBR
PLIOCENE (N21) TO PLEISTOCENE (N22)
NOEBUNU HIGH
OESENA HIGH
NOELE ANTICLINE
NOELE SUB BASIN
NOETUFI SYNCLINE
KAPAN
SOE
TIMOR SEA
km.
N

Facies B

Parallel sided arenites interbedded with the above marl succession. These consist of lithic sand with a large proportion of comminuted thin shelled molluscan debris and display parallel lamination or very low angle cross bedding. Two principal beds occur in the section and can be traced for 100 metres horizontally without appreciable change. In the type section, both upper and lower surfaces are abrupt, but elsewhere these are transitional.

Facies C

Conglomerate lenses varying in width from 1 to 10 metres, and in thickness from 50 to 150 centimetres (Plate 18). These occur within the marl and show high angle or trough cross bedding. The clasts are poorly sorted and consist mostly of well rounded Lolotoi and reef clasts.

A very shallow water origin for the Noebunu Marl is suggested by (a) the admixture of terrigenous clasts and comminution of molluscan debris and (b) the occurrence of the marl between the shallow water reef limestones and the fluviatile Noilbesi Conglomerate in a generally regressive sequence. The presence of Lolotoi clasts within the marls and conglomerates suggests a northern origin.

(ii) The Soe Limestone Formation of the Bokong Sub-basin and Panite High

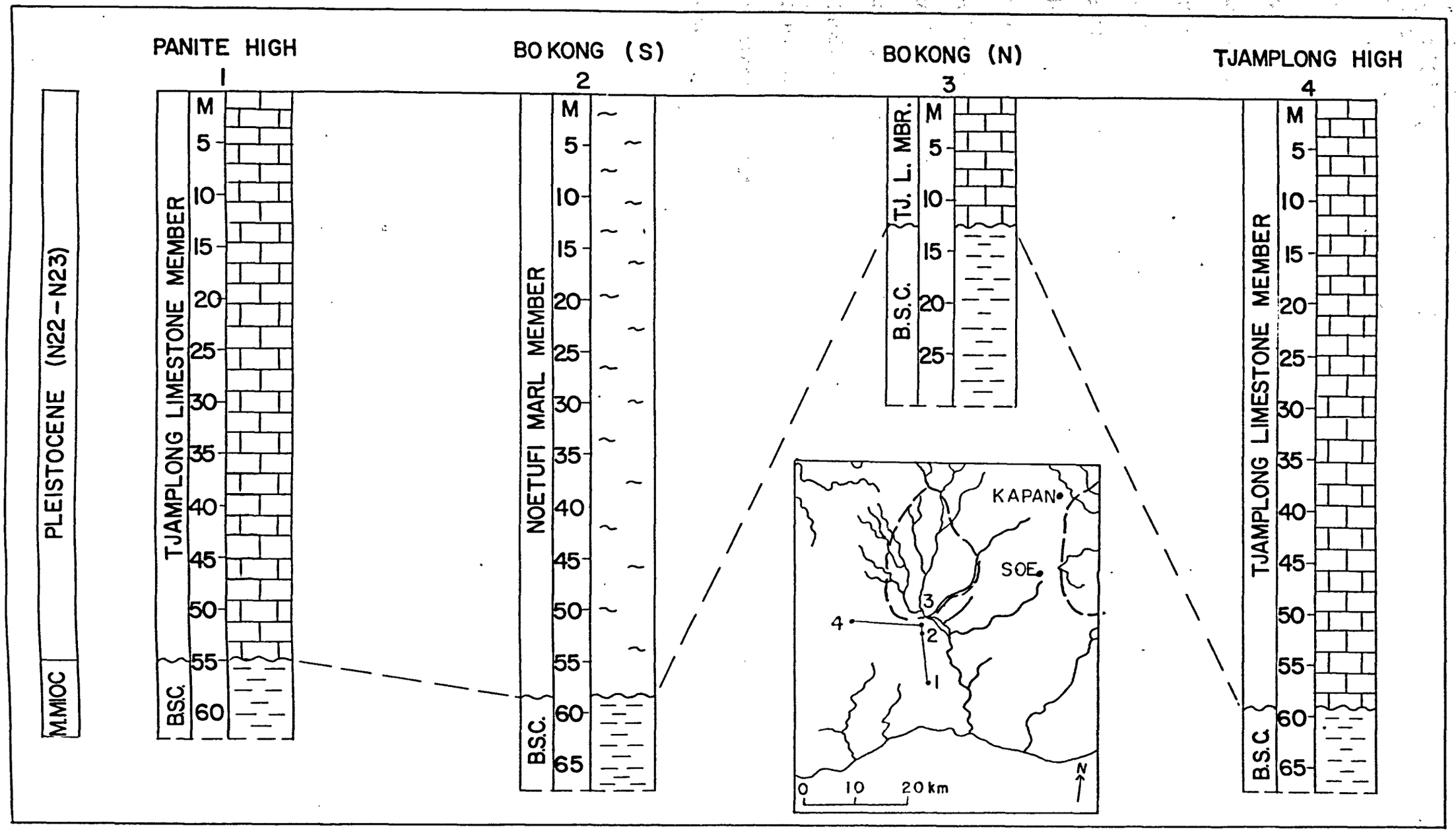
The Soe Limestone of the Bokong Sub-basin consists mostly of the Tjamplong Limestone Member, which forms large plateau areas covering the Bobonaro Scaly Clay around the margins of the basin (Fig. 61) and of the Noetufi Marl Member which is present in isolated, but sometimes extensive outcrops, within, and to the south of, the Sub-basin. In addition, isolated outcrops of the Noe Ko. U Member are present as a thin covering of the Tjamplong Limestone Member on the Tjamplong-Naifallo High.

(a) The Tjamplong Limestone Member

The Tjamplong Limestone Member (Fig. 61), consists everywhere of a white to light yellow, massive, crystalline, vuggy reef limestone containing numerous clasts of coral, coralline algae, gastropods and other molluscs. In the type section, 1 kilometre east of Tjamplong on the Tjamplong-Bokong road, the member attains a maximum thickness of 59 metres. In this section, the member overlies the Bobonaro Scaly Clay unconformably and forms the uppermost stratigraphic unit of the Viqueque Group.

In many localities the limestone has the appearance of a reef breccia, in that the proportion of in situ colonial corals appears to be very small in relation to the enormous quantities of coralline reef debris present. Studies of the present day reefs of Kupang Bay however, (later section) suggest that the present day reef platform is growing largely by the accumulation of wave-broken corals and other debris, rather than by simple constructional colonial growth. Most of the Tjamplong Limestone Member is therefore not a fore reef deposit .

Fig. 61: Correlation of stratigraphic sections of the Soe Limestone Formation around the margins of the Bokong Sub - basin. Most sections of the Soe Limestone Formation in the sub - basin itself consist of isolated outcrops of the Noetufi Marl Member.


PLEISTOCENE (N22–N23)
M.MIOC
PANITE HIGH
1
BO KONG (S)
2
BO KONG (N)
3
TJAMPLONG HIGH
4
TJAMPLONG LIMESTONE MEMBER
NOETUFI MARL MEMBER
TJ. L. MBR.
B.S.C.
M
5
10
15
20
25
30
35
40
45
50
55
60
65
KAPAN
SOE
0 10 20 km
N

The present day, living reefs of Timor do, however, show one important difference from those of the Pleistocene. The present day reefs can be classified as fringing reefs, forming generally narrow belts along the present coastline. Cloud (1952) suggested that fringing reefs are the reef forms of slowly rising, rapidly subsiding or stationary shores. However topography must undoubtedly play a part. The steep gradients of the shore and offshore areas of most parts of Timor are ideal for the growth of thin strips of reef parallel to the shoreline. In contrast, the existence during the Pleistocene of the Central Basin and surrounding areas of Indonesian Timor as a series of broad, low, flat-topped emerging islands was instrumental in the establishment of broad tabular reef masses, such as those now mantling the Tjamplong-Naifallo High in the Bokong Sub-basin, from which the Tjamplong Member type section is taken.

Plate 19: Tjamplong Limestone Member, near Noebunu, Noele Sub - basin.

A



B



(b) The Oemolo Member

The Oemolo Member consists of a series of red foraminiferal calcarenites and calcirudites exposed in a bluff of the Noilmina River near the village of Oemolo, west of Panite (Fig. 62). The member appears to be very restricted in extent and has not been found elsewhere in Timor.

The basal part of the succession consists of 12 metres of red foraminiferal calcarenite with isolated, reef derived clasts and calcareous concretions. This is succeeded transitionally by 3 metres of calcirudite. The latter consists of blocks of reef limestone separated by coral, molluscan and algal debris, floating in a red foraminiferal calcarenite matrix. The succession is completed by 8 metres of coarse calcirudite consisting of reef limestone blocks of maximum diameter 1.5 metres.

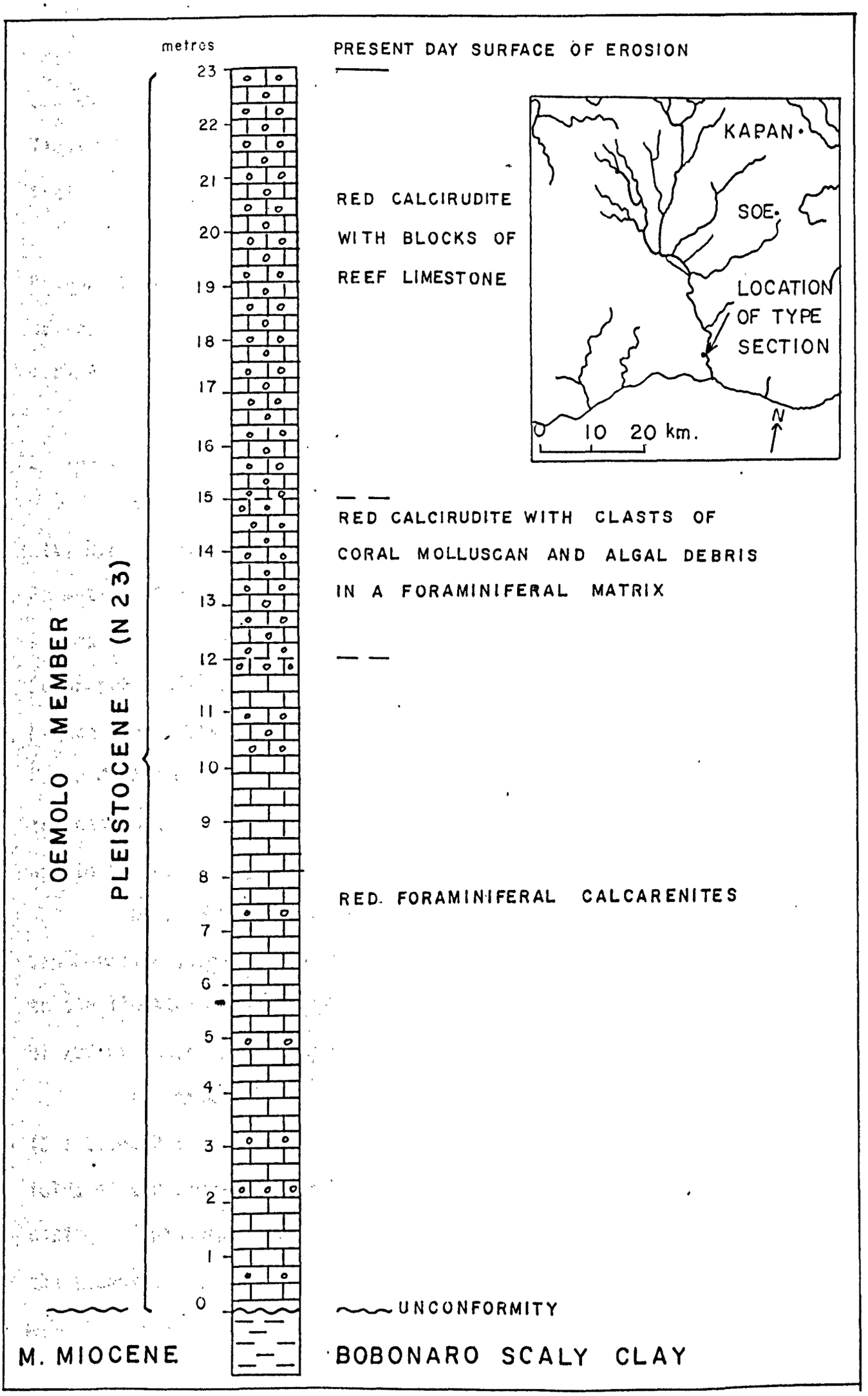
Interpretation

The predominance of reef derived material, and the upwards increase in coarse, reef derived blocks suggests that the member is a fore-reef deposit, probably related to the Tjamplong Limestone Member reef facies capping the Panite High to the north.

D Microfauna

Samples from the Noetufi Marl and Toi. O Lignite Members of the Soe Limestone Formation were examined by Carter (unpublished report, dated 1970a). Carter recognised a benthonic Miliolid-Peneroplidae-Elphidium assemblage within the Noetufi Marl, interpreting this as a typical lagoonal biofacies of abnormal salinity. Also present were a few, rare, broken and rolled contemporaneous planktonics and

Fig. 62: Oemolo Member, type section: Measured near Panite, south of the Bokong Sub - basin.


metres
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
PRESENT DAY SURFACE OF EROSION
KAPAN
SOE
LOCATION OF TYPE SECTION
10 20 km.
N
RED CALCIRUDITE WITH BLOCKS OF REEF LIMESTONE
RED CALCIRUDITE WITH CLASTS OF CORAL MOLLUSCAN AND ALGAL DEBRIS IN A FORAMINIFERAL MATRIX
RED. FORAMINIFERAL CALCARENITES
OEMOLO MEMBER
PLEISTOCENE (N 23)
UNCONFORMITY
M. MIOCENE
BOBONARO SCALY CLAY

abundant specimens derived from the Upper Cretaceous and from the Viqueque Globigerina nepenthes-Sphaeroidinellopsis zone, confirming that rocks of this age had by this time come within reach of erosion.

In a sample of Toi. O Lignite, Carter (op. cit.) found Planorbis and other gastropods, moulds of Charophyte roots and stems of fresh water origin, plus a few rare and broken planktonics representing marine inwash.

E The age of the Soe Limestone Formation

An Early Pliocene age was assigned by Felix (1915) to the 'Niki Niki Limestones' (reef limestones belonging to the Soe Limestone Formation of this thesis) on the basis of the presence within the limestones of 65.5% of Recent coral species. This was later revised by De Bruyne (1941) who estimated the percentage of present day lamellibranchs and gastropods in the pre-reef series (equivalent to the Noele Marl and Noil Lakoe Marl Formations of this thesis) as 67%, indicating a Plio/Pleistocene age, and thus assigned a Pleistocene age to the overlying coral limestones.

Later authors seem to have been in agreement with this dating; Van Bemmelen (1949) for instance, assigned a younger Quaternary age to the limestones on the basis of the finding by Umbgrove (1946) of 79% of Recent coral species in the Niki Niki rocks.

In Portuguese Timor, the presence of the Baucau Limestone (Soe Limestone Formation equivalent) on the eroded Late Pliocene folds of the Viqueque Formation caused Audley-Charles (1968) to assign a Pleistocene age to the oldest terraces and a Holocene age to the youngest. In this thesis it has been shown that the main Viqueque phase of folding occurred during the Pleistocene, thus firmly

establishing the oldest part of the Soe Limestone Formation and its Portuguese Timor equivalent as being of Pleistocene age.

In the age determination of samples from the type sections presented in this thesis, Carter (unpublished report, dated 1970a) determined that the N22/N23 boundary falls within the Soe Limestone Formation, although he was unable to locate the boundary precisely. The base of the Soe Limestone Formation can not therefore post-date the N22/N23 boundary. The base must be older than 0.5 m.y.

Some indication of how far the formation extends into the N22 zone can, however, be obtained by the fact that it is necassary to accommodate (a) the deposition of at least 650 metres (and possibly much more) of the Noele Marl Formation; (b) its folding and uplift from a basinal environment to a position above sea level; (c) its erosion and (d) its subsidence to at or below sea level (in which environment the first Soe Limestone sediments began to accumulate) all within the N22 zone.

For this reason, the age of the Soe Limestone Formation of the type section, and indeed most of the Soe Limestone Formation now exposed in the general Central Basin area of Indonesian Timor is here given as latest N22 to earliest N23. Outside the Central Basin, the occurrence of reef limestone terraces at all topographic levels, from the elevation of the Central Basin to sea level, suggests however that the Soe Limestone Formation throughout Timor be regarded as latest N22 to Holocene in age.

Reef limestones similar in character to the Soe Limestone occur at higher elevations than those of the Central Basin area. In Portuguese Timor, Audley-Charles (1968) regarded all reefs occurring above 500 metres as Lower Pliocene in age on the basis of their

microfauna. He called them the Lari Guti Limestone. It should however be noted that most of the reef limestones of the Central Basin of Indonesian Timor discussed above, whose base was dated as Pleistocene (Late N22) age are of this elevation or considerably above. It seems unlikely that the epeirogenic evolution of the two halves of the island could have been so dissimilar as to produce such widely differing ages. It is possible that the higher elevation reefs of Portuguese Timor were deposited during the Early Pliocene and were subsequently submerged and uplifted again to their present elevation. However as the microfaunal basis for the Pliocene age of the Lari Guti Limestone is very weak, these higher reefs in Portuguese Timor may also be Pleistocene and form part of the Baucau Limestone.

Also worthy of mention with regard to the age of the Soe Limestone Formation is the widespread occurrence of reef derived material within the strongly folded Noil Lakoe Marl Formation of the northern part of the Bokong Sub-basin. Clearly, this material cannot have been derived from the non-folded Soe Limestone Formation which overlies the Noil Lakoe Marl in this part of the basin, nor from any of the reef limestones of the Central Basin. It must have come from higher level terraces of possible Middle to Late N22 age. These terraces, which must have been situated to the north of the Central Basin, and which probably lay on the much more rigid substratum of the northern mountains would clearly not have been affected as much by the Mataian folding as were the sediments of the Central Basin. It is therefore possible that these reefs may today be found in the northern mountain region in a more or less unfolded state.

Pliocene and Pleistocene reef terrace limestones of Timor (Fig. 63) can thus be divided into:

(a) Reefs which may have been deposited during Sabaoe Limestone Formation times (Late Pliocene, or N21), which survived the subsequent orogenies, and which now exist at heights greater than 500 metres in Portuguese Timor.

(b) The reefs of the Soe Limestone Formation, deposited directly subsequent to the Pleistocene folding and comprising (i) those of the Central Basin ranging from approximately Late N22 to Early N23 in age and (ii) those occurring at various elevations between the Central Basin and sea level and ranging in age from Early N23 to Holocene.

(c) Higher level terraces in the Northern Mountains which pre-date the Pleistocene folding and which contributed clasts to the Early to Middle N22 Noil Lakoe Marl Formation.

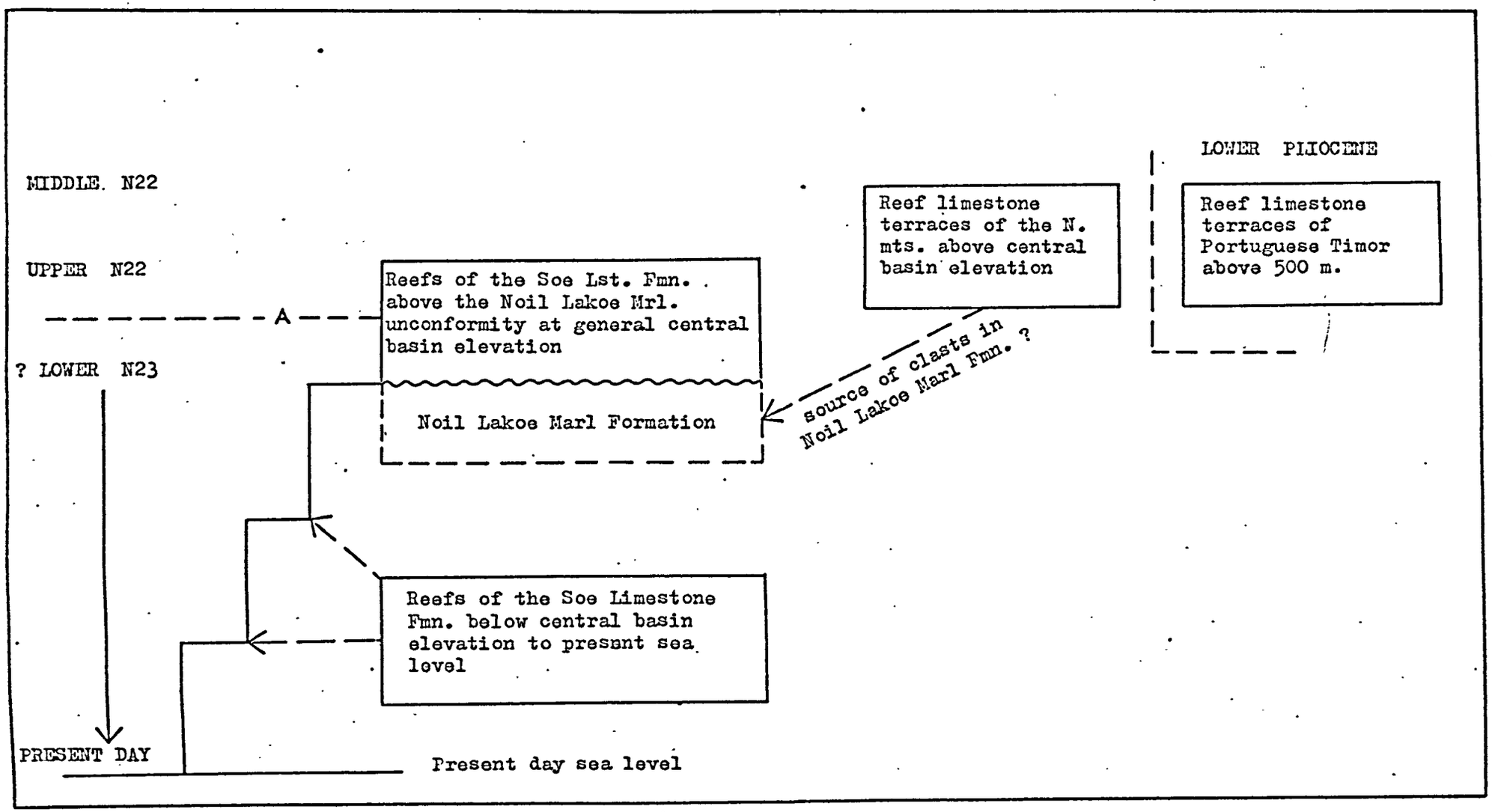
F. Origin of the Soe Limestone Formation reef terraces.

Reef terraces similar to those from the Pleistocene of Timor have been described from the Quaternary of the nearby Kai Islands and Tanimbar (Van Bemmelen 1949), from Malekula (Mitchell 1971) and Espiritu Santo (Stearns 1945) in the New Hebrides and from Hawaii (Stearns 1945). Audley-Charles (1968) regarded the terraces as marking phases of uplift in the Quaternary. Stearns (1945) however, pointed to the general similarity of the terraces on Hawaii to those of Espiritu Santo in the New Hebrides and used this to suggest the formation of the terraces during high eustatic stands. This explanation was questioned by Mitchell (1971), whose interpretation of the New Hebrides terraces involved a combination of continuous tectonic uplift, combined with eustatic oscillations.

Fig. 63: Diagram illustrating relationship of age to present elevation for the Plio - Pleistocene reef limestone terraces of Timor.

Note that the Soe Limestone of the Central Basin itself has a probable age range of Upper N22 to Lower N23, but that the formation as a whole includes reef limestone terraces at lower elevations, some of which are of very recent origin.

Line A represents the approximate position of the N22/N23 boundary, as determined from microfaunal analysis.


LOWER PLIOCENE
MIDDLE. N22
Reef limestone terraces of the N. mts. above central basin elevation
Reef limestone terraces of Portuguese Timor above 500 m.
UPPER N22
A
Reefs of the Soe Lst. Fmn. above the Noil Lakoe Mrl. unconformity at general central basin elevation
? LOWER N23
source of clasts in Noil Lakoe Marl Fmn. ?
Noil Lakoe Marl Formation
Reefs of the Soe Limestone Fmn. below central basin elevation to present sea level
PRESENT DAY
Present day sea level

To resolve this question in the present thesis would require extensive knowledge of the configuration of terraces on Timor. It is emphasised however, that during the period of deposition of the Soe Limestone Formation (N22 to present day) significant sea level changes are known to have taken place in response to the freezing and melting of ice at higher latitudes. As the Timor terraces are obviously the result of relative changes in land and sea then it seems likely that the glacial sea level changes must have played some part in their formation.

However, the likelihood that major tectonic uplift in island arcs takes place at a non-uniform rate (Fitch and Scholz 1971) does suggest that differential uplift must also have played some part. The many minor terraces which are seen in parts of Timor (see profile, Fig. 78) are evidence of this.

It is therefore concluded that the Pleistocene reef limestone terraces of Timor are the result of an interaction during the Quaternary of glacial sea level changes and differential rates of tectonic uplift.

Chapter 8: The Noilbesi Conglomerate Formation

A. Introduction

The Noilbesi Conglomerate Formation is the youngest formation of the Viqueque Group in Indonesian Timor. Although interfingering laterally in places with the Late Pleistocene Soe Limestone Formation, the Noilbesi Conglomerate usually overlies this formation, forming extensive plateau deposits in both Noele and Bokong Sub - basins of Indonesian Timor and less frequently over the area to the south of the Central Basin (Fig. 64).

Similar deposits are present in Portuguese Timor, where Audley - Charles (1968) distinguished the Ainaro Gravels, the Seketo Block Clay and the Dilor Conglomerate. Of these, the Ainaro Gravels appear to be most closely similar lithologically to the Noilbesi Conglomerate, although probably slightly younger in age.

In Portuguese Timor, a more complex relationship appears to exist between the Ainaro Gravels and the Baucau Limestone (Soe Limestone equivalent), the two often visibly interfingering on a relatively small scale.

The frequent vertical and lateral facies changes which characterise the Noilbesi Conglomerate succession of Timor make formal stratigraphic subdivision difficult. Part of the formation is therefore discussed by reference to the most commonly occurring facies types.

B. Stratigraphy

(i) The Noilbesi Conglomerate Formation of the Bokong Sub - basin

The Noilbesi Conglomerate Formation is present over a large part of the surface of the Bokong Sub - basin, forming large plateau areas between the rivers Noil Obernaik and Noilbesi (Fig. 64,A) and between the Noilbesi and Noil Leke (Fig. 64,B). The southern boundary

Fig. 64: Noilbesi Conglomerate Formation; distribution in mapped area (outlined).

A: Noil Obernaik/Noilbesi outcrop.

B: Noilbesi/Noil Leke outcrop.

C: Noilbesi Conglomerate Formation type section.

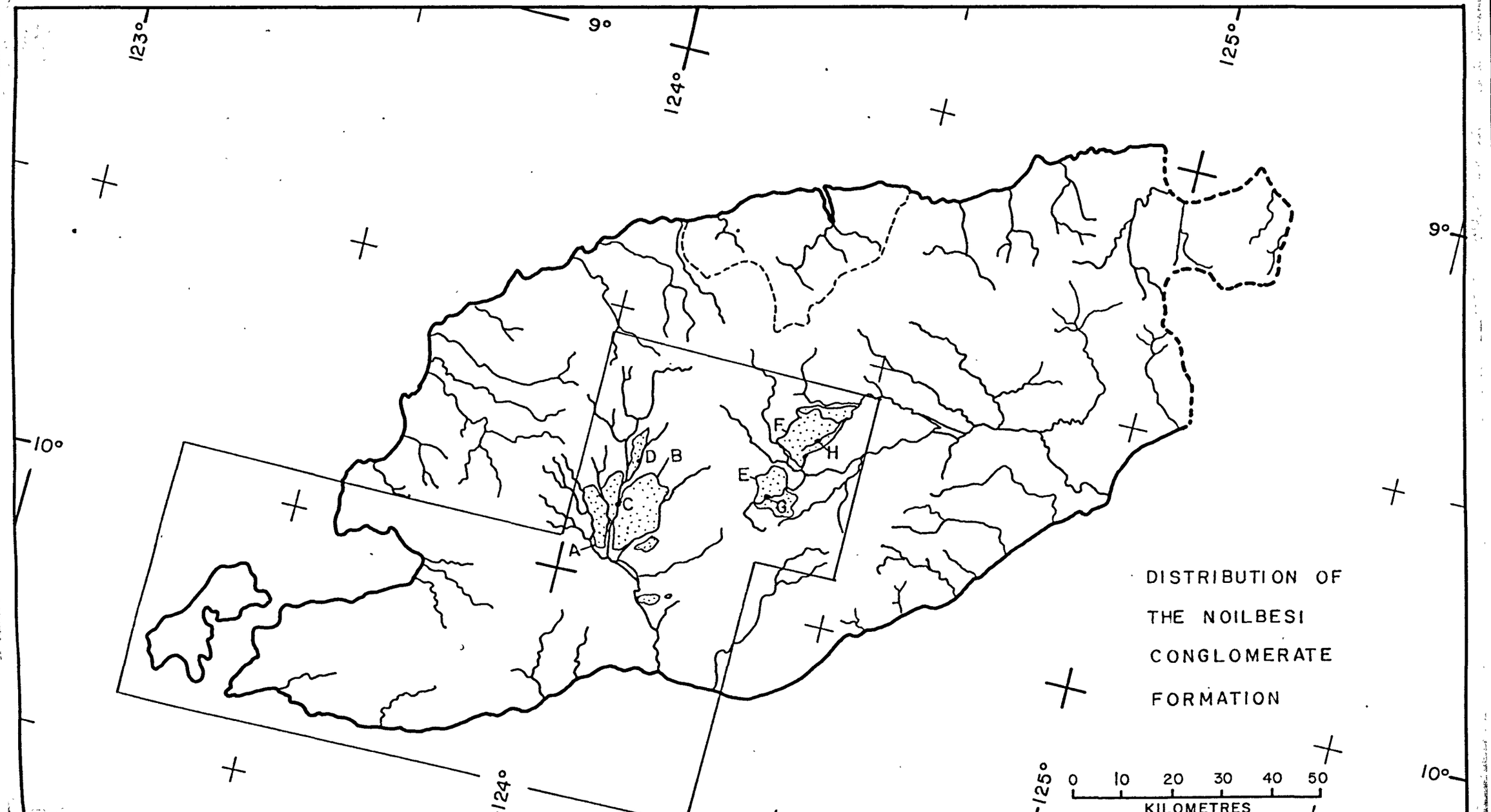
D: Mollo outcrops.

E: Noil Lakoe outcrop.

F: Noil Benain outcrop (north of Meo).

G: Pene Member type section.

H: Oeajo Clay Member type section.


123°
9°
124°
125°
10°
A
B
C
D
E
F
G
H
DISTRIBUTION OF
THE NOILBESI
CONGLOMERATE
FORMATION
0 10 20 30 40 50
KILOMETRES

of the outcrop ends abruptly at the Bokong-Batu Putih fault zone in the south of the sub-basin. To the north, the formation extends as far as the metamorphic complex of the Mollo Mountains, onto which it laps via an erosional, strongly unconformable contact.

In the central and southern part of the sub-basin, the contact with the underlying Noele Marl Formation is not seen. This contact is seen west of the Kali Obernaik, beyond the western limit of the main outcrop, where isolated remnants of Noilbesi Conglomerate Formation unconformably overlie an eroded Noele Marl surface.

(a) The succession of the Noilbesi River: the type section

The thickest sequence of Noilbesi Conglomerate is that exposed along the Noilbesi River in the centre of the Bokong Sub-basin, where an estimated 162 metres of succession is present above the Noele Marl Formation unconformity. The thickest exposed section (62.3 metres) was measured at locality 212 (Fig. 64) and is illustrated in Fig. 65. An overall upwards-fining takes place within the succession, from poorly sorted, generally massive conglomerates (units A to E), to interbedded gravels, arenite and silt (unit F) to parallel sided silts and arenites (unit G) at the top of the succession. Although the base of this succession is not seen anywhere along the Noilbesi River, the contact with the underlying marls of the Noele Marl and Noil Lakoe Marl Formations is strongly unconformable elsewhere in the Bokong Sub-basin.

Environment of deposition

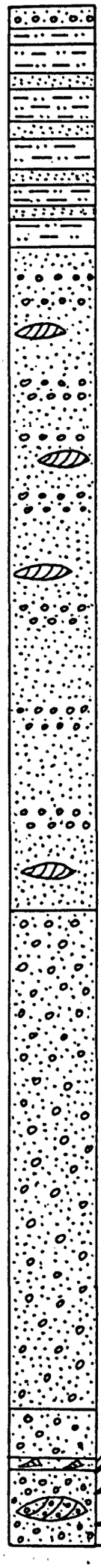
The coarseness and poorly sorted nature of the succession, abundance of cross bedding, absence of marine fauna and presence of plant root structures and calcareous concretions suggests a high energy,

Fig. 65: Noilbesi Conglomerate Formation: Type section, River Noilbesi, Bokong Sub - basin.

The section is subdivided into 7 units, A to G. Note the overall upwards - fining of the exposed section. Approximately 100 metres of unexposed conglomerate is present beneath the drawn section. Total thickness of type section is 162 metres.

For location see Fig. 64.

SECTION 212



TOP OF EXPOSED SECTION

G

PARALLEL SIDED SILTS AND ARENITES

0 m.
3
6

INTERBEDDED GRAVEL ARENITES AND LENSES OF CROSS-BEDDED SAND AND SILT.

F

POORLY SORTED, MASSIVE CONGLOMERATE
M C S = 9" (22 cm.)

E

SILT AND FINE SANDSTONE PARALLEL BEDDED.

CONGLOMERATE, IMBRICATED
M S C = 4" (10 cm.)

GRAVEL POORLY SORTED, CROSS-BEDDED
M C S = 2" (5 cm.)

D
C
B
A

STRUCTURELESS CONGLOMERATE M C S = 11"

UNEXPOSED: 100 m OF POORLY SORTED CONGLOMERATE

fluviatile environment of deposition. The paucity of interbedded fines suggests that the depositing river system was probably braided, rather than meandering.

(b) Conglomerate - silt facies

In exposures along the Noilbesi River, north of the type section, the Noilbesi Conglomerate consists mostly of alternating, often parallel - sided, beds of poorly sorted conglomerates and silts, similar to unit E of the type section. The conglomerates display internal channelling and possess a maximum clast size of approximately 15 cm. The silts are characterised by an abundance of calcareous concretions and plant root structures. Some display cross bedding.

Interpretation

The coarseness of the deposits, the poor sorting, and the channelling, suggest deposition by braided rivers, with widespread sheet floods being responsible for the lateral continuity of the beds. Deposition of silts upon waning of these floods would account for the finer beds, and colonisation of these deposits by vegetation in between flood periods would account for the plant root structures and calcareous concretions.

These deposits are unlike any forming at the present day in Timor, in that (a) individual beds show a greater degree of lateral persistence and (b) the proportion of silts to conglomerates in the older deposits is much greater. At the present time the river channels of the Central Basin of Timor are incising into the older Noilbesi Conglomerate deposits, reflecting the state of uplift of the island. The floodplain is consequently relatively narrow and constantly reworked, resulting in winnowing of most of the silt and its transport

to the south coast.

(c) Alluvial fan facies

The Noilbesi Conglomerate exposed in the Noilbesi River adjacent to the mountain of Mollo (Fig. 64, D) consists of parallel - sided, thin bedded, poorly sorted, fine gravels and silts, consisting entirely of dark green (metamorphic) Lolotoi clasts. These deposits are part of an extensive series of alluvial fans, radiating outwards from the western side of Mollo. Present - day metamorphic debris from the mountain is being delivered to the Noilbesi River main channel by tributaries, the bed load of which contrasts strongly to that of the main river.

Deposits elsewhere in the Bokong Sub - basin

The Noilbesi Conglomerate Formation is exposed extensively along the rivers Noil Obernaik and Noil Leke within the main outcrop of the formation. Elsewhere, such as west of the Noil Obernaik, small outliers of Noilbesi Conglomerate overlie the Noele Marl Formation unconformably.

(d) The Tacari Limestone Member

Unconformably overlying the Batu Putih Limestone and Bobonaro Scaly Clay in the structurally complex and extensively faulted area between Bokong and Batu Putih in the Bokong Sub - basin is a thick deposit of coarse limestone breccia. The clasts within the breccia consist of white, foraminiferal calcilutites derived mostly from the Batu Putih Limestone of the region. Most are angular and some reach 1 metre in diameter. The larger clasts are usually somewhat rounded, and the deposit as a whole is unstratified. The type section, consisting

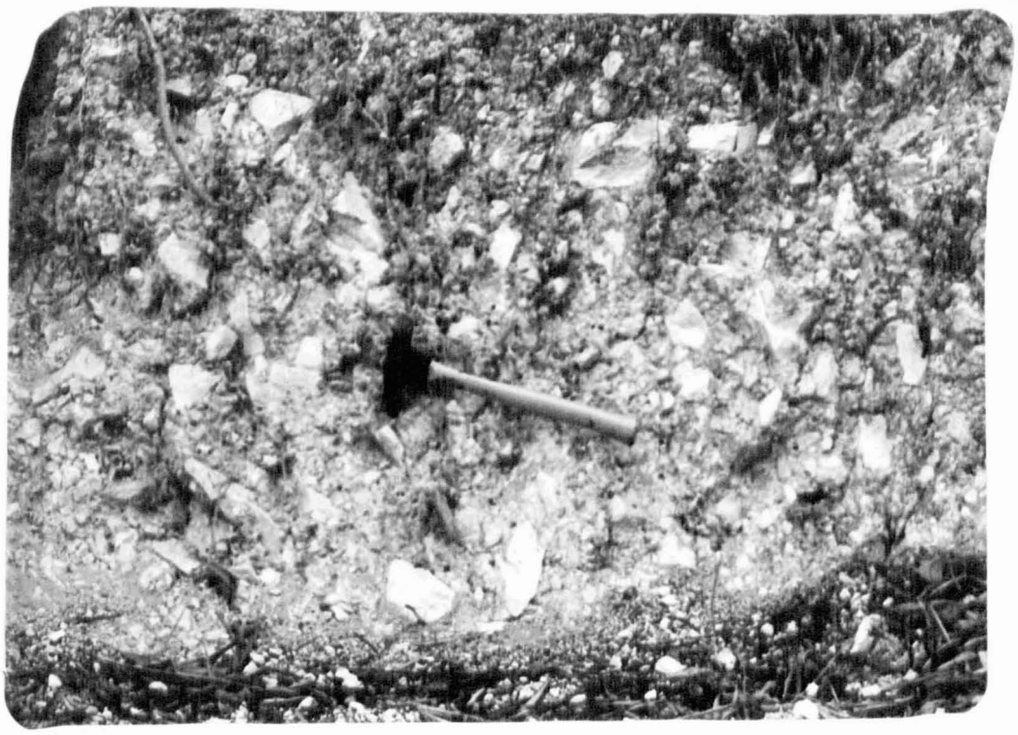
Plate 20: Noilbesi Conglomerate Formation

A: Breccia of angular blocks of Batu Putih Limestone in fault - zone north - west of Noilmina. Similar fault breccias are present in the main area of outcrop of the Tacari Limestone Member, along the Bokong - Batu Putih fault zone in the Bokong Sub - basin.

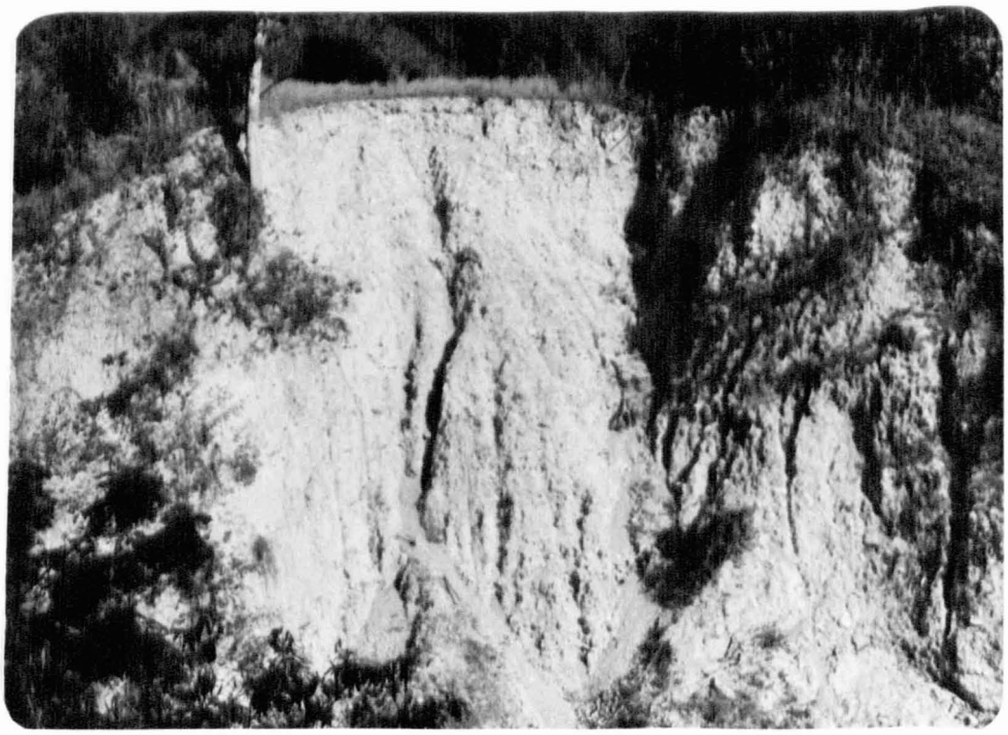
B: Cliff section of the Tacari Limestone Member between Tacari and Batu Putih, Bokong Sub - basin.

C: Calcareous concretions in red clays of the Oeajo Clay Member, north of Meo, Noele Sub - basin.

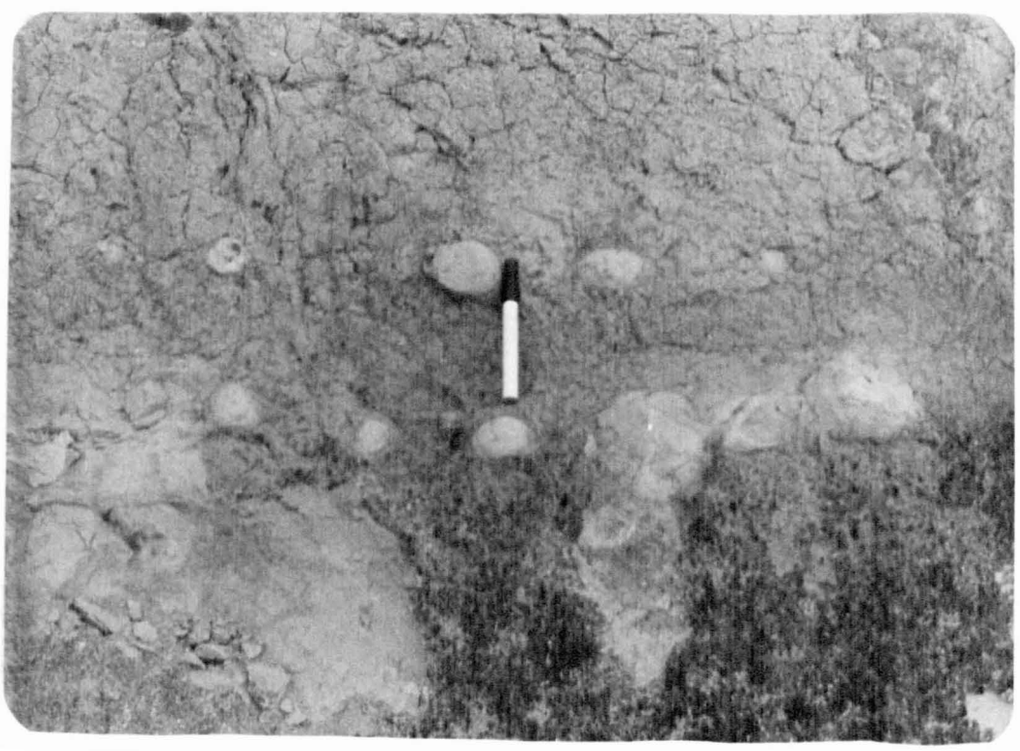
A



B



C



of 22 metres of limestone breccia is taken from a roadside exposure 1 kilometre east of Tacari.

The lack of sorting or stratification of the deposit, the extreme angularity of the clasts and the monomictic composition suggest that the deposit is a locally derived gravity flow deposit which accumulated as a talus breccia from the Batu Putih Limestone escarpment on the northern side of the fault zone. The extensive shearing which can now be seen in the Batu Putih Limestone of this district probably originated during this movement, and would have provided a ready source of loose, angular blocks in the form of fault breccia. The presence of slickensiding in nearly all of the blocks in a similar breccia exposed between Batu Putih and Soe supports this conclusion.

(ii) The Noilbesi Conglomerate Formation of the Noele Sub - basin

The Noilbesi Conglomerate Formation overlies the Noele Marl, Noil Lakoe Marl and Soe Limestone Formations in the following areas of the Noele Sub - basin:

(a) north of the Noele anticline, along the Noil Lakoe syncline;

(b) north of Meo

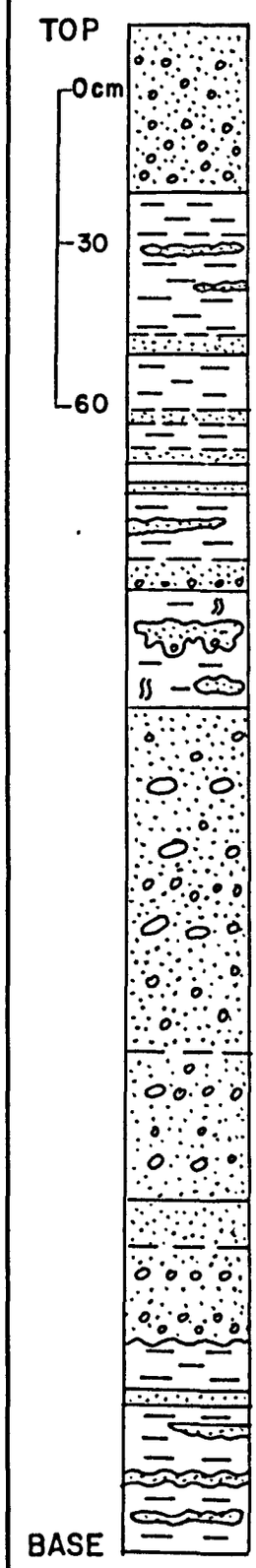
Over most of this region (Fig. 64, E and F), the formation consists generally of poorly sorted, silty conglomerates of the type forming unit F of the type section. Two additional lithologies, the Pene Member and Oeajo Clay are recognised in this region.

(a) The Pene Member

The Pene Member succeeds the Noil Lakoe Marl in the Noil Lakoe syncline, and is there taken as the lowermost unit of the Noilbesi Conglomerate Formation. It is overlain by coarse conglomerates of

Fig. 66: Noilbesi Conglomerate Formation: Pene Member, Noil Lakoe River, Noele Sub - basin.

Representative, detailed section of part of the Pene Member, showing alternation of pink and grey clays, with conglomerates and graded arenites.



GRADED COARSE ARENITE WITH METAMORPHIC CLASTS.

INTERLAMINATED SILTS, CLAYS AND GRADED ARENITES.

GRADED ARENITES AND PINK CLAYS.

POORLY SORTED CONGLOMERATE WITH COARSE PULSES OF GNEISSOSE AND VEIN QUARTZ M.C.S.4".

GREEN ARENITE WITH GRAVEL PULSES.

PINK-GREY CLAY WITH SANDSTONE LENSES AND LAYERS.

PENE SANDSTONE
SECTION 70/729

the latter. It achieves a maximum thickness of 17 metres.

The member (Fig. 66) consists of a series of pink to grey, very fine clays and silts containing layers of carbonised plant remains. Within the clay sequences are lenses and thin beds of gravel and sand. The clays and silts are interrupted at intervals by thick beds (maximum 1 metre) of dark coloured gravel, some of which are graded and contain clasts up to 10 cm. in diameter.

The poor sorting of the gravels, together with the lensing and lateral changes of bed thickness suggest rapidly fluctuating conditions of high and low energy sedimentation. Marine fossils appear to be absent. No indication of subaerial exposure, such as mudcracks, can be seen. A fresh water environment is therefore indicated. The abundance of graded beds within the clay sequences suggests that these may be the deposits of shallow lakes. As the Central Basin emerged from the sea, there would have been ample opportunity for the trapping of surface run - off, especially as at this stage, most of the basin was underlain by impervious Noil Lakoe or Noele Marl Formation.

(b) The Oeajo Clay Member

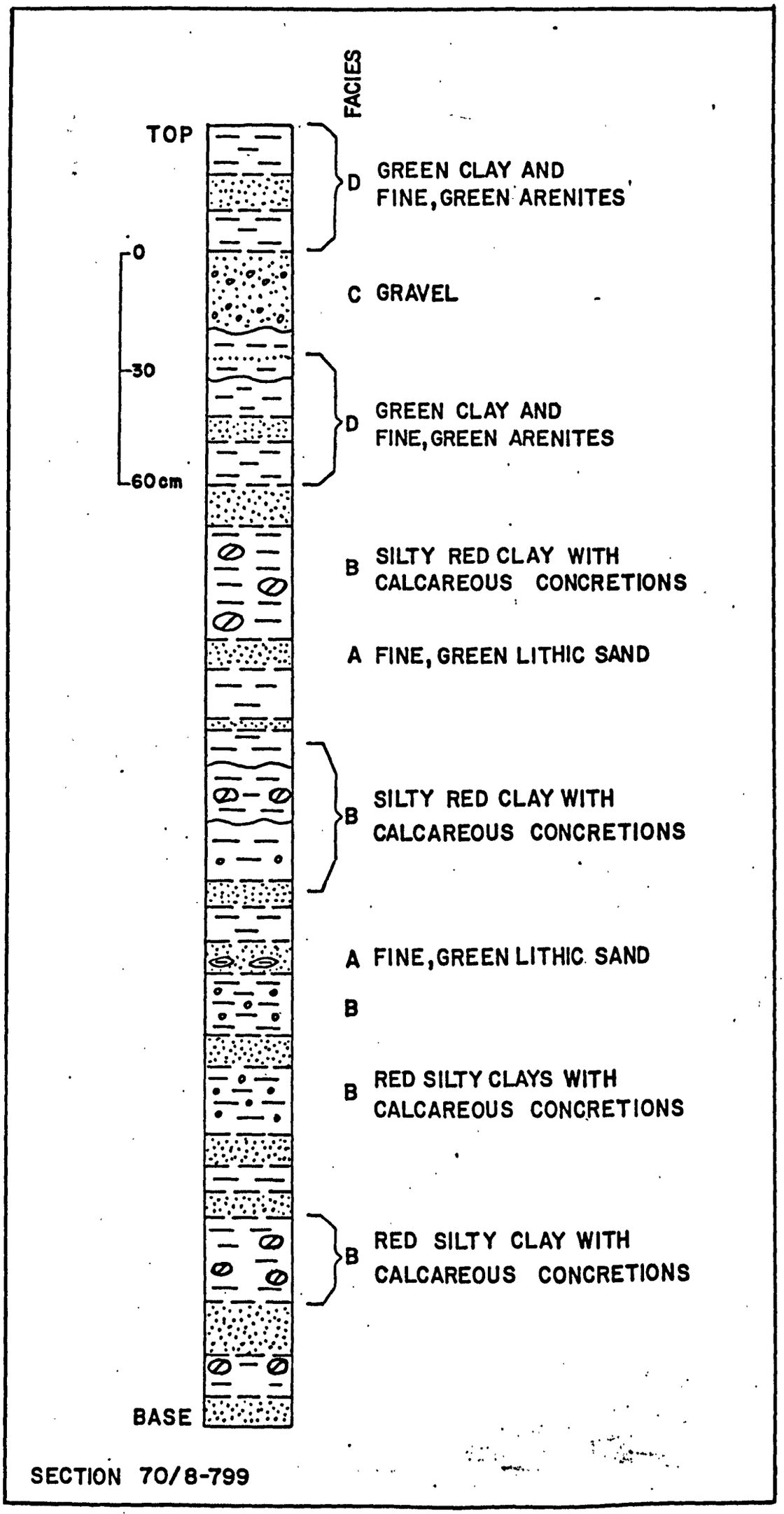
The Oeajo Clay Member occurs near to the base of the Noilbesi Conglomerate between Niki Niki and Kefamananoe in the Noele Sub - basin (Fig. 64, H). It consists of an interbedded series of clays, silts and arenites of maximum thickness 13 metres, displaying the following facies (Fig. 67):

Facies A:

Consists of thin, (10 to 15 cm.), laterally continuous beds of fine, green lithic sand containing no foraminifera or shell material. Each sandstone bed grades upwards and downwards into interbedded red

Fig. 67: Noilbesi Conglomerate Formation: Oeajo Clay Member.

Representative section of part of the Oeajo Clay Member. Note the abundance of calcareous concretions and fine grained lithologies between the main clastic units.



SECTION 70/8-799

clays and contains clasts of the latter. One of these was seen to be dish - shaped and suggestive of a mud flake.

Facies B:

Comprises a series of silty, structureless, red clays which contain many isolated, terrigenous clasts and some very thin shelled Planorbis gastropods. Discontinuous layers of hard, cemented clay and single, rounded, calcareous concretions are found at intervals within this facies.

Facies C:

Consists of thick, laterally discontinuous beds of gravel or coarse sand. Sorting is generally good and cross bedding is common.

Facies D:

Consists of interbedded, green clays and fine green arenites.

The member as a whole is well bedded and tabular. It is underlain by a thin bedded, poorly sorted conglomerate and succeeded by another conglomerate, the base of which displays flute casts. The red clays immediately beneath these have calcite - filled cylindrical structures within them. These are interpreted as plant root structures.

The poorly sorted channel conglomerates (interpreted as braided river deposits) above and below, and the presence of apparently fresh water gastropods in the finer lithologies suggests that the latter were deposited in a low energy abandoned channel or overbank environment of a braided river. The abundance of the finer lithologies suggests that the more permanent of these environments, the abandoned channel, should be favoured. The fine arenites were presumably introduced by settling at times of high water level in the main channel, and the depression gradually filled, finally becoming colonised by vegetation, now represented by the plant root structures at the top of the succession. The meandering of the main channel later caused downcutting into the Oeajo Clay.

C. Age of the Noilbesi Conglomerate Formation

Direct age determination of the Noilbesi Conglomerate Formation is hindered by its totally continental origin and absence of diagnostic fauna. In Indonesian Timor, however, the formation is younger than the underlying Late Pleistocene (N23) Soe Limestone Formation.

That the deposit is probably extremely young is suggested by the widespread continuity of the present day plateau surface in the Bokong Sub - basin, erosion having been effected to a maximum depth of only 75 metres along the major rivers.

The corresponding Ainaro Gravels of Portuguese Timor were given a post - Pliocene age by Audley - Charles (1968).

D. History of uplift of the Noilbesi Conglomerate Formation

The accumulation of thick deposits of parallel bedded silt and conglomerate of the Noilbesi Conglomerate Formation in the Bokong and Noele Sub - basins during Quaternary times implies either (a) a lessening of the rate of post - Mataian uplift of the island of Timor; (b) a subsidence during this time of the Central Basin area relative to the island as a whole or (c) a Pleistocene increase in sea level.

Subsidence of the Central Basin during or after Noilbesi Conglomerate deposition is evidenced by an elevation difference which exists between the base of the Noilbesi Conglomerate south of the Bokong Sub - basin compared to that north of the basin. Deposits immediately north and south of the southern structural limit of the sub - basin (i.e. the Bokong - Batu Putih fault zone) show a difference in elevation of +55 metres on the southern side. Because of the progressive thickening of the Noilbesi Conglomerate deposits into the centre of the sub - basin, however, the total elevation difference amounts to some 210

metres, reflecting the marked negative behaviour of the Central Basin during this time.

Although this subsidence could have taken place subsequent to Noilbesi Conglomerate deposition, the anomalously thick deposits in the Central Basin compared to those elsewhere in Timor, together with the abundance of finer clastic material, particularly towards the top of the succession (see type section) does suggest that subsidence was taking place during deposition itself. This subsidence presumably took place in part by means of a northerly downthrow on the Bokonq - Batu Putih fault zone.

In contrast to the Noilbesi Conglomerate Formation, the Ainaro Gravels of Portuguese Timor were deposited mainly upon the relatively stable older autochthon, the positive behaviour of which prevented the accumulation of terraces thicker than the 15 metres reported by Audley - Charles (1968).

Chapter 9: Summary of the tectonic history of the Viqueque Group of Timor.

1. The Fatu Laob Uplift (N15 to N21)

General uplift of Timor between N15 and Early N21 (Middle Miocene to Late Pliocene times). During this time, little or no relief existed between the northern mountains and the present Central Basin. Relief did exist, however, between the latter and the Oekabiti, Tjamplong - Panite and Kolbano Highs to the south by at least the end of Fatu Laob Marl times (Early N21), marking the earliest known evidence of the formation of the Central Basin.

Minor diapirism and possible local earthmovements took place during deposition of the calcilutite unit of the Batu Putih Limestone Formation (N18 to N19).

2. Early, Late Pliocene folding: (N21)

Localised folding took place mainly along the southern edge of the Central Basin at the close of Fatu Laob deposition, resulting in the production of a local unconformity between the Fatu Laob Marl and the overlying Sabaoe Limestone Formation.

3. The Sabaoe Stable Phase (Early and Middle N21)

A period of relative tectonic stability occurred between Early and Middle N21 times over at least the Central Basin and the region to the south, producing a succession of high energy shelf and deeper shelf limestones.

4. The Bidjeli Subsidence (Middle N21)

Subsidence of the entire Central Basin region took place at the close of Sabaoe Limestone deposition (Middle N21), beginning in the north. This resulted in the production of a steep gradient between the Noele Sub - basin and the northern mountains, causing slumping into the northern part of the Central Basin. Subsidence was less marked

in the southern part of the Central Basin. Some movement occurred at this stage along the Napsanuna fault and the Bokong - Batu Putih fault zone.

5. The Bidjeli Folding Phase (N21)

Folding of the Sabaoe Limestone Formation in the southern part of the Noele Sub - basin adjacent to the Kolbano High took place together with possible reactivation of movement on the Kolbano anticline and incorporation of pre - Sabaoe Limestone sediments into imbricate thrust slices within the latter. An angular unconformity between the Sabaoe Limestone Formation and the Noele Marl of the southern part of the Central Basin was the result.

6. Continuation of the Bidjeli Subsidence

Subsidence of the Central Basin, which took place from Middle N21 to Middle N22 times was coincident with gradual and increasing elevation of the northern mountain area, resulting in turbidity current deposition in the Central Basin, and possible slumping, perhaps triggered by the very earliest movements of the Mataian Orogeny.

7. The Noele Uplift: (Middle N22 to Early N23)

Uplift of the Central Basin region and the Northern Mountains began in N22 times, together with the beginning of tectonic compression associated with the ensuing Mataian Orogeny.

8. The Mataian Orogeny (N22)

Major folding, uplift and erosion of the island of Timor took place between Early N22 and Early N23 times, resulting in the major folds which now characterise much of the pre - Soe Limestone Viqueque succession. This folding was accompanied by moderate wrench faulting.

9. The Soe Subsidence (Early and Middle N23)

Following erosion at the end of the Mataian Orogeny, subsidence

of the entire island of Timor relative to sea level occurred, and resulted in widespread reef limestone deposition over the eroded Noele Marl Formation surface. This apparent phase of subsidence may have been entirely the result of Quaternary sea level fluctuations resulting from the Pleistocene glaciation in higher latitudes. However it can be shown that at least part of the Central Basin was subsiding tectonically at this time.

10. The Noilbesi Uplift (Middle N23 to Present)

Renewed uplift of Timor took place in Middle N23 times, and a thick series of fanglomerates and braided river gravels (the Noilbesi Conglomerate Formation) was deposited.

11. Late stage normal faulting

Minor warping and normal faulting of post Noilbesi Conglomerate Formation origin occurred in Late Pleistocene times, together with renewed subsidence along the Bokong - Batu Putih fault zone.

Chapter 10 Structure of the Viqueque basins of Timor

A. Summary

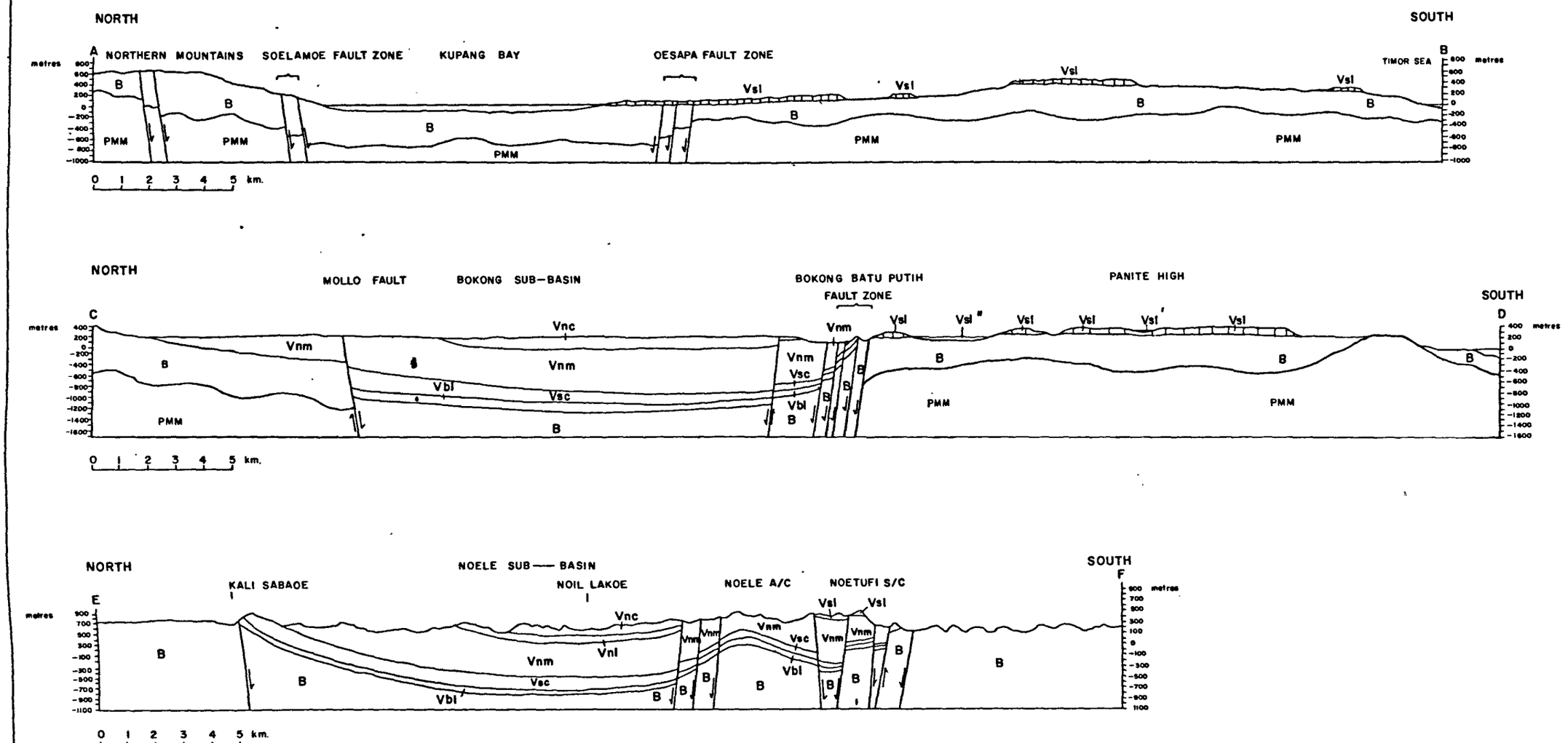
The Viqueque structural sub-basins of Timor are shown to be associated with a number of major megalinear features. The close correspondence of several of these megalinears with ground-mapped fault segments in both Indonesian and Portuguese Timor suggests that these megalinears are important fractures.

Three main trends are recognised. Two of these, the N-S and NW-SE megalinears appear to form a conjugate wrench-fault system induced by a NNW maximum principal stress direction ($\sigma 1$) of probably Timorean origin. The SW-NE Noil Moeki- Niki Niki and Mollo faults appear to be normal faults, and are tentatively correlated with the Ramelauean phase. The apparently anomalous E-W Bokong-Batu Putih fault zone, which forms the southern margin of the Bokong Sub-basin is regarded as an overall SW-NE fault zone with N-S and E-W components, and appears to be in approximate alignment with the southern structural limit of the Kupang Bay Sub-basin.

B. The Kupang Bay Sub-basin.

The Kupang Bay Sub-basin is a simple, SW-NE trending basin situated at the extreme western end of the island of Timor. It differs from those further east in possessing only the Batu Putih Limestone Formation and the Soe Limestone Formation above the Bobonaro Scaly Clay (Fig. 68). The embayment is bounded on its southern side by the Oekabiti High (Enclosure 2), consisting mostly of Bobonaro Scaly Clay, with a thin, northwards dipping cover of the Tjamplong Limestone Member of the Soe Limestone Formation. Most of the region to the north of the sub-basin is covered by Bobonaro

Fig. 68: Structural cross - sections of the Kupang Bay, Bokong and Noele Sub - basins. For location of lines of cross - section see Enclosure 1.



STRUCTURAL CROSS SECTIONS, KUPANG BAY, BOKONG AND NOELE SUB— BASINS

C.S.K.

Scaly Clay and older rocks. To the east the basin is bounded by the Tjamplong-Panite High. The presence of numerous E-W trending faults affecting the Soe Limestone and Bobonaro Scaly Clay in the eastern part of the sub-basin suggests that the easternmost part of Kupang Bay is a graben bounded on the southern side by the northwards dipping Oesapa fault zone, and on the north by the Soelamoe fault zone (Fig. 68). The presence of a NE-SW trending fault zone, however, along the northern edge of the submerged portion of Kupang Bay is suggested by the three aligned diapirs of Pulau Kera, Pulau Tikus and Pulau Burung, discussed in the chapter on Kupang Bay. It should be noted, furthermore, that the trend of at least the submerged portion of Kupang Bay and of the general strike of the southern onshore portion of the bay is similarly NE-SW, this trend being similar to that of the Noele Sub-basin. The depocentre of Kupang Bay is, furthermore, in approximate alignment with the depocentre of both the Bokong and Noele Sub-basins, the combined depoaxis trending NE-SW. It is likely that the E-W Oesapa and Soelamoe fault zones are relatively young in origin and have merely modified the eaternmost part of the Kupang Bay graben, whereas the northern structural limit of the graben proper, coinciding with the boundary between the thick Bobonaro Scaly Clay deposits in the bay and the older rocks of the Northern Mountains is formed by a southeastwards (unseen) extension of the Mollo fault zone (Figs. 69, 70). Late Pleistocene movement on both the Oesapa and Soelamoe fault zones and a relatively young origin is suggested by vertical displacement of the Soe Limestone Formation present along some component faults of the southernmost fault zone (Enclosure 1). That the overall Kupang Bay depression was in existence prior to, and during deposition of the Soe Limestone Formation is proven by the series of depositional terraces present

Fig. 69: Diagram illustrating control of the Viqueque basins of western Indonesian Timor by major faults interpreted from ERTS satellite photographs.

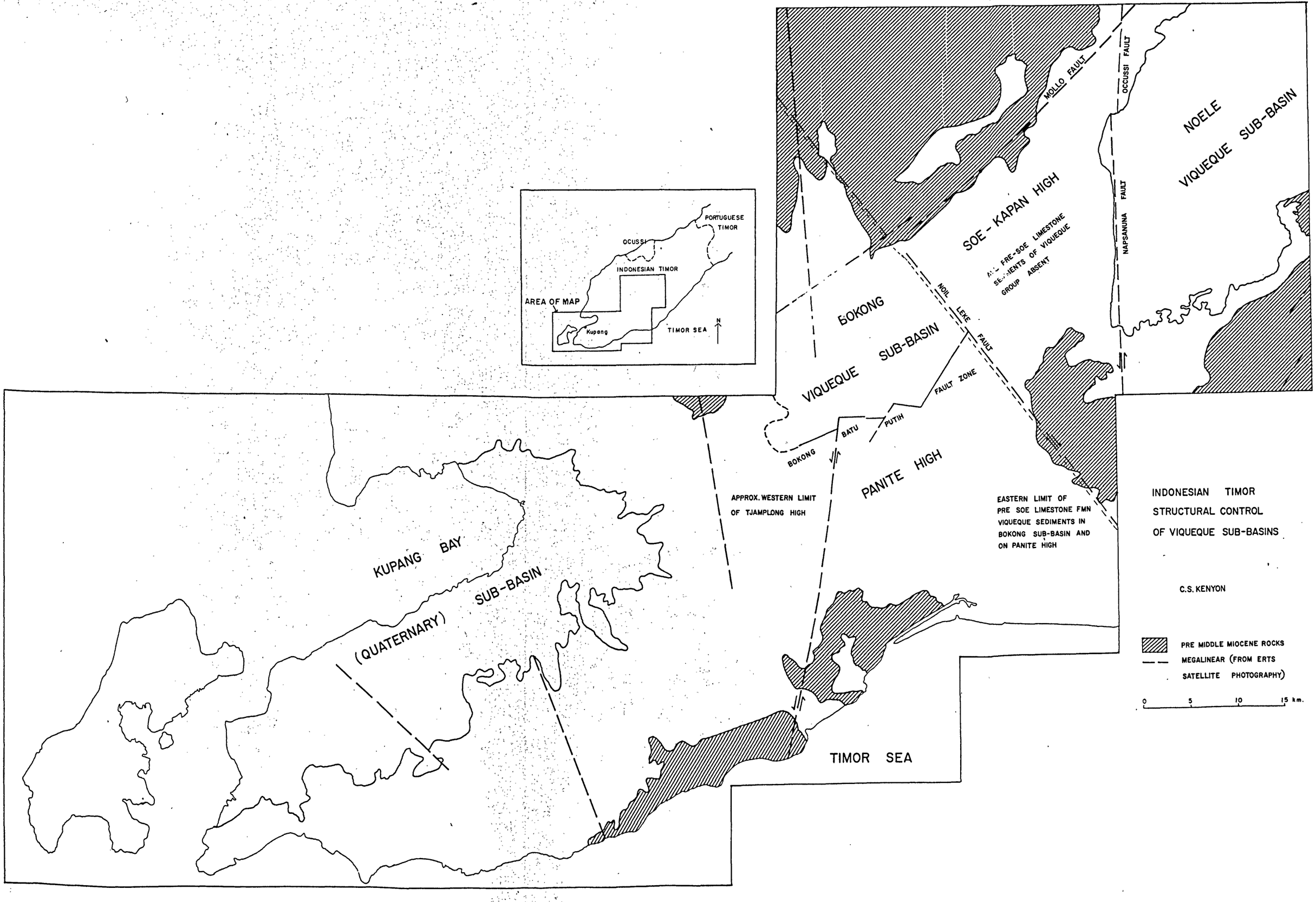

PORTUGUESE TIMOR
OCUSSI
INDONESIAN TIMOR
AREA OF MAP
Kupang
TIMOR SEA
N
MOLLO FAULT
OCCUSSI FAULT
NAPSANUNA FAULT
NOELE
VIQUEQUE SUB-BASIN
SOE-KAPAN HIGH
ALL PRE-SOE LIMESTONE SEDIMENTS OF VIQUEQUE GROUP ABSENT
BOKONG
SUB-BASIN
VIQUEQUE
NOIL LEKE FAULT
FAULT ZONE
BATU PUTIH
BOKONG
PANITE HIGH
APPROX. WESTERN LIMIT OF TJAMPLONG HIGH
EASTERN LIMIT OF PRE SOE LIMESTONE FMN VIQUEQUE SEDIMENTS IN BOKONG SUB-BASIN AND ON PANITE HIGH
KUPANG BAY
(QUATERNARY)
SUB-BASIN
TIMOR SEA
INDONESIAN TIMOR
STRUCTURAL CONTROL
OF VIQUEQUE SUB-BASINS
C.S. KENYON
PRE MIDDLE MIOCENE ROCKS
MEGALINEAR (FROM ERTS SATELLITE PHOTOGRAPHY)
0 5 10 15 km.

Fig. 70: Distribution of megalinears in Indonesian and Portuguese Timor, interpreted from MSS Band 5 (near infra - red) ERTS satellite photography of Timor. Note the arrangement of these megalinears into three sets: (a) a NW - SE (to NNW - SSE) set, represented by the Kupang, Noil Leke - Tandjung Nailot, Wini, Halilulik faults and fault 'A' in Portuguese Timor, (b) a set of predominantly north - south orientation, represented by the Tjamplong fault, the Eno Buni fault and its northerly continuation, the Naifallo fault, the Napsa nuna - Ocussi faults, the Kefamananoe fault and possibly faults B, C and D of Portuguese Timor.

The linearity and known wrench - fault behaviour of the Eno Buni fault (mapped) and of the Wini - Halilulik fault suggests that sets (a) and (b) form a conjugate pair of wrench faults formed by a maximum principal stress orientation of NNW-SSE. This orientation is also that which would produce both the SW - NE axial direction of the Timorean folds and the overall structural grain of the island of Timor. Hence sets (a) and (b) may be Timorean in origin.

The third set (c) consists of the SW - NE Noil Moeki - Niki Niki - Netenaro fault system, the Mollo fault system, and other similar megalinears in Portuguese Timor. The nature and origin of this fault system is less certain. However, the set corresponds to the overall trend of the Bokong - Batu Putih fault zone, which had an origin at least as early as Late Pliocene times. Set (c) is regarded as a normal fault system because of the large downthrow shown by the Niki Niki, Mollo and Bokong - Batu Putih faults.



TIMOR

MEGALINEAR DISTRIBUTION FROM ERTS SATELLITE PHOTOGRAPHY

C.S. KENYON

1/74

SCALE IN KILOMETRES

0 10 20 30 40 50 100

SCALE IN MILES

0 10 20 30 40 50

on the north slope of the Oekabiti High (Enclosure 1). These terraces show a progressive decrease in height towards Kupang Bay and clearly prove the existence of a high on the south side of the bay prior to Soe Limestone deposition.

The complete absence of the deep water Noele Marl and Noil Lakoe Marl Formations of the Viqueque Group in the Kupang Bay graben suggests either (a) that the latter is of post- Noele Marl origin, the Noele Marl Formation never having been deposited, or (b) that erosion subsequent to deposition removed the Noele Marl Formation from the bay region. However, as most of the basin is currently at, or below sea level, and no trace of the Noele Marl Formation exists on the onshore part of the bay, the conclusion must be that the Kupang Bay depression was formed essentially at the end of Noele Marl Formation deposition, although probably by reactivation of older structural weaknesses, during, or immediately after the Mataian orogenic phase.

Formation of the Soelamoe and Oesapa fault zones probably coincided with a Pleistocene period of E-W tensional faulting noted from the Bokong and Noele Sub-basins.

Two well-defined, northerly trending linears (the Tjamplong and Naifallo faults) can be seen on ERTS satellite imagery of Timor (Figs. 69, 70) and may form the structural boundary between the Kupang Bay Sub-basin and the Tjamplong-Naifallo High.

C. The Bokong Sub-basin

Reference to the isopachyte map (Enclosure 2) shows the Bokong Sub-basin to be a circular structural basin achieving an estimated thickness of 1400 metres of Viqueque sediments at the depocentre.

On the southern side, the basin is bounded by the complex Bokong-Batu Putih fault zone, a series of E-W normal faults with downthrow to the north. This fault zone is cut by a series of NE-SW wrench faults, of which the most important are the Eno Buni and Tanah Merah faults. The Eno Buni fault is visible also on satellite photographs, and appears to extend to the south coast of Timor, west of Noilmina (Fig. 70).

The east side of the basin is bounded by the Noil Leke fault, which appears from ERTS satellite imagery as a NW-SE megalinear, extending from the south Timor coast east of Noilmina across Timor to Tandjung Nailot on the north coast (Figs 69, 70). The fault, which also forms the boundary between the Panite and Kolbano Highs to the south, is downthrown to the west.

In the northern part of the sub-basin, the Noilbesi Conglomerate and Noele Marl Formations lap onto the Bobonaro Scaly Clay and Northern Mountains autochthon, and the younger units of the Viqueque Group are not seen. Because of this onlap, no major, well-defined fault zone can be detected by surface mapping. A possible eastwards extension of the Mollo fault, which crosses the northern part of the sub-basin, can be seen on ERTS satellite imagery (Fig. 70) and appears to coincide with that detected by surface mapping (see Fig. 68).

Folding in the Bokong Sub-basin

Owing to the extensive cover of the relatively undeformed, young Noilbesi Conglomerate Formation, surface folding in the Bokong Sub-basin is rare. One well-defined, E-W trending fold is present, however, in the outcropping Tanah Putih Marl Member of the Noele Marl Formation in the extreme western portion of the sub-basin (Enclosure 1).

The fold is symmetrical, with dips on the limbs averaging 15 degrees. The age of folding is post-Tanah Putih Marl Formation and therefore Mataian. Some degree of deformation is also present in the Noilbesi Conglomerate Formation which overlies this. In general, dips on the latter do not exceed 7 degrees, and this later, Late Pleistocene or N23 folding amounts to no more than gentle warping. Normal faults with small to moderate downthrow also affect the Noilbesi Conglomerate Formation (Fig. 68).

Diapirism

A large diapir (the Naimona Diapir) of Bobonaro Scaly Clay pierces the entire Viqueque succession in the westernmost part of the Bokong Sub-basin (Enclosure 2). The youngest formation exposed in the vicinity of the diapir is the Tanah Putih Marl Member of the Noele Marl Formation. The strongly quaquaversal dip exhibited by these sediments suggests considerable movement of the diapir during, or prior to, deposition of the Tanah Putih Marl. This coincides with the main period of movement along the Bokong-Batu Putih fault zone which occurred during the Mataian phase. The diapir is presently capped by a deformed mass of Soe Limestone Formation, suggesting its presence as a positive high during Soe Limestone deposition.

D. The Noele Sub-basin

The westernmost boundary of the Noele Sub-basin is formed by the well-defined N-S trending Napsanuna fault, which throws the Bobonaro Scaly Clay on the west against the Sabaoe Limestone and Noele Marl Formations on the east (Enclosure 2, Figs. 69, 70). The Napsanuna fault and its northwards continuation, the Ocussi fault,

appear on the satellite photographs as well-defined linear trends extending due northwards from a point east of the Noilmina river on the south coast of Timor, towards the north coast in the region of Ocussi.

On the south-eastern side of the basin, the contact with the Bobonaro Scaly Clay is not fault controlled, the Viqueque sediments dipping and thickening gently basinwards away from the present day erosional scarp (Fig. 68). However, the original southwards limit of the Noele Viqueque Sub - basin probably coincided with the Noil Moeki-Niki Niki megalinear, seen on satellite photographs, and extending from Noil Moeki to a point near Halilulik. The fault appears to continue as a discontinuous series of linears in Portuguese Timor, extending towards the north coast of the latter near Netenaro (Fig. 70).

On the north side of the basin, the cover of Noilbesi Conglomerate effectively obscures the contact of the older formations of the group with the Bobonaro Scaly Clay or autochthon. The northern boundary of the combined Bobonaro Scaly Clay and Viqueque structural sub - basin is, however, formed by the SW-NE trending Mollo fault, an ill-defined linear trend. West of the confluence with the Noil Leke fault, the Mollo fault appears to deviate somewhat to the north, and its westerly continuation (not visible on satellite photographs) may form the northern shoreline of the Kupang Bay depression. At the eastern edge of the Noele Sub-basin, a NW-SE trending megalinear, here named the Wini fault, is visible on ERTS satellite photographs (Fig. 70). This fault extends across northern Timor to the north coast near Wini. A parallel, NW-SE trending fault also exists to the east, near Halilulik.

Folding.

The Noele Marl Formation is characterised by a number of relatively sharp, (30 - 40 degree flank dips) NE-SW trending anticlines and synclines. The most prominent anticline is the Noele anticline (Fig. 68, and Enclosure 2), traceable over a distance of approximately 16 kilometres, and probably continuous with the Meo anticline to the north west. On the south side of the Noele anticline are the Noetufi and Niki Niki synclines. Folding in the Noele anticline strongly affects both the Noil Lakoe and Noele Marl Formations. The succeeeding Noilbesi Conglomerate Formation is also affected by gentle warping, forming the axis of the Noil Lakoe syncline and of the Noil Benain syncline towards the east. The steeper dips exhibited by the Noilbesi Conglomerate Formation of the Noele Sub-basin compared to those of the Bokong Sub-basin may suggest somewhat stronger late-stage compression in the former. Minor folding from two earlier phases in the Late Pliocene (N21) is also seen in outcropping Saboe Limestone and Batu Putih Limestone rocks in the Noele Sub-basin.

Diapirism.

A number of small diapirs are present along the south side of the Noele Sub-basin, piercing the Sabaoe Limestone, Batu Putih Limestone and Noele Marl Formations of the Viqueque Group (Enclosure 2).

E. Portuguese Timor

Large-scale fault control of the Portuguese Timor Viqueque basins is less apparent than in Indonesian Timor. However, the south coast Viqueque basins appear generally to lie to the south of a discontinuous series of short, NW-SE trending megalinear features (Fig. 70).

These faults are sub-parallel to, and in some cases coincide with, surface faults mapped by Audley-Charles (1968).

In addition to the Netenaro fault, and its continuation, other apparently SW-NE trending megalinears are present in Portuguese Timor. One of these clearly coincides with the edge of the Lolotoi thrust belt mapped by Audley-Charles (1968). Also present are a number of N-S megalinears, one of which coincides with the edge of another prominent thrust belt mapped by Audley-Charles (1968).

F. Age of major faulting

(i) The Bokong- Batu Putih fault zone

Northwards downthrow on the Bokong-Batu Putih fault zone has been shown to have existed at the end of Fatu Laob Marl deposition (Chapter 3). The major period of movement on the fault zone however, appears to have occurred during the Pleistocene (suggested by the strong deformation of the Tanah Putih Marl Member of the Noele Marl Formation). The Eno Buni and Tanah Merah wrenches, which cross the Bokong-Batu Putih fault zone displace the Tanah Putih Marl two miles in a left-lateral sense. Clearly, north-south compressive movements must have continued for some time after deposition of the Tanah Putih Marl Member.

(ii) The Napsanuna Fault zone

Small-scale depositional thinning of the the Sabaoe Limestone Formation towards the Napsanuna fault, visible in outcrop, suggests movement along the fault zone during, or shortly after deposition of the Sabaoe Limestone Formation. The major period of downthrow along this fault zone, during Viqueque deposition, must have been post-Noele Marl or Mataian as the Noele Marl Formation is strongly downthrown to the east along the fault.

(iii) The Mollo, Wini, Halilulik, Noil Leke-Tandjung Nailot and Noil Moeki-Netenaro faults.

Owing to the complexity of the tectonic history of Timor, any attempt to date the ages and modes of origin of the satellite photography megalinears must necessarily be speculative. However, the following points should be noted:

(a) The present day trend of both Timorean (E. Eocene) and Ramelauean (M. Miocene) folds in Portuguese Timor is approximately SW-NE (Audley-Charles, 1968), implying a primary compressional direction (or maximum principal stress orientation) of NW-SE. Conjugate shear faults resulting from such a system would have primarily a NW-SE and N-S orientation. Major conjugate faults with these orientations are:

(1) NW-SE The Noil Leke-Tandjung Nailot, Wini and Halilulik faults.

(11) N-S The Napsanuna-Ocussi fault, the Tjamplong and Naifallo faults, the Eno Buni fault and the Kefamananoe fault (Fig. 70).

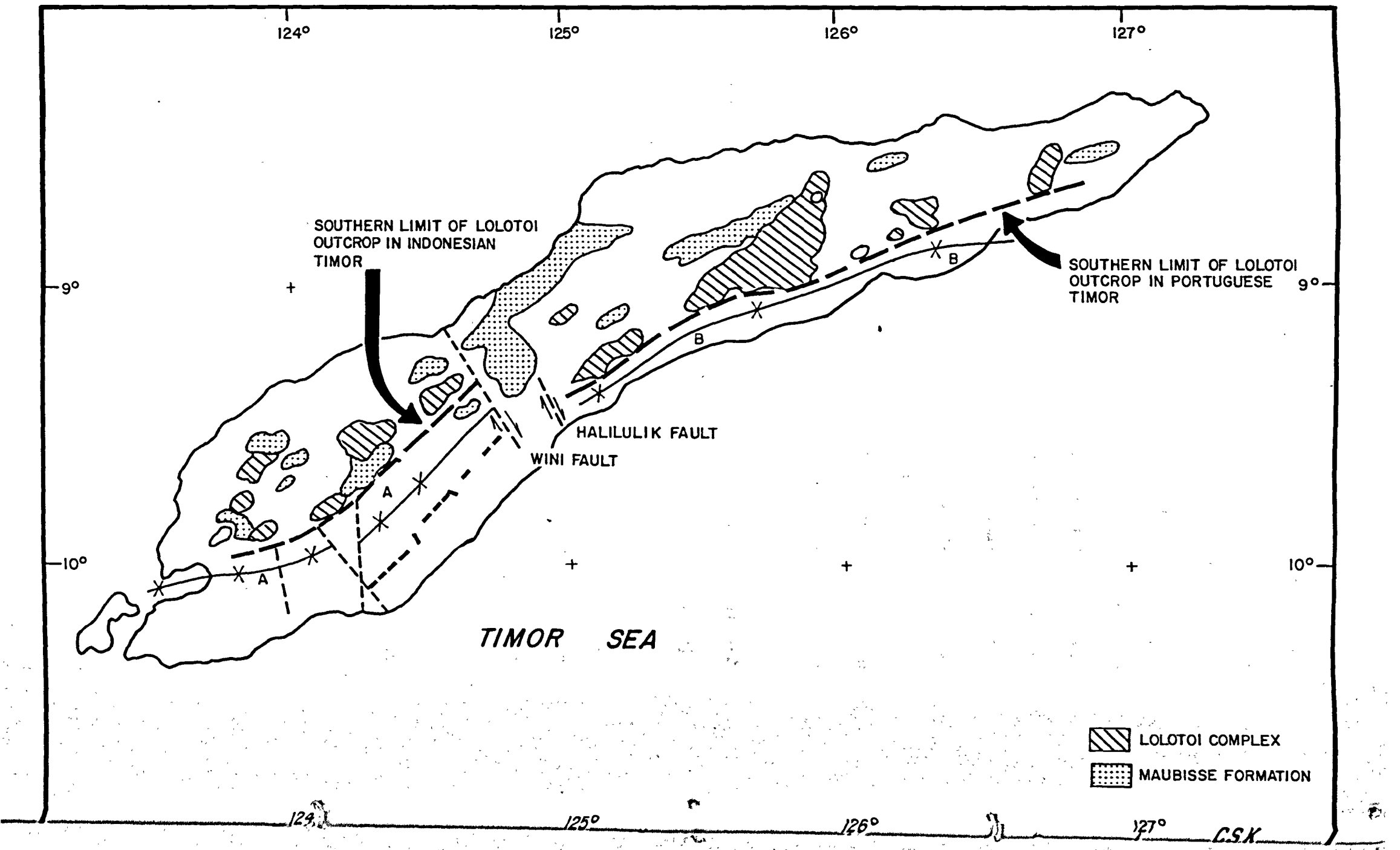
If this theory is correct, a NW-SE maximum principal stress orientation would require displacement along the N-S oriented shear faults to be in a left lateral sense. Such a displacement has already been demonstrated for the Eno Buni and Noil Leke N-S wrenches by surface mapping. Similarly, faults with a NW-SE orientation must possess a right-lateral displacement.

(b) One immediately apparent, and hitherto inexplicable facet of Viqueque Group distribution is that the principal, post Late Pliocene Viqueque basins (i.e. deep sea depressions of Noele Marl deposition) occur south of the principal Lolotoi outcrops in both Portuguese and Indonesian Timor. However, the Kupang Bay-Bokong Sub-basin-Noele Sub-basin negative trend does not continue directly across into Portuguese Timor, the Viqueque basins of the latter occurring somewhat

Fig. 71: Relationship of the distribution of Viqueque basins to present day distribution of the Lolotoi Complex and Maubisse Formation in Timor. Note (a) the apparent southwards displacement of the southern limit of Lolotoi Complex outcrop in Timor in the region of the Wini and Halilulik faults, interpreted as major right - lateral wrench faults, (b) the occurrence of the major Viqueque sub - basins to the south of the area of Lolotoi outcrop in both Indonesian and Portuguese Timor.

A and B refer to the depoaxes of Viqueque basins in Indonesian and Portuguese Timor respectively.

Distribution of Lolotoi Complex and Maubisse Formation in Timor after Audley - Charles (1974).


124°
125°
126°
127°
9°
10°
SOUTHERN LIMIT OF LOLOTOI OUTCROP IN INDONESIAN TIMOR
SOUTHERN LIMIT OF LOLOTOI OUTCROP IN PORTUGUESE TIMOR
HALILULIK FAULT
WINI FAULT
A
A
B
B
TIMOR SEA
LOLOTOI COMPLEX
MAUBISSE FORMATION
CSK

to the south of the continuation into Portuguese Timor of the Indonesian Timor basinal trend. Coincidentally with this, the southernmost Lolotoi outcrop occurs much further south in Portuguese Timor than in Indonesian Timor.

Superimposition of the ERTS satellite photograph megalinears upon a map of Lolotoi distribution in Timor (Fig. 71, after Audley-Charles 1968) suggests that a major southwards displacement of the southernmost edge of the Lolotoi thrust sheets occurs between the Wini and Halilulik NW-SE trending megalinears, both of which would be expected to possess right-lateral displacement, each being the left hand set of a conjugate pair. The resultant combined displacement of both faults may therefore have resulted in the southwards displacement of the entire region east of the Halilulik fault. It should also be pointed out that the Wai Bua (overthrust during the mid-Miocene orogenic phase) does not show a marked southwards deviation in this region, hence the major wrench movement may indeed have been Timorean, having occurred between the emplacement of the Lolotoi Complex in the Lower Eocene orogenic phase and emplacement of the Maubisse Formation in the Middle Miocene Ramelauean phase.

It has been shown in a previous chapter that subsequent Early Pleistocene movement took place along the Eno Buni and associated wrench faults in Indonesian Timor. Such a reactivation of pre-existing wrench faults would be expected during a compressional phase almost coincident in direction with the earlier Timorean compression.

The above hypothesis provides an explanation for the orientation of the NW-SE and SW-NE fault systems. It does not, however, explain the orientation of the major Mollo and Noil Moeki-Niki Niki fault systems. The latter systems are, however, parallel both to

the Timorean folding directions and to the thrusts mapped by Audley-Charles (1968). The fault systems do not, furthermore, appear to be substantially affected by the wrench systems. Hence it is likely that both the Mollo and Niki Niki faults are large-scale normal faults of probably Ramelauean origin. It should be noted that this fault system is parallel with mapped normal faults in the Portuguese Timor south coast basins, and to many of the normal faults of this thesis.

The NE-SW Mollo and Niki Niki faults apparently closely control the shape of the present Noele Sub-basin. However in the Bokong Sub-basin, the southern margin at least is formed by the apparently east-west Bokong-Batu Putih fault zone. However, if the E-W and N-S components of the total Bokong-Batu Putih fault zone are considered together (Fig. 69) the result is a broad NE-SW fault zone, an extension of which would coincide approximately with the southern edge of Kupang Bay.

The above hypothesis assumes that the major Viqueque basins of Indonesian Timor developed subsequently to the major Timorean wrench movement, along a zone of weakness lying to the south of the major Lolotoi thrust 'front' and the relatively positive area of older rocks behind it. Hence the Middle Miocene to Recent basins of Portuguese Timor occur in an arc south of this thrust front, and therefore occur considerably to the south of the Indonesian Timor Central Basin. The only real evidence that major movement along the Halilulik and related wrenches did not occur subsequent to Viqueque deposition, for example during the Mataian Orogeny, is that the compression necessary to produce a lateral displacement of the order of 30 miles along these faults would have been likely to have had more effect on the Viqueque succession than the mere production of the relatively gentle Mataian folding.

Chapter 11 Middle Miocene to Recent structural development of the Timor - Sahul Shelf region.

The above tectonic and stratigraphic history of the Viqueque basins of Timor and recent work in the Timor Trough and on the Sahul Shelf to the south make possible a reconstruction of the structural history of the entire Timor- Sahul Shelf region.

According to Audley-Charles (1966) and Audley-Charles and Carter (1971), the Timor Trough was initiated during the Early Eocene as a deep water area north of the predominantly shallow water Sahul Shelf. This interpretation was questioned by Veevers (1969) who suggested an Early Pleistocene age for the Timor Trough and later amended this to Late Miocene (Veevers 1971),on evidence which suggested that the important Late Miocene to Pliocene regional hiatus of the Sahul Shelf continued downwards into the Timor Trough beneath a thickening wedge of Late Tertiary sediments.

Evidence from recent DSDP (1973) drilling of the Timor Trough has, however, revealed a total of 414 metres of planktonic ooze of Quaternary and Late Pliocene age overlying 13 metres of shallow marine, foraminiferal dolomitic mud of Late Pliocene age and 15 metres (to total depth) of very shallow marine dolomitic shell calcarenite, also of Late Pliocene age. It is here suggested that this Late Pliocene shell calcarenite may correlate with the Late Pliocene shell calcarenite of the Sabaoe Limestone Formation, shown to be present throughout much of Indonesian and part of Portuguese Timor. Clearly, as the Sahul Shelf was the site of shallow water deposition throughout much of the Tertiary (Veevers 1969) then shoal water conditions could have existed over the entire Sahul Shelf-Timor Trough-Timor region throughout at least part of the Late Pliocene (Fig.72,3). The age of the Timor Trough in its

Fig. 72: Diagrammatic profiles illustrating the Middle Miocene to present day evolution of the Wetar Strait - Timor - Sahul Shelf region.

Profile 1 (Middle to Late Miocene) shows deep water conditions (evidenced by the deep water Batu Putih Limestone, present over most of Timor) extending throughout the Wetar Strait - Timor - Timor Trough region, with shoal water conditions present on the Sahul Shelf to the south.

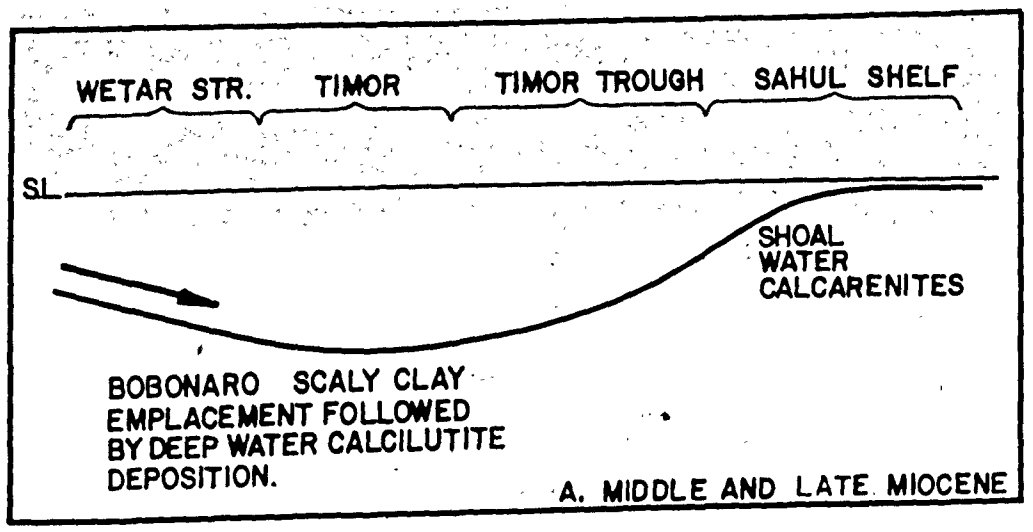
A gradual shallowing of the region, resulting in shoal water calcarenite deposition throughout the Sahul Shelf - Timor Trough - Timor region in the Late Pliocene is illustrated in profiles 1 to 3, and later (Late Pliocene) simultaneous subsidence of both the Central Basin of Timor and the Timor Trough in profile 4.

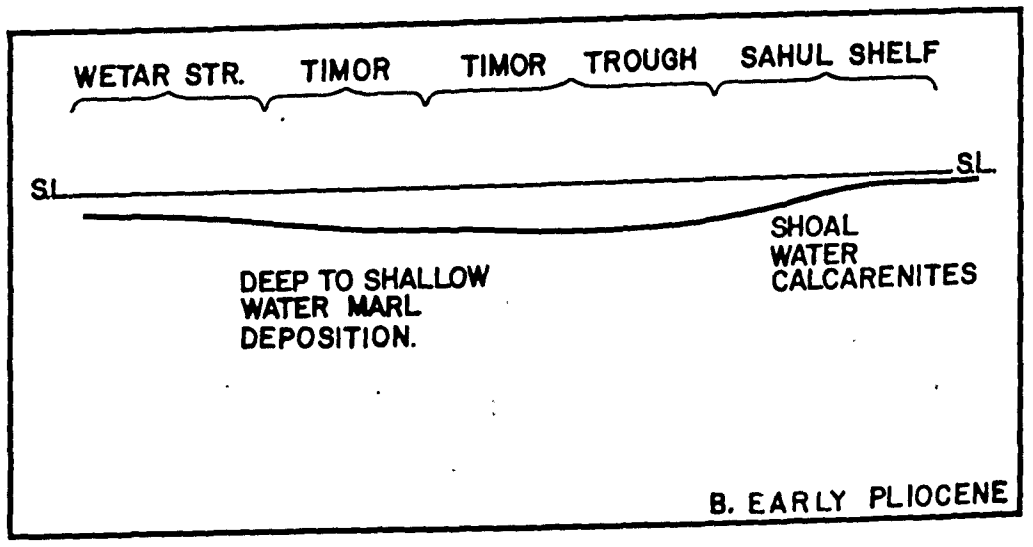
The gradual subsidence of the Central Basin and Kolbano High and resulting rotation of the Kolbano High/Central Basin structural unit, causing ponding of the Pleistocene Nuanain Sandstone turbidites in the Central Basin is shown in profile 5.

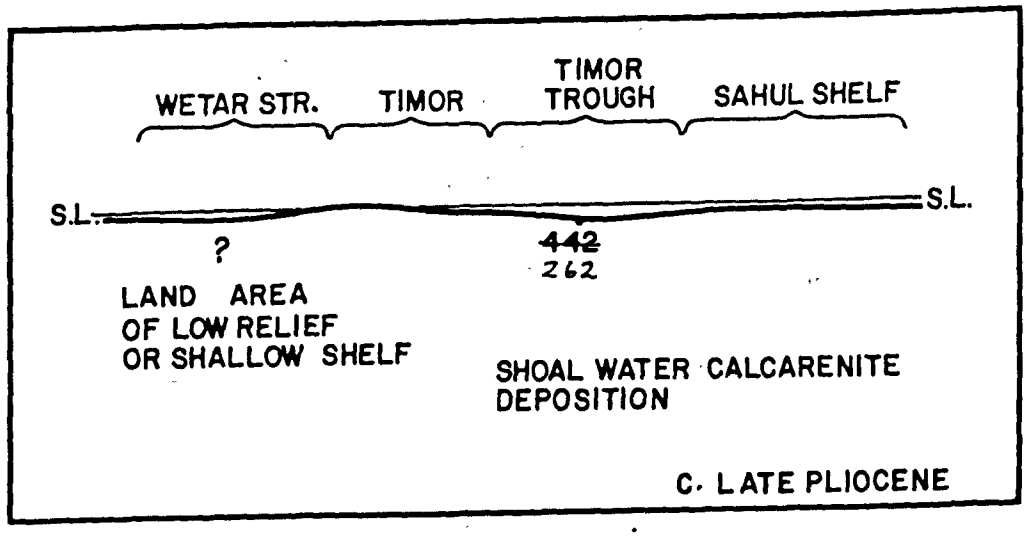
Subsidence of the Wetar Strait occurred in the Middle or Late Pleistocene.

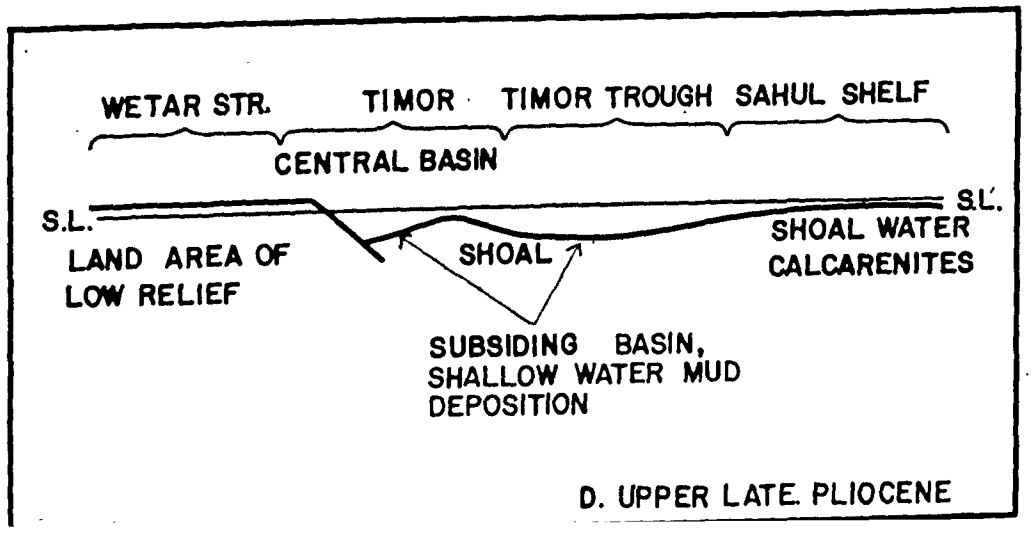
Note that in these profiles, the width of Timor is exaggerated relative to that of the Timor Trough, in order to show the developing Central Basin. Present day width of the Wetar Strait is approximately 100 km. (opposite Indonesian Timor); of Timor approximately 100 km.; of the Timor Trough approximately 200 km. and of the Central Basin approximately 30 to 50 km.

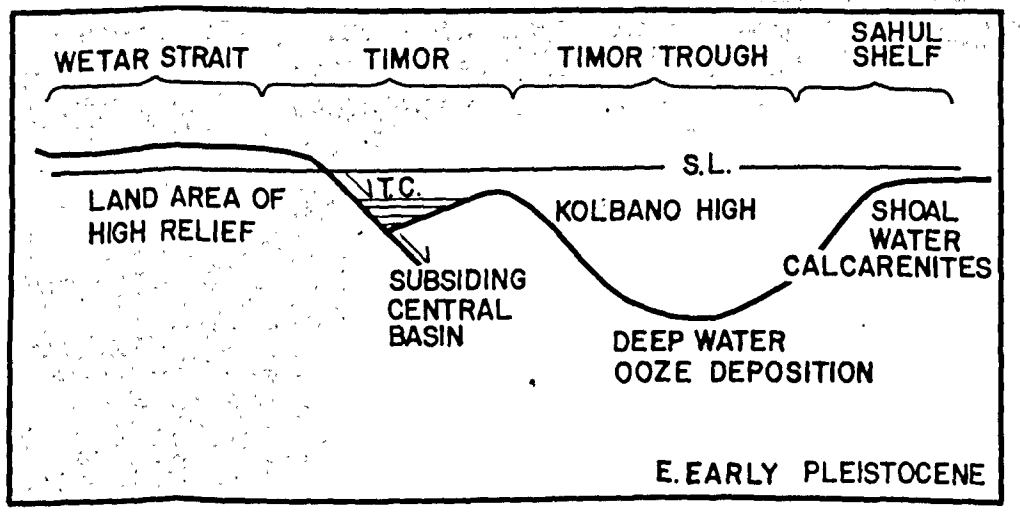
Location of DSDP borehole 262 shown in C.

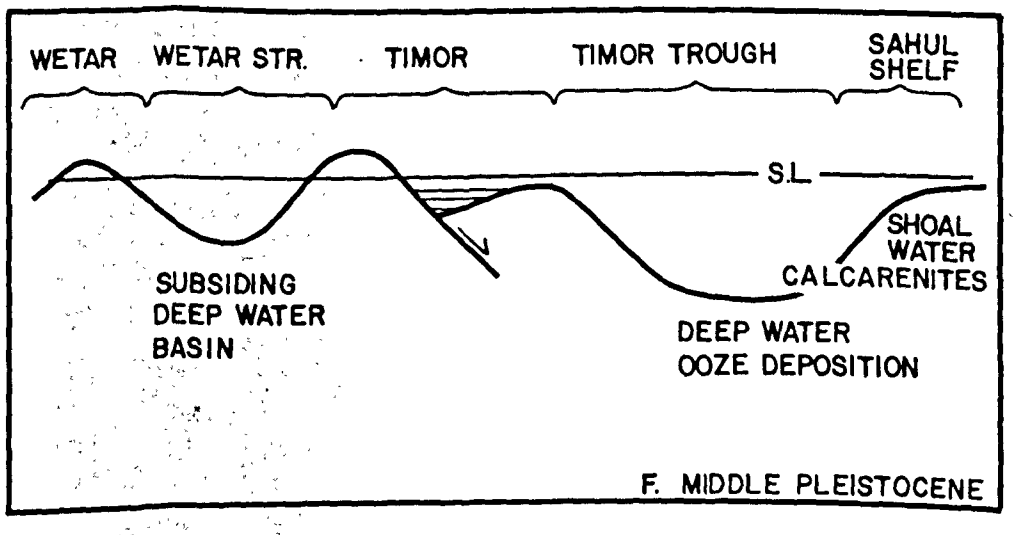


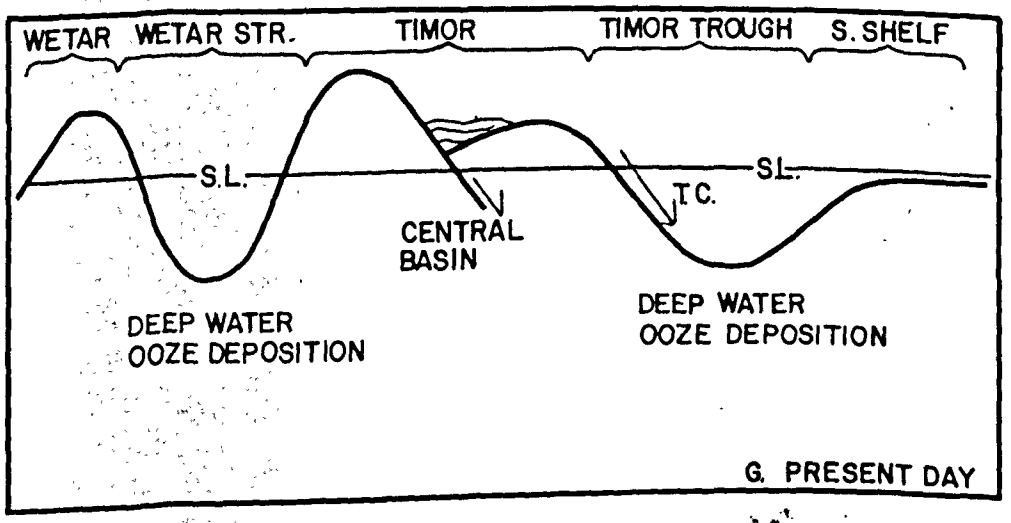












MIDDLE MIOCENE TO PRESENT DAY EVOLUTION OF THE WETAR STRAIT-SAHUL SHELF REGION.

C.S. KENYON

present form most probably therefore dates from the incipience of deeper water conditions (Fig. 72,4), marked by the Late Pliocene mudstone in borehole 262. Continued subsidence during the Late Pliocene and Quaternary then led to the deposition of a thick, Late Pliocene and Quaternary foraminiferal ooze sequence. A precisely similar sequence has been shown in this thesis to exist in the Viqueque Group of the Noele Sub-basin during N21 times (Late Pliocene) when subsidence of the shallow water calcarenite of the Sabaoe Limestone Formation of the Central Basin gave rise to deeper water, Late Pliocene and Quaternary foraminiferal ooze deposition.

The major southwards downthrow on the Central Basin northern boundary fault (the Mollo fault) may therefore have coincided with subsidence of the Timor Trough in the Late Pliocene (Fig. 72,4). To the north of Timor evidence suggests that downfaulting of the Wetar Trough occurred slightly later, in the Pleistocene (Audley-Charles and Hooijer 1973, and in this thesis), subsequent to major uplift of the northern positive area, north of the Central Basin (Fig. 72,6). The Middle Miocene to present day structural history of the Wetar Strait-Timor-Timor Trough-Sahul Shelf region is therefore as summarised in Figure 72.

Note that in these profiles, the area forming the present day Kolbano High is depicted as a sill between the developing Central Basin and Timor Trough areas (Fig. 72,4-7). This sill must have been present, as no lateral equivalent of the thick, proximal turbidite deposits of the Pleistocene Nuanain Sandstone Member of the Central Basin is present in the Pleistocene of borehole 262 in the centre of the Timor Trough.

Chapter 12 The nature of the Timor Trough and classification of the Viqueque basins of Timor.

The Timor Trough has been interpreted as a conventional submarine trench, along the axis of which is a northwards dipping subduction zone, marking the site of subduction of oceanic crust beneath continental crust (Chipping, 1971). Seismic profiles published recently by Beck (1974) reveal the presence, at the base of the northern flank of the Timor Trough, of large, southwards directed overthrusts accompanied by imbrication and compressional folding. Beck concluded that these 'foothill tectonics' showed a close similarity to those along the landward slopes of the Java Trench. Warris (1973) suggested the Tertiary collision of Australia and South - East Asia and the uplifting of Timor as a Tertiary melange of Australian sediments behind a north - dipping subduction zone along the Timor Trough.

These interpretations were recently challenged by Audley-Charles, et al (1972), who suggested that since the Middle Cretaceous, oceanic crust has been subducted northwards below oceanic crust to the north of Timor. They interpreted the important orogenic phases which occurred in Timor in the Late Cretaceous to Early Eocene, in the Middle Miocene, and in the Late Pliocene to Early Pleistocene as the result of collisions between the northwards drifting Timor, which formed the leading edge of Australia, and a succession of subduction zones. According to Audley - Charles (1973) there is no evidence to indicate that a subduction zone has ever existed along the Timor Trough.

Evidence from recent earthquake activity presented by Fitch (1970) suggests, however, that a northwards dipping Benioff zone exists along the Timor Trough, although determination of the focal mechanisms of this earthquake activity suggested the absence of present day

underthrusting in that region. Fitch (1970) suggested that subduction has ceased along the Timor Trough.

Whatever the true tectonic relationships between Timor and Australia, several things are clear from the above summary:

(i) A northwards inclined, seismic zone exists along the axis of the Timor Trough, dipping under Timor. Whether or not this zone is or was a subduction zone in the true sense of the word is not known; however a structural discontinuity must be assumed. This discontinuity dips under Timor, away from the Timor Trough, and has therefore the inclination expected of a thrust or reverse fault, with the material to the north (Timor) overriding that to the south.

(ii) Evidence exists for strong compression along the base of the north wall of the Timor Trough, and independent evidence of strong compression along the south coast of Timor is seen in Viqueque Group rocks of the Kolbano and Panite Highs.

Study of the tectonic evolution of the Central Basin reveals a remarkable similarity to the known history of present day and ancient 'arc - trench gap basins' (Dickinson, 1970). Dickinson defined the arc - trench gap as an 'elongate geographical gap, typically 150 - 250 km. wide between the volcanic front of the arc and the slope break above the crest af an accoustic basement ridge at the top of the inner trench wall'. Within this gap, both uplifted belts, like the outer sedimentary arcs, and subsiding belts occur. The subsiding belts include the arc - trench gap basins, which have accumulated thick sequences of undisturbed sediments.

Comparison of the present - day profiles of arc - trench [illegible] couples over the entire Pacific and elsewhere reveals the almost universal presence of arc - trench gap basins (hereafter called 'trench slope basins' in this thesis) on the slopes of such trenches as the Puerto Rico Trench

(Ewing and Ewing, 1962), the Tonga Trench (Raitt, Fisher and Mason, 1955), the Phillipine Trench (Hayes and Ludwig, 1967), the Aleutian Trench and Terrace (Gates and Gibson, 1956), and many others.

These sediment-ponded basins and their relationships with arc-trench couples were mentioned briefly by Ludwig et al. (1966), who pointed to the presence over many trench profiles of two gravity minima, separated by a relative positive anomaly, one negative minimum located directly over a sediment filled trough situated between the floor of the trench and the continental shelf, and the other located in the trench itself.

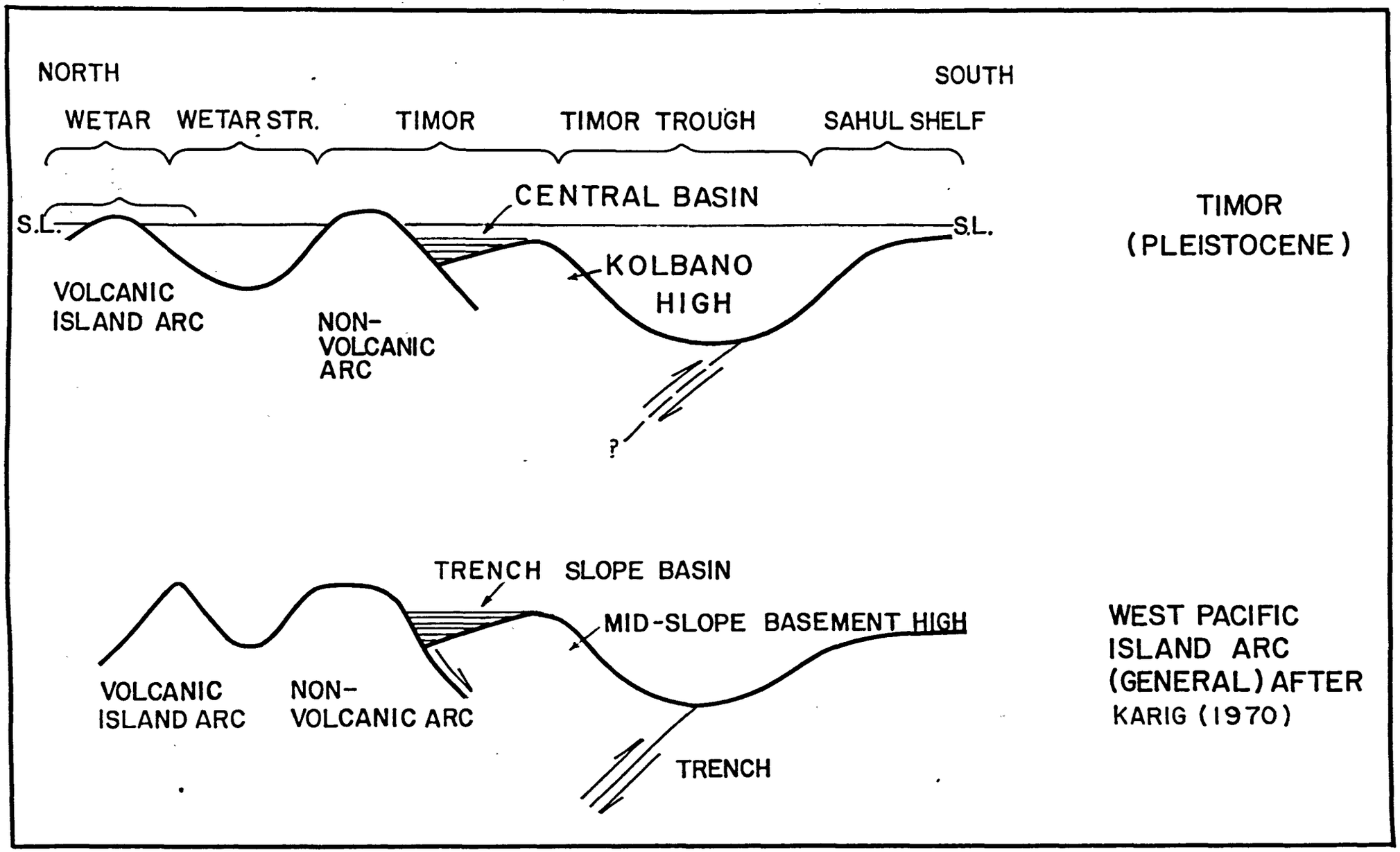
A wide arc-trench gap basin figures prominently in the Karig model of Pacific island arc evolution (Karig, 1970). Karig developed his model from studies of the Manila Trench and the Luzon Trough, the latter being a trench slope basin, separated from the trench by a well developed mid-slope basement high, composed of folded sediments. Karig demonstrated the following sequence of events for both the Manila Trench/Luzon Trough and the Tonga-Kermadec island arc.

(i) Underthrusting and deepening of the trench accompanied by formation and downthrow of an arc-trench gap basin along a normal fault zone along the front of the major non-volcanic arc. (Fig. 73).

(ii) Concurrent extension and subsidence of the region between the outer, non-volcanic arc and the volcanic arc.

It should be noted that this is precisely similar to the demonstrated tectonic development of the Timor Viqueque basins and the Timor Trough and Wetar Strait (Fig. 73). Major similarities to note are: (a) the downthrow of Karig's trench slope basin along a normal fault zone present along the side nearest the non-volcanic arc, and the resultant 'rotation' of the block between this fault zone and the zone of underthrusting in the trench (cf. the normal fault zone along the

Fig. 73: Comparison of the Wetar - Timor - Sahul Shelf profile of Pleistocene times with the general model for West Pacific island arc development (after Karig, 1970). Points to note are (a) the similarity in size, shape and tectonic position of the Central Basin of Timor to Karig's trench slope basin; (b) the presence of Karig's 'mid - slope basement high' (consisting of folded sediments) between the trench slope basin and the trench, mirrored in Timor by the folded sediments of the Kolbano High; (c) the rotation of the floor of the trench slope basin and of the mid - slope basement high towards the trench by downthrow along a normal fault zone situated on the arc side of the trench slope basin and the exactly similar sequence of events in Timor (see also Fig. 72, profiles 4 to 7); (d) the simultaneous deepening of the trench and trench slope basin in both Karig's model and in the Wetar - Timor - Sahul Shelf region.


NORTH
SOUTH
WETAR
WETAR STR.
TIMOR
TIMOR TROUGH
SAHUL SHELF
CENTRAL BASIN
S.L.
S.L.
KOLBANO HIGH
VOLCANIC ISLAND ARC
NON-VOLCANIC ARC
?
TIMOR (PLEISTOCENE)
TRENCH SLOPE BASIN
MID-SLOPE BASEMENT HIGH
VOLCANIC ISLAND ARC
NON-VOLCANIC ARC
TRENCH
WEST PACIFIC ISLAND ARC (GENERAL) AFTER KARIG (1970)

northern side of the Central Basin, and the rotation of the Central Basin and Kolbano High structural units during formation of the Central Basin).

(b) the confining of the major compressional effects of the under-thrusting to the mid-slope basement high (cf. the equivalent Kolbano High in Timor south of the Central Basin, which underwent imbrication whilst the northern margin of the basin was subsiding in Sabaoe Limestone times (N21).

(c) the implied deepening and major period of trench formation at the same time as subsidence of the trench slope basin (cf. the probable contemporaneous formation of the Central Basin and the Timor Trough.

(d) the presence of sediments in the uppermost part of the trench slope basin sequence lapping smoothly onto the crest of the frontal arc (Karig 1970). Karig implies that the major downthrow along the front of the arc occurred early in the history of sedimentation of the basin (cf. Timor, where the maximum subsidence of the Central Basin occurred shortly after its formation, towards the end of the Sabaoe Limestone Formation (Late Pliocene) times.

Dickinson (1970) presented the most comprehensive account to date of trench slope basins. He mentioned as prime characteristics:-

(a) 'complex zones of severe tectonic dislocation....which separate the deformed rocks of subduction zones from the structurally overlying, undeformed strata of the arc-trench gap' (cf. the folded and imbricated Kolbano High lying between the Central Basin and the Timor Trough).

(b) widespread submarine and locally sub-aerial unconformities, where the strata of the arc-trench gap onlap the 'inboard' flank of the mid-slope basement high (cf. the local unconformities in the Sabaoe Limestone and Batu Putih Limestone, wich lap onto the Kolbano High and which are not present at the northern edge of the basin).

(c) the observation that the only coeval tectonic disruptions of

the arc-side contact that can be inferred from profile records of modern systems are normal faults associated with a back-tilt of the arc-trench gap sequence, 'as if the block upon which it (the arc-trench gap sequence) rode had rotated slightly backwards to lift the trench-side flank and to depress the arc-side flank'. This is similar to Karig's (1970) observations and to the Central Basin.

(d) a highly variable sedimentological character, with an expected predominance of turbidites without volcanic intercalations ('except possibly tuffs') from distant sources (cf. the Viqueque Group of the Noele, Bokong and Portuguese Timor Sub-basins, where up to 75% of the exposed section consists of turbidites with minor tuff intercalations).

(e) a remarkable consistency in width of trench slope basins, most being of the order of 50 kilometres wide. For instance the Great Basin of California, interpreted by Dickinson as a trench slope basin, has a width of 65 kilometres. The western marginal syncline of New Zealand varies in width from 25 to 75 kilometres (Dickinson, 1970) and the Central Basin of Timor is generally 30 to 55 kilometres in width.

According to the demonstrated histories of other circum-Pacific trench slope basins, the best defined boundary (in plan view) of the Central Basin should be the northern (arc-side) one, because this is a normal fault, whereas the tectonically complex southern boundary should be ill-defined. In fact the southern boundary of the Central Basin is remarkably discontinuous.

The study of trench-slope basins is relatively new. Not only are most incompletely known, but most examples are still underlain by water, or are Early, or pre-Tertiary age, and although occasionally well preserved in themselves (e.g. the Alaskan Bench, Gates and Gibson 1956) show a complex relationship to the arc-trench systems to

which they relate.

The above account suggests a close correspondence of known trench slope basin characteristics with those of the Central Basin of Indonesian Timor. The writer believes that there is evidence to suggest that at least limited underthrusting has occurred along the north wall of the Timor Trough. This underthrusting may not, or may not formerly have amounted to large scale subduction, and the Central Basin of Indonesian Timor may not be a trench slope basin as originally defined by Dickinson (1970). The reason for the close similarities in morphology and development between the Central Basin and true trench slope basins may lie in the fact that the latter seem to be genetically related to the underthrusting process in subduction zones, there being evidence to suggest that a condition of tension exists in the overriding block some distance from the thrust plane itself (Malahoff, 1970). This process causes downfaulting and rotation of the arc-trench gap block, whilst still maintaining compression in that portion of the overriding block nearest the thrust. Clearly, if such a process is responsible, then the only requirement for the development of a basin similar to a conventional trench slope basin is the presence of underthrusting, regardless of the kinds of crust involved in the underthrusting or of the presence of a true subduction zone. Timor has clearly undergone strong compression on occasions in its Late Neogene history. From the history of the Timor/Sahul Shelf region as reconstructed in this thesis, the beginning of the underthrusting beneath Timor may have been in the Late Pliocene when both the Central Basin of Timor and the Timor Trough began to subside and the Viqueque rocks nearest to the Kolbano High underwent compressional folding.

The above discussion is of course tentative. The main object of this thesis has been primarily to determine the stratigraphy of the Viqueque rocks of Indonesian Timor. These rocks cannot in themselves provide direct evidence as to the nature of the crustal materials underlying Timor and the Timor Trough. It is hoped that the resulting stratigraphy and tectonic history of the Late Miocene to Quaternary rocks of Indonesian Timor as presented in this thesis will be used by workers in the field of general Indonesia - Australia stratigraphy to further the knowledge of the true relationships between the two regions.

Chapter 13 Recent and modern sedimentation in Kupang Bay, Timor.

A Introduction

Kupang Bay is an oblong marine embayment some 200 square miles in area, situated at the western end of the island of Timor (Fig. 74). The bay forms the submerged western continuation of the series of depressions comprising the Central Basin of Timor. In addition to providing a modern example of the interaction of carbonate and terrigenous regimes of sedimentation, the object of this study was to aid the determination of the depositional environments within the Viqueque Group, parts of which were deposited within a depression of similar size and shape to that of the modern Kupang Bay. Most of the offshore sediment study was conducted by drag sampling.

B Summary and conclusions

Modern sedimentation in Kupang Bay can be subdivided into a carbonate regime, comprising three fringing reef complexes and a terrigenous regime comprising an offshore mud zone, a barrier island/lagoonal complex and a northern shoreline clastic complex. (Figs.74, 75)

Seven principal environments of deposition with their associated sediment types can be recognised within the fringing reef complexes and comprise:- (i) an active reef front, (ii) a back-reef lagoonal area, (iii) a reef front breccia zone, (iv) a zone of reef front silty calcarenites, (v) a zone of fore reef foraminiferal silts, (vi) a zone of reef flat calcarenites and (vii) a beach skeletal calcarenite zone.

Within the terrigenous regime, the barrier island/lagoonal complex comprises:- (i) an offshore silt zone, (ii) a barrier beach or island zone, (iii) an inner lagoonal zone, (iv) an intertidal

FORMATION BOUNDARY

OFFSHORE FACIES BOUNDARY

ONSHORE FACIES BOUNDARY

REEF TERRACE

FAULT WITH DOWNTHROW

SEE FACING PAGE FOR EXPLANATION OF SYMBOLS

123° 35' E

123° 40' E

123° 45' E

10° 00' S

10° 05' S

Vsl

P. Tikus

Tg. Paloelak

P. Burung

P. Kera

KUPANG

T. Pasir

Vsl'

B

I

II

III

IV

V

VI

VII

VIII

IX

A

B

E

F

H

KUPANG BAY RECENT AND MODERN SEDIMENTATION

KILOM.

0 5 8

TIMOR

C.S.K.

Fig. 75: Kupang Bay: Major sedimentary complexes, current systems and onshore sediment supply.

I: Southern and Pulau Kera fringing reef complexes.

II: Northern fringing reef complex.

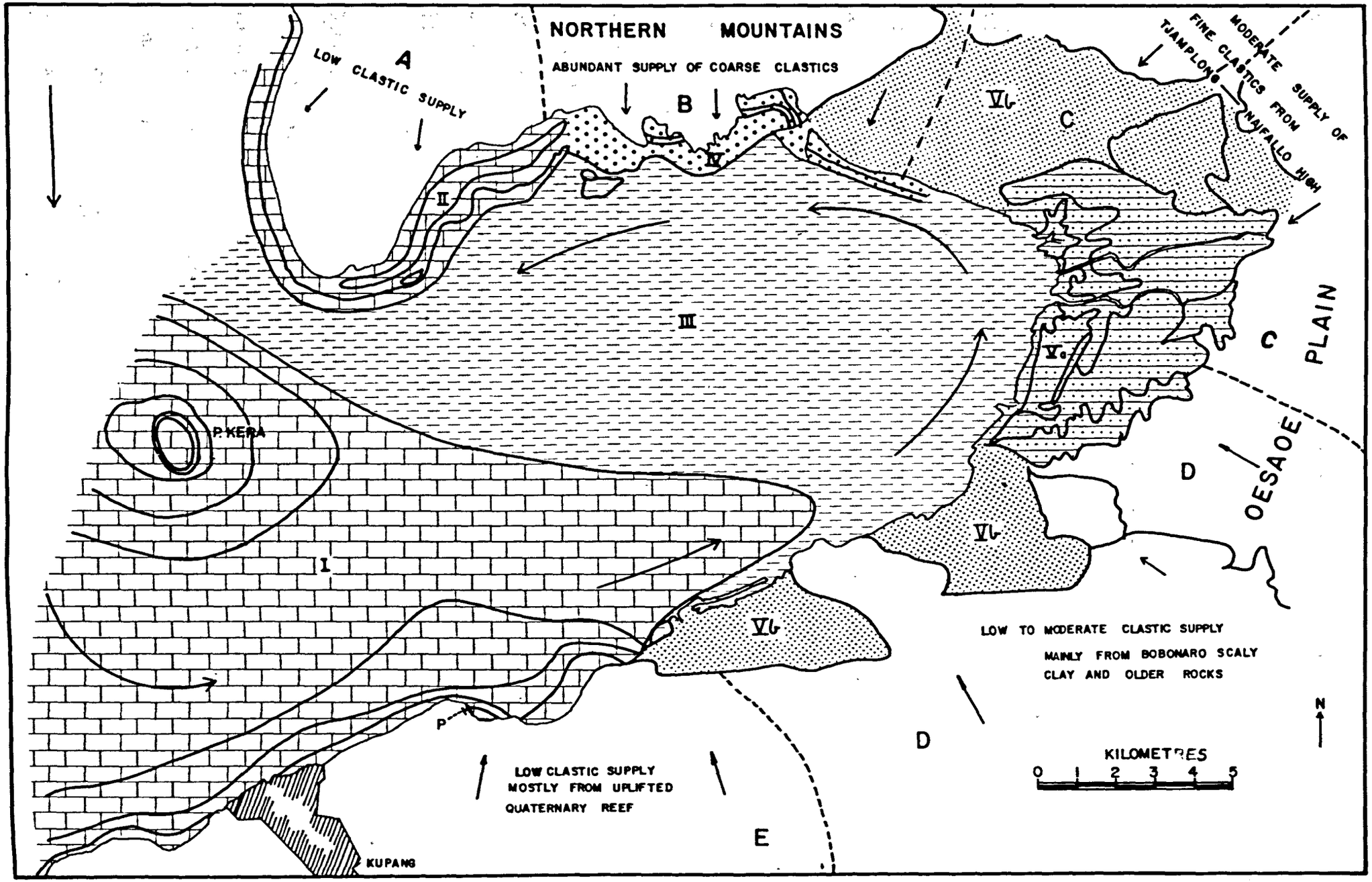
III: Offshore terrigenous muds.

IV: Northern shoreline clastics.

Va: Barrier island/lagoonal complex.

Vb: Uplifted bay floor and lagoonal terrigenous muds.

Note the influence upon the distribution of the above complexes of the two major controlling factors: (a) an anticlockwise current system (long arrows) and (b) a variable supply of onshore clastic debris (short arrows). Dashed lines indicate approximate boundaries between drainage zones A to E.


NORTHERN MOUNTAINS
ABUNDANT SUPPLY OF COARSE CLASTICS
A
LOW CLASTIC SUPPLY
B
TJAMPLONG
MODERATE SUPPLY OF FINE CLASTICS FROM NAIFALLO HIGH
C
PLAIN
OESAOE
D
P. KERA
I
II
III
IV
V
VI
P
LOW TO MODERATE CLASTIC SUPPLY
MAINLY FROM BOBONARO SCALY CLAY AND OLDER ROCKS
LOW CLASTIC SUPPLY
MOSTLY FROM UPLIFTED QUATERNARY REEF
E
KUPANG
N
KILOMETRES
0 1 2 3 4 5

zone, (v) a supratidal zone, (vi) a zone of raised lagoonal sediments, (vii) a mangrove swamp zone and (viii) a number of tidal distributary channels.

The northern shoreline clastic complex consists mostly of a series of small clastic deltas, beaches, barrier bars and lagoons.

The two major present-day factors controlling sediment distribution are;- (i) bay and hinterland topography (both largely functions of geological structure), which control depth of offshore deposition, onshore distribution of orographic and other rainfall, and stream density, and thus nature and amount of clastic sediment supply; (ii) an anticlockwise system of currents which results in a net westerly sediment transport direction along the northern shore of the bay and a net easterly transport direction along the southern shore.

Similarities are noted between many of the sediments now forming in Kupang bay and those of the following parts of the onshore Viqueque Group:- (a) the Fatu Laob Member of the Batu Putih Limestone Formation, (b) the Sabaoe Limestone Formation, (c) the Tanah Putih marl Member of the Noele Marl formation, and (d) the marls and limestone of the Soe Limestone Formation.

C Geographic setting of Kupang bay

To the north of Kupang Bay is a range of mountains (the western extension of the Northern Mountains High of the Bokong and Noele Sub-basins) consisting mostly of rocks of pre-Middle Miocene age and to the south is an area of lesser relief consisting mostly of Bobonaro Scaly Clay with a capping of Quaternary reef (Figs. 74, 75). At the eastern end of the bay is an extensive low-lying plain,

(the Oesaoe Plain), extending as far as the Tjamplong-Naifallo High at the western end of the Central Basin.

Each of these three geomorphological regions has an important influence on both the size and quantity of clastic material entering the basin. At the eastern end of the bay, rivers crossing the flat Oesaoe Plain carry fine suspended material to the bay itself (Fig. 75), although in the monsoon season this is probably augmented by some silt and sand size material. A similar situation exists over most of the area south of the bay, where a few widely-spaced rivers, with gentle gradients, carry erosional products of carbonate reef and Bobonaro Scaly Clay into the bay. By contrast, larger amounts of coarser clastic material as well as large quantities of suspended clay minerals are carried into the northern part of the bay by short, steep mountain streams.

D Climate

Timor follows the general climatic pattern of the Indonesian archipelago, with an easterly dry monsoon period from July to November and a westerly, rainy monsoon period from December to June. Personal observations before the start of the 1971 wet monsoon season suggest however that the mountains north of Kupang Bay are also subject to orographic rainfall for some time before the west monsoon begins. The combined effect of this pre-monsoon orographic rainfall and that of the wet season itself is to bring large quantities of suspended material from the northern mountain area and from the Tjamplong-Naifallo High into the northern and eastern parts of Kupang Bay.

Also important are the high wind velocities in the east monsoon season, values of six on the Beaufort scale being repeatedly

reported at Kupang Airfield, to the south of the bay. ENE-WSW and NE-SW tropical cyclones also frequently occur during this period.

These high wind velocities in the east monsoon period may be the driving force for the anticlockwise current system which appears to operate in Kupang Bay (Fig. 75), and which is a major factor in the present distribution of modern sediments. The presence of this current system is inferred from (a) the distribution of clastic spits and sand bars on the southern shore of Kupang Bay (Fig. 74 and 75) which indicates a net sediment transport direction of west to east (i.e. towards the interior of the embayment) and similar spits on the northern shore which there indicate a direction of transportation in the opposite direction (i.e. towards the ocean) and (b) aerial photographs of the bay, taken towards the close of the dry season which reveal the apparent confinement at that time to the north eastern part of the bay of suspended material entering the bay at its eastern end (Fig. 74).

It is tentatively suggested that this system originates from the impingement onto the prominent oceanward part of the south coast of Kupang Bay, of surface currents flowing south westwards along the northern coast of Timor (Fig. 75) and their subsequent deflection into the southern part of the bay. Such currents would be expected to operate in this direction under the influence of the strong easterly winds and cyclones of the dry monsoon period.

E. Sediment distribution in Kupang Bay

Introduction

Two major regimes of sedimentation can be recognised in Kupang Bay (Fig. 75):-

(i) a carbonate regime occupying most of the south western portion

of the bay and the northern headland.

(ii) a terrigenous regime lying mostly in the north and east portions of the bay.

(i) The carbonate regime

The carbonate regime comprises three major fringing reef complexes (Fig. 75) situated:-

(a) along the southern shore of Kupang Bay

(b) along the north western headland (Tg. Pakoelak)

(c) around Pulau Kera Island in the bay entrance.

In addition to the active reef flat itself are six major associated sedimentary environments, each with its characteristic sediment type (Table 3). On the landward side of the reef flat, within the intertidal zone and above, are a series of beach skeletal calcarenites. Coarser and less well sorted calcarenites mantle parts of the reef flat and are named the reef platform calcarenites. Mantling the reef front and consisting of blocks of reef debris with a finer matrix is the reef breccia, which is succeeded further off-shore by a broad zone of reef front silty calcarenites, comprising low energy, deeper water sediments with in situ thin shelled molluscs. Finally, the floor of the centre of the bay is covered by a veneer of off reef foraminiferal silts, consisting almost entirely of benthonic foraminifera with other subordinate microfauna (D.J. Carter, personal communication). Within the northern fringing reef complex a seventh sediment type, consisting of carbonate muds and silts with coral and molluscan debris, occurs in the inter reef lagoon.

The above distribution of sediment types is similar to that noted within the Pleistocene and present day fringing reefs of Barbados (Mesolella et al. 1970).

Table 3: Summary of sediment composition, fauna and depositional environment of the major sediment types of the carbonate regime.

		ENVIRONMENT/ SEDIMENT TYPE	SEDIMENT COMPOSITION	SEDIMENT CLASSIFN. FOLK	SEDIMENT CLASSIFN. GRAIN SIZE	MATRIX	FAUNA	SORTING	CONTROL OF DEPOSITION	WATER DEPTH
CARBONATE REGIMS	FRINGING REEF COMPLEXES	ACTIVE REEF FRONT	Actively growing corals, coralline algae and molluscs	Biolithite & Biosparrudite	MASSIVE	-	Coral, algal and molluscan material	-	Flow of fresh ocean water along south side of bay. Favourable topography. Limited clastic supply.	0 - 15m
		REEF FRONT BRECCIA	Breccia with fragments of abraded coral, algal, and molluscan material	Biosparrudite	2"- 6" (dredged) Upper limit unknown	None dredged Probably mud and silt	As above	Very poor	Related entirely to distribution of fringing reefs.	20 - 66m
		BEACH SKELETAL CALCARENITE	Abraded molluscan debris, coral fragments and large foraminifera	Biosparite	Medium to coarse	Clean-washed. No matrix.	Foraminifera, lamellibranchs gastropods and corals	Very good	As above. Forms beaches on landward side of reef flats.	-
		REEF PLATFORM CALCARENITE	Skeletal calcarenite with clasts of coral and algal material. Individual clasts have pitted & frosted appearance	Biorudite & Biosparite	Coarse (3" max.)	Matrix of coarse sand sized benthonic foraminifera	Gastropods, thick-shelled lamellibranchs foraminifera	Poor	Related to distribution of fringing reefs.	1 - 2m
		REEF FRONT SILTY CALCARENITE	Molluscan debris with matrix of benthonic foraminifera	Biomicrite Biomicrudite	Mostly fine-grained Maximum shell size 4"	Silt-size matrix of small, globular, benthonic foraminifera pteropods and ostracods	Thin-shelled lamellibranchs forams, pteropods and ostracods	Very poor	As above.	40 - 70m
		FORE-REEF SILTS	Mostly small, benthonic foraminifera	Biomicrite	Silt	Carbonate mud	Benthonic foraminifera	Poor	As above. Increased depth and distance from reef responsible for rarity of larger fauna.	39 - 113m
		BACK-REEF LAGOON	Carbonate muds and silts with coral debris	Biomicrite Biomicrudite	Mud to silt		Molluscs, foraminifera	Poor	Found in low-energy environment behind reefs.	3 - 5m

A general sedimentary model of fringing reef distribution in Kupang Bay is presented in Figure 76. Examination of the sediments from each of these major sub-environments suggests that breakdown, abrasion and subsequent onshore transport of reef front material is primarily responsible for the accumulation of high energy calcarenite material in the reef platform and beach zones. Seaward of the active reef front, gravity feed results in supply of reef front derived material to the reef breccia zone.

The influence of the reef upon sediment supply ends abruptly at the seaward limit of the reef front breccia zone. Seaward of this zone, the reef front silty calcarenites, although mainly carbonate, grow by the in situ accumulation of benthonic foraminifera and indigenous thin-shelled lamellibranchs. Similar fore reef deposits were noted in the windward reefs of the Seychelles by Lewis (1969).

The boundary (in Kupang Bay) between carbonate and terrigenous sedimentation occurs at the junction of the offshore mud and off reef foraminiferal silt depositional zones.

(ii) The terrigenous regime

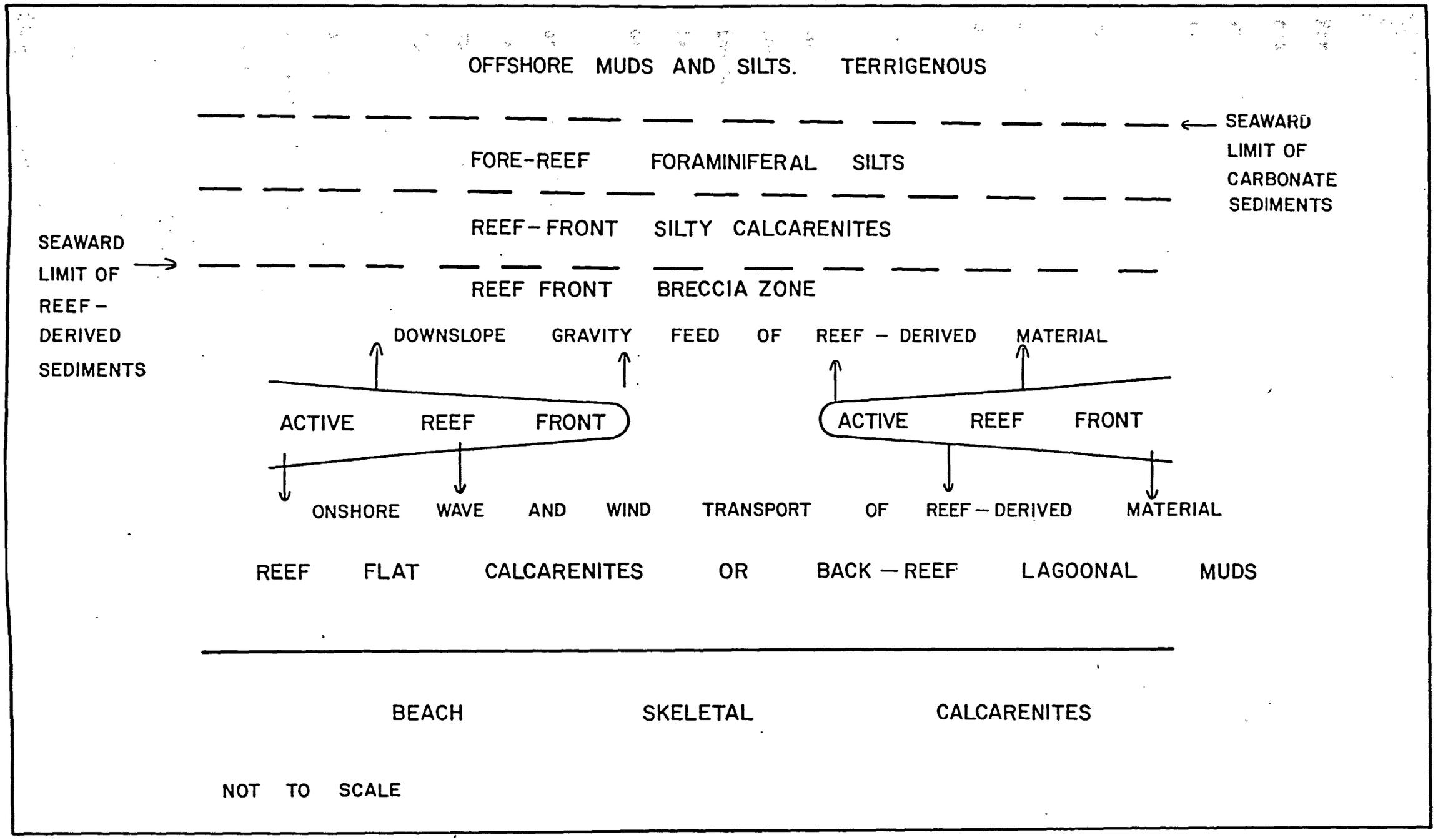
Included in the terrigenous regime is a northern shoreline clastic complex, consisting mostly of erosional products derived from the Northern Mountains, which enter the bay to form a series of small deltas interspersed with discontinuous small reef masses (Fig. 75 and Table 4). The suspended fine sediment from these rivers is deposited in the northern half of the bay to form a widespread blanket of terrigenous mud which passes transitionally southwards into the carbonate sands and silts of the central and southern fringing reef complexes.

Fig. 76: Fringing reef depositional model, Kupang Bay

Note the apparent onshore transport of sediment derived from the reef front and flat by wave and current action, and the seaward limit of reef influence at the seaward edge of the reef front breccia zone.

A non reef - derived carbonate zone exists seaward of the reef front breccia zone, comprising the reef - front silty calcarenites and fore - reef foraminiferal silts. The boundary between carbonate and terrigenous regimes of sedimentation occurs between the latter zone and the offshore mud and silt zone.

Approximate width of entire carbonate regime (beach to fore reef foraminiferal silts) is 1.5 to 2.0 km.


OFFSHORE MUDS AND SILTS. TERRIGENOUS
SEAWARD LIMIT OF CARBONATE SEDIMENTS
FORE-REEF FORAMINIFERAL SILTS
REEF-FRONT SILTY CALCARENITES
SEAWARD LIMIT OF REEF-DERIVED SEDIMENTS
REEF FRONT BRECCIA ZONE
DOWNSLOPE GRAVITY FEED OF REEF - DERIVED MATERIAL
ACTIVE REEF FRONT
ACTIVE REEF FRONT
ONSHORE WAVE AND WIND TRANSPORT OF REEF-DERIVED MATERIAL
REEF FLAT CALCARENITES OR BACK-REEF LAGOONAL MUDS
BEACH SKELETAL CALCARENITES
NOT TO SCALE

Part of this suspended terrigenous material originates from the eastern end of the bay where a barrier/island lagoonal complex exists, which includes barrier beaches, lagoons, raised lagoons and mangrove swamps separated by numerous distributary channels.

Description of sediments

Reference should be made to Tables 3 and 4 in which the main aspects of sediment composition, environment and faunal content are tabulated.

Origin of the barrier island/lagoonal complex

Samples collected from the barrier beaches at the eastern end of Kupang Bay consist almost entirely of large, unbroken lamellibranch shells with interspersed quartz grains. In this respect the beaches appear to be similar to the shell beaches of Padre Island, Texas (Watson, 1971), which consist of the calcareous skeletal debris of nearshore benthonic invertebrates.

The barrier beaches of Kupang Bay pass on both the seaward and landward sides into areas of fine grained sediment deposition. On the seaward side of the beaches, the bay floor is covered by muddy light grey silt containing numerous large, whole, thin shelled lamellibranchs of the type which form the adjacent barrier islands.

To the landward side of the beaches are large lagoonal areas containing organic-rich clays. The abundance of molluscan material of nearshore origin in the beach sediments suggests winnowing by wave and current action and subsequent onshore transport of lamellibranchs present in the offshore muddy silts. This explanation is similar to that advanced for the origin of the Padre Island shell beaches (Watson, 1971), and for those of Essex, England (Greensmith and Tucker, 1969).

Table 4: Summary of sediment composition, fauna and depositional environment of the major sediment types of the terrigenous regime.

		ENVIRONMENT/ SEDIMENT TYPE	SEDIMENT COMPOSITION	GRAIN SIZE	MATRIX	FAUNA	SORTING	CONTROL OF SEDIMENTATION	WATER DEPTH
TERRIGENOUS REGIME	N. SHORELINE CLAS. COMPL	Sands and muds in delta, beach, lagoon and mangrove swamp environments	Not sampled in detail	-	-	-	-	Large supply of erosional products from adjacent N. mountains	0 - 3m
	OFFSHORE MUD ZONE	2 Offshore terrigenous muds	Muds and silty muds with little macro- or microfauna	Mud and silt	-	In situ, large, burrowing lamellibranchs	-	Suspended material from N. mountains and east end of bay controlled by anticlockwise current system	5 - 54m
	BARRIER ISLAND / LAGOONAL COMPLEX	3 Offshore silts	Muddy, light grey silt with in situ lamellibranchs	Fine sand and mud	Mud	Thin-shelled lamellibranchs Benthonic forams	Good	Shallow water with some wave agitation	1 - 3m
		4 Barrier islands, beaches and spits	Lamellibranch shells with some terrigenous debris	¼" - 2"	Sand-size terrigenous grains	(Displaced) lamellibranch shells	Moderate	Onshore transport of molluscan debris from (3)	1
		5 Lagoons	Organic-rich muds	Mud	-	None seen	-	Low energy environment protected by (4)	0 - 2m
		6 Mangrove swamps	As above	Mud	-	-	-	Trapping of muds by roots etc.	0 - 2m
		7 Distributary channels	Silts and muds in upper parts, sands in lower	Mud to medium sand	-	-	Moderate to poor	-	0 -3m
		8 Raised lagoonal sediments	Organic-rich peats and black soils	Clay	-	Vegetation	-	-	1
		9 Intertidal zone	Grey and dark grey muds	Clay	-	Molluscan shells	Poor	Limited to intertidal zone	0 - 1m
		10 Supratidal zone	Salt encrusted muds	Clay	-	-	-	Limited to narrow belt above intertidal zone	1

Wind deflation also appears to be an important factor in further increasing the proportion of shell to terrigenous material. The carbonate beaches of the barrier island/lagoonal complex represent the only non-reef associated carbonate sediments in Kupang Bay and suggest that large carbonate accumulations can occur solely as the result of sorting processes in an area of great terrigenous sediment supply.

Accumulation of the present-day beach/barrier island-lagoonal complex has also been aided by the recent period of tectonic stability suggested by the present-day wide reef platform on the southern side of Kupang Bay. A profile across uplifted reef deposits in this region suggests that this period of tectonic stability was preceded by similar phases of stability separated by shorter periods of more rapid uplift (Fig. 77). An abandoned beach ridge (chenier) from a previously higher sea level is present 1.6 kilometres east of the present shoreline (Fig. 74).

(3) Summary of factors affecting Recent and modern sedimentation in Kupang Bay.

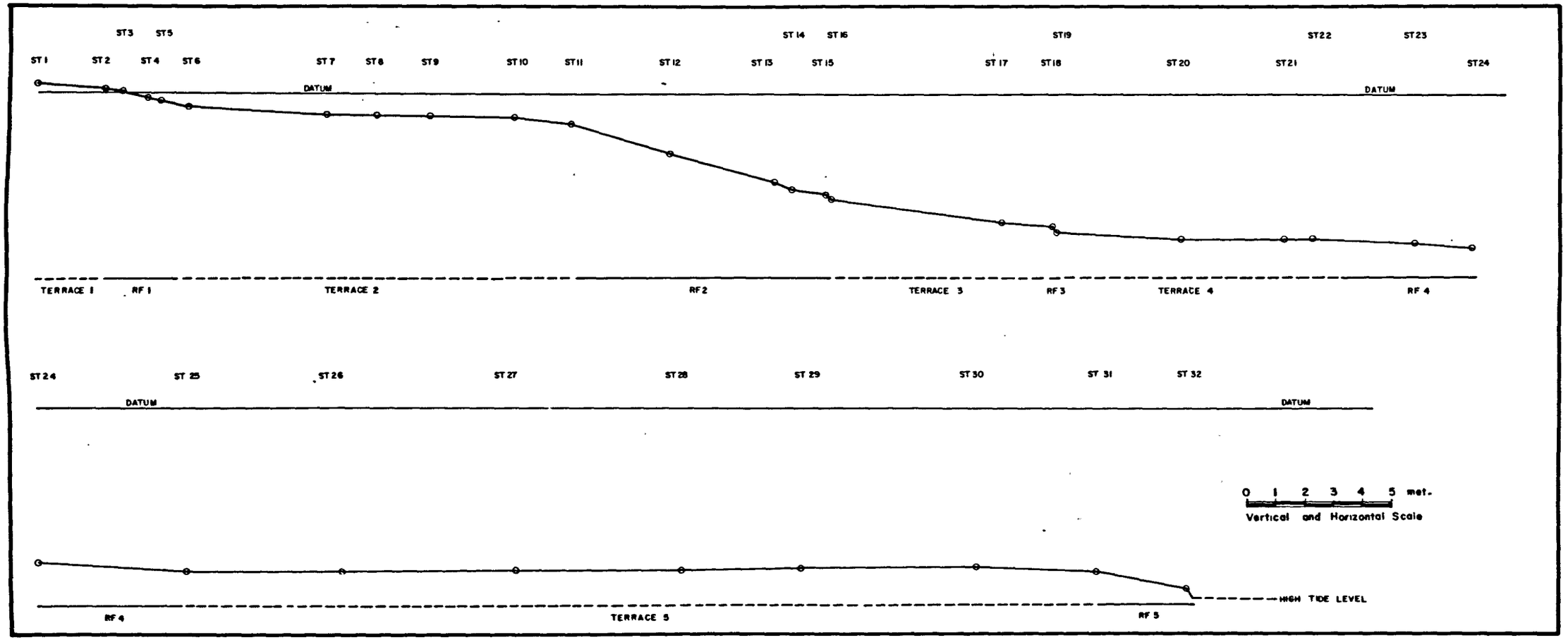
The present-day distribution of sediments in Kupang Bay is primarily a function of (a) topography, (b) recent tectonic activity and (c) the action of surface currents.

(a) Topographic control

Attention has already been drawn to the geological similarities between the Central Basin and Kupang Bay and to their respective bordering areas. During the later stages of the Pleistocene (Noele) uplift, a distinction existed between the areas to the north and south of both Kupang Bay and the Central Basin. To the north lay

Fig 77: North - south profile across uplifted Quaternary reef near Kalappa Lima, Kupang Bay, illustrating terraces and scarps, representing former reef platforms and reef fronts (RF) respectively.

For profile location see Fig.75.


ST 1
ST 2
ST 3
ST 4
ST 5
ST 6
ST 7
ST 8
ST 9
ST 10
ST 11
ST 12
ST 13
ST 14
ST 15
ST 16
ST 17
ST 18
ST 19
ST 20
ST 21
ST 22
ST 23
ST 24
DATUM
DATUM
TERRACE 1
RF 1
TERRACE 2
RF 2
TERRACE 3
RF 3
TERRACE 4
RF 4
ST 24
ST 25
ST 26
ST 27
ST 28
ST 29
ST 30
ST 31
ST 32
DATUM
DATUM
0 1 2 3 4 5 met.
Vertical and Horizontal Scale
RF 4
TERRACE 5
RF 5
HIGH TIDE LEVEL

a mountainous area of irregular topography, consisting largely of thrust sheets of Lolotoi and other pre-Middle Miocene rocks with a mantling of Bobonaro Scaly Clay. To the south of both depressions, a number of isolated pinnacles consisting of limestone of Cretaceous or Permian age projected above a thick development of Bobonaro Scaly Clay. This southern region is likely to have been of overall lower relief than its northern counterpart, and during the subsequent emergence provided a much more stable environment for the development of what Cloud (1952) called 'table reefs', which now mantle its uplifted surface. Successive pulses of uplift appear to have produced a series of terraces around the edges of the individual reefs, the youngest of which now occurs several feet above present-day sea level (Fig. 77).

In contrast to this southern area, however, the emergence of the jagged Northern Mountains did not present ideal conditions for the establishment of table reefs, especially as an appreciable amount of terrigenous material must have been shed from these into the surrounding waters. Apart from isolated examples, therefore, reefs are relatively rare in the northern mountain area.

The process described above, which led to the segregation of carbonate and terrigenous sedimentation in the Kupang Bay region was probably self perpetuating in that progressive covering of the southern area with a mantle of carbonate reef must have made the erosion of the underlying clays increasingly more difficult. Thus modern sedimentation is very much influenced by this older relief, the southern half of Kupang Bay recieving relatively little terrigenous material and the northern half recieving most of the weathering products of the Northern Mountains.

Sometime after the emergence of the Northern Mountains, and at the time when the southern area was developing its first reefs, Kupang Bay must have occupied a much wider area than at present, extending at least as far as the Tjamplong-Naifallo High in the east. Further uplift led to a narrowing and shallowing of the bay and to progradation of lagoonal, organic-rich silts and muds over the previously deposited bay floor sediments. These organic-rich sediments now mantle much of the abandoned bay floor of the Oesaoe Plain west of the Tjamplong-Naifallo High (Fig. 74). Contemporaneously with this uplift the growth of fringing reefs was slowly extending the reef cover of the area south of the bay.

(b) Tectonic control

Certain aspects of the later Tertiary tectonic history were indirectly responsible for the formation of reef complexes in the central part of the bay and on its northern shores. These were (a) the development of a number of important normal faults (Fig. 78) along the margins of Kupang Bay trending sub-parallel to the present shores, and (b) the resulting downthrown Bobonaro Scaly Clay over most of the bay floor. Because of the mobile nature of the clay and the abundance of gas in pre-Viqueque rocks of Timor (Audley-Charles 1968) a number of mud volcanoes and diapirs developed. One such mud volcano forms the island of Pulau Burung on the northern shore of Kupang Bay and a similar origin appears likely for the islands of Pulau Kera and Pulau Tikus (Fig 74). This interpretation is supported by the presence on the flanks of Pulau Tikus (at 15 fathoms) of a red-brown mud comtaining fragments of pre-Viqueque rock material and by the presence of similar fragments within the beach calcarenites of Pulau Kera. The alignment of these islands along a trend sub-

Fig. 78: Transverse and longitudinal profiles across Kupang Bay, illustrating probable fault control of basin margin (Profiles 1, 2 and 3) and diapiric nature of Pulau Kera (Profile 1), Pulau Tikus (Profile 2) and Pulau Burung (Profile 3).

Note also asymmetry of bay (shallower at the eastern and northern ends - Profiles 4 and 2), probably due to higher sedimentation rate of clastic debris in these regions.

Profiles also show the distribution of modern sediments:

A: reef platform calcarenites or active reef front.

B: reef breccia.

C: reef front silty calcarenites.

D: fore reef silts.

E: reef platform calcarenite.

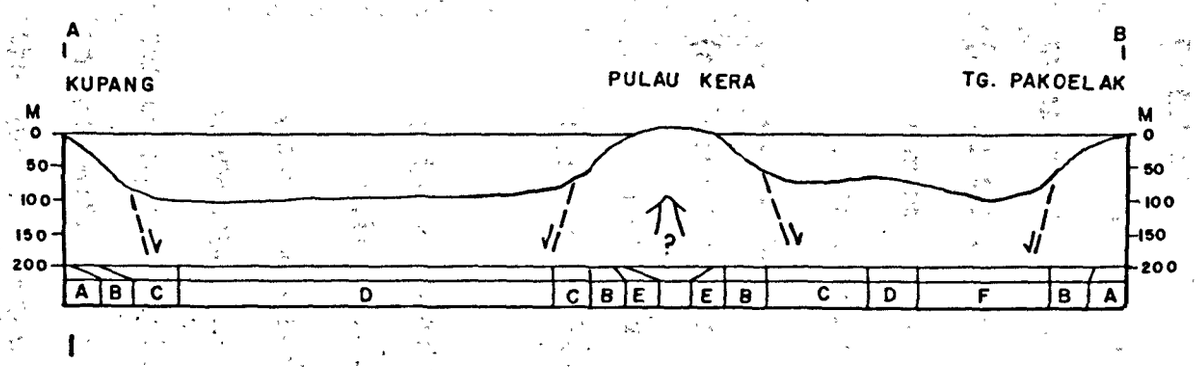
F: offshore terrigenous muds.

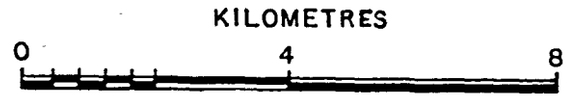
G: northern shoreline clastics.

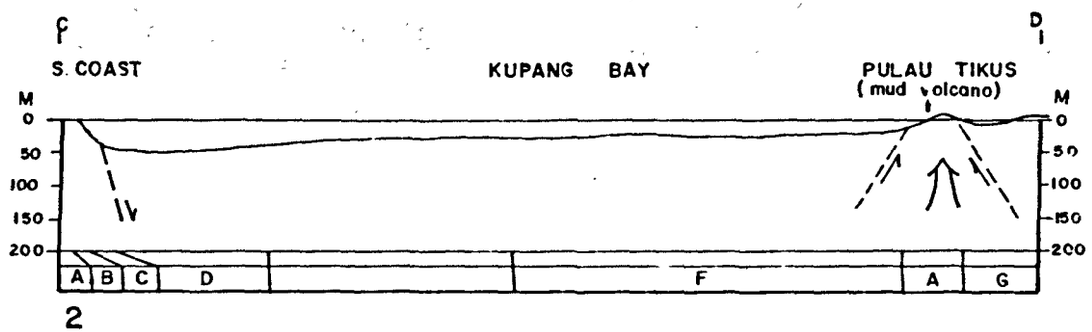
H: back reef lagoon.

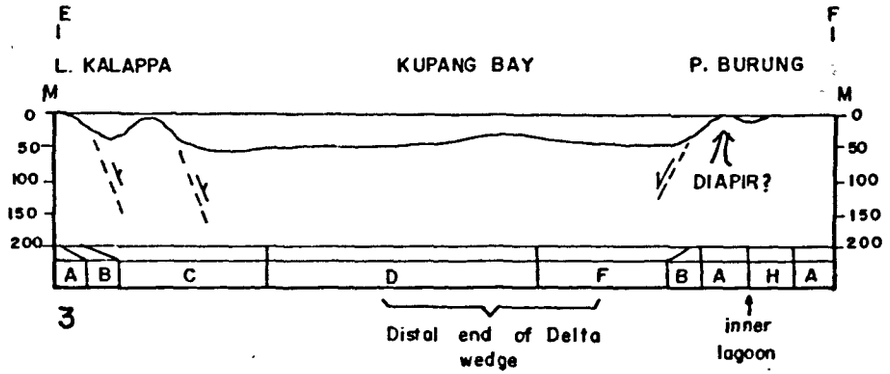
I: offshore silts.

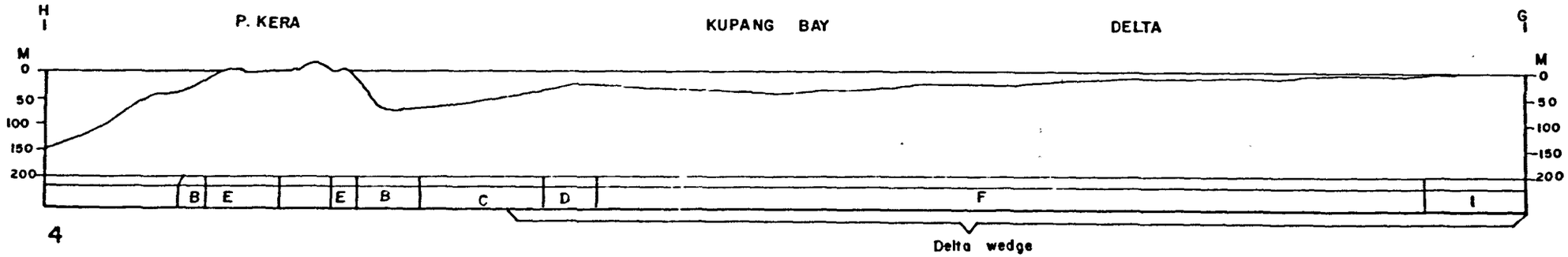
For locations of profiles see Fig. 84.


A
KUPANG
PULAU KERA
TG. PAKOELAK
B
M
0
50
100
150
200
?
A B C D C B E E B C D F B A
1


KILOMETRES
0
4
8


C
S. COAST
KUPANG BAY
PULAU TIKUS
(mud volcano)
D
M
0
50
100
150
200
A B C D F A G
2


E
L. KALAPPA
KUPANG BAY
P. BURUNG
F
M
0
50
100
150
200
DIAPIR?
A B C D F B A H A
3
Distal end of Delta wedge
inner lagoon


H
P. KERA
KUPANG BAY
DELTA
G
M
0
50
100
150
200
B E E B C D F I
4
Delta wedge

parallel to the northern and southern shorelines suggests the presence of a large fault or fault zone, movement on which probably initiated the growth of the diapirs.

(c) Current control

The present distribution of carbonate and terrigenous sedimentation in Kupang Bay is also controlled by the current system described earlier which ensures (a) that the suspended terrigenous material present in the eastern and north eastern parts of the bay is confined to these parts and (b) that an abundant supply of fresh ocean water is available for growth of the southern carbonate complex.

F. A comparison of ancient and modern environments

Shallow water marine environments existed at the following times during deposition of the Viqueque Group:-

(a) at the end of the Fatu Laob Uplift (Pliocene, Late N21);
(b) during the Sabaoe Stable Phase (Pliocene, Late N21);
(c) at the beginning of the Bidjeli Subsidence (Pliocene, Late N21);
(d) during the later stages of the Noilbesi Uplift (Pleistocene, N23) and
(e) during the Soe Subsidence (Pleistocene, N23).

Sediments deposited during these periods show many similarities in lithology and fauna to the sediments now forming in Kupang Bay.

(a) The shallow water sediments of the Fatu Laob Uplift

Silty calcarenites of the type now forming in the off reef environment of the fringing reef complexes of Kupang Bay are present in the uppermost part (Fatu Laob Member) of the Batu Putih Limestone succession of the Central Basin, where their presence is taken as an indication of the shallow water conditions which persisted throughout the area at the end of the Early to Late Pliocene regression.

(b) The shallow water sediments of the Sabaoe Stable Phase and beginning of the Bidjeli Subsidence.

Silty calcarenites similar to those of the Fatu Laob Member are also found within the Sabaoe Limestone succession of (a) the southern margin of the Bokong Sub-basin (in the Bokong section) and (b) in outcrops throughout the Noele Sub-basin

The replacement south of the Bokong-Batu Putih fault scarp of the silty calcarenites by clean-washed, foraminiferal calcarenites of a type similar to those forming the beach sediments of Pulau Kera Island in Kupang Bay marks an important break between the subsiding Bokong Sub-Basin and the Panite High,

(c) Shallow water sediments of the Noilbesi Uplift and Soe Subsidence

During the Noilbesi Uplift, the island of Timor was uplifted to its present position. The widespread table reefs which were developed on the exposed surface of the Noele Marl and older rocks are only slightly higher in elevation than those on the southern side of Kupang Bay and therefore are probably fairly recent in age. The reefs of both areas are closely similar in morphology and lithology.

Sediments of a different kind were, however, deposited in the depression of the Bokong Sub-basin, where a series of bedded clays and fine arenites (the Tanah Putih Marl Member) occurs at the top of the Noele Marl Formation. These sediments bear a strong resemblance to the offshore terrigenous muds of the northern part of Kupang Bay. Study of the Tanah Putih Marl foraminifera by Carter (unpublished report, dated 1970b) suggests their deposition in a fairly shallow water environment of the kind prevailing in the northern part of Kupang Bay at the present time. Although no arenites similar to those occurring at intervals in the Tanah Putih Marl were dredged from the area of Kupang Bay it is highly likely that they exixt in the subsurface.

References.

Audley-Charles, M.G. 1966. The Age of the Timor Trough. Deep Sea Res. 13, pp761-763.

Audley-Charles, M.G. 1968. The Geology of Portuguese Timor. Mem. Geol. Soc. London No. 4, 1968.

Audley-Charles, M.G. 1973. Palaeoenvironmental significance of chert in the Franciscan Formation of Western California: Discussion concerning the significance of chert in Timor. Geol. Soc. Am. Bull. Vol. 84, pp363-368.

Audley-Charles, M.G. 1974. The Banda Arcs. In Mesozoic and Cenozoic Orogenic Belts. Geol. Soc. London Spec. Publ. 1974.

Audley-Charles, M.G. and Carter, D.J. 1972. Palaeogeographical significance of some aspects of Palaeogene and Neogene stratigraphy and tectonics of the Timor Sea region. Palaeogeog., Palaeoclimat., Palaeoecol. Vol. 11, pp247-264.

Audley-Charles, M.G., Carter, D.J. and Milsom, J. 1972. Tectonic development of eastern Indonesia in relation to Gondwanaland dispersal. Nature Phys. Sci. 239, pp35-39.

Audley-Charles, M.G. and Hooijer, D.A. 1973. Relation of Pleistocene migrations of pygmy stegodonts to island arc tectonics in eastern Indonesia. Nature Vol. 241 No. 5386, pp197-198. Jan. 19 1973.

Bagnold, R.A. 1956. The flow of cohesionless grains in fluid. Roy. Soc. London Phil. Trans. Ser. A. Vol. 249, pp235-297.

Beck, R.H. and Lehner, P. 1974. Oceans, New Frontier in exploration. Am. Assoc. Petrol. Geol. Bull. Vol. 58 No. 3 (March 1974), pp376-395.

Berggren, W.A. 1973. The Pliocene Time Scale: calibration of Planktonic foraminiferal and calcareous Nannoplankton zones. Nature Vol. 243, pp391-396. June 15 1973.

Birkenmjaer, K. 1959. Systematyka warstwowán w ut worach fliszowych i prodobnych. Polska Akad. Nauk, Studia. Geol. Polonica 3. 113.

Blow, W.H. 1969. 'Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy'. In First International Conference on planktonic microfossils, Geneva 1967 (Ed. Bronniman, P. and Renz, H.H.) Brill, Leiden 1969.

Bouma, A.H. 1962. Sedimentology of some flysch deposits: A graphic approach to facies interpretation. Elsevier, Amsterdam, Netherlands. 168pp.

Brouwer, H.A. 1919. Jaarb. Mijnw Ned-oost Indie 2, (1919).

Brouwer, H.A. 1925. The Geology of the Netherlands East Indies. New York MacMillan and Co. 160pp.

Brouwer, H.A. 1942. Summary of the geological results of the expeditions. Geol. Exped. Lesser Sunda Islands. 4, 349 (1942).

Bourcart, J. 1964. Les sables profonds de la Méditerranée occidentale. In 'Turbidites', A.H. Bouma and A. Brouwer (Eds). Developments in Sedimentology 3. Elsevier Publ. Co. Amsterdam. pp148-155.

Bull, W.B. 1972. Recognition of alluvial fan deposits in the statigraphic record. In 'Recognition of ancient sedimentary environments'. Rigby, J. Keith; Hamblin, W.K. (Eds.), Soc. Econ. Pal. Min. Spec. Publ. No. 16. Feb 1972. p 70.

Burri, P., Masse, J.P. and Wagner, C.W. 1971. Characteristics and regional implications of a belt of high energy coastal deposits in the Barrhemian of Provence (SE France). Geol. Mijnbouw, Vol. 50 No. 3 pp349-357.

Chipping, D.H. 1971. Palaeoenvironmental significance of chert in the Franciscan Formation of Western California. Geol. Soc. Am. Bull. Vol. 82 pp1707-1712.

Cloud, P.E. 1952. Facies relationships of organic reefs. Bull. Am. Assoc. Pet. Geol. Vol. 36 No. 11 (Nov. 1952) pp2125-2149.

Curray, J.R. 1960. Sediments and history of the Holocene transgression, continental shelf, northwestern Gulf of Mexico. In Shepard, F.P., Phleger, F.B., and Van Andel, T.H. (Eds.), 'Recent Sediments, Northwest Gulf of Mexico'. Am. Assoc. Petrol. Geol. pp221-266.

De Bruyne, D.L. 1941. Sur la composition et la genèse du bassin central de Timor. Geol. Exped. Lesser Sunda Islands 3, pp135-238. (Amsterdam University, 1941).

Deep Sea Drilling Project 1973. Deep sea drilling project in the Indian Ocean. Geotimes 18/4. April,1973 pp16-18.

De Waard, D. 1954 (a). Geological Research in Timor, an introduction. Indonesian Jour. Nat. Sci. 110. pp1-8.

De Waard, D. 1954 (b). The second Timor Geological Expedition, preliminary results. Indonesian Jour. Nat. Sci. 110. pp154-160.

De Waard, D. 1955. Contributions to the geology of Timor, VII: On the tectonics of the Ofua Series. Indonesian Jour. Nat. Sci. VIII pp137-143.

De Waard, D. 1957. Contributions to the geology of Timor, XII: The 3rd Timor Geological Expedition, preliminary results. Indonesian Jour. Nat. Sci. Vol. 113, pp7-42.

Dickinson, W.R. 1970. Clastic sedimentary sequences deposited in shelf, slope, and trough settings between magmatic arcs and associated trenches. Pacific Geol. Vol. 3, pp1-14.

Dixon, E.E.L. and Vaughan, A. 1911. The Carboniferous succession in Gower (Glamorganshire) with notes on its fauna and conditions of deposition. Quart. Jour. Geol. Soc. London. Vol. 67, pp477-565.

Djulynski, S. and Sanders, J.E. 1962. Current marks on firm mud bottoms. Trans. Conn. Acad. Arts. Sci. 42, pp57-96.

Dott, R.H. Jr. 1958. Cyclic patterns in mechanically deposited Pennsylvanian limestones of N.E. Nevada. Jour. Sed. Pet. Vol. 28, pp3-14.

Dott, R.H. Jr. and Howard, H. 1962. Convolute lamination in non-graded sequences. Jour. Geol. Vol. 70, pp114-120.

Duff, P.M.D., Hallam, A., and Walton, E.K. 1967. Cyclic Sedimentation. Elsevier, Amsterdam. 280pp. (p 735).

Evans, G. 1965. Intertidal flat sediments and their environments of deposition in the Wash. Quart. Jour. Geol. Soc. London. Vol. 121, pp209-245.

Ewing, J. and Ewing, M. 1962. Reflection profiling in and around the Puerto Rico Trench. Jour. Geophys. Res. Vol. 67, pp4729-4739.

Ewing, M. and Heezen, B.C. 1955. Puerto Rico Trench, topographical and geophysical data. Geol. Soc. Am. Spec. Paper 62. 1955. pp255-268.

Felix, J. 1915. Jungtertiäre und quartäre Anthozoën von Timor und Obi I et II. Paläontologie von Timor II, p6. 1915.

Fisher, R.I. 1961. Middle America Trench, topography and structure. Geol. Soc. Am. Bull. Vol. 72, pp707-720.

Fisher, R.I. and Raitt, R.W. 1962. Topography and structure of the Peru-Chile Trench. Deep Sea Res. 9. pp423-443.

Fitch, T.J. 1970. Earthquake mechanisms and Island arc tectonics in the Indonesia-Phillipine region. Seismol. Soc. Am. Bull. Vol. 60, pp565-591.

Fitch, T.J. and Scholz, Christopher H. 1971. Mechanism of underthrusting in southwest Japan: A model of convergent plate interactions. Jour. Geophys. Res. Vol. 76, No, 29. Oct 10 1971.

Folk, R.L. 1962. Spectral subdivision of limestone types. Am. Assoc. Petrol. Geol. Mem. 1 'Classification of carbonate rocks- a symposium'. (Ed. William E. Ham). pp62-84.

Gageonnet,R. and Lemoine, M. 1957 (a). Sur la statigraphie de l'autochthone du Timor Portugais. c.r. hebd. Séanc Acad. Sci. Paris, 244. pp2168-71.

Gageonnet, R. and Lemoine, M. 1957 (b). Composition et subdivisions du complex charrié du Timor Portugais. c.r. hebd. Séanc. Acad. Sci. Paris, 244. pp2246-9.

Gageonnet, R. and Lemoine, M. 1958. Contribution à la connaissance de la géologie de la province Portugais de Timor. Estudos Ensanos Docum. Jta. Invest. Ultramar Vol. 48, 1-138.

Gates, O. and Gibson, W.M. 1956. Interpretation of the configuration of the Aleutian Ridge. Bull. Geol. Soc. Am. Vol. 67, pp127-146.

Gibson, W.M. and Nichols, H. 1973. Configuration of the Aleutian Ridge, Rat Islands- Semispochnoi I to west of Buldir I. Bull. Geol. Soc. Am. Vol. 64, pp1173-1188.

Greensmith, J.T. and Tucker, E.V. 1969. The origin of Holocene shell deposits in the Chenier Plain facies of Essex. Marine Geol. 7 (1969). pp403-425.

Grunau, H.R. 1953. Geologie von Portugiesisch ost-Timor. Eine Kurze Übersicht. Eclog. Geol. Helv. 46, pp29-37.

Harland, W.B. et al. 1972. A concise guide to stratigraphic procedure. Jour. Geol. Soc. London. Vol. 128, pp295-305.

Hayes, D.E. and Ludwig, W.J. 1967. The Manila Trench and West Luzon Trough II: Gravity and magnetic measurements. Deep Sea Res. Vol. 14, No. 5. pp545-560. 1967.

Heezen B.C., Menzies, R.J., Schneider, E.D., Ewing, W.M. and Granelli, N.C.L. 1964. Congo submarine canyon. Bull. Am. Assoc. Petrol. Geol. Vol. 48 No.7, ppl126-1149.

Horn, D.R., Ewing, M., Delach, M.N. and Horn, B.M. 1971. Turbidites of the N.E. Pacific. Sedimentology Vol. 16, pp55-67.

Horne, R.R. 1969. Sedimentology and palaeogeography of the Lower Cretaceous depositional trough of south-eastern Alexander Island. Brit. Antarctic Survey Bull. No. 22, pp61-76. 1969.

Houbolt, J.J.H.C. 1957. Surface sediments of the Persian Gulf near the Qatar peninsula. Thesis. Univ. of Utrecht, Moutron, The Hague. 113pp.

Karig, D.E. 1970. Ridges and basins of the Tonga-Kermadec island arc system. Geophys. Res. Vol. 75 No, 2. January 10 1970.

Karig, D.E. 1971. Structural history of the Mariana island arc system. Bull. Geol. Soc. Am. Vol. 82, pp323-344.

Kinsman, D.J.J. 1964. The Recent carbonate sediments near Halat El Bahrani, Trucial Coast, Persian Gulf. In 'Deltaic and shallow marine deposits' Developments in Sedimentology. Vol. 1. (Ed. L.M.J.U. Van Straaten) ppl85-192. 1964

Klein, G. 1964. Sedimentary facies in the Bay of Fundy intertidal zone, Nova Scotia, Canada. In 'Deltaic and shallow marine deposits' Developments in Sedimentology. Vol. 1. (Ed. L.M.J.U. Van Straaten) 1964.

Kuenen, Ph.H. 1951 (a) Mechanics of varve formation. Geologiska Foreningens 1. Stockholm Fordhandlingar Bard 73, 1251. pp69-84.

Kuenen, Ph. H. 1951 (b) Properties of turbidity currents of high density. Soc. Econ. Pal. Min. Spec. Publ. 2, Turbidity Currents. pp14-33.

Kuenen, Ph.H. 1952. Estimated age of the Grand Banks turbidity current. Am. Jour. Sci. Vol. 250, pp874-884.

Kuenen, Ph.H. 1964. Deep sea sands and ancient turbidites. 'Turbidites' Developments in Sedimentology 3. A.H. Bouma and A. Brouwer (Eds) Elsevier Publ. Co. Amsterdam.

Kuenen, Ph.H. and Menard, H.W. 1952. Turbidity currents, graded and non-graded deposits. Jour. Sed. Pet. Vol. 22 No. 2. pp83-96. 1952.

Kuenen, Ph.H. and Migliorini, C.I. 1950. Turbidity currents as a cause of graded bedding. Jour. Geol. Vol. 58, pp91-127.

Kuenen, Ph. H. and Sanders, J. 1956. Sedimentation phenomena in Kulm and Flozleeres Greywackes, Sauerland and Oberharz, Germany. Am Jour, Sci. Vol. 254. pp647-671.

Lemoine, M. 1959. Un example de tectonique chaotique. Timor Rev. Geogr. Phys. Geol. Dyn. 2. (4) pp205-230.

Lewis, K.B. 1971. Slumping on a continental slope inclined at 1° to 4°. Sedimentology 16. pp97-110.

Lewis, M.S. 1969. Sedimentary environments and unconsolidated carbonate sediments of the fringing coral reefs of Mahé, Seychelles. Mar. Geol. 7 (1969), pp95-127.

Ludwig,W.J., Ewing, J., Ewing, M. et al. 1966. Sediments and structure of the Japan Trench. Jour. Geophys. Res., Vol. 71, No. 8. pp2121-2137.

Malahoff, A. 1970. Some possible mechanisms for gravity and thrust faults under ocean trenches. Jour, Geophys, Res., Vol. 75 No. 11. April 10 1970.

McKee, E.D. and Sterret, T.S. 1961. Laboratory experiments on the form and structure of longshore bars and beaches. In 'Geometry of Sandstone Bodies' Peterson, J.A. and Osmond, J.C. (Eds.) Tulsa. Am. Assoc. Petrol. Geol.

McKerrow, W.S. and Campbell, C.J. 1960. Stratigraphy and structure of the Lower Palaeozoic rocks of N.W. Galway. Royal Dublin Soc. Sci. Proc.; Series A, Vol. 1, pp27-52.

Mesolella, K.J., Sealy, H.A. and Matthews, R.K. 1970. Facies geometries within Pleistocene reefs of Barbados, West Indies. Am. Assoc. Petrol. Geol. Bull. Vol. 54 No. 10 (Oct. 1970). pp1899-1917.

Mitchell, A.H.G. 1971. Geology of northern Malekula: Brit. Serv., New Hebrides, 56pp. (Reg. Rep. New Hebrides Condominium Geol. Surv.).

Molengraaf, G.A.F. 1915. Folded mountain chains, overthrust sheets and block-faulted mountains in the East Indian Archipelago. C.R. xii th Int. Geol. Congr. Toronto, 689-702.

Molengraaf, G.A.F. 1916. On the occurrence of nodules of manganese in Mesozoic deep sea deposits from Borneo, Timor, and Roti, and their significance and modes of formation. Proc. Acad. Sci. Amsterdam, 18. pp415-430.

Molengraaf, G.A.F. 1922. On manganese nodules in Mesozoic deep sea deposits of Dutch Timor. Proc. Acad. Sci. Amsterdam, 23. pp997-1012.

Normark, W.R. 1970 Growth patterns of deep sea fans. Am. Assoc. Petrol. Geol. Bull. Vol. 54 pp2170-2195.

Normark, W.R. and Piper, D.J.W. 1969. Deep-sea fan valleys, past and present. Geol. Soc. Am. Bull. Vol. 80, pp1859-1866. September 1969.

Nota, D.S. 1958. Sediments of the Western Guiana Shelf. Med. Van de Land bouishegeschool le wageniger. Nederland. Vol. 58. No. 2.

Piper, D.J.W. 1970. A Silurian deep-sea fan deposit in Western Ireland and its bearing on the nature of turbidity currents. Jour. Geol. Vol. 78, pp509-522.

Purlet, H. 1963. Sedimentologie des formations du Visean Superieur Vgb dans la vallie de Samson (Bassin de Namur, Belgique). Ann. Soc. Geol. Belg. Bull. 86, pp4-41.

Raitt, R.W., Fisher, R.I. and Mason, R.G. 1955. Tonga Trench. Geol. Soc. Am. Spec. Paper 62. pp237-255. 1955.

Reineck, H.E. and Wunderlich, F. 1968. Classification and origin of flaser and lenticular bedding. Sedimentology 11, pp99-104.

Sanders, J.E. 1960. Origin of convolute laminae. Geol. Mag. Vol. 97, pp409-421.

Sanders, J.E. and Friedman, G.N. 1967. Origin and occurrence of limestone. In 'Developments in Sedimentology' 9A, Chilingas,G.V., Bissell, H.J. and Fairbridge, R.W. (Ed,) Carbonate Rocks, Origin, Occurrence and Classification.

Shepard, F.P. and Dill, R.F. 1966. Submarine canyons and other sea valleys. Rand-McNally, New York. N.Y. 381pp.

Shinn, E.A. 1969. Submarine lithification of Holocene carbonate sediments in the Persian Gulf. Sedimentology 12. 1969.pp109-144.

Stanley, D.J. and Unrug, R. 1972. Submarine channel deposits, fluxo-turbidites and other indicators of slope and base-of-slope environments in modern and ancient marine basins. In 'Recognition of ancient sedimentary environments' Rigby, J.Keith and Hamblin, W.K. (Eds) . Soc. Econ. Pal. Min. Spec. Publ. No. 16 Feb. 1972, p295.

Stearns, H.T. 1945. Euststic shore lines in the Pacific. Geol. Soc. Am. Bull. Vol. 56, No. 11. pp1071-1077.

Tappenbeck, D. 1940. Geologie des Mollogebirges und einibergen achbarter gebiete. Geol. Exped. Lesser Sunda Islands, Vol. 1, ppl-105.

Terwindt, J.H.J., Breusers, H.N.C. and Svasek, J.N. 1968. Experimental investigation on the erosion sensitivity of a sand-clay lamination. Sedimentology 11, pp 105-114.

Uchupi, E. and Jones, G.F. 1967. Woody debris on the mainland shelf off Ventura, S. California. Sedimentlogy 8. 1967. ppl47-151.

Umbgrove, J.H.F. 1934. Topogr. K. Ned. Aardrijk Genoot 51, 20. 1934.

Umbgrove, J.H.F. 1935. De Pretertiare Histoire van der Indischen Archipel, met. bijdragen van Dr Friedr. Weber. Leid. Geol. Meded. 7, 119-155.

Umbgrove, J.H.F. 1946. Evolution of reef corals in East Indies since Miocene time. Am. Assoc. Petrol. Geol. Bull. Vol. 30 No. 1, pp23-31.

Umbgrove, J.H.F. 1949. Structural history of the East Indies. Cambridge University Press. 63pp.

Van Andel, T.H. and Moore, J.C. Jr. 1974. Cenozoic calcium carbonate distribution and calcite compensation depth in the central equatorial Pacific Ocean. Geology, Vol. 2 No. 2, pp87-92. Feb. 1974.

Van Andel,T.H. and Veevers, J.J. 1967. Morphology and sediments of the Timor Sea. Bur. Min. Res., Geol. and Geophys., Australia. Bull. 83, ppl-173.

Van Bemmelen, R.W. 1949. The Geology of Indonesia. Vol. 1A (2nd. printing ,1970). The Hague. Martinus Nijhoff. 732pp.

Van Der Vlerk, I.M. and Umbgrove, J.H.F. 1927. Tertiare gidsforaminiferen Van Nederlandsch Oost-Indie. Wetensch. Meded. Dienst. Mijnb. Ned. Indie 9. 44pp.

Van Straaten, L.M.J.W. 1950. Environment of formation and facies of the Wadden Sea sediments. Tijdsche Koninkl. Ned. Aardrijkskindig Genoot. 67, pp354-368.

Van West, F.P. 1941 Geological investigations in the Miamaffo region (Neth. Timor). Geol. Exped. Lesser Sunds Islands 3, ppl-131.

Veevers, J.J. 1969. Palaeogeography of the Timor Sea Region. Palaeogeog., Palaeoclim., Palaeoecol. Vol. 6 (1969) pp125-140.

Veevers, J.J. 1971. Shallow stratigraphy and structure of the Australian continental margin beneath the Timor Sea. Mar. Geol. Vol. 11 (1970) pp209-249.

Walker, R.G. 1966. Shale Grit and Grindslow Shales: transition from turbidite to shallow water sediments in the Upper Carboniferous of Northern England. Jour. Sed. Pet. Vol. 36 pp90-114.

Walker, R.G. 1967. Turbidite sedimentary structures and their relationship to proximal and distal depositional environments. Jour. Sed. Pet. Vol. 37 No. 1., pp25-43. March 1967.

Wanner, J. 1913. Geologie von Westtimor. Geol. Rundschau Bd. IV, 2. pp136-150. 1913.

Wanner, J. 1956. Zur stratigraphie von Portugiesisch Timor 2 dt. Geol. Ges. 108, 109-140.

Warris, B.J. 1973. Plate tectonics and the evolution of the Timor Sea, N.W. Australia. Austr. Petrol. Expl. Assoc. Journal, 1973.

Watson, R.L. 1971. Origin of shell beaches, Padre Island, Texas. Jour. Sed. Pet. Vol. 41 No.4, pp1105-1111 . December 1971.

Wilson, J.L. 1969. Microfacies and sedimentary structures in "deeper water" lime mudstones. In 'Depositional environments in carbonate rocks'. Friedman, G.M. (Ed.). Soc. Econ. Pal. Min. Spec. Publ. No. 14. March 1969. pp4-19.

Unpublished reports and theses.

Audley-Charles, M.G. 1965. The Geology of Portuguese Timor. Ph. D. Thesis, Univ. of London. 401pp.

Audley-Charles, M.G. 1970. Results of geological reconnaissance of Indonesian Timor, Roti, Sabu and Raidjua. Report to International Oils Exploration, N.L. April 30 1970.

Audley-Charles, M.G. 1971. Unpublished report to International Oils Exploration, N.L.

Carter, D.J. 1970 (a). The zonation and dating of the Viqueque Group, Portuguese and Indonesian Timor, Roti and Sabu. Palaeontological Report No,2 to International Oils Exploration, N.L. July 1970.

Carter, D.J. 1970 (b). Report on the Tanah Putih Marls. Palaeontological Report to International Oils Exploration, N.L.

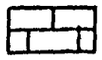
Carter, D.J. 1971 (a). Correlation of the Viqueque Group, southern Indonesian and southern Portuguese Timor. Palaeontological Report No. 3 to International Oils Exploration, N.L. 15 March 1971.

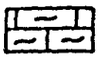
Carter, D.J. 1971 (b). Progress Report on the micropalaeontology of the Kolbano structure. Report to International Oils Exploration, N.L. April 30, 1971.

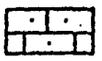
Hopper, R.W. 1942. Nederlandsche Pacific Petroleum Maatschappij, Prelim. Reconn. Report (unpublished), January 18, 1942.

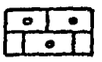
Kenyon, C.S. 1970. The stratigraphy, tectonics and petroleum prospects of the Viqueque Group of Indonesian Timor. First Interim Report to International Oils Exploration, N.L. April 1970.

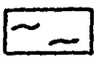
LITHOLOGY

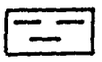

Limestone

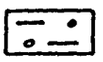

Marly limestone


Sandy limestone

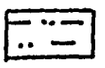

Calcirudite

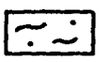

Marl


Clay

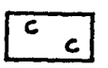

Clay with isolated terrigenous clasts


Sandstone or sand

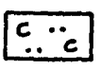

Silt or siltstone


Sandy marl

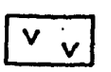

Conglomerate or gravel



Carbonaceous earth

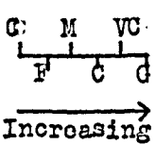


Silty carbonaceous earth



Tuff

GRAIN SIZE

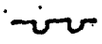


C. Clay
F. Fine sand
M. Medium sand
C. Coarse sand
VC. Very coarse sand
G. Gravel

BED BOUNDARIES:

Abrupt

Transitional


Loaded

Erosional

Irregular

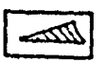
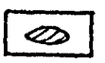
SEDIMENTARY STRUCTURES

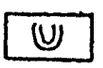
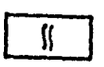

Parallel lamination


Wavy lamination

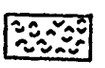

Convolute lamination


Cross-bedding



Ripple cross-lamination

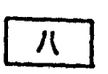


Burrowing

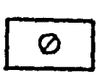

Channelling (in conglomerate)

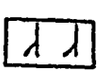

Shell debris


Isolated lamellibranch shells


Marl or clay pellet inclusions

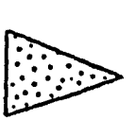

Water expulsion structure


Calcareous concretion


Plant root structures


Lensed bed


Sedimentary boudinage


Lateral wedge-out

LEGEND

RECENT	RA	Barrier beach/ lagoonal complex
	RA^{in}	Intertidal sediments
	RA^{l}	Uplifted intertidal/ lagoonal sediments
	RA^{r}	Undifferentiated Recent alluvium
QUATERNARY	QA	Alluvium
	Vnc	Noilbesi Conglomerate Formation
	Vsl^{re}	Soe Limestone Formation (undiff.)
	Vsl^{re}	Displaced reef blocks.
PLEISTOCENE	Vsl^{r}	Noehoti Mori Member
	Vsl^{l}	Uplifted moat depression and deposits
	Vsl	Tiimplong Limestone Member
	Vnl	Nali Lakes Formation
PLIOCENE TO PLEISTOCENE	Vnm	Noele Mori Formation
PLIOCENE	Vsc	Sabosa Limestone Formation
MIOCENE TO PLIOCENE	Vbl	Batu Putih Limestone Formation
MIDDLE M. AND OLDER	B	Baboseno Scaly Clay
	B'	Baboseno Scaly Clay with abundant exotic blocks
	PMM	Pre - Middle Miocene (undifferentiated)
	PMM(Ex?)	Pre - Middle Miocene, possible exotic block

Soe Limestone Fm.
Viqueque Group

- Fault with downthrow
- Fault, downthrow uncertain
- Fault, position uncertain
- Fault from photogeology
- Fault, concealed
- Formation boundary
- Formation boundary, exact position uncertain
- Formation boundary from photogeology
- Reef terrace
- Linear reef depositional feature
- Slump scar
- Regional dip (< 30°)
- Regional dip (>30°)
- Dip, amount in degrees
- Synclinal axis
- Anticlinal axis
- Synclinal axis, uncertain
- Anticlinal axis, uncertain

KUPANG BAY

TIMOR SEA

TIMOR SEA

Tg OESAPA

Tg BENNIL

Tg OLIMATMOETI

Tg TARSA

Tg MALL

KUPANG

TELUK KUPANG

9° 45'S

10° 00'S

10° 15'S

123° 30'E

123° 45'E

124° 00'E

124° 15'E

STRAT
O
QU

Ph.D THESIS

GEOLOGY OF THE VIQUEQUE GROUP OF INDONESIAN TIMOR

PULAU SAMAU

KILOMETRES

MILES

123° 00'E
124°15'E
124°30'E
9°45'S
10°00'S
10°15'S
TIMOR SEA
KAPAN
SOE
NIKINIKI
BORONG
PMM (EX?)

ENCLOSURE I OF
STRATIGRAPHY AND SEDIMENTOLOGY OF THE LATE MIOCENE TO QUATERNARY DEPOSITS OF TIMOR

Ph.D THESIS 3/74 AUTHOR: C.S. KENYON

ENCLOSURE 2 OF
STRATIGRAPHY AND SEDIMENTOLOGY
OF THE LATE MIOCENE TO
QUATERNARY DEPOSITS OF
TIMOR

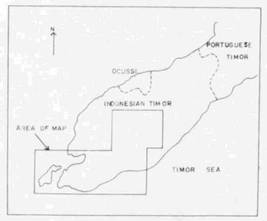
PhD THESIS · 3/74 AUTHOR: G.S. KENYON

INDONESIAN TIMOR

TOTAL VIQUEQUE GROUP

ISOPACHYTE AND TECTONIC MAP

km 0 1 2 3 4 5 6 7 8
miles 0 1 2 3 4 5



FAULT
FAULT, PROBABLE
900 ISOPACHYTE CONTOUR, VALUE IN METRES
ANTICLINAL AXIS
SYNCLINAL AXIS
REGIONAL DIP

NORTHERN MOUNTAINS HIGH
SOE-KAPAN HIGH
NO ELE SUB-BASIN
SABU OE FAULT
KAPAN
NOIL BENAIN SYNCLINE
NOIL LAKOE SYNCLINE
NOELE ANTICLINE
NAPOMNAIN FAULT
SOE
BOKONG SUB-BASIN
NAIMONA DIAPIR
KOLBANO HIGH
TJAMPLONG-PANITE HIGH
NOILMINA DELTA
NORTHERN MOUNTAINS HIGH
SOELAMOE
FAULT ZONE
Tg SOELAMOE
KUPANG BAY SUB-BASIN
OESAPA FAULT ZONE
TG. OESAPA
KUPANG
SAMAU
PULAU
OEKABITI
HIGH
TG. BENINL
TG. MALI
TG. OILMATMOETI
TG. TARBA
TIMOR SEA

LEGEND

RECENT
- RA — Barrier beach/ regional complex
- RA* — Intertidal sediments
- RA* — Uplifted reef/shelf/ regional sediments
- RE — Undifferentiated Recent alluvium

QUATERNARY
- QA — Alluvium

PLEISTOCENE
- Vnc — Noelbesi Conglomerate Formation
- Vn* — Soe Limestone Formation (undiff.)
- Vn* — Displaced reef blocks
- Vm* — Noelmiti Marl Member
- Vk* — Uplifted reef deposits and deposits
- Vk — Tjamplong Limestone Member
- Vkl — Kali Lakes Formation

PLIOCENE TO PLEISTOCENE
- Vnm — Noele Marl Formation

PLIOCENE
- Vbc — Bokong Limestone Formation

MIOCENE TO PLIOCENE
- Vbl — Batu Putih Limestone Formation
- B — Bobonaro Scaly Clay
- B' — Bobonaro Scaly Clay with abundant exotic blocks

MIDDLE M AND OLDER
- PMM — Pre - Middle Miocene (undifferentiated)
- PMM(Ex?) — Pre - Middle Miocene, possible exotic block

Fault with Dip and throw
Fault, downthrow uncertain
Fault, position uncertain
Fault from photogeology
Fault, concealed
Formation boundary
Formation boundary, exact position uncertain
Formation boundary from photogeology
Reef terrace
Linear reef depositional feature
Dip, amount in degrees
Regional dip (< 30°)
Regional dip (>30°)
Dip, amount in degrees
Synclinal axis
Anticlinal axis
Synclinal axis, uncertain
Anticlinal axis, uncertain

Kupang
KUPANG BAY
TIMOR SEA
Kapan
Soe
Oenasse
Batu Putth
Bokong
Notlmina
Obernaik
Tjamplong
Ts NOELANOE
Ts GESAN
Ts BENUL
Ts OLIMATMOETI
Ts HALL
Ts TAMAN

(R.) Kali Bidjeli
(R.) Kali Sabaoe
(R.) Noli Leke
(R.) Kali Fekufatu
(R.) Kali Oemenu
(R.) Kali Cacu
(R.) Noli Noni
(R.) Obernaik
(R.) Kali Bokong
(R.) Notlmina

FATU LADU MEMBER TYPE SECTION
SABADE LIMESTONE FMN. TYPE SECTION
NEKANA SANDSTONE MEMBER TYPE SECTION
OEAJO CLAY MEMBER TYPE SECTION
KAPAN LIMESTONE MEMBER TYPE SECTION
NOIL LAKDE MARL FMN. TYPE SECTION
PENE MEMBER TYPE SECTION
NANFUA SANDSTONE MEMBER TYPE SECTION
TOI Q LIGNITE MEMBER TYPE SECTION
NOELEKAT MARL MEMBER TYPE SECTION
NUANAIN SANDSTONE MEMBER TYPE SECTION
FAUTAO CONGLOMERATE BED TYPE SECTION
NUETUFI MARL MEMBER TYPE SECTION
NOE KO. U MEMBER TYPE SECTION
OFUA SANDSTONE MEMBER TYPE SECTION
OEMENU SANDSTONE MEMBER TYPE SECTION
OBERNAIK MEMBER TYPE SECTION
NOILBESI CONGLOM. FMN. TYPE SECTION
TANAH PUTIH MARL MEMBER TYPE SECTION
FATU ANTONI MEMBER TYPE SECTION
BATU PUTIH LIMESTONE FMN. TYPE SECTION
TJAMPLONG LIMESTONE MEMBER TYPE SECTION
TANAH KUNTU MEMBER TYPE SECTION
NOTLMINA LIMESTONE MEMBER TYPE SECTION
TACAKI LIMESTONE MEMBER TYPE SECTION
OEMAKO MEMBER TYPE SECTION

NOTE 1: NOELE IS THE NAME GIVEN TO THE GENERAL REGION IN WHICH THE OEMENU SANDSTONE MEMBER AND NOE KO. U MEMBER TYPE SECTIONS ARE SITUATED

NOTE 2: FOR LOCATION OF NOELE MARL AND SOE LIMESTONE FORMATION TYPE SECTIONS SEE TEXT.

ENCLOSURE 3 OF STRATIGRAPHY AND SEDIMENTOLOGY OF THE LATE MIOCENE TO QUATERNARY DEPOSITS OF TIMOR

LOCATION MAP OF TYPE SECTIONS AND GEOGRAPHIC PLACE - NAMES

Ph.D THESIS 3/74 AUTHOR C.S. KENYON

GEOLOGY OF THE VIQUEQUE GROUP OF MODNESIAN TIMOR
PULAU SABAU