LITHOSTRATIGRAPHY OF THE MISOOL ARCHIPELAGO, IRIAN JAYA, INDONESIA[1]

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ABSTRACT

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The Misool Archipelago contains one of the most complete and richly fossiliferous Mesozoic sequences in southeast Asia and the southwest Pacific. The excellent exposures offer an opportunity to establish a reference biostratigraphy for the region as well as a detailed lithostratigraphy. Metamorphics form a basement overlain by ?Triassic flysch which was block-faulted and uplifted during the Carnian, after which platform carbonates were deposited followed by a period of non-deposition. Marine sedimentation resumed in the Early Jurassic with fine clastics and bathyal carbonates. Early Cretaceous volcanism was accompanied by a change to a fluvio-deltaic environment. By Tertiary times sediment supply waned and a marine carbonate regime was established. Marl was deposited after Late Oligocene folding and by middle Miocene times a carbonate regime was re-established until Quaternary uplift formed the Misool Archipelago. The Misool stratigraphy is a continuation of the northwestern Australian rift-drift sequence formed during the breakup of northern Gondwana. It provides precise timing for these events and hence vital information for the assessment of hydrocarbon potential.

INTRODUCTION

The Misool Archipelago is located in the Ceram Sea in eastern Indonesia approximately midway between the Island of Ceram and the Birds Head of Irian Jaya. Misool Island is bisected by longitude 130° E and latitude 2° S (Fig. 1).

VAN BEMMELEN (1949) was the first to note that:
'Misool occupies a singular position in the eastern part of the (Indonesian) archipelago; it lies more or less outside the reach of the various younger orogenic systems which can be distinguished in the area. Consequently its sedimentary strata are generally only gently tilted, the stratigraphical succession being clear. Moreover these Mesozoic deposits are rich in well preserved fossils and the series is rather completely developed' (p. 69).

The excellent exposures found around the southern and southwestern coastline and on numerous islands to the southeast permit detailed mapping and, in view of the completeness of the succession and diversity of the fauna, afford an opportunity to establish a reference biostratigraphy for the region.

Furthermore, the recent recognition of the continuation of the northwestern Australian rift-drift sequence into eastern Indonesia (PIGRAM & PANGGABEAN, 1981) highlights the potential of the region for the generation and entrapment of petroleum. In the region subjected to rifting the Misool Archipelago is one of the few exposed areas with a nearly complete and largely undeformed marine sequence which provides precise dating of breakup events, and hence vital information for the assessment of hydrocarbon potential.

However, SKWARKO (1981) has pointed out that despite excellent outcrop and rich faunas the published stratigraphies of the Misool Archipelago contain many anomalies and the stratigraphic positions of several lithological units and biostratigraphic zones are uncertain.

During 1981 an expedition, organised by the Geological Research and Development Centre (GRDC) of the Indonesian Department of Mines and Energy, visited the Misool Archipelago with the following objectives:

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Fig. 1
Locality map

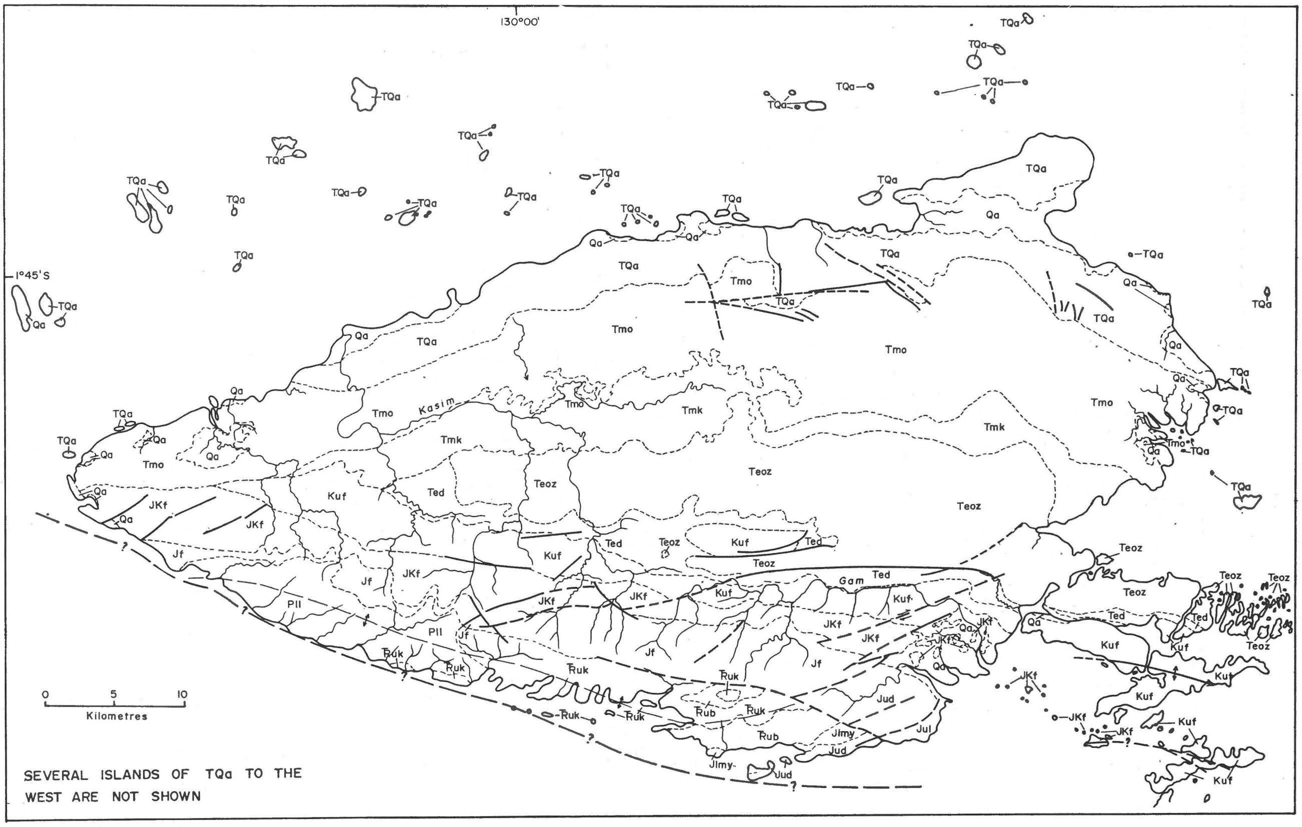


Fig. 2
Geological map of the Misool Archipelago. The map is presented in several parts at different scales to permit the portrayal of important outcrops on islands otherwise too small to show. See Fig. 3 for letter symbols used for map units.
A. Geological map of Misool Island.

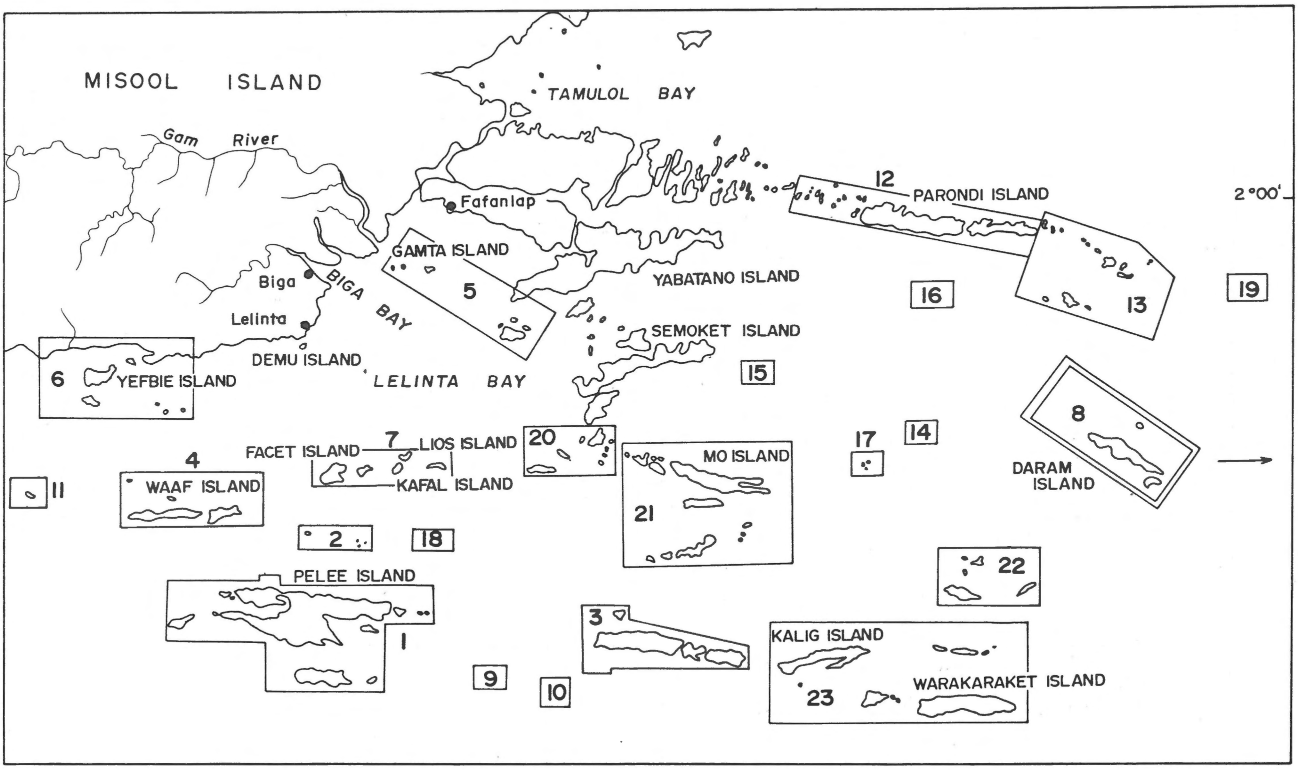


Fig. 2 (continued)
B. Locality map for the geological maps of the islands to the southeast of Misool Island presented in parts 2C and 2D.

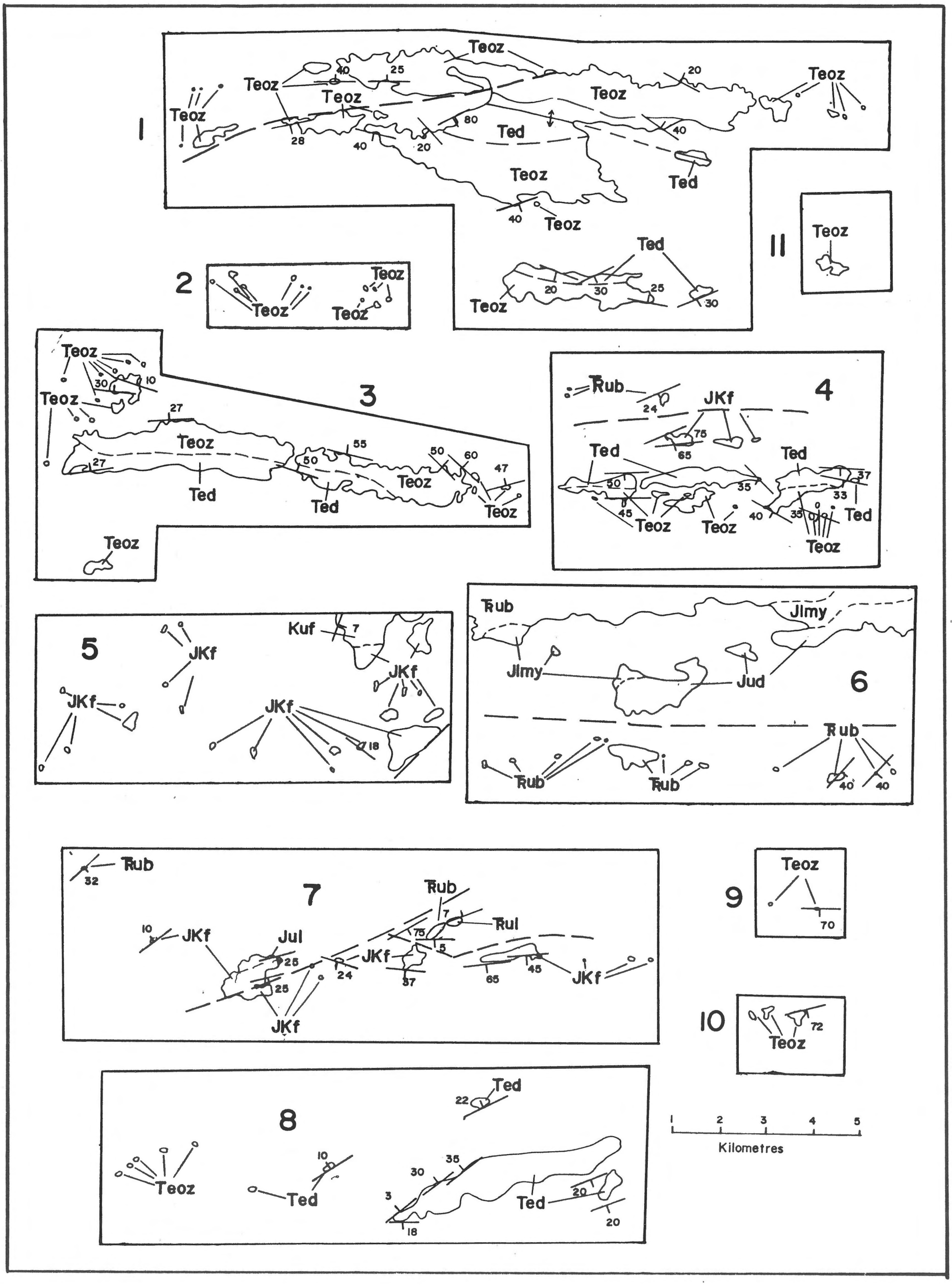


Fig. 2 (continued)
C. Geological maps of the islands to the southeast of Misool Island.

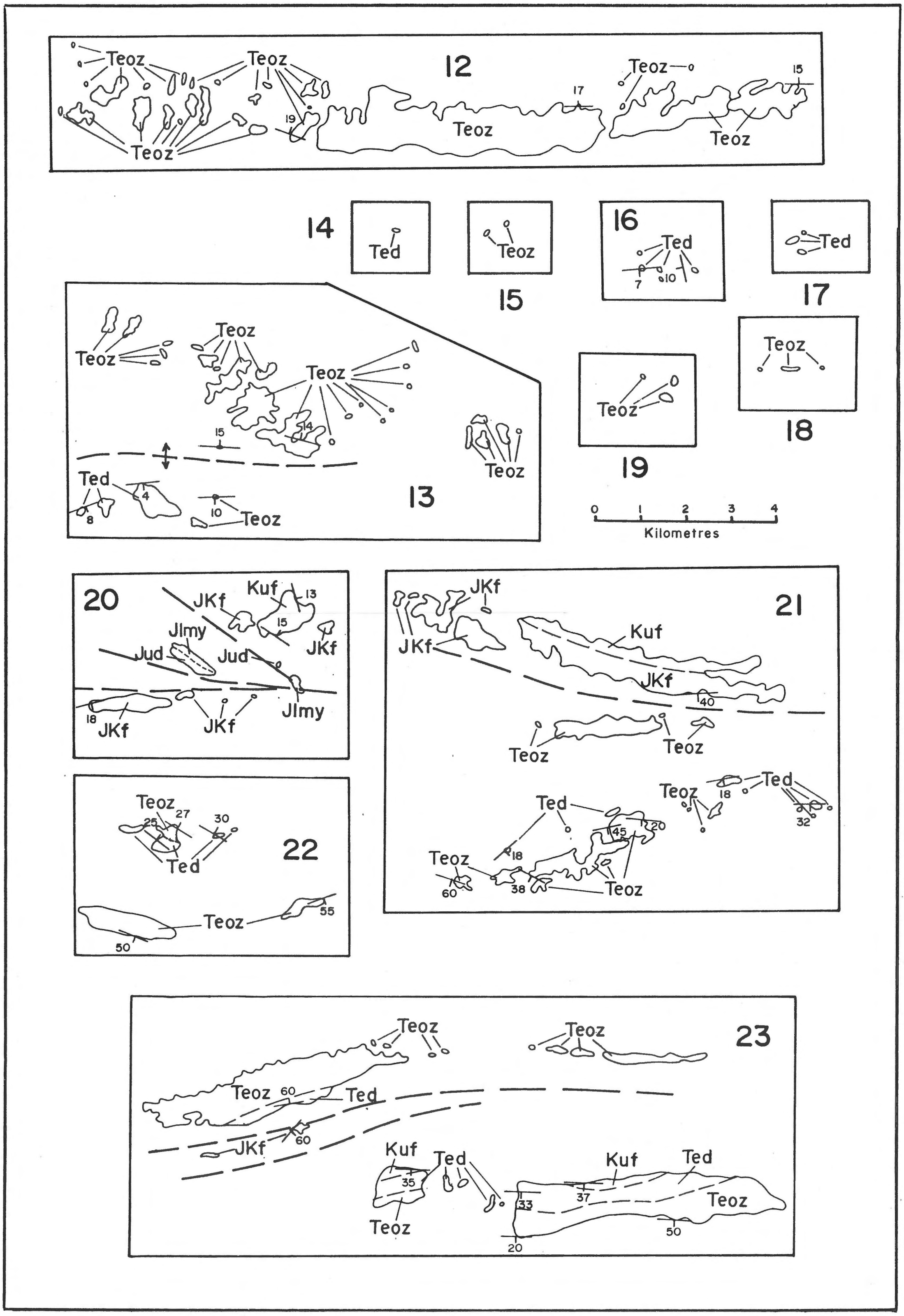


Fig. 2 (continued)
D. Geological maps of the islands to the southwest of Misool Island.

Table I
Comparison of the principal stratigraphic columns erected for the Misool Archipelago since 1910 and the lithostratigraphic column proposed in this paper (column 1). Correlations between columns and ages thereby implied are only approximate.

AGE			1 This paper	2 van Bemmelen 1949	3 Skwarko 1981	4 Sato 1975	5 Stevens 1965b	6 Hermes 1959
CAINOZOIC	QUAT	RECENT	ALLUVIUM					CORAL LIMESTONE, CLAYEY LIMESTONE, CLAYS, LIGNITE
		PLEISTOCENE	ATKARI LIMESTONE	PLIO-PLEISTOCENE LIMESTONE				
	TERTIARY	PLIOCENE						
		MIOCENE	OPENTA LIMESTONE KASIM MARL	MIOCENE LIMESTONE				SHOAL LIMESTONE SANDY, MARLY LIMESTONE, CLAYS AND LIGNITE
		OLIGOCENE	ZAAG LIMESTONE	EOCENE LIMESTONE				NUMMULITES LIMESTONE
		EOCENE						ALVEOLINA-LACAZINA LIMESTONE
		PALAEOCENE	DARAM SANDSTONE					CLAYSTONE, SANDSTONE, SANDY LIMESTONE, DOLOMITE, OOLITES
MESOZOIC	CRETACEOUS	UPPER	YABATANO MEMBER FAFANLAP FORMATION	MARLS	INOCERAMUS -RUDISTIDS BEDS			MARLY GLOBOTRUNCANA LIMESTONE, RUDIST LST, TUFFACEOUS MATERIAL
		LOWER	FACET LIMESTONE GROUP: WAAF FORMATION GAMTA LIMESTONE	UPPER FACET LIMESTONE	UPPERMOST FACET LIMESTONE UPPER FACET LIMESTO LOWER FACET LIMESTONE	OVERLYING	UPPER FACET LIMESTONE LOWER FACET LIMESTONE	BATHYAL LIMESTONE, RADIOLARIA, CHERT, PELAGIC FORAMINIFERA TUFFACEOUS MATERIAL.
	JURASSIC	UPPER	FAGEO GROUP: LELINTA SHALE DEMU FORMATION	LOWER FACET LIMESTONE LELINTA BEDS: FACET SHALE PLATEY LIMESTONE LELINTA MARLY SHALE DEMU LIMESTONE AUCELLA SANDSTONE	UPPERMOST FACET SHALE UPPER FACET SHALE AUCELLA SANDSTONE MARL LOWER FACET SHALE INOCERAMUS PLATEY LIMESTONE LELINTA CLAY DEMU LIMESTONE	FACET LIMESTONE ? LELINTA BEDS: INOCERAMUS LIMESTONE ? LELINTA CLAY ? DEMU LIMESTONE ? AUCELLA SANDSTONE	UPPER FACET SHALE AUCELLA SST & MARLS ABOVE THE DEMU LST LOWER FACET SHALE LELINTA MARL DEMU LIMESTONE DEMU M26 DEMU M139 BASAL DEMU	BATHYAL LIMESTONE RADIOLARIA CHERT BATHYAL CLAYS
		MIDDLE	YEFBIE SHALE	PRODICOELITES & PERSULCATES MARLS AND LIMESTONE MARLY SHALES AND LIMESTONE QUARTZ SANDSTONE	SANDY LIMESTONE WITH GROOVED BELEMNITES VARIEGATED SANDSTONE HARPOCERAS BED HAMMATOCERAS BED MARLY LIMESTONE QUARTZ SANDSTONE	MARLY SHALE AND SANDSTONE ?		RADIOLARIA TUFFITE
		LOWER	LIOS MARL MEMBER			BASAL CONGLOMERATE		BASAL CLASTICS
	TRIASSIC	UPPER	BOGAL LIMESTONE	MISOLIA LIMESTONE NUCULA MARL	MISOLIA LIMESTONE NUCULA MARL	SUBSTRATUM		MARLY LIMESTONE
		MIDDLE	KESKAIN FORMATION	KESKAIN BEDS	KESKAIN BEDS ?—?—?			FLYSCH LIKE CLASTICS
		LOWER	? ? ? nondeposition and erosion ? ? ?		BASAL METAMORPHICS			
PALAEOZOIC			LIGU METAMORPHICS					

A. to collect from the known fossil horizons with a view to establish a reference biostratigraphy for the area, and
B. to produce a detailed lithostratigraphy in which to place the biostratigraphy and thus resolve the confusion in nomenclature and stratigraphy that exists in the literature.

The first part of objective A was accomplished and several new collecting sites discovered. The second part of objective A will be achieved in due course as detailed palaeontological reports are prepared by various specialists who are currently working on the fossil collection.

The purpose of this paper is to fulfil objective B by presenting a lithostratigraphic column of the Misool Archipelago and eliminating the anomalies in previous publications.

A geological map is presented (Figure 2A-D). Misool Island is depicted at a smaller scale than the numerous small islands to the southeast. These islands contain most of the reference sections and provide the best exposures for mapping and collecting; hence they are presented at a larger scale to enable these essential features to be portrayed.

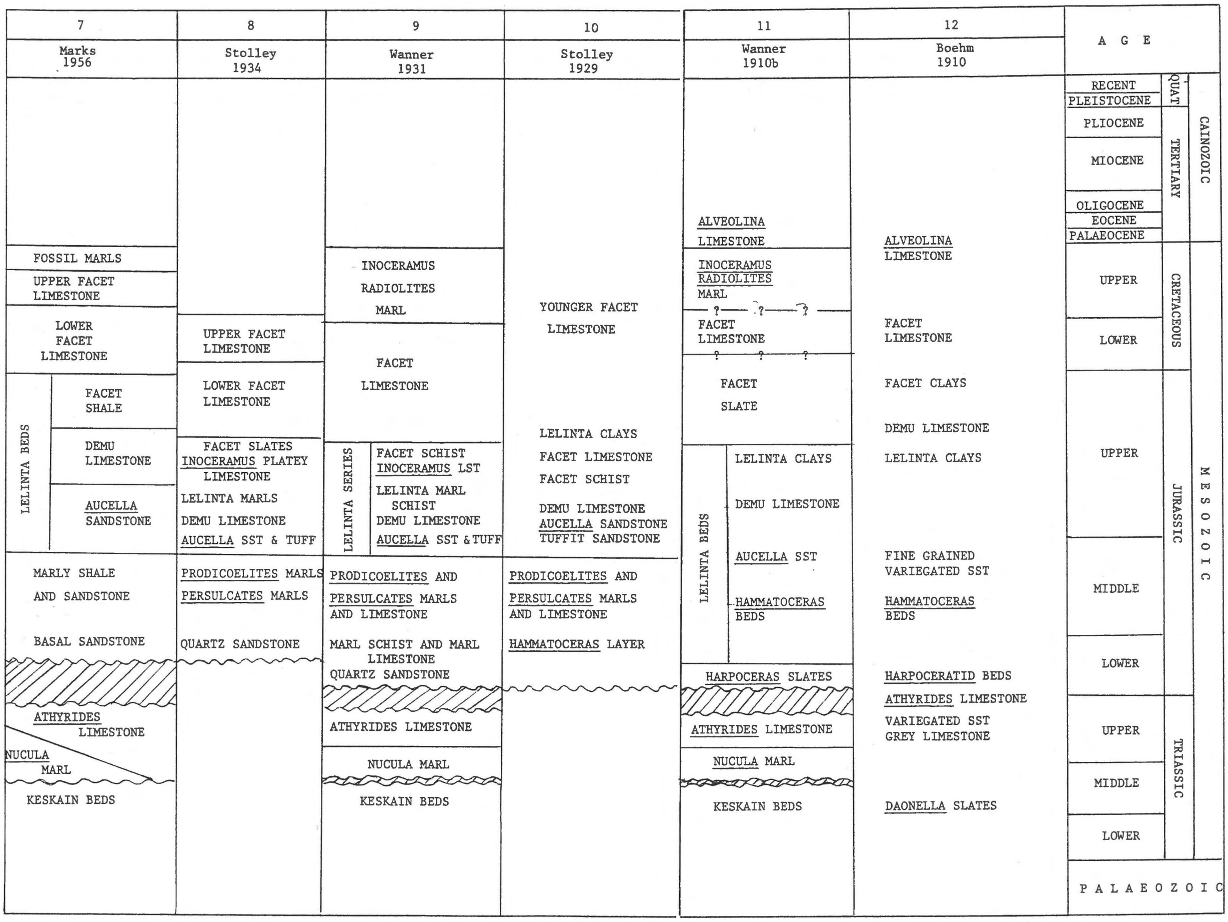
A geological map of the Misool Archipelago at 1:250,000 scale will be published by GRDC and 1:100,000 scale locality and compilation maps are available from the senior author on request. Spelling of place names has been altered to conform to modern Indonesian usage (e.g. Fatjet to Facet).

Previous Work

SKWARKO (1981) has compiled a detailed synthesis of previous work undertaken in relation to the geology and palaeontology of the Misool Archipelago.

Numerous stratigraphic columns have been published for various parts of the stratigraphic sequence exposed in the Misool Archipelago and eleven of these are reproduced in Table I. Only three of them (columns 10,11,12) are based on fieldwork; the others are largely revisions effected by palaeontologists studying one or other of the major fossil groups and are basically biostratigraphic subdivisions which use mixed lithostratigraphic and biostratigraphic terminology e.g. *Aucella* Sandstone.

Fossils from the Misool Archipelago were first collected by the Siboga Expedition of 1899 (WEBER, 1902). BOEHM (1901) retraced the route of the Siboga Expedition and while in Misool during late 1900 and early 1901 recognised eight



horizons, which he later (BOEHM, 1910) incorporated into the first published stratigraphic column of the Misool Archipelago (Table I, column 12).

WANNER (1910b) visited Misool during 1909 and on his return published a new stratigraphic column (Table I, column 11). Geologists do not appear to have visited the Misool Archipelago again until 1929 when Dr. Fr. Weber of the Bataafsche Petroleum Maatschappij N.V. mapped the north coast and nearby islands (WEBER, 1930). No further work was undertaken until ROGGEVEEN (1939) mapped the south coast of Misool. The unpublished reports of WEBER (1930) and ROGGEVEEN (1939) formed the basis for the stratigraphic column published by VAN BEMMELEN (1949) (Table I, column 2). This column is essentially correct, although it contains errors in the Jurassic section and no low-grade metamorphic basement is recognised.

The only fieldwork since 1939, prior to our own, that we know of, is by FROIDEVAUX (1974) of the Phillips Petroleum Company Indonesia who visited the Misool Archipelago in 1970. He produced a summary of the stratigraphy and a geological map, both little different from those published previously by VAN BEMMELEN (1949), but was first to recognise a basement of low-grade metamorphics beneath the Keskain Formation.

Since the fieldwork of BOEHM (1910) and WANNER (1910a) several stratigraphic columns published by various authors have been based entirely on a reassessment of the palaeontology. These include the columns of STOLLEY (1929, 1934, Table I, columns 8 and 10), WANNER (1931, Table I, column 9), MARKS (1956, Table I, column 7), STEVENS (1965b, Table 1, column 5), SATO (1975, Table I, column 4), and SKWARKO (1981, Table I, column 3).

Aspects of the palaeontological faunas from the Misool Archipelago have been discussed by BOEHM (1910), BÖHM (1924), WANNER (1910b), KRUMBECK (1913, 1934), SOERGEL (1913, 1915), JAWORSKI (1915), HEINZ (1928), STOLLEY (1935), WANDEL (1936), JELETZKY (1963) and STEVENS (1965b). Papers on regional biostratigraphy of the Indonesian region which include important references to the Misool fauna include FRECH (1905), RENZ (1905), WANNER (1910c, 1925, 1931), KRUMBECK (1913), ZWIERZYCKI (1925), RUTTEN (1927), STOLLEY (1929), UMBGROVE (1935), WANDEL (1936), FLEMING (1960), STEVENS (1965a) and SATO (1975); SKWARKO (1981) contains a succinct summary of the papers referred to above.

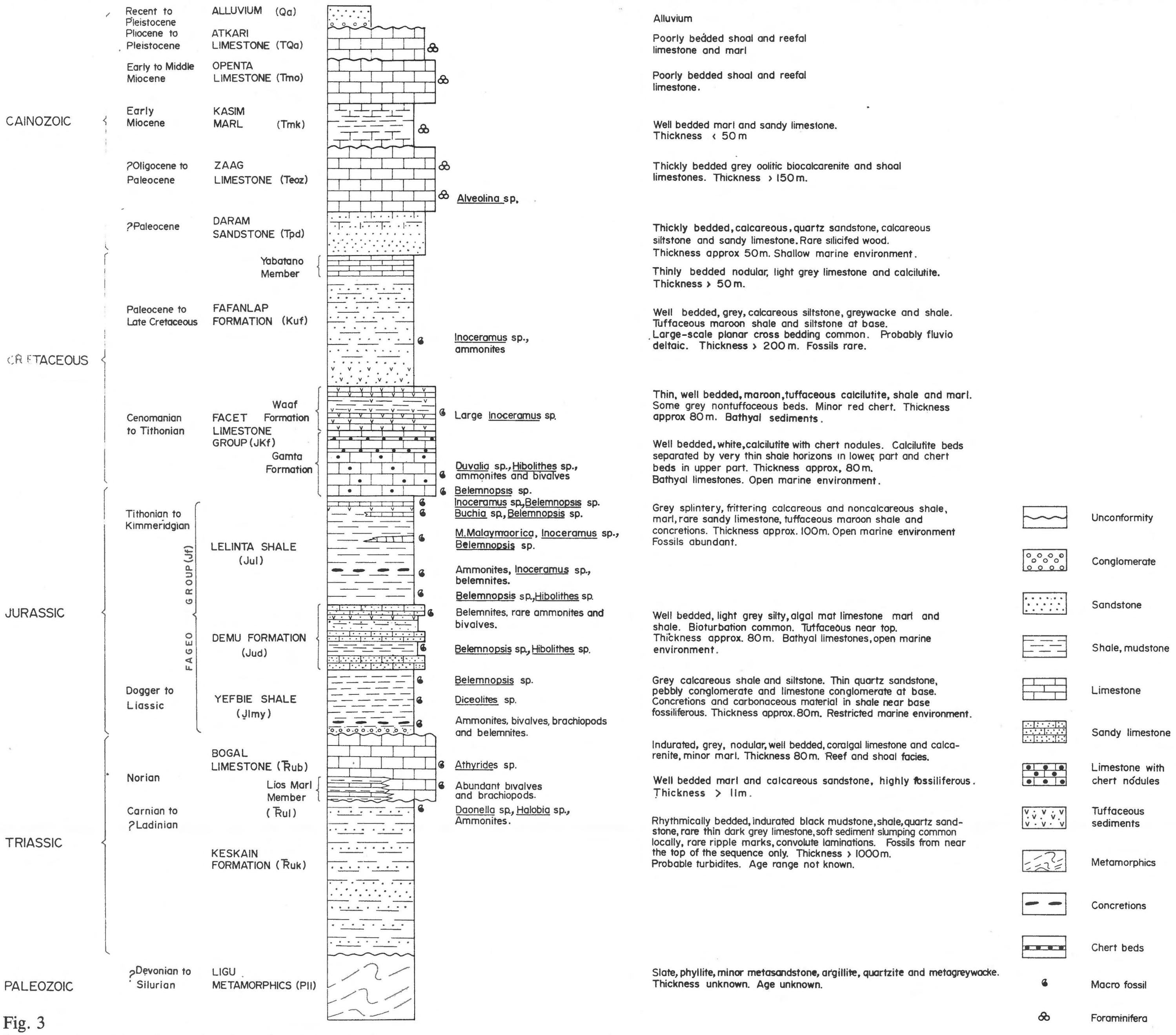


Fig. 3
Lithostratigraphic column for the Misool Archipelago.

STRATIGRAPHY

The island of Misool is the north flank of an anticlinorium plunging southeast; the section becomes younger northward across the island. A large fault zone controls the southern coastline. The small islands to the southeast occupy the southern flank of the anticlinorium. Fig. 3 is the lithostratigraphic column summarizing results of our field observations in 1981 and it provides detailed lithological descriptions not repeated in the text.

The oldest rocks exposed are slate, phyllite and metasandstone of the Ligu Metamorphics which are unconformably overlain by the thick flysch deposits of the Triassic Keskain Formation, in turn unconformably overlain by the Late Triassic Bogal Limestone. Thereupon, unconformably once more, lies the Jurassic Fageo Group which consists of a lower unit – Yefbie Shale – a middle unit – the Demu Formation – and the uppermost Lelinta Shale. The Fageo Group is conformably overlain by the Late Jurassic – Early Cretaceous Facet Limestone Group which comprises two formations – a lower thickly bedded calcilutite with chert nodules and beds (Gamta Limestone) and an upper thinly bedded maroon tuffaceous calcilutite, marl and shale (Waaf Formation).

Although the Late Cretaceous Fafanlap Formation lies conformably on the Facet Limestone it represents a major change of sedimentation and consists of well bedded siltstone, greywacke and shale that is tuffaceous at the base. Large-scale (up to 20 m) planar cross bedding is characteristic of the Formation. At the top of the Fafanlap Formation the Yabatano Member is a very well bedded nodular limestone and is conformably overlain by thickly bedded calcareous quartz sandstone and sandy limestone of the Daram Sandstone. The Paleocene to ?Oligocene Zaag Limestone rests conformably on the Daram Sandstone and comprises well bedded oolitic biocalcarenite and calcarenite representing shoal limestones.

The sequence was folded and eroded in Late Oligocene and Early Miocene times, and the Miocene Kasim Marl and Openta Limestone onlap the older rocks to lie directly on the Jurassic Fageo Group in western Misool Island. The Openta Limestone is partly conformably and partly uncomformably overlain by the Plio-Pleistocene Atkari Limestone.

In the following discussion of the stratigraphic units the relationships between the old nomenclature and new lithostratigraphic nomenclature are discussed in an attempt to clarify the anomalies and uncertainties in the literature.

Ligu Metamorphics (PII)
Reference section: south coast of Misool Island between Cape Bug and Cape Wee.

FROIDEVAUX (1974) was the first to recognise that a basement of low-grade metamorphic rocks might exist beneath the Keskain Formation. Our work has confirmed the presence of this basement and it has been mapped along the southern margin of Misool Island between the main east-west range and the coastline between Cape Bug and Cape Wee. The age of the Ligu Metamorphics is not known but similar metamorphics occur to the south on Ceram and Buru Islands (Fig. 1) (VAN BEMMELEN, 1949; AUDLEY-CHARLES ET AL., 1979) and to the northeast in the Birds Head of Irian Jaya (VISSER & HERMES, 1962). FROIDEVAUX (1974) postulated a Permian age for the Ligu Metamorphics; however, the age of deposition of the metamorphosed sediments of the Birds Head has been determined as Siluro-Devonian and the age of their metamorphism as Devonian to Early Carboniferous (VISSER & HERMES, 1962; YOUNG & NICOLL, 1979). The consistent presence of a low-grade metamorphic basement throughout the Ceram Sea region suggests that these ages may be applicable to the Ligu Metamorphics.

Keskain Formation (TRuk)
Reference section: south coast of Keskain Island

The Keskain Formation (originally the Daonella Slates of BOEHM (1910) and the Keskain Beds of WANNER (1910b)) are a readily mappable, thick sequence of turbidites, whose age range remains unknown. Fossils have only been found near the top of the sequence near the eastern end of Keskain Island and on the adjacent mainland. SKWARKO (1981) states that these bivalves indicate an early Carnian (Late Triassic), possibly Ladinian (Middle Triassic) age. A single ceratitic ammonite found in outcrop on the mainland near Keskain Island during our fieldwork may help define this range. In the adjacent Birds Head of Irian Jaya marine sedimentation resumed in the Late Carboniferous with the deposition of the fluvio-deltaic Aifam Group (VISSER & HERMES, 1962; PIGRAM & SUKANTA, 1982). The Keskain Formation might be, in part, a deep-water equivalent of the Aifam Group.

Bogal Limestone (TRub)
Reference section: Cape Bogal, southern Misool Island

Deep-water sedimentation came to an abrupt halt during the late Carnian, when uplift and block faulting produced a very shallow marine environment which led to the deposition of reefal and platform limestones (Bogal Limestone) throughout the Buru-Misool region. Bogal Limestone and the Lios Marl Member are lithostratigraphic names for the *Athyrides* (or *Misolia*) Limestone and *Nucla* Marl of BOEHM (1910), WANNER (1910b) and VAN BEMMELEN (1949). The highly fossiliferous Lios Marl Member crops out only on Lios Island which is now joined to Kafal Island by a sand spit. The Lios Marl appears to be a very local sandy bank subfacies developed within platform facies represented by the Bogal Limestone.

Fageo Group (Jf)

It is within the Fageo Group that the greatest confusion and readjustment has occurred in the past (see Table I).

The two principal stratigraphic problems are the correlation within the upper part of the Fageo Group (our Lelinta Shale), and the position of the '*Aucella* Sandstone' (which we no longer recognize).
These problems have been solved by demonstrating in the field that:
– the shale around Lelinta Village (Lelinta Clays, etc.) and the shale on the north side of Facet Island (Facet Clays, etc.) form parts of the same lithostratigraphic unit. Table I shows that most previous workers have regarded these as separate units, one either overlying or underlying the other, and that some authors have inserted a third unit in between.
– the '*Aucella* Sandstone' occurs only in western Misool Island where it is the basal sandy part of the Facet Limestone Group overlying the Lelinta Shale (Fig. 4).

Yefbie Shale (Jlmy).
Reference section: west coast, Yefbie Island.

The Yefbie Shale (Fig. 3) is the lithostratigraphic unit which contains BOEHM's (1910) *Harpoceratid* Beds and *Hammatoceras* Beds near the base and STOLLEY's (1929) *Prodicoelites* and *Persulcates* marl and limestone in the upper part (Table I). The basal quartz sandstone horizon was first noted by WANNER (1931). Subsequent authors used combinations or variations on these names for their columns.

The Yefbie Shale outcrop is restricted to the Yefbie Island region and both the basal contact and the top contact of the Formation are seen in outcrop; the base is exposed at Cape Bogal and the contact with the overlying Demu Formation is exposed on the west coast of Yefbie Island.

Demu Formation (Jud).
Reference section: southwestern Yefbie Island.

The Demu Formation is synonymous with BOEHM's (1910) Demu Limestone which he placed wrongly above his 'Lelinta Clays' (Table I). WANNER (1910b) changed it to the correct position beneath the 'Lelinta Clays'. Several belemnite zones exist within the Demu Formation. STEVENS (1965a) placed four belemnite assemblage zones within the Demu Formation, but confirmation or otherwise of these zones awaits detailed work on our collections. We have placed SKWARKO's (1981) unit 10, 'Sandy limestone with grooved belemnites', at the base of the Demu Formation and his unit 15, 'Marls above Demu Limestone', in the Lelinta Shale.

Lelinta Shale (Jul).
Reference section: coastline near Lelinta Village (base) and northeast Facet Island (top).

The youngest formation within the Fageo Group is the Lelinta Shale of which the outcrop is comparatively poor, but its Kimmeridgian-Tithonian beds are richly fossiliferous and therefore of considerable importance.

Our lithostratigraphic unit, Lelinta Shale, established by correlating the shales near Lelinta Village and at Facet Island, includes the following units defined by earlier authors: Lelinta Clays and Facet Clays (BOEHM, 1910), Lelinta Clays (STOLLEY, 1929), Lelinta Marl Schist, *Inoceramus* Limestone and Facet Schist (WANNER, 1931), Lelinta Marl, lower Facet Shale, upper and uppermost Facet Shale (STEVENS, 1965a) and Lelinta Marly Shale, Platey Limestone and Facet Shale (VAN BEMMELEN, 1949), and SKWARKO's (1981) Lelinta Clay, *Inoceramus* platey limestone, lower Facet Shale, upper Facet Shale, uppermost Facet Shale and the 'marl above the Demu Limestone'.

BOEHM (1910) wrongly inserted the Demu Limestone between his Lelinta Clays and Facet Clays. The Lelinta Clays were assigned to a number of positions until VAN BEMMELEN (1949) placed them correctly above the Demu Limestone.

Several assemblage zones, recognised within the Lelinta Shale, provide reference points that permit resolution of the nomenclature problems that have plagued this part of the stratigraphic succession. The lowest assemblage consists of two belemnites (*Belemnopsis* sp. and *Hibolithes* sp.) scattered throughout the basal layers of the Lelinta Shale along the coast of Misool Island near Lelinta Village. The second level is a characteristic horizon of dark grey shale with abundant highly fossiliferous concretions, which contain well preserved ammonites, *Belemnopsis* sp. and *Inoceramus* sp. This horizon is only known from two localities, one on the southern side of Biga Bay and the other on the south coast of Misool Island approximately 7 km west of Lelinta Village. The third assemblage zone corresponds to WANNER'S (1931) '*Inoceramus* platey limestone' which crops out in Biga Bay as a 30 cm thick bed of limestone with a very rich fauna of large *Inoceramus* sp., *Malayomaorica* sp. and rare ammonites and belemnites. The same fauna is found in the overlying shale but is more difficult to sample as the shale fractures on exposure. This same fauna is the lowest assemblage exposed on Facet Island where it occurs in shales and minor marl. This fauna provides the link between the outcrops of Biga Bay and Facet Island and the proof that the Lelinta Clay and Facet Shale of previous authors are the same lithostratigraphic unit. A fourth assemblage zone on Facet Island, crops out 22 m above the third assemblage, in a maroon (?tuffaceous) shale and marl and contains *Buchia* sp. and *Belemnopsis* sp.. This assemblage is important in the following discussions of the '*Aucella* Sandstone' problem. The maroon shales are overlain by the transition zone from the Lelinta Shale to the Facet Limestone Group. The fifth assemblage zone of *Inoceramus* sp. and *Belemnopsis* sp. is found in siltstones within this transition zone. The base of the Facet Limestone Group is placed where calcilutite becomes dominant over the shales in the sequence. This occurs over a 10 m interval and possibly within the fifth assemblage zone.

The 'Aucella Sandstone' Problem. The '*Aucella* Sandstone' was erected by WANNER (1910b), but the stratigraphic position of this unit has since changed more frequently than that of any other unit from the Misool Archipelago. We propose to abandon the name since we can demonstrate in the field that the *'Aucella* Sandstone' is in fact the basal part of the Facet Limestone Group, in western Misool Island.

The *'Aucella* Sandstone' is confined to the southern coast of Misool Island near the western tip (WANNER 1910b, p. 484) and consists of well bedded sandy limestone separated by very thin shale horizons less than 5 cm thick. The limestone usually contains grey chert nodules. Well preserved *Aucella* (now *Buchia* and *Malayomaorica*), belemnites and rare ammonites occur within the limestone. Minor faulting near the southwestern tip of the island and the great distance of these rocks from exposures around Lelinta Bay are probably the principal causes of the longstanding ucertainty regarding the correct stratigraphic level of the *'Aucella* Sandstone'.

Lithologically the *'Aucella* Sandstone' belongs to the Facet Limestone Group, and more specifically to the Gamta Limestone. Biostratigraphically the fauna of the *'Aucella* Sandstone' is identical to that of the fourth assemblage zone found in the tuffaceous maroon shales at the top of the Lelinta Shale on Facet Island.

Deposition of sandy limestone began a little earlier in western Misool Island than at Facet Island and the transition zone above the fourth assemblage zone at the top of the Lelinta Shale on Facet Island is equivalent to the base of the Facet Limestone Group (*'Aucella* Sandstone') in western Misool Island (Fig. 4). Furthermore the Facet Limestone forms a very prominent dip slope on Misool Island (crossed in several places by field parties) and can be traced on airphotos from the Biga Bay region to outcrops of *'Aucella* Sandstone' in western Misool Island.

The 'Tuffit Sandstone' of STOLLEY (1929) is presumed to be a very weathered tuffaceous sandstone cropping out near Lelinta Village which might correlate with the maroon shale

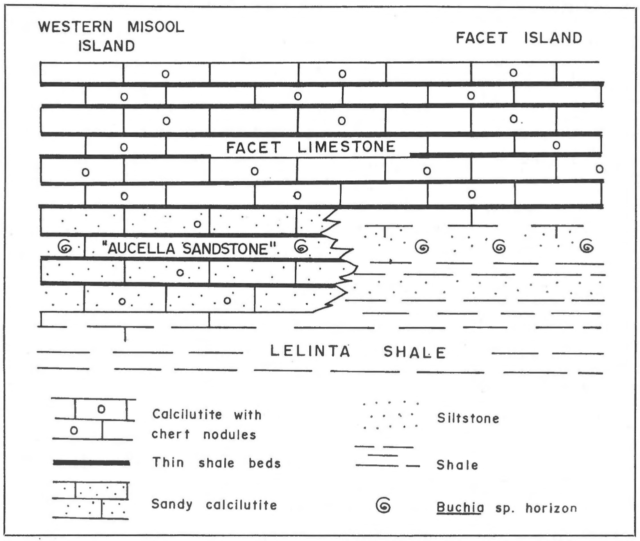


Fig. 4
Diagram showing inferred relationship between the base of the Facet Limestone Group in western Misool Island (formerly the *'Aucella* Sandstone') and the top of the Lelinta Shale at Facet Island.

near the top of the Lelinta Shale and hence the *'Aucella* Sandstone', or it may be an older horizon. Detailed palaeontological study may provide the answer.

Facet Limestone Group (JKf)
Reference section: eastern Facet Island

The Facet Limestone Group is a very distinctive sequence in which all previous workers have recognised a lower and upper unit, which are here referred to as the Gamta Limestone and Waaf Formation, respectively.

The Jurassic-Cretaceous boundary occurs within the Gamta Limestone and is taken at the first appearance of the compressed belemnite *Duvalia* sp., approximately 15 m above the base of the Facet Limestone Group at Facet Island.

The Waaf Formation is highly tuffaceous and the source of volcanic detritus was probably to the north where thick volcanics of this age have been penetrated in petroleum exploration wells.

Fafanlap Formation (Kuf)
Reference section: Fafanlap Formation; west coast of Yabatano Island, Yabatano Member; northwest coast of Yabatano Island

The Fafanlap Formation is named after Fafanlap Village in northern Lelinta Bay. The conformable contact between the underlying Facet Limestone Group and the Fafanlap Formation can be seen on the southwest coast of Babalan-Batano and Yabatano Islands. The base of the Formation is highly tuffaceous and volcanism continued through the radical change from a bathyal to a shallow-marine deltaic environment during the deposition of the Fafanlap Formation. The Fafanlap Formation crops out extensively on the islands forming the eastern side of Lelinta Bay.

The Yabatano Member of the Fafanlap Formation has not been recognised previously. The upper part of the Fafanlap Formation clastic section becomes progressively finer and is rapidly replaced by thinly bedded nodular limestone of the Yabatano Member.

Daram Sandstone (Ted)
Reference section: Daram Island

The Daram Sandstone is named after Daram Island in the eastern part of the Misool Archipelago. The thinly bedded Yabatano Member is abruptly succeeded by coarse to medium grained calcareous quartz sandstone and sandy limestone of the Daram Sandstone. The contact between the Yabatano Member and the Daram Sandstone is exposed on the north and west coasts of Kalig Island.

The source of the coarse detritus making up the Fafanlap Formation and Daram Sandstone is not known. It may have been the western Birds Head of Irian Jaya, as basement highs were known to persist in this area until the Miocene (PIGRAM & PANGGABEAN, 1981).

Cainozoic limestone

The age range and distribution of the Tertiary limestones of the Misool Archipelago have been known since ROGGEVEEN'S (1939) survey, but until now no lithostratigraphic nomenclature has been applied. Although the facies are similar throughout the Tertiary, the limestones comprise several units separated by angular unconformities and paraconformities. The entire section is similar to the New Guinea Limestone of Irian Jaya (VISSER & HERMES, 1962) although no unconformities have yet been recognised there. Descriptions of the Cainozoic limestones is restricted to that presented in Fig. 3, as we did not examine the Cainozoic section in the same detail as the Mesozoic section.

Zaag Limestone (Teoz)
Reference section: Pana Pana Strait, eastern Misool Island

The Palaeocene to Oligocene Zaag Limestone is named after the Zaag Mountains which are capped by this Formation. The Zaag Limestone is equivalent to the Faumai Limestone of the Birds Head in Irian Jaya (VISSER & HERMES, 1962).

A G E		STRATIGRAPHIC UNIT	TECTONIC STAGE
CAINOZOIC		CARBONATES	open marine POST BREAK UP
		DARAM SANDSTONE	
CRETACEOUS	L	FAFANLAP FORMATION	
	E	FACET LIMESTONE	
JURASSIC	L	LELINTA SHALE	
		DEMU FORMATION	
	M	YEFBIE SHALE	?—?—?—?—? restricted marine
	E	post break up unconformity	BREAK UP uplift, block faulting
TRIASSIC	L	BOGAL LIMESTONE	
	M	KESKAIN FORMATION	
	E		PRE BREAK UP stable platform
PERMIAN			
CARBONIFEROUS			
DEVONIAN			
SILURIAN		LIGU METAMORPHICS	
ORDOVICIAN			

Fig. 5
Generalised stratigraphic table relating the stratigraphy of the Misool Archipelago to the tectonic stages of a rift-drift sequence.

Kasim Marl (Tmk)
Reference section: middle reaches Kasim River, Misool Island
The Zaag Limestone is partly unconformably and partly paraconformably overlain by the Early Miocene Kasim Marl which is named after the Kasim River and underlies a large central depression on Misool Island. The Kasim Marl is equivalent to the Sirga Formation of the New Guinea Limestone Group of Irian Jaya.

Openta Limestone (Tmo)
Reference section: On the track, south of Atkari Village

The Miocene Openta Limestone rests conformably on the Kasim Marl and unconformably on the Fafanlap Formation and Facet Limestone Group in western Misool. This unconformity is not found in the platform sequence of western Irian Jaya and is discussed below. The Openta Limestone is equivalent to the Kais Limestone of the New Guinea Limestone Group.

Atkari Limestone (TQa)
Reference section: Cape Yamtu, northeast Misool Island

The north coast of Misool Island, east of the Kasim river and the islands to the north, consists mainly of uplifted Plio-Pleistocene reef complexes herein called the Atkari Lime stone after Atkari Village.

REGIONAL IMPLICATIONS OF THE MISOOL STRATIGRAPHY

The Misool Archipelago lies on a prominent east-west salient of continental crust (BOWIN ET AL., 1980) which is now linked to the Australian continent through western Irian Jaya.

In an attempt to explain the rapid facies changes found throughout the Mesozoic of western Irian Jaya, PIGRAM & PANGGABEAN (1981) proposed a continuation of the northwestern Australian rift-drift sequence into eastern Indonesia.

The timing of events related to the break-up of northern Gondwana and the opening of the Indian Ocean are well documented in northwest Australia (POWELL, 1976; BROWN, 1979) but within eastern Indonesia the timing of events is obscured by young tectonism (Ceram) and lack of dateable sediments (Irian Jaya). The Misool Archipelago, with an almost complete and highly fossiliferous Mesozoic section, provides precise timing of the major events related to the opening of the Indian Ocean in this region.

Fig. 5 relates the stratigraphy of the Misool Archipelago to the tectonic stages of a rift-drift sequence and Fig. 6 compares the timing of events in western Irian Jaya with those of northwest Australia.

The Keskain Formation belongs to the pre-break-up phase;

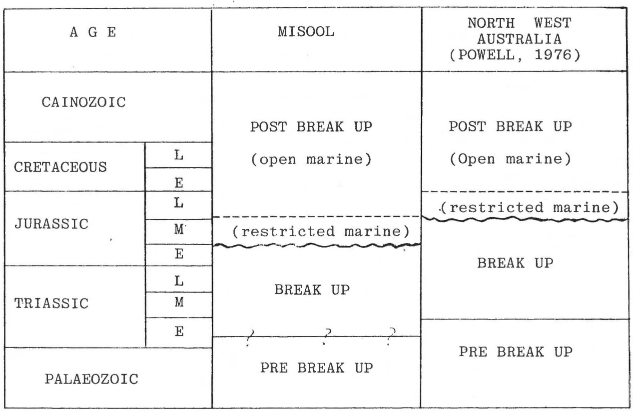


Fig. 6
Comparison of the timing of events in the rift sequence of northwest Australia and western Irian Jaya (after Pigram & Panggabean, 1981).

while the block faulting of the Keskain Formation in the early Late Triassic marks the beginning of the break-up phase, during which thermal doming, uplift and block faulting changed the sedimentation regime from deep water marine to shallow marine and eventually non-marine in which initially reef and platform carbonates (Bogal Limestone) were deposited. The break-up unconformity is of early Jurassic age. This marks the return of marine conditions as the region subsided again due to cooling as the continental crust separated from the spreading centre.

By comparison with northwest Australia the break-up and post-break-up phases both occur a little earlier in eastern Indonesia. The post-break-up unconformity is late Early Jurassic at Misool and late Middle Jurassic on the northwest shelf of Australia (POWELL, 1976). As might be expected, this timing of events indicates that drifting started earlier in eastern Indonesia and progressed southward, eventually separating India from southern Western Australia.

Late Oligocene Unconformity

The Late Oligocene folding episode on Misool appears to be a unique event for a platform area in this region. No folding of this age occurred in the southern Birds Head or on the platform area of southern Irian Jaya; AUDLEY-CHARLES ET AL. (1979) suggested that the deformation of Ceram is much younger; Late Miocene to Early Pliocene.

However, Late Oligocene is the age of the major orogenic movements in the central orogenic belt of Irian Jaya and Papua New Guinea, where the deformation is attributed to a north-facing continent-island arc collision (DOW, 1977; JAQUES & ROBINSON, 1977).

The deformation of the Misool Archipelago which is situated almost centrally on a salient of continental crust, at the same time as the start of the major orogenic event in Irian Jaya is enigmatic and not understood by us. One possible solution is that the folding was a product of the large-scale wrench faulting, along the Sorong Fault Zone to the north, which saw the Sula spur detached and transported westward at about this time (HAMILTON, 1979). Contemporaneous folding may have occurred in the Ceram-Buru region but has been obscured by younger deformation.

GEOLOGICAL HISTORY

The Palaeozoic sediments comprising the Ligu Metamorphics were deposited by turbidity currents in deep water and then subsequently folded and metamorphosed during Devonian to Carboniferous times. The turbidite sequence of the Keskian Formation was deposited in deep water. Deep water sedimentation ceased abruptly in the early Late Triassic when thermal doming, accociated with the initiation of break-up of northern Gondwana, caused uplift and block faulting. Reefal and platform limestones (Bogal Limestone) were deposited on horst blocks initially, followed by a period of nondeposition caused by continuing block faulting and uplift, accompanied by a worldwide lowering of sea level.

Marine sedimentation returned to the region in the late Early Jurassic owing to the combined effects of thermal subsidence as the continents moved away from the newly formed spreadings centres, and a rise in sea level (VAIL & MITCHUM, 1979).

The area received only very fine sediments throughout the Jurassic and Early Cretaceous during the deposition of the Fageo Group and the Facet Limestone Group. During periods in which the area was starved of mud, bathyal limestones (Demu Formation and Gamta Limestone) were deposited.

Conditions changed dramatically in the Late Cretaceous with a rapid influx of thick deltaic deposits of the Fafanlap Formation. A carbonate regime started to re-establish itself during the early Tertiary although sand was still coming into the region. By Eocene times shoal carbonates were being deposited throughout eastern Indonesia. This carbonate regime was interrupted at the end of the Oligocene by a folding event which produced the anticlinorium and faults which control the present distribution of islands within the Misool Archipelago.

Sedimentation resumed in the Early Miocene with deposition of the Kasim Marl. As source areas were drowned, carbonate platform facies deposition resumed (Openta Limestone). Uplift and minor faulting at the end of the Miocene produced the irregular basement across which the Atkari Limestone was depositied. Minor continuing uplift has exposed the younger limestone around the north coast and on the many small islands to the north.

CONCLUSIONS

The following conclusions have been drawn from our recent work in the Misool Archipelago:

1. An almost complete, highly fossiliferous marine Mesozoic and Cainozoic sequence is present in the Misool Archipelago.
2. The only major graps in the sequence are dated as Early Triassic, Early Jurassic and Late Oligocene.
3. Unconformities exist between the Ligu Metamorphics and Keskain Formation, Keskain Formation and Bogal Limestone, Bogal Limestone and Yefbie Shale, and the Zaag Limestone and Kasim Marl. These unconformities are of approximately ?Late Palaeozoic, early Late Triassic (?Carnian), Early Jurassic and Late Oligocene age, respectively.
4. A basement of metamorphosed turbidites, probably of Siluro-Devonian age, is present.
5. The Lelinta Clays, Facet Clays, Facet Slates, Facet Schist and Facet Shale are all the same lithostratigraphic unit, here called the Lelinta Shale.
6. The '*Aucella* Sandstone' forms the base of the Facet Limestone Group, in western Misool.
7. Late Jurassic limestone deposition started slightly earlier in western Misool Island than at Facet Island.
8. The Misool sequence is part of a rift-drift sequence related to the opening of the Indian Ocean.
9. Rifting and spreading were initiated approximately 10-15 Ma before similar events off northwest Australia (post break up unconformity in the Misool Archipelago is 185 Ma compared to 170 Ma in northwest Australia).
10. A major folding and faulting event affected the Misool region during Late Oligocene-Early Miocene times.

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