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## RECOGNITION AND CORRELATION OF THE KAPITEAN STAGE (UPPER MIOCENE, NEW ZEALAND)

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### ABSTRACT

The salient features of New Zealand Upper Miocene and Lower Pliocene microfaunas are outlined, and criteria for recognising the Kapitean Stage are summarised. Paleoeological evidence suggests that the Kapitean Age was a time when seas were relatively shallow, that the shallowing took place in the latest part of the Tongaporutuan Age, and that deepening took place in the earliest part of the Opoitian Age. The changes in sea level caused many changes in the fauna, and the Kapitean Stage is soundly based only on relatively few permanent changes of both macrofauna and microfauna. The Kapitean Stage is represented by shallow-water facies at many places, but it contains some moderately deep-water facies at other places. The two facies contain very few diagnostic fossils which are common to both, but usually can be correlated by a bioseries of planktonic Foraminifera—the *Globorotalia crassaformis* bioseries. In nearly all sections the Kapitean Stage is thin compared with the overlying Opoitian and the underlying Upper Tongaporutuan, and this is attributed to a decreased rate of deposition caused by shallowing and increased by-passing of sediment. Kapitean microfaunas show a slight but distinct change from north to south, and this is attributed to latitudinal temperature difference.

The previously proposed correlation of the Kapitean Stage with the Pontian Stage of Europe is probably correct. The predominantly shallow seas during the Kapitean Age in New Zealand appear to have coincided with a regression in Europe and in other parts of the world, and are likely to have a eustatic rather than a tectonic cause.

### INTRODUCTION

The following account summarises the results of a thesis prepared for the Doctor of Philosophy degree at Victoria University of Wellington. The thesis comprises regional studies of the Upper Miocene to Lower Pliocene succession in New Zealand, with special reference to the Kapitean Stage.

The distribution of Kapitean strata was summarised by Finlay and Marwick (1948), and Hornibrook (*in Fleming*, 1959), and is here shown by a map (Fig. 1). The intercorrelations of foraminiferal and molluscan zones established for different parts of New Zealand, and their relationship to the New Zealand stages, are shown in Table 1.

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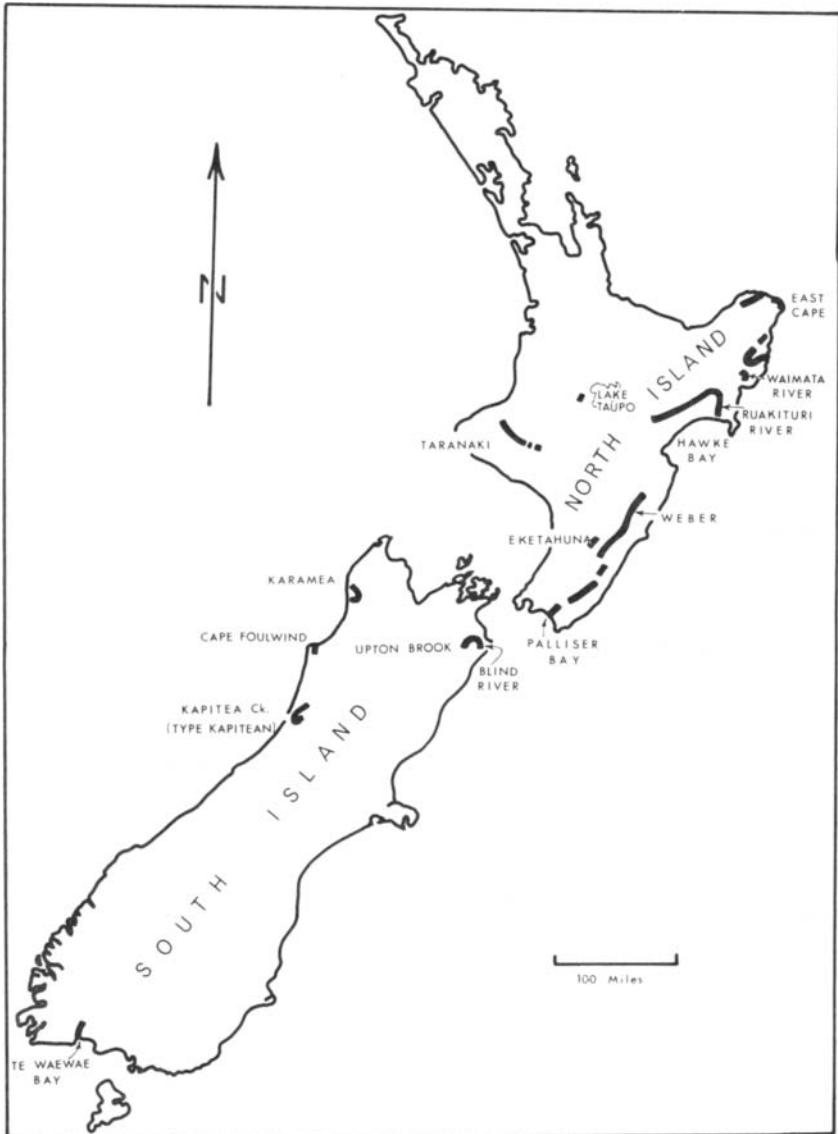


FIG. 1—Distribution of sediments of Kapitean Age (solid black lines). The width of outcrop of Kapitean sediments is exaggerated.

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## KENNETT - KAPITEAN STAGE

TABLE 1. Chart Showing Intercorrelation of Foraminiferal and Molluscan Zones for the Upper Miocene to Lower Pliocene of New Zealand

STAGES		NORTH WESTLAND ZONES (Kennett, 1965)		MARLBOROUGH ZONES (Kennett, 1965)		WAIKARAPPA ZONES			DAMES BAY FORAMINIFERAL ZONES (Kennett, 1965)	TARANAKI ZONES			
Europe	New Zealand	Foraminiferal Zones	Molluscan Zones	Foraminiferal Zones	Molluscan Zones	Foraminiferal Zones		Molluscan Zones		Informal zones based on present work; Gibson, 1963; and Boreham 1961.		Foraminiferal Zones (Geiger, 1962)	
						Mauriceville (Vella, 1962)	Kennett 1965			Foraminifera	Mollusca		
Aetian - Pliaisancien	Waitotaran - Opoitian	Finlayi	Chrydsea	-	-	Molestus ?	Inflata		-		-	Globorotalia Truncatulinoides Zone	
	Opoitian	Crassaformis	-	Crassaformis	Allani	Inflata	Crassaformis		Crassaformis		Phialopecten aff. triphoki	Globorotalia inflata Zone	
Pontian	Kapitean	Conomiozea	Coerulescens Wollastoni	Conomiozea	Wollastoni	Zeserus		Wollastoni			Sectipecten wollastoni	Globigerina Nepenthes Zone	
Sarmatian	Upper	Mecinesei	Grangei				Zeserus		Conomiozea		Globorotalia conomiozea		Sectipecten grangei
				Pilozoa	-	Compressa	Pilozoa		Compressa		Bolivinita compressa (rare)		?
	Middle	missing	missing					Grangei					
	Tongaporutuan			Pohana	Harupensis		Pohana		Pohana		Bolivinita pohana		
Lower		Quadrilatera	Cliftonensis							Bolivinita quadrilatera			
Tortonian	Waiuan	Truncatum	-										

## CRITERIA FOR RECOGNISING THE KAPITEAN STAGE

The writer has examined 17 stratigraphic sections between Westland and East Cape (Kennett, 1966a, b, c, e). The Kapitean Stage is represented by shallow and moderately deep-water facies; the diagnostic Kapitean fossils in shallow-water facies are in the main different from those in moderately deep-water facies. The two main facies divisions are therefore discussed separately.

*Shallow-water Facies*

(1) In shallow-water facies the base of the Kapitean Stage is generally marked by the appearance of the key Kapitean Mollusca *Sectipecten wollastoni* (Finlay) and *Austrofusus coeruleus* (Finlay), and by the absence of the Tongaporutuan species *Sectipecten grangei* Boreham. The top of the stage is usually determined by the appearance of the planktonic foraminiferal species *Globorotalia crassaformis* (Galloway and Wissler) as discussed below.

The shallow-water facies at Upton Brook, Marlborough, does not contain the critical planktonic species, and the upper boundary there was assumed by me to be at a horizon where a marked change takes place in the molluscan faunas—immediately above the highest occurrence of *Cucullaea*, which marks the top of the Kapitean.

(2) The foraminiferal species *Textularia miozea* Finlay became extinct at the end of the Tongaporutuan Age, its highest known occurrences being in the uppermost Upper Tongaporutuan at Cape Foulwind on the West Coast and at Ruakituri River in northern Hawke's Bay. *T. kapitea* Finlay, the derivative of *T. miozea*, occurs spasmodically in pre-Kapitean sediments at a few localities, but was most abundant during the Kapitean.

(3) The *Siphotextularia wairoana* bioseries (Kennett, 1966c) is useful for recognising the Kapitean Stage in shallow-water facies in the South Island and the southern part of the North Island. In these areas *Siphotextularia dawesi* Kennett gradually changes from the Upper Tongaporutuan through the Kapitean, to give rise to *Siphotextularia wairoana* Finlay just above the base of the Opoitian Stage. Absence of much of this bioseries in the Mangatainoka Valley, 6 miles south-west of Eketahuna, Wairarapa, supplies supporting evidence for a disconformity cutting out the Kapitean Stage. In sections where there is a continuous succession of suitable facies from the Upper Tongaporutuan to the Opoitian, the *S. wairoana* bioseries is unbroken.

The Significance of *Bulimina aculeata* and *Textularia kapitea*

Until recently (Hornibrook, 1958) the first appearances of the shallow-water species *Bulimina aculeata* d'Orbigny and *Textularia kapitea* were thought to mark the base of the Kapitean Stage, but these species have recently been found in sediments somewhat older than Kapitean (Boreham, 1961; Gibson, 1967; Kennett, 1966b). In the Eketahuna district, Wairarapa, *B. aculeata* and *Textularia kapitea* occur in shallow-water sediments of Middle Tongaporutuan age, are absent for some thousands of feet in deep-water

sediments of Middle to Upper Tongaporutuan age, but reappear in abundance in the shallow-water sediments of uppermost Tongaporutuan and Kapitean age. Similarly, in the Palliser Bay section *B. aculeata* occurs in shallow-water sediments of Lower Tongaporutuan and uppermost Tongaporutuan–Kapitean age, but is absent in the intervening deep-water sediments of Middle Tongaporutuan age. Thus it is easy to understand how the mistaken impression arose that *B. aculeata* and *T. kapitea* make their first appearance at the base of the Kapitean Stage.

#### *Deep-water Facies*

Until recently (Kennett, 1966b) the base of the Kapitean Stage could not be recognised definitely in deep-water facies. The *Globorotalia crassaformis* bioseries (Kennett, 1966d), a succession of planktonic Foraminifera showing gradual changes in form, has proved to be extremely useful for determining the base and top of the Kapitean Stage in both shallow and deep-water facies. It has been possible to utilise the gradational morphological changes to determine stratigraphic ranges of short-ranging deep-water and shallow-water benthonic fossils, including the key Kapitean Mollusca.

The base of the Kapitean Stage, as shown at Kapitea Creek, Westland, and Blind River, Marlborough, lies within the range of *Globorotalia conomiozea* Kennett, a member of the *Globorotalia crassaformis* bioseries, and is distinguished by the following characteristics of the *Globorotalia* population:

- (1) a dominance of strong-keeled forms with the number of non-keeled forms increasing above the boundary;
- (2) eighty to ninety percent of specimens with 4–4½ chambers, with the number of chambers increasing below and decreasing above the boundary;
- (3) the umbilical side strongly conical (average "conical angle" between 62°–65°) with the average "conical angle" decreasing below and increasing above the boundary;
- (4) the aperture generally narrow and high-arched, with more dominant slit-like or low and arched apertures below the boundary.

Throughout New Zealand the lowest part of the range of *G. conomiozea* is uppermost Upper Tongaporutuan, and at several places is associated with *Sectipecten grangei* and *Textularia miozea*. Most of the stratigraphic range of *G. conomiozea* overlaps with that of the key Kapitean Mollusca. The top of the Kapitean Stage is generally easy to recognise in all facies because, by definition, it is just below the first appearance of the planktonic species *G. crassaformis* (Galloway and Wissler) = *G. crassula* Cushman and Stewart, which is found in almost all marine strata of Opoitian age. This species is the end member of the *G. crassaformis* bioseries, and its first appearance in the type section of the Kapitean Stage marks the top of the Kapitean as defined by Finlay and Marwick (1947).

McInnes (1965), when describing the same bioseries from northern Hawke's Bay, placed the Kapitean–Opoitian boundary at the position of

the lowest sample containing forms of the *G. crassaformis* (*G. inflata*)† type. However, as *G. crassaformis* was a member of an evolving bioseries, I have arbitrarily placed the Kapitean-Opoitian boundary where *G. crassaformis* constitutes 50% of the *G. conomiozea* - *G. crassaformis* sample. Consequently, in McInnes's section I regard the Kapitean-Opoitian boundary as occurring about 200 ft stratigraphically above his boundary.

#### LISTS OF SPECIES USED FOR DETERMINING THE KAPITEAN

The following lists show those species which seem to be useful for recognizing the Kapitean Stage. As work proceeds the ranges of many species are bound to be modified. Only the more useful molluscan species are included, as fairly complete lists are given by Marwick (1965). Species marked with an asterisk (\*) have been abstracted from literature and have not been found in the sections studied by the writer.

#### TONGAPORUTUAN STAGE

##### Last appearances, Foraminifera

- |  |   |
|--|---|
| <i>Textularia miozea</i> Finlay                            | * <i>Rectobolivina maoriella</i> Finlay                     |
| <i>Textularia crater</i> Kennett                           | <i>Rectobolivina parvula</i> Finlay                         |
| <i>Siphotextularia kreuzbergi</i> Finlay                   | <i>Bolivinita quadrilatera</i> (Schwager)                   |
| <i>Vulvulina pennatula</i> (Batsch)                        | <i>Ehrenbergina willetti</i> (Finlay)                       |
| <i>Migros medwayensis</i> (Parr)                           | <i>Pleurostomella parviapertura</i> Kennett                 |
| <i>Clavulinoides instar</i> Finlay                         | <i>Nonionella novozealandica</i> Cushman                    |
| <i>Ruakituria pseudorobusta</i> Kennett                    | <i>Planulinoides hamasuturalis</i> Kennett                  |
| <i>Karrieriella fastigata</i> Kennett                      | <i>Buningia creeki</i> Finlay                               |
| <i>Arenodosaria turris</i> Kennett                         | <i>Ceratobulimina kellumi</i> Finlay                        |
| <i>Martinottiella massami</i> Gibson                       | * <i>Ceratobulimina (Ceratobulimina)</i>                    |
| <i>Massilina subaequalis</i> (Parr)                        | <i>clifdenensis</i> Finlay                                  |
| <i>Cruciloculina ericsoni</i> Loeblich and Tappan          | <i>Notorotalia cf. depressa</i> Vella                       |
| <i>Spiroloculina canaliculata</i> d'Orbigny                | <i>Notorotalia macinnesi</i> Kennett                        |
| <i>Spiroloculina kennetti</i> Gibson                       | <i>Notorotalia pristina</i> Vella                           |
| <i>Parafrendicularia fyfei</i> (Finlay)                    | <i>Notorotalia mammiligera</i> Kennett                      |
| * <i>Bulimina miolaavis</i> Finlay                         | <i>Discorotalia aranea</i> (Hornibrook)                     |
| <i>Bulimina senta</i> Finlay                               | <i>Globoquadrina debiscens</i> (Chapman, Parr, and Collins) |
| <i>Bulimina vellai</i> Gibson                              | <i>Globorotalia opima continuosa</i> Blow                   |
| <i>Fursenkoina bramletti</i> (Galloway and Motrey)         | <i>Globorotalia menardii</i> panda Jenkins                  |
| <i>Eouvigerina notobispida</i> (Finlay)                    | <i>Anomalina aotea</i> Finlay                               |
| <i>Hofkeruva mioschwageri</i> (Finlay)                     | <i>Cibicides mediocris</i> Finlay                           |
| <i>Rectuvigerina pobana</i> (Finlay)                       | <i>Cibicides cf. novozealandicus</i> (Karrer)               |
| *? <i>Angulogerina australis</i> (Heron-Allen and Earland) | <i>Cibicides thiaracutus</i> Hornibrook                     |
| * <i>Rectobolivina hangaroana</i> Finlay                   | * <i>Planulina catillus</i> (Finlay)                        |
|  | Last appearance, Mollusca                                   |
|  | <i>Sectipecten grangei</i> Boreham                          |

†*Globorotalia inflata* (d'Orbigny) of McInnes (1965) and *G. miozea sphericomiozea* Walters (1965) are regarded by the writer as synonyms of *G. crassaformis*. *Globorotalia miozea* (spherical variety) of McInnes is regarded by the writer as a thicker-shelled variant of *G. conomiozea*.

## KAPITEAN STAGE

## Restricted, Foraminifera

*Quinqueloculina waimea* Kennett  
*Fronidularia longistriata* Cushman  
*Eponides tuberculatus* (Balkwill and Wright)

Last appearances, Foraminifera  
*Textularia subrhombica* Stache  
*Siphotextularia awamoana* Finlay  
*Bulimina mapiria* Finlay  
*Bulimina truncanella* Finlay  
*Kolesnikovella zealandica* Kennett  
*Brizalina lapsus* (Finlay)  
*Brizalina turbiditorum* (Vella)  
*Bolivinita elegantissima* Boomgaardt  
*Cassidulina cuneata* Finlay  
*Melonis mauricus* (Stache)  
*Florilus olsoni* Kennett  
*Valvulineria stachei* Hornibrook  
*Cancris lateralis* Finlay  
*Globoquadrina altispira globosa* Bolli  
*Cibicides araroa* Kennett

## Restricted, Mollusca

*Secipecten wollastoni* (Finlay)  
*Syrthiolaria cincta* Hutton  
*Austrofusus coerulescens* (Finlay)  
*Alciiboë gravicostata* King

## First appearances, Foraminifera

*Bolivinita finlayi* Kennett  
*Ammonia aoteana* (Finlay)  
*Elphidium novozealandicum* Cushman  
*Globigerinoides obliquus* Bolli

## Last appearances, Mollusca

*Cucullaea* n.sp.  
*Notocorbula humerosa* (Hutton)

## First appearances, Mollusca

*Marama* cf. *murdochi* Marwick  
*Nemocardium quinarium* Marwick  
*Dentalium zelandicum* Sowerby

## OPOITIAN STAGE

## First appearances, Foraminifera

*Siphotextularia wairoana* Finlay  
 \**Staffia multicostrales* (Finlay)  
*Neouvigerina bellula* Vella  
*Hofkeruva delicatula* Vella  
*Hofkeruva rodleyi tutamoides* Vella  
*Hofkeruva pliozea* Vella  
*Bolivina robusta* Brady  
*Bolivina silverstrina* Cushman  
*Ehrenbergina mestayeri* Cushman  
*Melonis lutorum* Vella

*Rosalina paupereques* Vella  
*Gavelinopsis hamatus* Vella  
*Notorotalia finlayi* Vella  
*Notorotalia kingmai* Vella  
*Notorotalia olsoni* Vella  
*Globigerinoides rubra* (d'Orbigny)  
*Globorotalia crassaformis* (Galloway and Wissler)  
*Globorotalia hirsuta* (d'Orbigny)  
*Globorotalia inflata* (d'Orbigny)

## CHANGES IN DEPTH OF THE SEA DURING LATE MIOCENE AND EARLY PLIOCENE TIMES

In most Upper Miocene to Lower Pliocene sections studied by the writer, marked changes in faunas and sediments indicate that the sea shallowed appreciably near the end of the Tongaporutuan Age, remained shallow during the Kapitean Age, and deepened again about the beginning of the Opoitian Age. The sections that show this sequence of depth changes are as follows:

Cape Foulwind, Nelson  
 Upton Brook, Marlborough  
 Blind River, Marlborough  
 Palliser Bay coast  
 Mangaoranga Road, Eketahuna  
 Putara, Mangatainoka Valley

Ngamaia Stream, Mangatainoka Valley  
 Maraetotara River, central Hawke's Bay  
 Ruakituri River, northern Hawke's Bay  
 Waimata River, Gisborne



Details of lithological and faunal changes which indicate the depth fluctuations are given in Kennett (1962, 1966a, b, c, e).

No detailed paleoecological analysis of the faunas from Taranaki region was made, but the lithological succession there suggests depth changes similar to those elsewhere. The uppermost Tongaporutuan and Kapitean sediments are generally much coarser than those above and below, and they contain more numerous pebbly shell beds and conglomerate bands.

Sections where the uppermost Miocene shallowing was not recorded occur in the Greymouth basin in north Westland and at Weber in southern Hawke's Bay. In these areas much or all of the Tongaporutuan is missing owing to unconformities. The sea deepened during Kapitean time because of rapid tectonic downwarping.

### *Discussion*

The parallel biofacies changes in so many widely distributed sections strongly indicate that the Late Tongaporutuan shallowing and the Early Opoitian deepening affected a large part of New Zealand. From this it may be inferred that just before the Kapitean Age either sea level fell or the land over almost the entire area rose; and that just after the Kapitean either sea level rose or the lithosphere over almost the entire area sank.

The tectonic explanation requires synchronous vertical movements of the crust over a highly mobile area in which numerous blocks are known to have been tilting differentially (Wellman, 1956). This explanation is unlikely, because the synchronous depth changes occurred in at least two major tectonic units, the East Coast basin and the Wanganui basin, and these were probably affected by unrelated tectonic movements.

Changes of sea level provide a much less complicated mechanism. The chief objection to this mechanism is that the only sea level changes known to have occurred were glacio-eustatic changes caused by advances and retreats of continental ice sheets. Suess (1885) and Wells (1960) considered, however, that such changes of sea level could have been caused by increase and decrease in the capacity of the ocean basin caused by tectonic and sedimentational processes. Even if such processes are considered inadequate, as suggested by Vella (1965), there is no real evidence against the existence of a continental ice sheet in Antarctica during the Tertiary, and the possibility of glacio-eustatic changes in sea level in periods other than Pleistocene (or Late Paleozoic) times cannot be discounted.

Accurate values for the depth changes could not be determined because in each section the temporary depth changes are superimposed on secular deepening or shallowing caused by a combination of vertical crustal movements, sedimentation, and compaction of sediments. For example, the sequence of biofacies changes at Palliser Bay is from *Robulus* Biofacies to *Karreriella* Biofacies and back to *Robulus* Biofacies, suggesting little secular change in depth; but at Ruakutiri River the sequence is from the *Robulus* Biofacies through the *Karreriella* Biofacies to the *Elphidium* Biofacies, and back to the *Karreriella* Biofacies, suggesting secular shallowing. In general the temporary shallowing effect, as shown by depth correlation of the fossil

biofacies with present-day biofacies (Vella, 1962) was of the order of a few hundred feet. If the shallowing was caused by a lowering of the sea level, evidence for it should be found in uppermost Miocene to Lower Pliocene sediments elsewhere in the world. The Pontian Stage of Europe and North Africa has been considered equivalent to the Kapitean (Finlay, 1947; Fleming, 1959). According to Gignoux (1955) "the Miocene sedimentary cycle always ends in all Western Europe and North Africa with a period of emergence with which we associate the continental formation designated . . . the Pontian".

Shallowing during the Late Miocene is seen also in California, where littoral and terrestrial deposits were laid down in numerous basins (Kleinpell, 1938, p. 180); in Trinidad, where the uppermost Miocene Lengua Formation becomes coarser upwards and planktonic foraminifera become very rare (Bolli, 1957, p. 102); in the Dominican Republic, where sediments of uppermost Miocene age are of shallower-water facies than lower in the succession and are overlain by unfossiliferous and possibly non-marine deposits thought to be Pliocene (Bermudez, 1949); and in the State of Falcon, Venezuela, where the uppermost Miocene Ojo de Agua Formation is much coarser than the underlying sediments (Renz, 1948).

The changes in sea level were accompanied by marked changes in marine invertebrate faunas. Hornibrook (1958, p. 31) described the Tongaporutuan microfaunas as very distinctly "Miocene", containing many species that are known in the Southland Series (Lower and Middle Miocene), but not in the Wanganui Series (Pliocene to Pleistocene). At the end of the Tongaporutuan Age, and during the Kapitean Age, many Miocene species became extinct and many Recent species appeared. At the end of the Kapitean Age the microfauna was already similar to that of present day New Zealand seas. The most striking and significant changes were in the planktonic foraminifera; for instance, the planktonic species *Globigerina pachyderma* (Ehrenberg) and *Globigerina quinqueloba* Natland, which are generally regarded as characteristic of temperate and cool seas, and which occur only spasmodically in the Tongaporutuan, are abundant in the Kapitean; and *Globorotalia crassaformis* first appears and becomes a dominant species immediately above the Kapitean. At the same time keeled *Globorotalia* became relatively uncommon, though they did not disappear until the beginning of the Pleistocene. These changes in the planktonic foraminifera have generally been regarded as indicating a change from warm subtropical to more temperate sea temperatures (Hornibrook, 1958). This is confirmed by modern oceanographic research, as keeled *Globorotalia* have been found to be restricted to much warmer waters than are non-keeled ones (Bandy, 1964). The change in molluscan faunas that took place during Kapitean time, especially the extinction of *Cucullaea*, supports the suggestion of significant cooling.

#### LATITUDINAL VARIATION OF KAPITEAN FAUNAS

Faunas are generally richer in species to the north. Among the planktonic foraminifera the cool-water species *G. pachyderma* and *G. bulloides* d'Orbigny increase in abundance towards the south. Planktonic species which

occur in variable abundance in the north, and which are rarely found in the south, are *Globigerinoides trilobus* (Reuss), *Sphaeroidinella seminulina* (Schwager), *Globigerinoides obliquus* Bolli, and *Globoquadrina altispira globosa* Bolli.

The following benthonic species were found in the Kapitean Stage only to the north of Gisborne:

<i>Textularia</i> cf. <i>sagittula</i> DeFrance	<i>Brizalina lapsus</i> (Finlay)
<i>Frondicularia longistrata</i> Cushman	<i>Rectobolivina digitata</i> Parr
<i>Brizalina albatrossi</i> (Cushman)	<i>Rectobolivina maoria</i> Finlay
<i>Brizalina barnwelli</i> (Finlay)	<i>Kolesnikovella zealandica</i> Kennett

The following species were found only from Eketahuna northwards:

<i>Cibicides araroa</i> Kennett	<i>Bolivina plicatella</i> Cushman
<i>Cibicides porrodeliquatus</i> Kennett	

The following species are common only south of southern Hawke's Bay:

<i>Sigmoilopsis zeaserus</i> Vella	<i>Bolivinita pliozea</i> Finlay
<i>Fursenkoina vellai</i> Kennett	<i>Cibicides gibsoni</i> Kennett

The Kapitean microfaunas thus show a slight but distinct latitudinal variation, somewhat more pronounced amongst planktonic species than amongst benthonic species. The latitudinal range of the microfaunas studied, from Westland in the south to East Cape in the north, is approximately 5°, and the faunal differences are almost certainly due to differences in water temperature.

#### THICKNESS OF KAPITEAN SEDIMENTS

The following table shows the thickness in feet of sediments for the Upper Tongaporutuan and the Kapitean Stages in six sections throughout New Zealand. The base of the Upper Tongaporutuan was taken at the first appearance of *Bolivinita pliozea* and/or *Bolivinita compressa*.

	Up. Tongaporutuan	Kapitean
Upton Brook, Marlborough .....	2,200	900
Blind River, Marlborough .....	2,400	600
Palliser Bay .....	350	250
Mangaoranga Road, Eketahuna .....	400	300
Ruakituri River, northern Hawke's Bay .....	2,000	650
Waimata River, Gisborne .....	>2,300	900

In all cases the Kapitean Stage is thin compared with the Upper Tongaporutuan. It is likewise usually thin compared with the Opoitian Stage. The Kapitean Stage has generally been considered to represent a relatively short time compared with other Tertiary Stages (Squires, 1960), but is unlikely to represent a substantially shorter time than the Upper Tongaporutuan. The relative thinness, compared with the Upper Tongaporutuan and other units at each area, is probably due largely to the decrease in depth of the sea during the Kapitean Age, which almost certainly would have caused a significant increase in by-passing of sediment and consequent decrease in the rate of deposition. It is perhaps significant that at Palliser Bay and Mangaoranga the Kapitean is represented by mudstone deposited

in quite deep water, probably an environment where by-passing was not important, and at these localities the Kapitean is comparable in thickness to the Upper Tongaporutuan.

#### OVERSEAS CORRELATION OF THE KAPITEAN STAGE

Finlay (1947) compared the Kapitean faunas with those of the Californian Repetto Formation. The Repetto was considered to be Pontian in age by Kleinpell (1938, p. 181), who emphasised the good correlation that can be made by means of mammalian faunas between the Sarmation-Pontian sequence of Europe and the Delmonitian-Lower Pliocene sequence of California. Consequently, the Kapitean Stage was correlated by Finlay (1947, p. 352) with the Pontian Stage of Europe, the highest stage of the Miocene.

The appearance of a fauna of planktonic foraminifera substantially like that of the present seas around New Zealand marks the base of the Opoitian Stage, directly above the Kapitean. Hornibrook (1958, p. 32) compared this with a similar change at the base of the Pliocene of Italy, and considered that the Kapitean-Opoitian boundary corresponds to the Miocene-Pliocene boundary.

In Taiwan, Chang (1962) likewise placed the Miocene-Pliocene boundary at the first appearance of *G. inflata* and *G. crassaformis* (*G. punctulata*).

In Japan, *G. crassaformis* appeared earlier than *G. inflata* (Saito, 1963). Sediments containing *G. inflata* have been assigned to the Pliocene, and those containing *G. crassaformis* to the uppermost Miocene. Takayanagi and Saito (1962) tentatively classed the Nobori Formation, which contains *G. crassaformis* (*G. cf. oceanica*), as Miocene, but were uncertain whether it is uppermost Miocene or Lower Pliocene. If the *G. crassaformis* bioseries of Kennett (1965d) represents evolution, then the sediments in Japan containing *G. crassaformis*, but below the first appearance of *G. inflata*, are correlatives of the Lower Opoitian of New Zealand, here considered to be lowermost Pliocene.

At southern Iloilo in the Philippines, Bandy (1963) placed the Miocene-Pliocene boundary at the upper limit of *Globoquadrina altispira globosa* and *Globoquadrina debiscens debiscens* (Chapman, Parr, and Collins), and the lower limit of *Sphaeroidinella debiscens debiscens* (Parker and Jones), and *Globorotalia truncatulinoides* (d'Orbigny). This horizon cannot be determined in New Zealand. *G. debiscens debiscens* makes its last appearance near the top of the Tongaporutuan Stage and *G. altispira globosa* occurs in the Kapitean but probably makes its last appearance below the Opoitian. Neither *S. debiscens* nor *G. truncatulinoides* was found in any of the sections studied by the writer.

#### CONCLUSIONS

Detailed study of the Kapitean Stage has revealed some significant features. Faunal changes that occurred during Kapitean times are almost certainly related to widespread ecological changes caused not only by a

marked cooling in climate at the end of the Miocene, but by changes in sea depth coincident with the climatic change. Much more work is required before overseas correlations can be carried out with certainty, but if the present Upper Miocene - Lower Pliocene correlations are correct, it would seem that a shallowing of facies took place synchronously in several parts of the world in the uppermost Miocene. A general shallowing of the sea, coinciding with faunal changes caused by decreasing temperature, is similar to the situation occurring at the onset of glacial periods during the Pleistocene. This can be most easily explained as being caused by a glacio-eustatic lowering of sea level (the Kapitean representing an interval of relatively intense cold).

Strongly supporting evidence for very cold temperatures during the Kapitean Age is the occurrence of *Globigerina pachyderma* (Ehrenberg) with 99% of specimens coiling to the left as in Antarctic and Arctic waters of today. This can be compared with the occurrence in New Zealand waters today of populations of *G. pachyderma* coiling dominantly to the right.

Objections to the theory of an intensely cold period during the uppermost Miocene are that there is no evidence of glaciation in Late Miocene times, and that during the Kapitean Age, when the sea was shallow, some warm-water invertebrates such as *Cucullaea* continued to live in New Zealand waters. However, *Cucullaea*, and other presumably warm-water species which were important elements throughout the Miocene in New Zealand, became extinct towards the end of the Kapitean as the sea was about to deepen again, and these extinctions seem to be consistent with a simple glacio-eustatic hypothesis.

On the other hand, while no evidence has yet been put forward for glaciation during Late Miocene times, there is equally no evidence against the existence of a major ice-cap during this period. The fossil evidence of temperature changes during the Tertiary has generally been interpreted as indicating gradual changes, but has seldom been examined in detail, and does not refute the idea of marked fluctuations in temperature superimposed on an overall progressive decrease in temperature during the Late Tertiary.

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