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NUMBER 21

MID-CRETACEOUS EVENTS

—HOKKAIDO SYMPOSIUM, 1976—

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—HOKKAIDO SYMPOSIUM, 1976—

(Proceedings of the Second International Conference on "Mid-Cretaceous Events,"
IGCP Project, Mikasa, Hokkaido, August-September, 1976)

Organized by

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PREFACE

The second international conference on "Mid-Cretaceous Events" was held at Mikasa and in the neighbouring districts of Hokkaido from August 29th to September 6th 1976 as one of the activities of the IGCP [International Geological Correlation Program] Projects under the auspices of IUGS [International Union of Geological Sciences].

This conference was on a small scale, but was successful in stimulating fruitful discussion, not only on the papers presented, but also on observations made in the field on the outcrops of the Cretaceous. The sequences studied were: (1) those on the main course of the River Ikushumbetsu (near the Katsura-zawa dam) (on August 31st), where fundamental work has been done since that of YABE (1903-4); (2) the continuous outcrops along the creek of the Pombetsu (on Sept. 1st), where Upper Albian to Coniacian sequences are in a nearer-shore facies than that of the first route; (3) the beautiful stream of the Hakkin-zawa, a tributary of the River Yubari, in the Oyubari forestry area (on Sept. 2nd), where mid-Cretaceous sequences are well exposed in a more off-shore facies than that of the first; and (4) the Takino-sawa, another tributary of the Yubari, in the Oyubari area, to examine in more detail the strata of the Lower Turonian and Upper Cenomanian (on Sept. 3rd). Many of the participants have obtained a valuable knowledge of the characteristics of the Cretaceous deposits and their fossils in the Japanese Province, comparing them with those of other provinces.

Two days, August 30th and September 4th, were reserved for the presentation of papers at Mikasa City-Hall. They are assembled here for publication in one volume. Each of these papers has concentrated on one of the following three major problems:

1) *Mid-Cretaceous biostratigraphy or history of the areas around the northern Pacific.*—On the occassion of the first international conference of MCE at Uppsala 1975, a series of reports was presented on the current knowledge of the mid-Cretaceous of Japan. Still more papers are added here to report the results of the recent studies by some members of our domestic working group. Two other papers on the USSR Pacific region and the Pacific slope of Canada are very valuable contributions.

2) *Interregional correlation.*—Attempts towards a correlation of the European or other sequences of fossils with those of Japan or the Pacific region give fruitful or suggestive results. Some new information on the standard sequences of Europe may be included here and a paper concerning the Cretaceous of southwest Asia is also a valuable addition.

3) *The problem of Cretaceous transgressions and regressions.*—This is one of the most important problems of mid-Cretaceous events. Three papers have been presented on this problem with somewhat dissimilar viewpoints from their respective authors. They should certainly simulate us into further study of the subject.

During the meetings a representative range of fossils from the region was collected, and the participants are indebted to the MURAMOTOS, the well-known family of collectors, for the considerable help they gave. The collections of several private collectors were shown in the Town Hall and the famed MURAMOTO collection was on display in the Mikasa City Museum. In addition, another set of excellent collections was open for our inspection at the Geological Section of the Hokkaido Colliery and Steamship Company at Yubari. They all include specimens of great interest from an international viewpoint, quite apart from their local importance.

This conference was officially sponsored by the Science Council of Japan, and financially supported by the Japan Society for the Promotion of Science. The Board of Education of Mikasa City greatly helped us with both indoor and field work, including the provision of transport. Thanks are also extended to the MURAMOTO family, the Geological Section of the Hokkaido Colliery and Steamship Company (Chief Geologist Mr. HONDA), the Japan Petroleum Exploration Company, the Oyubari and the Iwamizawa branch offices of the Forestry Bureau, the Deputy Governor of Hokkaido, and the Mayor and Deputy Mayor of Mikasa, as well as to our project leader Professor R. A. REYMENT and all other participants for their hearty cooperations. Dr. Hiromichi HIRANO cheerfully did the dull job of secretary.

Finally this publication has been made possible by the efficient organisation of the Palaeontological Society of Japan. Drs. Kametoshi KANMERA, Juichi YANAGIDA Kazushige TANABE and Miss Mutsuko HAYASHIDA have all assisted me in the business of editing. Thanks are due to Drs. J. A. JELETZKY, J. M. HANCOCK and W. J. KENNEDY in rephrasing the Engligh of some of the manuscripts.

October 10, 1976

Tatsuro MATSUMOTO

MID-CRETACEOUS STRATIGRAPHY OF THE OYUBARI AREA, CENTRAL HOKKAIDO

By

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Abstract

Good display of Cretaceous strata, consisting of mudstone sometimes alternated with sandstone and occasionally with acid tuff, is found along several streams of the Oyubari area, on the west side of the Yubari mountain range, central Hokkaido. In addition to the previously studied Shiyubari valley [=the River Shuparo] (MATSUMOTO, 1942), two other routes are selected to see the biostratigraphic succession from Upper Albian to Turonian. Although the exposure is continuous, minor folds and thrusts occur frequently, resulting in repeated occurrence of the Zone of *Inoceramus hobetsensis* (main part of Turonian). The subjacent Lower Turonian Zone of *Inoceramus labiatus* (s. l.) is well exposed with scattered occurrence of *Fagesia* and *Pseudaspidoceras* and followed below by the Upper Cenomanian Zone of *Inoceramus pennatulus* (s. l.). Large shells of the Puzosiinae and smaller ones of the Desmoceratinae occur along with some other ammonites. There is furthermore a continuous exposure of probably Upper Albian to Lower Cenomanian sequence, but fossils occur rather sparsely there. Middle Cenomanian is indicated by *Calycoceras* of *newboldi* group and horned *Acanthoceras* in the intervening part.

1. Introduction

One of us, T. M., has endeavoured to improve the interregional correlation, with special attention to the molluscan fossils and also to the isotope dating, in connection with the Mesozoic historical geology of the circum Pacific region for some fourty years. As a result, the Cretaceous system of Japan, specially that of Hokkaido has been biostratigraphically analysed so accurately as to be regarded as a reference scale in the circum Pacific region.

In view of the advances in global tectonics, the interregional correlation is required to be more accurate. Studies of the Cretaceous system in Hokkaido may meet such requirements. Among various areas of Hokkaido, the Oyubari area is surpassing in the successive large exposures, where a field conference by the members of the 2nd International Conference of MCE Project has been performed. On this occasion we describe the biostratigraphy along the selected two routes as examples of reference sequence of the Mid-Cretaceous in Hokkaido.

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During this study, Mr. Junichi YAZAKI, the head, Mr. Katsuo YAMAZAKI, the chief of a section and other members of the Oyubari Local Forestry Office, Mr. Hitomaro HONDA, the head, and many other members of the Geological Survey of the Hokkaido Colliery & Steamship Co. and Mr. Kikuwo MURAMOTO and his family offered facilities in various ways for our study. Dr. Seijuro MAIYA kindly gave us an important information on the results of his foraminiferal analysis. Our field research was financially supported partly by the Science Research Fund of the Ministry of Education (MATSUMOTO, No. 154280 for 1976; HIRANO, No. 074202 for 1975, No. 174269 for 1976) and partly by the Matsunaga Research Grant (HIRANO and TANABE). The 2nd International Conference of MCE Project in Hokkaido was financially supported by the Japan Society for the Promotion of Scientific Researches and municipal authorities of Mikasa City. Miss Mutsuko HAYASHIDA helped us in drawing figures. Here we express our sincere gratitude to these ladies, gentlemen and authorities.

2. Geological Setting

Oyubari is about 60 km eastward from Sapporo and situated in the central part of the outcropping Cretaceous system in Hokkaido (Fig. 1). The Cretaceous system is underlain with unconformity or faulting by the lower Mesozoic Sorachi Group which forms the Yubari mountain range and overlain with unconformity or faulting by the Tertiary system which forms the Ishikari Coal Field. The Cretaceous system is distributed with the general trend of N-S or NNE-SSW and the E-W width of 9 km. In this area the River Shuparo [=the Shiyubari valley] streams westward from the Yubari mountain range, turning southward and then westward at the Hakobuchi gorge. Along some tributaries which empty into the River Shuparo from east to west, including the River Hakkinzawa and the River Takinosawa described below, favourable exposures are observable. The Cretaceous strata in this area are cut at intervals by thrusts and faults of the general N-S trend and steeply overturned to the west. Being covered with the coal bearing Tertiary, they crop out again on the Yubari [=Hatonosu] (MATSUMOTO and HARADA, 1964) and the Manji domes (OBATA and FUTAKAMI, 1975) in the west where they are of shallower facies. The upper reaches of the River Shuparo were biostratigraphically studied in detail by one of us (MATSUMOTO, 1942). A general geological map of the Oyubari area was published by NAGAO *et al.* (1954). MATSUMOTO and NODA (1975) studied biostratigraphy and palaeontology of *Inoceramus labiatus*, showing a provisional correlation of the Cenomanian and the Turonian within Hokkaido, which includes the Oyubari area. Another report has already outlined this area (MATSUMOTO *et al.* in REYMENT ed., in press) and further knowledge after that report is added in this paper.

3. Mid-Cretaceous Stratigraphy along the River Hakkinzawa and Takinosawa

Fairly successive exposures from the Upper Albian to the Middle Turonian are displayed along the mapped part of the River Hakkinzawa (Fig. 2). No major fault is detected across the route between Y5091 and Y5221, although the Cretaceous strata are overturned in general. A columnar section along the route is shown in Fig. 3, in

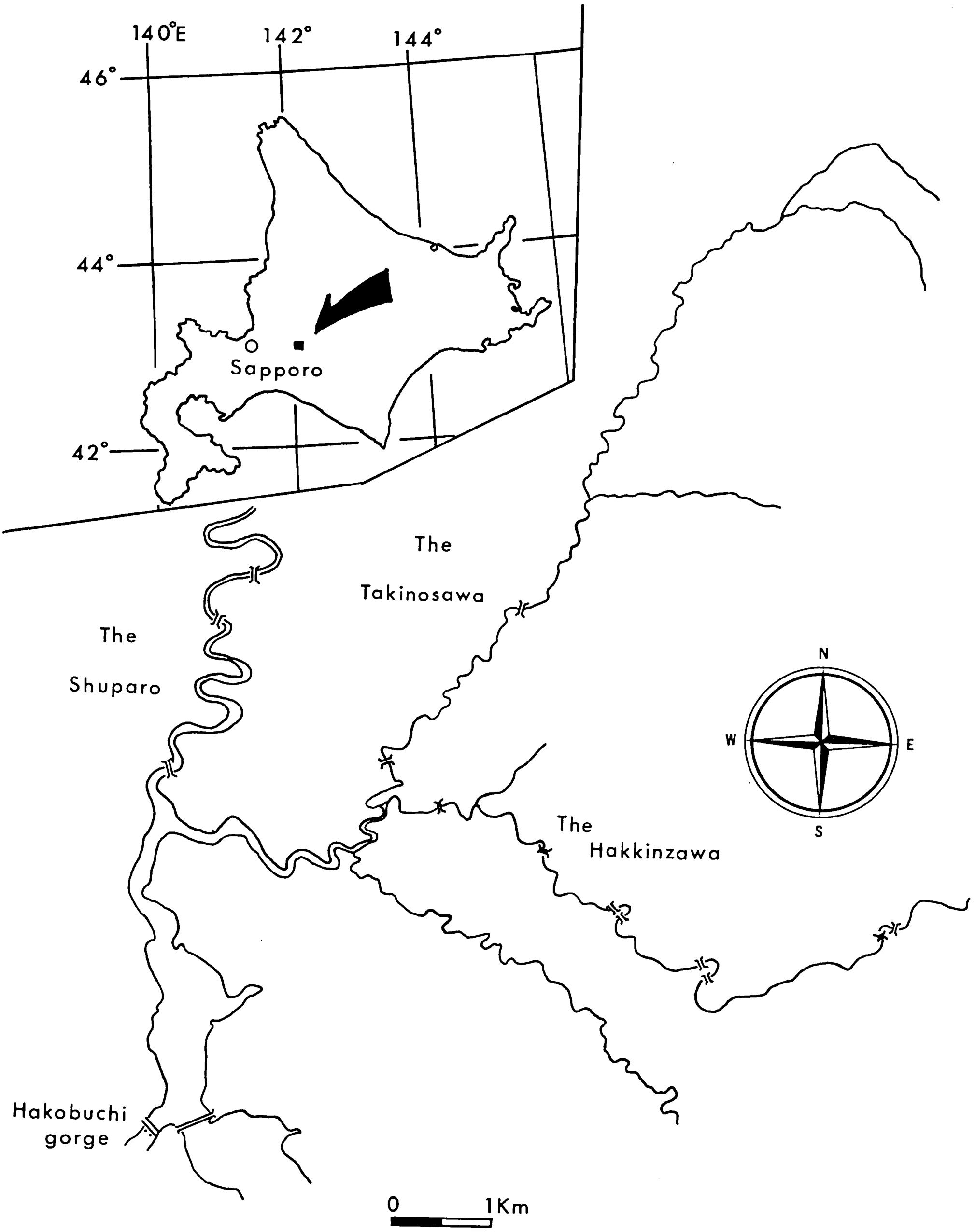


Fig. 1. Index-map showing the studied area.

which selected fossils are also indicated. Some minor faulting and folding are observed at intervals westward from Y5221. Presumably the strata are repeatedly exposed by those faults and folds, but in general the strata are younging westward.

We can observe another sequence from the Lower Cenomanian to the Lower Turonian along the River Takinosawa within the mapped route (Figs. 4, 5). The exposed strata are extended northward from those of the River Hakkinzawa, with

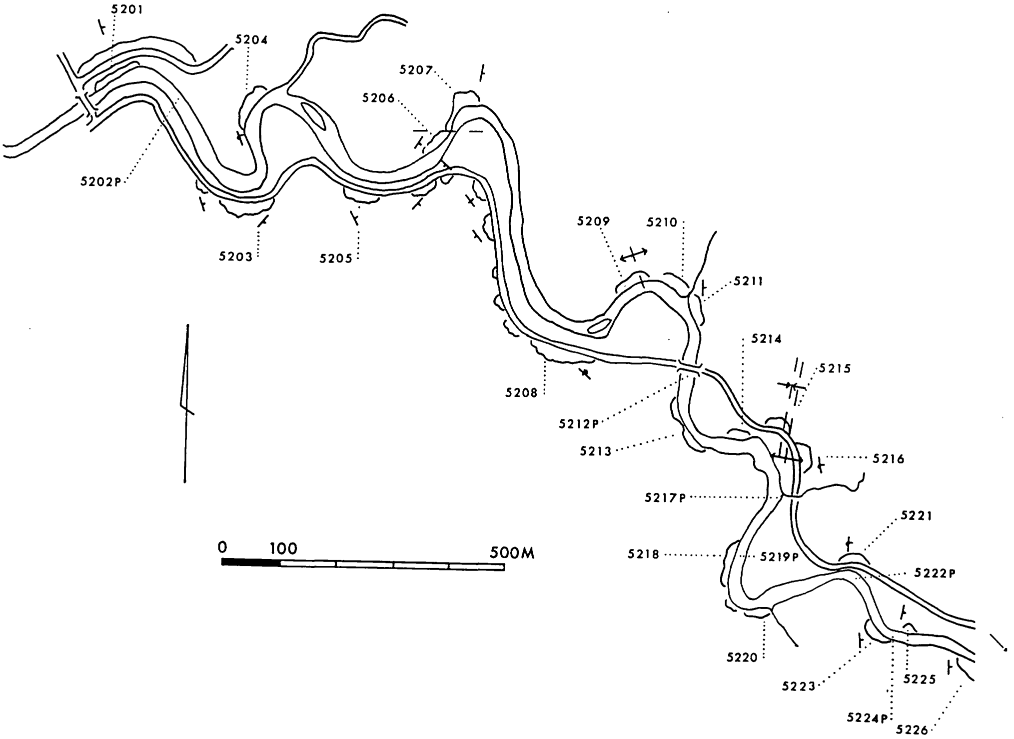


Fig. 2. Route map of the River Hakkinzawa.

the general structural trend of N-S and the dip of 50-70° to E.

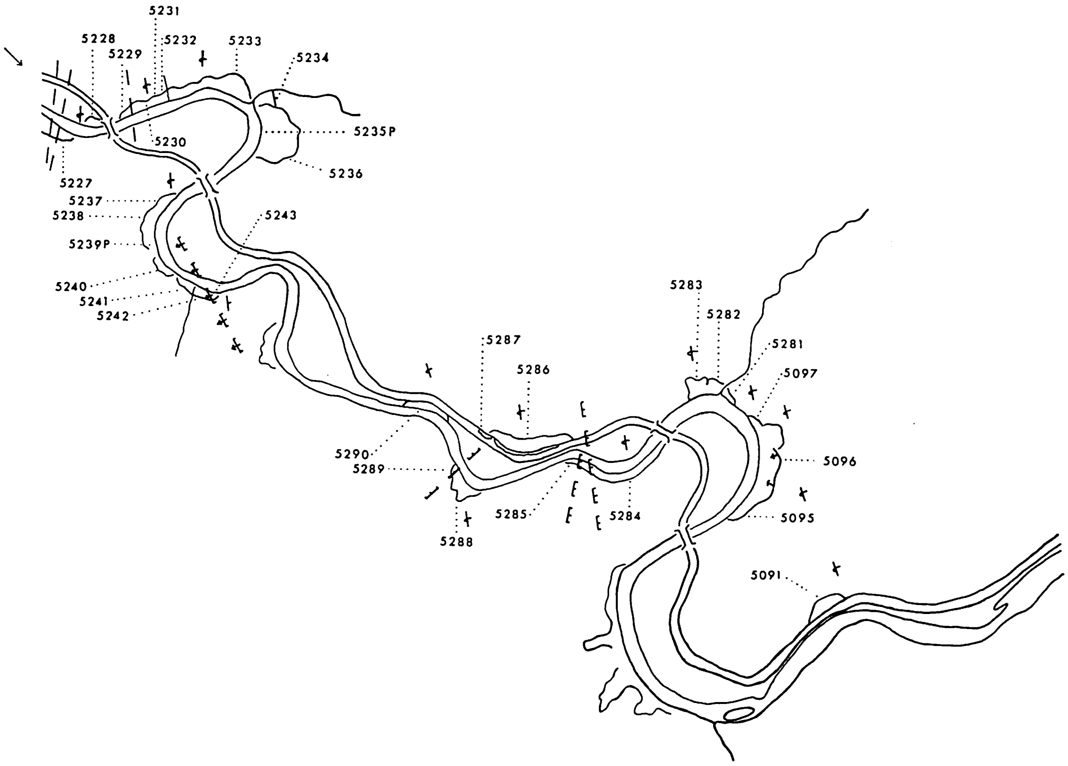
The lithofacies and biofacies observed along these two routes are concisely described below in ascending order. The detailed locality records and faunal lists are omitted in this paper for brevity.

A. Upper Albian

The Upper Albian is exposed in the middle stream of the Hakkinzawa, from Y5091 to Y5282. It is mainly composed of mudstone with thin but frequent intercalates of fine sandstone and acid bentonite tuff. Calcareous concretions are common, but they have no or poorly preserved fossils. Ammonites are rather common in comparison with other mollusks and especially *Desmoceras* predominates and the ammonites of Acanthocerataceae like *Stoliczkaia* rarely occur. At Y5091 *Desmoceras* (*Pseudouhligella*) *dawsoni* and *D.* (s. s.) *latidorsatum* are common. Four foraminiferal species, *Hedbergella washitaensis*, *H. trochoides*, *H. planispira* and *H. delrioensis*, which indicate Albian, were obtained from the same locality by us (analysed by Dr. S. Maiya). Matsumoto and Okada (1973) collected *D.* (*P.*) *dawsoni shikokuense*, *Pachydesmoceras* (?) sp., *Pseudohelicoceras* aff. *spinosum*, *Hamites* cf. *duplicatus* and *Psilohamites* sp. from Y5091, 5092 and 5094. *Desmoceras* (*P.*) *dawsoni* also occurs at Y5097. These species indicate the Upper Albian. From Y5281, *Desmoceras kossmati*, *Parajaubertella* sp. and *Scaphites* sp. which somewhat resembles *S. costatus* Mantell are obtained. The foraminifers from this outcrop, *Praeglobotruncana stephani* and *Globigerinelloides carsei*, sampled by us indicate Cenomanian (analysed by Dr. MAIYA). Many fallen calcareous concretions are obtained at Y5282 and the fossils in these concretions are *Inoceramus anglicus*, *Desmoceras latidorsatum*, *Pachydesmoceras denisonianum* (?), *Turrilitoides* (?) sp. and *Hamites* sp. From these facts the Albian-Cenomanian boundary should be between Y5097 and Y5281. The higher part of the cliff numbered as Y5282 is probably the extension of the Upper Albian.

B. Cenomanian

The Cenomanian is obserable at many exposures from Y5281 to Y5233 along the River Hakkinzawa and from Y6031 to 6014 along the River Takinosawa. Mudstone predominates in general, but in the upper part the mudstone is frequently intercalated with fine-sandstone, and the rhythmic alternation is dominant in the Takinosawa. Acid tuff also becomes more frequent upward. The uppermost mudstone is brown coloured but the concretions in the subjacent part is green coloured owing to glauconite.



The Cenomanian fauna is characterized by abundant *Inoceramus* and large ammonites with diameter over 30 cm, e. g., *Austiniceras* and *Pachydesmoceras*. The ammonite fauna is divisible into four faunules in ascending order [(1) *Desmoceras kossmati*, *Gaudryceras* cf. *intermedium*; (2) *Calycoceras asiaticum*, *C.* sp., *Euomphaloceras* sp. and

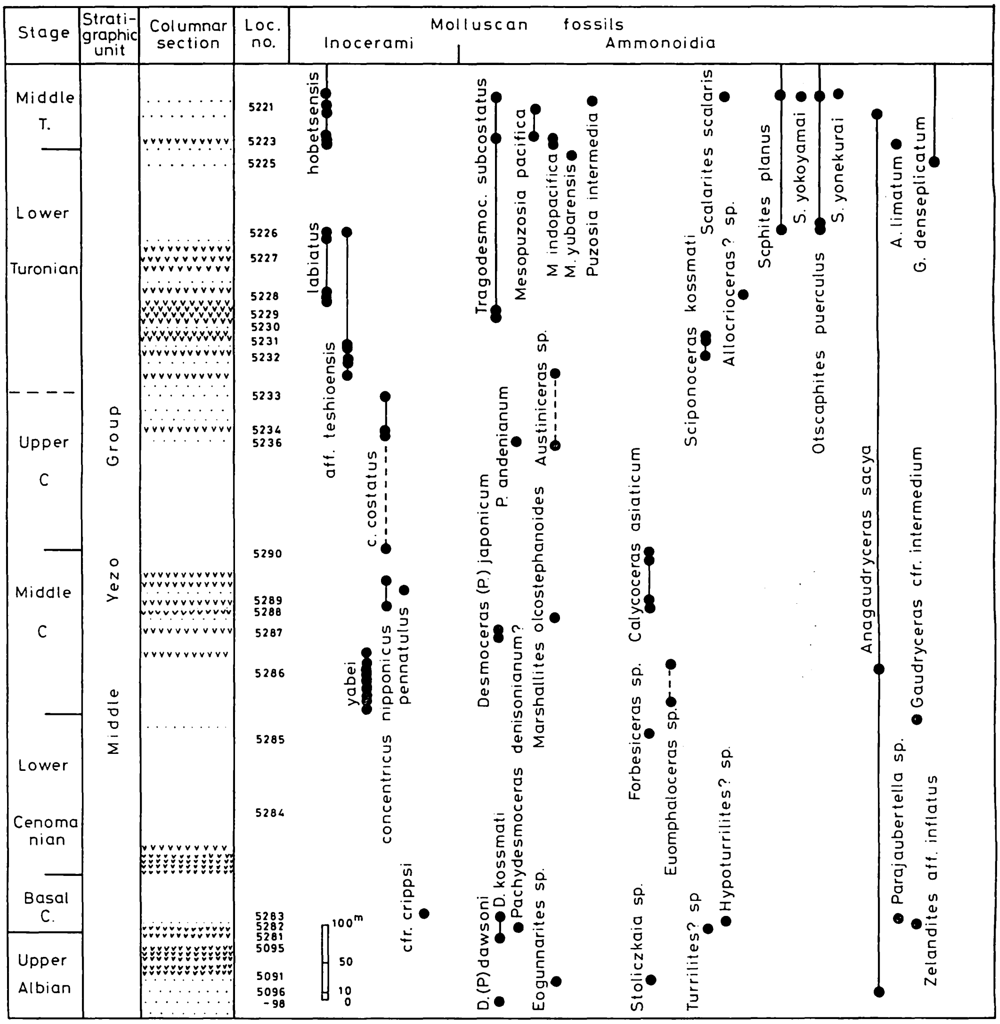
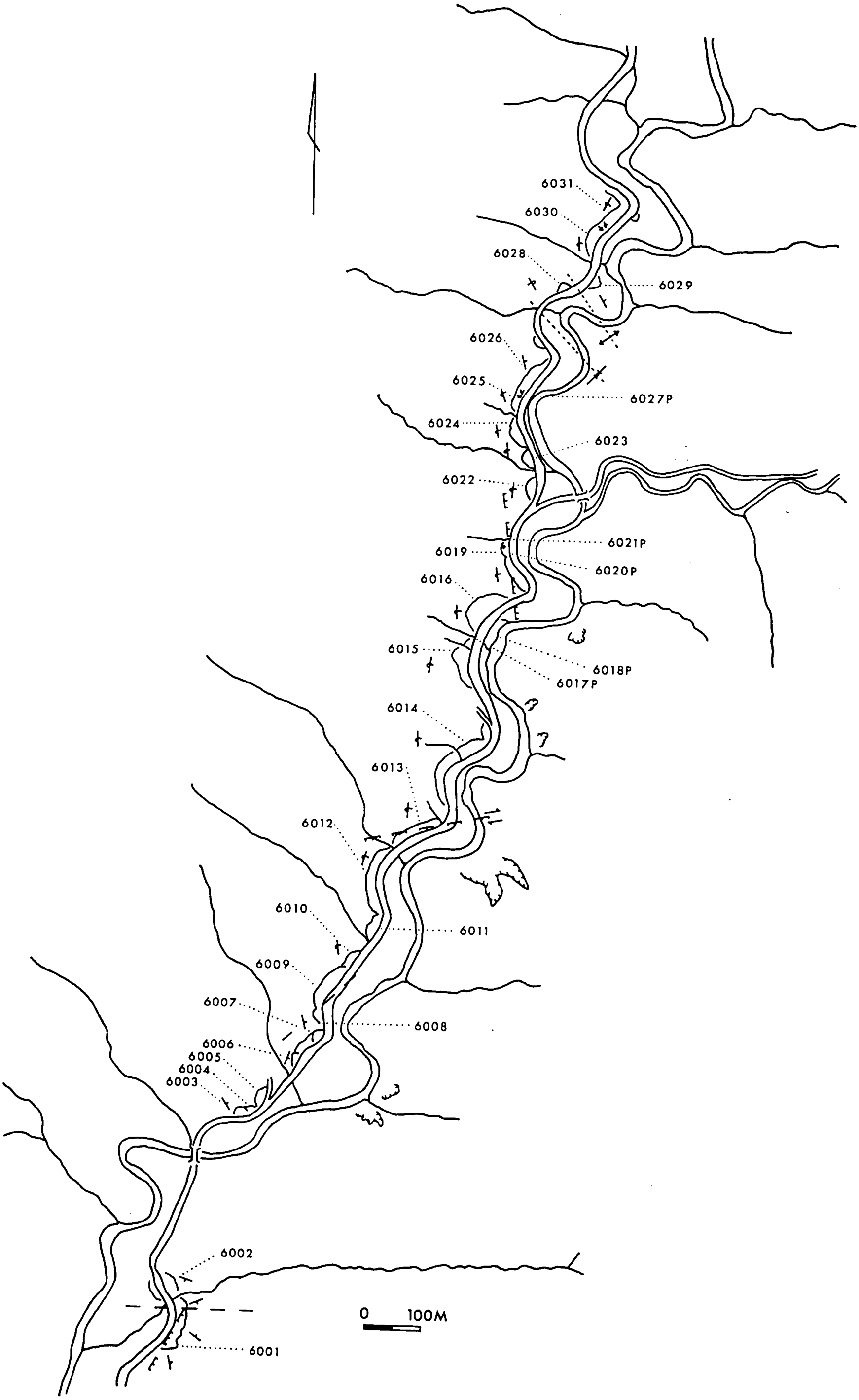


Fig. 3 Columnar section and the representative fossils of the River Hakkinzawa. Legend of columnar section. blank: mudstone, dots: intercalated sandstone, v: tuff. (Read Ammonoidea for Ammonoidia and *Otoscaphites* for *Otscaphites*.)

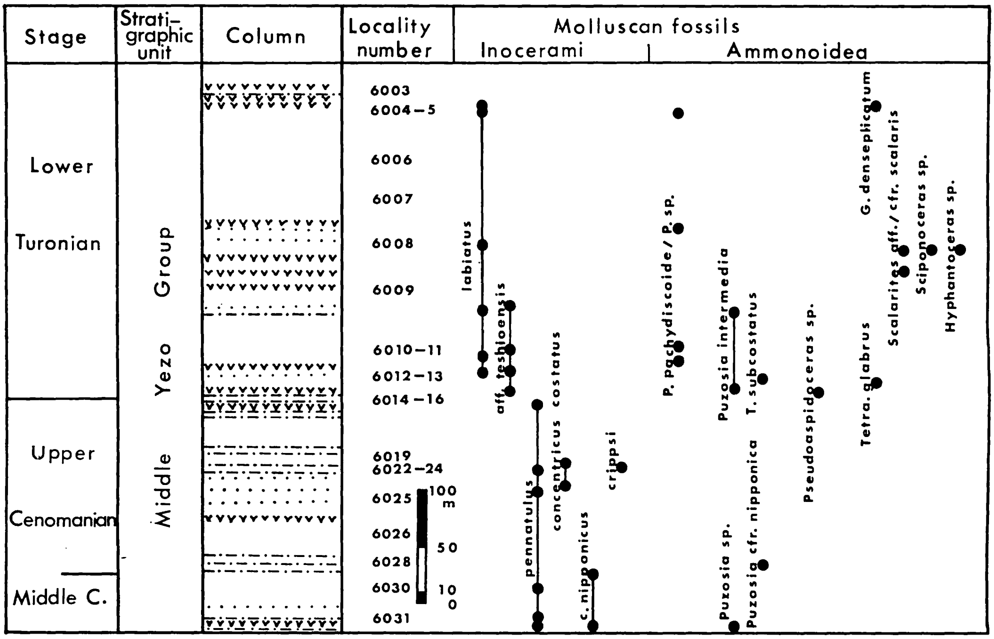
Acanthoceras sp. When these are absent *Desmoceras* (*P.*) *japonicum*, *Marshallites olcostephanoides* and *Neophylloceras* sp. are present; (3) *Austiniceras* sp. and *Pachydesmoceras* sp.; (4) *Tetragonites* sp. and *Sciponoceras kossmati*], which may respectively represent different palaeoenvironments and also different ages. This kind of faunal change is often parallel with minor lithofacies change.

In the Basal Cenomanian, represented by mudstone of locs. Y5282-84, *Desmoceras kossmati* is representative and *I.* aff. *crippsi*, *Scaphites* sp., *Parajaubertella* sp., *Hypoturrilites* (?) sp. and *Zelandites inflatus* sometimes occur. At loc. Y5283, six foraminiferal species, *Praeglobotruncana stephani*, *P. delrioensis*, *Hedbergella planispira*, *H. delrioensis*, *Globigerinelloides carsei* and *Rotalipora evoluta*, which indicate the lower part of Cenomanian, were obtained (analysed by Dr. MAIYA).

The succeeding part, presumably Lower Cenomanian, is represented by claystone



Eig. 4. Route map of the River Takinosawa.



Fgi. 5. Columnar section and the representative fossils of the River Takinosawa. Legend of columnar section is the same as that of Fig. 3; chain :· alternating sandstone and shale. (Read *Pseudaspidoceras* sp. for *Pseudoaspidoceras* sp.)

and is poor in fossils. *Forbesiceras* sp., *Gaudryceras* cf. *intermedium*, an echinoid and a crub were obtained at loc. Y5285.

In the Middle Cenomanian, *Calycoceras asiaticum*, *C.* sp., *Euomphaloceras* sp., *Desmoceras* (*P.*) *japonicum*, *Marshallites olcostephanoides*, *Anagaudryceras sacya*, *Neophylloceras* sp., *Inoceramus pennatulus*, *I. concentricus nipponicus* and *I. yabei* occur fairly commonly. Among them, *Calycoceras* and *Euomphaloceras* usually do not occur with ammonites of other families and *Inoceramus*. This part is correlated with units IIj and IIk established by MATSUMOTO (1942) in the upper stream of the River Shuparo. The boundary between *Inoceramus concentricus costatus* and *I. c. nipponicus* is between Y5289 and Y5290. Three foraminiferal species, *Praeglobotruncana stephani*, *Hedbergella planispira* and *Rotalipora greenhornensis*, which indicate Cenomanian, were obtained (analysed by Dr. MAIYA). The Middle Cenomanian is exposed from loc. Y5286 to loc. Y5290 in the River Hakkinzawa and from Y6030 to Y6031 in the River Takinosawa.

The Upper Cenomanian is characterized by *Inoceramus concentricus costatus*, *I. pennatulus*, *I. yabei*, *Pachydesmoceras andenianum*, *P.* sp., *Austiniceras* sp., *Sciponoceras kossmati* and *Tetragonites* sp. nov. They occur fairly commonly in the exposures from Y5236 to Y5233 in the River Hakkinzawa and from Y6028 to Y6014 in the River Takinosawa. This part is correlated with unit IIm of MATSUMOTO (1942).

C. Turonian

The squences from the Lower Turonian to the lower Middle Turonian are exposed from loc. Y5232 to loc. Y5201 along the River Hakkinzawa and from Y6016 to Y6001 along the River Takinosawa. Many minor faults and some folds are observed or presumed at intervals in the distributional area of the Middle Turonian, and therefore the true thickness of this part is hardly estimated.

The Lower Turonian consists generally of mudstone. It is frequently intercalated by several distinct layers of acid tuff, which is especially dominant in the lower part and often altered to bentonite. The mudstone is usually silty and frequently sandy. This part is very similar in lithofacies to IIn of the northern area (MATSUMOTO and NODA, 1975). The lower part of the Middle Turonian looks rather finer in comparison with the Lower but the mudstone is still silty.

The Lower Turonian is characterized by *Inoceramus labiatus*, *I.* aff. *teshioensis*, *Tetragonites* sp., *Puzosia intermedia orientalis* and *Sciponoceras orientale*. *Pseudaspidoceras* sp. and *Fagesia* sp. are also found immediately above the Cenomanian-Turonian boundary. Many small *Tetragonites* sp., small desmoceratids and *Sciponoceras kossmati* occur in the lower Lower Turonian through the upper Upper Cenomanian. *Tragodesmoceroides subcostatus*, *Scaphites planus*, *Otoscaphites puerculus*, *Scalarites scalaris*. *S.* aff. *scalaris* are common not only in the Lower but also in the Middle Turonian. At loc. Y6012, eight foraminiferal species, *Globotruncana helvetica*, *G. imbricata*, *G. canaliculata*, *G. renzi*, *G. marginata*, *Gloigerinelloides carsei*, *Whiteinella archaeocretacea* and *W.* sp. were obtained (analysed by Dr. MAIYA).

The Zone of *Inoceramus labiatus* is overlain by the Zone of *I. hobetsensis*. We have recently recognized that the Zone of *I. hobetsensis* is divisible into two, the Zone of small *I. hobetsensis* below and that of large *I. hobetsensis* above. The palaeontological study on this phenomenon of *I. hobetsensis* is necessary but actually we can use this phenomenon for zonation. At loc. Y5206, in the Zone of small *I. hobetsensis*, *Collignoniceras woollgari* and *Romaniceras* aff. *deverianum* were found (MATSUMOTO, 1971, p. 130; 1975, p. 118). *Romaniceras deverioide* was obtained at Y5207 (coll. K. OSHIMA) and *Romaniceras* cf. *yezoense* at Y5218 (coll. W. J. KENNEDY). *Anagaudryceras limatum*, *Gaudryceras denseplicatum*, *Tetragonites glabrus*, *Sciponoceras intermedia*, *Eubostrychoceras* sp., *Jimboiceras planulatiforme* (?), *Puzosis intermedia orientalis*, *Mesopuzosia pacifica*, *M. indopacifica*, *Acila* sp. and *Teredo* sp. with wood trunks are also fairly common in the Zone of small *I. hobetsensis*.

The Zone of large *I. hobetsensis* is exposed for a considerable distance westward from Y5201 along the River Hakkinzawa, but its details are omitted in this paper.

4. Conclusion

The obtained results from the recent study of the Oyubari area do not contradict with the scheme by MATSUMOTO (e. g., 1959; 1977 with his coworkers in REYMENT ed., in press). In conclusion we look over the biostratigraphic characteristics of the Oyubari area.

Upper Alibian: *Inoceramus anglicus*, *Desmoceras* (*P.*) *dawsoni* and *D.* (s. s.) *latidorsatum* are characteristic. Besides them, *Pachydesmoceras* (?) sp., *Stoliczkaia* sp., sp., *Hypophylloceras velledae*, *Anagaudryceras sacya*, *A. madraspatanum*, *Pseudohelicoceras* aff. *spinosum*, *Hamites* cf. *duplicatus*, *Psilohamites* sp., *Scaphites* sp. and *Turritoides* (?) sp. commonly or sometimes occur. Although our study is insufficient, they are probably a part of the Upper Albian fauna.

Basal Cenomanian: *Desmoceras kossmati* is representative. *I.* aff. *crippsi*, *Scaphites* sp., *Parajaubertella* sp., *Hypoturrilites* (?) sp. and *Zelandites* aff. *inflatus* sometimes occur.

Lower Cenomanian: The Lower Cenomanian does not yield so many fossils and only *Forbesiceras* sp., *Gaudryceras* cf. *intermedium*, an echinoid and a crab rarely occur.

Middle Cenomanian: *Calycoceras asiaticum*, *C.* sp., *Euomphaloceras* sp., *Desmoceras* (*P.*) *japonicum*, *Marshallites olcostephanoides*, *Anagaudryceras sacya*, *Neophylloceras* sp., *Inoceramus pennatulus*, *J. concentricus nipponicus* and *I. yabei* occur fairly commonly.

Upper Cenomanian: *Inoceramus concentricus costatus*, *I. pennatulus*, *I. yabei*, *Pachydesmoceras andenianum*, *P.* sp., *Austiniceras* sp., *Sciponoceras kossmati* and *Tetragonites* sp. nov. are characteristic.

Lower Turonian: *Inoceramus labiatus*, *I.* aff. *teshioensis*, *Pachydesmoceras pachydiscoide*, *P.* sp., *Tragodesmoceroides subcostatus*, *Puzosis intermedia orientalis*, *Pseudaspidoceras* sp. (nov. ?), *Fagesia* sp., *Tetragonites glabrus*, *T.* sp. nov., *Sciponoceras kossmati*, *S.* sp., *Scalarites scalaris*, *S.* sp., *Scaphites planus* and *Otoscaphites puerculus* occur commonly. Besides them *Gaudryceras denseplicatum*, *Allocrioceras* (?) sp. and *Hyphantoceras* sp. occur occasionally.

Lower Middle Turonian: Small forms of *Inoceramus hobetsensis*, *Mesopuzosia pacifica*, *M. indopacifica*, *Puzosis intermedia orientalis*, *Tragodesmoceroides subcostatus*, *Scalarites scalaris*, *Scaphites planus* and *Otoscaphites puerculus* occur commonly. *Gaudryceras denseplicatum*, *G. intermedium*, *Anagaudryceras limatum*, *Scaphites yokoyamai*, *S. yonekurai Collignoniceras woollgari*, *Romaniceras* aff. *deverianum*, *R. deverioide*, *R.* cf. *yezoense* and *Neophylloceras* sp. sometimes occur.

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MID-CRETACEOUS SCAPHITID AMMONITES FROM HOKKAIDO

By

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Abstract

The stratigraphic distribution and mode of occurrence of 12 species of Scaphitidae from the Turonian and Coniacian of Hokkaido and south Sakhalien are described in this paper. The paper also contains systematic descriptions of 5 species (including one new species), not previously known from Japan.

1. Introduction

Scaphitid ammonites occur abundantly in the silty mudstone facies of the Turonian and Coniacian of Japan (especially Hokkaido) and south Sakhalien. Paleontological studies on them have been done by JIMBO (1894), YABE (1910), SAITO (1962), MATSUMOTO (1963) and TANABE (1975, 1977a). However, the stratigraphic distribution and mode of occurrence of each species have not yet been clarified to our satisfaction; nor have details of their ontogeny, variation and evolutionary patterns, except for the two Turonian species, *Otoscaphites puerculus* (JIMBO) and *Scaphites planus* (YABE), studied by TANABE (1975, 1977a). The Japanese material needs to be re-examined to take account of the recent work on the classification of the Scaphitidae by COBBAN (1951, 1969), WRIGHT (1953) and WIEDMANN (1965, 1969).

The purpose of this paper is to describe the distribution and mode of occurrence of scaphitid ammonites in Hokkaido and south Sakhalien. I also give systematic description of 5 newly discovered species, including one new species.

Acknowledgements.— I wish to express my sincere gratitude to Professor Tatsuro MATSUMOTO of Kyushu University, Dr. W. J. KENNEDY of Oxford University and Dr. J. M. HANCOCK of the University of London for their kind advice and critical reading of the manuscript, and to Dr. Hiromichi HIRANO of Kyushu University for his useful discussion. Thanks are extended to Professor Tokio SHIKAMA (Yokohama National University), Professor Tetsuro HANAI (University of Tokyo), Dr. Ikuwo OBATA (National Science Museum), Dr. Yasumitsu KANIE (Yokosuka City Museum) and Messrs. Tatsuo MURAMOTO and Takemi TAKAHASHI who have given me an opportunity to examine the Type Collections in their care.

2. Material

This paper is based on an examination of 1,946 individuals belonging to the following 12 species of 3 genera from the Turonian and Coniacian of the Naibuchi area

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of south Sakhalien; the Saku, Kotanbetsu, Obira, Ashibetsu, Ikushunbetsu, Oyubari and Hobetsu areas of Hokkaido; the Coniacian of the Futaba area of northeast Honshu, and the Uwajima area of southwestern Shikoku (N: number of specimens of each species).

Scaphites sp. aff. *S. obliquus* J. SOWERBY (N=3)
Scaphites planus (YABE) (N=739)
Scaphites yokoyamai JIMBO (N=39)
Scaphites yonekurai YABE (N=16)
Scaphites sp. aff. *S. subdelicatus* COBBAN and GRYC (N=6)
Scaphites pseudoequalis YABE (N=163)
Scaphites formosus YABE (N=6)
Otoscaphites (*Otoscaphites*) *puerculus* (JIMBO) (N=757)
Otoscaphites (*Otoscaphites*) *klamathensis* (ANDERSON) (N=162)
Otoscaphites (*Hyposcaphites*) *perrini* (ANDERSON) (N=2)
Otoscaphites (*Hyposcaphites*) *matsumotoi* sp. nov. (N=41)
Clioscaphites (?) sp. indet. (N=12)

The majority of the specimens examined were collected by T. MATSUMOTO, H. OKADA, T. MURAMOTO, H. HIRANO, Y. MIYATA and the author between 1937 and 1975.

The repositories of specimens are as follows: GK. H.: Department of Geology, Kyushu University, MM.: University Museum, University of Tokyo, GIYU. M.: Geological Institute, Yokohama National University, NSM. PM: National Science Museum, YCM. GP.: Yokosuka City Museum.

3. Distribution

The stratigraphic and geographic distribution of the 12 species examined in the areas studied may be summarized as follows (main localities are shown in parentheses).

1) *Scaphites* aff. *obliquus.*—The Uppermost Cenomanian or Lowest Turonian (*Kanabiceras septemseriatum* Zone) of the Ikushunbetsu area (loc. IK 1038, 987f).

2) *S. planus.*—From the Uppermost Cenomanian or Lowest Turonian to the Upper Turonian (*K. septemseriatum* to *Inocceramus teshioensis* Zones) of the Aikawa, Naibuchi, Saku, Kotanbetsu (R 134p), Obira, Ikushunbetsu (IK 1038), Oyubari, Hobetsu (H 2115) and Hidakacho areas. The fossil localities in the Naibuchi, Saku, Obira and Oyubari areas are summarized in TANABE (1977a).

3) *S. yokoyamai.*—From the Lower to the Middle Turonian (*Inoceramus labiatus* to *I. hobetsensis* Zones) of the Naibuchi (N 315, 123c, see MATSUMOTO, 1942), Saku (T 5054), Obira (see TANABE *et al.*, 1977) and Oyubari (Y 460, 135, 5221g, see MATSUMOTO, 1942).

4) *S. yonekurai.*—From the Lower to the Middle Turonian of the Naibuchi (Ug 5-6p), Saku (T 680),Obira (see TANABE *et al.*, 1977) and Oyubari (Y 132-9, 5209a, 130d, 134) areas.

5) *S.* aff. *subdelicatus.*—From the Middle to the Upper Turonian (*I. hobetsensis* to *I. teshioensis* Zones) of the Obira (R 2203p), Ashibetsu (As 1111p), Ikushunbetsu (IK 2014) and Oyubari (Y 63, 132-5, 5251a) areas.

6) *S. pseudoequalis.*—From the Lower to the Middle Coniacian (*Inoceramus uwajimensis* Zone) of the Naibuchi (N 26), Kotanbetsu (R 140p), Obira (see TANABE *et al.*,

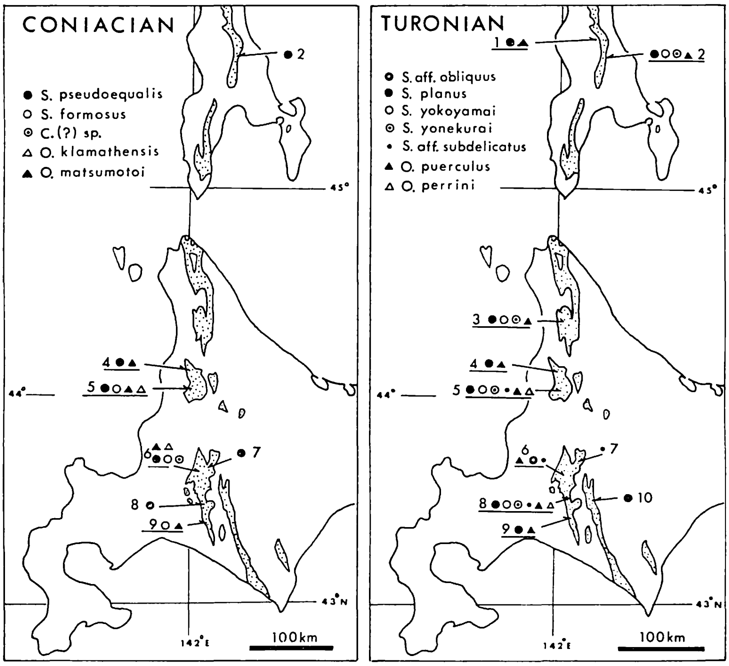

Fig. 1. The locations of the scaphitid ammonites in the Mid-Cretaceous (Turonian to Coniacian) of Hokkaido and south Sakhalien. 1: Aikawa area, 2: Naibuchi area, 3: Saku area, 4: Kotanbetsu area, 5: Obira area, 6: Ikushunbetsu area, 7: Ashibetsu area, 8: Oyubari area, 9: Hobetsu area, 10: Hidakacho area. The post-Aptian Cretaceous outcrops are dotted.

1977), Ashibetsu (As 1140), Ikushunbetsu (see Fig. 2), Oyubari (Y 105), Futaba (Ashizawa and Sakurazawa) and Uwajima (U 8, 49, see TANABE, 1972, fig. 4) areas.

7) *S. formosus.*—The Upper (?) Coniacian (associated with *Inoceramus mihoensis* and *I. yokoyamai*) of the Obira (R 5026p) and Hobetsu (H 2052p) areas.

8) *Otoscaphites puerculus.*—From the Uppermost Cenomanian or Lowest Turonian to the Upper Turonian of the Aikawa, Naibuchi, Saku, Kotanbetsu (R 134p), Obira, Ikushunbetsu (IK 1038b), Oyubari and Hobetsu (H 2073p) areas. The localities in the Naibuchi, Saku, Obira and Oyubari areas are summarized in TANABE (1977a).

9) *O. perrini.*—The Middle Turonian of the Obira (R 6551p) and Oyubari (Y 5218b) areas. Recently, T. MURAMOTO collected several specimens of this species from the Upper Turonian (*Reesidites minimus* Zone) of the Ikushunbetsu area (IK 2113).

10) *O. klamathensis.*—From the Lower to the Middle Coniacian of the Obira (see Fig. 2), Ikushunbetsu (see Fig. 2), Futaba (Ashizawa and Sakurazawa) and Uwajima (U 8) areas.

11) *O. matsumotoi.*—From the Lower to the Upper Coniacian (*I. uwajimensis* to *I. mihoensis* Zones) of the Naibuchi (N 29p), Kotanbetsu (R 140p, 533p), Obira (see Fig. 2), Ikushunbetsu (see Fig. 2), Hobetsu (H 2052p), Futaba (Yachi) and Uwajima (U 8) areas.

12) *Clioscaphites* (?) sp.—From the Lower to the Upper Coniacian of the Ikushun-

betsu (see Fig. 2) and Futaba (Yachi) areas.

The occurrence of each species in the Turonian and Coniacian of Hokkaido and south Sakhalien, and the stratigraphic distribution of each species in the sequences of the Obira and Ikushunbetsu areas are shown in Figs. 1-2 respectively.

Furthermore, *S. planus*, *S. pseudoequalis*, *S. formosus*, *O. perrini* and *O. matsumotoi* occur in northeastern Siberia (VERECHAGIN *et al.*, 1965). *O. klamathensis* was originally described by ANDERSON (1902) from the Upper Cretaceous of Oregon. *O. perrini* is also known from Oregon (ANDERSON, 1902) and northern Alaska (COBBAN and GRYC, 1961). *Scaphites yonekurai* YABE by WIEDMANN (1965, pl. 56, fig. 7; text-fig. 3d) from the Cenomanian of France, Madagascar, northern Australia and India is not identical with true *S. yonekurai* (YABE, 1910, p. 165, pl. 15, figs. 4-7), because the latter has a narrower unmbilicus, more globose septate whorls and weaker ornament (TANABE,

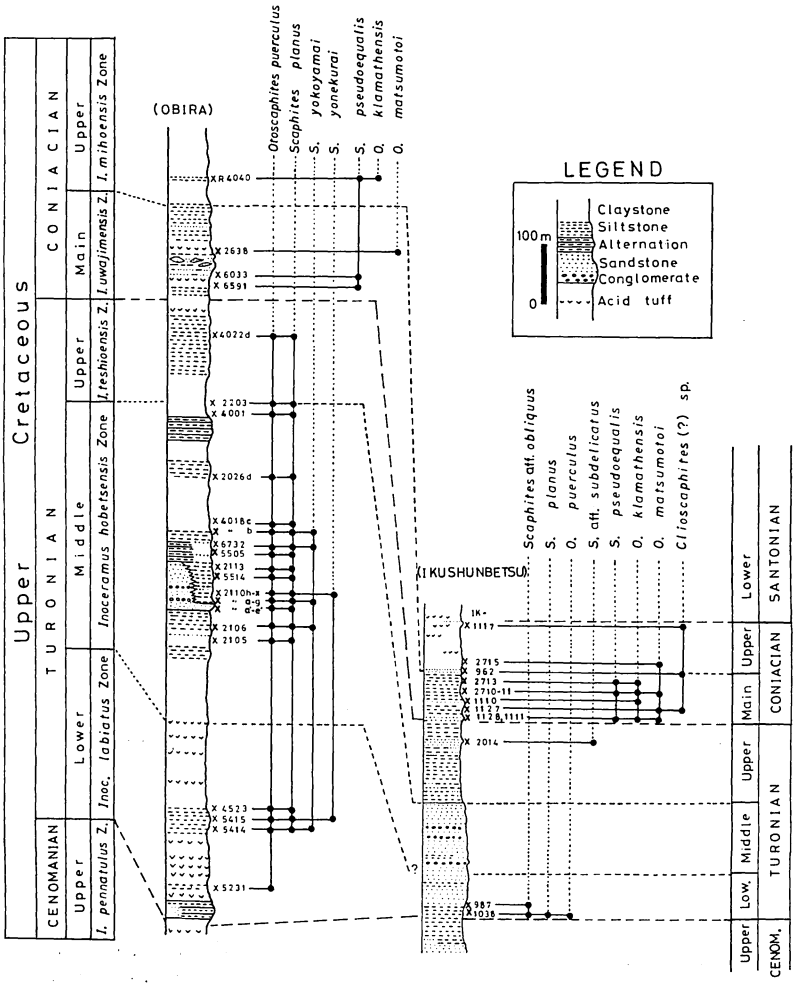

Fig. 2. Stratigraphic distributions of the scaphitid ammonites in the Turonian-Coniacian sequences of the Obira and Ikushunbetsu areas. Stratigraphic columnar sections of the Obira and Ikushunbetsu areas are adapted from TANABE *et al.* (1977) and MATSUMOTO (1965) respectively.

1977b). Judging from the geographic distribution outlined above, the 12 species examined are essentially north Pacific faunal elements. The frequency of occurrence of each species in Hokkaido and south Sakahlien is summarized in Table 1. Generally speaking, scaphitid ammonites occur abundantly in silty mudstone or sandy siltstone facies and are rare in sandstone or claystone facies. This observation may reflect the sporadic distribution of each species. The Turonian group, represented by *S. planus*, *S. yonekurai*, *S. yokoyamai*, *S.* aff. *subdelicatus*, *O. puerculus* and *O. perrini*, occur abundantly in the Naibuchi, Saku, Obira and Oyubari areas, but rare in the Ikushunbetsu and Ashibetsu areas (see Fig. 2). On the other hand, the Coniacian group, represented by *S. pseudoequalis*, *S. formosus*, *O. klamathensis*, *O. matsumotoi* and *Clioscaphites* (?) sp., are abundant in the Ikushunbetsu area as compared with other areas. *S. planus* and *O. puerculus* are coexistent over the whole range of their occurrences, and together dominate the scaphitid element of the faunas (ca. 90-97%). The same relationship is also observed between *S. pseudoequalis* and *O. klamathensis*.

Table 1. Frequency of occurrences of scaphitid ammonites in selected areas of Hokkaido and south Sakhalien. *: southwestern Shikoku. O. p.: *O. puerculus*, S. pl.: *S. planus*, S. yok.: *S. yokoyamai*, S. yonek.: *S. yonekurai*, S. sb.: *S.* aff. *subdelicatus*, S. ob.: *S.* aff. *obliquus*, O. pr.: *O. perrini*, O. kl.: *O. klamathensis*, Sp. ps.: *S. pseudoequalis*, O. mat.: *O. matsumotoi*, C. (?) sp.: *Clioscaphites* (?) sp., S. f.: *S. formosus.*

[Turonian group]

Area	O. p.	S. pl.	S. yok.	S. yonek.	S. sb.	S. ob.	O. pr.	Total
Naibuchi	21(51.2%)	17(41.5%)	2(4.9%)	1(2.4%)	0(-----)	0(-----)	0(----)	41
Saku	96(53.6%)	76(42.5%)	5(2.8%)	2(1.1%)	0(-----)	0(-----)	0(----)	179
Kotanbetsu	3(37.5%)	5(62.5%)	0(-----)	0(-----)	0(-----)	0(-----)	0(----)	8
Obira	533(48.8%)	524(47.9%)	26(2.4%)	8(0.7%)	1(0.1%)	0(-----)	1(0.1%)	1093
Ashibetsu	0(-----)	0(-----)	0(-----)	0(-----)	1(100%)	0(-----)	0(----)	1
Ikushunbetsu	2(28.6%)	1(14.3%)	0(-----)	0(-----)	1(14.3%)	3(42.9%)	0(----)	7
Oyubari	97(42.9%)	114(50.4%)	6(2.6%)	5(2.2%)	3(1.3%)	0(-----)	1(0.4%)	226
Hobetsu	5(71.4%)	2(28.6%)	0(-----)	0(-----)	0(-----)	0(-----)	0(----)	7
Total number	757(48.5%)	739(47.3%)	39(2.5%)	16(1.0%)	6(0.4%)	3(0.2%)	2(0.1%)	1562

[Coniacian group]

Area	O. kl.	S. ps.	O. mat.	C.(?) sp.	S. f.	Total
Naibuchi	0(-----)	3(75.0%)	1(25.0%)	0(-----)	0(-----)	4
Saku	0(-----)	0(-----)	0(-----)	0(-----)	0(-----)	0
Kotanbetsu	0(-----)	5(45.5%)	6(54.5%)	0(-----)	0(-----)	11
Obira	28(45.2%)	28(45.2%)	5(8.0%)	0(-----)	1(1.6%)	62
Ashibetsu	0(-----)	2(100 %)	0(-----)	0(-----)	0(-----)	2
Ikushunbetsu	124(45.4%)	114(41.8%)	20(7.3%)	10(3.7%)	5(1.8%)	273
Oyubari	0(-----)	2(28.6%)	0(-----)	0(-----)	0(-----)	2
Hobetsu	0(-----)	0(-----)	3(100 %)	0(-----)	0(-----)	3
Uwajima*	3(25.0%)	6(50.0%)	3(25.0%)	0(-----)	0(-----)	12
Total number	155(42.0%)	160(43.4%)	38(10.3%)	10(2.7%)	6(1.6%)	369

4. Systematic Descriptions

The following abbreviations are used for measurements. D: maximum size of adult shell, B: maximum breadth of adult shell, d: maximum size of spiral portion, h: maximum whorl height of septate whorls, b: maximum whorl breadth of septate whorls, u: umbilical diameter of spiral portion.

Superfamily Scaphitaceae MEEK, 1876

Family Scaphitidae MEEK, 1876

Genus *Scaphites* PARKINSON, 1811

Type-species.—*Scaphites equalis* J. SOWERBY, 1813

Scaphites sp. aff. *S. obliquus* J. SOWERBY

Pl. 1, Fig. 9; Fig. 3-(1).

Compare.—

1813. *Scaphites obliquus* J. SOWERBY, p. 54, pl. 18, figs. 4-7.
1965. *Scaphites* (*Scaphites*) *obliquus* J. SOWERBY: WIEDMANN, p. 415-417, pl. 56, figs. 5-6; text-fig. 3c.

Description.—Shell medium-sized for the genus, stout, quadrangular in outline with moderately open umbilicus; body chamber somewhat inflated as compared with phragmocone; surface ornamented with primary (lateral) and secondary (ventral) ribs, primaries gently curved adapically with regular spacing. Secondaries bi- or trifurcate from primaries at mid-flank; lateral tubercles well-developed from last septate whorl to middle part of body chamber, but tending to weaken towards the aperture; suture characterized by a simple bifid L and trifid p_1 (see Fig. 3-(1)).

Measurements in mm.—

specimen	D	B	d	b(b/d)	h(/d)	u(u/d)
GK. H. 5807 (IK 987f)	28	13	18	9.2(0.54)	9.8(0.58)	3.8(0.22)
GK. H. 5808 (IK 1038b)	?	?	17	9.2(0.54)	9.8(0.58)	2.3(0.14)

Comparison.—The present species resembles the European Cenomanian species *Scaphites obliquus* J. SOWERBY (1813) in the surface ornament, inflation of body chamber and suture, but the latter has a much narrower umbilicus. At this time I have studied only 3 specimens, which are provisionally refered to as *Scaphites* sp. aff. *S. obliquus* J. SOWERBY.

Scaphites sp. aff. *S. subdelicatus* COBBAN and GRYC

Pl. 1, Fig. 16; Fig. 3-(2).

Compare.—

1961. *Scaphites subdelicatus* COBBAN and GRYC, p. 179, pl. 37, figs. 1-15; text-fig. 2c.

Description.—Shell large in size up to 45 mm, strongly inflated; body cheamber relatively short, tightly enrolled with well-developed umbilical swellings at base; at apertural end shell wall abruptly bends inside blocking up about a half of mouth opening; septate whorls globose, depressed with coronate cross section; surface ornamented by straight primary and weak secondary ribs, primaries terminating in

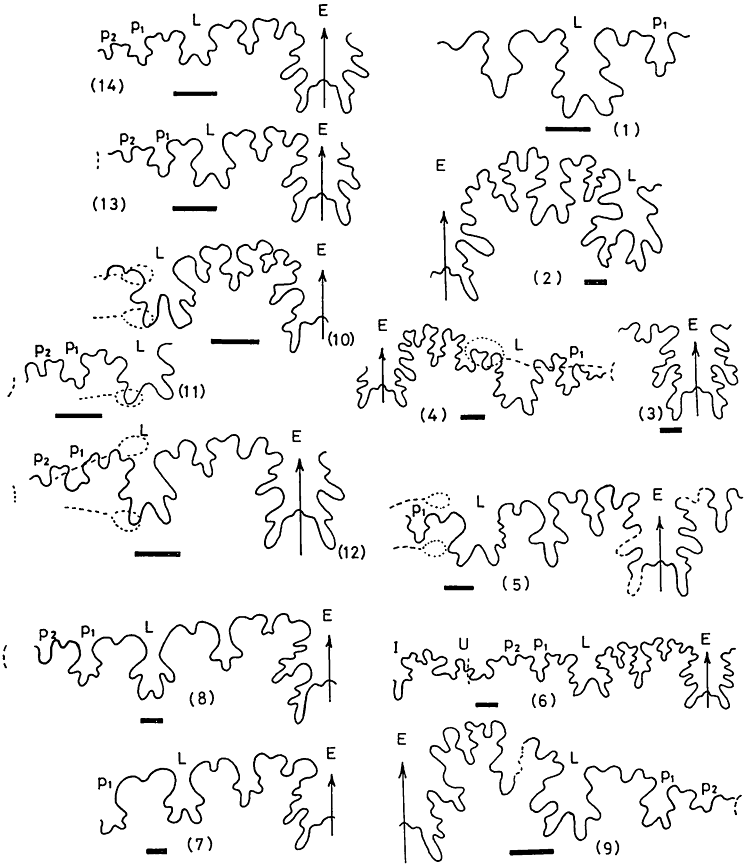

Fig. 3. Sutural patterns of the scaphitid ammonites from Hokkaido and south Sakahlien. Scale: 1 mm. (1), (3), (5), (7)-(8) and (10)-(14) are adult sutures. (1): *S.* aff. ***obliquus***, GK. H. 5807 from IK 987f, (2): *S.* aff. ***subdelicatus***, suture at b=15 mm, GK. H. 5809 from R 2203p, (3)-(4): *S. yokoyamai*, (3): YCM. GP. 2-1 from the gravel of the Kamikinembetsu River, Obira area, (4): suture at b=8 mm, GK. H. 5812 from Y 135, (5)-(6): *S. yonekurai*, (5): GK. H. 5813 from R 2025p-11, (6): suture at b=11 mm, GK. H. 5814 from Y 132-9, (7)-(8): *S.* ***peudoequalis***, (7): GK. H. 5816 from IK 2711p-24, (8): GK. H. 5817 from IK 2106p, (9): *S. formosus*, suture at b=12 mm, GK. H. 5822 from H 2052p, (10)-(11): *O.* ***perrini***, (10): GK. H. 5826 from R 6511p-1, (11): GK. H. 5825 from Y 5218b, (12): *O. matsumotoi* sp. nov., GK. H. 5834 from H 2052p, (13)-(14): *O. klamathensis*, (13): GK. H. 5793 from IK 3117p, (14): GK. H. 5792 from IK 2117p.

conspicuous bullae from which 3 or 4 secondaries extend across venter; lateral tubercles sometimes developed on last one or two septate whorls; suture characterized by its L-like lobe incision in the middle of saddle EL.

Comparison.—The present species is simlar to *Scaphites subdelicatus* COBBAN and GRYC (1961) from the Lower Turonian of northern Alaska in the inflation of body chamber, compressed globose septate whorls and suture, but is distinguished by the larger size of adult shells and stronger projection of aperture.

Genus *Clioscaphites* Cobban, 1951

Type-species.—Clioscaphites montanensis Cobban, 1951

Clioscaphites (?) sp. indet.

Pl. 1, Fig. 21.

The present species is represented by 12 imperfect, immature shells. It is characterized by its inflated septate whorls with a circular-quadrate cross section, narrow umbilicus and a combination of strong primary and regular-spaced secondary ribs. In the inflation of septate whorls and the mode of ribbing the present species is similar to *Scaphites arnaudiformis* Collignon (1965, p. 17, pl. 420, fig. 1743) from the Coniacian of Madagascar. However, the precies comparison is difficult, because the diagnostic characters at maturity including suture, can not be ascertained in the present material of the two species. Although diagnostic generic characters such as a tightly enrolled body chamber and sutures with trifid or asymmetrically bifid L are unknown, the present species resembles *Clioscaphites novimexicanus* (Reeside) (Cobban, 1951, p. 37–38, pl. 21, figs. 1-9) and *C. saxitonianus* (McLearn) (Cobban, 1951, p. 36-37, pl. 13, figs. 1-10) from the Santonian of the Western Interior Province in the surface ornament and inflated outline of septate whorls; hence the present species may belong to *Clioscaphites*. In this paper I tentatively treat it under *Clioscaphites* (?) sp.

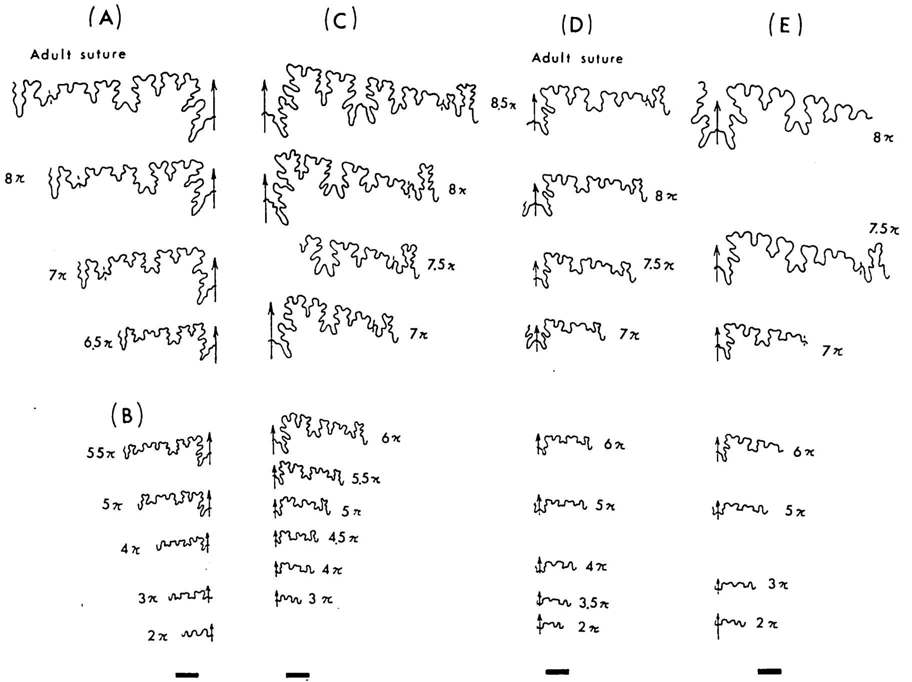

Fig. 4. Sutural ontogeny in 4 selected species. Scale: 1 mm. (A)-(B): *O. puerculus*, GK. H. 5740-41 from R 4018b, (C): *S. planus*, GK. H. 5776 from R 4018c, (D): *O. klamathensis*, GK. H. 5836 from IK 2711p-3, (E): *S. pseudoequalis*, GK. H. 5821 from IK 2711p-3.

Genus *Otoscaphites* Wright, 1953

Type-species.—Ammonites bladenensis Schlüter, 1871

Subgenus *Otoscaphites* (*Otoscaphites*) Wright, 1953

Type-species.—Ammonites bladenensis Schlüter, 1871

Remarks.—The present subgenus was defined by Wiedmann (1965) as *Scaphites* (*Otoscaphites*) for the lappeted scaphitids with subcircular whorl sections.

Otoscaphites (*Otoscaphites*) *klamathensis* (Anderson)

Pl. 1, Figs. 4-6; Figs. 3-(13, 14); Fig. 4-(D).

1902. *Scaphites klamathensis* Anderson, p. 115, pl. 3, figs. 5, 7.
1962. *Otoscaphites teshioensis* (Yabe): Saito, p. 80, pl. 5, figs. 5, 7; text-figs. 11a-b.

Remarks.—As Matsumoto (1959) has already mentioned, Anderson's original types from the Shasta Valley, Oregon, are lost. The 162 specimens examined can be refered to *Scaphites klamathensis* Anderson (1902) because of the characteristic surface ornament, lateral lappets and suture. The present species is somewhat similar to the Turonian *Otoscaphites puerculus* (Jimbo) (Jimbo, 1894, p. 37, pl. 5, fig. 4; Tanabe, 1975, 1977a) in the marginal outline and inflation of the body chamber, but the former species has a much simpler adult suture (see Figs. 3-(13, 14)), stronger primary ribs, smaller protoconch (ca. 350-440μ in maximum size) and nepionic size (ca. 660-760μ). Except for the differences of apertural shape, shell size and rate of involution of adult shells, the present species resembles *Scaphites pseudoequalis* Yabe (1910, p. 163, pl. 15,

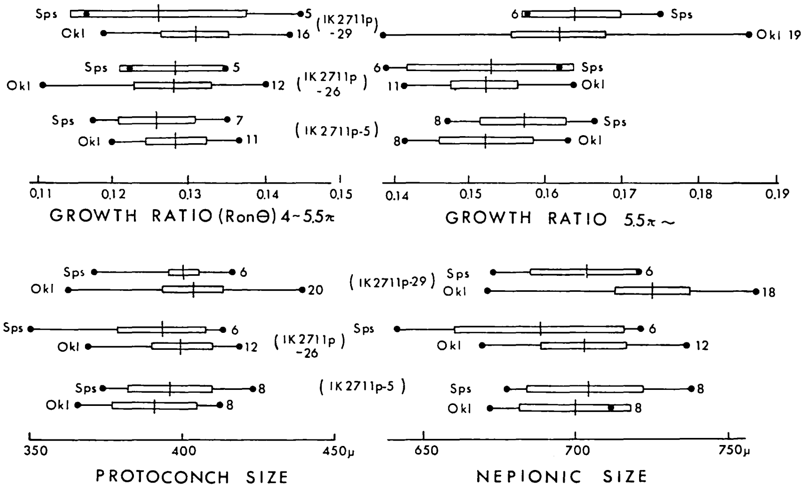

Fig. 5. Variation of growth ratio of radius length to total rotation angle and nepionicic and protoconch size in selected samples of *O. klamathensis* and *S. pseudoequalis* from the same localities. The sample mean and its 95% confidedce, observed range and sample size are indicated for each case. Okl: *O. klamathensis*, Sps: *S. pseudoequalis.*

figs. 1, 3) in the growth pattern of whorls until about the 4th volution, and in variation of suture, protoconch and nepionic size (see Fig. 5).

Subgenus *Otoscaphites* (*Hyposcaphites*) WIEDMANN, 1965

Type-species.—Scaphites perrini ANDERSON, 1902

Remarks.—WIEDMANN (1965) established the present subgenus as *Scaphites* (*Hyposcaphites*) for species with coronate whorl sections and tubercled or keeled ornament. He designated *Scaphites stephanoceraides* YABE (1909, p. 442-443) as the type-species of *Hyposcaphites*. YABE's *stephanoceroides* is, however, invalid, and moreover the specimen illustrated in WIEDMANN's paper (pl. 59, fig. 3) is a synonym of *O. perrini*, as MATSUMOTO (1963) have already pointed out.

Otoscaphites (*Hyposcaphites*) *matsumotoi* sp. nov.

Pl. 1, Figs. 7-8; Fig. 3-(12)

1965. *Scaphites puerculus* JIMBO: VERECHAGIN *et al*., p. 42, pl. 33, fig. 4.

Types.—Holotype, GK. H. 5827 from a fallen nodule (nodule no. IK 2714p-10) derived from loc. IK 2710-11, upper course of the Gonosawa River (location lat. 43° 18′N, long. 141° 59′E), Pombetsu, Ikushunbetsu area (Coll. T. MATSUMOTO). Paratypes, GK. H. 5830, 5832-33, from fallen nodules also collected at the type-locality (=IK 2710-11).

Material.—In addition to the above-mentioned 4 type-specimens, 37 specimens including GK. H. 5828 (loc. IK 962), H. 5829 (IK 1127), H. 5831 (R 2638j), H. 5834 (H 2052p), NSM. PM 7351 (Yachi, Futaba area) and GIYU. M. 106 (U 8, Uwajima area) are referable to the present species.

Diagnosis.—Large-sized species of *Otoscaphites*, characterized by its stout, depressed whorls, with coronate cross sections, strongly constricted aperture with a pair of long and narrow lappets, moderately involute, deep, umbilicus and strongly tuberculated primary ribs.

Description.—Shell large-sized for the genus, sometimes ataining 22 mm in maximum size; stout, moderately inflated, *Clioscaphites*-like in ventral view; the body chamber, which begins after the 4th whorl, short, about 1π in spiral length, wider than high, with broadly rounded venter in cross section; aperture strongly constricted with long and narrow lateral lappets; septate whorls moderately involute with compressed coronate cross section and deep umbilicus; surface ornamented with a combination of strong primary and secondary ribs, primaries high and sharp in cross section, adorally concave, forming a prominent keel and tubercles on inner and middle parts of flank respectively; secondaries tri- or quadrifurcate from primaries on middle part of flank, but bifurcate on body chamber; tubercles well-developed on middle third of body chamber, but tending to be weaker towards the aperture; strength of development of tubercles varies from specimen to specimen, the holotype being of the strongly tuberculated type; sutures simple and resemble those of other species of *Otoscaphites*.

Measurements in mm.—

specimen	D	B	d	b(b/d)	h(h/d)	u(u/d)
GK. H. 5827 (Holotype)	21.0	10.3	13.6	7.8(0.57)	5.7(0.42)	4.7(0.35)
GK. H. 5832 (Paratype)	20.3	10.6	13.9	8.7(0.63)	5.6(0.40)	3.5(0.25)
GK. H. 5830 (Paratype)	20.0	8.5	13.6	6.6(0.49)	5.2(0.38)	? (—)
GK. H. 5831	18.1	8.8	12.9	7.0(0.54)	5.6(0.44)	3.8(0.29)
NSM. PM 7351	22.1	9.4	12.9	6.5(0.50)	6.2(0.48)	4.5(0.35)

Comparison.—The present species is somewhat similar to *Otoscaphites seabeensis* Cobban and Gryc (1961, p. 184, pl. 38, figs. 13-27) from the Lower Turonian of northern Alaska in the surface ornament and suture, but the latter species has more compressed whorls, and the tubercles situated on the inner side of flank as against the middle part in the present species.

Scaphites perrini Anderson (1902, p. 114, pl. 2, figs. 71-73) from the Upper Cretaceous of Oregon also resembles the present species in the depressed septate whorls and deep umbilicus, but is distinguished by its much weaker ornament, directian of primary ribs, and the smaller size of adult shells.

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Explanation of Plate 1

Two lateral (b, d), ventral (a) and frontal (c) views are shown on each specimen, unless otherwise stated.

Figs. 1-2. *Otoscaphites* (*Otoscaphites*) *puerculus* (JIMBO). 1. GK. H. 5753 from R 2110e', ×2. (H. HIRANO and K. TANABE coll.). 2. Septal face of MM. 6884 from T 335, ×2. (T. MATSUMOTO coll.).

Fig. 3. *Otoscaphites* (*Hyposcaphites*) *perrini* (ANDERSON). GK. H. 5826 from R 6551p-1, ×2. (Y. MIYATA coll.).

Figs. 4-6. *Otoscaphites* (*Otoscaphites*) *klamathensis* (ANDERSON). 4. GK. H. 5835 from IK 2711p-5 (derived from IK 2711), ×2. (T. M. coll.). 5. Septal face of GK. H. 5836 from IK 2711p-1, ×2. (T. M. et al. coll.). 6. Lateral view of GIYU. M. 107 from U 8, ×2. (K. T. coll.).

Figs. 7-8. *Otoscaphites* (*Hyposcaphites*) *matsumotoi* sp. nov. 7. Septal face of GK. H. 5832 (one of the paratypes) from a fallen nodule derived from IK 2710-11, ×2. (T. M. coll.). 8. Holotype, GK. H. 5827 from a fallen nodule derived from IK 2710-11, ×2. (T.M. coll.).

Fig. 9. *Scaphites* sp. aff. *S. obliquus* J. SOWERBY. GK. H. 5807 from IK 987f, ×1. (T. M. coll.).

Figs. 10-11. *Scaphites yokoyamai* JIMBO. 10. YCM. GP. 2-1 from the middle course of the Nakakinembetsu River, Obira area, ×1. (Y. KANIE coll.). 11. Septal face of GK. H. 5812 from Y 135, ×1. (T. M. coll.).

Figs. 12-13. *Scaphites yonekurai* YABE. 12. GK. H. 5813 from R 2052p-11, ×1. (T. M. et al. coll.). 13. Septal face of GK. H. 5814 from Y 132-9, ×2. (T. M. coll.).

Figs. 14-15. *Scaphites planus* (YABE). 14. GK. H. 5780 from R 2112p, ×1. (T. M. et al. coll.). 15. Septal face of GK. H. 5815 from R 6732a, ×2. (M. Y. coll.).

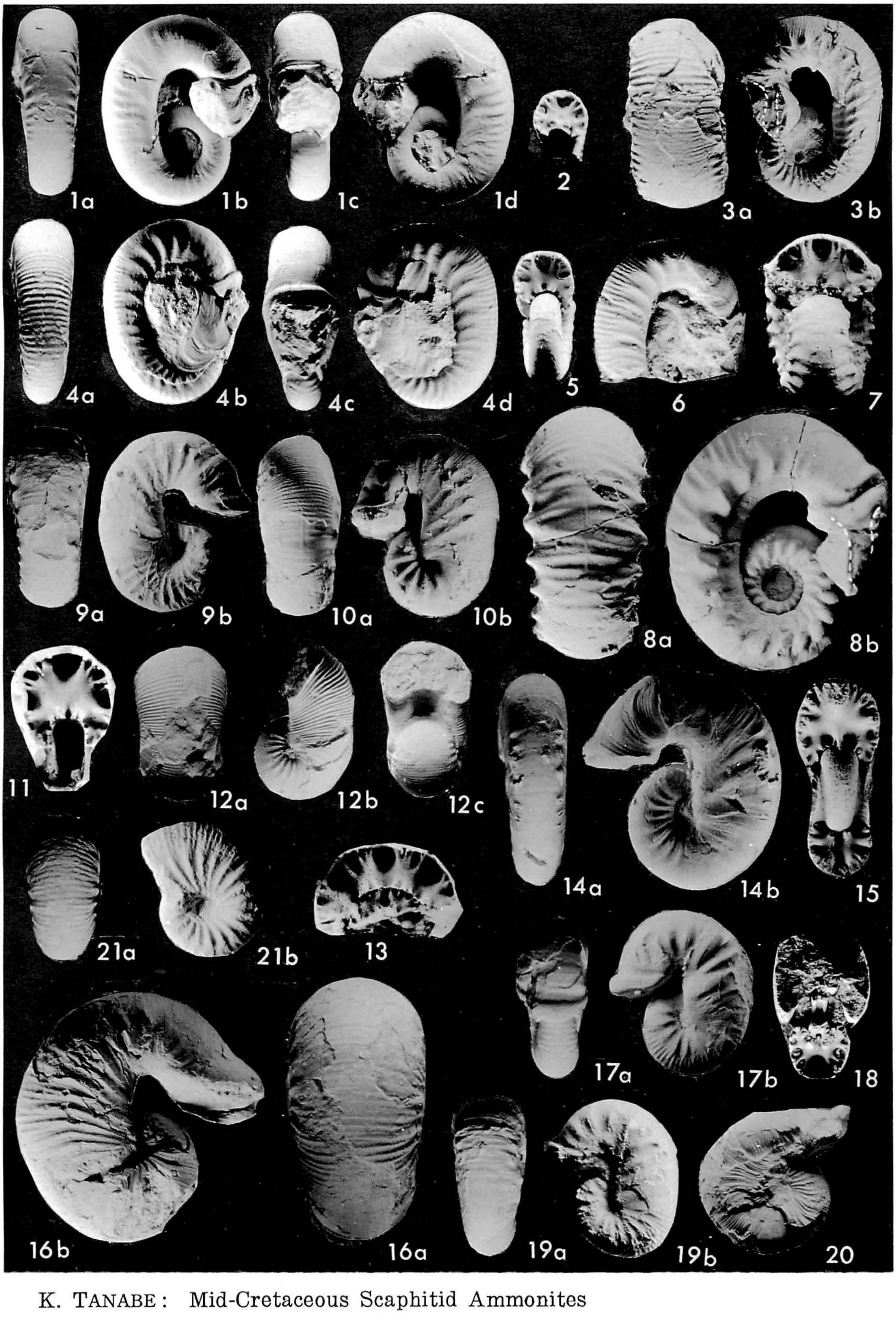
Fig. 16. *Scaphites* sp. aff. *S. subdelicatus* COBBAN and GRYC. GK. H. 5811 from As 1111p, ×1. (T. M. coll.).

Figs. 17-19. *Scaphites pseudoequalis* YABE. 17. Frontal (a) and lateral (b) views of GK. H. 5818 from IK 2151p-3, ×1. (T. M. coll.). 18. Septal face of GK. H. 5819 from IK 2710c, ×1. (T. M. coll.). 19. GK. H. 5820 from IK 1128, ×1. (T. M. coll.).

Fig. 20. *Scaphites formosus* YABE. Lateral view of GK. H. 5823 from R 5026p, ×1. (H. H. and K. T. coll.).

Fig. 21. *Clioscaphites* (?) sp. indet. GK. H. 5824 from IK 1117p, ×1. (T.M. coll.).

Photos, with whitening, by TANABE.



K. TANABE: Mid-Cretaceous Scaphitid Ammonites

THE CRETACEOUS SEQUENCE OF THE MANJI DOME, HOKKAIDO

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Abstract

On the fossil evidence, the subdivided units in the Manji area correlate clearly with the reference scale at home and abroad. Thus the Cretaceous sequence in the area ranges from Upper Albian to Upper Santonian. The biostratigraphy of certain species from the area may be considered briefly in the present paper. The Cretaceous sediments of the area are much thinner than those in the central part of the Yezo geosyncline and those in the eastern part. There may have been a break in sedimentation in the Upper Turonian, in the Lower Coniacian and also in the Upper Santonian. Generalized stratigraphic facies sections, along the Manji and the neighbouring areas, in the western part of the Cretaceous sedimentary basin are shown. *Subprionocyclus neptuni* occurs commonly in sediments of a particular facies which represents a relatively western, probably inshore part. *Reesidites minimus* occurs abundantly in an intermediate facies between inshore sandy and the rather off-shore muddy one. If we attach great importance to the ostreids, *S. neptuni* and *R. minimus* as facies indicators, an attempt to work out the paleogeographic occurrences of these fossils would be justified. We should like to suggest that the change in fossil occurrences may be the result of some difference in the environment related to the Turonian coast line.

1. Introduction

The Manji dome is a southern extension of an anticline that traverses the celebrated Ikushumbetsu valley, Hokkaido. The Cretaceous sequence exposed there is incomplete in that its upper part had been considerably eroded away before the deposition of the coal-bearing Tertiary, and in that the underlying part is not observable from the surface outcrops. Yet the area is important, because it represents the relatively western part of the Cretaceous basin of Hokkaido and because the area is expected to yield fairly abundant Turonian fossils.

As a subject for the Hokkaido meeting of the "Mid-Cretaceous Events" project of the International Geological Correlation Programme, re-examination of the biostratigraphy of the Manji area was suggested to us by Professor T. MATSUMOTO of Kyushu University. We have surveyed the area in 1974 to 1976, obtained numerous im-

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portant fossils, and published a preliminary report in Japanese (OBATA and FUTAKAMI, 1975). The present paper covers the biostratigraphy of the Manji area. Another paper deals with part of the paleontological description of faunas (OBATA and FUTAKAMI, 1977). We wish to record here a debt of gratitude to Professor MATSUMOTO of Kyushu University, Dr. J. M. HANCOCK of King's College, London, and Dr. W. J. KENNEDY of Oxford University, who spared their precious time in fruitful discussion on this study, and critically read the first draft. Miss Reiko FUSEJIMA of the National Science Museum read through the manuscript and typed it up for print. The study was in part financially supported by the Grant in Aid for Scientific Research, defrayed from the Ministry of Education.

2. Biostratigraphy

The geological map which shows the localities of the molluscan specimens obtained from the Cretaceous beds is summarized in Fig. 1. On the fossil evidence, the subdivided units, i. e., M1, M2, M3 (Main part of the Middle Yezo Group), Mk1, Mk2, Mk3 (Mikasa Formation of the Group); U1 and U2 (Upper Yezo Group), correlate clearly with the reference scale at home and abroad. Thus, the Cretaceous sequence in the Manji dome ranges from Upper Albian to Upper Santonian. The individual columnar sections along the selected routes are illustrated in Fig. 2, in which the horizons of the zonal indices are indicated.

The biostratigraphy of certain species from the Manji area may be considered briefly.

Mortoniceras (*Deiradoceras*) aff. *albense* SPATH and *Mortoniceras* sp. occur in M1.

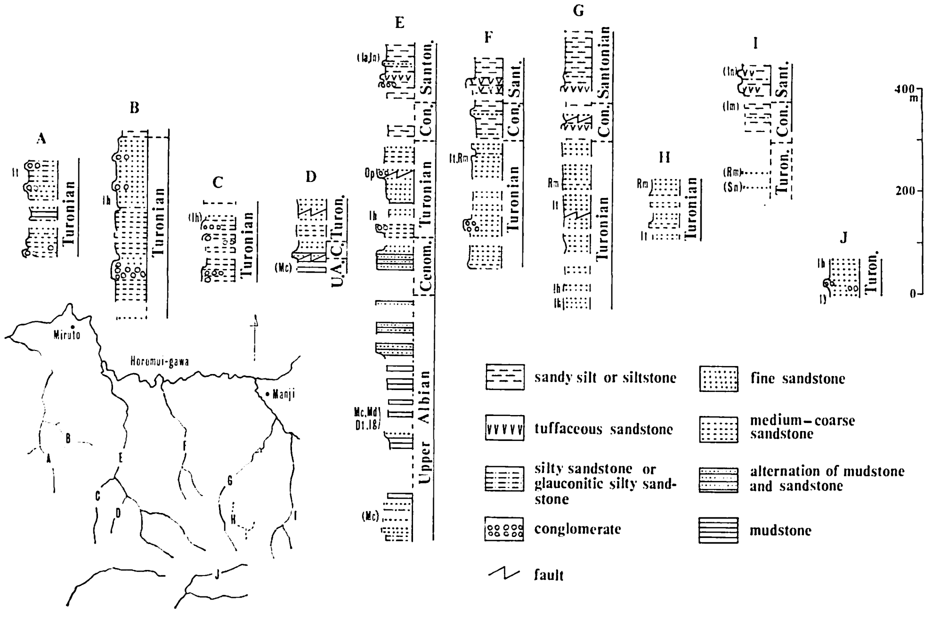

Fig. 2. Geological columnar sections along the selected routes in the Manji area, in which horizons of the zonal indices are indicated (adapted from OBATA and FUTAKAMI, 1975). See the explanation of Fig. 1.

M. (*D.*) *albense* is reported from the *orbignyi* and *varicosum* subzones of the lower Upper Albian of England (SPATH, 1923, p. 4; 1933, p. 429).

Diplasioceras tosaense MATSUMOTO and HIRATA was found in the same rock as M2 that yielded *Mortoniceras* (*Deiradoceras*) aff. *balmatianum* (PICTET), *M.* (*Cantabrigites*) *imaii* (YABE and SHIMIZU) and *Neophlycticeras* aff. *spathi* BREISTROFFER. In England species of *Mortoniceras* (*Deiradoceras*) are frequently reported from the *orbignyi* and *varicosum* subzones, and sometimes from the lower *auritus* subzone of the lower Upper Albian. *Diplasioceras* is often regarded as a subgenus of *Dipoloceras*, and the *Diplasioceras* species from Japan and Madagascar are regarded as the Middle Albian indices. However, the morphologic characters of *Diplasioceras* appear to be nearer to those of Upper Albian mortoniceratids than to those of Middle Albian dipoloceratids.

Mortoniceras (*Cantabrigites*) species are known from the uppermost Albian in England. *M.* (*C.*) *imaii* closely resembles *Hysteroceras carinatum* from the *aequatorialis* subzone of the Upper Albian of England. In short, apart from the taxonomic problem, the association of *Diplasioceras tosaense* with *Mortoniceras* (*C.*) *imaii* suggests lower Upper Albian. Furthermore, the association of *D. tosaense* with *Mortoniceras* (*Deiradoceras*) species also implies that the two species may define a zone in the lower Upper Albian. Thus, the geological age of M1 and M2 is probably lower Upper Albian. No zonal index was obtained from M3.

Inoceramus yabei NAGAO and MATSUMOTO, zonal index of the Middle to Upper Cenomanian, occurs in Mk1. *Inoceramus hobetsensis* NAGAO and MATSUMOTO, zonal index of the Middle Turonian, occurs generally in Mk2. A large specimen of *Ryugasella* n. sp., which resembles *Scalarites mihoensis* (WRIGHT and MATSUMOTO) in some respects, was obtained from the *I. hobetsensis* Zone, *i. e.*, Middle Turonian. *Ryugasella* was hitherto known only from Upper Santonian to Campanian. It may follow that *Ryugasella* was derived from *Scalarites* in the Turonian.

Inoceramus teshioensis NAGAO and MATSUMOTO, zonal index of the Upper Turonian, occurs in Mk3. *Subprionocyclus neptuni* (GEINITZ) occurred together with *Inoceramus teshioensis* at several localities. The former species shows a wide variation and seems to approach *Subprionocyclus branneri* (ANDERSON) in morphological characters (OBATA and FUTAKAMI, 1977).

It is noted that *Subprionocyclus neptuni* and *Inoceramus teshioensis* are associated with an *Inoceramus* which very closely resembles *Inoceramus concentricus nipponicus* NAGAO and MATSUMOTO. The latter is known from the Cenomanian. *Yokoyamaoceras* aff. *minimum* MATSUMOTO, *Y.* cf. *ornatum* MATSUMOTO and *Eubostrychoceras* cf. *woodsi* (KITCHIN) are associated with *Subprionocyclus neptuni* or *Inoceramus tenuistriatus* NAGAO and MATSUMOTO. Thus, some Senonian ammonites seem to range down into the Upper Turonian.

Subprionocyclus normalis ANDERSON is not found in the Manji area. This may suggest a hiatus. The zone of *Reesidites minimus* (HAYASAKA and FUKADA), the uppermost Turonian, is recognized in the upper part of Mk3. In the type Ikushumbetsu area most of the localities of *R. minimus* have become inaccessible since the construction of the Katsurazawa dam. It should be noted that numerous new localities of *R. minimus* have now been found in the Manji area as well as in the Yubari area

(MATSUMOTO and HARADA, 1964) in the western part of the Yezo geosyncline.

Despite the prolific occurrence of *Inoceramus uwajimensis* in the Coniacian deposits in the Japanese Islands, this species has not been found in U1 of the Manji area. Taking these facts into account, we are inclined to suggest that this area lacks the main part of the Lower Coniacian. U1 will be assigned to Upper Coniacian because of the presence of *Inoceramus* cf. *mihoensis* MATSUMOTO. *Inoceramus amakusensis* NAGAO and MATSUMOTO, zonal index of Lower Santonian, and *I.* cf. *orientalis nagaoi* MATSUMOTO and UYEDA, that of Upper Santonian, were obtained from U2. However, *I. japonicus* NAGAO and MATSUMOTO, was not found there. In short, the upper limit of the Cretaceous strata in the Manji dome is assigned to the Upper Santonian.

3. Biofacies and Sedimentary Environment

The Cretaceous sediments of the Manji dome are much thinner (ca. 1,130 m) than those in the central part of the Yezo geosyncline (*e.g.*, ca. 3,000 m at Shuyubari, MATSUMOTO, 1954) and those in the eastern part (*e.g.*, ca. 4,000 m at Hidaka, OBATA *et al.*, 1973). Thus, they show a characteristic feature of the western part of the Cretaceous sedimentary basin (MATSUMOTO and OKADA, 1971).

The Cenomanian of the Manji area is rather thin (ca. 80 m), as compared with that of the Ikushumbetsu area (ca. 257 m, MATSUMOTO, 1965). It is thus similar to that of the Yubari area (ca. 30 m, MATSUMOTO and HARADA, 1964), but is thicker than the latter. The Coniacian of the area is much thinner (ca. 70 m, OBATA and FUTAKAMI, 1975) than that of the Ikushumbetsu area (ca. 160 m, MATSUMOTO, 1965), but is thicker than that of the Yubari area (ca. 10 m, MATSUMOTO and HARADA, 1964).

The sedimentary accumulation was thus thinner, and the rate of deposition slower in the Manji dome area than in the northern Ikushumbetsu valley and in the eastern Shuyubari valley in the Cenomanian and Coniacian (Cenomanian, ca. 1,300 m; Coniacian, ca. 700 m, at Shuyubari, MATSUMOTO, 1954). In this way, the sedimentary features are similar to those in the area of the southern Yubari dome (MATSUMOTO and HARADA, 1964), although the Turonian (ca. 360 m) and Albian (ca. 430 m+) deposits are thicker in the Manji dome area than in the Yubari (Turonian, ca. 140 m+; Albian, ca. 300 m; MATSUMOTO and HARADA, 1964).

Inoceramus uwajimensis occurs very frequently in glauconitic silty sandstones and siltstones in Hokkaido. Despite the wide occurrence of such rocks this species is not found in U1 of the Manji area. There may thus have been a break in sedimentation, with at least a local diastem if not a regional disconformity, at the base of the Upper Yezo Group in the Manji dome as in the Yubari dome. Even upheaval and erosion may have taken place in the early Coniacian. The situation of *Inoceramus japonicus* in the Upper Santonian may have been nearly the same as that of *Inoceramus uwajimensis.* A stratigraphic break possibly exists at the top of the Upper Yezo Group in the Manji area.

The Mikasa Formation of the Manji area closely resembles that of the northern Pombetsu valley in both litho- and biofacies. The coarse sediments of the Mikasa

Formation (385 m+) of the former area are the thickest among those in Ikushumbetsu (ca. 305 m), Pombetsu (ca. 285 m) and Yubari (ca. 170 m). In the Mikasa Formation of the Manji area, the grain size of sand and gravel decreases from west to east. Furthermore, there are several ostreid banks in the middle part (Mk2) of the formation, *i. e.*. *Inoceramus hobetsensis* Zone, in the western area of the dome, whereas in the eastern area ornate ammonites, *e. g.*, *Subprionocyclus neptuni* and *Reesidites minimus*, predominate in the upper part of the formation, *i. e.*, *Inoceramus teshioensis* Zone.

In short, the site of the Manji dome clearly represents a relatively western part of the Turonian basin of sedimentation, situated near the land or mountains in the farther west. A generalized stratigraphic facies section from west to east, *i. e.*, along the line of Manji—Shuyubari—Hidaka, is shown in Fig. 3. The biofacies vary with the sedimentary environment; the facies changes from north to south, *i. e.*, Ikushumbetsu—Pombetsu—Manji—Yubari, are presented in Fig. 4.

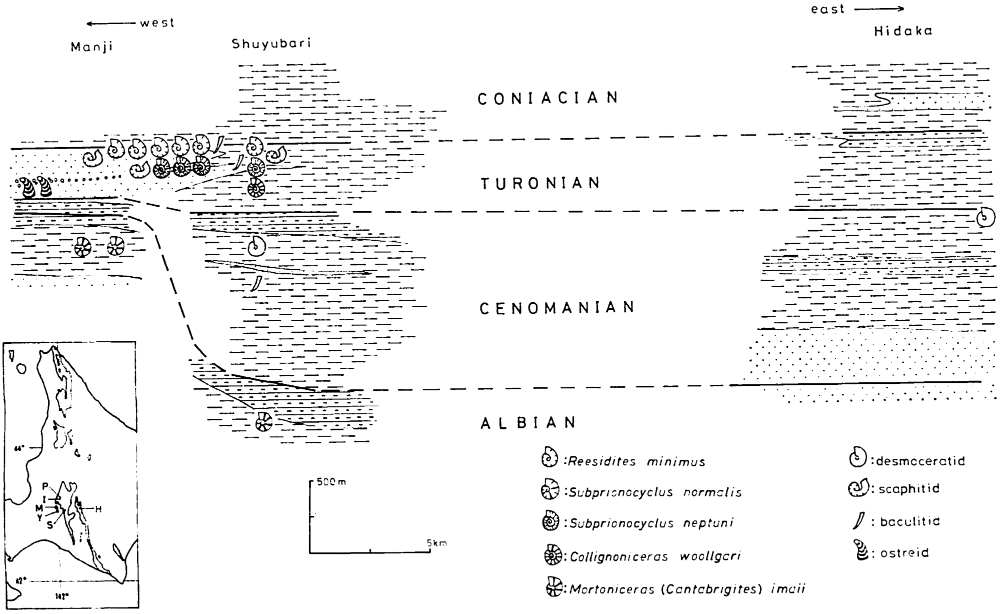

Fig. 3. Generalized stratigraphic facies section from west to east, *i. e.*, along the line of Manji-Shuyubari-Hidaka. The predominate ammonites are shown.

4. Occurrence of *S. neptuni* and *R. minimus*

The exposed strata in Hokkaido are predominantly muddy sediments of a geosynclinal basin. They may be a rather offshore facies, in which the collignoniceratid ammonites occur sparsely (MATSUMOTO, 1971). However, in the western part of the basin where the presence of silty sandstone or sandy siltstones indicate less off-shore, more favourable conditions, collignoniceratid ammonites, *e. g.* *S. neptuni* and *R. minimus*, are rather abundant through the Middle to Upper Turonian. Thus, we have obtained about eighty specimens of *S. neptuni* from several localities and about one hundred and fifty individuals of *R. minimus* from twenty localities in the Manji area. Numerous specimens of *R. minimus* occur in the greenish-bluish gray fine sandy siltstone and

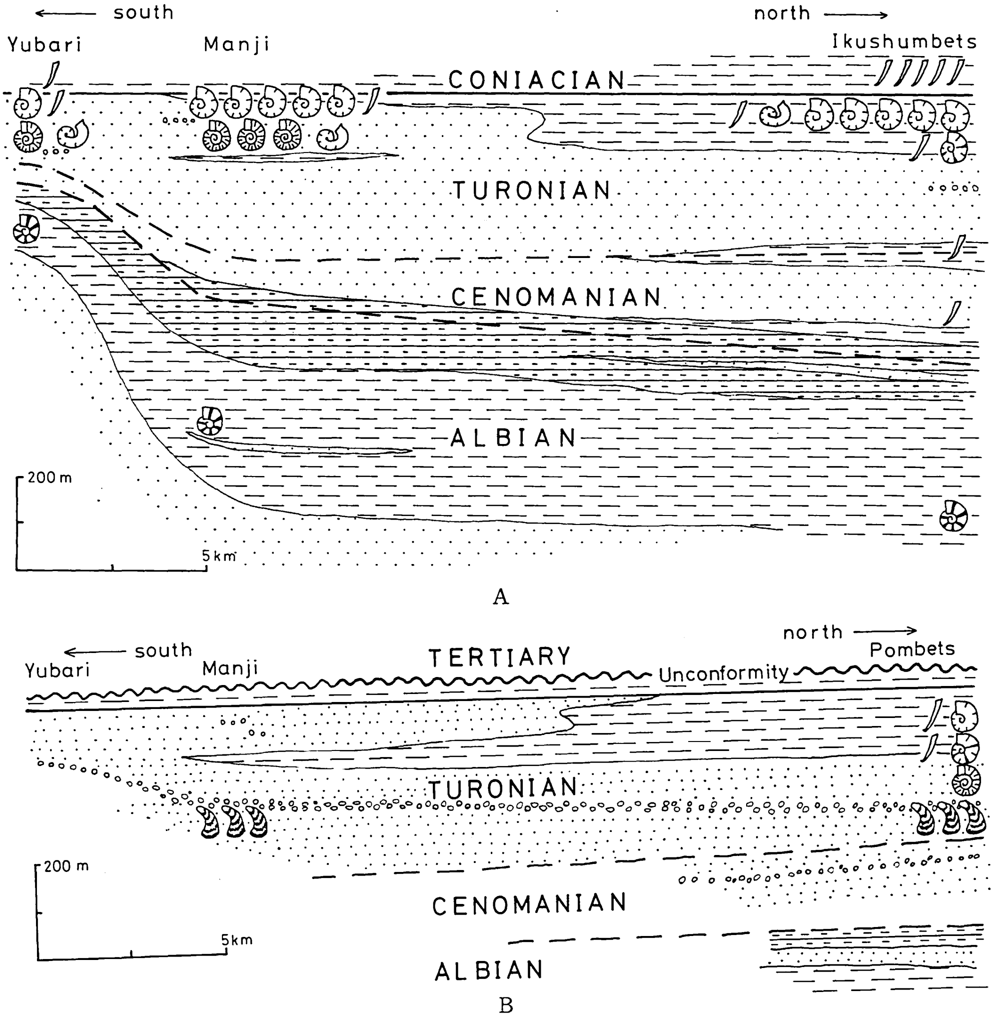

Fig. 4. Generalized stratigraphic facies section from north to south, *i. e.*, Ikushumbetsu-Pombetsu-Manji-Yubari. A: eastern part; B: western part. The predominate ammonites are shown.

silty fine sandstone between the First and the Second Green Sandstones of Member IIIa in the Ikushumbetsu valley (MATSUMOTO, 1965).

S. neptuni occurs commonly in sediments of a particular facies which represents a relatively western, probably inshore part of the Upper Cretaceous marine basin, represented by sediments of the Manji area in Hokkaido. On the other hand, *R. minimus* occurs abundantly in the silty fine sandstone or fine sandy siltstone of an intermediate facies between inshore shallow sandy facies and the rather off-shore muddy one, which is a similar facies to that which contains the baculitid species (MATSUMOTO and OBATA, 1962, 1963). In California and Oregon, as MATSUMOTO (1960) has pointed out, *Subprionocyclus* species occur in comparatively shallow sea sediments of a marginal facies, in which pelecypods and gastropods are predominant over ammonites. In better known regions outside Japan, the collignoniceratids, such as *Prionocyclus*, which is frequently associated with *Scaphites*, are generally common in some sediments of epicontinental, probably shallow seas, as exemplified by the Western Interior to Gulf-Atlantic province of North America, central Europe, Madagascar and South Africa (MATSUMOTO, 1971). The kind of associated bottom sediment is not consistent, being sometimes mudstone, sometimes marl, and at other times chalk and even calcareous sandstone.

From the morpholocic analysis of shell form, the ornamentation and septal fluting, we are inclined to consider that the phylogenetic line of *C. woollgari—S. neptuni—S. normalis—R. minimus* represents the result of adaptation for less shallower sea environments (OBATA and FUTAKAMI, 1977). This interpretation may be in harmony with the occurrence of collignoniceratids described above.

If we attach great importance to the ostreids, *S. neptuni* and *R. minimus* as facies indicators, an attempt to work out the paleogeographic occurrences of these fossils would be justified (Fig. 5A-C). The lithologic data are based on the studies by MATSUMOTO (1965) on Ikushumbetsu, OBATA and FUTAKAMI (1975) on Manji and MATSUMOTO and HARADA (1964) on the Yubari areas. From TANAKA's map (1970, fig. 48) the paleocurrent pattern in the Mikasa Formation is indicated by the short arrow (Fig. 5A-C), and the presumed major point sources for the coarse semiments of the main part of the Middle Yezo Group are shown by the open arrow (Fig. 5A).

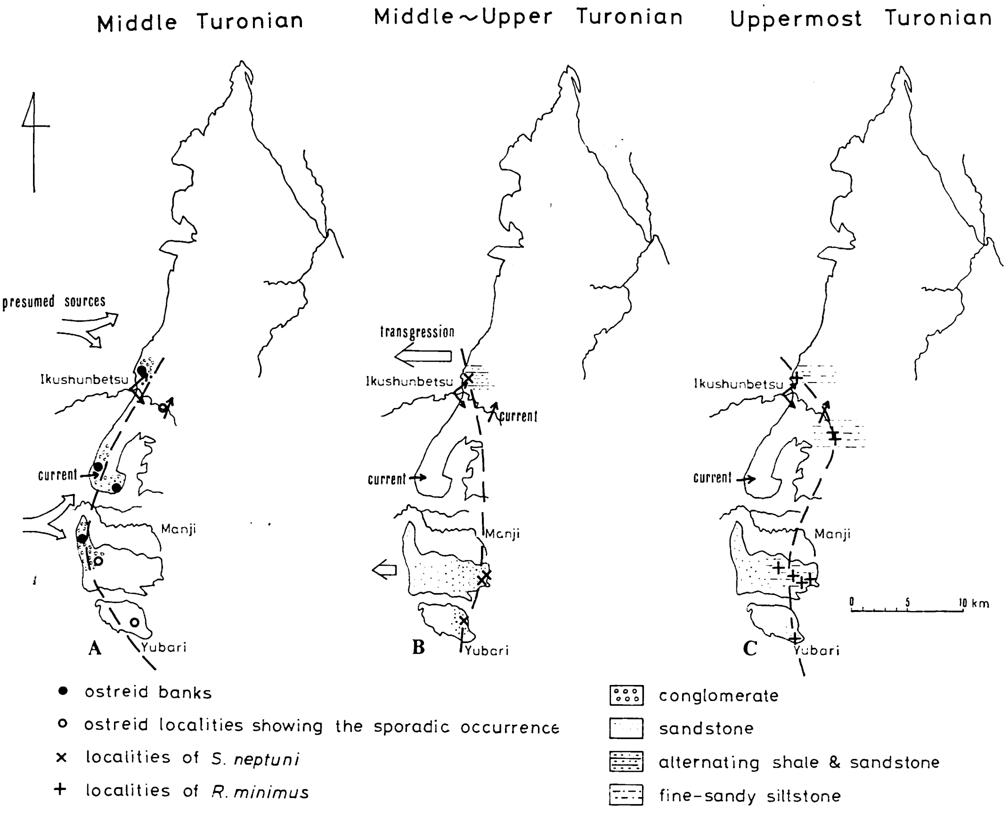

Fig. 5. Maps showing the distribution of ostreid localities and conglomeratic beds (A), and the occurrences of *Subprionocyclus neptuni* (B) and *Reesidites minimus* (C).

The broken lines indicate the main occurrences of the above fossils.

The broken line of Fig. 5A shows a curve which is open to the east. The existence of a Middle Turonian bay could be suggested for the Ikushumbetsu—Manji—Yubari area from the curved distribution line of the ostreid and conglomerate localities. The broken line of Fig. 5B shows a roughly north—south direction. Judging from the distribution of *S. neptuni* localities and the lithofacies, a possible interpretation would be that the regional transgression in the northern Ikushumbetsu area was greater than that in the southern Manji and Yubari areas. This interpretation may be in harmony with TANAKA's conclusion on the sedimentary basin in the Turonian (1963, fig. 39).

The broken line of Fig. 5C shows the distribution of *R. minimus* localities which are represented by a sigmoidal curvature. Thus the suggested broken line changes in curvature from Middle Turonian to Uppermost Turonian. We should like to suggest that the change may be the result of some difference in the environment related to the Turonian coast line.

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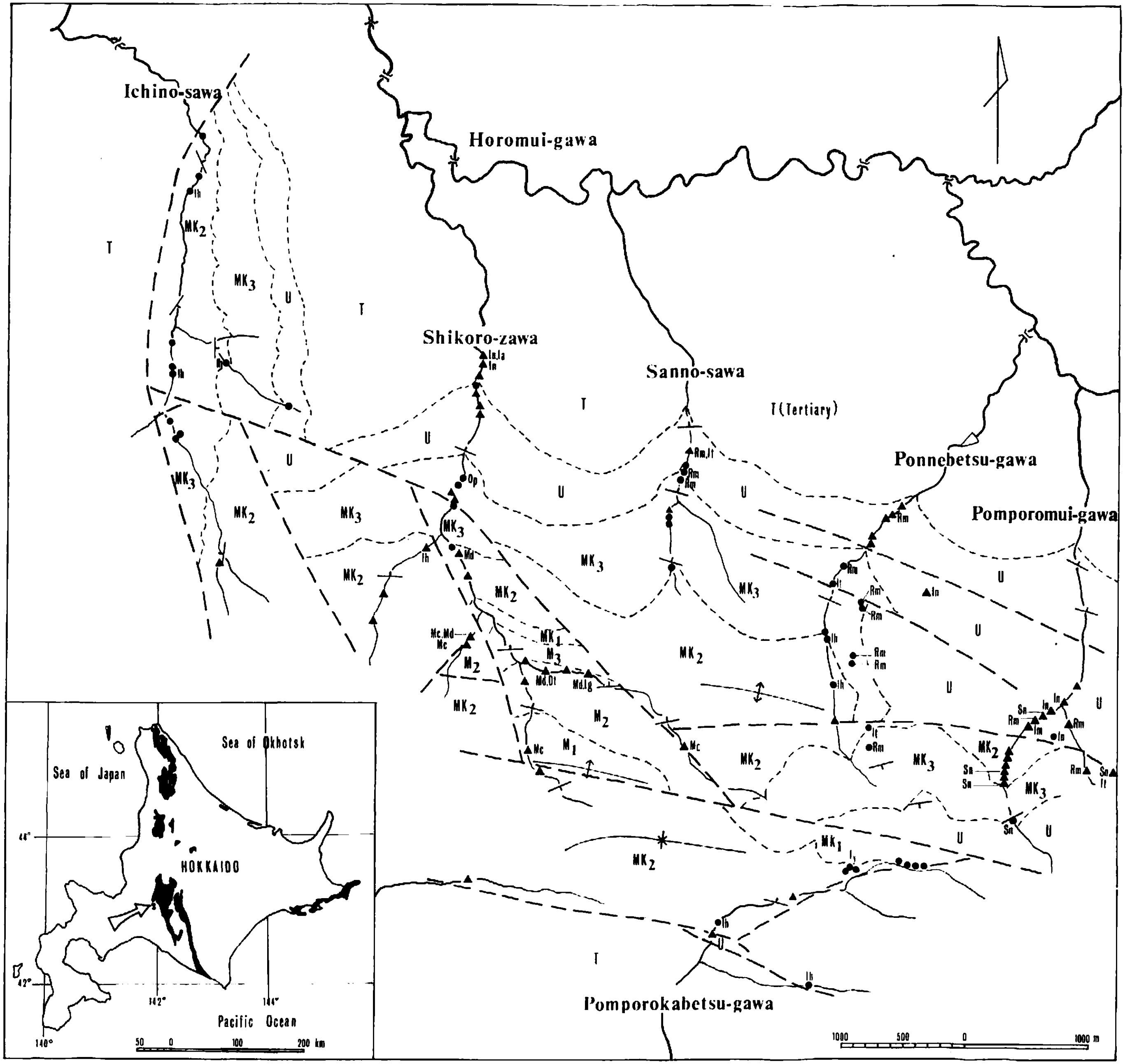

Fig. 1. Geological map of the Manji area showing the localities of the molluscan fossils (adapted from OBATA and FUTAKAMI, 1975). Fossil locality: ● in situ, ▲ in fallen or rolled block. Ig: *I. anglicus*, Iy: *I. yabei*, Ih: *I. hobetsensis*, It: *I. teshioensis*, Im: *I. mihoensis*, In: *I. naumanni*, Ia: *I. amakusensis*, Md: *M. cf. devonense*, Mc: *M. imaii*, Op: *O.* cf. *perrini*, Dt: *D. tosaense*, Sn: *S. neptuni*, Rm: *R. minimus*.

MID-CRETACEOUS PLANKTONIC MICROFOSSILS FROM THE OBIRA AREA, RUMOI, HOKKAIDO

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Abstract

In search for the stratigraphic succession of the planktonic microfossils in the Middle Cretaceous deposits of Hokkaido, selected is a section along the course of Obirashibe River, which flows in the midst of the Obira area. Generally speaking, calcareous nannoplanktons are fairly common but not evenly distributed, while planktonic foraminiferas are very meager throughout. Based upon these fossils, the Middle Cretaceous sequence from the main part of the Middle Yezo Group to the main part of the Upper Yezo Group in this area is correlated to the Cenomanian to Coniacian. The Cenomanian/Turonian boundary may be placed between the lower part of the unit Mh and the upper part of the unit Mj, and the Turonian/Coniacian boundary at around the base of the unit Ub.

1. Introduction

During the last decade, Cretaceous microbiostratigraphy has made considerable progress on a global scale. Although many results were primarily concerned in deep sea sediments, calcareous nannoplanktons have proved quite satisfactory for stratigraphic resolution as compared with other microfossil zonations. In Japan the first record on the Cretaceous smaller foraminifera and that on calcareous nannoplanktons were incidentally made from the Futaba district of the Honshu Island (ASANO, 1950; TAKAYAMA and OBATA, 1968). However, subsequent studies on foraminifera are almost concentrated upon the Cretaceous of the Hokkaido Island, because of faunal abundance there. The junior author has been engaged in studies on the Cretaceous nannoplanktons from Hokkaido, and a preliminary result on the Saku area was already reported (OKAMURA *et al.* in press).

The purpose of the present paper is to present a stratigraphic succession of the calcareous planktonic microfossils in the Middle Cretaceous strata distributed in the Obira area, Rumoi-gun, Teshio Province. The studied section lies along the course of the Obirashibe River, which flows from east to west in the midst of the Obira area. The Cretaceous sequence exposed along the section mainly comprises mudstone and fine-grained sandstone, and attains about 6,000 m in total thickness. The present paper deals with the interval from the main part of the Middle Yezo Group to the main part of the Upper Yezo Group, covering about 1,600 m in thickness. Since this area has been under intensive studies in geology as well as paleontology by various

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workers, the section is considered as one of the ideal ones for microbiostratigraphy and for correlating the result with those of megafaunal groups.

2. Geological Setting

The Obira area is situated along the coast of the Sea of Japan, and is bordered on the eastern side by the Teshio mountain range (Fig. 1). The geology of the Cretaceous deposits occupying the eastern hilly side of the area was investigated by TANAKA (*In*: TSUSHIMA *et al.*, 1958; IGI *et al.*, 1958). Subsequently litho- and megafaunal biofacies of these deposits were fully analysed by the same author (TANAKA, 1963). According to him, the Cretaceous deposits comprising the western wing of large-scale anticline is classified into the Lower Yezo, Middle Yezo and Upper Yezo Groups in ascending order. The Lower Yezo Group consists mainly of alternation of sandstone and shale, but is limited its distribution within a narrow area. The Middle Yezo Group overlying disconformably the former unit and the Upper Yezo Group are conformable in relation, and they constitute the principal part of the Cretaceous of the Obira area. The Hakobuchi Group, the uppermost Cretaceous unit widely recognized within the meridional zone of Hokkaido, is not present due to denudation before the Tertiary transgression. The Middle Yezo Group, about 3,500 m thick, is subdivided into three units; the lower is composed mainly of sandstone with subordinate mudstone and conglomerate; the main part is represented by comparatively monotonous, fine-grained sediments with sandstone and tuffaceous intercalations; the uppermost part comprises sandstone in the lower, and mudstone with intercalation of sandstone in the upper. The Upper Yezo Group attains to more than 1,700 m in thickness and

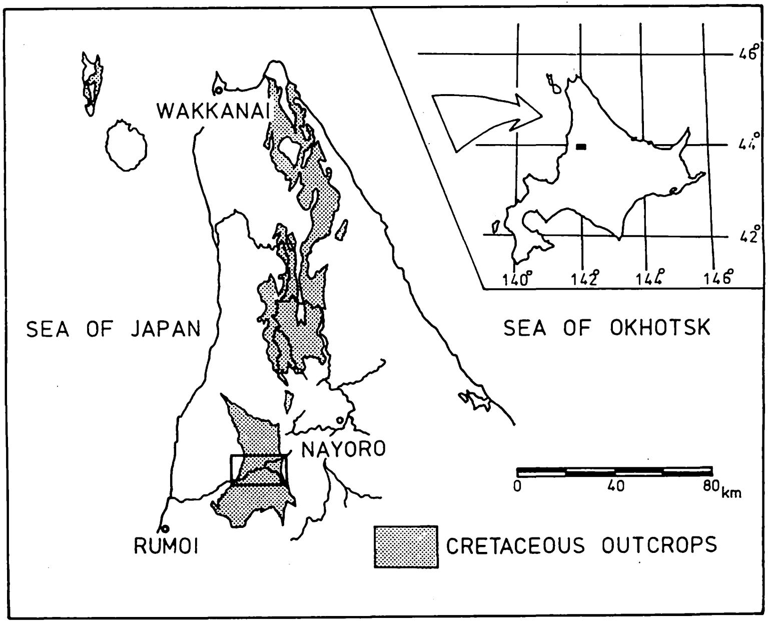

Fig. 1. Index map of the Obira area.

is divided into two parts; the main part is made up mostly of monotonous, fine-grained sediments with calcareous concretions and tuffaceous intercalations; the uppermost part is generally coarser-grained and much less tuffaceous as compared with the main part. Throughout the whole sequence distinct is cyclic sedimentation in a definite order.

Foraminifers from the Middle Yezo and Upper Yezo Groups along the Obirashibe River were first examined and a total of 99 species was recorded by TAKAYANAGI (1960). Cyclic fluctuation in foraminiferal abundance was then noticed, though it was not always coincident with the sedimentational one. Recently, MATSUMOTO and his collaborators accomplished a biostratigraphical survey of the same section based upon ammonites and inocerami (TANABE *et al.*, 1977). Thus the Obira section may be said as one of the few sections examined in diverse aspects.

3. Materials

Mudstone samples were collected from the Middle Yezo and Upper Yezo Groups at a stratigraphic interval of about 5 m along the main course and a branch, Kanajiri-zawa, of the Obirashibe River (Fig. 2). The Cretaceous sequence is fairly continuous in exposure along these streams, and approximately 70 per cent of the portion was recovered. A tuffaceous shale bed within the unit Mj of the Middle Yezo Group furnishes with a good key marker so that exact correlation was made between the sequence of Kanajiri-zawa and that of the main course. According to TANAKA (1963), such units of the Middle Yezo Group as the upper part of Mh, Mi and lower part of Mj are missing in the present section due to fault. These parts are estimated to be about 50 m in total thickness.

All samples were from a few ten centimeters below the river bed, except for one from a new road cutting. Location of samples is shown in Figs. 3 and 4, and their

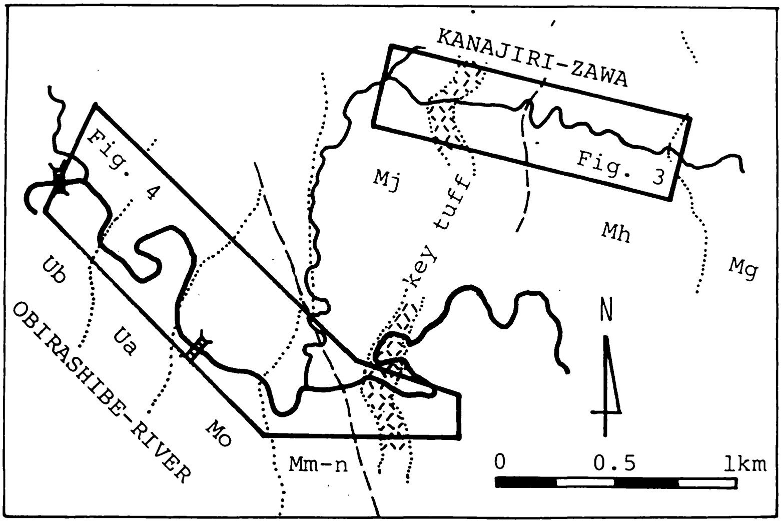

Fig. 2. Map showing the location of the Obira section.

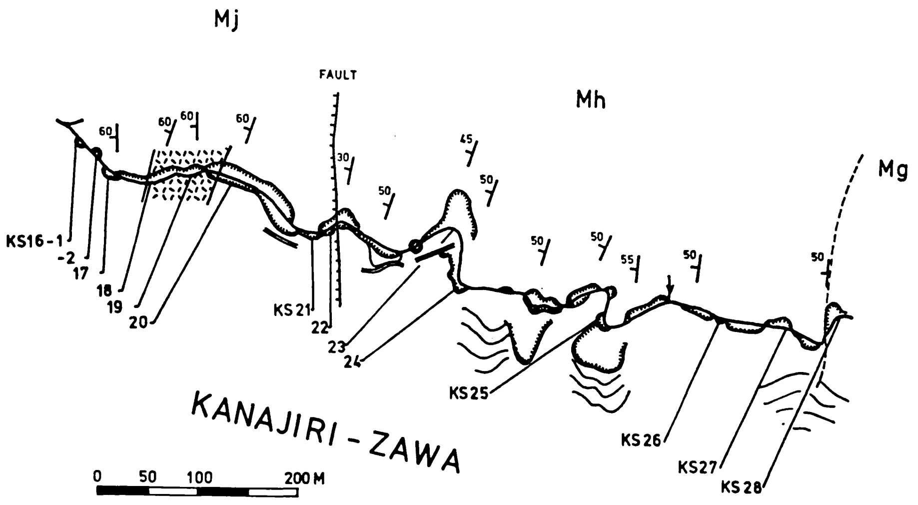

Fig. 3. Map showing the sampling site of the Kanajiri-zawa.

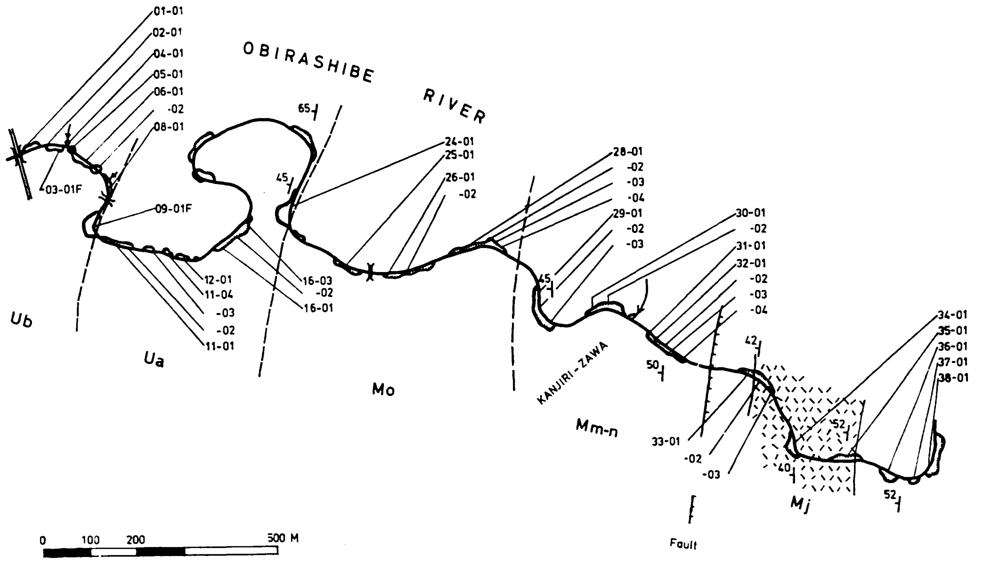

Fig. 4. Map showing the sampling site of the main cource of the Obirashibe River.

stratigraphic positions are indicated in columnar sections (Figs. 5 and 6). Among a total of 121 samples collected, almost a half of them were found to yield calcareous nannoplanktons. Thirty-two samples were selected from these nannofossiliferous ones, and were examined for foraminiferal study.

4. Calcareous Nannoplanktons

Calcareous nannoplanktons analysed in the present study are generally well preserved as compared with assemblage from other areas in Hokkaido. A total of 20 genera and 29 species were identified under a light microscope. Their stratigraphic distributions are shown in Figs. 5 and 6. Abundance of nannoplanktons remarkably differs by horizon, although it appears independent from lithofacies. They are abundant in the units as Mh (upper part), Mj (upper part), Mm-n (lower part), Ua (lower and upper parts) and Ub, but rare in the units as Mh (lower part), Mj (middle part), Mo and Ua (middle part). It is distinct that the floral diversity tends to increase from the lower to upper horizons. For instance, the nannoplanktons encountered in the lower part of the unit Mh consist of three families, eight genera and ten species, while those in the uppermost part of Ub are five families, 15 genera and 17 species. Among the species identified, *Watznaueria barnesae* and *Nephrolithus gorkae* are consistently found throughout the sequence studied. Especially it is remarkable that *W. barnesae* dominates over all other taxa throughout the sequence, making up 50 to 90 per cent of the total population in each assemblage. Similar feature was observed during the experimental dissolution of the Cenomanian Del Rio Clay by Hill (1975). Calcium carbonate solution in the present material may be also substantiated by the fact that the abundance of such forms with large element and stout stem and the

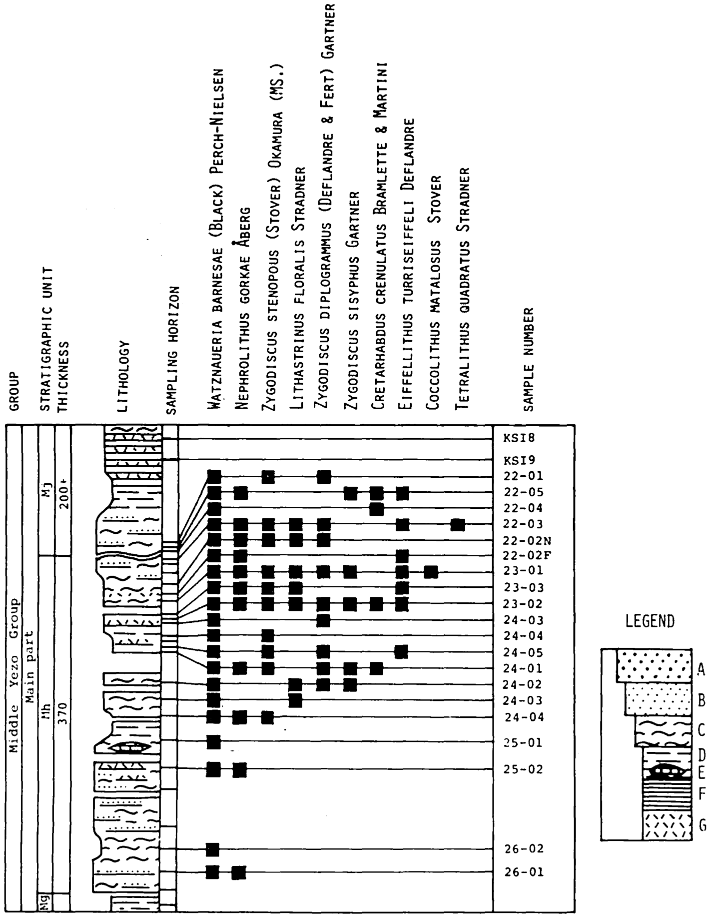

Fig. 5. Stratigraphic distribution of calcareous nannoplanktons in the Cretaceous along the Kanajiri-zawa. A: Medium-grained sandstone, B: Very fine-grained sandstone, C: Siltstone, D: Claystone, E: Limestone, F: Shale, G: Tuff.

scarcity of forms with delicate structures in assemblage.

Among the species appeared in the unit Mh, *Zygodiscus stenopous* is a form which made its initial appearance in the Cenomanian (STOVER, 1966). Furthermore, *Z. sisyphus* is hitherto unknown below the upper Cenomanian (GARTNER, 1968). All the remaining species, including *Eiffellithus turriseiffeli*, are the older forms appeared already in the Lower Cretaceous (Cf. THIERSTEIN, 1973 and others). Based upon the megafaunal examination, TANABE *et al.* (1977) correlated the unit Mh, except for its top part, to the upper Cenomanian. The present microfloral evidence is not inconsistent with their view.

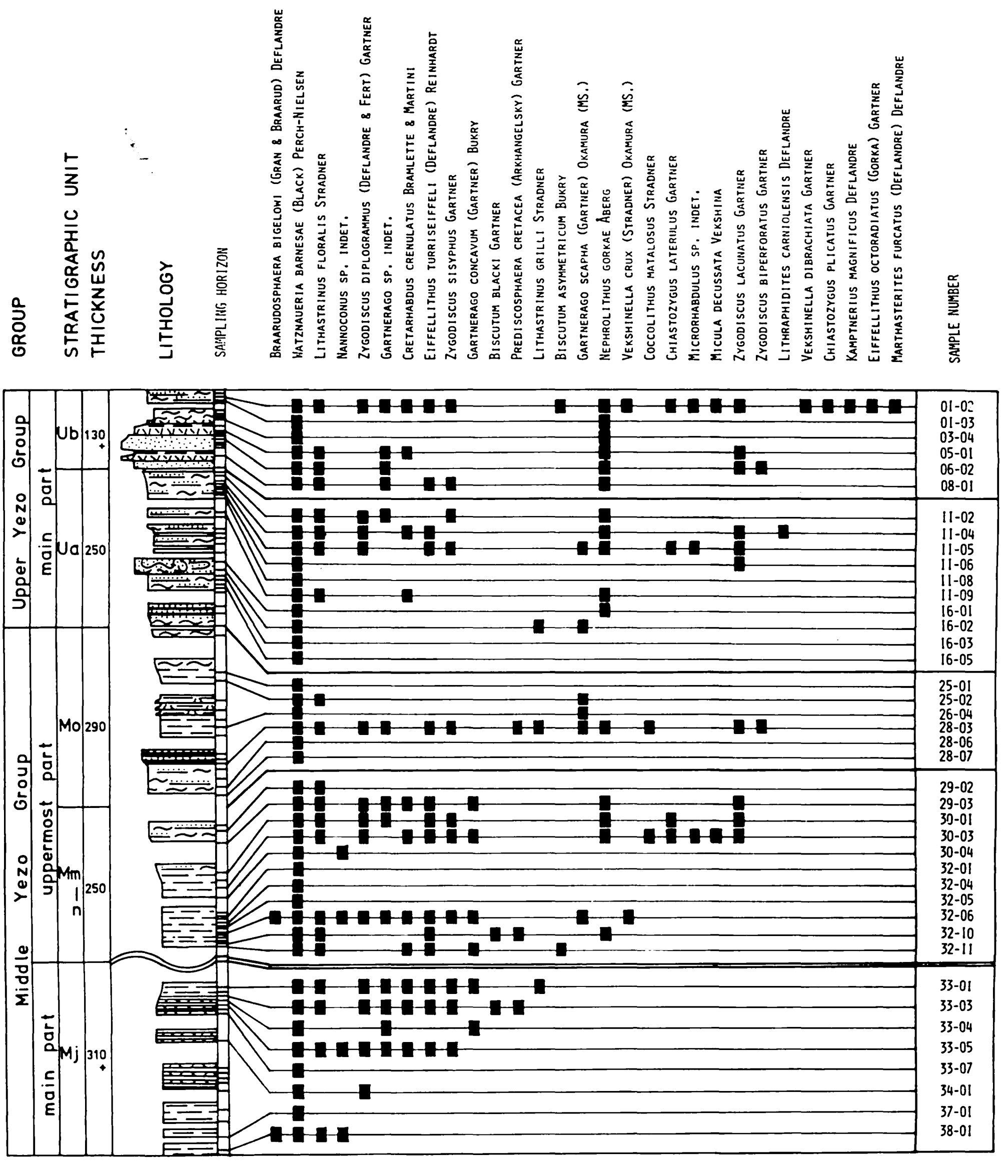

Fig. 6. Stratigraphic distribution of calcareous nannoplanktons in the Cretaceous along the Obirashibe River. See Fig. 5 for legend of geologic column.

The nannoplankton assemblage in the lower part of the unit Mj is similar to that of the underlying unit, but it is noted that *Gartnerago concavum* appeared first in the upper half. According to STOVER (1966), *Discolithus segmentatus* STOVER made the initial appearance in the Turonian. This species is, however, considered as a junior synonym of *G. concavum* at present. Consequently, the upper part of the unit Mj at least is judged to be younger than Cenomanian in age.

There is a considerable break caused by fault between the units Mj and Mm-n. It corresponds to the top of Mj, Mk, Ml and the base of Mm-n, and is estimated to attain to 300 m in thickness. Nevertheless, no distinct microfloral change is observed across this stratigraphic break. The upper part of the unit Mm-n is marked by the first appearance of *Micula decussata*. This is a species known to make its initial appearance in the upper Turonian of Europe and deep-sea sediments (STRADNER, 1963; ROTH, 1973; BUKRY, 1974). In addition, the genus *Microrhabdulus* is also assumed to have its first appearance in the Turonian. Thus the upper part of the unit Mm-n is considered as not older than late Turonian.

It is interesting that *Gartnerago concavum* disappeared at near the top of this unit. Notwithstanding the species is known to range into much younger horizon outside Hokkaido, it was restricted within the Turonian in the Saku area, Teshio Province (OKAMURA *et al.* in press). Although further study is needed to establish exact distribution, this species seems to be a workable Turonian index so far as Hokkaido is concerned.

There is no marked change in specific composition within the units Mo and Ua. The unit Ub is characterized by the first appearance of *Marthasterites furcatus* in its upper part. This species is widely recognized to have its lowest occurrence in the Coniacian (STOVER, 1966; GARTNER, 1968; BUKRY, 1974). The Coniacian age of the unit Ub is supported by megafossils (TANABE *et al.* 1977) and planktonic forminfera as discussed in the later section.

5. Planktonic Foraminifera

Generally speaking, foraminiferal assemblages found in the present section were very poor in planktonic forms, and were dominated by benthonic forms composed mainly of agglutinated taxa most resistant to solution. The effect of dissolution appears more severe on foraminiferal tests than coccoliths.

The forms identified from each stratigraphic unit are:

Mj (Sample 37-01)
    Hedbergella delrioensis (CARSEY) ....very rare
Mm-n (Sample 30-01)
    Whiteinella archaeocretacea PESSAGNO.............................very rare
Ua (Sample 16-01)
    Heterohelix sp. ....very rare
Ub (Sample 08-01)
    Whiteinella archaeocretacea PESSAGNO.............................very rare
    (Sample 06-01)
    Heterohelix sp. ....very rare

(Sample 01-02)

Whiteinella baltica DOUGLAS and RANKIN	common
Archaeoglobigerina bosquensis PESSAGNO	common
Globotruncana angusticarenata GANDOLFI	very rare
G. canaliculata (REUSS)	very rare
G. coronata BOLLI	common
G. cf. *helvetica* BOLLI	very rare
G. marginata (REUSS)	common
G. pseudolinneiana PESSAGNO	very rare
G. renzi THALMANN	very rare

Hedbergella delrioensis is known to range from Early to Late Cretaceous (TAKAYANAGI and IWAMOTO, 1962), but is assumed to have its maximum development during Albian to Cenomanian (PESSAGNO, 1967). It is very scarce in the strata above the Cenomanian (MAIYA and TAKAYANAGI, in this volume). *Whiteinella archaeocretacea* was primarily described from the Gulf Coast and recorded to have a range from Turonian to early Santonian, with its maximum development in late Turonian. Another species, *W. baltica*, was recorded from the Turonian to lower Santonian of Germany and Poland (DOUGLAS and RANKIN, 1969). The genus *Whiteinella* occurs rather commonly in the Turonian to Coniacian but rarely in the Santonian throughout Hokkaido (MAIYA and TAKAYANAGI, in this volume). *Archaeoglobigerina bosquensis* is restricted its occurrence within the Coniacian and Santonian of the Gulf Coast, and is also found in the lower Santonian of Denmark (PESSAGNO, 1967; DOUGLAS and RANKIN, 1969). Most of species of *Globotruncana* appeared together in the unit Ub are commonly found in the Turonian to Santonian of the Gulf Coast region, except for *G. helvetica* which is confined within the Turonian. Similar faunal distribution is recognized in the Cretaceous of Hokkaido. The *Globotrucana*-bearing horizon will be referable to the Coniacian, because common occurrence of *G. marginata* is a characteristic feature of the Coniacian of Hokkaido, besides the joint occurrence of *Archaeoglobigerina bosquensis*. The presence of a form comparable to *G. helvetica* may suggest the closeness of this horizon to the Turonian/Coniacian boundary. Therefore the unit Mm-n will be correlated to the Turonian, though age assignment of the unit Mj is reserved for other fossil evidence.

6. Summary and Conclusion

Based upon calcareous nannoplanktons and planktonic foraminifera, the Middle Cretaceous sequences from the main part of the Middle Yezo Group to the main part of the Upper Yezo Group in the Obira area were correlated to the Cenomanian to Coniacian. The Cenomanian/Turonian boundary may be placed somewhere within the interval between the lower part of the unit Mh and the upper part of the unit Mj, and the Turonian/Coniacian boundary at around the base of the unit Ub. In general, the nannoplanktons were better preserved than the foraminfera, but calcium carbonate solution was more or less evident in the material studied. Nevertheless, age assignment on the basis of the lowest occurrence of each characteristic nannoplankton taxon in the sequence is consonant with those of planktonic foraminifera as well as ammonites and inocerami.

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CRETACEOUS FORAMINIFERAL BIOSTRATIGRAPHY OF HOKKAIDO

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Abstract

Dual biostratigraphic zonal schemes based on both planktonic and benthonic foraminifera are proposed for the Middle to Upper Cretaceous sequence developed in the meridional zone of Hokkaido; the planktonic zonation consists of seven zones, while the benthonic one does six zones. Their relationship with the Japanese as well as European chronostratigraphic units are shortly discussed.

1. Introduction

The Cretaceous deposits distributed within the meridional zone of Hokkaido are represented by fairly continuous, thick marine sediments, and are rich in fossils. Since reconnaissance works were undertaken in the latter part of the 19th century, numerous paleontological contributions have been added to the Cretaceous geology of Hokkaido. Research in micropaleontology is, however, still young from a historical point of view, and contributions are very limited in number. It was 1950 when ASANO first recorded smaller foraminifera from the Cretaceous of Hokkaido. Among several papers appeared subsequently, there was a monograph of the Cretaceous foraminifera from the meridional zone of Hokkaido which was brought forth by TAKAYANAGI (1960). He summarized stratigraphic distributions of taxa in the Lower Miyakoan (Aptian) to Lower Hetonaian (Campanian), but did not establish zonal scheme on the basis of foraminifera. A few years later, the Albian planktonic fauna from the Ishikari Province was described by TAKAYANAGI and IWAMOTO (1962). With a background of these investigations, MAIYA, one of the present authors, has been engaged in a detailed survey on the Cretaceous foraminifera from the several detached areas as Soya, Saku, Soeushinai, Ikushumbetsu and Urakawa within the meridional zone for the past ten years. The purpose of the present paper is to propose the biostratigraphic zonations based upon both planktonic and benthonic forms, and to discuss concisely their relationship with the Japanese as well as European chronostratigraphic schemes (Fig. 1).

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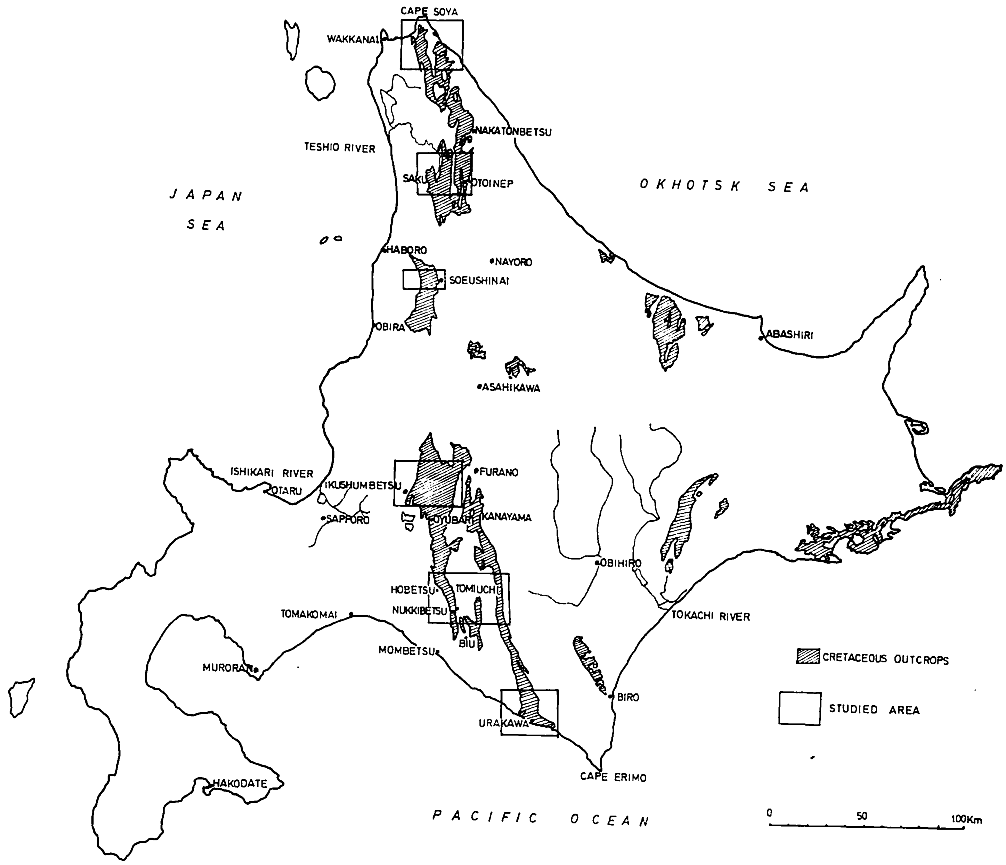

Fig. 1. Map showing the distribution of the Cretaceous deposits and the studied area in Hokkaido.

During the course of study, many rock samples were found to suffer from leaching on calcareous foraminifera in disregard of careful sampling in field. Absence of planktonic forms in many cases were possibly due to loss during diagenesis, though they were originally small in number as compared with benthonic ones. On the other hand, agglutinated forms are solution-resistant and found rather ubiquitously throughout the Cretaceous deposits. Considering such difference in a state of preservation, special attention was paid to elucidate precise relation in occurrence of planktonic and benthonic forms in well preserved rock sequences. Under these circumstances, it is considered most practical to establish a dual system of zonal schemes based on planktonic and benthonic forms, respectively. Although the corresponding planktonic and benthonic zones in this system bear different names, they are mostly defined by an identical rock body, and their boundaries coincide with each other in their type locality. Generally it is accepted that planktonic zones will furnish reliable criteria for long-distance correlation and age determination. However, the present benthonic zones are useful at least for intraregional correlation and easier in recognition within the meridional zone of Hokkaido. In other words, such duality

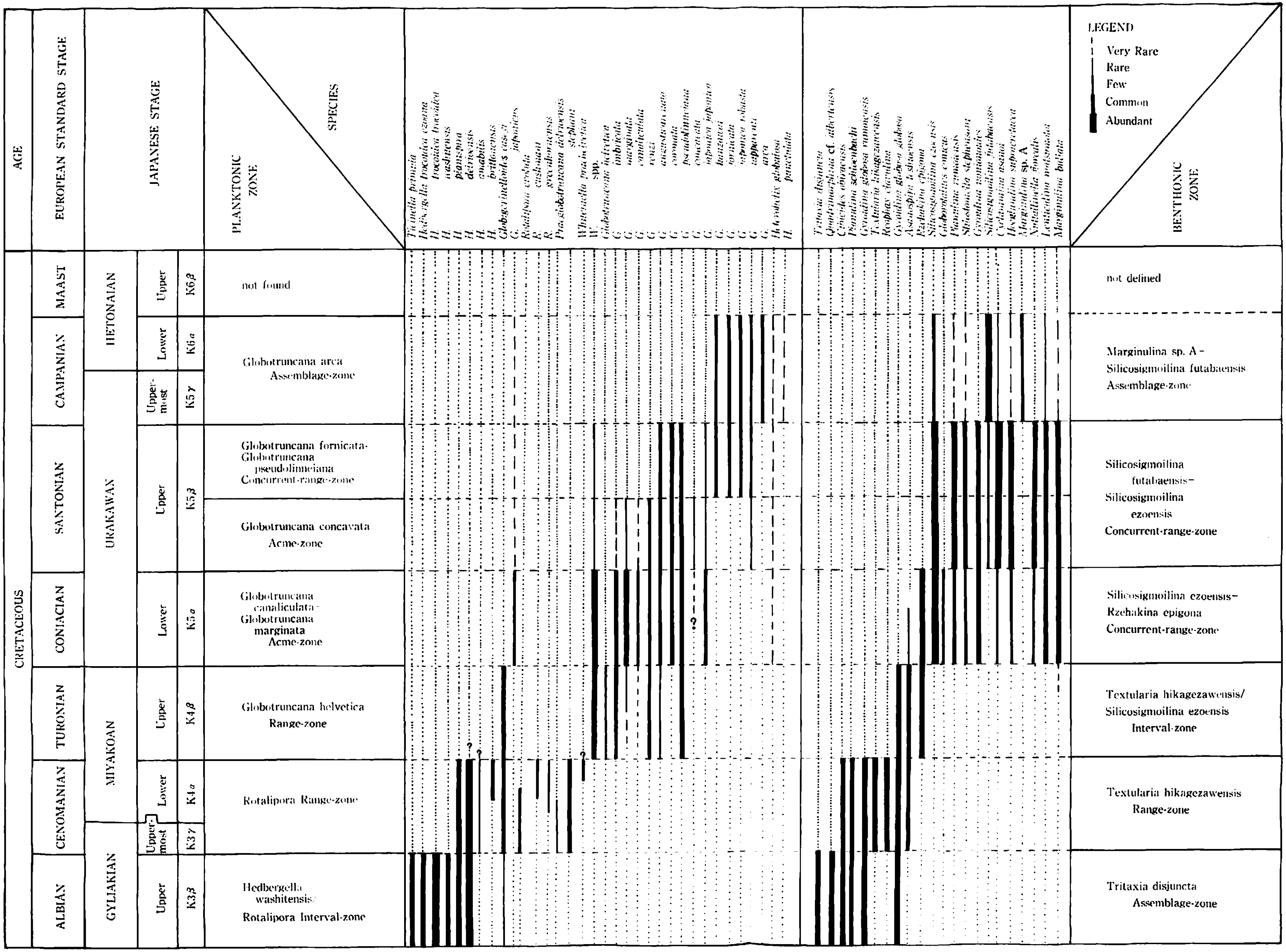

Figure. 2. Stratigraphic distribution of the selected foraminifera in the Cretaceous System of Hokkaido. (Read MIYAKOAN for GYLIAKIAN and *vice versa*.)

of the zonation will establish a basis of improved classification and correlation of surface as well as subsurface sections.

2. Methods

In this study more than 2,000 samples, principally of mudstone, were examined. All of them were prepared in accordance with a combination method of sodium sulfate and naphtha described by MAIYA and INOUE (1973). For dispersion, however, phenol was found effective instead of sodium hexametaphosphate.

3. Biostratigraphic Zonations

Seven planktonic and six benthonic foraminiferal zones are recognized based on the stratigraphic distribution of the characteristic planktonic and benthonic species (Fig. 2). These zones can be widely traced from the Cape Soya, which is situated at the northernmost part of Hokkaido, to the Urakawa area near the southern tip of the meridional zone, and can be successfully applied to the regional and interregional correlations (Fig. 3).

The biostratigraphic zones proposed in this study are to be placed in the category of the concurrent-range-zone, interval-zone, range-zone, assemblage-zone and acme-zone defined by the International Subcommission on Stratigraphic Classification (1971).

A. Planktonic biostratigraphy

Based on the stratigraphic occurrence of planktonic foraminifera, the authors have been able to recognize the following biostratigraphic subdivisions for the Cretaceous sequence of Hokkaido, in descending order:

7. *Globotruncana arca* Assemblage-zone
6. *Globotruncana fornicata—Globotruncana pseudolinneiana* Concurrent-range zone
5. *Globotruncana concavata* Acme-zone
4. *Globotruncana canaliculata—Globotruncana marginata* Acme-zone
3. *Globotruncana helvetica* Range-zone
2. *Rotalipora* Range-zone
1. *Hedbergella washitensis/Rotalipora* Interval-zone.

In the following lines the planktonic zones and their faunal elements are described briefly.

1. *Hedbergella washitensis/Rotalipora* Interval-zone

Type section.—The lower part of the Middle Yezo Group (Md of MATSUNO *et al.*, 1964) along the Honzawa River, a tributary of the Ikushumbetsu River, Poronai, Mikasa City, Ishikari Province.

Lithology.—Laminated black mudstone with marly nodules.

Remarks.—The *Hedbergella washitensis/Rotalipora* Zone is defined by the limited concurrence of *Hedbergella washitensis* (CARSEY), *Ticinella primula* (LUTERBACHER), *Hedbergella trocoidea* (CARSEY), *H. trocoidea ezoana* TAKAYANAGI and IWAMOTO, which are indicative of an age older than the lowest Cenomanian. Additinal species appeared

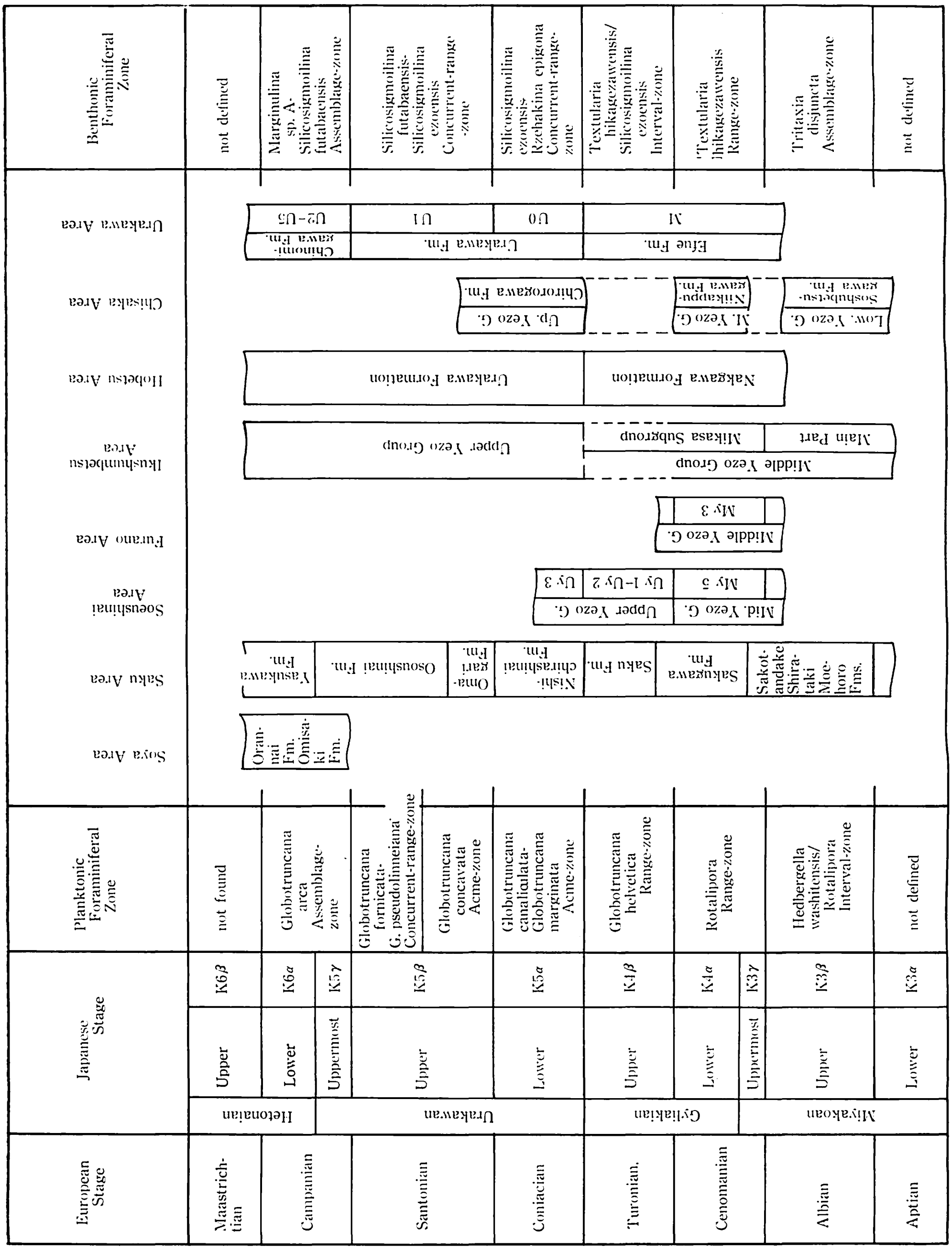

Fig. 3. Typical Cretaceous sequences in Hokkaido showing correlations based on foraminifera.

in this zone include *Hedbergella delrioensis* (CARSEY), *H. planispira* (TAPPAN) and *Globigerinelloides caseyi* (BOLLI, LOEBLICH and TAPPAN), all of which are known to range from Albian to Cenomanian or still younger. The base of the zone is placed at the horizon of the first appearance of *Hedbergella washitensis*. This is the lowest of the planktonic foraminiferal zones in Hokkaido and includes the upper part of the Miyakoan stage distributed in the Saku, Furano, Ikushumbetsu, Yubari, Hobetsu, Chisaka and Urakawa areas. The planktonic species of this zone, except for *Ticinella primula* and *Hedbergella planispira*, were descibed by TAKAYANAGI and IWAMOTO (1962) from the lower part of the Middle Yezo Group (approximately equivalent to the Upper Miyakoan) of the Ikushumbetsu area. As discussed by them, the specific composition of this zone is similar to the planktonic assemblage in the Lower Cretaceous of Madagascar (SIGAL, 1956). Furthermore, *Ticinella primula* has been recorded from the upper to middle Albian of Europe by various workers (RENZ, LUTERBACHER and SCHNEIDER, 1954). This zone is thus correlated with the Albian of Europe, Africa and their adjacent regions without contradiction.

2. *Rotalipora* Range-zone

Type section.—The lower part of the Efue Formation (KANIE, 1966) along the Tanebetsu River, Urakawa-cho, Urakawa-gun, Hidaka Province.

Lithology.—Black mudstone with thin, laminated sandstone layers and marly nodules.

Remarks.—The *Rotalipora* Zone is distinguished by the continuous occurrence of *Rotalipora evoluta* SIGAL, *R. greenhornensis* (MORROW), *R. cushmani* (MORROW), *Praeglobotruncana stephani* (GANDOLFI) and *P. delrioensis* (PLUMMER) throughout the interval, and the common occurrence of *Hedbergella delrioensis* and *H. planispira.* The top of the zone is defined by the extinction of the afore-mentioned *Rotalipora* species. Although *Praeglobotruncana stephani* is known to range up to the lower Turonian in North America, it has not been found in strata younger than the present zone in Hokkaido. Hedbergellas are also almost absent in the younger horizons. Since *Rotalipora* and *Praeglobotruncana delrioensis* are known only from the Cenomanian in North America and Europe, the *Rotalipora* zone, which corresponds to the Lower Gyliakian, is correlated with the Cenomanian. Especially in the Urakawa area it is possible to subdivide this into two subzones based on the range of Rotaliporas and Praeglobotruncanas, namely *Rotalipora evoluta/Praeglobotruncana delrioensis* subzone in the lower part, and *Rotalipora greenhornensis/Praeglobotruncana stephani* subzone in the upper. The present zone is represented in the Sakugawa Formation of the Saka area (HASHIMOTO *et al.*, 1967) and the Soeushinai area (HASHIMOTO *et al.*, 1965), the lower part of the Mikasa Subgroup of the Ikushumbetsu area (YOSHIDA and KAMBE, 1955), the lower part of the Nakagawa Formation of the Hobetsu area (HASHIMOTO, 1956), the Niikappugawa Formation of the Chisaka area (SAKO and OSANAI, 1962), and the lower part of the Efue Formation of the Urakawa area (KANIE, 1966).

3. *Globotruncana helvetica* Range-zone

Type section.—The Saku Formation (Uy 1) and the dark gray siltstone (Uy 2) of the Upper Yezo Group (HASHIMOTO *et al.*, 1965) along the Futamatazawa River of the Soeushinai area, Tomamae-cho, Tomamae-gun, Rumoi Province.

Lithology.—Alternations of sandstone and mudstone (Uy 1), and dark gray siltstone (Uy 2).

Remarks.—The *Globotruncana helvetica* Zone is separated from the underlying zone by the appearance of double-keeled Globotruncanas and Whiteinellas, and is defined by the restricted occurrence of *Globotruncana helvetica* BOLLI. The planktonic assemblage includes the common occurrence of *Globotruncana imbricata* (MORNOD), *G. renzi* GANDOLFI, *G. pseudolinneiana* (PESSAGNO), *G. marginata* (REUSS) and *Whiteinella* spp. The zone also contains *Globigerinelloides caseyi* (BOLLI, LOEBLICH and TAPPAN), which ranges from the Albian to Turonian in Hokkaido. The upper boundary of the present zone is placed at the horizon of the extinction of the nominal species. Although *G. helvetica* is rather small in number within the zone, it is one of the characteristics of the Turonian in Algeria, Morocco, Tunisia, Switzerland, California, the Gulf Coast and Caribbean regions (BOLLI, 1966; DOUGLAS and SLITER, 1966; PESSAGNO, 1967; DOUGLAS, 1969). Consequently, the *Globotruncana helvetica* zone as a whole is of Turonian, and roughly corresponds to the Upper Gyliakian. It is well represented in the Saku Formation of the Saku area (HASHIMOTO *et al.*, 1967) and the Soeushinai area (HASHIMOTO *et al.*, 1965), the upper part of the Mikasa Subgroup of the Ikushumbetsu area (YOSHIDA and KAMBE, 1955), the upper part of the Nakagawa Formation of the Hobetsu area (HASHIMOTO, 1956), and the upper part of the Efue Formation of the Urakawa area (KANIE, 1966).

4. *Globotruncana canaliculata—Globotruncana marginata* Acme-zone

Type section.—The Urakawa Formation (UO) of the Upper Yezo Group (KANIE, 1966) along the Tsukisappu River, Urakawa-cho, Urakawa-gun, Hidaka Province.

Lithology.—Thinly laminated mudstone.

Remarks.—The *Globotruncana canaliculata—Globotruncana marginata* Zone is characterized by the continuous and abundant occurrence of *Globotruncana marginata*, *G. angusticarenata* Gandolfi, *G. canaliculata* (REUSS) and *Whiteinella* spp., and by the first appearance of *Globotruncana japonica* TAKAYANAGI, *s. s.* and *Globigerinelloides japonicus* (TAKAYANAGI) in the basal part of the zone. Among others, *Globotruncana marginata* and *G. canaliculata* seem to reach their acme in this zone. In association with the species mentioned above, the forms such as *Globotruncana imbricata*, *G. renzi* and *G. pseudolinneiana* continuously occur from the subjacent zone. It is difficult to define clearly the top of the present zone, because the zonal constituents are all long-ranging species. At present it is distinguished by the abrupt decrease of *G. imbricata*, *G. marginata*, *G. canaliculata* and *Whiteinella* spp. They are abundantly found in strata assigned to Coniacian age in the Gulf Coast region (PESSAGNO, 1967). Based on such features of the assemblage together with the absence of *Globotruncana helvetica* which is diagnostic to the underlying zone, the present zone is correlated to the Coniacian, and is almost equivalent to the Lower Urakawan. It is recognized in the Nishichirashinai Formation of the Saku area and the dark gray sandy siltstone (Uy 3 of HASHIMOTO *et al.*, 1965) of the Soeushinai area, the lower part of the Upper Yezo Group (ul of YOSHIDA and KAMBE, 1955) of the Ikushumbetsu area, the lower part of the Urakawa Formation of the Hobetsu area, the Chirorogawa Formation of the Chisaka area (SAKO and OSANAI, 1962), and the lower part of the Urakawa Formation (UO of KANIE, 1966) of the Urakawa area.

5. *Globotruncana concavata* Acme-zone

Type section.—The Urakawa Formation of the Upper Yezo Group (Ul of KANIE, 1966), along the Tanebetsu River, Urakawa-cho, Urakawa-gun, Hidaka Province.

Lithology.—Thinly laminated black mudstone.

Remarks.—The *Globotruncana concavata* Zone is characterized by the rather rare but continuous occurrence of *Globotruncana concavata* (BROTZEN), which occurs sporadically in the underlying zone. Besides this species, *G. pseudolinneiana*, *G. coronata*, *G. renzi*, *G. imbricata* and *G. canaliculata* also occur in the *Globotruncana concavata* Zone, and the assemblage as a whole has great resemblance to that of the underlying zone. Many constituents such as *G. concavata*, *G. renzi*, *G. canaliculata* and *G. imbricata* disappear at the upper boundary of this zone, in a similar way to the Gulf Coast area. Specific composition of the zone is very close to the early Santonian assemblage of the Gulf Coast (PESSAGNO, 1967). In addition, *G. concavata* is well known to range from late Coniacian to early Santonian in Europe as well as the Gulf Coast (BARR, 1962; HERB, 1963; PESSAGNO, 1967). On this account the present zone may be correlated with the lower Santonian and with the lower part of the Upper Urakawan. It is typically represented in the lower part of the Osoushinai Formation of the Saku area, the middle part of the Upper Yezo Group of the Ikushumbetsu area, and the Urakawa Formation (lower part of U1) of the Urakawa area.

6. *Globotruncana fornicata—Globotruncana pseudolinneiana* Concurrent-range-zone

Type section.—The middle part of the Osoushinai Formation (HASHIMOTO *et al.*, 1967) along the Nio River, a tributary of the Teshio River, Saku, Nakagawa-cho, Nakagawa-gun, Teshio Province.

Lithology.—Dark gray mudstone with abundant molluscan fragments.

Remarks.—The *Globotruncana fornicata—Globotruncana pseudolinneiana* Zone is distinguished by the first appearance of *Globotruncana fornicata*, *G. japonica robusta* TAKAYANAGI, and *G. hanzawai* TAKAYANAGI. The top of the zone is placed at the horizon of the last occurrence of *G. pseudolinneiana*, *G. coronata* and *G. angusticarenata*, which occur continuously from the underlying zone. In the Gulf Coast area, *G. coronata* ranges from late Turonian to Santonian, possibly persisting into Campanian, and *G. fornicata* does from Santonian to Maastrichtian (PESSAGNO, 1967). On the other hand, in California the extinction levels of *G. coronata* and *G. pseudolinneiana* are together placed within the basal portion of the Campanian (DOUGLAS, 1969). This zone is thus nearly equivalent to the upper Santonian, and corresponds with the upper part of the Upper Urakawan. It is well represented in the middle part (dark gray mudstone) of the Osoushinai Formation of the Saku area, the upper part of the Urakawa Formation of the Hobetsu area, and the uppermost part of the Urakawa Formation (upper part of U1) of the Urakawa area.

7. *Globotruncana arca* Assemblage-zone

Type section.—Upper part of the Osoushinai Formation (HASHIMATO *et al.*, 1967) along the Nio River, Saku, Nakagawa-cho, Nakagawa-gun, Teshio Province.

Lithology.—Yellowish or light gray siltstone.

Remarks.—The *Globotruncana arca* Zone is defined by the first appearance of *Globotruncana arca* (CUSHMAN) at its base, and is characterized by the common occurrence of *Globotruncana lapparenti* (BROTZEN) (=*G. linneiana* of DOUGLAS, 1967), *G. fornicata*, *G. japonica robusta* and *G. hanzawai*, all of which appeared in the subjacent zone. *G. arca* has been recognized as a species restricted to the Campanian to Maastrichtian in various regions. Since the zone is overlain by the coarse grained sediments which are almost barren in foraminifera within the meridional zone of Hokkaido, it is hardly defined under a category of range-zone. However, similarity of specific association between the present zone and the Campanian of other regions as the Gulf Coast strongly suggests that the zone is to be assigned to Campanian in age. It also corresponds with the Lower Hetonaian. The *Globotrnncana arca* Zone is represented in the Omisaki and Orannai Formations of the Soya area, the upper part of the Osoushinai Formation of the Saku area, the uppermost part of the Urakawa Formation of the Hobetsu area, and the Chinomigawa Formation (U2-U5 of KANIE, 1966) of the Urakawa area.

B. Benthonic biostratigraphy

By the limited occurrences of several guide species of benthonic foraminifera, the Cretaceous strata of Hokkaido can be divided into six zones in descending order as:

6. *Marginulina* sp. A—*Silicosigmoliina futabaensis* Assemblage-zone
5. *Silicosigmoilina futabaensis*—*Silicosigmoilina ezoensis* Concurrent-range-zone
4. *Silicosigmoilina ezoensis*—*Rzehakina epigona* Concurrent-range-zone
3. *Textularia hikagezawensis/Silicosigmoilina ezoensiy* Interval-zone
2. *Textularia hikagezawensis* Range-zone
1. *Tritaxia disjuncta* Assemblage-zone.

The definition and the diagnostic components of each zone are briefly noted as below.

1. *Tritaxia disjuncta* Assemblage-zone

Type setcion and lithology.—Same as in the *Hedbergella washitensis/Rotalipora* Interval-zone.

Remarks.—The *Tritaxia disjuncta* Zone is defined by the restricted occurrences of *Tritaxia disjuncta* (CUSHMAN) and *Quadrimorphina* cf. *albertensis* MOLLEN and WALL within this interval. The top of this zone is placed at the horizon of the last occurrence of these species. Besides these forms, prominent species appeared in this zone are: *Cibicides obiraensis* TAKAYANAGI, *Dorothia hokkaidoana* TAKAYANAGI, *Epistomina carpenteri* (REUSS), *Gavelinella rudis* (REUSS), *Gavelinopsis infracretacea simionescui* NEAGU, *Globulina prisca* REUSS, *Gyroidina globosa globosa* (HAGENOW), *G. globosa rumoiensis* TAKAYANAGI, *G. naranjoensis* WHITE, *Pelosina complanata* FRANKE, *Planulina schloenbachi* (REUSS) and *Pleurostomella reussi* BERTHELIN. This zone is equivalent to the *Hedbergella washitensis/Rotalipora* Interval-zone.

2. *Textularia hikagezawensis* Range-zone

Type section and lithology.—Same as in the *Rotalipora* Range-zone.

Remarks.—This zone is distinguished by the first appearance of *Textularia hikagezawensis* TAKAYANAGI and *Reophax clavulina* (REUSS) after the extinction of *Tritaxia disjuncta* and *Quadrimorphina* cf. *albertensis.* The top of this zone is defined by the extinction of *T. hikagezawensis* and *R. clavulina.* Within the upper part of the zone *Cibicides obiraensis*, *Gyroidina globosa rumoiensis* and *Gavelinella rudis* disappear. Besides the species mentioned above, the important forms from this zone are: *Asanospira nakagawaensis* (ASANO), *A. teshioensis* (ASANO), *Dorothia hokkaidoana* TAKAYANAGI, *Gyroidina globosa globosa* and *Lenticulina yabei* TAKAYANAGI. The *Textularia hikagezawensis* Range-zone corresponds to the *Rotalipora* Range-zone.

3. *Textularia hikagezawensis/Silicosigmoilina ezoensis* Interval-zone

Type section and lithology.—Same as in the *Globotruncana helvetica* Range-zone.

Remarks.—The base of this interval-zone is placed at the horizon of the disappearance of *Textularia hikagezawensis*. It is characterized by the first appearance of *Rzehakina epigona* (RZEHAK) in the lower part, and by the predominance of agglutinated forms such as *Haplophragmoides*, *Bathysiphon*, *Asanospira*, *Ammodiscus*, etc. The top of the zone is placed immediately below the horizon of the first appearance of *Silicosigmoilina ezoensis* TAKAYANAGI which is characteristic of the overlying zone. In addition to the species mentioned above, the followings are commonly found in this zone: *Ammodiscus gaultina* (REUSS), *A. hashimotoi* (TAKAYANAGI), *Asanospira nakagawaensis*, *A. teshikensis*, *Glomospira charoides* (JONES and PARKER), *Gyroidina globosa globosa*, *Haplophragmoides asanoi* TAKAYANAGI, and *H. obesus* TAKAYANAGI. The present zone corresponds to the *Globotruncana helvetica* Range-zone.

4. *Silicosigmoilina ezoensis—Rzehakina epigona* Concurrent-range-zone

Type section and lithology.—Same as in the *Globotruncana canaliculata—Globotruncana marginata* Acme-zone.

Remarks.—The base of the present zone is marked by the first appearance of *Silicosigmoilina ezoensis*. Moreover, *Planulina rumoiensis* TAKAYANAGI, *Globorotalites conicus* (CARSEY), *Nuttallinella florealis* (WHITE), *Gavelinella sandidgei* (BROTZEN) and *Stilostomella stephensoni* (CUSHMAN) make their first appearance also just above the base of this zone. The calcareous forms are rich within this interval compared with the underlying zone. The top of the zone is placed at the horizon of the last occurrence of *Rzehakina epigona*, which lies immediately below the horizon of the first appearance of *Silicosigmoilina futabaensis* ASANO. Besides the above-mentioned species, prominent forms appeared are: *Cyclammina asanoi* TAKAYANAGI, *Globorotalites michelinianus* (d'ORBIGNY), *Gyroidina nonionoides* (BANDY), *Lenticulina matsumotoi* (TAKAYANAGI), *Marginulina bullata* REUSS and *Quadrimorphina allomorphinoides* (REUSS). The present zone is equivalent to the *Globotruncana canaliculata—Globotruncana marginata* Zone.

5. *Silicosigmoilina futabaensis—Silicosigmoilina ezoensis* Concurrent-range-zone

Type section.—The lower part of the Osoushinai Formation (HASHIMOTO *et al.*, 1967) along the Nio River, a tributary of the Teshio River, Saku, Nakaga-cho, Nakagawa-gun, Teshio Province.

Lithology.—Dark gray mudstone.

Remarks.—The present zone is characterized by the first appearance of *Silicosigmoilina futabaensis* at its base, and by the abundant occurrence of the calcareous forms as *Planulina rumoiensis*, *Lenticulina matsumotoi*, *Stilostomella stephensoni*, *Hoeglundina supracretacea* (TEN DAM), *Marginulina bullata*, *Nuttalline florealis* and many nodosariids. In this zone, the ratio of the calcareous forms to the total is generally very high in contrast with the sub- and superjacent zones. The top of the zone is placed immediately below the horizon of the first appearance of *Marginulina* sp. A. The present zone corresponds to the *Globotruncana concavata* zone and the *Globotruncana fornicata—Globotruncana pseudolinneiana* Concurrent-range-zone.

6. *Marginulina* sp. A—*Silicosigmoilina futabaensis* Assemblage-zone

Type section and lithology.—Same as in the *Globotruncana arca* Assemblage-zone.

Remarks.—This zone is defined by the first appearance of *Marginulina* sp. A at the base, and is marked by the abundant occurrence of *Silicosigmoilina futabaensis* throughout the interval. In addition to the afore-mentioned species, dominant species appeared in the zone are: *Bathysiphon* spp., *Haplophragmoides horridus* TAKAYANAGI, *H. asanoi* and *Lingulina* sp. Within the zone the ratio of the calcareous forms to the total becomes extremely low compared with the underlying zone, and the number of species also decreases, though it is very variable. Although the top of the present zone is tentatively limited by the extent of the concurrence of the nominal taxa, it can be hardly allocated on the basis of a definite biohorizon within the sequence studied. Because the present zone is overlain by the sediments which are almost barren in foraminiferal fossils. Consequently, it may come under the category of assemblage-zone. The *Marginulina* sp. A—*Silicosigmoilina futabaensis* Zone is equivalent to the *Globotruncana arca* Zone.

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SUCCESSION OF THE CRETACEOUS PATELLIFORM GASTROPODS IN THE NORTHERN PACIFIC REGION

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Abstract

Many species of patelliform gastropods occur in the marine Cretaceous deposits of the northern Pacific region. I (KANIE, 1975) presented a scheme of taxonomy, systematic description and biostratigraphic succession of several *Anisomyon* species, with some reference to their paleoecology and evolutional history. *Anisomyon* appeared at least in the Upper Barremian and disappeared in the Lower Maestrichtian in the northern Pacific region. The examined fossils are *Anisomyon annulatus* from the Upper Barremian, *A. cassidarius* from the Turonian to Santonian, *A. transformis* from the Lower Campanian, *A. giganteus* from the Middle Campanian and *A. problematicus* from the Lower Maestrichtian. The anisomyonid species are thus useful for the biostratigraphical division of the Cretaceous deposits of the northern Pacific region. Some other patelliform species from various areas are also discussed: *Anisomyon ezoensis* from Hokkaido; *Capulus corrugatus* and *Helcion giganteus vancouverensis* from British Columbia; *A. meekii* from California; *A. centrale*, *A. borealis*, *A. patelliformis* and *C. monroei* from the Western Interior and Gulf provinces of North America; *Brunonia grandis* and *B. irregularis* from Germany; *H. corrugatum* and *Tectura* (?) *elevata* from southern India; *A. africanus* from Algeria.

1. Introduction

Many species of patelliform gastropods occur in the marine Cretaceous deposits of the northern Pacific region (MATSUMOTO, 1942-'43; KANIE, 1966). In 1975, I presented a scheme of taxonomy for the Anisomyonidae (Mesogastropoda), systematic descriptions and the biostratigraphic succession of several *Anisomyon* species, with some reference to their paleoecology and evolutionary history. The genus *Anisomyon* appeared as early as the Barremian, and disappeared in the Lower Maestrichtian in the northern Pacific region. Anisomyonid species have rather short stratigraphical ranges, and are useful for the biostratigraphical division of the Cretaceous deposits in the northern Pacific region.

In this study, the fossils discussed are *Anisomyon* (?) *annulatus* from the Upper Barremian, *A. cassidarius* from the Turonian to Santonian, *A. transformis* from the Lower Campanian, *A. giganteus* from the Middle Campanian and *A. problematicus* from the Lower Maestrichtian. Some other patelliform species from various areas are also discussed: *A. ezoensis* from Hokkaido; *Capulus corrugatus* and *Helcion gigan-*

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teus vancouverensis from British Columbia; *A. meekii* from California; *A. centrale*, *A. borealis*, *A. patelliformis* and *C. monroei* from the Western Interior of North America.

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2. Biostratigraphic Succession

Collections of fossil patelliform gastropods, as well as field observations on their occurrence were made in the Upper Cretaceous deposits of Urakawa district, South Hokkaido, whilst specimens from other areas of Hokkaido and Saghalien were also examined. The group is often associated with ammonites and inoceramids, allowing precise dating, and is abundantly in calcareous nodules in neritic sediments.

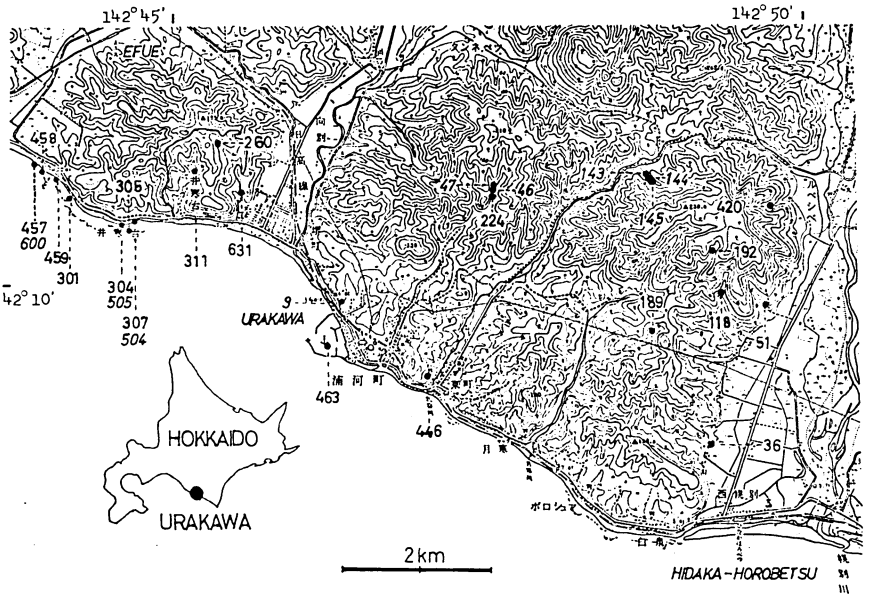

Fig. 1. Anisomyonid localities in the Urakawa district, South Kokkaido. e.g. 457: in KANIE (1966); *600*: in MATSUMOTO (1942).

A. Urakawa district, South Hokkaido

I collected three species of *Anisomyon* from the continuous section of the Santonian to the Middle Campanian deposits of the Urakawa district, South Hokkaido (Figs. 1, 2): *A. cassidarius* (YOKOYAMA) from member U1 (Santonian), e.g. Loc. 36 in claystone with *Inoceramus naumanni*; *A. transformis* DUNDO from member U2 (Lower Campanian), e.g. Loc. U311 in fine-grained sandstone with *I. orientalis*, and *A. giganteus* (SCHMIDT) from member U3-U5 (Middle Campanian), e.g. Loc. U224 in a calcareous sandy nodule with *I. schmidti*.

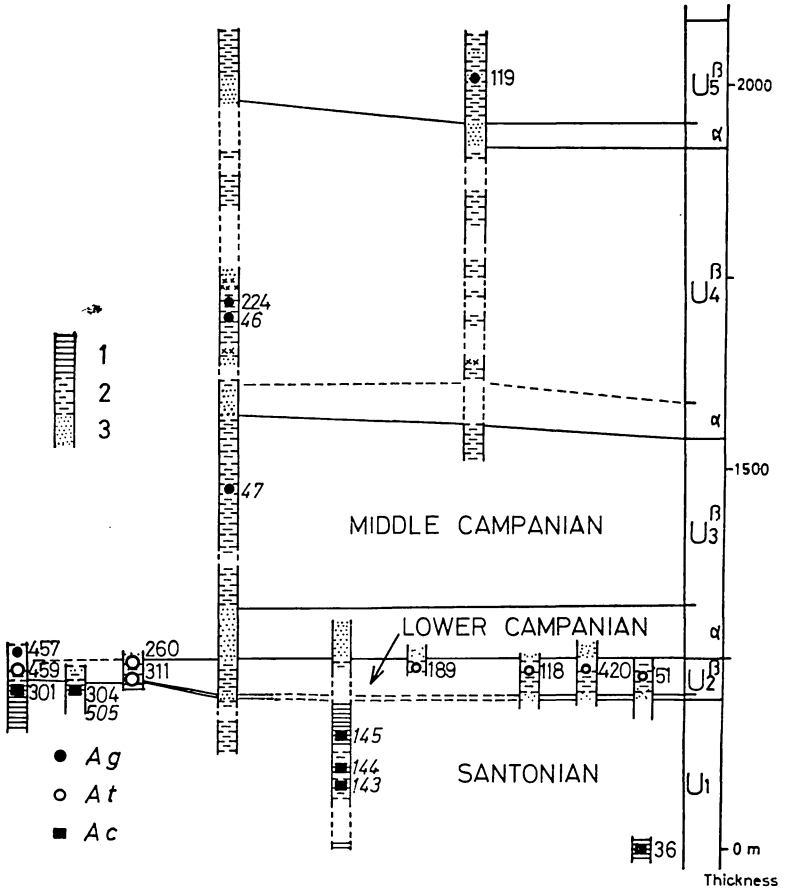

Fig. 2. Occurrences of *Anisomyon cassidarius* [*Ac*], *A. transformis* [*At*] and *A. giganteus* [*Ag*] from the Urakawa section. For locality numbers see Fig. 1. 1: claystone, 2: siltstone, 3: sandstone (Adapted from KANIE, 1975).

B. Various localities in the northern Pacific and other regions

The same succession of occurrences of the three species has also been found in various other districts in Hokkaido (*Anisomyon cassidarius* from Urakawa by YOKOYAMA, 1890; *A. transformis* and *A. giganteus* from Abeshinai by JIMBO, 1894 and MATSUMOTO 1942; *A. transformis* from member U3, Lower Campanian of the Chisaka district in OBATA *et al.*, 1973); Southwest-Japan (*A. cassidarius* from Uwajima, Coniacian, in TANABE, 1972; *A. transformis* from Shimo-Koshiki-jima, Lower Campanian; *A. giganteus* from Dogo-Himezuka, Middle Campanian, in KASHIMA, 1972 and MATSUMOTO, 1973); Northeast Japan (*A. cassidarius* (?) from Nakaminato, Lower Maestrichtian, in SAKAMOTO *et al.*, 1972, p. 22); Saghalien (*A. giganteus* from Alexandrovsk by SCHMIDT, 1873; *A. cassidarius*, *A. transformis* and *A. giganteus* by ITOH, 1932; *A. giganteus*, from Naibuchi, member Ray, Middle Campanian, in MATSUMOTO, 1942); the Koryak Highlands, Kamchatka (*A. cassidarius*, from the Zone of *Inoceramus* *yokoyamai*, *A. transformis*, from the Zone of *I. orientalis* and *A. giganteus*, from the Zone of *I. schmidti* in DUNDO and EFREMOVA, 1974); Chitina Valley, southern Alaska (*A. giganteus*, probably from the Middle Campanian,D. L. JONES, personal communication).

No species of *Anisomyon* has been collected from tho Upper Campanian (Zone of *Metaplacenticeras subtilistriatum* in MATSUMOTO's zonal scheme).

Anisomyon problematicus (NAGAO and ÔTATUME) has been found in the Lower Maestrichtian of the Tomiuchi district, Hokkaido (NAGAO and ÔTATUME, 1938), Awaji district, Southwest-Japan (SASAI, 1936; TANAKA *et al.*, 1952) and the Zone of *Inoceramus shikotanensis* of the Koryak Highlands (DUNDO and EFREMOVA, 1974).

Anisomyon (?) *annulatus* (YOKOYAMA) has been reported from the "Upper Neocomian" or "Aptian" Ishido formation (TAKEI, 1963) of the Sanchu area in the Kanto Mountains, now known to be the Upper Barremian because of *Barremites* (*Barremites*) aff. *strettostoma* and *Heteroceras* aff. *astieri* etc. (OBATA *et al.*, 1976), and the Albian Yatsushiro formation of Kyushu (personal communication by MATSUMOTO; MATSUMOTO *ed.*, 1954, p. 115).

Several species, morphologically somewhat similar to *A. cassidarius*, have been reported from Upper Cretaceous fine-grained sediments in North America (Fig. 3). These are almost all known only as internal moulds, so it is difficult to relate them satisfactorily to Japanese taxa. They are: *A. meekii* GABB from the Cenomanian of California (GABB, 1864; ANDERSON, 1958); *A. patelliformis* MEEK and HAYDEN from the Lower Maestrichtian of Nebraska (MEEK and HAYDEN, 1857, 1860; SOHL, 1967);

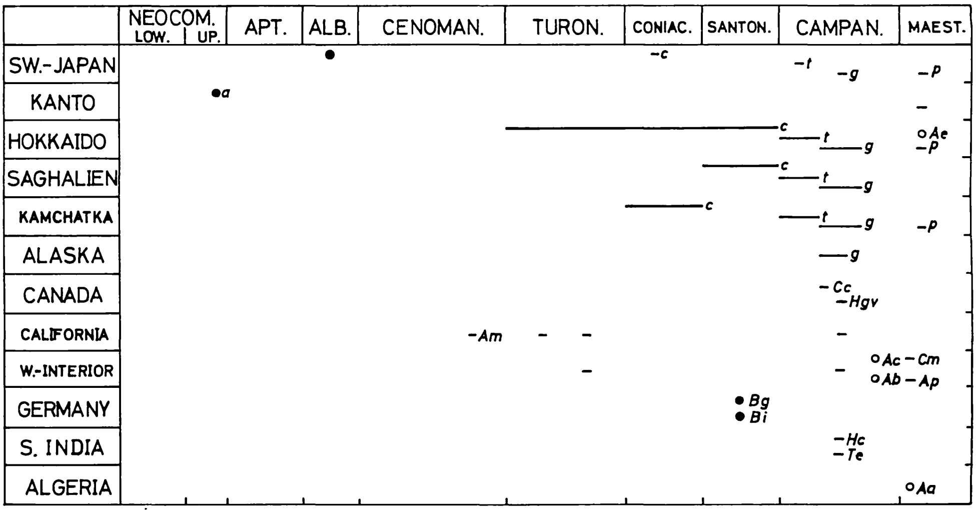

Fig. 3. Distribution of the anisomyonid species in the northern Pacific and other regions.

— : *Anisomyon*, *c*: *A. cassidarius*, *t*: *A. tansformis*, *g*: *A. giganteus*, *p*: *A. problematicus*, *Cc*: *Capulus corrugatus*, *Hgv*: *Helcion giganteus vancouverensis*, *Am*: *Anisomyon meekii*, *Cm*: *Capulus monroei*, *Ap*: *A. patelliformis*, *Hc*: *Helcion corrugatum*, *Te*: *Tectura* (?) *elevata*.

●: *Brunonia*, *Bg*: *B. grandis*, *Bi*: *B. irregularis*, *a*: *A.* (?) *annulatus*.

○: (?) *Anisomyon*; *Ae*: *A. ezoensis*, *Ac*: *A. centrale*, *Ab*: *A. borealis*, *Aa*: *A. africanus*.

Capulus corrugatus WADE and *Helcion giganteus vanconverensis* WHITEAVES from the Campanian of British Columbia (WHITEAVES, 1903), and *Capulus monroei* SOHL from the Lower Maestrichtian of Tennessee (SOHL, 1960).

Closely allied species have been known from the Campanian sediments of southern India since the work of FORBES (1846) (see also STOLICZKA, 1868). They are: *Helcion corrugatum* (FORBES) and *Tectura* (?) *elevata* (FORBES).

Five or more species of Lower to Upper Cretaceous *Anisomyon* have been reported from the north Pacific and southern India, and seem to be common in this vast Pacific region; further occurrences may be expected in the east Pacific region, especially California.

Brunonia grandis MÜLLER and *B. irregularis* MÜLLER have been reported from the Zone of *Inoceramus cardissoides* (Santonian) in Germany (MÜLLER, 1898). Certain species described under the *Brunonia* are somewhat similar to the Japanese species *Anisomyon* (?) *annulatus*, with anterior elevated sectors (Pl. 2, Fig. 7).

These Anisomyonidae generally occur abundantly in muddy to sandy sediments as shown in the Campanian of Japan, Saghalien, and Kamchatka (Fig. 3). The geographical distribution of the known species of the Anisomyonidae is shown on a world map in Fig. 4, which illustrates that they are unknown outside the northern Pacific region, southern India, Germany, England, Zululand and Antarctica. Several specimens described as *Anisomyon* are of doubtful generic position and should be placed elsewhere. These are: *Anisomyon ezoensis* NAGAO and ÔTATUME from the upper Hakobuchi Group (Lower Maestrichtian) of the Tomiuchi district, southern Hokkaido (NAGAO and ÔTATUME, 1938); *A. centrale* MEEK and *A. borealis* (MORTON) from the Upper Campanian of South Dakota and Wyoming (SOHL, 1964a, b, 1967), and *A. africanus* COLLIGNON from the Lower Maestrichtian of the Sahara (COLLIGNON, 1971).

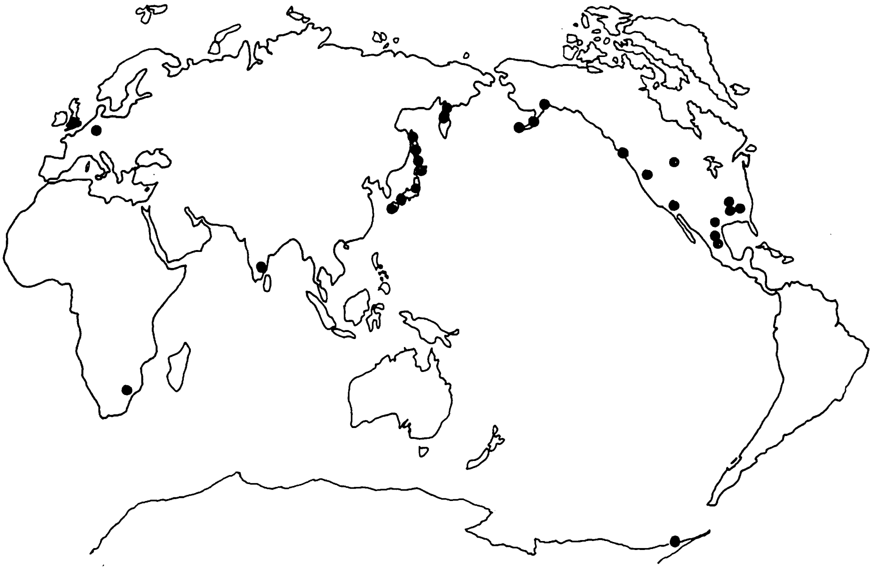

Fig. 4. Geographical distribution of the Anisomyonidae (Adapted from KANIE, 1975).

3. Evolutionary Changes

The general evolutionary changes in size, shell form, shell thickness and ornamentation of the *Anisomyon* species studied (*A. cassidarius*, *A. transformis* and *A. giganteus*) from Japan and Saghalien are summarized diagramatically in the Figure 5. During the Middle to Upper Cretaceous (Turonian-Lower Campanian), *Anisomyon* became larger (Fig. 6). *A. cassidarius* from member U1 (Santonian) of the Urakawa section is ornamented with fine concentric rings and ribs (Pl. 2, Fig. 1), while in *A. transformis* radial ribs are added in later growth stages; examples are shown in Figs. 2-3 of Pl. 2. Generally the specimens with radial ribs appeared in member U2β, but those without radial ribs are also found in the same member. This fact seems to suggest that populations of non-ribbed forms changed gradually to those of ribbed forms with time. *A. giganteus* from member U3-U5 (Middle Campanian), is ornamented with radial ribs throughout growth (Pl. 2, Figs. 4, 5). The maximum thickness of the shell is less than 1 mm in *A. cassidarius*, 4 mm in *A. transformis* and more than 20 mm in *A. giganteus*. I have also noticed the same order of occurrence and evolutionary changes in the Chisaka district of southern Hokkaido and other areas, and believe that *A. giganteus* evolved from *A. cassidarius* by way of *A. transformis*.

The shell-apex apparently tended to shift posteriorly with time. It can be considered that the animals had a high patelloid shape adapted to sedentary life, until the late Santonian, and then changed to a somewhat low, flattened patelloid shape (Fig. 5). The random orientation of shell-apex and thin shell of Santonian and Lower

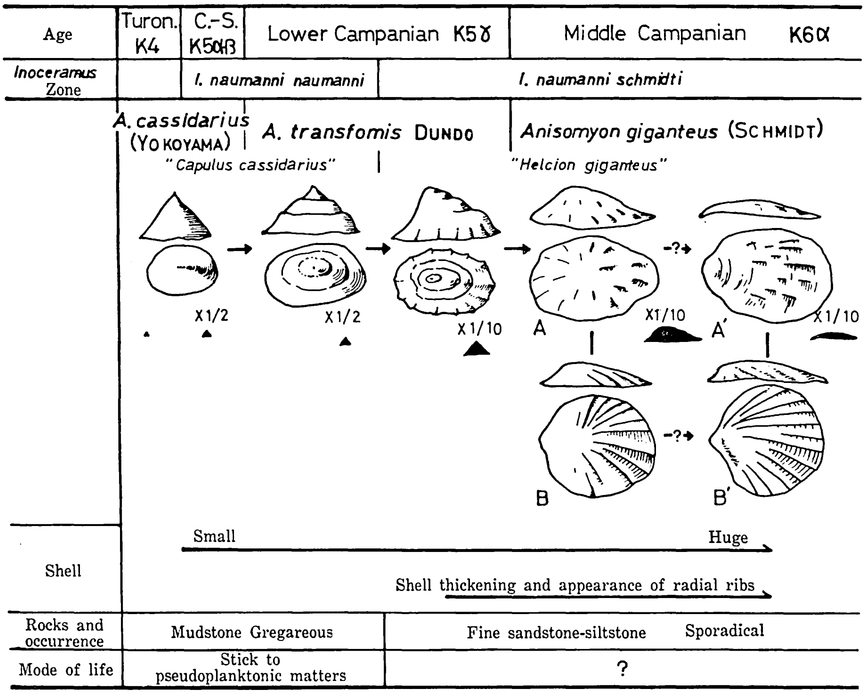

Fig. 5. Evolutionary changes in three species of *Anisomyon* (Adapted from KANIE, 1975).

Campanian species may indicate that they had a planktonic or pseudoplanktonic (epiplanktonic) mode of life, and were attached at various portion on the host. In some specimens I have recently seen, huge *Anisomyon giganteus* occur attached to exceptionally large *Inoceramus schmidti.*

Anisomyon seems to have a close ecological similarity to the group of *Inoceramus* (*Sphenoceramus*) *naumanni*, since it always occurs in association with that species group from the Coniacian through Middle Campanian. The appearance of radial ribs and a tendency for shell thickening seen in both groups are regarded as adaptations to changing environmental conditions. TANABE (1973) has explained these morphological changes in *I. naumanni* as a result of adaptation to a mode of life which changed from pseudoplanktonic (epiplanktonic) to benthonic.

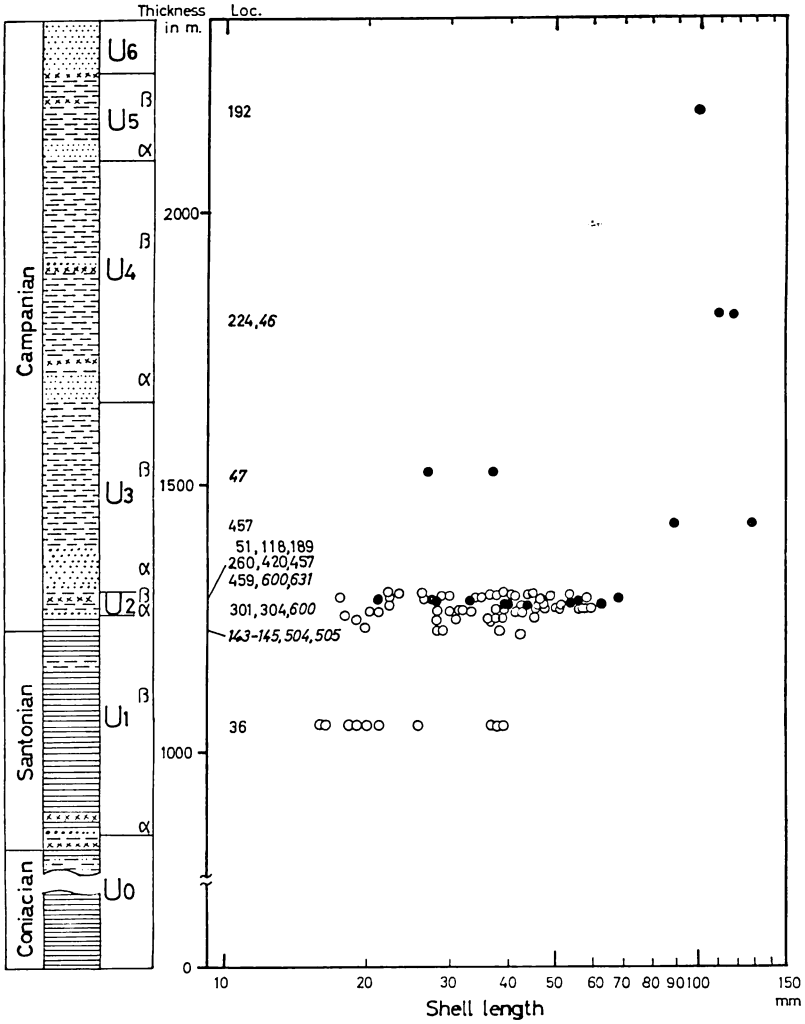

Fig. 6. Stratigraphic occurrences in the Urakawa district of *Anisomyon transformis* and *A. giganteus* with radial ribs. Black dots equal radial rib stages; white dots equal non radial rib stages. Note that radial ribs do not appear before the Campanian and that then they continue on to larger shells (Localities as in Fig. 1).

The change from *Anisomyon cassidarius* to *A. giganteus* might represent an ecological adaptation analogous to that shown in the series of *Inoceramus naumanni naumanni-I. naumanni schmidti* (TANABE, 1973). The irregular basal outline of the shell of the Santonian *A. cassidarius* is regarded as being possibly due to the shell having been attached to other material. On the other hand, some Campanian *A. giganteus* are considered to have lived sparsely on sandy bottoms. But sometimes *A. giganteus* may have attached to a host. This may indicate that they adapted themselves to increased current action during the Campanian age as seas became shallower.

The phylogenetic relationship between the Middle Campanian *A. giganteus* and Lower Maestrichtian *A. problematicus* (Pl. 1, Fig. 6) is uncertain, because none have been found in the Upper Campanian, and no gradations are known between the two species. However, the similarity in shell shape and the relative stratigarphical occurrence of the two species suggests that the latter could be a descendant of the former.

4. Conclusions

In this study, the biostratigraphy of three species of the Middle to Upper Cretaceous patelliform gastropods from the northern Pacific region are examined; furthermore, two other species from Japan and some similar species from elsewhere are discussed.

In 1975, I showed the taxonomic position of the three species, *Anisomyon cassidarius* (Turonian-Santonian), *A. transformis* (Lower Campanian) and *A. giganteus* (Middle Campanian) to be in *Anisomyon* of the family Anisomyonidae (Mesogastropoda). *A. problematicus* from the Lower Maestrichtian of Hokkaido and *A.* (?) *annulatus* from the Upper Barremian of Kanto Mountains were also discussed.

Furthermore their mode of life may have changed from being probably pseudoplanktonic (epiplanktonic) to benthonic under shallow seas of moderate depth during the Cretaceous, and they may have fed on microorganisms as in Recent Mesogastropoda.

Among some other patelliform gartropods from the Cretaceous, the genus *Anisomyon* is represented by *A. meekii* which ranges from the Upper Cenomanian to the Lower Maestrichtian. (?) *Anisomyon*, probably a new genus is represented by *A. ezoensis, A. centrale, A. bolealis* and *A. africanus*, ranging from the Upper Campanian to the Lower Maestrichtian. *Brunonia*, as represented by *Brunonia grandis* and *B. irregularis*, is known from the Santonian (Fig. 3). Whether *A.* (?) *annulatus* is truly *Anisymyon* or *Brunonia* is open to question.

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Locality Guide

		East Long.	North Lat.
Abeshinai	安平志内	142° 3′	44°35′
Alexandrovsk		142° 5′	50°50′
Awaji	淡 路	134°50′	34°19′
Chisaka	千 栄	142°33′	42°53′
Chitina Valley		142°40′(W)	61°20′
Dogo-Himezuka	道後姫塚	132°38′	33°50′
Jon-Quière		142° 5′	50°50′
Kawakami	川 上	142°30′	47°20′
Koryak		178°	63°
Naibuchi	内 淵	142°30′	47°20′
Nakaminato	那 珂 湊	140°37′	36° 4′
Sebayashi	瀬 林	138°50′	36° 4′
Tomiuchi	富 内	142°13′	42°17′
Urakawa	浦 河	142°47′	42°11′
Uwajima	宇 和 島	132°14′	33°30′

Explanation of Plate 2

Fig. 1. *Anisomyon cassidarius* (Yokoyama) YCM. GP 544, from Abeshinai, northern Hokkaido, Nigorikawa formation, Santonian (Kanie coll.).

Figs. 2, 3. *Anisomyon transformis* Dundo 2. YCM. GP. Ur 311001, from Loc. U311, Urakawa, South Hokkaido, U2α, Lower Campanian (Kanie, 1975); 3. IGPS 50907, from Kawakami, South Saghalien, Campanian (Itoh coll.).

Figs. 4, 5. *Anisomyon giganteus* (Schmidt) 4. [Type B], IGPS 50910, from Jon-Quière, North Saghalien, Campanian, *Inoceramus schmidti* Zone (Itoh coll.); 5. [Type A], USGS. M 2840, from Loc. 65-AMK33, Chitina Valley, southern Alaska, Middle (?) Campanian (Jones coll.).

Fig. 6. *Anisomyon problematicus* (Nagao and Ôtatume) GK. H. 10340, from Loc. H 122p 10, Tomiuchi, southern Hokkaido, Hakobuchi Group, Lower Maestrichtian (Matsumoto coll.).

Fig. 7. *Anisomyon* (?) *annulatus* (Yokoyama) NSM. PM 1249, from Loc. Sa 231, Sebayashi, Kanto Mountains, Ishido formation, Barremian (Matsukawa, 1977).

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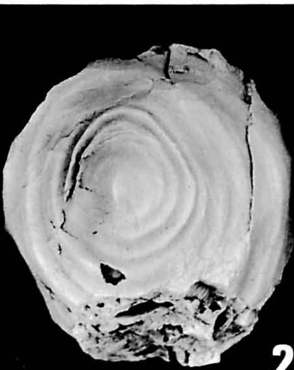

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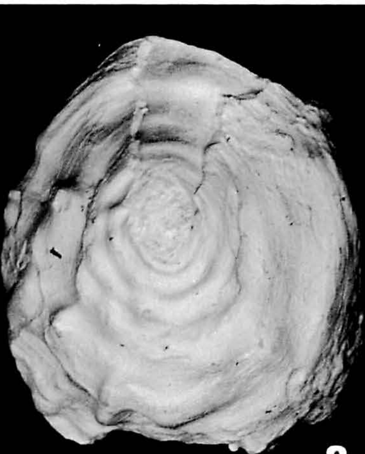

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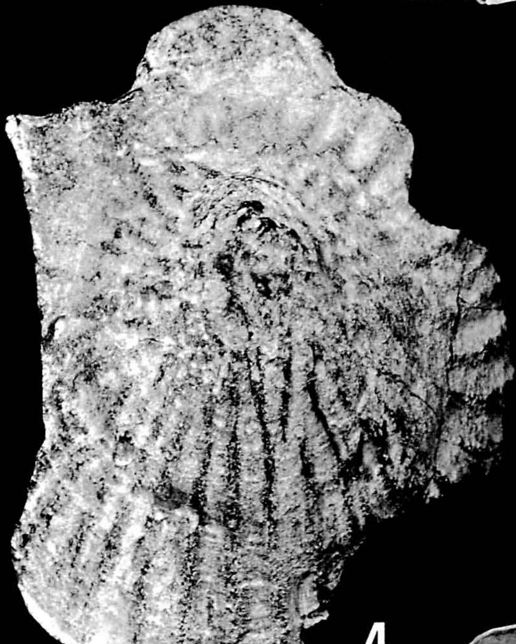

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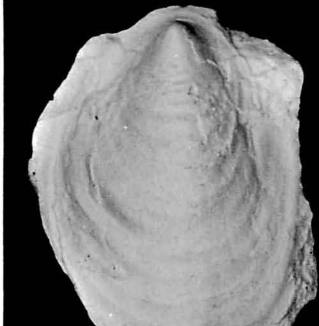

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5

Y. KANIE: Succession of the Cretaceous Patelliform Gastropods

ZONAL CORRELATION OF THE UPPER CRETACEOUS IN JAPAN

By

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Abstract

Initially a scheme of zonation (Fig. 1) is proposed for the Upper Cretaceous of Hokkaido, based on currently available data; although, no doubt, further work will refine this further.

Upper Cretaceous marine formations also occur in other areas of Japan (Fig. 2), although their outcrop is not so continuous as in central Hokkaido. Correlation of these formations with the Hokkaido reference scale is attempted primarily on the basis of the occurrence of zonal indices and associated species. The lack of such material for zonal correlation can sometimes be supplemented by other faunas, such as bivalve assemblages, which enable us to distinguish major units (e.g. distinction of K6b from K6a).

The results are summarized in a correlation chart (Fig. 3), although there are still numerous unresolved problems, which are discussed in the body of the paper.

1. Introduction

I have studied in detail the zonal succession of inoceramids and certain groups of ammonites in the Upper Cretaceous of Hokkaido, resulting in the scheme of zonation which is summarized in Figure 1. On this basis I attempt in this paper the zonal correlation of the marine Upper Cretaceous deposits in other areas of Japan.

The zones established in Hokkaido can be correlated approximately with the international stages, but several speices which occur more commonly in some areas (within Japan) outside Hokkaido are also useful for international correlation. These will be included in the discussion below.

2. Zonation of the Upper Cretaceous in Hokkaido

In addition to my previous works, younger friends of mine, I. OBATA, Y. UEDA, H. OKADA, M. HARADA, H. HIRANO, K. TANABE, K. TANAKA, A. INOMA, Y. KANIE, M. NODA and Y. MIYATA, and also more friends in Hokkaido, e. g. Messrs. T. MURAMOTO, K. MURAMOTO, T. TAKAHASHI and T. MIYAUCHI have helped me greatly in biostratigraphic field work in various areas of Hokkaido. Results of local stratigraphy and palaeontological studies of certain biological groups have been, and will be described in separate papers by relevant authors and myself elsewhere (references omitted here for brevity).

As our work proceeds, knowledge of the biostratigraphic successions of the Upper Cretaceous in the reference sequences of Hokkaido is improved, year by year. On

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		Inoceramus (s. l.)	AMMONITINA				LYTOCERATINA						This paper		Previous papers	
			Desmocerataceae			Acanthocerataceae & Hoplitaceae	Baculitidae	Scaphitidae etc.		Tetragonitidae						
MAEST-RICHTIAN	K6b₂	*hetonaianus-kusiroensis*	*Pach. (Neodesm.) obsoletus-Pachydiscus subcompressus*			[*Sphenodiscus* not yet found]	*Baculites rex*			*Zelandites varuna*	*Pseudophyll. indra*		K6b₂		K6β	HETONAIAN
	K6b₁	*shikotanensis*	*P. (Neodesm.) japonicus-Damesites heotonaiensis*					*Nostoceras hetonaiense*					K6b₁			
CAMPANIAN	K6a₃	*balticus* n. subsp. ?	*Canadoceras multicostatus*		*Desmophyllites diphylloides*	*Metaplacenticeras subtilistriatum*	*B. subanceps-* *B. inornatus-* *B. occidentalis*	*Schluterella* (?) n.sp.		*A.* n. sp.	*G. striatum*		K6a	3	K6α	
	K6a₂	*schmidti*	*Canadoceras kossmati*					[*Didymoceras awajiense*]						2		
	K6a₁	*orientalis*	*Anap. (Neopachy.) naumanni*			[*Submortoniceras*]	*B. tanakae-* *B. chicoensis*	*Ainoceras kamuy*		*A. yokoyamai*	*Gaudryceras denseplicatum*			1	K5γ	URAKAWAN
SANTON-IAN	K5b₂	*japonicus*	*Eupachydicus haradai*		*Damesites damesi* *D. semicostatus*	*Texanites shiloensis*	*B. uedae-* *B. princeps-* *B. bailyi*	*Hyphantoceras orientale* *H. oshimai*				*G. tenuiliratum*	K5b	2	K5β	
	K5b₁	*amakusensis*	*Anapachydiscus fascicostatus*			*Texan. (Plesiot.) kawasakii* *Prot. (Anat.) fukazawai*								1		
CONIAC-IAN	K5a₂	*mihoensis*	*Kossmaticeras theobaldianum*			*Paratexanites orientalis*	*B. schencki-* *B. yokoyamai*	*Scaphites formosus*		*Anagaudryceras limatum*			K5a	2	K5α	
	K5a₁	*uwajimensis*				*Prionocycloceras sigmoidale* *Forresteria allaudi*		*S. pseudoequalis-* *Otosc. klamathensis*						1		
TURONIAN	K4b₃	*teshioensis-incertus*	*Tragodesmoceroides subcostatus*	*Damesites ainuanus*		*Reesidites minimus* *Subprionocyclus normalis* *Subpr. bravaisianus*	*B. undulatus-* *Sciponoceras intermedium*	*Scaphites planus* *Otosc. puerculus*	*Eubostrychoceras* cf. *woodsi*				K4b₃		K4β	GYLIAKIAN
	K4b₂	*hobetsensis-teraokai*			*Desmoc. (Pseudo.)* n. sp.	*Subprionocyclus neptuni* *Collignoniceras woollgari*	*Sciponoceras orientale*		*Eubostrycho. japonicum*				K4b₂			
?	K4b₁	*labiatus*		*Damesites laticarinatus*		*Fagesia thevestensis* *Kanabiceras septemseriatum*			*Hyph.* n. sp. *Sc. obliquus*				K4b₁			
CENOMANIAN	K4a₄	*pennatulus*	*Desmoceras (Pseudouhligella) japonicum-* *D. (P.) ezoanum*			*Calycoceras* cf. *naviculare* *Eucalycoc. pentagonum*	*Sciponoceras kossmati*				*G.* sp.		K4a	4	K4α	
	K4a₃	*yabei-costatus*				*Calycoceras orientale* *Acanthoceras takahashii*		*Turrilites costatus*		*Anagaudryc. sacya*				3		
	K4a₂	*nipponicus*				*Mantelliceras japonicum*	*S. baculoides*				*Zeland. inflatus*			2		
	K4a₁	aff. *crippsi*	*Desmoceras kossmati*			*Graysonites wooldridgei*		*Scaphites* n. sp.						1	K3γ	

Fig. 1. Zonal scheme of the Upper Cretaceous in Hokkaido.
(Read *Scaphites* aff. *obliquus* for *Seaphites obliquus*.)

several occasions (e. g. MATSUMOTO, 1954, pl. 2; 1959, pl. 8; 1963, chart b; 1967, table 12.8; 1969, table 1) I tried to establish a provisional zonal scheme; a revised one is shown here (Fig. 1), although this also is still tentative.

In this paper I have omitted the basic data on which this zonation is founded. The most up-to-date knowledge on the Upper Albian to Coniacian was reported on the occasion of the Uppsala Meeting (1975), and I shall publish that relevant to the Santonian to Maestrichtian in the future.

In the summarized scheme, zonal successions are established on the basis of four biological groups, (1) inoceramids, (2) ammonites of the Desmocerataceae and the Phyllocerataceae, (3) those of the Acanthocerataceae and the Hoplitaceae and (4) those of the Lytoceratina including the heteromorphs. Although these groups often occur as fossils in the same bed, in life they often had their own habitat preferences, and represent different biofacies. The species of the first group are widespread, occurring in sediments of both the sandy and muddy lithofacies; those of the second group occur commonly in sediments of off-shore facies, including some species which are distributed widely in the regions around the Pacific and Indian oceans; those of the third group were thought as rare in Japan but have recently been found not infrequently in shallower water facies, including many species which are useful for correlation with the standard zonal sequences of western Europe and elsewhere. The fourth group comprises normally coiled tetraganotids and various heteromorphs, e. g. baculitids, scaphitids, turrilitids, nostoceratids, diplomoceratids etc. In life these ammonites may have occupied diverse habitats, some swimming actively in the sea water, others living on the sea bottom at various depths, whilst some others were probably capable of up-and-down locomotion. In spite of this, their post-mortal remains (i. e. fossils) occur together or with remains of members of the other three groups. Although some of the fourth group are long-ranging, they may be useful as supplementary members of zonal assemblages, and certain species have sufficiently short-ranges as to be used as zonal indices. Thus a zone can in fact be recognized from a combination of species of more than one biological group.

3. Correlation of the Upper Cretaceous between Hokkaido and Other Areas

Fig. 2 shows the outcropping areas of the fossiliferous Cretaceous deposits in Japan. On the inner (i. e. continental) side they are non-marine and often contain volcanic material. Marine Upper Cretaceous deposits are distributed mainly on the outer, Pacific side, and also along the Median Tectonic Line in the central zone of Southwest Japan. Descriptions of local stratigraphy are omitted here, as there are numerous published papers. Numbers in the map refer to those in the correlation chart (Fig. 3).

Among many kinds of fossils those of the inoceramids are most useful for the extensive zonal correlation, because they are distributed widely and are commonly independent, to a certain extent, of facies change. Some of the associated ammonites, which sometimes include members of the third group defined above, play only a supplementary role for intra-Japanese correlation, because they occur less frequently.

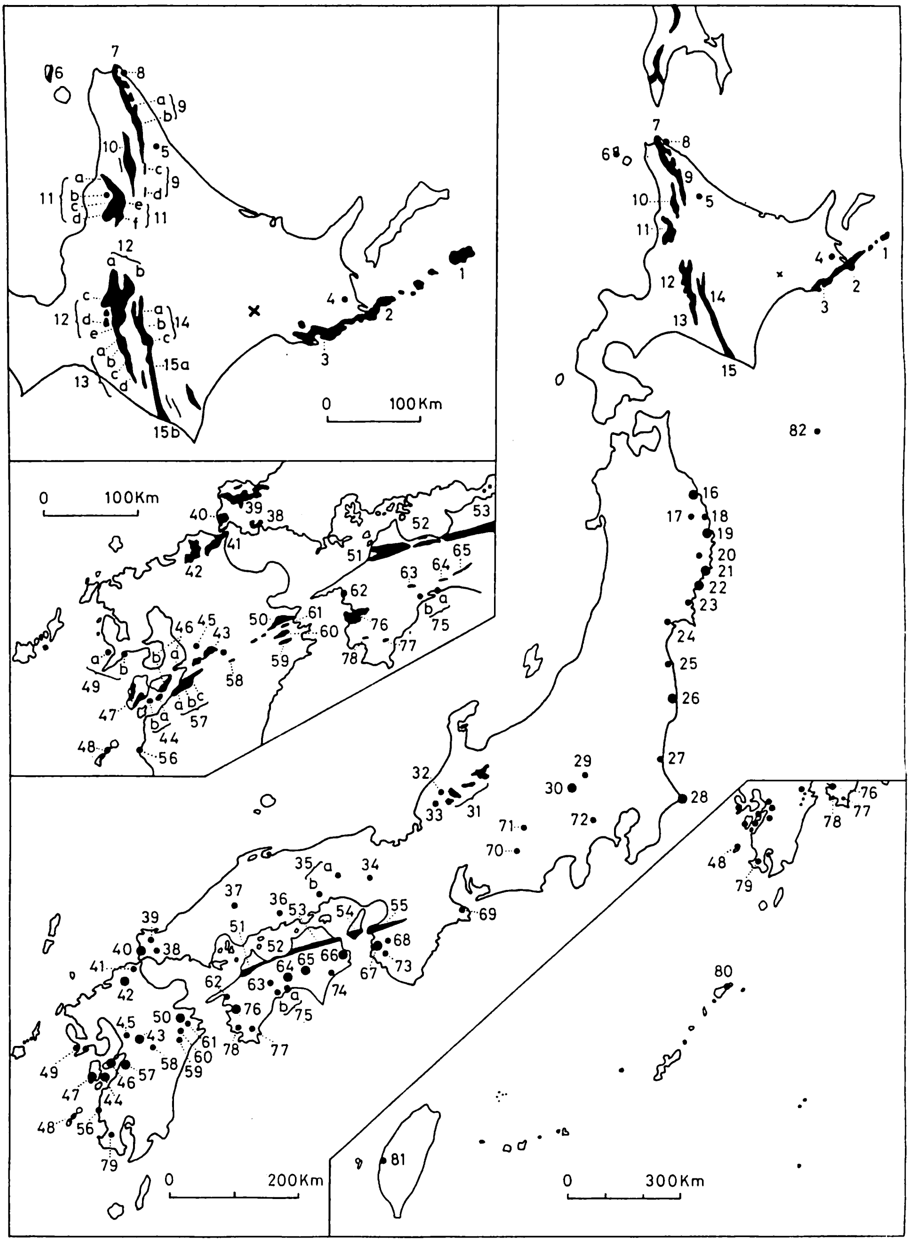

Fig. 2. Map of Japan and adjacent areas showing the locations of outcropping fossiliferous Cretaceous deposits. Hokkaido and a part of Southwest Japan enlarged at upper left corner.

Some are important for interregional correlation, however, and supplement the evidence obtained in Hokkaido.

In Late Cretacenus times no significant difference is recognized in the biogeographic distribution of species between Hokkaido and other parts of Japan, but the facies variation was considerable. Bivalve faunas, for instance, demonstrate this facies-control, particularity in certain basins. The Mifune fauna in central Kyushu is an extreme case of endemic nature, but the recent discoveries of inocerami and ammonites have enabled us to correlate this precisely with the Hokkaido sequence (TAMURA *et al.*, 1974).

Let us examine the available material briefly from northeast to southwest.

(1) *Kuji Group, northeastern Kitakami massif* (loc. 16).—The Kuji Group, about 600 m thick, rests unconformably on early Cretaceous granite, and dips gently eastward. The lower formation, of conglomerate and sandstone, containing banks of ostreids, is followed by the middle formation of shallow marine silty fine-sandstone and sandy siltstone, which often show traces of bioturbation. This includes the type-locality of *Inoceramus japonicus* NAGAO and MATSUMOTO (forma γ=lectotype as designated by MATSUMOTO and UEDA, 1962). Recently *Inoc.* cf. *naumanni* and *Polyptychoceras* spp. have been reported at Taneichi, in the northern extension of the same formation (TERUI and TERUI, 1975). They all indicate a K5b (Santonian) age. The upper formation, tuffaceous sandstone and mudstone with some tuff and thin coal, contains fossil plants which are being studied by palaeobotanists.

(2) *Futaba Group, Abukuma massif* (loc. 26).—The Futaba Group (TOKUNAGA and SHIMIZU, 1926; SAITO, 1961-62; OBATA and SUZUKI, 1969) consists of about 500m of shallow marine sandstone and siltstone, resting unconformably on mid-Cretaceous granites. *Inoceramus uwajimensis* YEHARA occurs abundantly in the lower and middle parts in which *Yabeiceras orientale* TOKUNAGA and SHIMIZU, *Forresteria* sp., *Anagaudryceras limatum* (YABE), *Eubostrychoceras indopacificum* MATSUMOTO, *Baculites yokoyamai* TOKUNAGA and SHIMIZU, *Scaphites pseudoequalis* (YABE), *Otoscaphites klamathensis* (ANDERSON), *O. matsumotoi* TANABE (see TANABE, 1977) and *Didymotis akamatsui* (YEHARA) also occur. OBATA (1967) and OBATA anc SUZUKI, (1969) obtained *Inoceramus mihoensis* from the upper part, and *Inoc. amakusensis* NAGAO and MATSUMOTO and *Texanites* (?) from the uppermost part. As OBATA has concluded, the Futaba Group thus ranges from K5a1 to K5b1, in terms of the Hokkaido succession.

(3) *Nakaminato Formation, northeastern Kwanto* (loc. 27).—The fairly thick Nakaminato Formation (see SAITO, 1958-59, 61-62) resembles and is correlated with the main part of the better known Izumi Group (5) by *Didymoceras awajiense* (YABE) in the middle member and *Baculites inornatus* MEEK, *B.* cf. *rex* ANDERSON and *Inoceramus* cf. *shikotanensis* NAGAO and MATSUMOTO in the upper member.

(4) *Other scattered localities in the Kwanto massif.*—The Sanyama Formatiom in the northern part (loc. 30) and Kobotoke Formation in the southern part (loc. 72) of the massif contain some inoceramids which should be studied more precisely for accurate correlation.

(5) *Izumi Group, central zone of Southwest Japan* (locs. 51-55).—This is a thick (5500-7000 m) series of submarine clastic deposits. It consists of a vast number of repeated units of conglomerate, sandstone and shale, which shows the characteristic features of a flysch facies, with traces of bottom currents moving from east to west. It includes fossiliferous shales and also tuff layers at several horizons. It extends about 400 km from east (south of Osaka) to west (Matsuyama), generally forming a synclinorium with an eastward plunge. This implies that the basal part of the group is

time transgressive, younging eastward. The fossils from the shales of the basal part are thus not of the same assemblage throughout the outcrop. Near Matsuyama (loc. 51) in the west, *Inoceramus schmidti* MICHAEL is characteristic, with *Inoc. balticus* BOEHM, *Anisomyon giganteus* (SCHMIDT), *Gaudryceras striatum* (JIMBO); *Bevahites* cf. *lapparenti* came from Hotokezaki (loc. 52), about 40 km east of Matsuyama. In the Asan Mountains (loc. 53) and in the island of Awaji (loc. 54) *Didymoceras awajiensis* (YABE) is characteristic, associated with *Pravitoceras sigmoidale* YABE. In the Izumi Mountains, south of Osaka, *Baculites regina* OBATA and MATSUMATO is characteristic, with which *B. occidentalis* MEEK may be associated. *Pachydiscus kobayashii* SHIMIZU (closely allied to *P. preegertoni* COLLIGNON), *Canadoceras* n. sp. (?) aff. *C. ramaraoi* COLLIGNON and *Nostoceras* n. sp. (?) are found rarely. These fossils suggest an eastward younging of the basal part of the Izumi Group within the Campanian stage.

Didymoceras awajiense (YABE, 1902 emend), which has not yet been found in Hokkaido, is closely allied to *D. hyrnbyense* (WHITEAVES) from the Nanaimo Group of British Columbia which, in turn, resembles *D. nebrascense* (MEEK and HAYDEN), index of a zone in the middle part of the Upper Campanian in the North American Western Interior province. Their relationships should be studied more carefully. Inocerami of the *balticus* group, which occur fairly commonly in Southwest Japan, including the Izumi belt, also need more refined taxonomic and biostratigraphic study.

Inoceramus shikotanensis NAGAO and MATSUMOTO and *Solenoceras* sp. occur in the middle part of the Izumi Group and *Inoc. hetonaianus* MATSUMOTO, *Tenuipteria* (?) *awajiensis* (MATSUMOTO), *Pachydiscus subcompressus* MATSUMOTO, etc. in the upper part. This succession is readily correlated with K6b of Hokkaido, although some species are awaiting full descriptions. Thus the Izumi Group is Campanican (K6a) and Maestrichtian (K6b) in age.

For local stratigraphy of the Izumi Group, readers may refer to KOBAYASHI (1931), SASAI (1936), TANAKA *et al.* (1952), NAKANO (1958), NAKAGAWA (1961), ICHIKAWA and MAEDA (1958), MATSUMOTO and OBATA (1963), TANAKA (1965), SUYARI (1973), NODA and TASHIRO (1973) and NISHIMURA (1976), among many others.

(6) *Onogawa Group, eastern central Kyushu* (loc. 50).—This is another thick series of clastics resembling in facies the Izumi Group and was studied by MATSUMOTO (1936), NODA (1969) and TERAOKA (1970), who made clear the succession of *Inoceramus* species, from *I. hobetsensis*, through *I. teshioensis*, *I. uwajimensis*, *I. mihoensis*, *I. naumanni* to *I. amakusensis* which is readily correlated with that of Hokkaido. The shale above the lower conglomerate again youngs northeastward, containing the first two zones. The associated ammonites, *Subprionocyclus neptuni* (GEINITZ), *S. bravaisianus* (D'ORBIGNY) and then *S. normalis* (ANDERSON) support this conclusion. *Romaniceras* cf. *yezoense* MATSUMOTO was found in the Zone of *Inoc. hobetsensis* and *Mesopuzosia pacifica* MATSUMOTO occurs also in the shale. *Didymotis akamatsui* (YEHARA) is associated with *Inoc. uwajimensis.*

(7) *Mifune Group, central Kyushu* (loc. 43).—This crops out on the southwestern foot of the volcano Mount Aso. It forms a syncline, resting on mid-Paleozoic metamorphic rocks and serpentine in the north and late Permian formations in the south. It has red beds and some tuff layers at the base and in the upper part. Its lower part,

mostly sandstone with shale, contains endemic shallow marine to brackish water bivalves and gastropods (MATSUMOTO, 1939; TAMURA, 1975 among many others). Recently, *Inoceramus concentricus costatus* NAGAO and MATSUMOTO and *Eucalycoceras* cf. *spathi* COLLIGNON were found in a portion of the lower part of the group (TAMURA *et al.*, 1974), which can now be correlated with the assemblage of the same two species in the upper part of the Middle Cenomanian in the Ikushumbetsu sequence in Hokkaido.

The Mifune Group is therefore older than Onogawa, although the tuff in the Upper Mifune may be correlated with that in the basal Onogawa. It is unconformably overlain by a marginal facies of the Senonian Himenoura Group in the southwest. It probably ranges from the upper half of the Cenomanian to the lower half of the Turonian.

(8) *Goshonoura Group, western central Kyushu* (loc. 44).—This is exposed in Goshonoura [=Goshora] and Shishi-jima islands, consisting of deltaic to neritic sandstones with some conglomerate, red beds and siltstone, in total about 1000 m thick (MATSUMOTO, 1938; AMANO, 1962). It contains shallow marine molluscan faunas and some brackish water elements. Several diagnostic species are common to the Upper Goshonoura and the Lower Mifune (TAMURA *et al.*, 1968). The Middle Goshonoura contains more open-sea elements, among which *Mortoniceras* aff. *rostratum* (SOWERBY) came from the second member (IIb) and *Graysonites* aff. *fountaini* (YOUNG), *Stoliczkaia amanoi* MATSUMOTO and INOMA and *Desmoceras kossmati* MATSUMOTO from the fifth (i. e. top) member (IIe) (see MATSUMOTO, 1960 and MATSUMOTO and TASHIRO, 1975). This means that the Middle Goshonoura ranges from Upper Albian to lower Lower Cenomanian.

To sum up, the three mid-Cretaceous basins in central Kyushu, represented by the Goshonoura, the Mifune and the Lower Onogawa, are younging northeastward, from Albian to Turonian.

(9) *Himenoura Group, western Kyushu* (locs. 45-48).—This not only rests unconformably on the Mifune and the Goshonoura but also oversteps onto basement metamorphic and granitic rocks. The basin seems to have shifted westward, the Lower Himenoura occuring in the east (UEDA, 1962) and the Upper Himenoura in the west (TASHIRO and NODA, 1974). The former contains *Inoc. amakusensis* NAGAO and MATSUMOTO, *Inoc. japonicus* N. & M. (forma α which may be distinct from forma β and γ) and *Inoc. orientalis nagaoi* MATSUMOTO and UEDA. *Texanites oliveti* (BLANCKENHORN), *T.* (*Plesiotexanites*) *kawasakii* (KAWADA), and *Protexanites* (*Anatexanites*) *fukazawai* (YABE and SHIMIZU) occur in the Zone of *Inoc. amakusensis* and *Eupachydiscus haradai* (JIMBO) from the Zone of *Inoc. japonicus* and that of *Inoc. orientalis nagaoi*. *Gaudryceras intermedium* YABE and *Polyptychoceras haradanum* (YOKOYAMA) are common associates. Thus the Lower Himenoura is of Santonian (K5b) age.

The Upper Himenoura contains *Inoceramus orientalis* SOKOLOW, *Inoc. sachalinensis* SOKOLOW, *Inoc.* spp. of the *balticus* group and also several poorly preserved ammonites including *Glyptoxoceras* cf. *indicum* (FORBES). Other bivalve faunas are distinct from those of the Lower Himenoura, and themselves consist of lower and upper faunas of dissimilar assemblages, which, in turn, are similar to those of the Izumi Group (TA-

SHIRO, 1976). Thus the Upper Himenoura is approximately referred to K6 (Campanian and Maestrichtian), but further study on inocerami and ammonites are necessary.

(10) *Sotoizumi Group, Outer Zone of Southwest Japan* (locs. 61, 63, 65-68).—This is a comprehensive name for the Upper Cretaceous in the Chichibu terrain of the Outer Zone. It is usually distributed in the same areas as the Lower Cretaceous, but its outcrops are more limited than the latter, probably because of the effect of subsequent erosion.

In the Yuasa-Aridagawa area (loc. 67-68) the Upper Cretaceous is better preserved, but owing to the complicated geologic structure and lithologic uniformity (with shale predominant) the succession of fossils has not yet been firmly established. A "*Sharpeiceras* sp." from the Kanaya Formation, in the collection of Tohoku University, seems to be a Turonian *Romaniceras*. *Inoceramus uwajimensis* YEHARA occurs here and there (e. g. Izeki and Goryo) in shales, indicating the Coniacian. *Inoceramus japonicus* NAGAO and MATSUMOTO was found at Matsubara, *Damesites* sp. at Futakawa, *Hauericeras* sp. in the lower part of the Toyajo Formation, suggesting the Santonian. The main part of the Toyajo, consisting of silty fine-sandstone with calcareous nodules, is more fossiliferous, yielding *Inoc. schmidti* MICHAEL, *Inoc. balticus toyajoanus* NAGAO and MATSUMOTO, *Tetragonites* (*Saghalinites*) *nuperus* VAN HOEPEN, *Didymoceras awajiense* (YABE), *Eubostrychoceras* cf. *elongatum* (WHITEAVES), *Baculites occidentalis* MEEK, *Glyptoxoceras* sp. and *Natalites* sp. (revised from YABE, 1915 and other works). It is therefore of Campanian (K6a) age, but a finer biostratigraphic sequence within the Toyajo should be worked out. At the top there are alternating sandstone and shale but no good age indicator is available.

In other areas of the Chichibu terrain the biostratigraphic data for the Upper Cretaceous are much more scattered. Lower Cenomanian is indicated by the Miyanohara Formation (loc. 63) with *Sharpeiceras* sp. and the Nagase Formation (loc. 65) with *Mantelliceras japonicum* MATSUMOTO, MURAMOTO and TAKAHASHI in central Shikoku; Middle Turonian by the Tano Formation (loc. 61) with *Inoc. hobetsensis* and *Inoc. teraokai* MATSUMOTO and NODA in southeastern Kyushu; Coniacian by the Kushibuchi Formation (loc. 66) with *Inoc. uwajimensis* in eastern Shikoku; Santonian by the Kajisako Formation (loc. 65) with *Inoc. japonicus* in central Shikoku; Campanian by the Tatsuye Formation (loc. 66) with *Inoc.* sp. of the *balticus* group in eastern Shikoku.

(11) *Uwajima Group, western Shikoku* (loc. 76).—This belongs tectonically to the Shimanto belt (see 12) but it considerably resembles in litho- and biofacies the Onogawa Group in the northwest. As the geological structure is complicated (a major syncline plus faulting), the stratigraphy is interpreted in different ways by different authors (e. g. TANABE, 1971; TERAOKA and OBATA, 1975). The succession of *Inoceramus* is the most reliable for the correlation. Uwajima includes the type-locality of *Inoc. uwajimensis* YEHARA and the species is prolific there. Associated with it are *Didymotis akamatsui* (YEHARA), *Anagaudryceras limatum* (YABE), *Eubostrychoceras* sp., *Scalarites* sp., *Baculites yokoyamai* TOKUNAGA and SHIMIZU, *B. schencki* MATSUMOTO, *Scaphites pseudoequalis* YABE, *Otoscaphites* (*Hyposcaphites*) *matsumotoi* TANABE, *Forresteria* (*Muramotoa*) aff. *muramotoi* MATSUMOTO, *Subprionotropis* aff. *columbianus*

BASSE, etc. The *I. mihoensis* Zone is not well distinguished in this area, but NODA (1975) recognized an evolutionary change of *I. uwajimensis* within the Coniacian. The Santonian is indicated by the assemblage of *Inoceramus amakusensis* NAGAO and MATSUMOTO, *Inoc. naumanni* YOKOYAMA and *Protexanites* (*Anatexanites*) *fukazawai* (YABE and SHIMIZU).

TANABE (1972) recognized the Turonian in the lower part of the Uwajima Group on account of the occurrence of *Inoc.* cf. *teshioensis* and then *Inoc.* cf *hobetsensis* below *Inoc. uwajimensis*, but TERAOKA and OBATA seem to deny his conclusion, regarding all these poorly preserved inocerami as *Inoc. uwajimensis.*

(12) *Shimanto Group, Outer Zone of Southwest Japan.*—The Shimanto [=Shimantogawa] Group is the so-called geosynclinal deposits. It includes units of black shale with pelagic microfossils (in shale or in lenticular limestone), associated with green rocks and red chert; alternating sandstone and shale of the flysch facies, and also massive sandstone. Owing to intense folding and thrusting, it is fairly difficult to determine correctly original sequences. Occasional discovery of molluscan fossils (at locs. 72–80) has enabled us to recognize various stages from Aptian to Maestrichtian (e. g. MATSUMOTO and HIRATA, 1969; MOROZUMI, 1970; NODA, 1974), in which Upper Cretaceous ages are indicated by certain species of *Inoceramus* (*I.* aff. *crippsi*, *I.* cf. *labiatus*, *I. uwajimensis*, *I.* cf. *mihoensis*, *I.* cf. *yubarensis*, *I.* cf. *amakusensis*, *I.* cf. *ezoensis*, *I.* of *balticus* group, *I. yuasai*, *I.* cf. *schmidti*) and some poorly preserved ammonites. *Collignoniceras* (*Selwynoceras*) sp. among the latter is noteworthy for it is of an ornate type and is the first record of this subgenus in Japan, suggesting a Turonian age (MATSUMOTO *et al.*, 1966). It is interesting to note that certain heteromorphs (e. g. *Polyptychoceras*) occur in a particular shale unit (MATSUMOTO *et al.* 1973). In any case, more work is needed for the stratigraphic division and correlation of the Shimanto Group.

4. Concluding Remarks

The results of the correlations discussed in the foregoing pages are summarized concisely into a correlation chart (Fig. 3). A small solid circle in the chart means that zonal indices (or a zonal index) occur in a marked stratigraphic position of a given formation. Almost all the zones established in Hokkaido have been recognized somewhere in the sequences outside Hokkaido, with the exception of units K4a4 (*Inoc. pennatulus* Zone) and K6a3 (*Metaplacenticeras subtilistriatum* Zone). This may be due to the inadequate facies development in some cases, and to the actual absence of the equivalent beds in other cases. Anyhow, we need more careful observation and collecting to determine the reasons for these apparent absences.

The correlation demonstrated in this paper show that the depositional development of the marine Upper Cretaceous was not synchronous from province to province. This implies that each sedimentary basin was largely independent of the others, and this is supported by the considerable changes of facies described.

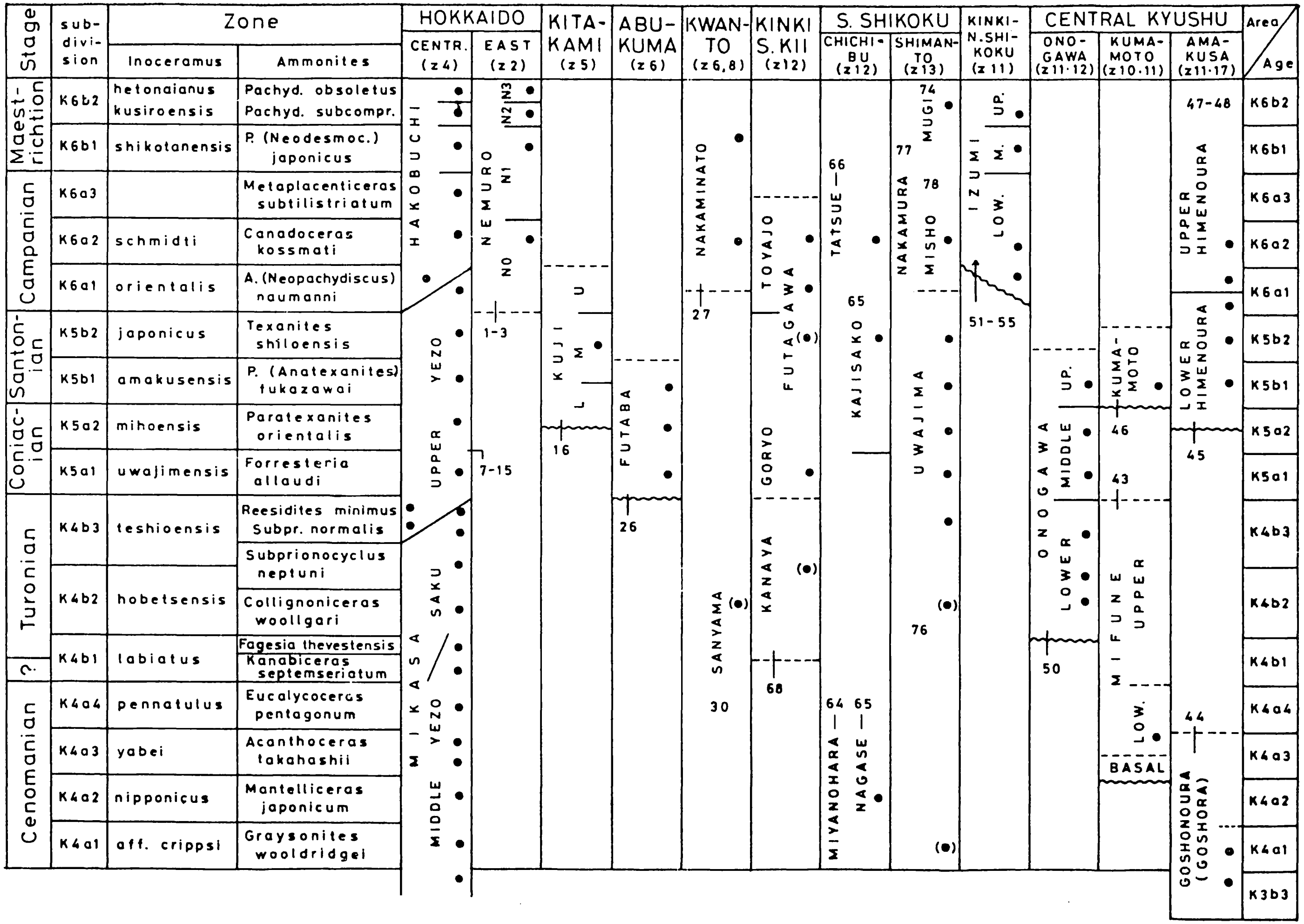

Fig. 3. Tentative correlation chart of the Upper Cretaceous fossiliferous marine formations in Japan. Numbers refer to the locations indicated in Fig. 2. Symbols z4, z5 etc. mean the tectonic units, although their explanation is omitted here for brevity. A small solid circle indicates the occurrence of a zonal index or zonal indices.

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ON THE SO-CALLED CRETACEOUS TRANSGRESSIONS

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Abstract

To understand the nature of transgressions in the Cretaceous period the timing of these phenomena is critically examined in this paper. Two cases are taken for the investigation: one in such mobile areas as Japan and the other in stable areas.

In the Cretaceous of Japan the epochs when marine sediments are better developed are distinguished from those when they are absent or poorly developed. In some case the subsidence of sedimentary basins shifted from one province to another as time went on. From a comparison of the periodicity of transgressions and regressions with igneous and tectonic activity, it is suggested the the tectono-magmatic causes may have been the most important factors which controlled the apparent transgressions and regressions in the Cretaceous of Japan. Further study of other mobile areas is needed.

More extensive Cretaceous transgressions are well known on the shelf regions of stable continents. A preliminary result of correlations based on available evidence shows that the marine transgressions, and especially their maxima, were not always synchronous in the shelf regions. For example, there was a widespread Neocomian transgression on the lowlands around the Arctic Sea and some parts of South America and southern Africa-Madagascar, whereas the Neocomian is represented by nonmarine sediments of the Wealden facies in northwestern Europe, eastern and interior North America and elsewhere. In Australia the Aptian-Albian transgression was more extensive than the Upper Cretaceous ones. In many other continents the Upper Cretaceous transgressions were the most extensive and of the longest duration, but their maxima, or the sedimentary cycles within them, were not necessarily synchronous between different regions. However, it seems that the areas around the same oceanic unit had similar, if not identical, sedimentary cycles.

In conclusion transgressions must have occurred by a combination of several causes. The effect of eustatic sea-level change, which itself may have been caused by more than one factor, may indeed have been important for transgressions, but it seems to have been modified by other factors which were peculiar to individual shelf regions, or provinces within them, and also by the mode of movement of the continent or the plate to which a given shelf belonged.

1. Introduction

In many text-books of historical geology the Cretaceous period is dsecribed as one of the periods of extensive marine transgressions. It indeed comprises favourable examples through which the nature of the phenomena can be studied.

Transgressions may have more than one cause. What kind of cause(s) was actually effective in a given example should be discovered by analysing various stratigraphic records. Careful correlation of marine formations between distant provinces

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is especially important to reach sound conclusions. Let us examine the evidence for the Cretaceous along this line. I am taking examples from two settings: some from a mobile area and some from stable regions.

2. Cretaceous Transgressions in Japan

Japan belonged to the circum-Pacific belt which was mobile in the Mesozoic and the Cenozoic. During the Cretaceous period tectonic movements were active, comprising folding, thrusting, en block faulting, horizontal displacement and warping. There were also much metamorphism, granitic emplacement and volcanism in some belts. Despite such mobile conditions marine formations were deposited in several provinces, and these record a series of transgressions and regressions.

In the preceding paper I have summarized the correlation of the Upper Cretaceous marine formations in Japan. For the correlation of the Lower Cretaceous marine formations OBATA and I (1977) have given a tentative correlation chart. From these I note two interesting facts for which I propose an interpretation that may throw light on the nature of transgressions in a mobile area.

Despite the local difference in stratigraphic records, there are, in general, times when marine formations occur in several different provinces. Intercalated with them there are times when marine formations are scarcely developed. Actual examples are

(1) Berriasian: transgression which continued from the Tithonian
(2) Up. Valanginian-Lower Hauterivian: general regression
(3) Up. Hauterivian-Lower Barremian: transgression
(4) Upper Barremian-Lower Aptian: regression
(5) Upper Aptian: beginning of transgression
Albian: extensive transgression, though with minor local variations
(6) Cenomanian-Turonian: shallowing or regression
(7) Coniacian-Santonian: most extensive transgression
(8) Campanian-Maestrichtian: shallowing or regression, with minor oscillations
(9) Paleocene: extensive regression

It is significant that the many K-Ar age determinations on granitic rocks in Japan (see compilations by NOZAWA, 1970, 1975) show a periodicity in the frequency of the dates with three peaks, at about 120 m.y., 90 m.y. and 60 m.y. with a range of about 20 m.y. respectively. These ages of granitic emplacement and cooling correspond approximately with those of the regressions (4), (6) and (8-9), and the intervening epochs between the peaks correspond with the epochs of the transgressions (5) and (7). There is no good radiometric data for the early Neocomian within Japan, but we could expect some in Korea, and in fact the sandstones of that Upper Valanginian-Hauterivian age (2) are remarkably arkosic (an older peak at about 180 m.y. is distinct in the Hida mountains of Japan and also in Korea).

There are also records of structural unconformities and other sedimentological features that indicate tectonic instability, of which the significant ones are found to correspond to times of regression, or immediately before the onset of transgression.

This correspondence between transgression-regression and tectono-magmatic activity in the Cretaceous of Japan has already been pointed out by myself (MATSU-

MOTO, 1969) and further refined in a separate paper (MATSUMOTO, 1977 in press). A similar conclusion was independently presented by EVERDEN and KISTLER (1970) on the Mesozoic batholithic complexes in California and western Nevada. Subsequent works in the United States (e. g. ARMSTRONG and SUPPE, 1973) have confirmed the periodicity of the age data but also shown a shifting of the peaks of frequency from place to place.

From the recent data it can be concluded that the age of the granitic batholiths in the Inner Zone of Southwest Japan shifted from province to province, with a younging toward the east. This is roughly parallel to the eastward younging of the Upper Cretaceous marine sedimentary basins from western Kyushu to central Kinki which I have discussed in the correlation paper. This relationship is diagrammatically shown by SHIBATA *et al.* (1977) in another paper.

These observations do not imply that the "apparent" transgressions in the mobile belt occurred at random. Batholithic intrusion, volcanism, tectonic movement and metamorphism may have occurred in the circum-Pacific belt in accordance with the subduction of an oceanic plate underneath a continental plate. There must have been a regularity in the movement of the plate, such as increase or decrease of the speed, or a halt, or changes in the orientation of plate motion. Although the direct or indirect responses (including upheaval and downwarping of basins) to the subduction may apparently differ or shift from one province to another, the plate motion itself must have been of more extensive scale, affecting for instance the entire area around the northern Pacific.

We need precise correlations of Cretaceous deposits within and between the regions around the northern Pacific, e. g. Japan, the Sikote Alin, Sakhalin, Kamchatka, the Koryak, and a number of basins in the North American Cordillera from Alaska to Baja California, to find some regularity in the timing of the transgressions and regressions and to discuss further its implication. The interpretation given above of examples in Japan may be one of various causes of transgressions in a mobile region.

3. Cretaceous Transgressions in Stable Areas

Transgressions and regressions of epicontinental seas are well recorded in the stable areas. The earlier concept of a great transgression in the Cretaceous period was too rough, since the areas invaded by the sea were plotted on a map as a single Cretaceous sea area, disregarding the differences in the dates of the transgressions.

Although the work of correlation in our MCE group is in progress, I attempt here to examine tentatively the timing of the transgressions. Fig. 1 is a summary map in which transgressions of different epochs are broadly discriminated. Fig. 2 shows major cycles of sedimentation in representative regions.

I outline below the essential features of these events, but for brevity, the descriptions of the basic data and references are mostly omitted in this paper (see MATSUMOTO, 1967 and selected references with * in the list below for more details).

(1) *Neocomian* (Berriasian to Barremian).—Over wide areas of western Europe this was an epoch of regression, represented by the deposition of the non-marine Wealden

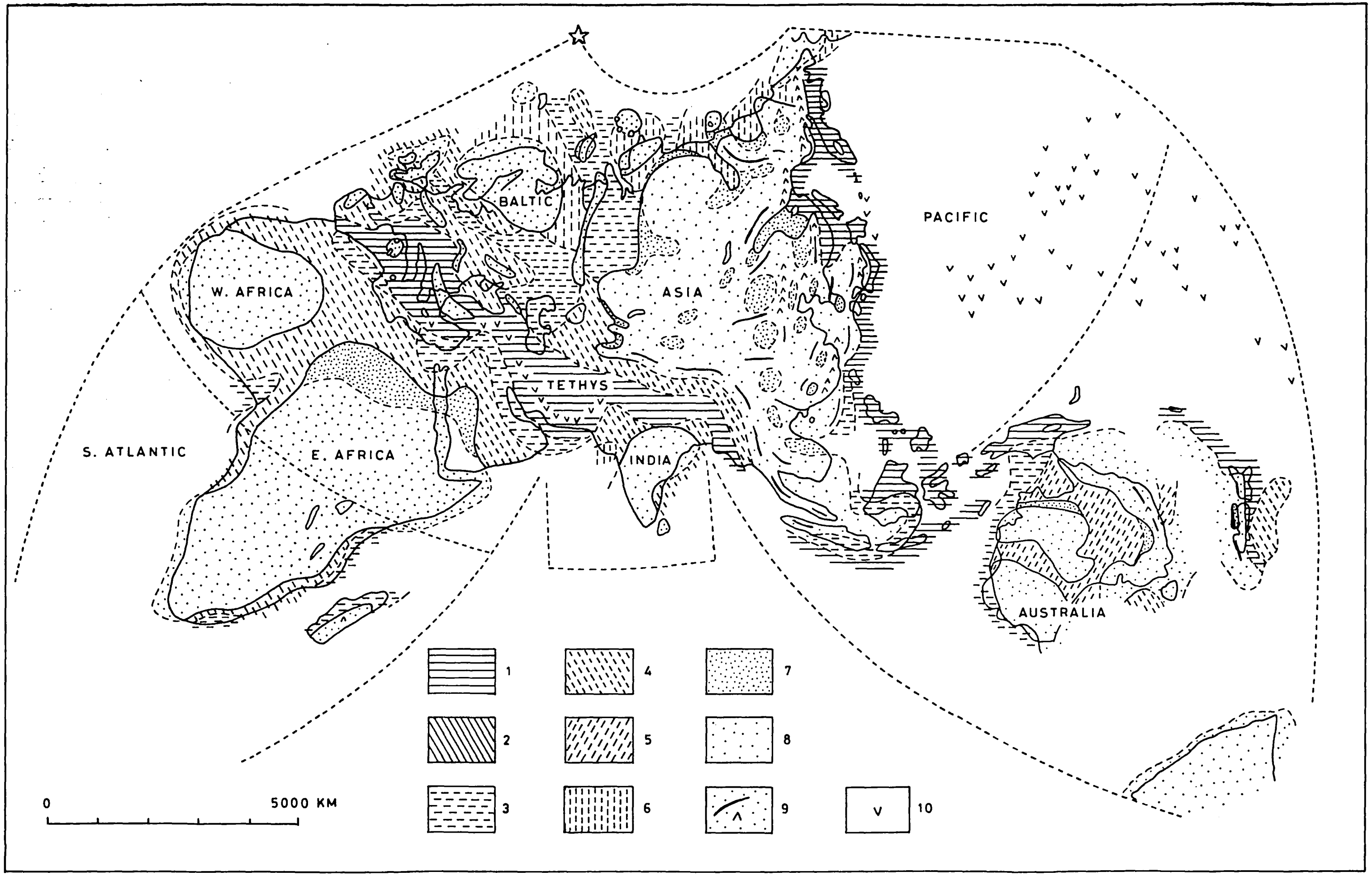

Fig. 1A. Cretaceous palaeogeographic map of the world. 1=marine orthogeosoncline (whole period), 2=*ditto* (in Late Cretaceous), 3=platform [shelf] covered with both the Lower and the Upper Cretaceous marine transgressions, 4=shelf mainly with the Upper Cretaceous transgression only, 5=shelf with the Aptian-Albian transgression only, 6=shelf with the Neocomian transgression only, 7=continental basin and lowland of non-marine sedimentation, 8=continent or large island not covered by the Cretaceous sea, 9=mountain-range and subaerial volcano, 10=ocean and submarine volcano. N.B. This map is drawn on the present configuration of continents, without restoring the effect of drifting. [compiled by MATSUMOTO on the basis of the references with indication of * in the list, with much revision of MATSUMOTO, 1967, fig. 1] facies. In the same epoch the Atlantic coast of North America as well as its interior province was a land area.

In southern Europe, in the marginal miogeosyncline of the western Tethys, the marine Neocomian calcareous pelagic sediments are well developed, including the type sequences from the Berriasian to the Aptian. The shallow marine Urgonian facies limestones are widely developed in the Upper Barremian to Lower Aptian.

Neocomian marine formations consisting mainly of black shales, with characteristic boreal faunas, were deposited extensively on the Russian platform, western Siberia, and also some lowlands around the Arctic Sea, e. g. northern and northeastern Siberia, Alaska, Arctic areas in Canada and Greenland. The Neocomian sea, with its boreal fauna, extended as far south as northern Germany and eastern England in Europe. Subsequently in Barremian to Aptian times the epicontinental seas retreated from most parts of the area around the Arctic sea, except for western Siberia.

Tithonian to Berriasian marine formations are known in southern Argentina and some miogeosynclinal basins of the Andes. Likewise, shallow Neocomian seas covered Madagascar and southeastern Africa. The Valanginian with olcostephanid ammonites and certain pelecypods seems to represent the inundation phase in this cycle of sedimentation, whereas marine Barremian and Aptian sediments merge into continental facies in some areas and are less developed.

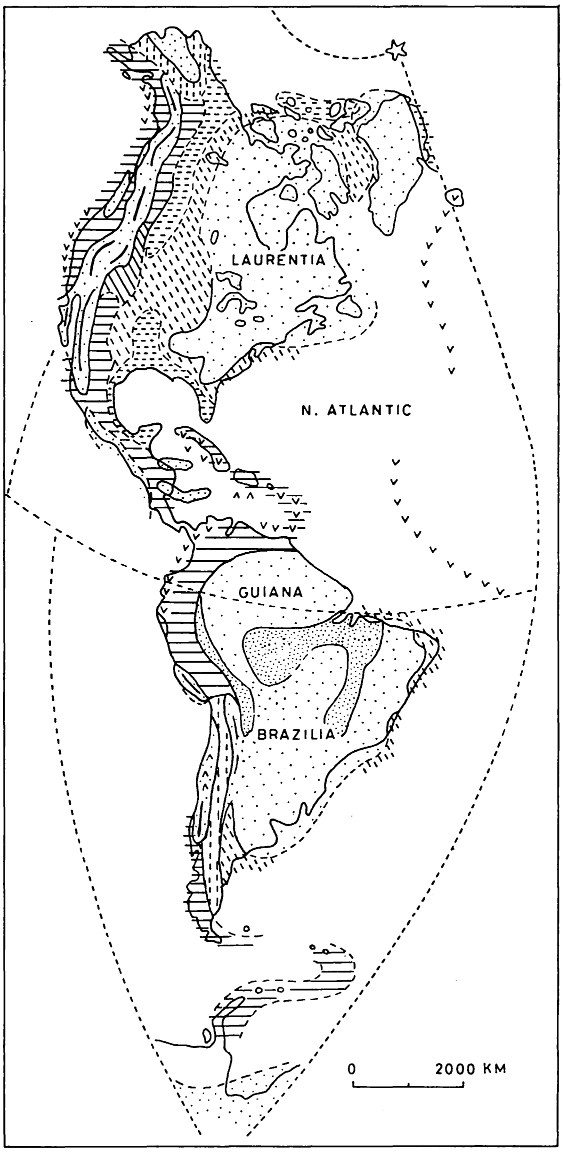

Fig. 1B. Cretaceous palaeogeographic map of the world (continued). Legend same as in Fig. 1A.

(2) *Aptian-Albian transgressions.*—The stable area of Australia may be the sole example where shallow seas spread more extensively in the Aptian aed Albian than in other ages of the Cretaceous.

In the Cutch area of India, which may have been closer to Australia at that time, the marine Lower Aptian Ukra Formation is known.

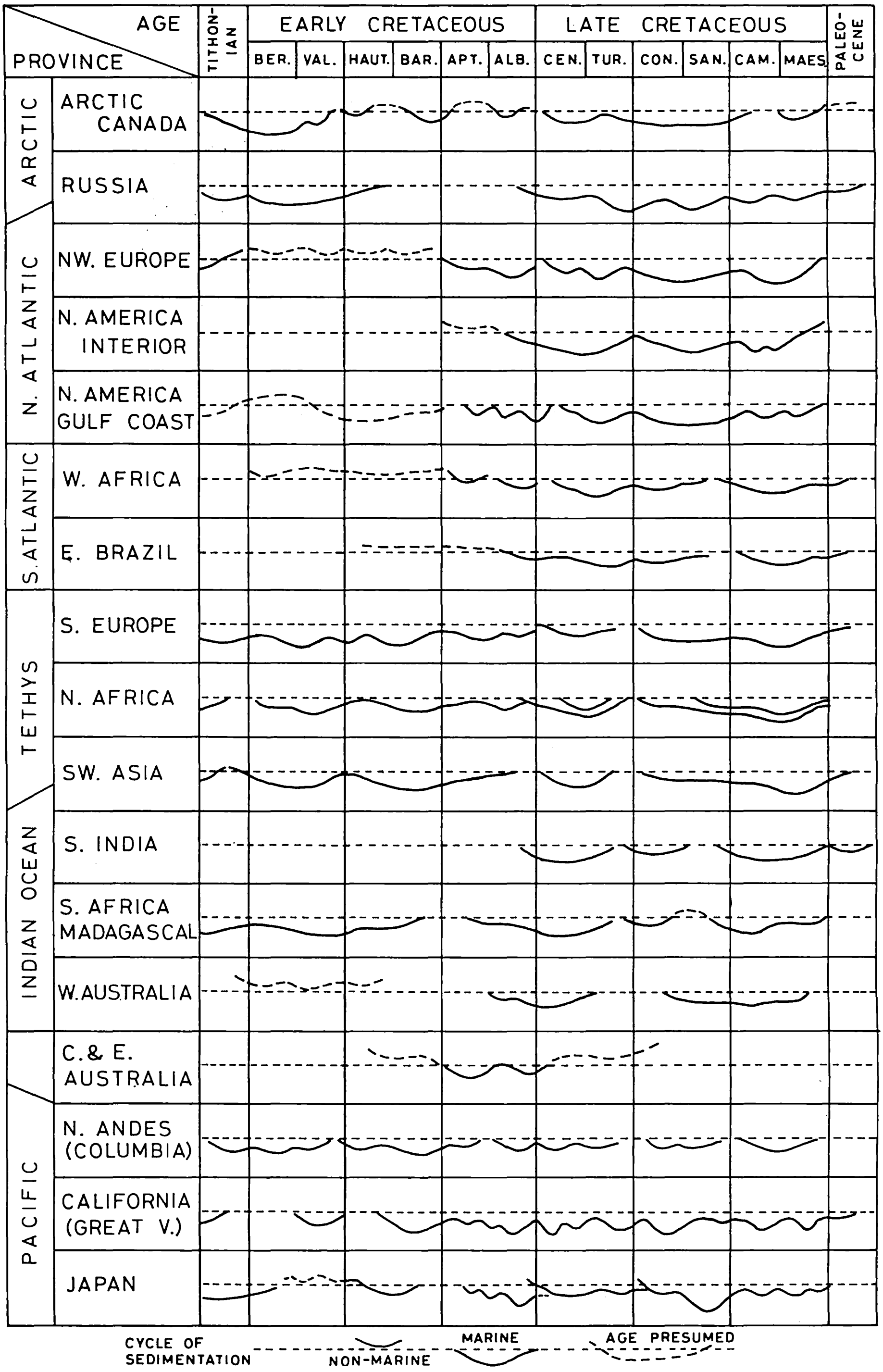

Fig. 2. Diagram showing major cycles of sedimentation during the Cretaceous period in some representative areas of the world. [revised from MASTUMOTO, 1967, fig. 2] (Read MADAGASCAR for MADAGASCAL in this diagram.)

In many other regions, marine transgressions began in the Aptian and extended more widely in the Albian. The Lower Greensand and the Gault of England mark the typical record in western Europe. As the Upper Albian is partly represented by a regressive sandstone facies, the maximum of this transgression was probably in the Middle Albian.

At approximately the same time, the sea invaded the Gulf Coast of North America, depositing the Comanche Series. The maximum of the transgression is likewise in the Middle (precisely late Middle) Albian, because the *Oxytropidoceras* bearing beds reach as far north as Kansas. However, the sedimentary cycle of the Comanche Series is not the same as that in western Europe, since it began in the Upper Aptian, with the Zone of *Dufrenoya justinae* at its base, and lacks the main part of Lower Albian, probably due to a temporary retreat of the sea, and ends in the Lower Cenomanian, with the Zone of *Budaiceras texanum- Mantelliceras cantianum* at its summit.

The interior province of Canada was covered by a transgressive boreal sea which reached as far south as Montana and Wyoming in the Lower to Middle Albian with *Subarcthoplites* and *Gastroplites* faunas and again in the late Upper Albian with a *Neogastroplites* fauna.

In Angola and adjacent areas of western Africa and in Sergipe and adjacent areas of eastern Brazil the Aptian is non-marine, containing evaporites, but the Albian is marine with the maximum transgression probably in the late Middle Albian.

(3) *Upper Cretaceous transgressions.*—Marine Upper Cretacenus sediments ranging from the Cenomanian to the Maestrichtian are extensively developed in most parts of the stable areas. In this sense the Upper Cretaceous transgression was on a grand scale in its global extension and its long duration. If we carefully examine the facts, it will be noticed that the so-called Late Cretaceous transgression is not uniform but composite. This composite nature may imply the combined effects of more than one cause. For instance, the eustatic uprise of the sea-level by some global cause seems to have been modified in different ways by regional or provincial tilting or warping, or by other entirely different factors (e. g. geoidal eustasy of Mörner, 1976).

Let us see some distinct examples.

In western Europe (which includes the type localities of the stages of the Upper Cretaceous) the Upper Cretaceous is mainly represented by chalk. The beginning of the transgression was in Cenomonian times, with time-transgressive overstep onto the older strata. The basal part of the Cenomanian is incompletely distributed there. When was the maximum of the transgression? The answer may differes between authors and between provinces. As has been shown in Hancock's (1975) recent paper, the Upper Cretaceous sequences seem to record several oscillations. For instance, in the type area of France there is a slight unconformity near (but not at) the base of the Turonian. Being interrupted by this kind of minor oscillation, the transgression seems to have reached its maximum extent in Lower Turonian (Zone of *Inoceramus labiatus*) time. Then the sea retreated or shallowed in the Late Turonian, followed by another extensive transgression, which reached its maximum extent in the Santonian and another in the Late Campanian.

A large scale regression occurred at the end of the Cretaceous, extending into the beginning of the Tertiary.

On the Russian platform, where changes in facies and thickness are well studied in relation to the tectonic configuration (NAIDIN, 1959, 1960, 1969), the transgressions started in late Albian time and the maxima of the transgressions were in the Early Cenomanian, the Late Turonian and the Santonian, showing some discrepancy from the records in western Europe. A tectonic reconfiguration in Campanian time gave rise to a seaway from the north with the incoming of the *Pteria tenuicosta* fauna. As NAIDIN has clearly shown, the thickness of the Upper Cretaceous sediments, and accordingly the amount of downwarping, varies to a considerable extent between basins within the stable Russian platform. The same is true of every platform.

Upper Cretaceous marine sediments are extensively recognized in the western Siberian lowland (from subsurface evidence), and in the Turonian age the boreal sea was connected with the epicontinental sea of central Asia, where the invasion came from the Tethys.

In the Gulf Coast and Interior provinces of North America marine Upper Cretaceous sediments are extensively distributed. In this region the transgression began in the Middle Cenomanian, with the *Acanthoceras* fauna and its first maximum is marked by the Greenhorn Limestone and Britton Shale, which are of latest Cenomanian to Early Turonian age. The second maximum may be represented by the Smoky Hill Chalk-middle Austin Chalk, which are of Late Coniacian-Early Santonian age, and the third somewhere in the Pierre Shale and the Taylor Marl, within the Campanian. The Maestrichtian sediments represent a regressive phase of the major Late Cretaceous transgression but its early part marks the last minor transgression.

The lowlands on the stable areas around the Tethys (Middle East and northern Africa) were invaded by the Upper Cretaceous transgression, which started in the Late Albian in some areas but as late as the Late Cenomanian (with a *Neolobites* fauna) in others. Its maximum was in the Early Turonian, with a rich fauna of Vascoceratidae and Tissotiidae. In the Middle to Late Turonian the sea retreated extensively. Marine Coniacian and Santonian are developed only locally, if not absent in the region. Another transgression occurred in the Late Campanian-Maestrichtian, with a sphenodiscid ammonite fauna in the offshore facies and phosphatic beds in the marginal areas.

The above summary is a general outline of the history of certain areas around the Tethys, but the more detailed features may differ from one basin to another. I know little about the biostratigraphic correlation of the oil bearing Cretaceous deposits in the stable areas of southwestern Asia. According to the recent compilation by SUGDEN and STANDRING (1975), for instance, the Turonian is regarded as a time of regional unconformity in the Qatar Peninsular, although it is not certain whether their Turonian means the whole of the age or only its later half.

Recent investigations in western Africa and eastern South America have revealed a similar history of transgressions on both sides of the opening South Atlantic Ocean, i. e. the Early Turonian inundation, as a result of which the Tethyan faunas migrated to the South Atlantic through the Nigerian seaway; the Coniacian and the Late Companian-Early Maestrichtian were also times of transgression.

The lowlands around the present Indian Ocean were overlain mainly by Cretaceous shallow sea sediments. The well studied sequences in Madagascar show, in addition to the Neocomian cycle, a second major cycle from the Albian to the Coniacian, with maximum transgression in the Cenomanian and an evident regression in the Late Turonian, and finally a third cycle from the Late Santonian to the Maestrichtian with a probable inundation in the Early Campanian. The sequences in southern India record a similar if not identical history of transgressions. The sequences on the western and northwestern margin of Autsralia also show a similar history. The timing of the marine sedimentary cycles in the areas around the Indian Ocean is not, however, identical with that on both sides of the south Atlantic.

4. Concluding Remarks

Summarizing the above observations and discussion, it may be concluded that transgressions were the result of more than one cause. In the case of such mobile areas as Japan, tectonomagmatic activity seems to have been effectively related to the apparent transgressions and regressions. Further study is needed, however, to provide examples in other mobile areas.

More extensive transgressions are well recorded on the stable shelf regions of the continents. As a result of an examination on the timing of events it becomes evident that the marine trangressions, especially their maxima (i. e. the inundation phases), were not always synchronous between separate shelf regions, although the areas around the same oceanic unit seem to have a similar, if not identical, history of sedimentary cycles. Apart from some regional differences, the Upper Cretaceous transgressions were as a whole very extensive and of long duration, and the regression at the end of the Cretaceous and the beginning of the Tertiary was on a global scale. The global eustatic rise and fall of sea-level may have been caused by such global tectono-magmatic processes as the rise of midoceanic ridges, rising or sinking of the ocean floor, or other features related to the plate motions. However, the actual transgressions may have occurred as a combined result of this kind of global eustatic sea-level change and other tectonic processes (e. g. warping, tilting, etc. as well as sedimentation) which are peculiar to individual regions, and also entirely different kinds of causes (e. g. geoidal eustacy of MÖRNER, 1976).

This paper presents my tentative interpretation based on an examination of timing. Further study would ellucidate more clearly the true nature of the Cretaceous transgressions.

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STRATIGRAPHY AND CORRELATION OF MID-CRETACEOUS OF THE USSR PACIFIC REGIONS

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Rather thick Mid-Cretaceous deposits of different facies (marine, mostly terrigenous, fresh-water continental (coal-bearing), effusive-volcanogenic) play an important role in the geological structure of the USSR Pacific regions (from Primorie and Sakhalin in the south to Chukotka in the north). The distribution, composition, mode of occurrence and the concepts on stratigraphic subdivisions of these deposits have been elucidated in literature (Geology of the USSR, v. 30-33, 1964-1970; VERESHCHAGIN, 1957, 1963; PERGAMENT, 1961, 1965a, b, 1966, 1971; AVDEIKO, 1968; PARAKETSOV and oth., 1974; "Stratigraphy and lithology....", 1974).

The most complete sections of these deposits are known in Primorie, North-East Prikolymie, Koryak Upland (Pekulnei Ridge, the Main River basin, etc.), the North-western Kamchatka, and the western Sakhalin. In the most regions the Middle Cretaceous sediments contain, as a rule, abundant remains of Bivalvia (*Inoceramus*, in particular) and ammonites that serve as the basis for their detailed subdivision and correlation. The reliable correlation of the recognized units within the individual regions and with equivalent units of the adjacent regions is based on the common and similar genera and species, including the key forms of the Mid-Cretaceous of Japan, Canada and USSR, as well as on the analysis of the evolution of the faunistic groups. The author outlined previously a scheme of the zonal subdivision and correlation of the North Pacific Cretaceous. However new personally assembled materials and the data of the Soviet and foreign researchers necessitate an introduction of some amendments to this scheme.

It is evident now that the marine Mid-Cretaceous of the Pacific regions of the northeastern Asia and North America contains numerous faunas of ammonites, inocerami, aucellines, foraminifers, etc. These faunas contain a number of genera and many species which are not known in the Atlantic biotic province. Many myarians (pectinides, ostreans, etc.) are much less abundant in the above mentioned Pacific regions and their faunas here are relatively monotonous, as compared to the composition of the myarians of carbonate chalk of the same latitudes of the Atlantic province. This is a direct result of the temperature differences and other peculiarities of the environment. This conclusion is also supported by the absence (or sporadic findings) of belemnites and echinoids in the Cretaceous of the here discussed Pacific regions.

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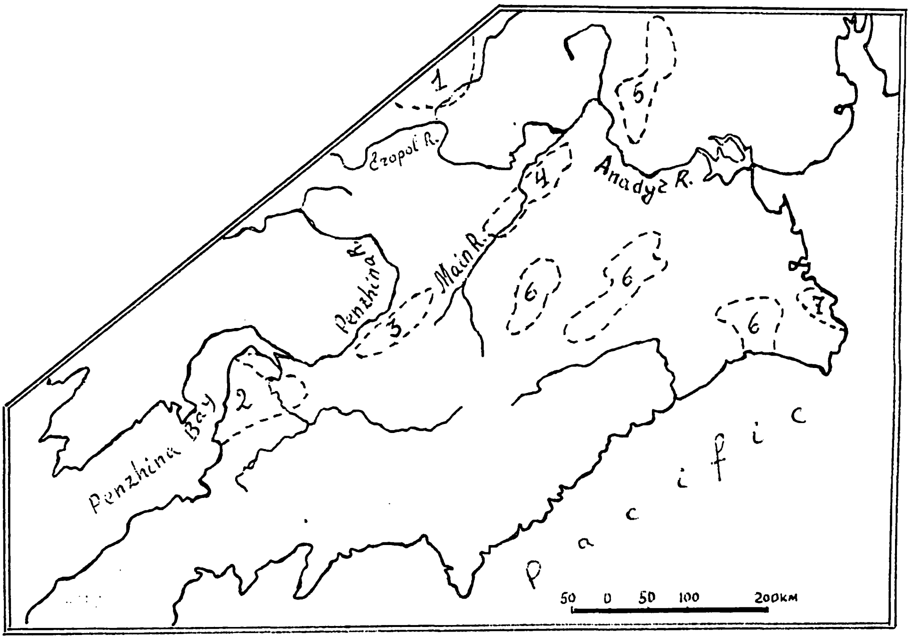

Fig. 1. Middle Cretaceous key sections of the USSR Pacific regions. 1-Umkuveen Depression (North-East Prikolymie), 2-North-West Kamchatka, 3-Pontoney Mountains, 4-Main River basin, 5-Pekulney Ridge, 6-Koryak Upland, 7-Ugolnaya Bay region.

The composition of the Mid-Cretaceous fauna of the North Pacific province is rather peculiar. However, the faunistic assemblages of this province include, in addition to the endemic forms, widespread genera and species of ammonites, inocerami and other groups, which include the zonal indices of West European sections. In the early stages of the study of the North Pacific assemblages the local species were found to be prevalent. This circumstance has made it difficult to recognize not only the European zonal units but also the stage subdivisions of the international stratigraphic scale.

The composition of faunal complexes of stratigraphic subdivisions in the northern Pacific regions concerned and in West Europe is, naturally, different. However, the succession of widely distributed genera and species proved to be the same in these regions and in the sections of other regions of Europe and America. This enabled us to elucidate the common features and peculiarities of the development of the faunal complexes of the Pacific basins with those of other basins of the world. We have established that the above mentioned faunal peculiarities do not prevent the recognition of the universal stage subdivisions in our regions. This permits to carry out the correlation of refined biostratigraphical units of various realms and provinces. The importance of interregionally distributed taxa (species) is quite evident in this case. Though the number of such taxa is not great in each assemblage, they are usually the well known index fossils. It is these taxa that allow to "mark" the age of local forms and effect the correlation of North Pacific faunas with the zones of other continents and stratotypical sections.

The study of the composition and development (morphogenesis) of Cretaceous inocerami of the North Pacific and the Atlantic provinces from this standpoint enabled the author to prove the great importance of the recognition of the stages of development of faunas (MENNER, 1962) for the purpose of zonal subdivision and that of the correlation of the zones (PERGAMENT, 1976). An analysis of the space-time evolution of the faunas (groups) allows to distinguish two main categories of zonal subdivisions: a) the zone of the universal (international) scale representing a part of a stage, and representing a stage evolution of a zonally diagnostic fossil group traced over large regions (on intercontinental scale); b) the regional zone-"rena"— a subdivision reflecting a stage of the evolutionary development of geographically restricted faunal groups (i. e. those characterizing a region, area, proviece, or their parts), which cannot yet be traced beyond the limits of these palaeobiotic units. These "renas" are not correlated with the zones of the international scale.

The zones of the two above mentioned categories can be outlined in the Mid-Cretaceous deposits of the Pacific regions studied. However, the author also recognizes there "layers with fauna"— an auxiliary subdivision determined through the actual distribution of certain fossils in a section. This subdivision appears to be synonimous with the term "range-zone" suggested by the American authors.

A thick succession of marine, terrigenous (arenaceous to clayey) Mid-Cretaceous deposits of the Pacific regions of USSR is subdivided into three major cycles of sedimentation separated from each other by breaks in sedimentation and either stratigraphic or angular unconformities. The first, oldest cycle lasted from the late Hauterivian through the greater part of the Albian. The second cycle lasted from the end part of the Albian through the Cenomanian. The third, youngest cycle lasted from the second half of the Turonian through the early Senonian. Because of subregional variations of the tectonic regime different sections studied differ in the degree of their completeness. These variations of the tectonic regime are also responsible for complex lateral and vertical variations of facies within each of the above mentioned cycles observed in different parts of the regions studied.

In the present state of knowledge the Aptian deposits of the Pacific regions of USSR include (on the basis of a section of the Umkuveem depression described by PARAKETSOV and PARKETSOVA, 1973, 1974): 1. Lower Aptian beds with *Australiceras* ex. gr. *gigas* (SOW.) (claystones, 80-120 m), and 2. Upper Aptian beds with *Tropaeum* (?) *kajgorodzevi* (VER.) (mostly claystones, siltstones and sandstones, 170-250 m). The index ammonite of the first unit is similar to the above mentioned *Australiceras* species diagnostic of the *Deshayesistes deshayesi* zone of England and Povolzhie. In the North-West Kamchatka the thickness of this unit increases to some hundreds meters. In that area the unit contains *Eotetragonites jacobi* (KILIAN), *Lytoceras* aff. *traski* AND., *Gabbioceras* cf. *wintunium* IMLAY, *Cheloniceras* spp. This unit appears to be correlated with the lower part of the Starosuchanskaya sequence of marine rocks of the Primorie area. This sequence contains *Deshayesites* cf. *consobrinoides* SINZ. below and *Tetragonites* aff. *duvalianus* (ORB.) above.

The fauna of the beds containing *Tropaeum*? *kajgorodzevi* is more diverse. Heteromorphous ammonites (TEREKHOVA, 1972) occur throughout the thickness of these sandstones and siltstones which are up to 450 m in the Pekulnei Ridge and up to 700m thick in the North-West Kamchatka. In this unit numerous Bivalvia of the genus *Aucellina*, including Caucasian and North American species, appear. The unit also contains *Nucula*, *Nuculana*, *Goniomya*, *Mytilus*, *Modiolus*, *Thracia*, *Tancredia*, *Pinna*, *Lima*, *Entolium*, *Astarte*, *Panope*?, *Pleuromya*, rare *Phyllopachyceras* aff. *infundibulum* (ORB.) and rare *Tetragonites duvalianus* (ORB.).

Ammonites appear to be diagnostic enough to indicate the Aptian age of the deposits concerned. Furthermore they indicate the correlation of the beds with *Tropaeum*? *kajgorodzevi* with the middle (and upper?) subzones of the *Gabbioceras wintunium* zone of California (MURPHY, 1956; POPENOE *et al.*, 1960) and the zones containing *Tropaeum* (JELETZKY, 1964, 1968, 1971) in the Boreal Province of Canada.

The Albian fauna is much richer and more diverse than the Aptian fauna. Besides Bivalvia, it contains genera and species of ammonites diagnostic of various horizons of Albian stage of several North Pacific countries, as well as those diagnostic of the Albian of the Western Interior regions of North America and those diagnostic of the European Albian. The sections of the Albian stage frequently begin with coarse sandstones and conglomerates transgressively overlying the older beds including those of the Valanginian. In complate sections the arenaceous-clayey series of the Albain in the North-West Kamchatka reaches up to 4200 m, in the Pekulnei Ridge up to 1500-2000 m, and in the Main River basin up to 1000-1100 m. The Albian rocks overlie the Upper Aptian rocks gradationally and are lithologically similar to them. Hence, they can only be recognized palaeontologically. The composition and succession of Albian faunas in the above mentioned regions makes it possible, as it was mentioned above, to distinguish the following stratigraphical subdivsions in the Albian of the Pacific regions of the USSR (upward sequence):

1. Beds with *Leconteites deansi-Kennicottia bifurcata*. These beds from the basal part of the faunal sequence of the Albian stage and are characterized by *Leconteites deansi* (WHITEAVES), *Kennicottia bifurcata* IMLAY, *Anagaudryceras aurarium* (AND.), *Eogaudryceras shimizu menneri* AVDEIKO, *Phyllopachyceras* cf. *chitinanum* IMLAY, *Colvillia* ? cf. *crassicostata* IMLAY, *Moffitites* cf. *crassus* IMLAY. Bivalvia of the genera *Aucellina* (ex gr. *aptiensis-caucasica*), *Tancredia*, *Nuculana*, *Pleuromya*, *Tracia*, *Astarte*, *Entolium*, *Camptonectes*, and others occur in these beds. The beds with *Leconteites deansi-Kennicottia bifurcata* correspond to the basal Albian, and may be reliably correlated with the synchronous *Colvillia crassicostata* zone of northern Alaska (IMLAY, 1961), the *Moffitites robustus* zone of the Chitina River basin, and the *Leconteites lecontei* zone of southern Alaska, Oregon and California (MURPHY, 1956; JONES, MURPHY and PACKARD, 1965; JONES, 1960, 1967). Furthermore, the ammonites of these beds indicate their correlation with the *Leconteites lecontei-L. lecontei whiteavesi* zone of the northern Pacific province of Canada and the lower part of the broad *Grantziceras affine* zone of the Boreal regions of Canada (JELETZKY, 1968, 1971).
2. The next younger beds of the Albian sections contain the faunistic assemblage of the *Brewericeras hulenense-Freboldiceras singulare* zone. In addition to the zonal species it contains *Calliphylloceras nizinanum* IMLAY, *Anagaudryceras aurarium* (AND.), *A. penjiensis* (VER.), *Eogaudryceras* cf. *shimizui* BREISTROFFER, ? *Kennicottia* cf. *rugosa* IMLAY, *Kennicottia* sp., *Cleoniceras* aff. *subbaylei* SPATH, *Arcthoplites talkeetnanus* (IMLAY), *Arcthoplites* sp., *Parasilesites* cf. *bullatus* IMLAY, *Grantziceras affine* (WHI-

TEAVES), *G. glabrum* (WHITEAVES), *Beudanticeras ? penjiensis* AVDEIKO, *Callizoniceras* (*Wellmanites*) sp., numerous *Aucellina*, *Tancredia*, etc. This zone represents the second half of the Early Albian and evidently correlative with the *Brewericeras hulenense* zone of the Pacific Coast of North America. The presence of *Douvilleiceras* cf. *mammillatum* (SCHLOTHEIM) in the latter zone determines its correspondence with the *D. mammillatum* zone of the international scale. This zone of the Pacific regions of USSR corresponds to the upper part of the *Grantziceras affine* zone and to the *Brewericeras hulenense-Douvilleiceras spiniferum* zone of the above mentioned regions of Canada. The latter was placed by JELETZKY (1968, 1971) into the Middle Albian. However, even considering the ranging of the *Douvilleiceras* and *Arcthoplites* up into the Middle Albian deposits, the age of these zones cannot be younger than the very beginning of the Middle Albian.

3. The overlying zone of *Cleoniceras sablei-Gastroplites* sp. has the same volume and correlations as its synonym—beds with *Cleoniceras* cf. *mangyschlakense-Gaudryceras aininensis* (AVDEIKO, 1968), or the *Cleoniceras* cf. *mangyschlakense-Gastroplites* sp. zone (PERGAMENT, 1969, p. 114). The zone is most completely developed in the North-West Kamchatka, in the Main River basin, and in the Pontoney Mountains. In all these areas the zone corresponds to the following *Inoceramus* zones: *Inoceramus comancheanus-I. bellvuensis*, *I. cadottensis* zone (COBBAN, 1951; PERGAMENT, 1965b). Furtheremore, the zone appears to correspond to the lower part of the *I. anglicus* range zone.

In the above montioned regions the rocks of the *Cleniceras sablei-Gastroplites* sp. zone are also denoted as the beds with *Cleoniceras dubium-Cl. sablei.* They are characterized (PARAKETSOV *et al.*, 1974) by *Cleoniceras dubium* TERECHOVA (MS) (?= *Cl.* cf. *mangyschlakense* LUPPOV in AVDEIKO, 1968), *Cl. sablei* IMLAY, *Cl.* aff. *perezianum* (WHITEAVES), *Arcthoplites talkeetnenus* (IMLAY), *Arcthoplites* sp., "*Gastroplites*" sp., *Paragastroplites* aff. *flexicostatum* IMLAY, *Grantziceras glabrum* (WHITEAVES), *Parasilesites* sp. n., *Yokoyamaoceras* sp. n., *Anagaudryceras penjiensis* (VER.).

All researchers assign the deposits concerned (i. e. the *Cleoniceras sablei-Gastroplites* sp. zone) to the greater part of the Middle Albian, and correlate them with synchronous *Oxytropidoceras packardi* zone of California (MURPHY, 1956; MURPHY and RODDA, 1959) and Oregon (JONES, 1960, 1967), the *Cleoniceras* (*Grycia* ?) *perezianum* zone of Queen Charlotte Islands (McLEARN, 1972), the *Gastroplites kingi* zone of northern Alaska (IMLAY, 1961) and Montana (COBBAN, 1951) and with the *Grycia*? *perezianum-Pseudouhligella* cf. *alamoensis* zone of the Pacific province of Canada (JELETZKY, 1968, 1971). In particular, the presence of typical *Gastroplites* in the Middle Albian of the North-West Kamchatka makes it probable that all above mentioned zones correspond with one another, with the *Gastroplites* zone of the Boreal Province of Canada, and with the "*Hoplites*" *dentatus-Lyelliceras lyelli* and *Eohoplites lautus-E. nitidus* zones of the European Middle Albian.

4. The above discussed early and middle Albian rocks are overlain conformably by succession of Upper Albian rocks. The middle or upper part of these Upper Albian rocks contain in some sections thick basal conglomerates and an unconformity. The lower part of the sequence is characterized by numerous *Inoceramus anglicus* WOODS (s. l.) and *I. kedroviensis* PERG. These beds are called by us "layers with *Grantzi-*

ceras multiconstrictum-Inoceramus anglicus". Previously they were singled out as the *Anagaudryceras madraspatanum-Grantziceras multiconstrictum* zone. However, the presence of *Freboldiceras singulare* IMLAY mentained in it (and also in overlying layers with *Neogastroplites*) (AVDEIKO, 1968, pl. 16, figs. 2, 3, 5-7) requires substantiation. Other reseachers (PARAKETSOV *et al.*, 1974) designate the sequence of rocks confined between the *Cleoniceras sablei-Gastroplites* zone below and the *Neogastroplites* zone above as the beds with *Tetragonites timotheanus-Inoceramus anglicus*, because of their poor fauna. However, in the North-West Kamchatka the rocks of this sequence yielded representatives of the genera *Pleurohoplites*, *Hulenites*, *Grantziceras*, *Stoliczkaia praecursor* AND., and *Aucellina*. On the whole, the here discussed sequence may be correlated, because of its fauna and stratigraphic position, with the lower part of the *Mortoniceras hulenanum* zone of the Pacific Coast of the United States and *Mortoniceras* (*Deiradoceras*) sp. - *Desmoceras* (*Pseudouhligella*) *dawsoni* zone of Canada. The latter two zones are correlative (MCLEARN, 1972) with the *Mortoniceras inflatum* zone of the Upper Albian of Europe.

5. The upper part of the Upper Albian, or the *Neogastroplites* zone, is clearly recognizable in the west and north of Kamchatka, in the Koryak Upland because of the presence of *Neogastroplites americanus* (REESIDE et WEYMOUTH), *N.* cf. *maclearni* REESIDE et COBBAN and *N.* cf. *mulleri* REESIDE et COBBAN. These ammonites indicate the correlation of this zone with the corresponding *Neogastroplites* zone of the Western Interior regions of the USA and Canada. *Inoceramus anglicus* WOODS, its subspecies, and *Aucellina* (ex gr. *aptiensis-gryphaeoides*) ascend to the lower part of the zone. In the upper beds of the zone also occur: *Marshallites columbianus* MCLEARN, *Parajaubertella kawakitana* MATS., *Mikasaites matsumotoi* VER., *Scaphites mametensis* AVD. and *Stoliczkaia* sp. These fossils indicate the correlation of this Late Albian zone with the *Desmoceras* (*Pseudouhligella*) *dawsoni* zone of southern Alaska, the upper part of the *Mortoniceras* (*Deiradoceras*) sp. - *Desmoceras* (*Pseudouhligella*) *dawsoni* zone of Canada, and with the upper part of the Albian of Japan. The presence of representatives of *Mortoniceras*, *Stoliczkaia* and other ammonite genera, as well as the presence of such well-known inocerami as *Inoceramus concentricus* PARK., *I. sulcatus* PARK., *I. salomoni* ORB., *I. concentricus subsulcatus* WHIT. and *I. nahwisi* MCLEARN, present in some sections of several countries of the North Pacific province, make it possibile to distinguish the Upper Albian in these contries. These palaeontological data permit also the correlation of the late Albian deposits of the corresponding contries and their correlation with the *Mortoniceras inflatum* and *Stoliczkaia dispar* zones of Europe.

The Upper Cretaceous deposits of the Pacific regions of USSR contain a more diagnostic fauna than the above discussed Lower Cretaceous deposits of these regions. The inocerami along with ammonites are of paramount importance for the biostratigraphical subdivision of these Upper Cretaceous rocks.

Sandstones and siltstones of the Cenomanian and Upper Albian of our regions differ in their fauna only. At the Lower-Upper Cretaceous boundary we have a good example of a noncorrespondence of the litho- and biostratigraphic boundaries, the above mentioned thick conglomerates being usually located at the base of the *Neogastroplites* zone. The boundary between the series of the Cretaceous system in the sections of the North-West Kamchatka and Koryak Upland is recognized because of the replacement of an assemblage of forms of the *Neogastroplites* zone by an assemblage of the *Inoceramus* aff. *crippsi-Desmoceras kossmati* zone, which is also well presented on Sakhalin (Naiba River). This zone is characterized mostly by the long ranging zonal species, such as *Anagaudryceras sacya* (FORBES), *Parajaubertella kawakitana* MTS., etc.

The similar, and even better defined position of the boundary between the Lower and the Upper series of the Cretaceous System is recognized by ammonites on the Hokkaido and Kyushu. There the beds with Late Albian *Mortoniceras* are overlain by the Early Cenomanian *Desmoceras kossmati* zone. However, the relation of the latter zone with the allegedly Cenomanian beds of the Tesio province containing *Graysonites* spp., *Stoliczkaia* spp. requires confirmation. The same is true of the beds of Shasta County, California containing the same ammonite genera (MURPHY, 1956; MATSUMOTO, 1960; POPENOE *et al.*, 1960; MATSUMOTO *et al.*, 1968). The author considers it possible that the genus *Graysonites* ranges down into the upper part of the Albian.

Cenomanian deposits are subdivided by the author into three inocerami zones: a) *Inoceramus* aff. *crippsi* - cm_1; b) *I. pennatulus* - cm_2; c) *I. nipponicus - I. scalprum* - cm_3. These zones have been traced into, or have analogues in, the sections of the Pacific Coast of the USSR, USA, Canada, Japan, etc. (PERGAMENT, 1966, 1969). The correlation of the two lower zones with one Early Cenomanian "*Turrilites costatus* zone" containing *Turrilites costatus* LAM., *T. dilleri* MURPHY et RODDA, *T. desnoyersi* ORB., *Turrilites* sp. n., *Hypoturrilites* sp. n., *Anagaudryceras sacya* (FORB.), *Parajaubertella kawakitana* MATS., *Tetragonites* sp. n., *Eogunnarites* sp. n., *Marshallites olcostephanoides* MATS., is hardly correct for the following reasons. The basal part of this "zone" is characterized by *I.* aff. *crippsi* MANT. (PARAKETSOV *et al.*, 1974), while the "*Turrilites* assemblage" characterizes the overlying sandy siltstone layers composing the lower part of the *Inoceramus pennatulus* zone. The species-index of the latter zone appears in the section of the Ugolnaya Bay somewhat lower than the first *Turrilites.* Furthermore, D. P. NAIDIN found *Mantelliceras* sp. in 1968 in the North-West Kamchatka at the base of the *I. pennatulus* zone. In the Sakhalin this zone is characterized by the common presence of *Anagaudryceras sacya* (FORBES), *Desmoceras* (*Pseudouhligella*) *japonicum* YABE, *Puzosia planulata nipponica* MATS. and *Turrilites* cf. *acutus* PASSY. In sections of Hokkaido the "group *I. pennatulus* PERG. and similar forms" were found together with Late Cenomanian ammonites (MATSUMOTO *et al.*, 1969, p. 269). The above data indicate that the deposits of the *I. pennatulus* zone correspond to the end of the Early - beginning of Late Cenomanian, or the middle part of that age. As the underlying *I.* aff. *crippsi* zone is the Early Cenomanian zone, the age of the beds with the "*Turrilites* assemblage" corresponds mainly to the second half of the Early Cenomanian, this being in accordance with distribution of its principal species from Japan (MATSUMOTO, 1959) to Europe (WRIGHT, 1963). The Late Cenomanian *I. nipponicus-I. scalprum* zone is characterized by these species of *Inoceramus* (PERGAMENT, 1966) on Sakhalin and Koryak Upland. This zone also contains relatively rare representatives of the genera *Acanthoceras, Calycoceras, Marshallites,* etc. of the above mentioned zones representing the Cenomanian stage in the Pacific regions of USSR, only the *I.* aff. *crippsi* zone corresponds to the *Desmoceras kossmati* zone. The exact relationships of the two other zones with those characterized elsewhere by ammonites (MATSUMOTO, 1959, 1965, 1971; PERGAMENT, 1969) are to be elucidated.

The upper boundary of the Cenomanian in the North Pacific is established by an almost ubiquitous occurrence of the Early Turonian *Inoceramis labiatus* or *Kanabiceras septemseriatum* zones. Yet, in the Pacific regions of the USSR there are no palaeontological indications of the presence of these zones. Only in the southern Sakhalin (the Losovaia River) V. N. VERESHCHAGIN (1971) managed to establish the presence of a thin Lower Turonian sandstone with *Fagesia* sp. However we may believe that the basal layers (150-200 m) of the Turonian of the North-West Kamchatka and Sakhalin (Naiba River), which contain the first *Inoceramus* ex gr. *lamarcki* (s. l.), were deposited as far back as in the Early Turonian and correspond to the *I. labiatus* zone. This is evidenced, first of all, by their stratigraphic position between the Upper Cenomanian *I. nipponscus-I. scalprum* zone and the Upper Turonian zone of *I. lamarcki.*

The extent of the *I. lamarcki* zone, and its two-fold subdivision are clearly defined in most sections. The subdivisions of the zone appear to correspond to the following two ammonitic zones. The lower subdivision, the *I. indefinitus* subzone, correspond to the lower of them - the *Collignoniceras woollgari* zone. In our regions this subzone is represented by the beds with early gigantic forms of the *I. lamarcki* group, which contains also *Collignoniceras*, etc. The upper subzone (zone), that of *I. cuvieri cuvieri* (or the *I. woodsi* zone) approximates the *Subprionocyclus neptuni* zone. Using the composition and development of inocerami and ammonites, these subdivisions of the Upper Turonian were traced also in Alaska, California and Japan. It was also possible to correlate them with synchronous subdivisions of the Western Interior regions of Canada, USA and of the West European sections.

It must be pointed out in this connection that: a) In Japan and California an interval which is somewhat greater than our *I. indefinitus* subzone is designated as the "*I. hobetsensis* zone". It corresponds to the greater part of the *Collignoniceras woollgari* and *Subprionocyclus neptuni* zones (MATSUMOTO, 1959, 1960, 1971). It has been established that the "species *I. hobetsensis* NAGAO et MATSUMOTO" is heterogenous. Furthermore, this "species" was found to range beyond the upper limit of its "zone" (PERGAMENT, 1971, 1973). That is why the suggested index-species of a still wider *I. iburiensis-Jimboiceras planulatiforme* zone proved to be unsuitable (VERESHCHAGIN, 1963, 1971).

b) In Japan and California some subzones of peculiar ammonites correspond to the *I. lamarcki* zone. In particular, the upper boundary of the above "*I. hobetsensis* zone" in California is drawn in the upper half of the *S. neptuni* subzone. The latter, contrary to the West European scheme, does not constitute the uppermost Turonian. The latter is represented in California by the next younger *S. normalis* subzone, and in Japan by the *Reesidites minimus* subzone. The entire corresponding interval is distinguished in Japan as the *I. teshioensis-I. tenuistriatus* zone. In California this interval is characterived by *I. costellatus-I. latus.* In the Pacific regions of USSR the stratigraphic ranges of the above mentioned, widespread inocerami species enable us to conclude that the here discussed Japanese and Californian ammonite zones correspond to the upper (greater) part of the *I. lamarcki* zone, i. e. the subzone (zone) of *I. cuvieri*, or to its equivalent-the *Subprionocyclus neptuni*+*S.* spp. zone.

Coniacian rocks gradually replace the Turonian rocks in the key sections of our regions. They are divided into two zones, approximatelly corresponding to substages: the *Inoceramus stantoni* (or *I. uwajimensis*) zone and the *I. involutus* zone. These zones unite the local synchronous biostratigraphic subdivisions (see PERGAMENT, 1971, 1973) the different inocerami assemblages of which are facies bound faunas the distribution of which is mainly controlled by the ecologo-climatic conditions within the corresponding regions. The two above mentioned zonal assemblages provide for a reliable correlation of the Coniacian sections of the west and east Pacific. The boundary of the lower zone with Turonian in Japan and California is also based on the time range of characteristic ammonites. The upper boundary of the Coniacian stage in the Pacific regions of USSR is placed at the Early Santonian *Inoceramus undulatoplicatus* zone conformably overlying the *I. involutus* zone.

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MID-CRETACEOUS (APTIAN TO CONIACIAN) HISTORY OF PACIFIC SLOPE OF CANADA

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Abstract

Marine Aptian and Albian rocks of the Pacific slope of Canada are restricted to several successor basins completely isolated from mid-continental Albian seas. Their faunas form part of the North Pacific biotic province of the Tethyan Realm. Early and late Aptian rocks are present but are poorly fossiliferous and cannot be zoned as a rule. Albian rocks are respresented by all substages and include (upward sequence): *Brewericeras lecontei*, *Brewericeras hulenense*, *Cleoniceras* (*Grycia*) *perezianum*, and *Desmoceras* (*Pseudouhligella*) *dawsoni* Zones.

In the central part of Tyaughton Trough early early Albian (*Brewericeras lecontei* Zone) marine rocks overlie latest Aptian marine rocks with *Acanthoplites reesidei* gradationally. On its margins and in other depositional basins (e. g. in Vancouver area, on Queen Charlotte Islands, and in northwestern British Columbia) marine to nonmarine, commonly conglomeratic Albian rocks overlap pre-Aptian rocks transgressively and often discordantly. On Vancouver Island Aptian and Albian rocks are either absent (a hiatus) or represented by coarse, nonmarine clastics.

At the end of the Albian the seas retreated completely and permanently from the British Columbia mainland and became restricted to the Insular Trough of northern Vancouver Island and Queen Charlotte Islands. The Cenomanian and Turonian faunas of the trough remained part of the North Pacific biotic province. Only the broadly Cenomanian *Desmoceras* (*Pseudouhligella*) *japonicum* fauna was found in the argillaceous rocks of the Queen Charlotte Islands. However, early and late Cenomanian rocks are present on the Vancouver Island. Fossiliferous early Turonian shale with *Inoceramus labiatus* is known only on Queen Charlotte Islands but may be present elsewhere. Turonian (? mid-Turonian) shale of northern Vancouver Island with *Romaniceras* (*Yubariceras*) sp. appears to be the youngest known marine mid-Cretaceous rock of the Insular Trough.

The late Turonian and Coniacian appear to be the time of a general uplift of the Pacific slope of Canada when the seas also left the Insular Trough and only some nonmarine rocks were deposited in disconnected intermontane basins.

1. Introduction and Acknowledgments

This paper written for the proceedings volume of the Hokkaido Symposium of the International Mid-Cretaceous project attempts to summarize the present state of knowledge of macrofossil biochronology, palaeogeography, and biogeography of the Aptian to Coniacian rocks of the Pacific slope of Canada. As defined in this paper the term is restricted to the Canadian Western Cordillera of British Columbia west

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of the Central Plateaux Province and including the Insular Belt of SUTHERLAND BROWN (1966).

The term Mid-Cretaceous, as defined by the International Mid-Cretaceous events project, includes the Albian, Cenomanian, and Turonian stages of the international standard. To clarify the lower limit of the Albian stage adopted in this paper and the stratigraphic relationships of this stage with adjacent Cretaceous rocks, brief descriptions of the Aptian rocks of the Pacific slope of Canada will also be included. The Coniacian rocks present no such problems being totally unknown and apparently only represented by a hiatus throughout the Pacific slope of Canada.

As with all recent synthetic papers dealing with the Cretaceous geology and palaeontology of Western and Arctic Canada (e. g. JELETZKY, 1968, 1970a, 1971a, 1973), the growth of a number of ideas presented in this paper was greatly facilitated by oral and written discussions with many colleagues within and outside the Geological Survey of Canada, during the last twenty-five years or thereabouts. Limitations of space and, even more important, those of the writer's memory make it impossible to thank individually all of the numerous individuals in Canada and abroad who have furthered the writer's researches in one way or another. Sincere thanks are expressed to all these colleagues.

It must be pointed out that Mid-Cretaceous history of the Pacific slope of Canada is still poorly known. This is caused by the prevalent great structural complexity of the Mid-Cretaceous rocks, combined with the common inaccessibility of their outcrop-areas occurring in a densely wooded, mountainous terrain. Furthermore, many of these "eugeosynclinal" rock types are poorly fossiliferous to unfossiliferous. This is particularly true of the locally common to prevalent volcanic types. Hence, this summary of the Mid-Cretaceous history of the region is but a progress report. It may be subject to major emendation and revision as new data will become available.

2. General Remarks

It must be pointed out that the writer only uses the term "Mid-Cretaceous" in this paper published in the proceedings volume of the International Mid-Cretaceous events project in order to conform with the usage of the project. Otherwise, he only uses the terms Lower (or Early) and Upper (or Late) Cretaceous being unalterably opposed to the now mostly abandoned tripartite subdivision of the Cretaceous System. As already pointed out elsewhere (JELETZKY, 1968, p. 3-5; *in* DOUGLAS *et al.*, 1970, p. 649-651, table XI-8), the term Lower Cretaceous is interpreted as including the Berriasian (beginning with the *Berriasella grandis* Zone) to Albian stages of the international standard while the term Upper Cretaceous is interpreted as including the Cenomanian (beginning with the zone of *Mantelliceras mantelli* as defined by KENNEDY, 1971, p. 2, 106, table 2) to Maestrichtian stages of the international standard.

The term "biochronology" proposed and defined by JELETZKY (1956, p. 682-688) is preferred to the later, more commonly used synonym "chronostratigraphy" (see HEDBERG, 1976, p. 8, 67) because of its priority and self-explanatory character. As defined by JELETZKY (1956, p. 686), biochronology covers palaeontological zonation within any one area or region, the correlation of these regional zonal schemes with

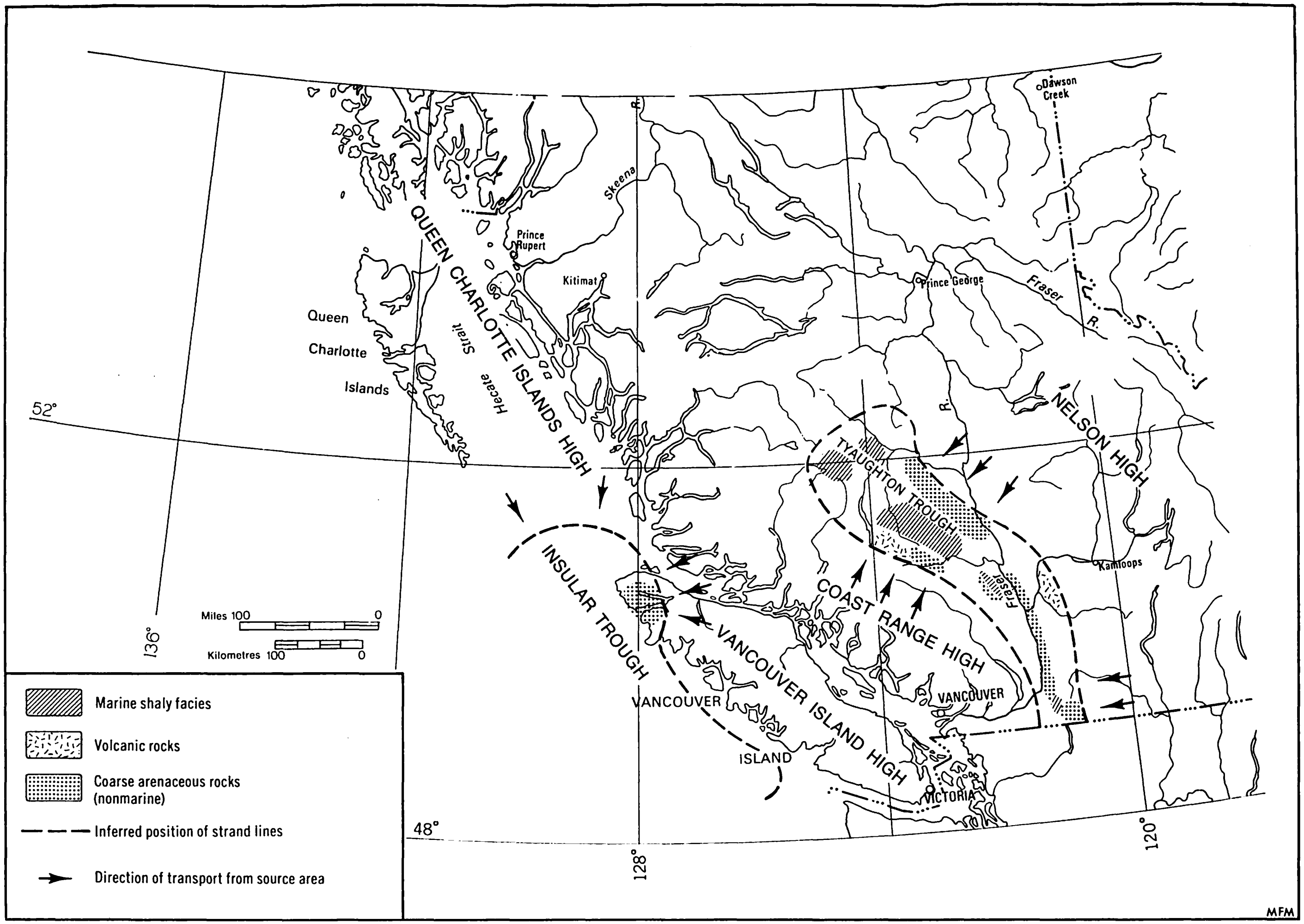

Fig. 1. Distribution of volcanic and sedimentary rocks of Aptian age.

one another, and their correlation with the standard zones and stages based on the European type localities and faunas.

Only rock (=rock-stratigraphic) and biochronological (=rock-time) units are used in this paper for reasons presented elsewhere (JELETZKY, 1956, p. 699-701; 1971a, p. 7, 10). In the writer's opinion, the biostratigraphic units of the North American Stratigraphic Code and the International Stratigraphic Guide are synonymous with the biochronological units.

The steadfast refusal of the writer (e. g. JELETZKY, 1956, p. 690-691; 1971a, p. 7, 10) to admit the practical usefulness of "all available methods of the physical age determination of the layered rocks of the geological column, including all radioactive methods known to date" is maintained in this paper. The gross imprecision or even an outright unreliability of the generally used radioactive methods of age determination on the palaeontological stage and zone level is, finally, becoming evident to at least some of the proponents of their use (e. g. BALDWIN, CONEY and DICKINSON, 1974).

The Mid-Lower Cretaceous rocks of the Pacific slope of Canada belong exclusively to the North Pacific faunal province of the Tethyan Realm as defined by JELETZKY (1965, p. 61, fig. 3; 1970a, p. 654, table XI-8; 1971a, p. 10-12). The validity of this palaeobiotic province is recognized by all subsequent workers (i. e. SAKS *et al.*, 1971, p. 201 etc; SHULGINA, SAKS and SAZONOVA, *in* SAKS *et al.*, 1972, p. 274-285, figs. 18-21; KAUFFMAN, 1973, p. 369; RAWSON, 1973, p. 140; CASEY and RAWSON, 1973, p. 417-418; JONES, 1973, p. 12, 16; WILLIAMS and STELCK, 1975, p. 5). However, all recent Soviet workers consider the North Pacific Province to form part of the Boreal Realm (*see* in JELETZKY, 1971a, p. 11) while some American (i. e. IMLAY and JONES, 1970; JONES, 1973, p. 16, fig. 10) and British (e. g. RAWSON, 1973, p. 140) workers treat it as a region transitional between the Boreal and Tethyan realms.

3. General Remarks about Mid-Cretaceous Depositional Basins

According to JELETZKY and TIPPER (1968, p. 3, 4, 75, 77, figs. 9, 10), the bulk of marine and nonmarine Mid-Cretaceous rocks were deposited in the following residual depositional troughs separated from each other by narrow, cordillera-like welts but connected by at least two narrow marine straits:

1. The Tyaughton Trough of the mainland of western British Columbia; and
2. The Vancouver Island-Queen Charlotte Islands Trough situated off the mainland of British Columbia.

The shorter and more euphonic name Insular Trough introduced somewhat earlier by SUTHERLAND BROWN (1966) was subsequently substituted by JELETZKY (1971a, p. 36) for the unwieldy name of Vancouver Island-Queen Charlotte Island Trough. Except for that nomenclatorial change, JELETZKY (1971a, p. 35, 36, figs. 5, 8, 9, 10, 11, 12, 13, 14) adhered to all basic ideas introduced by JELETZKY and TIPPER (1968).

Except for the Mid-Cretaceous rocks deposited in the Tyaughton and Insular troughs, only scant exposures of marine Mid-Albian [*Cleoniceras* (*Grycia*) *perezianum* Zone] rocks in the Whitesail area of northwestern British Columbia were known at the time of publication of JELETZKY and TIPPER's paper (1968, p. 56, fig. 9, table 2).

JELETZKY and TIPPER (l. cit.) were uncertain whether these rocks were deposited in an Albian embayment of the Tyaughton Trough or represented a scant erosional remnant of a third Mid-Cretaceous depositional basin. However, the presence of this depositional basin was made evident more recently by:

1. Discoveries of additional mid-Albian and entirely new Hauterivian and Barremian ammonites and other marine fossils by mapping geologists of the Geological Survey of Canada and others in the general Hazelton area (JELETZKY, 1976, p. 40 and unpublished intradepartmental fossil reports of the writer); and
2. The widespread occurrence of thick successions of nonmarine to marine Hauterivian to Barremian and Albian to ?early Late Cretaceous rocks in the Hazelton and Smithers map-areas of northwestern British Columbia (e. g. SUTHERLAND BROWN, 1960; TIPPER, 1972, p. 40; RICHARDS and DODDS, 1973, p. 39; RICHARDS, 1974, p. 36, geol. map; RICHARDS and O. L. JELETZKY, 1975, p. 34).

JELETZKY (1971a, p. 40) used the name Bowser Basin for this still very poorly known Mid-Cretaceous basin and this usage is maintained in this paper (Fig. 2). Although connected with the Tyaughton Trough, this Mid-Cretaceous generation of Bowser Basin was apparently separated from its northeastern end by a submeridionally oriented, elevated peninsular welt which was not flooded by Mid-Cretaceous seas (Fig. 2).

Mid-Albian *Cleoniceras* (*Grycia*) *perezianum* fauna (intradepartmental fossil report of the writer) was recently found by Dr. H. W. TIPPER in the previously undated, largely volcanic rocks in the Horseshoe Bay area on the eastern shore of Howe Sound (north of Vancouver). This discovery domonstrated the mid-Albian age of at least some part of the thick Gambier Group (RODDICK, 1965, p. 47-54, geol. map), which is widespread in this part of the Gulf of Georgia, and indicates the presence of a fourth, still very poorly understood Mid-Cretaceous depositional basin there. This depositional basin named herein the Georgia Basin (Fig. 2) is believed to represent either a synclinal structure or a downfaulted block. This negative structure was confined between the cordillera-like positive welt (a faulted anticlinorium) of Vancouver Island (JELETZKY, 1976, p. 125, 126) and the Albian generation of the Coast Mountain high. Neither the areal extent nor the duration of existence of the Mid-Cretaceous Georgia Basin are known so far. However, a tentative attempt to restore the extent and configuration of its mid-Albian generation is undertaken in Fig. 2 where the locations and presumed extents of the other three above discussed basins are also indicated.

All of the above discussed Mid-Cretaceous depositional basins are successor basins in the sense of KING (1966) and EISBACHER (1974, p. 274).

The above general description of the presently known Mid-Cretaceous depositional basins of the Pacific slope of Canada is illustrated by Figs. 1-3. These palaeogeographical maps reproduce the writer's current ideas about the extent of the above discussed depositional basins and the principal marine and nonmarine facies which existed in each of them in the Aptian (Fig. 1), Albian (Fig. 2), and Cenomanian-Turonian (Fig. 3) times. A detailed description of depositional-structural and palaeogeographical history of these depositional basins is beyond the scope of this paper. However, some of the most important aspects of this history shall be briefly com-

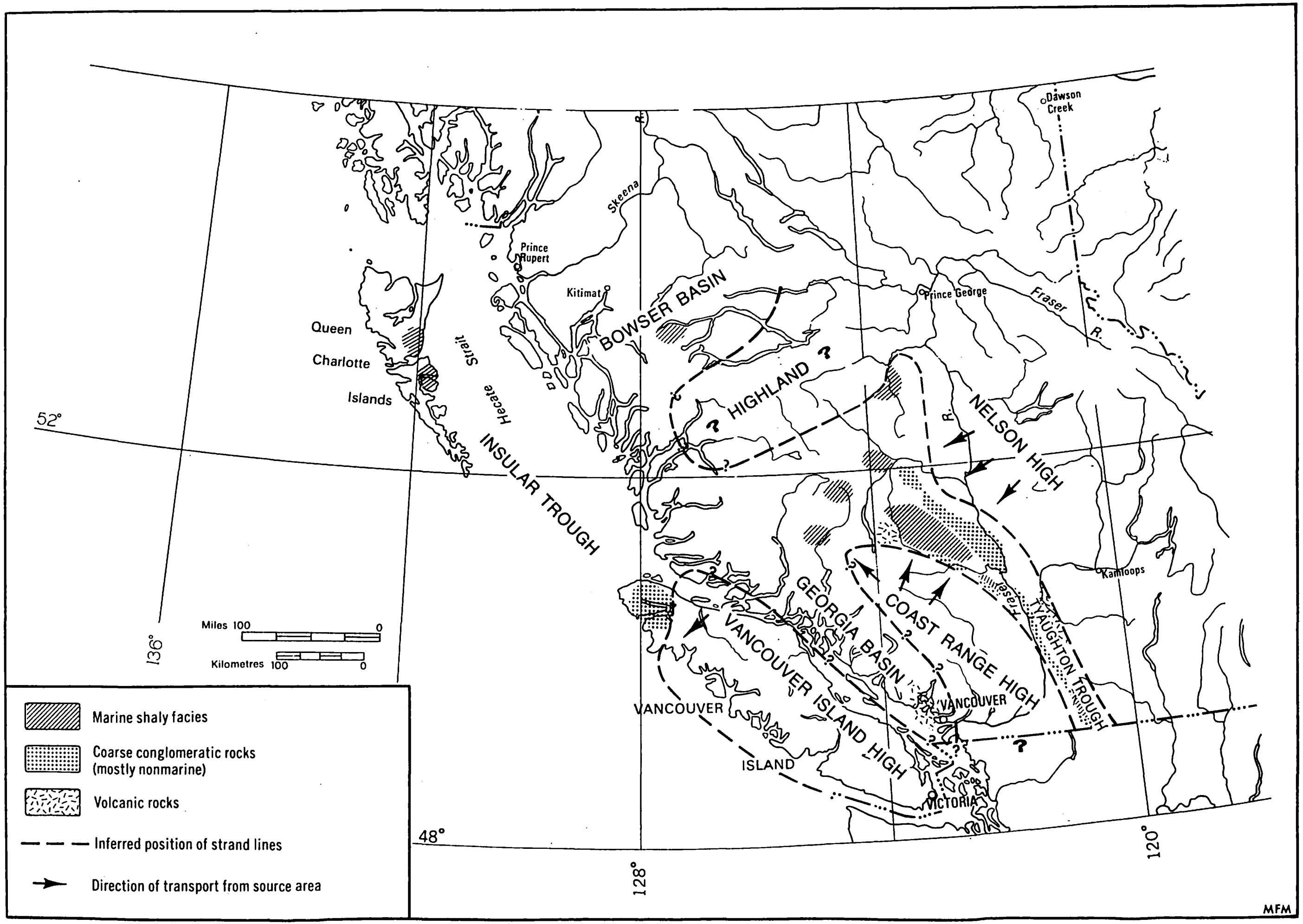

Fig. 2. Distribution of volcanic and sedimentary rocks of Albian age.

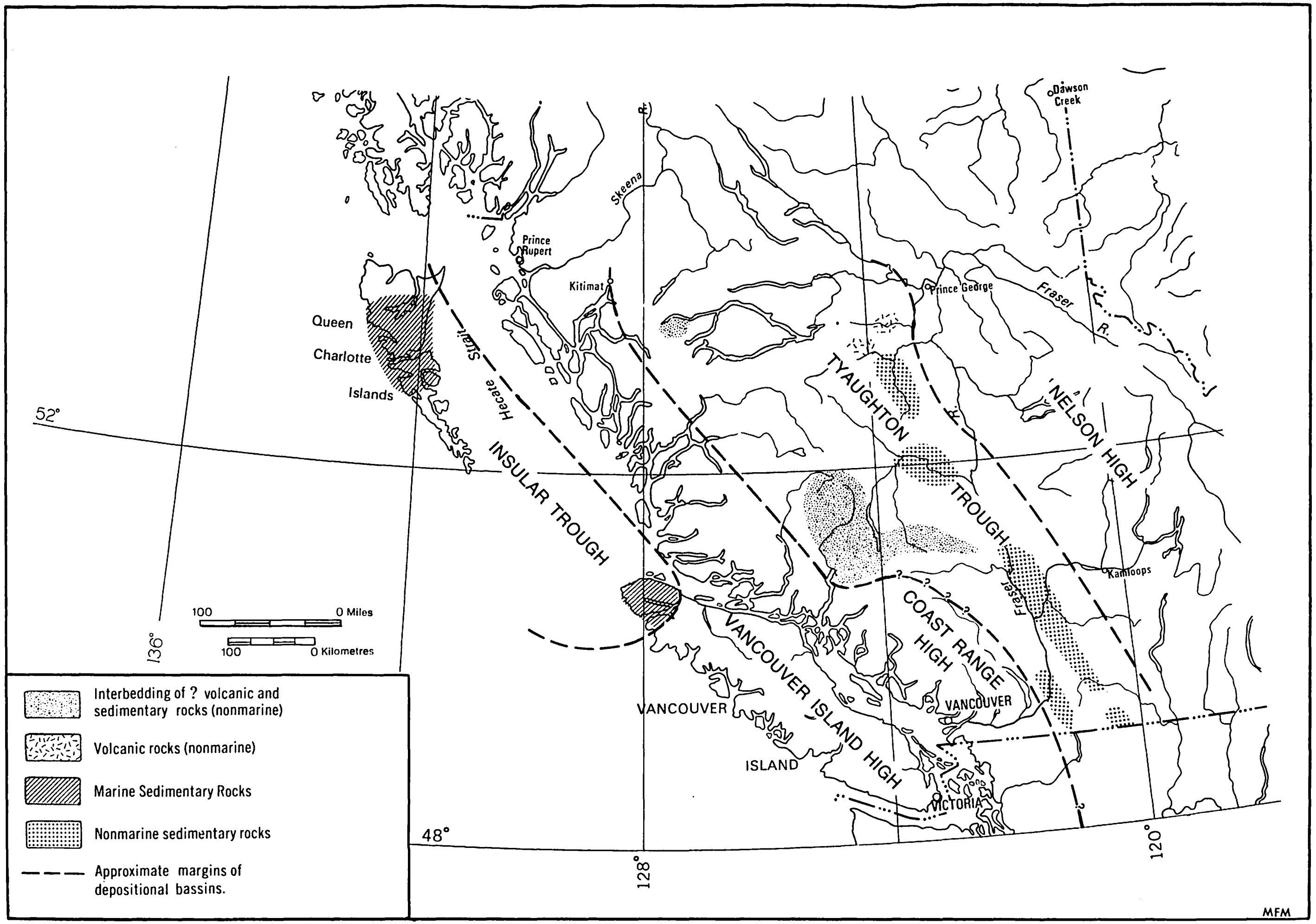

Fig. 3. Distribution of volcanic and sedimentary rocks of Cenomanian and Turonian age. (Read Marine sedimentary rocks for Marine Sedimentary Rocks.)

mented upon in the section dealing with the succession of Mid-Cretaceous zonal faunas and their correlation.

4. Succession of Zonal Faunas and their Correlation

A. Aptian faunas

Because of a strong regression caused by the Aptian interregional orogeny (JELETZKY and TIPPER, 1968, p. 88, 89; JELETZKY, 1971a, p. 41, fig. 8; this paper Fig. 1) the Aptian marine rocks are only known from and apparently were restricted to the central parts of the Tyaughton Trough extending from the Taseko Lakes map-area to Manning Park area. In the Insular Trough, these rocks were apparently represented either by a regional hiatus (e. g. in Queen Charlotte Islands; SUTHERLAND BROWN, 1968) or by the nonmarine coarse arenite unit (e. g. in the northern part of Vancouver Island; JELETZKY, 1976, p. 96-103, fig. 11). The apparently total absence of marine and nonmarine rocks of that stage in the Bowser and Georgia basins is also ascribed tentatively to their nondeposition there. However, our knowledge of Mid-Cretaceous geology of these basins is so poor that this conclusion may be subject to change in the future. Even within the known strongly restricted, outcrop-areas of marine Aptian rocks, only very few widely scattered occurrences of either definitively or only tentatively identified Aptian fossils are known. Most of these macro-invertebrates are too poorly preserved to be assigned to any specific Aptian zone and only indicate (or suggest) the presence of Aptian rocks in general. No definitive zoning or intercontinental correlation of most of these faunules is possible at present.

1) *Lower Aptian fauna(s)*.—Marine fossils indicative or suggestive of the early Aptian age of including rocks have so far only been found in the Manning Park and Pemberton areas of the Tyaughton Trough (JELETZKY, 1970b, p. 215, fig. 1; 1971b, p. 225).

In the western part of the Manning Park area (JELETZKY, 1970b, p. 221, fig. 1 and unpublished) the upper but not the uppermost beds of the Upper Barremian to Lower Albian siltstone unit had yielded poorly preserved macroinvertebrates of definite Aptian and almost certainly early Aptian affinities. The fauna includes: ? *Procheloniceras* sp. indet. (a solitary juvenile specimen found in the basal part of the beds concerned), *Eotetragonites* ex gr. *wintunius* (ANDERSON), ? *Toxoceratoides* n. sp. indet., *Aconeceras* sp. indet., a peculiar probably generically new ammonite resembling *Subpullchellia* and a small, densely and closely ribbed *Inoceramus* n. sp. aff. *neocomiensis* d'ORBIGNY.

This fauna occurs stratigraphically above beds containing rich, presumably latest Barremian ammonite fauna of the Upper greywacke member discussed by JELETZKY (1970b, p. 218, fig. 1) and lacks all of the characteristic Barremian elements of the latter. Therefore, and because of the presence of ? *Procheloniceras* sp. indet., it is dated tentatively as of a general early Aptian age and correlated even more tentatively with the *Prodeshayesites fissicostatus* Zone of the modern English standard (CASEY, 1961, p. 496, table 1; this paper Fig. 5).

Elements of this ? *Procheloniceras* sp. indet. fauna including *Eotetragonites* sp.

<table>
<tr><th colspan="2">BIOCHRONOLOGICAL UNITS</th><th colspan="2">Insular Trough</th><th rowspan="2">Georgia Basin</th><th rowspan="2">Tyaughton Trough</th><th rowspan="2">Bowser Basin</th></tr>
<tr><th>SERIES</th><th>STAGES</th><th>Queen Charlotte Islands</th><th>Vancouver Island</th></tr>
<tr><td rowspan="7">UPPER CRETACEOUS</td><td>CONIACIAN</td><td colspan="2">Unknown.</td><td rowspan="7">Unknown.
Presumed to be absent</td><td colspan="2">Unknown</td></tr>
<tr><td rowspan="3">TURONIAN</td><td colspan="2">Apparently absent by non deposition.</td><td colspan="2">Presumed to be absent</td></tr>
<tr><td>? ? Unfossiliferous shale ? ?</td><td>? ? *Romaniceras (Yubariceras)* sp.</td><td rowspan="5">? ? Represented by nonmarine volcanics and sediments of Kingsvale Group</td><td rowspan="5">Possibly represented by nonmarine sediments equivalent to Sustut Group</td></tr>
<tr><td>*Inoceramus labiatus*</td><td>Poorly fossiliferous marine shale</td></tr>
<tr><td rowspan="3">CENOMANIAN</td><td rowspan="3">*Pseudouhligella japonicum*, *Turrilites* sp.</td><td>*Inoceramus* aff. *I. incelebratus*</td></tr>
<tr><td>Poorly fossiliferous marine shale</td></tr>
<tr><td>*Sciponoceras* n.sp. ex aff. *kossmati*</td></tr>
<tr><td rowspan="7">LOWER CRETACEOUS</td><td rowspan="4">ALBIAN</td><td>*Pseudouhligella dawsoni*, *Mortoniceras* spp.</td><td rowspan="7">Represented by nonmarine molassoid rocks only</td><td>Unknown. Possibly present</td><td>*Mortoniceras* (s. lato) sp.</td><td>? ? Unknown. Possibly present</td></tr>
<tr><td>*Grycia perezianum*</td><td>*Grycia perezianum*</td><td>*Pseudouhligella* cf. *alamoense*</td><td>*Grycia perezianum*</td></tr>
<tr><td>*Brewericeras hulenense*, *Douvilleiceras* spp.</td><td rowspan="2">Unknown possibly present</td><td>*Brewericeras hulenense* *Douvilleiceras* spp.</td><td rowspan="2">Unknown. Possibly present</td></tr>
<tr><td>*Brewericeras lecontei*</td><td>*Breweiceras lecontei*</td></tr>
<tr><td rowspan="3">APTIAN</td><td rowspan="3">Unknown (nondeposition)</td><td rowspan="3">Unknown (? nondeposition)</td><td>*Acanthoplites reesidei*</td><td rowspan="3">Unknown (nondeposition)</td></tr>
<tr><td>No diagnostic fossils</td></tr>
<tr><td>*Prochelonicerass* sp., *Inoceramus* aff. *neocomiensis*</td></tr>
</table>

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Fig. 4. Succession and geographical occurrence of Mid-Cretaceous macroinvertebrate faunas on the Pacific slope of Canada. (See errata in p. 126.)

indet. and *Inoceramus* n. sp. aff. *neocomiensis* d'Orbigny were also found farther north in Tyaughton Trough. These fossils were found in Camelsfoot Range in the northeastern corner of Pemberton map-area (Jeletzky, 1971b, p. 225) in the uppermost part of the local Variegated clastic division. The fauna is also tentatively assigned an early Albian (i. e. *Prodeshayesites fissicostatus* Zone) in spite of the absence of *Procheloniceras*-like ammonites.

The above discussed ? *Procheloniceras* sp. indet. fauna of the Tyaughton Trough does not have any known equivalents anywhere else on the Pacific slope of North America. It could possibly correspond to the lower Subzone of "*Gabbioceras*" *wintunium* Zone of Northern California (Murphy, 1956, p. 2116, fig. 6; Popenoe *et al.* 1960, p. 1508-1509). This Subzone only contains long-ranging ammonites *Eotetragonites wintunius*, *Phylloceras onoense*, and *Lytoceras traski* and so cannot be dated closely. In particular, *Eotetragonites* ex gr. *wintunius* (Anderson) appear to range through the late (? latest only) Barremian to early late Aptian rocks in the Tyaughton Trough (Jeletzky, 1970, p. 218). However, the presence of *Australiceras argus* (Popenoe *et*

Biochronological units			Standard zones of Western Europe. A compilation of data from various sources cited in text and references	Paleontological zones and faunas of the Pacific Slope of Canada (this paper).	Paleontological zones and faunas of Japan. A compilation of data from various sources cited in the text and references of this paper.	Paleontological zones of California. Essentially a compilation of zonal standards of Murphy (1956) and Matsumoto (1960).
SERIES	INTERNATIONAL STAGES					
UPPER CRETACEOUS	CONIACIAN		No zoning attempted in this paper	Unknown presumably not deposited	No zoning attempted in this paper	No zoning attempted in this paper
	TURONIAN		*Subprionocyclus neptuni*			
			Prionocyclus (Selwynoceras) woollgari	*Romaniceras (Yubariceras)* sp. ?	*Prionocyclus (Selwynoceras) woollgari*	*Prionocyclus (Selwynoceras) woollgari* and *Romaniceras deverioide*
			Mammites nodosoides and *Inoceramus labiatus*	*Inoceramus labiatus*	*Fagesia thevestenensis, Mamites* sp., *Inoceramus labiatus*	*Plesiovascoceras californicum* and *Kanabiceras septemseriatum*
	CENOMANIAN		*Metoicoceras gourdoni* and *Metoicoceras geslinianum*	*Desmoceras (Pseudouhligella) japonicum* ?	*Kanabiceras septemseriatum* – *Pseudocalycoceras* aff. *P. dentonense*	
			Calycoceras naviculare	*Inoceramus* aff. *I. incelebratus*	*Calycoceras naviculare* – *Eucalycoceras pentagonum*	Unknown
			Acanthoplites rothomagense	?	*Euomphaloceras meridionale* – *Acanthoceras takahashii*	?
			Mantelliceras mantelli, Mantelliceras saxbii, etc.	*Sciponoceras* n. sp. ex. aff. *S. kossmati, Eogaudriceras* aff. *unicum*	*Mantelliceras japonicum* – *Sharpeiceras kongo* *Graysonites wooldridgei* *Euhistrichoceras nicasei*	*Mantelliceras* spp. *Graysonites wooldridgei*
LOWER CRETACEOUS	ALBIAN	UPPER	*Stoliczkaia dispar*	*Mortoniceras* spp. and *Desmoceras (Pseudouhligella) dawsoni*	*Mortoniceras (Durnovarites)* sp., *Mortoniceras (Deiradoceras)* sp., *Desmoceras (Pseudouhligella) dawsoni shikokuense*	*Mortoniceras (Durnovarites)* sp.
			Mortoniceras inflatum			*Mortoniceras hulenanum* *Mortoniceras kiliani*
		MIDDLE	*Euhoplites lautus*	*Cleoniceras (Grycia) perezianum*	*Dipoloceras* cf. *fredericsburgense*	*Oxytropidoceras packardi*
			Euhoplites loricatus		*Oxytropidoceras* sp. and *Hoplites* aff. *dentatus*	
			Hoplites dentatus			
		LOWER	*Douvilleiceras mammillatum*	*Brewericeras hulenense* *Douvilleiceras spiniferum*	*Douvilleiceras mammillatum*	*Brewericeras hulenense* and *Douvilleiceras* spp.
			Leymeriella tardefurcata	*Brewericeras lecontei*	Unknown	*Brewericeras lecontei*
	APTIAN	UPPER	*Hypacanthoplites jacobi*	*Acanthoplites reesidei* Unknown	*Diadochoceras nodosicostatiforme*	*Acanthoplites reesidei* *Acanthoplites gardneri*
			Parahoplites nutfieldiensis		*Parahoplites yaegashii* and *Cheloniceras subcornuelianum*	*Eogaudriceras wintunium* *Gabbioceras angulatum* *Colombiceras cerrosensis*
			Cheloniceras martinoides	? *Ammonitoceras* sp.		
		LOWER	*Tropaeum bowerbanki*	Unknown	Unknown	*Gabbioceras* sp., *Australiceras argus*
			Deshayesites deshayesi			
			Deshayesites forbesi			
			Prodeshayesites fissicostatus	?*Procheloniceras* sp. indet. *Inoceramus* n. sp. aff. *neocomiensis*		?

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Fig. 5. Correlation of Mid-Cretaceous macroinvertebrate faunas of the Pacific slope of Canada with the West European standard stages and zones, and zones of Japan and California. (See errata in p. 126.)

al., 1960, p. 1508) and *Australiceras percostatum* (unpublished results of a re-study of the holotype and other material of "*Tropaeum*" *percostatum* (GABB) by the writer) in the next younger middle part of "*Gabbioceras*" *wintunium* Zone suggests an either largely or entirely early Aptian age of the lower Subzone. As pointed out by CASEY (1961-1966, II, p. 45), *Australiceras argus* ANDERSON 1938 is a late Aptian form because of its association with *Colombiceras* of the type of *C. treffryanus* (KARSTEN). However, the equivalents of the Canadian beds with ? *Procheloniceras* sp. indet. could also be represented in northern California by the uppermost beds of the *Shasticrioceras poniente* Zone which contains a generically uncertain representative of Cheloniceratinae (MURPHY, 1975, p. 11-13, fig. 4; pl. 11, figs. 3, 4, 6).

2) *Upper Aptian faunas.*—The only reliably dated upper Aptian marine fauna on the Pacific slope of Canada is the *Acanthoplites reesidei* ANDERSON fauna (*see* Pl. 3, Figs. 1a-c) found by TIPPER (1969, p. 61) in the westernmost part of Taseko Lake map-area and assigned a late Aptian age by JELETZKY (1971a, p. 8, 24, fig. 2). This

fauna was found in poorly known sequence of rocks apparently representing the lower part of Tailor Creek Group. Well preserved ammonites of this fauna permit its confident correlation with the *Acanthoplites reesidei* Zone of northern California (MURPHY, 1956, p. 2117; POPENOE *et al.*, 1960, p. 1508). This North Californian zone, which was not previously known to occur anywhere else in the North Pacific biotic province to the best knowledge of the writer, was always placed at the top of the Aptian stage by American workers (e. g. MURPHY, 1956, p. 2117; POPENOE *et al.*, 1960, p. 1509). The Zones of *Acanthoplites gardneri* and *A. reesidei* combined have been believed to: "occupy the position of the European *Diadochoceras nodosocostatum* Zone and the lower part of the *Leymeriella tardefurcata* Zone" by POPENOE *et al.* (1960, p. 1509). However, in the writer's opinion, *Acanthoplites reesidei* Zone corresponds only to the *Diadochoceras nodosocostatum* Zone as defined by WRIGHT (*in* ARKELL *et al.*, 1957, p. 1128, table 4) because of the presence of *Wollemaniceras* in the next younger *Brewericeras lecontei* Zone (*see* p. 108-109). This South European zone corresponds approximately to the *Hypacanthoplites jacobi* Zone of the modern English and North European Standard (CASEY, 1961, p. 498, table 1). These two European zones are the topmost Aptian zones now when the Clansayan horizon is uniformly placed into that stage in the wake of BREISTROFFER's (1947) comparative analysis of Albian ammonite zones in England and France.

The exact generic nature of ancyloceratids from the Upper Barremian to Lower Aptian siltstone unit of the Manning Park area identified as *Ammonitoceras* sp. indet. by JELETZKY (1970b, p. 221, fig. 1) was subsequently queried (JELETZKY, 1971a, p. 24, table 5). However, it should be noted that these ? *Ammonitoceras* sp. indet. were not found in that particular section where ? *Procheloniceras*, sp. indet. and *Eotetragonites* ex gr. *wintunium* (GABB) were found. Nor were any representatives of these early Aptian ammonites or those of *Inoceramus* n. sp. aff. *neocomiensis* d'ORBIGNY found in association with the ? *Ammonitoceras* sp. indet. Therefore, it is possible but far from proven that the ? *Ammonitoceras* sp. indet. represent a younger, already early late Aptian fauna correlative with the Martinoides Zone of the English standard (CASEY, 1961, p. 498, 601, 608, table 1).

3) *Possible Aptian faunas.*—As already noted by JELETZKY and TIPPER (1968, p. 54), the presence of a solitary representative of *Aconeceras* sp. indet. in the basal conglomerate of the Taylor Creek Group in Taseko Lakes map-area does not prove the Aptian age of this unit as the genus *Aconeceras* does range into the upper Barremian and lower Aptian rocks. However, this find is suggestive of its Aptian age, especially as the somewhat younger beds in the lower part of Taylor Creek Group in the same general area yielded diagnostic latest Aptian *Acanthoplites reesidei* ANDERSON.

B. Albian faunas

Unlike the Aptian rocks, the marine Albian rocks of the Pacific slope of Canada contain a sequence of widespread ammonite faunas. This permits a regional subdivision of our Albian rocks into four well defined palaeontological zones (JELETZKY, 1971a, p. 8, fig. 2; MCLEARN, 1972, p. 16-19; this paper Figs. 4-5) most of which are also recognizable elsewhere on the Pacific slope of North America. The upward sequence is the following:

1) *Brewericeras lecontei Zone.*—The oldest Albian fauna known on the Pacific slope of Canada is that characterized by an ubiquitous presence of *Brewericeras* (= *Leconteites* CASEY 1954) *lecontei* (ANDERSON, 1938) (Fig. 4). The rocks characterized by this fauna were originally designated as *Leconteites lecontei* Zone by MURPHY (1956, p. 2118) in northern California. In Canada no diagnostic ammonites other than the name species and its variant *deansi* (WHITEAVES) are known from this zone and the accompanying ammonite fauna is restricted to some long-ranging, commonly only generically determinable phylloceratids and lytoceratids (e. g. JONES *et al.*, 1965, p. F7). However, much richer ammonite faunas of *Brewericeras lecontei* Zone are known from California (MURPHY 1956; JONES *et al.*, 1965, p. F4) and southeastern Alaska (IMLAY, 1960, JONES *et al.*, 1965, p. F7; JONES, 1967, p. 3).

The almost invariably depauperate pelecypod fauna of the Canadian outcrop-areas of the *Brewericeras lecontei* Zone mostly consists only of the depth-tolerant *Aucellina* ex gr. *gryphaeoides* (SOWERBY). However, *Inoceramus* ex gr. *anglicus* WOODS occurs locally in this zone. This reflects the mostly deep water (mostly or entirely bathyal turbidites; JELETZKY, *in* MONGER *et al.*, 1972, p. 61, 62) of this zone on the Pacific slope of Canada.

Brewericeras lecontei fauna is widespread along the Pacific slope of North America from California to southeastern Alaska (e. g. ANDERSON, 1938; MURPHY, 1956; IMLAY, 1960; JONES *et al.*, 1965; JONES, 1967; JELETZKY and TIPPER, 1968; JELETZKY, 1970; MCLEARN, 1972). However, on the Pacific slope of Canada this fauna is only known from the Beresford Bay area and questionably from the Skidegate Inlet area of Queen Charlotte Islands in the Insular Trough (JONES *et al.*, 1965, p. F6) and from a number of localities in Tyaughton Trough (JELETZKY, 1968, p. 104; 1970b, p. 218; 1971b, p. 224; COATES, 1974, p. 42 and in the list of fossil localities). This appears to reflect a rather limited scope of the earliest Albian transgression on the Pacific slope of Canada (JELETZKY, 1971a, p. 42, 43 and Fig. 4 of this paper).

Except for the northernmost part of its known geographical range (i. e. in Queen Charlotte Islands and southeastern Alaska; IMLAY, 1960; JONES *et al.*, 1965; JONES, 1967, 1973, p. 11, fig. 9), the provincial North Pacific *Brewericeras lecontei* fauna (JELETZKY, 1971a, p. 11, fig. 2) does not contain any diagnostic fossils which would permit its direct correlation with standard European zones of the Albian stage. However, in southeastern Alaska *Brewericeras lecontei* occurs in association with *Wollemaniceras alaskanum* and *Moffitites robustum* in the local zone named after the latter ammonite. Furthermore, this southeastern Alaskan zone occurs immediately below the zone of *Brewericeras hulenense* which in that area contains *Arcthoplites* spp. of the North Canadian and the European Arctic affinities, *Douvilleiceras mammillatum* (SCHLOTHEIM) and *Beudanticeras* (*Grantziceras*) *affine* (JONES *et al.*, 1965, p. F7, F8; JONES, 1967, p. 3-4). Similar stratigraphic relationships have been inferred for the *Brewericeras lecontei* Zone of Queen Charlotte Islands by JONES *et al.* (1965, p. F6, fig. 4). The admixture of above mentioned Boreal forms of the early lower Albian affinities (JELETZKY, 1968, 1975b, p. 241, fig. 3) and the stratigraphic position immediately underneath the late lower Albian *Brewericeras hulenense* Zone (*see* below) indicate an early lower Albian age of the *Brewericeras lecontei* Zone and its either partial (?upper part only) or approximate correspondence with the *Leymeriella tardefurcata* Zone of the European standard (Fig. 5). The presence of rare *Douvilleiceras* in the Californian sections of the *Brewericeras lecontei* Zone was interpreted as suggestive of its correlation with the upper part *Leymeriella tardefurcata* Zone only as *Douvilleiceras* makes its first appearance in that part of *Leymeriella tardefurcata* Zone (POPENOE *et al.*, 1960, p. 1509). However, the writer proposes tentatively an approximate correspondence of *Brewericeras lecontei* Zone with the whole of the European *Leymeriella tardefurcata* Zone because of the already mentioned presence of *Wollemaniceras* in the former zone in southeastern Alaska (IMLAY, 1960; JONES, 1967).

2) *Brewericeras hulenense Zone.*—So far as known, the zone of *Brewericeras lecontei* is immediately overlain by the *Brewericeras hulenense* Zone everywhere on the Pacific slope of Canada. The *Brewericeras hulenense* Zone is characterized by an almost ubiquitous presence of its name species on the Pacific slope of Canada, just as it does everywhere else on the Pacific slope of North America (MURPHY, 1956; POPENOE *et al.*, 1960, p. 1509; JONES *et al.*, 1965, p. F3–F9). The rocks characterized by the presence of *Brewericeras hulenense* fauna were originally designated as the *Brewericeras hulenense* Zone by MURPHY (1956, fig. 6, p. 2118) in northern California.

In Canada, the *Brewericeras hulenense* Zone commonly includes an abundant and variegated ammonite and other macroinvertebrate fauna. This fauna is best known from the Skidegate Island outcrop-area, the ammonites of which have been recently monographed by MCLEARN (1972). However, the pelecypods and other macroinvertebrates of *Brewericeras hulenense* Zone were not studied in Canada since the publication of Vol. I of the "Mesozoic Fossils of Canada" by WHITEAVES (1876). As pointed out by MCLEARN (1972, p. 16), the following short-ranging ammonite species appear to be diagnostic of *Brewericeras hulenense* Zone in addition to its name species: *Calliphylloceras* aff. *nizinianum* IMLAY ?, *Anagaudryceras fillicinctum* (WHITEAVES), *Parasilesites laperousianus* (WHITEAVES), *Douvilleiceras spiniferum* (WHITEAVES), *Douvilleiceras* sp. A, *Douvilleiceras* sp., and *Anahoplites yakounensis* (WHITEAVES). Only a few of these auxiliary ammonite indices, such as *Anahoplites yakounensis* and *Douvilleiceras* spp., have ever been found on the mainland of British Columbia (i. e. in the Tyaughton Trough) where the *Brewericeras hulenense* fauna mostly contains but a few forms other than the name species (e. g. JELETZKY and TIPPER, 1968, p. 54, 188, 209, 211, 216, table 2; JELETZKY, 1970b, p. 219). This probably reflects a considerably deeper water facies of *Brewericeras hulenense* Zone in the Tyaughton Trough (outer neritic to bathyal argillaceous rocks) than in the Skidegate Inlet area (inner neritic to littoral sandstone).

Like the *Brewericeras lecontei* fauna, the *Brewericeras hulenense* fauna is only known from the Queen Charlotte Islands in the Insular Trough (SUTHERAND Brown, 1968; MCLEARN, 1972, p. 16) and from a number of localities in the Tyaughton Trough (e. g. JELETZKY and TIPPER, 1968, p. 56, table 2, etc.; JELETZKY, 1970b, p. 219; COATES, 1974, this paper Figs. 2, 4). JELETZKY's (1971a, p. 44) previous opinion about a considerably more widespread occurrence of the *Brewericeras hulenense* sea as compared with the *Brewericeras lecontei* sea appears to be incorrect. As pointed out above (p. 104) this restriction of the late early Albian sea apparently was caused by the occurrence of a strong regression on the mainland of western British Columbia and in the greater southern part (i. e. throughout the Vancouver Island) of the Insular Trough.

The common presence of *Douvilleiceras spiniferum* (WHITEAVES) and other *Douvilleiceras* forms, including *D. mammillatum* (SCHLOTHEIM) and *D.* cf. *mammillatum* (SCHLOTHEIM) (e. g. ANDERSON, 1938; MURPHY, 1956, p. 2118; POPENOE *et al.*, 1960, p. 1509; JONES *et al.*, 1965, p. F4-F8; JONES, 1967, p. 3, 4; MCLEARN, 1972, p. 16, 20) indicates an approximate correlation of the *Brewericeras hulenense* Zone with the broadly interpreted (SPATH, 1923, 1943; BREISTROFFER, 1947), late lower Albian (early middle according to SPATH, 1923, p. 73; *see* JELETZKY, 1975b, p. 241 for further details) *Douvilleiceras mammillatum* Zone of the European standard (Fig. 5). However, the North Pacific zone apparently extends upward into the basal middle Albian in the sense of CASEY (1961, p. 498, table 1) and OWEN (1971, p. 118; 1973, p. 147, fig. 1) as these workers restrict *Douvilleiceras mammillatum* Zone to the lower half (i. e. *monile* Subzone) of the *mammillatum* Zone of SPATH (1923, p. 73; 1943, p. 707, table 3) and place its upper part into the middle Albian. This new interpretation of the lower-middle Albian boundary may be advantageous in northwestern Europe and elsewhere within the Hoplitinid province (OWEN, 1973, p. 147-149, fig. 1). However, the traditional interpretation (SPATH, 1923, p. 73; BREISTROFFER, 1947) makes much more sense in western North America and elsewhere on the intercontinental scale because of a widespread interprovincial and intercontinental occurrence of the genus *Douvilleiceras* which is one of the most important Albian index fossils. Therefore it is retained in this paper (Fig. 5).

Like the underlying *Brewericeras lecontei* Zone, the *Brewericeras hulenense* Zone is a regional North Pacific zone (JELETZKY, 1971a, p. 11, fig. 2) widespread along the Pacific slope of North America from California to southeastern Alaska (e. g. ANDERSON, 1938; MURPHY, 1956; IMLAY, 1960; JONES *et al.*, 1965; JONES, 1967; JELETZKY. 1970b; 1971a; JELETZKY and TIPPER, 1968; MCLEARN, 1972). Except in the northernmost part of that region, its ammonite fauna has pronounced Indo-Pacific (e. g. the abundance of phylloceratids, lytoceratids and various desmoceratids; *see* JELETZKY, 1971a, p. 11, 25, 26, table 6) and European (e. g. the presence of *Douvilleiceras* and *Anahoplites*) affinities. However, in the northernmost part of its known West American range (i. e. in Queen Charlotte Islands and southeastern Alaska; *see* IMLAY, 1960; JONES *et al.*, 1965; JONES, 1967, 1973, p. 16, fig. 9) *Brewericeras hulenense* fauna includes such North American Boreal forms as *Beudanticeras* (*Grantziceras*) *affine*, numerous *Arcthoplites* of the Canadian and North Alaskan affinities, and some fairly typical *Cleoniceras* s. str. (e. g. *C. overbecki* IMLAY, 1960). This intermingling of the North Pacific and North American Boreal forms permits an approximate correlation of the *Brewericeras hulenense* Zone with the generalized *Arcthoplites* Zone of the North American Arctic and the Western Interior of Canada as recently re-defined by JELETZKY (1975b, p. 241, 242, fig. 3). This conclusion is confirmed by the association of *Arcthoplites jachromensis* and *Brewericeras* cf. *hulenense* at one of the localities which yielded *Arcthoplites* fauna in Spitzbergen (NAGY, 1970, p. 21). This occurrence is, furthermore, important in confirming the conclusion about the exclusively late early Albian age of the *Brewericeras hulenense* Zone made earlier in this paper.

Namely, NAGY (1970, p. 21) considers the *Arcthoplites* fauna on Spitzbergen: "to be of Lower Albian age, because the five localities where this fauna occurs are situated considerably lower in the rock sequence than those localities which contain *Otohoplites* or *Hoplites* (See pls. 11-12). Both *Otohoplites* and *Hoplites* are well-known from southern England., where they occur in the upper part of the Lower Albian and in the lower part of the Middle Albian respectively."

3) *Cleoniceras* (*Grycia*) *perezianum Zone.*—As indicated by detailed stratigraphical research of McLEARN (1972, p. 6-17) in the Skidegate Inlet area, Queen Charlotte Islands, the zone of *Brewericeras hulenense* is immediately followed by the regional *Cleoniceras* (*Grycia*) *perezianum* Zone. As pointed out by McLEARN (1972, p. 16) *Brewericeras hulenense* may even extend up into the *Cleoniceras* (*Grycia*) *perezianum* Zone, locally, even though this may only reflect a mixing up of the old 1921 collections. The name species was only questionably assigned to *Grycia* by McLEARN (1972, p. 61, 62). However, the writer is satisfied that it does belong to this Boreal North American subgenus of *Cleoniceras.*

Cleoniceras (*Grycia*) *perezianum* Zone was originally proposed in the posthumous manuscript of Dr. F.H. McLEARN. However, this manuscript was available to JELETZKY who utilized and published this zone (JELETZKY, *in* JELETZKY and TIPPER, 1968; p. 54, table 2; JELETZKY, 1971a, p. 8, fig. 2) prior to the actual publication of the manuscript (McLEARN, 1972, p. 17).

Although *Cleoniceras* (*Grycia*) *perezianum* Zone is richly fossiliferous in the Skidegate Inlet area where it is represented by inner neritic to littoral sandstones (SUTHERLAND BROWN, 1968, p. 89) most of its ammonite and other species range upward and downward into the adjacent Albian zones. According to McLEARN (1972, p. 17) only *Desmoceras* (*Pseudouhligella*) cf. *alamoense* ANDERSON (*see* JELETZKY's comments on p. 6 and 48 of McLEARN's, 1972 paper for reasens why this name is continued to be used by the writer). Another biochronologically important feature of *Cleoniceras* (*Grycia*) *perezianum* Zone is the apparent absence of so far as known exclusively late Albian radially ribbed *Inoceramus* ex gr. *sulcatus* PARKINSON-*subsulcatus* WILTSHIRE in it. In contrast, the *Aucellina* ex gr. *gryphaeoides* SOWERBY do not seem to range up into the *Cleoniceras* (*Grycia*) *perezianum* Zone on the Pacific slope of Canada at least.

Unlike the underlying early Albian zones, the *Cleoniceras* (*Grycia*) *perezianum* Zone is a regional zone within the North Pacific Province. On the Pacific slope of North America it is all but unknown outside of western British Columbia, the recent record (JONES, 1973, p. 10) of: "one fragment that may be *Cleoniceras perezianum* (WHITEAVES)" in southeastern Alaska being the only exception known to the writer. However, in western British Columbia *Cleoniceras* (*Grycia*) *perezianum* Zone is much more widespread than any other Albian zone. In addition to the Queen Charlotte Islands' part of the Insular Trough (SUTHERLAND BROWN, 1968, p. 89, 90, 93; McLEARN, 1972, p. 7-17; JELETZKY, 1970a, p. 650, table XI-8), this zone is recorded from the Tyaughton Trough and Bowser Basin (JELETZKY and TIPPER, 1968, p. 54, 56, table 2 and unpublished intradepartmental fossil reports of the writer). Furthermore, *Cleoniceras* (*Grycia*) *perezianum* Zone is the only Albian zone known to be present in the Georgia Basin (p. 101 and unpublished intradepartmental fossil report of the writer).

Judging by the fossil records, the zone is widespread in the southern part of the Bowser Basin. Its rocks are assumed to be equally widespread in the Tyaughton Trough because of an apparent absence of any regional disconformities within the Taylor Creek and Jackass Mountain Groups there. However, only one record of *Desmoceras* (*Pseudouhligella*) cf. *alamoense* (JELETZKY and TIPPER, 1968, p. 55, 56, 199, table 2) supports this conclusion. This almost complete absence of diagnostic fossils in these apparent equivalents of *Cleoniceras* (*Grycia*) *perezianum* Zone may possibly reflect its largely or entirely bathyal character in the hitherto studied parts of the Tyaughton Trough. The uniquely wide extent of *Cleoniceras* (*Grycia*) *perezianum* Zone in western British Columbia (Figs. 2, 4) appears to reflect the occurrnce of a strong mid-Albian transgression on the mainland of the Canadian part of the Pacific slope of North America. However, this zone appears to be invariably restricted to the middle parts of thick, otherwise unfossilifeorus sequences of sedimentary and/or volcanic rocks in the Bowser and Georgia basins (e. g. DUFFELL, 1959, p. 66, 67 and personal communications of Dr. H.W. TIPPER). These overlying and underlying, so far unfossiliferous but at least partly marine rocks may correspond to the late and early Albian rocks of the Insular and Tyaughton troughs.

The *Cleoniceras* (*Grycia*) *perezianum* Zone of western Britsh Columbia does not contain any diagnostic fossils which would permit its direct correlation with either the American part of the Pacific slope of North America or with any of the palaeobiotic provinces of Europe (MCLEARN, 1972, p. 19, 20). As already pointed out by the writer (*in* MCLEARN, 1972, p. 6, 7, 48) the presence of *Desmoceras* (*Pseudouhligella*) tentatively compared with *D.* (*P.*) *alamoense* (ANDERSON) in the *Cleoniceras* (*Grycia*) *perezianum* Zone cannot be used for the purpose of its correlation with the Californian zonal sequence as this form is quite evidently neither conspecific nor geologically contemporary with the true *D.* (*P.*) *alamoense.* However, because of the stratigraphic position between the late lower Albian (i. e. *sensu* BREISTROFFER, 1947 *non* CASEY, 1961), *Brewericeras hulenense* Zone and the early late Albian (*sensu* SPATH, 1923, p. 73; 1943, p. 671-673, *non* BREISTROFFER, 1947; OWEN, 1971, p. 10, 118, table 1; 1973, p. 147, 148, fig. 1) *Mortoniceras* spp. and *Desmoceras* (*Pseudouhligella*) *dawsoni* Zone (Figs. 4, 5), *Cleoniceras* (*Grycia*) *perezianum* Zone must either roughly or at least partly (*see* below) correspond to the middle Albian *Hoplites dentatus* (exclusive of *Hoplites eodentatus* Subzone), *Euhoplites loricatus*, and *Euhoplites lautus* (inclusive of *Dipoloceras cristatum* Subzone) Zones of the Westeuropean standard (SPATH, 1923, p. 73; OWEN, 1971, p. 10, table 1, 2). In the American part of the Pacific slope of North America, this regional Canadian zone must correspond either approximately or at least partly (*see* below) to the *Oxytropidoceras packardi* Zone (e. g. MURPHY, 1956, p. 2119, fig. 6; POPENOE *et al.* 1960, p. 1509) which occupies a similar stratigraphic position in northern California. Because of the presence of a solitary ammonite fragment comparable with *Cleoniceras* (*Grycia*) *perezianum* in southern Alaska (JONES, 1973, p. 10), the Canadian zone is probably present but almost unfossiliferous in that region of the North Pacific biotic province.

The problem of correlation of *Cleoniceras* (*Grycia*) *perezianum* Zone with the rocks and faunas of the North American Boreal Province (or Gastroplitidan Faunal Province; OWEN, 1973, p. 149, fig. 1) traditionally placed into the middle Albian is too involved to be discussed in detail in this paper. However, it should be mentioned that the customary correlation of the generalized *Gastroplites* Zone with the *Dipoloceras cristatum* Subzone of the European standard (e. g. OWEN, 1973, p. 146, fig. 1) is now invalidated by the results of the writer's (JELETZKY in preparation) recent restudy of the holotype and the only known English representative of "*Gastroplites*" *cantianus* SPATH 1937. The writer feels confident that this specimen is not congeneric with the *Gastroplites* MCLEARN 1930 from the Western Interior of Canada. This finding necessitates complete re-evaluation of current ideas about the correlation of the Canadian *Gastroplites* and *Neogastroplites* Zones with the Albian substages and zones of the European and North Pacific biotic provinces.

Concerning the origin of *Cleoniceras* (*Grycia*) *perezianum*, the writer believes it to be a migrant from the North American Boreal Province (JELETZKY, 1971a, p. 13, 25, 26) where the apparently endemic cleoniceratid subgenus *Grycia* is now known to be widespread and to range at least from the late lower (*Arcthoplites* spp. Zone) to the ?latest middle or early upper (i. e. lowermost part of the *Gastroplites* Zone) Albian.

4) *Mortoniceras-Desmoceras* (*Pseudouhligella*) *dawsoni Zone.*—The latest Albian zone known on the Pacific slope of Canada is characterized by the association of several *Mortoniceras* species with *Desmoceras* (*Pseudouhligella*) *dawsoni* (WHITEAVES). This zone was originally proposed by the late Dr. F. H. MCLEARN in a posthumous manuscript for the Skidegate Inlet area, Queen Charlotte Islands. However, like the *Cleoniceras* (*Grycia*) *perezianum* Zone, it was published by JELETZKY and TIPPER (1968, p. 54, table 2) prior to the publication of this manuscript (MCLEARN, 1972, p. 18, 19).

Like the underlying *Cleoniceras* (*Grycia*) *perezianum* and older Albian zones, the *Mortoniceras-Desmoceras* (*Pseudouhligella*) *dawsoni* Zone is richly fossiliferous in its only known section (MCLEARN, 1972, p. 18) in the Skidegate Inlet area where it is represented by inner neritic to littoral sandstones (SUTHERLAND BROWN, 1968, p. 88). In this section, where the vertical distribution of the Albian ammonite faunas was studied by MCLEARN (1972, p. 8-16, 18, 19) in considerable detail, the following commonly present species appear to be diagnostic of the zone: *Pseudhelicoceras carlottense* (WHITEAVES), *Puzosia skidegatensis* MCLEARN 1972, *Desmoceras* (*Pseudouhligella*) *dawsoni* (WHITEAVES), *Mortoniceras* (*Deiradoceras*) sp. a, *Mortoniceras* (*Deiradoceras*) sp. b, *Mortoniceras* (*Styphloceras*) *downii* MCLEARN 1972. Also diagnostic but of rare occurrence are: *Ptychoceras* (*Diptychoceras*) *glaber* (WHITEAVES), *Mariella* sp., and *Kossmaticeras canadense* MCLEARN 1972. Yet another diagnostic feature of the zone is the common presence of *Inoceramus* ex gr. *sulcatus* PARKINSON-*subsulcatus* WILTSHIRE, which are not known in the underlying Albian rocks either in western British Columbia or in southeastern Alaska (JONES, 1973, p. 10).

According to MCLEARN (1972, p. 17, 18) it is not certain whether or not the *Mortoniceras-Desmoceras* (*Pseudouhligella*) *dawsoni* Zone immediately overlies the mid-Albian *Cleoniceras* (*Grycia*) *perezianum* Zone. The stratigraphic relationships of this late Albian zone with the underlying rocks also are obscure elsewhere on the Pacific Slope of Canada. The same appears, finally, to be true of the stratigraphic relationships of the equivalent *Mortoniceras hulenanum* Zone with the next older *Oxytropidoceras packardi* Zone in northern California (MURPHY, 1956, p. 2104, fig. 3). However, the immediate superposition of the zones concerned appears to be likely and is favoured by the writer (Figs. 4, 5).

As already pointed out by JELETZKY (1971a, p. 45), the fossiliferous rocks of the *Mortoniceras-Desmoceras* (*Pseudouhligella*) *dawsoni* Zone are rare in the Canadian Western Cordillera. In the Insular Trough they are only known in the Bearskin Bay section of Skidegate Inlet area (SUTHERLAND BROWN, 1968, p. 68; MCLEARN, 1972, p. 18). On the mainland of British Columbia they are only known in the Tyaughton Trough in the eastern part of the Taseko Lakes map-area (JELETZKY and TIPPER, 1968, p. 56, 57, 214; table 2 and unpublished finds of *Mortoniceras* (s. lato) sp. indet. on the float on the upper slopes of Relay Mountain) and in the Manning Park area (JELETZKY and TIPPER, 1968, p. 56, table 2; COATES, 1974, p. 42). This may reflect a strong regional regression which uplifted the Bowser and Georgia basins above sea level and severely restricted the marine areas within the Insular and Tyaughton troughs. However, as already noted by JELETZKY (1971a, p. 45): "there is ample room for this late Albian zone in most predominantly argillaceous Albian sections of the region stratigraphically above the highest occurrence of early or middle Albian marine fossils. This circumstance and the far-reaching similarity of the lithofacies throughout the Albian sections of the Tyaughton and Insular troughs suggests that the extent of the North Pacific late Albian sea in the Canadian Western Cordillera was similar to that of the late lower and middle Albian seas (figs. 9, 10)."

The so far exclusively argillaceous, presumably outermost neritic to bathyal facies of the rocks of *Mortoniceras-Desmoceras* (*Pseudouhligella*) *dawsoni* Zone in the Tyaughton Trough appears to be responsible for their almost unfossiliferous character. This is in contrast with the richly fossiliferous character of the same zone in the Insular Trough (i. e. Skidegate Inlet).

As pointed out by MCLEARN (1972, p. 20) the *Mortoniceras-Desmoceras* (*Pseudouhligella*) *dawsoni* Zone is correlative with the *Mortoniceras hulenanum* Zone of northern California (MURPHY, 1956, p. 2119, fig. 6) in spite of the absence of this species in Canada. Apart from the presence of the genus *Mortoniceras* in the two areas, this is indicated by the association of *Mortoniceras* with *Desmoceras* (*Pseudouhligella*) *dawsoni* and *Pseudhelicoceras petersoni* in northern California (MATSUMOTO, 1960, p. 24; POPENOE *et al.*, 1960, p. 1510).

In southeastern Alaska the presence of the Canadian *Mortoniceras-Desmoceras* (*Pseudouhligella*) *dawsoni* Zone is attested by the presence of late Albian fauna (JONES, 1973, p. 10): "dominated by *Desmoceras* (*Pseudouhligella*) *dawsoni* (WHITEAVES), *Pseudhelicoceras* sp., *Tetragonites jonesi* MURPHY, *Actinoceramus concentricus* (PARKINSON) and *A. subsulcatus* (WILTSHIRE), *Inoceramus anglicus*, and a proliferation of marshallitid ammonites, including *Marshallites cumshewaensis* (WHITEAVES) and several new species." As pointed out by JONES (1973, p. 10), the absence of *Mortoniceras* in this fauna must be climatically caused. There does not seem to be any reason to think (i. e. MATSUMOTO, 1959a, p. 81) that this *Desmoceras* (*Pseudouhligella*) *dawsoni* fauna may: "be either the Upper Albian or the Cenomanian" in age, all the more so as this species appears to be absent in all so far known early Cenomanian faunas of western British Columbia (*see* below).

Because of the common presence of *Mortoniceras* in all best known and most fossiliferous sections of the *Mortoniceras-Desmoceras* (*Pseudouhligella*) *dawsoni* Zone, this provnicial North Pacific zone (JELETZKY, 1971a, p. 10-12, 25, table 10) must correspond approximately to the *Mortoniceras inflatum* Zone of the European standard (Fig. 5) in the sense of SPATH (1923, p. 73) and BREISTROFFER (1947). It is impossible to be certain at present whether or not the *Mortoniceras-Desmoceras* (*Pseudouhligella*) *dawsoni* fauna includes the beds equivalent to the latest European Albian (Vraconnian) zone of the *Stoliczkaia dispar* (SPATH, 1923, p. 73; WRIGHT *in* ARKELL *et al.*, 1958, p. L128, table 4; OWEN, 1973, p. 148, fig. 1). However, the presence of *Mortoniceras* [e. g. *Mortoniceras* (*Deiradoceras*) *perinflatum*] in the *Stoliczkaya dispar* Zone in England (SPATH, 1923, p. 73) and the presence of *Stoliczkaia praecursor* ANDERSON (1958, p. 246, pl. 12, fig. 1, la) at an uncertain locality in northern California, which may or may not represent the *Mortoniceras-Desmoceras* (*Pseudouhligella*) *dawsoni* (MATSUMOTO, 1960, p. 24, 25) Zone, suggest that it does. Therefore it is suggested that the *Mortoniceras-Desmoceras* (*Pseudouhligella*) *dawsoni* Zone corresponds to both the *Mortoniceras inflatum* and the *Stoliczkaia dispar* Zones of the Northwesteuropean and Tethyan standard (Fig. 5).

As stressed repeatedly by the Canadian (MCLEARN and KINDLE, 1950, p. 96), American (REESIDE and COBBAN, 1960, p. 28-30) and British (OWEN, 1973, p. 149, fig. 1) workers, there is no faunal basis for a direct correlation of the *Neogastroplites* Zone of the Western Interior and Arctic regions of Canada with the late Albian of the North Pacific Province and Europe. Furthermore, the above mentioned (p. 113) proposed abandonment of the habitual transcontinental correlation of the Canadian *Gastroplites* Zone with the *Dipoloceras cristatum* Subzone of *Euhoplites lautus* Zone is apt to discredit the generally accepted late Albian dating of the bulk of *Neogastroplites* Zone (e. g. except for the youngest known *Neogastroplites septimus* Zone; *see* JELETZKY, 1971a, p. 8, fig. 2) in part at least.

C. Cenomanian faunas

Unlike the Aptian and Albian rocks the Cenomanian marine rocks are only known in and apparently were restricted to the Insular Trough of western British Columbia (JELETZKY, 1971a, p. 47, 48, fig. 11; this paper Fig. 3). Only nonmarine volcanic and sedimentary rocks of the Kingsvale Group, the upper Pasayten Group, ?Brian Boru Formation of the Skeena Group and their unnamed equivalents were apparently deposited at that time on the mainland of western British Columbia (JELETZKY and TIPPER, 1968, p. 59-64, tables 3, 4; JELETZKY, 1970b, p., 223, fig. 1; JELETZKY *in* MONGER *et al.*, 1972, p. 61, 63, 64, fig. 10: 1; COATES, 1974, p. 47, 48; SUTHERLAND BROWN, 1960; RICHARDS, 1974, p. 36, geol. map; RICHARDS and O. L. JELETZKY, 1975, p. 34).

Similarly to the Aptian marine faunas, the Cenomanian marine invertebrate faunas of the Pacific slope of Canada are known from a few widely scattered localities only. Furthermore, most of the diagnostic species are represented by poorly preserved, fragmentary, and scant (sometimes unique specimens only) material. This makes it impossible to propose a definitive zonal sequence for the Cenomanian rocks of the region and makes it difficult to correlate their faunas with the standard zones of Europe and the regional or provincial zones of other better known regions outside of North America. Even the correlation of the Cenomanian macroinvertebrate faunas of the Pacific slope of Canada with those described from other regions of the Pacific slope of North America within the North Pacific biotic province presents considerable difficulties.

1) *Desmoceras* (*Pseudouhligella*) *japonicum fauna.*—The best known Cenomanian fauna of the Pacific slope of Canada is the *Desmoceras* (*Pseudouhligella*) *japonicum* fauna which occurs in the Shale member of the Haida Formation in the Skidegate Inlet area, Queen Charlotte Islands (SUTHERLAND BROWN, 1968, p. 88, 92). The diagnostic ammonites of this fauna listed and described by MCLEARN (1972, p. 19, 40, 46, 47, 53) include *Desmoceras* (*Pseudouhligella*) *japonicum* (YABE) and specimens either very closely allied to or identical with this species, *D.* (*P.*) *subezoanum* MCLEARN, 1972, *Parajaubertella imlayi* MATSUMOTO, *Eogunnarites alaskaensis* MATSUMOTO, and *Anisoceras* sp. In western British Columbia this fauna was so far only found in some isolated sections situated east of Kwuna Point and west of Queen Charlotte townsite so that its exact stratigraphic relationships with the previously discussed Albian zones of the Skidegate Inlet area remained obscure. MCLEARN (1972, p. 19, 20) had assigned this fauna to the separate *Desmoceras* (*Pseudouhligella*) *japonicum* zone. However, he did not date the zone in terms of the international standard stages, except for pointing ont casually that its species have been dated as Cenomanian and thus post-Albian by MATSUMOTO (1959a, b, p. 81) in southeastern Alaska. However, the stratigraphic relationships of the *Desmoceras* (*Pseudouhligella*) *japonicum* fauna have been studied subsequently by GRANTZ (*in* JONES, 1967, p. 10, 11) in a paper which appeared after Dr. F. H. MCLEARN's death in 1964. This worker found that this fauna occurred in beds overlying those containing *Desmoceras* (*Pseudouhligella*) *dawsoni* fauna and thus confirmed its Cenomanian age originally recognized by MATSUMOTO (1959a, p. 81). The *Desmoceras* (*Pseudouhligella*) *japonicum* fauna of Southeast Alaska was accordingly unreservedly assigned to the Cenomanian stage by JONES (1967, p. 4).

JONES (1967, p. 4) lists but neither describes nor figures *Turrilites acutus* PASSY in the southeast Alaskan example of *Desmoceras* (*Pseudouhligella*) *japonicum* fauna. This species is an index fossil of a restricted zone in mid-Cenomanian rocks in southern England and Normandy according to the latest data of KENNEDY and JUIGNET (1975, p. 1221-1222, fig. 1). However, this narrow time-range of *T. acutus* evidently does not apply to the whole fauna as *D.* (*P.*) *japonicum* appears to range right through the Cenomanian stage in Japan according to MATSUMOTO and OBATA (1963, fig. 216). There it is shown to range through the subzones of *Mantelliceras* n. sp., *Calycoceras stoliczkai*, etc., and *Calycoceras* cf. *naviculare*. This range should correspond rather closely to the now generally accepted extent of the Cenomanian stage in its type-area (e. g. WRIGHT *in* ARKELL *et al.*, 1958, p. 2128, table 4; JUIGNET, KENNEDY and WRIGHT, 1973, p. 20, table 2; KENNEDY and JUIGNET, 1975, p. 1221-1224, tables 1, 2). Therefore the *Desmoceras* (*Pseudouhligella*) *japonicum* Zone of MCLEARN (1972, p. 19, 20) appears to correspond to most or all of the Cenomanian stage of the international standard (Fig. 5).

2) *Turrilites sp. Zone.*—Another Cenomanian zone recognized by MCLEARN (1972, p. 19) in the Shale member of Haida Formation has yielded *Turrilites* sp. in association with such long-ranging ammonites as *Tetragonites subtimotheanus* subsp. *haidaensis*

McLEARN 1972 and *Anagaudryceras sacya* (FORBES). Unlike the *Desmoceras* (*Pseudouhligella*) *japonicum* Zone, the *Turrilites* sp. Zone is known to overlie stratigraphically the late Albian *Mortoniceras-Desmoceras* (*Pseudouhligella*) *dawsoni* Zone in the Bearskin Bay Section A (McLEARN, 1972, p. 8, fig. 2, Sect. A). As known to McLEARN (1972, p. 19, 20) prior to his death in 1964, his zones of *Desmoceras* (*Pseudouhligella*) *japonicum* and *Turrilites* sp. lacked any species or genera in common and could have been assumed to be separate palaeontological zones. However, the above discussed association of *Turrilites acutus* with *D.* (*P.*) *japonicum* in southeastern Alaska indicates that the *Turrilites* sp. "zone" is but a faunal phase of *Desmoceras* (*Pseudoubligella*) *japonicum* Zone. Therefore, it is not included in Fig. 5.

The *Desmoceras* (*Pseudouhligella*) *japonicum* Zone appears to be widespread on the Pacific slope of North America as it is also known in several areas of northern California (POPENOE *et al.*, 1960, p. 1510; MATSUMOTO, 1959b, II, p. 54, 1960, plate 1, opp. p. 204). Unfortunately, the time range of *D.* (*P.*) *japonicum* in relation to more short-ranging, ornate Cenomanian ammonites remains obscure in California.

Like its southeastern Alaskan counterpart, the Canadian *Desmoceras* (*Pseudouhligella*) *japonicum* fauna is characterized by an almost complete specific identity of all its presently known ammonites to the Cenomanian faunas of Japan (MATSUMOTO, 1959a, p. 81). However, it appears to be dominated by long-ranging, feebly ornamented and generalized ammonites and to lack almost completely the ornate, short-ranging forms of the west European, Tethyan and Indo-Pacific affinities which form the backbone of the detailed zonal subdivision of the Cenomanian stage all over the world. Only the presence of *Turrilites* sp. in the *Desmoceras* (*Pseudouhligella*) *japonicum* fauna suggests the possibility of its future subdivision into more restricted palaeontological zones.

3) *Sciponoceras n. sp. ex aff. kossmati fauna.*—The conglomeratic lower beds of the previously unfossiliferous Upper shale unit outcropping in the Quatsino Sound, northern Vancouver Island have recently yielded a poorly preserved but extremely interesting Cenomanian molluskan fauna. This fauna is quite unlike the previously discussed *Desmoceras* (*Pseudouhligella*) *japonicum* fauna of Queen Charlotte Islands while being very closely allied to the early Cenomanian faunas of Japan and Soviet Far East (JELETZKY, 1970c, p. 210, 211; 1976, p. 109, 112). The following diagnostic species have been so far identified in this fauna; *Sciponoceras* n. sp. ex aff. *kossmati* (NOWAK), *Eogunnarites* aff. *E. unicum* (YABE), *Desmoceras* (*Pseudouhligella*) *ezoanum* MATSUMOTO and poorly preserved forms comparable with this species, *Inoceramus* ex aff. *I. crippsi* MANTELL and *Inoceramus* ex aff. *I. pictus* MANTELL. To document this extremely interesting new Cenomanian fauna, the best specimens of its above listed ammonites are reproduced in Pl. 3, Figs. 2-5, 7-8, of this paper.

The closest ally of the index species of the *Sciponoceras* n. sp. ex aff. *kossmati* fauna-*Sciponoceras kossmati* (NOWAK)- is a late Cenomanian to early Turonian species (MATSUMOTO, 1959b, p. 106; MATSUMOTO and OBATA, 1963, p. 17, 18, fig. 216 opp. p. 94). However, the presence in this fauna of the early Cenomanian to late Albian *Eogunnarites* aff. *E. unicus* (YABE) (MATSUMOTO, 1943, p. 130, fig. 19) suggests that it is older. The late Albian age of the *Sciponoceras* n. sp. aff. *kossmati* fauna is improbable because of the Cenomanian time range of the genus *Sciponoceras* HYATT, 1894 (*see*

WRIGHT *in* ARKELL *et al.*, 1958, p. 218; MATSUMOTO, 1960, plate 1 opp. p. 204; MATSUMOTO and OBATA, 1963, p. 9, fig. 216 opp. p. 94) and of *Desmoceras* (*Pseudouhligella*) *ezoanum.* Therefore, and because of the obvious Cenomanian affinities of all its other elements, including the inocerami, the fauna is believed to represent the early Cenomanian part of the known time range of *Eogunnarites unicum.* It is placed and correlated accordingly in Figs. 4, 5.

The *Sciponoceras* n. sp. ex aff. *kossmati* fauna of northern Vancouver Island appears to be most closely comparable to the early Cenomanian *Desmoceras kossmati* fauna of Japan (MATSUMOTO, 1959, p. 63, table 8) and Anadyr-Koriak Province of Soviet Far East (TEREKHOVA, 1969, p. 163). These faunal zones of the Western Pacific region combine the presence of *Eogunnarites unicum* (YABE) with that of Cenomanian *Inoceramus* ex aff. *crippsi-pictus* which appear to be either closely related or specifically identical to the corresponding forms of the *Sciponoceras* n. sp. ex aff. *kossmati* fauna. As it is known now, this Quatsino Sound fauna has no closely comparable equivalents anywhere on the Pacific slope of North America. The previously made suggestion (JELETZKY, 1976, p. 112) about the *Sciponoceras* n. sp. ex aff. *kossmati* fauna forming part of *Desmoceras* (*Pseudouhligella*) *japonicum* fauna must be emended in accordance with the above comments about the apparently different time ranges of these two faunas (*see* Figs. 4, 5).

4) *Inoceramus aff. incelebratus fauna.*—Another scant and poorly preserved, Cenomanian marine fauna was found recently in the higher, argillaceous beds of the Upper shale unit on the northern coast of Vancouver Island (JELETZKY, 1969, p. 130, 131; 1970c, p. 211-212; 1976, p. 113). The following fossils have been identified in this fauna confined to the middle part of the unit on the western limb of its Christensen Point synclinal outlier (JELETZKY, 1969, p. 131): *Inoceramus* aff. *I. incelebratus* PERGAMENT, *Puzosia* (*Puzosia*) aff. *P. dilleri* ANDERSON, *Tetragonites* ? sp. indet. and indeterminate desmoceratid ammonites. This fauna was originally assigned an "Albian or (?) Cenomanian" age by JELETZKY (1969, p. 131) because of the presence of a *Puzosia* (*Puzosia*) form morphologically similar to the Albian *Puzosia* (*Puzosia*) *dilleri* ANDERSON. However, the evidence of generally long-ranging *Puzosia* species is now believed to be less reliable than that of the apparently strictly late Cenomanian *Inoceramus* aff. *I. incelebratus* PERGAMENT (PERGAMENT, 1966, p. 16, 17, 33, 35, 62; figs. 6, 8). Furthermore, the *Inoceramus* aff. *I. incelebratus* fauna was found in beds of the Upper shale unit which, on the stratigraphical grounds, appear to be younger than the apparently basal beds of the same unit which yielded the definitely Cenomanian *Sciponoceras* n. sp. ex aff. *S. kossmati* fauna farther south in Quatsino Sound. Therefore, the *Inoceramus* aff. *I. incelebratus* was selected the name fossil of this fauna. As *Inoceramus incelebratus* PERGAMENT, 1966 appears to be restricted to the late Cenomanian *Inoceramus nipponicus-Inoceramus scalprum* Zone in northwestern Kamchatka (PERFAMENT, 1966, p. 62, 63, fig. 18), the Cenomanian *Inoceramus* aff. *incelebratus* fauna of northern Vancouver Island is more likely late than early to mid-Cenomanian in age (Figs. 4, 5).

As with the early Cenomanian *Sciponoceras* n. sp. ex aff. *kossmati* fauna, the *Inoceramus* aff. *I. incelebratus* fauna does not have any known equivalents on the Pacific slope of North America.

D. Turonian faunas

The Turonian marine macroinvertebrate faunas are even more rare on the Pacific slope of Canada than are the Cenomanian faunas. However, they occur in the same areas as the latter faunas and are represented by the same open sea facies. This indicates that the Turonian sea of the Insular Trough had about the same extent as the Cenomanian sea (Fig. 3).

1) *Inoceramus labiatus Zone.*—The presence of early Turonian rocks containing *Inoceramus* sp. cf. *Inoceramus labiatus* in the Queen Charlotte Series of Graham Island was apparently first reported by MACKENZIE (1916, p. 65) who erroneously assigned the beds containing this diagnostic fossil to the Skidegate and Honna formations. However, already WHITHAVES (1876, p. 7) mentions poorly preserved *Inoceramus* shells possibly referable to *I. concentricus* but more likely representing *I. labiatus* from the Upper shales and Sandstones of the Queen Charlotte Series in the Skidegate Inlet area.

The presence of *Inoceramus labiatus* ?-bearing beds in the topmost beds of the Haida Formation was recently confirmed by SUTHERLAND BROWN (1968, p. 88, 92) on the basis of identifications of the late Dr. F. H. MCLEARN. SUTHERLAND BROWN (1968, p. 88) states that in the Bearskin Bay section the *Inoceramus labiatus* Zone is restricted to a bed about 8.5 metres (28 feet) thick occurring about 55.5 metres (182 feet) stratigraphically below the top of the Haida Formation. The writer has studied *Inoceramus labiatus* ? material collected by Dr. F. H. MCLEARN in 1921 and that collected by SUTHERLAND BROWN (1968) and is satisfied that it belongs to this almost world-wide index fossil of the early Turonian.

In western British Columbia the *Inoceramus labiatus* Zone is only known from the above described locality in the Skidegate Inlet (Fig. 4). However, it is probably represented by an unfossiliferous interval underlying the *Romaniceras* (*Yubariceras*) sp. indet. beds in the Upper shale unit on the northern shore of Vancouver Island (*see* below and Fig. 4).

The *Inoceramus labiatus* Zone may also be represented by unfossiliferous siltstones of the Shale-siltstone member of the same unit in Quatsino Sound (Fig. 4). Outside of western British Columbia *Inoceramus labiatus* is known in California (POPENOE *et al.*, 1960, p. 1511; MATSUMOTO, 1960, p. 51) and in Japan (e. g. MATSUMOTO, 1959c, p. 85, plate 8; MATSUMOTO and NODA, 1975). However, this fossil does not appear to be present anywhere on the Pacific slope of USSR according to the latest data of PERGAMENT (1971, p. 8, 174, table 3).

2) *Romaniceras* (*Yubariceras*) *sp. indet. fauna.*—This fauna found in the argillaceous rocks of the middle third of the Upper shale unit outcropping on the eastern limb of the Christensen Point syncline (JELETZKY, 1970c, p. 211; 1976, p. 113) was originally considered to be "late Cenomanian or (?) basal Turonian" in age because of the presence of an ammonite then determined as *Eucalycoceras* ? ex aff. *shastense* Reagan. However, this ammonite was more recently identified as the Turonian *Romaniceras* (*Yubariceras*) sp. indet. It is figsured in Pl. 3, Figs. 6a-6c to document the Turonian age of the fauna proposed in this paper.

In Japan the genus *Yubariceras* MATSUMOTO, SAITO and FUKADA, 1957 appears to be restricted to the Turonian and is more common in the mid- to late Turonian than in the early Turonian (MATSUMOTO, 1975, p. 131). This time-range matches closely that of the *Romaniceras* (MATSUMOTO, 1975, p. 116) from which *Yubariceras* appears to differ only in the presence of periodic constrictions on the early whorls (MATSUMOTO, 1975, p. 131). In the writer's opinion, this distinction is too trivial for erection of a full genus, considering the apparently identical time ranges of *Yubariceras* and *Romaniceras* in Japan.

Furthermore, the writer was informed by Dr. W. J. KENNEDY (personal communication of September 30, 1975) that constrictions may also be present on the inner whorls of European *Romaniceras* species, including those of the type species *R. deverioide* (de GROSSOUVRE). Therefore, the writer believes *Yubariceras* to be no more than a subgenus of *Romaniceras.*

Except for the above discussed *Romaniceras* (*Yubariceras*) sp. indet., the here discussed Turonian fauna only includes an ammonite identified as *Tetragonites* ex aff. *T. jacksonense* ANDERSON and reproduced in Pl. 3, Figs. 9a, 9b of this paper. The presence of this ammonite suggests a mid- rather than late Turonian age of the *Romaniceras* (*Yubariceras*) sp. indet. fauna of northern Vancouver Island as *T. jacksonense* (under the name of *T. glabrus* JIMBO) was found to be associated with *Romaniceras* cf. *deverioide* (de GROSSOUVRE) and *Selwynoceras* sp. juvenile cf. *woollgari* (MANTELL) in northern California (MATSUMOTO, 1959b, II, p. 150, 151; 1960, p. 25). Because of the above considerations, the Canadian *Romaniceras* (*Yubariceras*) sp. indet. fauna is tentatively assigned a mid-Turonian age (Fig. 4) and is correlated with the all but world-wide mid-Turonian *Prionocyclus* (*Selwynoceras*) *woollgari* Zone (Fig. 5).

Romaniceras (*Yubariceras*) sp. indet. fauna is so far only known from the previously discussed, unique locality situated on the northern coast of Vancouver Island (Fig. 3). However, there is some room for it in the so far unfossiliferous uppermost beds of Haida Formation, which overlie its *Inoceramus labiatus*-bearing upper beds in the Skidegate Inlet area (SUTHERLAND BROWN, 1968, p. 88).

Although the state of our knowledge of the early Upper Cretaceous rocks of the Pacific slope of North America is poor, marine equivalents of the *Romaniceras* (*Yubariceras*) sp. indet. beds must be widespread in the American part of the region. This is suggested by the presence of faunally closely related mid-Turonian rocks containing *Romaniceras* cf. *deverioide* and *Prionocyclus* (*Selwynoceras*) cf. *woollgari* in California (MATSUMOTO, 1960, p. 25) and the re-appearance of faunally similar mid-Turonian *Inoceramus* ex gr. *I. cuvieri*- and *Subprionocyclus normalis*-bearing rocks in southeastern Alaska (JONES, 1967, p. 4).

E. Late Turonian to Late Santonian hiatus

The above discussed, presumably mid-Turonian *Romaniceras* (*Yubariceras*) sp. indet. fauna is the youngest Mid-Cretaceous marine invertebrate fauna known on the Pacific slope of Canada. Some 55.5 metres (182 feet) of unfossiliferous shale overlie the *Inoceramus labiatus*-bearing beds of the Haida Formation in the Skidegate Inlet area and some 152 metres (500 feet) of shale devoid of any diagnostic fossils were estimated to overlie the *Romaniceras* (*Yubariceras*) sp. indet.-bearing beds of the Upper shale unit on the northern coast of Vancouver Island. However, neither of these palaeontologically undated units is believed to be appreciably younger than the mid-Turonian. The uppermost beds of Haida Formation are believed to be too thin to include beds younger than the mid-Turonian, considering the average thickness of palaeontological zones in the Shale member of the formation. The unfossiliferous uppermost shales of the Upper shale unit are much thicker and could conceivably represent a longer period of geological time. However, they are overlain conformably and apparently gradationally by some 30.5 metres (100 feet) of sandy, shallow water siltstone. This siltstone unit is rich in poorly preserved shells and fragments of inocerami which appear to represent mid- to late Turonian forms (JELETZKY, 1970b, p. 211 and unpublished data).

No Coniacian and early to mid-Santonian marine (or for that matter nonmarine) rocks are known to exist anywhere on the Pacific slope of Canada (JELETZKY, 1971a, p. 55, 56, fig. 14). This fact and the above discussed, probable absence of the late Turonian rocks is now (i. e. contrary to JELETZKY, 1971a, p. 56) interpreted in the sense that following a rather localized but deep Cenomanian to Mid-Turonian submergence (Fig. 3), the Insular Trough experienced what appears to be (the record is still incomplete and partly ambiguous) a very strong and prolonged, regional uplift. The here favored interpretation of the here discussed hiatus as caused by a prolonged regional uplift resulting in nondeposition rather than by a brief, mid-Santonian uplift resulting in a regional destruction of the previously deposited late Turonian to early Santonian marine? and/or nonmarine sediments is suggested by:

1. The presence of definite signs of shallowing of the sea in the youngest preserved marine sediments on the northern coast of Vancouver Island (*see* p. 120); and
2. A discordant onlap rather than purely erosional superposition of the late Santonian basal beds of the Nanaimo Group and their presumed equivalents (i. e. Honna Formation) on Turonian and older rocks (MULLER *in* MULLER and JELETZKY, 1970, p. 4, 11; SUTHERLAND BROWN, 1968, p. 93).

According to this interpretation the Insular Trough (Fig. 3) was completely inverted in the late Turonian and represented a tectonic highland (i. e. a source area) throughout the Coniacian to mid-Santonian time. This tectonic highland may have been contiguous with the adjacent tectonic highland of the former Tyaughton Trough where the Late Cretaceous nonmarine deposition apparently ended sometime in the Turonian (JELETZKY *in* MONGER *et al.*, 1972, p. 61, fig. 10: 1).

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Explanation of Plate 3

Fig. 1. *Acanthoplites reesidei* ANDERSON. GSC loc. 64818. GSC Cat. No. 48257. Latest Aptian stage. Taylor Creek Group (lower part), Taseko Lakes map-area, western British Columbia. Ridge top, 1.61 km (1 mile) north of Konni Lake, Lat. 51°30′00″N, Long. 123°53′00″W. 1a. Lateral view, ×1; 1b. Ventral view of the adoral part of the whorl, ×1; 1c. Cross-section of the oral end and the earliest visible part of the venter, ×1.

Fig. 2. *Eogunnarites* aff. *unicus* (YABE). GSC loc, 92060. GSC Cat. No. 48258. Lower Cenomanian stage. Upper shale unit, Greywacke member. Vancouver Island, western British Columbia. Tidal shelf of the northern shore of Quatsino Sound, some 183 metres (600 feet) west of the mouth of Bish Creek (on southeastern limb of small markedly southwest-plunging anticline), Lat. 50°30′43″N.; Long. 127°44′12″W (*see* JELETZKY, 1976, p. 112, 113, 234, pl. X, fig. A for further details). 2a. Lateral view of the largest fragment found, ×1; 2b. Same view as in 2a but ×2 to elucidate details of characteristic ornamentation.

Fig. 3. *Desmoceras (Pseudouhligella)* cf. *ezoanum* MATSUMOTO. GSC loc. 83932. GSC Cat. No. 48263. The same unit, age, and locality as for the specimen shown in Fig. 2. Lateral view of a juvenile specimen apparently belonging to *D.* (*P.*) *ezoanum*, ×1.

Fig. 4. *Sciponoceras* n. sp. ex aff. *kossmati* (NOWAK). GSC loc. 83932. GSC Cat. No. 48259. The same unit, age, and locality as for the specimen shown in Fig. 2, ×2.

Fig. 5. *Sciponoceras* n. sp. ex aff. *kossmati* (NOWAK). GSC loc. 83932. GSC Cat. No. 48260. The same unit, age, and locality as for the specimen shown in Fig. 2, ×1.

Fig. 6. *Romaniceras* (*Yubariceras*) sp. indet. GSC loc. 83929. GSC. Cat. No. 48261. Mid-Turonian stage (? *Prionocyclus* (*Selwynoceras*) *woollgari* Zone). Upper shale unit (argillaceous facies). Vancouver Island, western Britisn Columbia. Tidal shelf of the northern coast at the point 1.61 km (≃1 mile) west of the tip of Christensen Point. Roughly estimated to be situated about 183 metres (600 feet) stratigraphically below the top of the section (*see* JELETZKY, 1970c, p. 211 for further details). 6a. Lateral view, ×1; 6b. View of inner whorls, ×2 to demonstrate the presence of strong constrictions characteristic of the subgenus *Yubariceras*; 6c. Ventral view, ×1.

Fig. 7. *Desmoceras (Pseudouhligella) ezoanum* MATSUMOTO. GSC loc. 83932. GSC Cat. No. 48262. The same unit, age, and locality as for the specimen shown in Fig. 2. A half-grown, somewhat deformed specimen. 7a. Left lateral view, ×1; 7b. Right lateral view, ×1; 7c. Ventral view, ×1; 7d. Cross-section of the oral end and the earliest visible part of the venter, ×1.

Fig. 8. *Desmoceras (Pseudouhligella)* cf. *ezoanum* MATSUMOTO. GSC loc. 83932. GSC Cat. No. 48264. The same unit, age, and locality as for the specimen shown in Fig. 2. 8a. Lateral view of a fragment believed to represent the adult form of *D.* (*P.*) *ezoanum*, ×1; 8b. Ventral view of the same, ×1.

Fig. 9. *Tetragonites* ex aff. *T. jacksonense* REAGAN. GSC loc. 83926. GSC Cat. No. 48265. Mid-Turonian stage (? *Prionocyclus* (*Selwynoceras*) *woollgari* Zone). Upper shale unit (argillaceous facies). Vancouver Island, western British Columbia. Tidal shelf of northern coast of Vancouver Island, about 1 km (≃0.6 miles) southwest of the tip of Christensen Point and 38 metres (125 feet) SW of the mouth of first nameless creek southwest of the above point. The locality is believed to be situated some 183 metres (600 feet) stratigraphically below the top of the section and to represent approximately the same horizon as the GSC loc. 83929 but the rocks are strongly faulted and sheared between the two (*see* JELETZKY, 1970c, p. 211 for further details). 9a. Lateral view, ×1; 9b. Cross-section of oral end and the earliest visible part of the venter, ×1.


1a


1b


1c

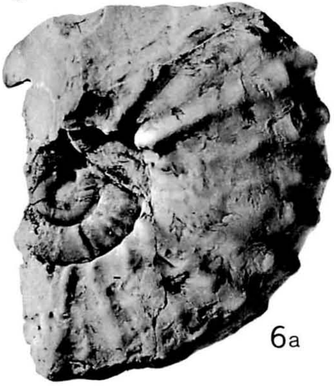

2b


5


4


3


2a


6a

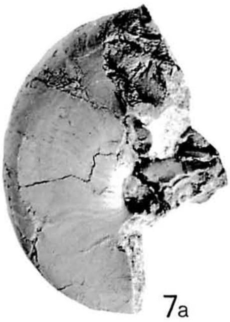

6b

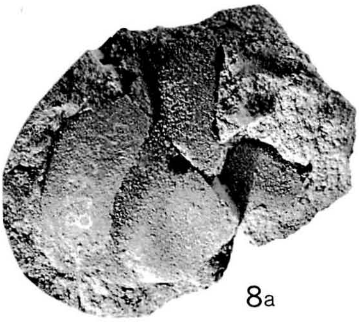

6c


7d

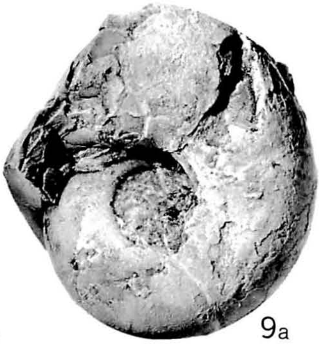

7c


7b


7a


8a


8b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9b

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Errata of Fig. 4

Column	Read	For
3rd	*Desmoceras* (*Pseudouhligella*) *japonicum*	*Pseudouhligella japonicum*
3rd	*Desmoceras* (*Pseudouhligella*) *dawsoni*	*Pseudouhligella dawsoni*
6th	*Desmoceras* (*Pseudouhligella*) cf. *alamoense*	*Pseudouhligella* cf. *alamoense*
3rd, 5th & 7th	*Cleoniceras* (*Grycia*) *perezianum*	*Grycia perezianum*

Errata of Fig. 5

Column	Read	For
2nd	*Acanthoceras rhotomagense*	*Acanthoplites rothomagense*
3rd	*Eogunnarites* aff. *unicum*	*Eogaudriceras* aff. *unicum*
4th	*Euhystrichoceras nicaisei*	*Euhistrichoceras nicasei*
	Diadochoceras nodosocostatiforme	*Diadochoceras nodosicostatiforme*
	Cheloniceras subcornuerianum	*Cheloniceras subcornuelianum*
5th	*Eotetragonites wintunius*	*Eogaudriceras wintunium*
	Colombiceras cerrosense	*Colombiceras cerrosensis*

TOWARDS A CORRELATION OF THE CENOMANIAN SEQUENCES OF JAPAN WITH THOSE OF NORTH-WEST EUROPE

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Abstract

Cenomanian successions in Japan and western Europe can be most accurately correlated on the basis of ammonite faunas, in spite of the fact that the two areas are in quite different faunal regions. In Europe, members of the Hoplitidae and Schloenbachiidae dominate, but are unknown in Japan, whilst the Desmoceratidae, important in the Pacific Region, are scarce in Europe. Common or related acanthoceratid species and genera are present in both areas, and the fivefold division of the Japanese sequence is tied to the European zonation by them.

Two outstanding problems are highlighted in this correlation, the absence of *Graysonites-Utaturiceras* bearing beds in western Europe outside Portugal (which is due either to a break in the sequence at that level or ecological exclusion of these genera) and the absence in both regions of transitional Lower to Middle Cenomanian faunas.

1. Introduction

Alcide D'ORBIGNY first used the term étage Cénomanien in 1847 (*Paléontologie Française, Terrains Crétáces, IV, Brachiopodes*, p. 270). Five years previously (1842), he had introduced the étage Turonien (loc. cit. *11*, *Gastropodes*, p. 404: "je propose de designer à l'avenir l'étage qui m'occupe [craie chloritée, glauconie crayeuse, craie tuffeau et grès verts] sous le nom de *Turonien*, de la ville de Tours (Turones) ou de la Touraine (Turonia) situées sur ces térrains"), only to recognise that two very distinct faunas could be recognised, and he subsequently restricted the term Turonian to the upper part of the sequence and Cenomanian to the lower ("et nous donnons a la partie inférieur le nom d'étage *Cénomanien*, le Mans (*Cenomanum*) en montrant a la fois le type sous-marin"). In the second volume of the *Prodrome de Palaéontologie Stratigraphique Universelle* (1850, pp. 145-188), D'ORBIGNY listed the organisms which formed the Cenomanian fauna, and in 1852, in the third volume of the *Cours Elementaire de Paléontologie et de Géologie Stratigraphiques* (pp. 630-652), the Cenomanian, by now his Vingtième Étage, was fully discussed, defined and characterised

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in several ways: faunally, in terms of well known formations referable to it, by its upper and lower limits and geographic extent, whilst the town of Le Mans, in the southern Paris Basin was confirmed as "le type le mieux caracterisé et le plus complet de l'étage qui nous occupé, sans qu'on puisse le confondre avec les autres' (D'ORBIGNY, 1852, p. 631).

In spite of recent views suggesting the area to be inadequate (e. g. MARKS, 1967a-b; THOMEL, 1973, p. 763), Le Mans was an excellent choice as a type area and the environs of Le Mans remain so today, for the diverse facies represented in the area yield invertebrate faunas of great richness and diversity. As such, the faunas absolutely typify the Cenomanian and that this may present problems when one attempts to recognise an upper and lower limit to the stage, or subdivide it on the basis of organisms suitable for long distance correlation, is irrelevant to its suitability as a type area. JUIGNET, elsewhere in the volume, fully deals with the stratigraphy of the type Cenomanian and its ammonite fauna, and fuller accounts of the overall faunas and sequences can be found in his other publications (JUIGNET, 1968, 1969, 1973, 1974; JUIGNET, KENNEDY and WRIGHT, 1973).

For our present purposes, that is correlation, problems of type areas are of subsidiary importance to the broader view of the biostratigraphic division of the stage recognised in Europe as a whole, and in particular, those divisions of global extent, or those which can be integrated with widely applicable schemes. Here, only three groups of organisms have appropriate distributions, the planktonic Foraminiferida, the inoceramid bivalves, and ammonites. Each of these groups poses problems when one attempts to correlate European and Japanese sequences. The planktonic foraminiferal zones (see discussion in HART and CARTER, 1975; CARTER and HART, in preparation, and RAWSON *et al.*, in press) are very broad; the state of our knowledge of detailed Cenomanian inoceramid distributions is sketchy (see KAUFFMAN, in press for the most complete recent review), whilst ammonites occur only sporadically over much of the areas considered, as discussed below. In spite of this, our following discussions are based upon attempts to correlate the ammonite successions recognised in the two regions, for this is the group about which most is known.

Limitations on the use of ammonites in inter-regional correlation

Use of ammonites in correlation of our two successions is limited by several quite unrelated factors. The most obvious to a European worker in the field is the very sporadic occurrence of the group. In marginal facies (see palaeogeographic and facies maps in HANCOCK, 1975 and KENNEDY and HANCOCK, in press), ammonites are absent in many of the higher energy units, often due to ecological exclusion during life, but also as a result of post-mortem leaching out of their aragonitic shells.

In the pelagic chalk facies which dominates in England and northern France, ammonites are absent through considerable intervals of rock due to ecological exclusion, and also (according to some workers) sea floor dissolution of their shells prior to burial (JEFFERIES, 1962, 1963; KENNEDY, 1969).

A second, and more significant difficulty is that the western European and Japanese areas belong to different faunal realms. In Europe, late Albian and Cenomanian ammonite faunas are dominated by representatives of the families Hoplitidae and

Schloenbachiidae (JUIGNET and KENNEDY, 1976; KENNEDY and COBBAN, 1976), the genus *Schloenbachia* comprising up to 99% of the assemblage at some levels in the Cenomanian. These groups are quite unknown in Japan, and are virtually restricted to the Boreal Realm (see maps in references cited above, and maps in MATSUMOTO, 1973). Similarly, the family Desmoceratidae, common, and of great importance in Japan, is scarce in much of western Europe, and there are no key species common to the two areas. Groupswhich do occur in both regions are often represented by different species of the same genus. Here, it is often unclear whether this is a reflection of the wide distance between the two areas, and the consequent separation of ancestral populations leading to geographic speciation, or whether slight differences between ammonite species is a reflection of slight differences in age which are too small to be detected at such distances.

These two factors—discontinuity of the record and regional differentiation of faunas—are a constantly recurring theme in following discussions.

2. European and Japanese Ammonite Successions Compared

Cenomanian ammonite zonations proposed for western Europe by recent workers are summarised in Fig. 1. As can be seen, the most detailed sub-divisions are those recognised in southern England and northern France (KENNEDY, 1969, 1970, 1971; JUIGNET and KENNEDY, 1976); the zonal scheme which can at present be fully applied over the whole area is that agreed for the synthesis *A Correlation of the Cretaceous Rocks in the British Isles* (RAWSON *et al.*, in press) with minor emendations. A full discussion of the correlation of these schemes is given by KENNEDY (1971) and KENNEDY and HANCOCK (in press). Known ranges of key ammonite genera are summarised in Fig. 2, and ranges of species important for inter-regional correlation are shown in Fig. 3.

The most recent zonation for the Japanese Cenomanian, including that presented by Professor Tatsuro MATSUMOTO and his collaborators at the *Mid-Cretaceous Events* meeting in Uppsala (1975) is shown in Fig. 4, and proposed correlations with the European sequence outlined.

A. The Position of the Albian-Cenomanian boundary

In western Europe, there is general agreement that the highest Albian (the Vraconian of authors) fauna is characterised by abundant hoplitids such as *Callihoplites*, *Lepthoplites* and *Arraphoceras*, together with diverse heteromorphs, most of which are of little value for long distance correlation. More significant are the presence of advanced mortoniceratids, notably *Mortoniceras* (*Durnovarites*), *M.* (*Cantabrigites*) and certain *M.* (*Mortoniceras*), together with *Euhystrichoceras* (also a mortoniceratid in our view), accompanied by *Stoliczkaia* (*Stoliczkaia*) (of which *S.* (*Villoutreysia*) is synonym), *S.* (*Shumarinaia*) and late *Faraudiella* species (see RENZ, 1968; KENNEDY and HANCOCK, in press and OWEN, 1976 for further discussions).

This fauna, characterising the European *Stoliczkaia dispar* Zone, is represented sparingly in Japan, in the higher parts of the Zone of *Mortoniceras* (*Durnovarites*) sp.

of MATSUMOTO (1959) and can be demonstrated in several areas, e. g. the Fujikawa Formation of Shikoku, which yields *Mariella* aff. *cantabridgensis* (JUKES-BROWNE) (NAKAI and MATSUMOTO, 1969) or from records in this symposium by HIRANO *et al.* (this volume), and MATSUMOTO and INOMA (1975).

In contrast, the recognition and placement of the Albian/Cenomanian boundary in both Europe and Japan are poorly understood, as elsewhere in the world. In much of western Europe, there is a sharp faunal discontinuity, and sediments with *dispar* Zone faunas (which often occur condensed or re-worked) are separated by erosion, omission or hardground surfaces (for definition of these terms see KENNEDY and GARRISON, 1975; BROMLEY, 1975), which represent minor breaks in the succession. Typical basal Cenomanian faunas in England, France, Germany, Switzerland, Poland and elsewhere thus include abundant *Schloenbachia*, *Hypoturrilites* and *Mantelliceras*, with scarcer, but typical *Sharpeiceras*, *Acompsoceras*, rare *Euhystrichoceras*, *Stoliczkaia* (subgen. nov.), *S.* (*Shumarinaia*) and distinctive heteromorphs (see KENNEDY, 1971, with references; KENNEDY and HANCOCK, in press and other papers in the same volume). Nowhere in western Europe, with the exception of Spain (WIEDMANN, 1959, 1964) do we find representatives of the genus *Graysonites*, now known to occur as part of a relatively low diversity fauna which occurs above the typical mortoniceratid rich faunas of the *dispar* Zone, but below *Mantelliceras* (sensu stricto) rich Lower Cenomanian faunas. This faunal association is best known from Texas (YOUNG, 1958) and northern Mexico, Brazil, California and Japan, but it is also represented in north Africa (*Sharpeiceras laticlavium byzacenica* PERVINQUIÈRE, 1907, p. 312, pl. 14, figs.

SUBSTAGE AS NOW USED	Sarthe Hancock (1959)	Southern England Kennedy (1971)	United Kingdom, N.France Kennedy and Hancock (in press)
LOWER TURONIAN		Middle Chalk (lower part)	Mammites nodosoides
UPPER CENOMANIAN	(gap in Sarthe)	Metoicoceras gourdoni Metoicoceras geslinianum	Sciponoceras gracile
	Calycoceras naviculare	Calycoceras naviculare	Eucalycoceras pentagonum 1
MIDDLE CENOMANIAN	Acanthoceras rhotomagense	Acanthoceras rhotomagense	Acanthoceras jukesbrownei
			Turrilites acutus
			Turrilites costatus
LOWER CENOMANIAN	Mantelliceras mantelli	Mantelliceras mantelli	Mantelliceras gr. dixoni
			Mantelliceras saxbii
		no ammonites	Hypoturrilites carcitanensis
UPPER ALBIAN	Stoliczkaia dispar	Stoliczkaia dispar	Stoliczkaia dispar

Fig. 1. A correlation of some recently proposed zonations

4a-b is a member of this group), whilst it seems likely that '*Utaturiceras*' *vicinale* (STOLICZKA) and '*Acanthoceras*' *discoidale* KOSSMAT, known from southern India and Madagascar, are also contemporaries.

This fauna, apparently that referred to by WIEDMANN (1959, 1964) as the Zone of *Submantelliceras* ? sp. or subzone of *Mantelliceras aumaulense* characterises limestone sequences where large ammonites are preserved; its precise equivalents in pyritic clays where only juveniles are known, as in north Africa and Madagascar is yet to be precisely established.

Absence of these faunas in most of western Europe may be due to the widespread disconformity or barren interval at the Albian-Cenomanian boundary, or ecological exclusion of the *Graysonites-Utaturiceras* group from boreal regions. Present evidence is inconclusive, and as a result we cannot say if this fauna, and hence the Japanese *Graysonites wooldridgei-Euhystrichoceras nicaisei* Zone is to be equated with the faunal hiatus in our sequence, or whether it is also equivalent to the lower part of our Lower Cenomanian, the *Hypoturrilites carcitanensis* Zone. As can be seen from Figs. 2 and 3, such few ammonites as are common to the two, notably *Euhystrichoceras nicaisei* (COQUAND), and *Stoliczkaia* (*Shumarinaia*), have too great a time range to be of help in clarifying this problem. That *Mantelliceras* and *Sharpeiceras* species common to Europe and Texas always occur above the *Graysonites* bearing beds in Texas (YOUNG and POWELL, in press) and are present in the lowest Cenomanian in Europe, is also of limited help in resolving this problem as the species concerned (chiefly *Mantelliceras cantianum* SPATH and *Sharpeiceras laticlavium* (SHARPE)) occur in both

S.E.France Thomel (1965)	S.E.France Thomel (1972)	S.E.France Thomel et.al.(1973)	Spain and Portugal Wiedmann (1959,1964)	Portugal
Mammites nodosoides	Fagesia superstes		Vascoceras gamai	Vascoceras gamai
	7.Calycoceras naviculare	Metoicoceras geslinianum	Metoicoceras swallovi Metoicoceras mulleri ? Neolobites choffati	? not represented
Calycoceras crassum	6.Calycoceras crassum	Calycoceras crassum		Neolobites vibrayeanus
Calycoceras naviculare	5.Calycoceras robustum	Calycoceras robustum		
Acanthoceras rhotomagense	4.Acanthoceras rhotomagense	Acanthoceras rhotomagense	Protacanthoceras jacobi Euomphaloceras africanum	
	3.Acanthoceras praecursor	Acanthoceras praecursor		
Mantelliceras mantelli	2.Mantelliceras mantelli	Mantelliceras mantelli	Mantelliceras mantelli	
Submantelliceras martimpreyi	1.Mantelliceras saxbii	Mantelliceras saxbii	Graysonites — Submantelliceras	
Stoliczkaia dispar	Stoliczkaia dispar	Stoliczkaia dispar	Stoliczkaia dispar	

of the Cenomanian in various parts of western Europe.

carcitanensis and *saxbii* Zone faunas in many areas (KENNEDY and HANCOCK, in press).

B. The so-called *martimpreyi* Zone

Mention should be made here of the nature of the so-called *Submantelliceras martimpreyi* zone, especially as MATSUMOTO (1975) recently equated the Japanese *Graysonites* level with this zone in Europe.

The *martimpreyi* zone was first introduced, by L. F. SPATH (in 1923) as the lowest zone of his earliest proposed Cenomanian zonal scheme, and in 1926, he clarified it, recognising below a pre-*martimpreyi* Zone. These schemes of SPATH's based on a combination of intuition and guesswork, and museum material rather than field collections, have become enshrined in the literature. As discussed elsewhere (KENNEDY, 1971; KENNEDY and HANCOCK, 1971; in press; HANCOCK, 1972) and not to be repeated here in detail, there are many flaws in these schemes of SPATH. However, much of the subsequent misconception has arisen from the fact that authors have persistently followed SPATH's earlier scheme, naming the basal zone of the Cenomanian the *martimpreyi* Zone and automatically ignoring his awkwardly named 'pre-*martimperyi* Zone' (e. g. MULLER and SCHENK, 1943; WRIGHT *in* ARKELL *et al.*, 1957). In fact, the beds which contain *Mantelliceras martimpreyi* (COQUAND)—which is a junior synonym of *M. saxbii* (SHARPE)—and its associated ammonite fauna correspond with the assemblage of the *M. saxbii* Zone herein. This occurs about half way up the Lower Cenomanian in southern England, in Normandy (JUIGNET and KENNEDY, 1976), in Sarthe, France (JUIGNET, 1974) and in Algeria and Tunisia.

SPATH's pre-*martimpreyi* Zone was based mainly on heteromorph ammonites found at Gore Cliff in the Isle of Wight. As shown by KENNEDY (1969) and KENNEDY and HANCOCK (1971), these heteromorphs occur at the base of the Glauconitic Marl with other ammonites which together characterise the Zone of *Hypoturrilites carcitanensis*.

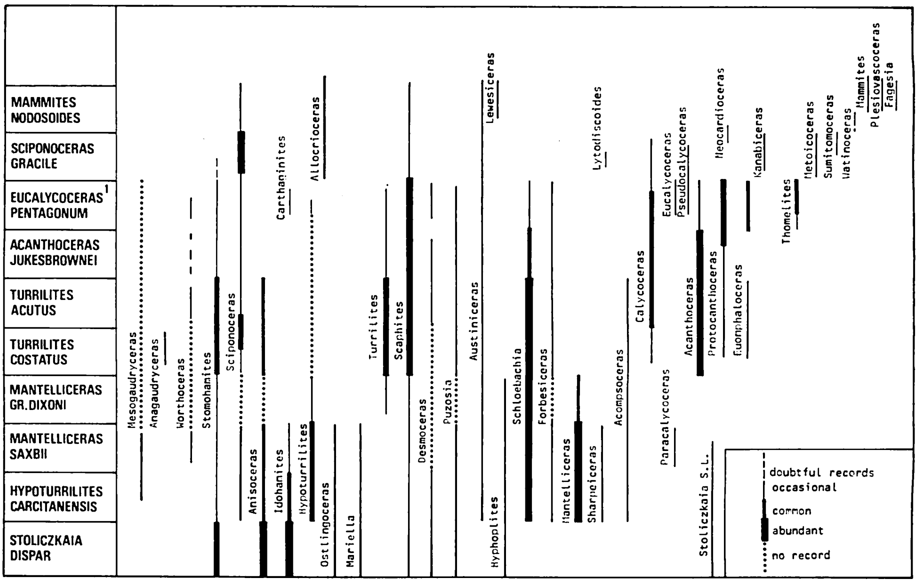

Fig. 2. Vertical distribution and relative abundance of selected ammonite genera in the late Albian to early Turonian of western Europe. 1—see footnote on p. 136.

This *carcitanensis* Zone has been found below the *saxbii* Zone in southern England, Normandy, Sarthe, Provence, Algeria, Tunisia, and Zululand and has also been recognised in western Germany and elsewhere (HANCOCK, KENNEDY, & KLAUMANN, 1972).

Whether the horizon with *Graysonites* correlates with the *carcitanensis* Zone or below it is discussed above; what it cannot correlate with is the '*martimpreyi* Zone'.

C. Lower Cenomanian correlations

The correlation of the *Mantelliceras japonicum-Sharpeiceras kongo* Zone with the European sequences is relatively straightforward. Common species to the two areas are restricted, but *Mantelliceras cantianum* is frequent only in the lower two thirds of the Lower Cenomanian, and species such as *Ostlingoceras puzosiforme* SPATH, and *Mantelliceras* of *japonicum* type-for example *M. tuberculatum* (MANTELL) and *Sharpeiceras* closest to *S. kongo* MATSUMOTO, MURAMOTO and TAKAHASHI, e. g. *S. florencae* SPATH, all reach their acme in the *carcitanensis* Zone, although partial equivalence with part or all of the succeeding *saxbii* Zone cannot be excluded.

So far unrecorded in Japan are the numerous later early Cenomanian *Mantelliceras*, which includes *Mantelliceras lymense* (SPATH), *M. dixoni* (SPATH), *M. souaillonense* (RENZ) and *M. orbignyi* (COLLIGNON) (the last may prove to be a better zonal index than the currently used *Mantelliceras* gr. *dixoni*). These are species which have *Calycoceras*-like outer whorls, but which lack a siphonal tubercle at any stage (and thus cannot be placed in *Calycoceras* as have many previous workers).

D. Middle Cenomanian correlations

In all areas of the world, there is a hiatus between Lower and Middle Cenomanian

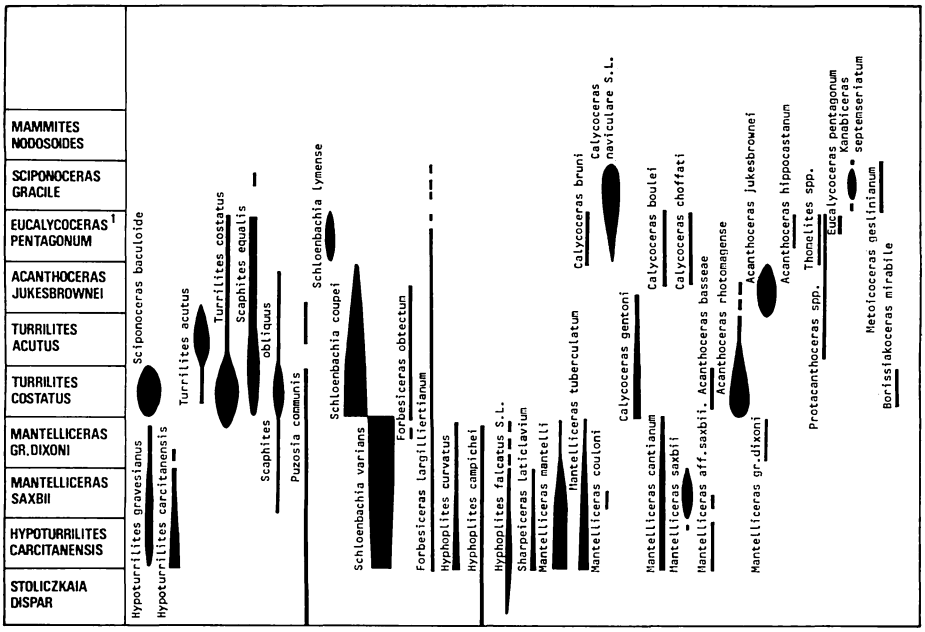

Fig. 3. Vertical distribution and relative abundance of selected ammonite species in the late Albian to early Turonian of western Europe. 1—see footnote on p. 136.

Acanthoceratid faunas. *Mantelliceras* and *Sharpeiceras* disappear, and their place is taken by primitive *Calycoceras* of the *gentoni* (Brongniart) and *Acanthoceras* of the *rhotomagense* (Brongniart) groups. *Scaphites* of *obliquus* (J. Sowerby) type give rise to *equalis* (J. Sowerby)-like forms, and *Turrilites* sensu stricto appear in profusion.

In areas of Europe which we have studied personally, this transitional interval has proved to be poor in ammonites (Kennedy, 1969, p. 476), but perhaps more significant to explain the abrupt faunal change is the recognition of a widespread intra-Cenomanian break at or about this level (Hart and Tarling, 1974). This break, detected on the basis of microfaunas, can be recognised in Europe from Scandinavia to the Mediterranean and in deep sea cores from Atlantic and Pacific regions. Although dated as Middle Cenomanian, over wide areas of Europe it corresponds to an erosion surface or hardground separating Middle and Lower Cenomanian deposits, and marking a Middle Cenomanian eustatic transgressive event. Above, it has proved possible to recognise three divisions in the European Middle Cenomanian based on heteromorphs and acanthoceratids (Fig. 1). Only Acanthoceratids can be used for inter-regional correlation at this time, and we may recognise a lower division, characterised by *Acanthoceras* of the *rhotomagense* group, early *Euomphaloceras*, e.g. *E. cunningtoni* (Sharpe), *E. inerme* (Pervinquière), *Calycoceras* of the *gentoni* group (=*Gentoniceras* Thomel, 1972). *Calycoceras* of the *newboldi* group (*Newboldiceras* Thomol, 1972) appear rarely at the top of this division; *Turrilites costatus* Lamarck is abundant in the lower part, *T. acutus* abundant in the upper part, their acmes defining the *costatus* and *acutus* Zones shown in Fig. 3. The higher parts of the Middle Cenomanian see a replacement of *Acanthoceras rhotomagense* by the *A. jukesbrownei* group, in which alternately long and short ribs are retained to maturity, accompanied by more frequent *Calycoceras* related to the *newboldi* (Kossmat), *choffati* (Kossmat), and *cenomanense* (d'Archiac) groups, together with rather scarce *Calycoceras* sensu stricto, represented by *C. boulei* (Collignon) and its allies.

SUBSTAGE	NORTH WESTERN EUROPE	JAPAN (MATSUMOTO 1975)	JAPAN (MATSUMOTO ,UPPSALA 1975)
LOWER TURONIAN	Mammites nodosoides	---------------------	Fagesia thevestensis - Mammites sp.
UPPER CENOMANIAN	Sciponoceras gracile	(5) Uppermost Zone	Kanabiceras septemseriatum Psendocalycoceras aff. dentonense
	Eucalycoceras pentagonum [1]	(4) Upper Zone	Calycoceras cf naviculare,Eucalycoceras pentagonum
MIDDLE CENOMANIAN	Acanthoceras jukesbrownei	(3) Middle Zone	Calycoceras orientale Euomphaloceras meridionale Acanthoceras takahashii
	Turrilites acutus		
	Turrilites costatus		
LOWER CENOMANIAN	Mantelliceras gr. dixoni	(not represented by ammonitiferous strata ?)	
	Mantelliceras saxbii	(2) Lower Zone	Mantelliceras japonicum-Sharpeiceras kongo
	Hypoturrilites carcitanensis	(1) Basal Zone	Graysonites wooldridgei-Euhystrichoceras nicaisei
UPPER ALBIAN	Stoliczkaia dispar	M.(Durnovarites) sp.	M.(Durnovarites) sp.

Fig. 4. Proposed correlations of north-west European Cenomanian with some recently proposed zonations of the Japanese Conomanian. 1—see footnote on p. 136.

This Middle Cenomanian interval is obviously to be correlated with part or all of the *Calycoceras orientale-Euomphaloceras meridionale-Acanthoceras takahashii* Zone of Fig. 4; that is to say the so-called Middle Zone of MATSUMOTO (1975, p. 157). Detailed correlations are rather difficult, but we would note that *Euomphaloceras* of *cunningtoni* type are known from Hokkaido (the *Euomphaloceras* cf. *euomphalum* and *Euomphaloceras* (*Acanthoceras*?) sp. indet. of MATSUMOTO *et al.*, 1957), and accompany *Acanthoceras* aff. *evolutum* SPATH [=*E. inerme* (PERVINQUIÈRE], an association indicative of the lower part of the Middle Cenomanian (top *costatus* or *acutus* Zone of Fig. 1). These occurrences are of great significance, because neither *Acanthoceras* of the *rhotomagense* group, nor *Gentoniceras* are yet known from Japan.

Further *Euomphaloceras*, *E. lonsdalei* (ADKINS), and *E. meridionale* (STOLICZKA) (which latter we are not certainly able to justify as a separate species from *E. cunningtoni* at this time) are both possibly present in Europe (our material is poor and incomplete at the time of writing) and definitely present in Japan, and better collections of this group may show them to be successive subspecies characterising several levels low in the Middle Cenomanian, rather than contemporaneous variants of one species as recently suggested (KENNEDY, 1971).

The horned *Acanthoceras* recorded from similar levels in Japan (e. g. *A. amphibolum* MORROW, *A. cornigerum* (CRICK) and *A. takahashii* MATSUMOTO seem to represent a different group from the European *A. rhotomagense*, close to some of the similarly horned species in the Western Interior of the USA (see forms described by COBBAN and SCOTT, 1972), and as such, precise correlation is difficult. If, as MATSUMOTO (1975, p. 129) suggests, the affinities of this group lie close to the European *A. jukesbrownei*, then the lower part of the Japanese Middle Zone is equivalent to all of the European Middle Cenomanian. Slight confirmation of this is to be found in the occurrence of a probable *Acanthoceras amphibolum* in the Chalk Basement Bed at Chardstock, England (BMNH 2399); the preservation of the specimen showing it to be no younger than *jukesbrownei* Zone.

Above, the higher parts of the Middle Zone yield faunas in which *Calycoceras* dominate, especially the *newboldi* group such as *Calycoceras asiaticum* (JIMBO) and probably also *C. spinosum* (KOSSMAT) and *C. orientale* MATSUMOTO, SAITO and FUKADA, together with *Calycoceras* (*Calycoceras*) (e. g. *Calycoceras* cf. *stoliczkai* COLLIGNON *in* MATSUMOTO *et al.*, 1957, identified by KENNEDY, 1971 as a possible *C. naviculare* but according to MATSUMOTO, 1975, probably too poor for certain determination and also to be compared with *C. boulei*).

These associations match those of the higher parts of the European Middle Cenomanian and the lower parts of the Upper Cenomanian. This is confirmed by records of *Eucalycoceras* aff. *spathi* (COLLIGNON) from the top of the Middle Zone (MATSUMOTO, 1975, p. 108), immediately above beds with *Calycoceras orientale;* in Europe this type of *Eucalycoceras* characterises the lower part of the Upper Cenomanian (e. g. *Eucalycoceras collignoni* (FABRE)). Whatever precise correlations are made, it is important to note that the acanthoceratid sequences in the Middle Cenomanian of Europe and Japan are similar. suggesting that we are seeing a truly evolutionary succession, rather than simply the results of migration and facies linked distributions (MATSUMOTO, 1975, p. 157).

E. Upper Cenomanian correlations

Good correlations can be recognised between the higher parts of the European *Eucalycoceras pentagonum* Zone* and the Japanese *E. pentagonum* and *Calycoceras naviculare* Zone, that is to say the so-called Upper Zone of MATSUMOTO (1975, p. 157). Both *E. pentagonum* and *C. naviculare* occur together in both areas, although *naviculare* is a long-ranging species which also occurs in the *gracile* zone in Europe and the United States (see JUIGNET and KENNEDY, 1976 for a discussion of recent controversies over the limits and range of this species). A further species which has potential for correlation at this level is *Euomphaloceras asura* of MATSUMOTO and MURAMOTO (in MATSUMOTO *et al.*, 1969, p. 277, pl. 35, fig. 1, pl. 36, fig. 1; text-fig.37). We have recently re-studied the type of *Acanthoceras meridionale* var. *multicostata* BASSE (1940, p. 446, pl. 6, figs. 2a-b) from the Lebanon, which proves to be a senior synonym of *asura*, and indicates the potential wider recognition of the species. Much richer common faunas characterise the highest zone recognised in the Cenomanian, that is to say the European *Sciponoceras gracile* Zone and the Japanese *Kanabiceras septemseriatum-Pseudocalycoceras* aff. *dentonense* Zone, MATSUMOTO's (1975) uppermost Zone. Common to the two regions are *K. septemseriatum* (CRAGIN), *Sumitomoceras faustum* MATSUMOTO and MURAMOTO and *Pseudocalycoceras* of the *dentonense* (MOREMAN) group. Furthermore, the *Sciponoceras* of the two areas, *S. gracile* (SHUMARD) and *S. kossmati* (NOWAK) are very closely allied, if not conspecific (COOPER, in press) and co-occur in California (MATSUMOTO, 1959).

F. The base of the Turonian

The position of the Cenomanian-Turonian boundary has been a matter of much argument and debate, and it is placed at several different levels by macro and microfaunal workers (see reviews in RAWSON *et al.*, in press and KENNEDY and HANCOCK, in press). Discussion here would be irrelevant; for our purposes, we regard the *gracile* Zone and its correlatives as the highest Zone of the Cenomanian, and draw the base of the Turonian at the base of a broad *Mammites nodosoides* assemblage Zone, in full cognisance of the fact that the index species occurs above the base of the Zone, and that the effective base of the zone is tentatively taken at the appearance of numerous *Watinoceras coloradoense* (HENDERSON).

In many parts of the world, particularly in Tethyan regions, the base of the Turonian is taken at the appearance of vascoceratids. Recently BERTHOU and LAUVERJAT (1974a, b; 1975) (see also BERTHOU, 1973; CROSAZ, 1976) have recorded *Vascoceras gamai* (CHOFFAT) and *V. mundae* (CHOFFAT) from beds in Portugal which they date as Cenomanian. We were originally sceptical about this dating because it depended on benthic foraminifera, but BERTHOU and LAUVERJAT (1976) and LAUVERJAT (in press) have now found *Calycoceras* gr. *naviculare* in the same beds. If this record is fully confirmed a Cenomanian age for these *Vascocaras* can hardly be doubted. However, the exact dating of these early vascoceratids in Portugal, and their correlation with

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* Footnote: *E. pentagonum* has been proposed as a substitute for *C. naviculare* as index species of this zone by JUIGNET and KENNEDY (1976), because of variable usage of the term *naviculare* Zone (Fig. 1) and the long range of the species. We find ourselves in disagreement over the appropriateness of this change.

France and England seems to have been mis-placed. BERTHOU and LAUVERJAT (1975) equated their *gamai-mundae* Zone with the *Metoicoceras muelleri* Zone in Spain, with the *Calycoceras crassum* Zone in south-east France, with the upper part of the Zone of *Calycoceras naviculare* sensu lato in the Sarthe (equivalent to the Marnes à *Ostrea biauriculata*). In our view all these correlations place the *Vascoceras gamai-mundae* Zone of Portugal (couche F) too low in the zonal sequence.

Below the Zone of *V. gamai-mundae* in the Portugal, the Assise à *Neolobites vibrayeanus* yields the following (determinations revised by us):

Eucalycoceras cf. or aff. *pentagonum* (JUKES-BROWNE), (CHOFFAT, 1898, pl. 4, figs. 4-5; pl. 6, fig. 4).

Calycoceras naviculare (MANTELL), (CHOFFAT, 1898, pl. 4, figs. 6a-b; pl. 6, figs. 1-3).

Calycoceras cf. *robustum* THOMEL, (CHOFFAT, 1898, pl. 4, figs. 5a-b; pl. 6, fig. 1).

Thomelites group of *hancocki* KENNEDY and JUIGNET, (CHOFFAT, 1898, pl. 5, figs. 1a-b).

Neolobites vibrayeanus (d'ORBIGNY), (CHOFFAT, 1898, pl. 5, figs. 3a-b, 4a-b, 5a-b, etc.).

These ammonites indicate several levels in our *pentagonum* Zone, the *Eucalycoceras* and *Thomelites* in particular being diagnostic of the higher parts, i. e. Zone 6 à *Calycoceras crassum* of south-east France (THOMEL, 1973). We therefore suggest that the Zone of *Vascoceras gamai-mundae* is later than the Zone of *Eucalycoceras pentagonum*, and that it actually correlates with all or part of the *gracile* Zone of north-west Europe and North America.

In southern England diverse vascoceratids, amongst other ammonites, occur a little above *Watinoceras coloradoense* (see HANCOCK, KENNEDY and WRIGHT, this volume), which fits the situation observed in Japan. However, there are now known to be single examples of *Vascoceras* from the *gracile* Zone of north-west Europe and North America.

WIEDMANN (1960, 1964) has recorded both *Vascoceras gamai* and *V. mundae* associated with other ammonites in his Zone 2 of the Turonian (=his Zone of *Vascoceras gamai*). The most certain identifications were from Los Paramos, where they were associated with the Turonian genus *Watinoceras*. In his zonal summary (1960, p. 726) he records from his *gamai* Zone: true *Vascoceras*, *Metoicoceras gourdoni* (DE GROSSOUVRE), *Plesiovascoceras*, *Watinoceras* and *Gombeoceras*. This is a stratigraphic mixture, since *M. gourdoni* [=*M. geslinianum* (d'ORBIGNY) (KENNEDY, JUIGNET and HANCOCK, in preparation)] belongs to the *gracile* Zone, and the last three genera are all typical of the Lower Turonian. A similar mixture is recorded by WIEDMANN (1960, p. 720) from the Puentedei Valley: *Plesiovascoceras*, *Vascoceras* cf. *gamai*, *Watinoceras* sp., and *Metoicoceras swallovi* (SHUMARD); the last species normally occurs even lower in the Upper Cenomanian which again suggests a mixed assemblage. Since WIEDMANN also records *V.* cf. *mundae* with other species of *Vascoceras* and a variety of species of *Choffaticeras*, all unequivocally Turonian; and at no locality does he record either species of *Vascoceras* with an entirely Cenomanian assemblage, we do not feel that WIEDMANN's records provide independent evidence for *V. gamai-mundae* being other than early Turonian in age.

It is, however, quite clear that these vascoceratids occur, in Portugal at least, associated with microfossils which are generally regarded as of Cenomanian age. Perhaps the situation is similar to that in northern France and southern England, where the main changes in macro- and microfauna occur at different levels, and the stage boundaries of macro- and microfaunal workers do not correspond (see RAWSON *et al.* in press). Certainly, this very interesting problem needs further study, in particular a search for other ammonites in association with *Vascoceras gamai-mundae* in Portugal, for we do not think this important biogeographic and biostratigraphic discussion can be concluded without a fuller clarification of the ammonite succession in Portugal.

Ironically, there is now independent evidence for the presence of Cenomanian vascoceratids. *Ammonites diartianus* d'ORBIGNY (1850, p. 146=*Pachydiscus* sp. of JEFFERIES, 1936, p. 4) is a *gracile* Zone *Vascoceras* (KENNEDY and JUIGNET in preparation).

3. Summary

From discussions outlined above, and in Fig. 4, the following correlations are proposed between the Japanese and European Cenomanian.

1. The European *Stoliczkaia dispar* Zone correlates with the higher parts of the Japanese Zone of *Mortoniceras* (*Durnovarites*).
2. Part or all of the European *Hypoturrilites carcitanensis* and *Mantelliceras saxbii* Zones correlates with the Japanese *Mantelliceras japonicum-Sharpeiceras kongo* Zone.
3. The European *Turrilites costatus*, *T. acutus*, *Acanthoceras jukesbrownei* and basal *Eucalycoceras pentagonum* Zones correlate with the Japanese *Calycoceras orientale-Euomphaloceras meridionale-Acanthoceras takahasii* Zone.
4. The higher parts of the European *Eucalycoceras pentagonum* Zone correlate with the Japanese *Calycoceras* cf. *naviculare-Eucalycoceras pentagonum* Zone.
5. The European *Sciponoceras gracile* Zone correlates with the Japanese *Kanabiceras septemseriatum-Pseudocalycoceras* aff. *dentonense* Zone.

The 'Basal Zone' of the Japanese Cenomanian characterised by *Graysonites wooldridgei* and *Euhystrichoceras nicaisei* cannot be recognised in Europe outside Portugal. It may correspond to a regional non-sequence or be a reflection of exclusion of the ammonites of the *Graysonites-Utaturiceras* group from the Boreal Realm. In Japan, equivalents of the high Lower Cenomanian *Mantelliceras* gr. *dixoni* Zone have yet to be recognised, whilst in both areas, there are no transitional assemblages between Lower Cenomanian *Mantelliceras* dominated faunas and Middle Cenomanian *Acanthoceras-Calycoceras* dominated faunas.

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AMMONITE FAUNAS FROM THE CENOMANIAN AROUND LE MANS (SARTHE, FRANCE)

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Abstract

New ammonite faunas collected during the revision of the stratigraphy of the type area of the Cenomanian stage have led to the recognition of a detailed succession of eight assemblage zones. These zonal faunas show strong affinities with those of Normandy and England, and the divisions recognised (Carcitanensis, Saxbii, Dixoni, Costatus, Acutus, Jukesbrownei, Pentagonum, Gracile) allow more accurate correlation of the stratotype succession with that of other major Cretaceous basins than was previously possible.

1. Introduction

d'Orbigny defined the Cenomanian stage in the last century (1842, 1847, 1850, 1852), on the basis of the area around Le Mans (Sarthe) on the western border of the Paris Basin. Localities in the area mentioned by d'Orbigny were Saint-Calais, La Flèche, Cerans, Ecommoy, Grand Lucé, Coudrecieux, Vibraye, Lamnay and La Ferté-Bernard, whilst he also listed 809 species as characteristic of the stage, including 46 ammonite species of which ten were specifically cited from Sarthe.

Following the publication of the *Paléontologie Française* and Guéranger's *Album Paléontologique du département de la Sarthe* (1867), the ammonite faunas of the area were neglected. Recently, however, Hancock (1960) listed these faunas, and established the main biostratigraphic divisions, whilst Juignet, Kennedy and Wright (1973) provided further observations. The faunal lists given below are based upon new collections of several thousand specimens, as well as a revision of museum material, in collaboration with W. J. Kennedy. Results are provisional, and some of the determinations are of a preliminary nature.

2. Sedimentary Formations in the Type Area

The revision of the Cenomanian stratotype formed part of a general study of the Cretaceous transgression of the Paris Basin, on the margins of the Armorican Massif. Marine conditions were established in Normandy in Aptian times, but only reached Sarthe during the latest Albian, and extended during the Cenomanian.

The Cretaceous succession of Sarthe includes both terrigenous clastic and car-

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bonate units. Their environment of deposition was largely sublittoral, on a shallow, epicontinental platform, the submerged flank of the Armorican Massif. In consequence, lithostratigraphic boundaries are rarely synchronous, whilst lateral facies variation hinders the recognition of biostratigraphic units, although having the advantage of allowing comparisons between diverse faunas in the wide range of sediments developed. The names of formations stem largely from nineteenth century workers, and are often based upon common or prominent species (e. g. Sables à *Catopygus obtusus*), utilised for their abundance, and not their stratigraphic value.

The sequence of lithostratigraphic units may be briefly summarised as follows (Fig. 1).

At the base, the Glauconie à *Ostrea vesiculosa* rests with a marked discordance on Jurassic sediments, and in the east, is overlain by the Craie glauconieuse à *Pecten asper*. This passes laterally into the Marnes de Ballon, which in turn passes into the Argile Glauconieuse à Minerai de Fer towards the Armorican Massif in the west.

The Marnes de Ballon and Craie Glauconieuse are overlain by the Sables et Grès de la Trugalle et Lamnay, whilst eastwards, towards the centre of the basin, these pass laterally into the top of the Craie Glauconieuse.

Above, the Sables et Grès du Mans pass eastwards into the Marnes de Nogent-le-Bernard and thence the Craie de Théligny. To the west, the two sandy formations (the Sables et Grès de la Trugalle et Lamnay and the Sables et Grès du Mans) cannot

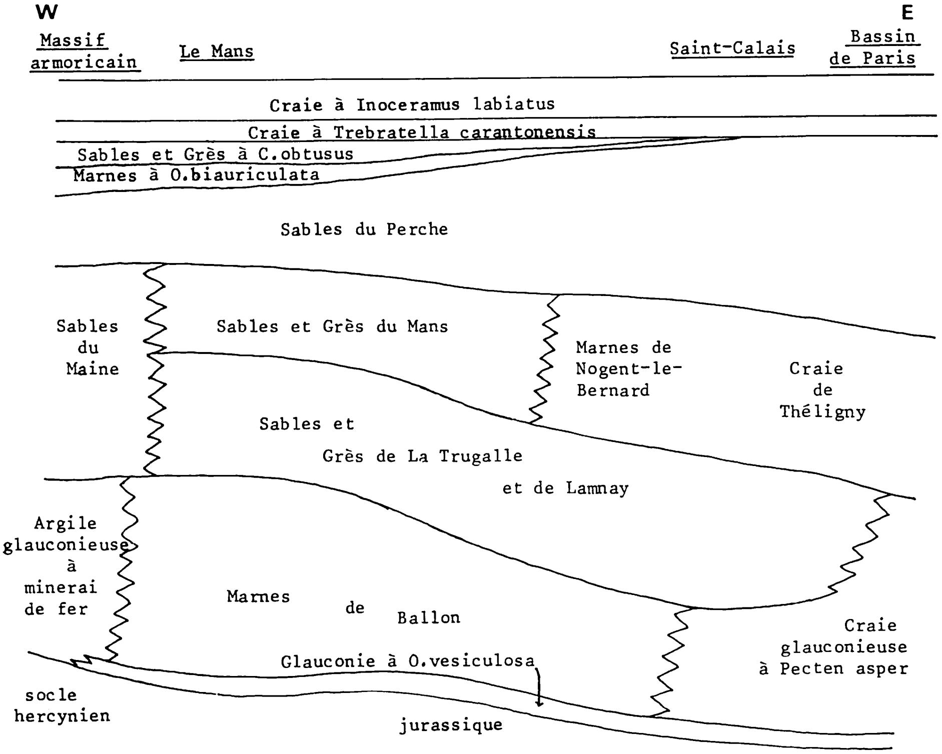

Fig. 1. Stratigraphic relationships between the various Cretaceous formations of the region around Le Mans (Sarthe).

be separated, passing into the Sables du Maine. Above, the Sables du Perche extend across the whole area. These are overlain by the Marnes à *Ostrea biauriculata* and the Sables et Grès à *Catopygus obtusus*, both of which attenuated markedly from west to east. They are absent in the Saint-Calais area, save as clasts and derived fossils at the base of the succeeding Craie à *Terebratella carantonensis* which, together with the succeeding Craie à *Inoceramus labiatus* extend uniformly over the whole region.

In summary, this succession may be perhaps interpreted as the deposits of three transgressive pulses; each comprises an initial carbonate or glauconite bearing phase overlain and passing up into terrigenous clastic sediments, the sequences being separated by region-wide discontinuities. The base of these sequences are at the base of the Glauconie à *O. vesiculosa*, the Craie de Théligny, and the Craie à *T. carantonensis.*

This account of the ammonites of the stratotype thus includes material from a wide range of facies, in an area 40 km by 20 km, delimited by the towns of Le Mans, Ballon, Théligny and Saint-Calais. Exposures are numerous, if small, but the regional dip is very low—a few degrees at most—and there is little other deformation to complicate interpretation and determination of relative horizon.

3. The Ammonite Faunas

The material is generally well preserved, and has commonly undergone little or no crushing, although original shell material has disappeared, leaving composite moulds, or is replaced by sparry calcite in many units. In some units of gaize (a distinctive siliceous facies), composite moulds are commonly deformed, although ornament and growth lines are well preserved. In contrast, early diagenetic cementation of fossil infillings in chalks, marls and calcareous sandstones has preserved original proportions. In some of the coarser clastic units cementation was only partial, and large specimens usually occur as whorl fragments only. In remanié horizons above sedimentary discontinuities (e. g. at the base of the Craie de Théligny) ammonites are phosphatised, and exquisitely preserved.

As noted above, the lists given below are preliminary, pending a full account of the fauna, a work which will complement HANCOCK's initial revision (1960), and the detailed accounts of the Cenomanian ammonite faunas of Normandy and southern England (KENNEDY, 1971; JUIGNET and KENNEDY, 1976). With this, synthesis of the Cenomanian ammonite faunas and zonation of the whole of the western Anglo-Paris Basin will be possible.

A. Craie glauconieuse à *Pecten asper*

The lower part is particularly rich in heteromorph ammonites, *Schloenbachia* and *Hyphoplites.* The association comprises *Austiniceras austeni* (SHARPE), *Euhystrichoceras nicaisei* (COQUAND), *Hyphoplites arausionensis horridus* WRIGHT and WRIGHT, *H. falcatus interpolatus* WRIGHT and WRIGHT, *H. pseudofalcatus* (SEMENOW), *Hypoturrilites* aff. *carcitanensis* (MATHERON), *H. mantelli* (SHARPE), *Idiohamites alternatus* (MANTELL), *I. a. vectensis* SPATH, *I. ellipticus ellipticus* (MANTELL), *I. e. radiatus* SPATH, *Mantelliceras* *cantianum* SPATH, *M. costatum* (MANTELL), *M.* cf. *mantelli* (J. SOWERBY), *M.* aff. *saxbii* (SHARPE), *M. tenue* SPATH, *M. tuberculatum* (MANTELL), *Mariella dorsetensis* (SPATH), *M. essenensis* (GEINITZ) *M. lewesiensis* (SPATH), *Schloenbachia varians* (J. SOWERBY) *subplana* (MANTELL), *S. v. subvarians* SPATH, *S. v. ventriosa* STIELER, *Sharpeiceras laticlavium* (SHARPE), and *Stoliczkaia* sp. nov.

A glauconitic horizon at the base (Glauconie à *Ostrea vesiculosa*) yields a slightly reworked, phosphatised fauna of Late Albian age comprising *Callihoplites variabilis* (SPATH), *Mortoniceras* sp. and *Semenovites* sp.

In the middle part, *Schloenbachia* and *Hyphoplites* persist in abundance, but *Mantelliceras* are much more frequent. The fauna includes *Euhystrichoceras nicaisei* (COQUAND), *Forbesiceras beaumontianum* (D'ORBIGNY), *F. largilliertianum* (D'ORBIGNY), *Hyphoplites arausionensis arausionensis* HÉBERT and MUNIER-CHALMAS, *H. a. horridus*, *H. campichei* SPATH, *H. costosus* WRIGHT and WRIGHT, *H. curvatus* (MANTELL), *H. falcatus falcatus* (MANTELL), *H. pseudofalcatus*, *Hypoturrilites gravesianus* (D'ORBIGNY), *Mantelliceras cantianum*, *M. costatum* (MANTELL), *M. couloni* (D'ORBIGNY), *M.* aff. *indianense* HYATT, *M. mantelli*, *M. tenue*, *M. saxbii*, *Mariella cenomanensis* (SCHLÜTER), *M. lewesiensis*, *Schloenbachia varians subtuberculata*, *S. v. subvarians*, and *S. v. ventriosa*.

The upper part is again rich in *Mantelliceras* and yields many *Acompsoceras*. The ammonite association includes *Acompsoceras essendiense* (SCHLÜTER), *A. renevieri* (SHARPE), *A. sarthense* (GUERANGER), *Forbesiceras obtectum*, (SHARPE), *Mantelliceras cantianum*, *M.* cf. *saxbii*, *Scaphites obliquus* J. SOWERBY, *Schloenbachia varians*. *Turrilites boersumensis* SCHLÜTER, and *Turrilites scheuchzerianus* Bosc.

B. Marnes de Ballon and Argile glauconieuse à minerai de fer

The base of these formations is probably also of late Albian age, on the basis of rare ammonites (*Callihoplites* and *Karamaiceras*) in the collections at Le Mans.

The lower part of the Marnes de Ballon yields an association with *Hyphoplites arausionensis arausionensis*, *H. falcatus aurora* WRIGHT and WRIGHT, *Hypoturrilites carcitanensis*, *Idiohamites alternatus alternatus* (MANTELL), *Schloenbachia varians subplana*, *S. v. subvarians*, *Sharpeiceras laticlavium*, and *Stoliczkaia* sp.

In the upper part, the fauna includes *Borissiakoceras* sp., *Hyphoplites falcatus falcatus*, *H. f. aurora*, *Mantelliceras saxbii*, *M. tenue*, *Schloenbachia varians subtuberculata*, and *S. v. subvarians*.

C. Sables et Grès de la Trugalle et de Lamnay

This formation, overlying the Marnes de Ballon, yields at its base *Mantelliceras* of the *cantianum*, *mantelli*, *saxbii* and *tenue* groups; above, it is characterised by the presence of *Mantelliceras orbignyi* (COLLIGNON), associated with *Forbesiceras* sp., *Hyphoplites curvatus*, *Hypoturrilites* sp., and a series of *Mantelliceras*, tentatively compared with *Mantelliceras* aff. *cantianum*, *M.* cf. *lateretuberculatum* COLLIGNON, *M.* aff. *letullieri* (COLLIGNON), *M.* aff. *spissum* COLLIGNON and *M.* sp. nov.; *Scaphites obliquus*, *Schloenbachia varians*, *S. v. subvarians*, *Turrilites costatus* LAMARCK, and *T. scheuchzerianus*.

D. Craie de Théligny et Marnes de Nogent-le-Bernard

These richly fossiliferous facies are extensions of the Craie de Rouen of Normandy. The lower part yields a rich association, especially as phosphatic moulds at the extreme base, with *Acanthoceras rhotomagense rhotomagense* (BRONGNIART), *A. r. clavatum* KENNEDY and HANCOCK, *A. r. confusum* (GUÉRANGER), *A. r. pseudeuomphalum* THOMEL, *A. r. subflexuosum* SPATH, *A. r. sussexiense* (MANTELL), *Acompsoceras renevieri*, *Anisoceras plicatile* (J. SOWERBY), *Austiniceras austeni*, *Calycoceras gentoni* (BRONGNIART), *Euomphaloceras cunningtoni* (SHARPE), *E. inerme* (PERVINQUIÈRE), *Forbesiceras largilliertianum*, *F. sculptum* CRICK, *Scaphites equalis* J. SOWERBY, *S. obliquus*, *Schloenbachia coupei* (BRONGNIART) and varieties, *Sciponoceras baculoide* (MANTELL), *Stomohamites simplex* (D'ORBIGNY), *Turrilites acutus* PASSY (rare), *T. costatus* (common), *T. scheuchzerianus*, and *Worthoceras* sp.

The upper part yields a rather similar assemblage, to which are added *Calycoceras* species, notably *C. gentoni*, *C. newboldi* (KOSSMAT), *C. n. spinosum* (KOSSMAT). *Acanthoceras jukesbrownei* (SPATH) appears at the summit.

E. Sables et Grès du Mans

The fauna of this unit is similar to that of the Craie de Théligny, with, in particular, *Acanthoceras rhotomagense* and varieties, *Calycoceras gentoni*, *C. newboldi spinosum*, *C. sarthense* (BAYLE), *Euomphaloceras cunningtoni*, *E. lonsdalei* (ADKINS), *Metengonoceras dumbli* (CRAGIN), *Scaphites equalis*, *S. obliquus*, *Sciponoceras baculoide*, *Stomohamites simplex*, *Schloenbachia coupei*, *Turrilites costatus*, *T. scheuchzerianus* and *Acanthoceras jukesbrownei* at the top (niveau du Jalais).

F. Sables du Perche

This unit, and those succeeding it, yield sparse ammonite faunas compared to those below, and our lists are largely based upon the well localised material in local museums, collected from the many small quarries open in the last century.

The base of the formation, (niveau à crustacés), yields *Acanthoceras jukesbrownei*, *Acompsoceras* sp., *Calycoceras gentoni* and varieties, *C. newboldi*, *Protacanthoceras* sp. The upper yields *Acanthoceras hippocastanum* (J. DE C. SOWERBY), *Calycoceras cenomanense* (D'ARCHIAC), *C.* aff. *naviculare* (MANTELL), and *Forbesiceras obtectum* (SHARPE).

G. Marnes a *Ostrea biauriculata*

Ammonites are very rare, but include *Acanthoceras hippocastanum*, *Calycoceras guerangeri* (SPATH), *C. naviculare*, *Pseudocalycoceras* gr. *harpax* (STOLICZKA), *P. haugi* (PERVINQUIÈRE), and *Thomelites sornayi* (THOMEL).

H. Sables et Grès à *Catopygus obtusus* or Sables de Bousse

These synchronous formations yield the following: *Calycoceras naviculare*, *Kanabiceras septemseriatum* (CRAGIN), *Metengonoceras dumbli*, *Metoicoceras geslinianum* (D'ORBIGNY), *Pseudocalycoceras* cf. *dentonense* (MOREMAN), *Sciponoceras gracile* (SHUMARD) (locally common), and *Proplacenticeras* sp. *Actinocamax plenus* (BLAINVILLE) also occurs.

I. Craie à *Terebratella carantonensis*

This unit has yielded only rare phosphatic moulds of ammonites (KENNEDY and JUIGNET, in press), e. g. *Sciponoceras gracile* and *Vascoceras diartianum* (D'ORBIGNY).

4. Limits and Subdivisions of the Cenomanian in the Type Area

If the faunal lists given above are compared with those previously published for southern England and Normandy (KENNEDY, 1971; JUIGNET and KENNEDY, 1976), it becomes immediately obvious that the biostratigraphic subdivisions established in these areas can be recognised within the stratotype succession. We recognise the following sequence.

Lower Cenomanian

1. *Hypoturrilites carcitanensis* assemblage zone, represented by the lower part of the Craie glauconieuse à *Pecten asper*, the Marnes de Ballon and Argile glauconieuse à minerai de fer: *Schloenbachia* and *Mantelliceras* appear, relative abundance of *Hyphoplites* and heteromorphs (*Idiohamites*, *Mariella* etc.), Locally, deposits of this zone rest on Upper Albian, *Stoliczkaia dispar* zone sediments.
2. *Mantelliceras saxbii* assemblage zone, represented by the middle part of the Craie glauconieuse, the upper part of the Marnes de Ballon and probably the base of Sables et Grés de Lamnay: *Mantelliceras* is common, whilst *Hyphoplites* and *Schloenbachia* persist.
3. *Mantelliceras dixoni* assemblage zone, represented by the top of the Craie glauconieuse à *Pecten asper* and the Sables et Grès de la Trugalle et de Lamnay: persistence of *Mantelliceras*, notably forms with *Calycoceras*-like outer whorls but lacking siphonal tubercles when young, and thus true *Mantelliceras*, e. g. *Mantelliceras orbignyi*, which may prove to be a more suitable zonal index fossil than the poorly understood *M. dixoni*. *Turrilites* appears at this level.

Middle Cenomanian

4. *Turrilites costatus* assemblage zone, represented by the lower part of the Craie de Théligny (including the basal phosphatic fauna), the Marnes de Nogent-le-Bernard and the Sables du Mans: abundance of *Acanthoceras* of the *rhotomagense* group, together with *Schloenbachia coupei*. which replaces *S. varians;* numerous heteromorphs, including *Scaphites*, *Sciponoceras baculoide* (abundant locally), *Stomohamites* and *Turrilites*, with *T. costatus* numerically dominant over *T. acutus;* appearance of *Calycoceras.*
5. *Turrilites acutus* assemblage zone, represented in the same formations as the preceeding *costatus* zone. The fauna is similar to that of the zone below, but *T. acutus* replaces *T. costatus* as the dominant turrilitid, although the latter survives; *Sciponoceras baculoide* becomes scarce, and *Calycoceras* of the *gentoni* group more frequent.
6. *Acanthoceras jukesbrownei* assemblage zone, represented by the top of the Craie de Théligny, Marnes de Nogent-le-Bernard and the Sables du Mans, as well as the base of the supradjacent Sables du Perche: *Acanthoceras* of *rhotomagense* group decline, being replaced by *Acanthoceras jukesbrownei; Calycoceras* of the *newboldi* group become more frequent, and heteromorphs less prominent.

Upper Cenomanian

7. *Eucalycoceras pentagonum* assemblage zone, reprented by the Sables du Perche

and the Marnes à *Ostrea biauriculata:* the lower part (Sables du Perche) is characterised by the common occurrence of *Calycoceras cenomanense* and the appearance of *Calycoceras* of the *naviculare* group. The upper part (Marnes à *O. biauriculata*) is characterised by *Calycoceras guerangeri*, with rare *Thomelites*, *Eucalycoceras* and *Pseudocalycoceras*.

8. *Sciponoceras gracile* assemblage zone, represented by the Sables á *Catopygus obtusus*-Sables de Bousse (the latter are an expanded equivalent of the former, developed around Bousse) and the Craie à *Terebratella carantonensis:* appearance of *Kanabiceras* and *Metoicoceras*, persistence of *Calycoceras naviculare*, and abundance of *Sciponoceras gracile.*

In the region around Le Mans, the Craie à *Terebratella carantonensis* grades up into marly Craie à *Inoceramus labiatus*. The base of the Turonian is taken at the level of replacement of *Inoceramus* of the *pictus* group by the *labiatus* group. Ammonites are scarce, but the presence of *Mammites*, *Lewesiceras*, *Watinoceras* and *Neocardioceras* in museum collections indicates that a similar succession to that occurring in the south of England (HANCOCK, KENNEDY and WRIGHT, this volume) will be eventually recognisable, the boundary thus corresponding to the base of a broad *Mammites nodosoides* assemblage zone.

5. Conclusions

This provisional revision of the ammonite faunas of the Cenomanian stratotype shows that the faunas are of predominantly Boreal type, and that they support, and can be precisely correlated with successions and zonal schemes previously proposed for Normandy and southern England. The faunas also include elements better known from the mesogean areas to the south (*Pseudocalycoceras*, *Thomelites*, *Neolobites*, *Metengonoceras*), albeit as rarities, permitting correlation in this direction. Furthermore, the extensive suite of acanthoceratids of near world wide distribution, notably *Mantelliceras*, *Acanthoceras*, *Calycoceras* and *Metoicoceras* will permit correlation of the type succession with sequences in widely separated areas of the globe. This theme is taken up by KENNEDY and HANCOCK elsewhere in this volume, where a detailed correlation of the zonal sequence outlined above with that recognised in the Japanese Islands is proposed.

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TOWARDS A CORRELATION OF THE TURONIAN SEQUENCES OF JAPAN WITH THOSE OF NORTH-WEST EUROPE

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Abstract

Each of the previously published ammonite zonations for the Turonian in western Europe differs from the others. This is because each region has its own small number of discrete assemblage zones separated by sediments with few or no ammonites, and they are particularly scarce in most of the chalk facies. An attempt has now been made to correlate the seemingly different zonations of southern England and the type area of the stage in Touraine, France.

For exact correlation over so great a distance as between Japan and north-west Europe, isolated assemblage zones are inadequate. It would be necessary to know actual phylogenetic sequences of the ammonites. Three groups are potentially useful: Vascoceratidae, Collignoniceratinae and *Romaniceras* spp. Of these, the Vascoceratidae are rare both in Japan and north-west Europe. The later phylogeny of the Collignoniceratinae is better displayed in Japan than in Europe. The succession of *Romaniceras* spp. was poorly known in both regions, but more has now been worked out of their European stratigraphy.

Introduction

Whereas a relatively detailed ammonite zonation has been worked out for the Cenomanian of north-west Europe (see preceding paper), our knowledge of the Turonian succession has been poor. The three standard ammonite zones erected by WRIGHT (in ARKELL *et al* 1957) have been repeatedly copied (e.g. HANCOCK 1972; KENNEDY and COBBAN 1976; RAWSON *et al.* in press), and can be recognised over long distances; their main limitation is that their boundaries are vague. Since the Turonian probably lasted only 2-3 Ma (OBRADOVICH and COBBAN, 1975) (though VAN

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HINTE 1976 has proposed 6 Ma), the three zones each represent on average 0.67-1 Ma (KENNEDY and COBBAN, 1976), comparable with zones of the higher Cretaoceous stages.

In Japan, not only can WRIGHT's three zones be recognised, but by 1971 MATSUMOTO had erected some five ammonite zones for the middle to upper Turonian. In a later work (in press) he has proposed a slightly modified six-fold ammonite zonation for the whole stage. The European sequences therefore need to be reviewed before a Japanese-north-west European correlation is attempted.

In order to understand the limitations of the zonation of the Turonian, it is necessary to explain the difficulties which face any geologist who works on north-west European Turonian ammonites and the type locality in Touraine. The first difficulty is a relative scarcity of the ammonites themselves. Most of the Turonian is in a chalk facies and chalk is notorious for its poverty of any fossils which originally had aragonitic skeletons. Whether ammonites did not live over most of the Chalk regions of north-west Europe for much of the Turonian, or whether they were there but have not usually been preserved, or some combination of these two, is not immediately germane to our problem.

In the underlying Cenomanian the limitations of the ammonite record in the chalk facies is compensated for by ammonite-rich beds in nearer shore facies, e. g. in Devon (KENNEDY, 1970) and Sarthe (JUIGNET, 1974), but there are relatively few nearer shore sediments of Turonian age. The regressive Turonian in north-west Europe is usually unrepresented by any sediment at all in the nearer shore regions (HANCOCK, 1975). Only in Touraine is there a well developed regressive sequence of marginal facies of Turonian age. Conveniently, this includes the stratotype of the Turonian stage.

It would be misleading to suggest that ammonites are consistently scarce throughout the Turonian chalk. There are certain beds in southern England and northern France in which ammonites are at least sufficiently common for an assemblage zone to be recognised after much patient collecting, e. g. in the upper part of the Melbourn Rock (see Fig. 2). A similar situation exists in the Turonian of Touraine: ammonites have been collected from several levels, and there are a few beds in which they are common enough to form an assemblage. So the second difficulty to be overcome is to piece together the correct stratigraphic order of a number of geographically isolated assemblages. This still leaves much Turonian from which no ammonites are known in north-west Europe. Moreover, the very different generic composition of successive ammonite assemblages that can be found might suggest that they represent migrations of ammonites into the region, rather than evolutionary developments within north-west Europe.

Many of the most widely quoted species of Turonian ammonites were first described from this region. As often happened with these early, almost haphazard, creation of new specific names, many of them were based on single specimens from uncertain horizons. Until the type material and type occurrences of these classic species have been adequately revised, each of them is impotent for detailed correlation; at present, a specific name in a list of ammonites is often no better than a generic record in modern terms. Two examples of important Turonian species will illustrate this third difficulty.

Collignoniceras woollgari (MANTELL) was based on several specimens, of which two were figured by MANTELL (1822; pl. 21, fig. 16; pl. 22, fig. 7), and one was designated lectotype by WRIGHT and WRIGHT (1951). The types were said by MANTELL to have come from the 'lower chalk' near Lewes in England, but we really have no knowledge of their precise horizon within the lower part of the Turonian. It is a species generally thought to be characteristic of the broad Zone of *Terebratulina lata* (middle Turonian) of the English Chalk. WRIGHT and WRIGHT (1951, p. 35) suggested that the lectotype came from the underlying Zone of *Inoceramus labiatus* (lower Turonian), but this was probably a mistake.

The genus *Collignoniceras* undoubtedly has a considerable stratigraphical range in the Turonian Chalk, and each species of this genus is known to show very wide intra-specific variation within a single horizon (see studies by HAAS, 1946; COBBAN, ROHRER and ERDMANN, 1956; MATSUMOTO and MILLER, 1958; MATSUMOTO, 1965). Hence correlation between the stratigraphic horizon of an isolated specimen from a poorly fossiliferous sequence and a region richer in *Collignoniceras*, can only be approximate.

At least there is an extant lectotype of *C. woollgari*, with a reasonable figure available since the last century (SHARPE, 1854, pl. 11, figs. 1a, b), and now illustrated photographically (KENNEDY and HANCOCK, in press, pl.17). In the case of *Romaniceras deverianum* (D'ORBIGNY) we are really in difficulties, quite apart from the action of DE GROSSOUVRE (1889) who mis-spelt the trivial name as '*deveriai*'. D'ORBIGNY'S figures (1841, pl. 110, figs. 1 and 2) were based on two different specimens, one from D'ORBIGNY's own collection, one from that of Prosper RENAUX. Both were recorded as coming from Uchaux (Vaucluse, France), and as being red and silicified. The surviving D'ORBIGNY specimen does not agree with his figure, and RENAUX's specimen has not been seen for some years. Nor can we assume that the two originals were really the same species in modern terms, and hence reasonably represented by D'ORBIGNY's synthetograph [thus his figures of *Ammonites prosperianus* (1841, pl. 100, figs. 3-4) were based, according to his own statement (1841, p. 336), on several specimens from his own collection and that of RENAUX; as a result the species is a chimera with the general shape of a pachydiscid and the ornament of the heteromorph *Hyphantoceras* (KENNEDY and COOPER, 1977)]. As for srtatigraphic horizon, it is widely assumed that *R. deverianum* comes from very high in the Turonian, but the ammonite stratigraphy at Uchaux is poorly known, and this can only be an assumption (MENNESSIER, 1950; SORNAY, 1950) (see pp. 161-163).

We shall not attempt in this paper to resolve all the tangles of taxonomy amongst Turonian ammonites. However, to avoid further confusion we shall use for European material, as far as possible, names whose type specimens are from known horizons and localities. Even if these names later prove to be junior synonyms, at least it should be possible to work out their meaning.

For convenience we have separated our descriptions of the Turonian in Touraine and England into low, mid and high Turonian. These are divisions of local convenience and not intended to be definitive sub-stages.

Touraine

At the beginning of the Turonian this region formed a south-western embayment of the chalk sea of the Paris basin. As sea-level fell, Touraine became a marginal shelf to the chalk sea in which were deposited metre-bedded carbonate-grainstones known in France as 'tuffeau'. In the upper part of the stage this tuffeau becomes sandy and glauconitic, and even non-carbonate greensands are developed in western Touraine (Fig. 1). Disconformities occur near the top, and sedimentologically the glauconitic beds may well represent as much time as the rest of the succession put together. There are no sharp lithic boundaries in this marginal regressive facies sequence. Ammonite occurrences are isolated both stratigraphically and geographically.

(1) low Turonian

The base of the stage is formed by the Craie Marneuse. Since nobody has yet defined this formation in precise terms, it is moot whether the top Cenomanian *gracile* Zone in the Cher Valley lies in the base of the Craie Marneuse (as is assumed in RAWSON *et al*, in press), or in the top of the Marnes à Ostracées (as shown in Fig. 1). There is a lithic passage between the two formations in spite of three sedimento-

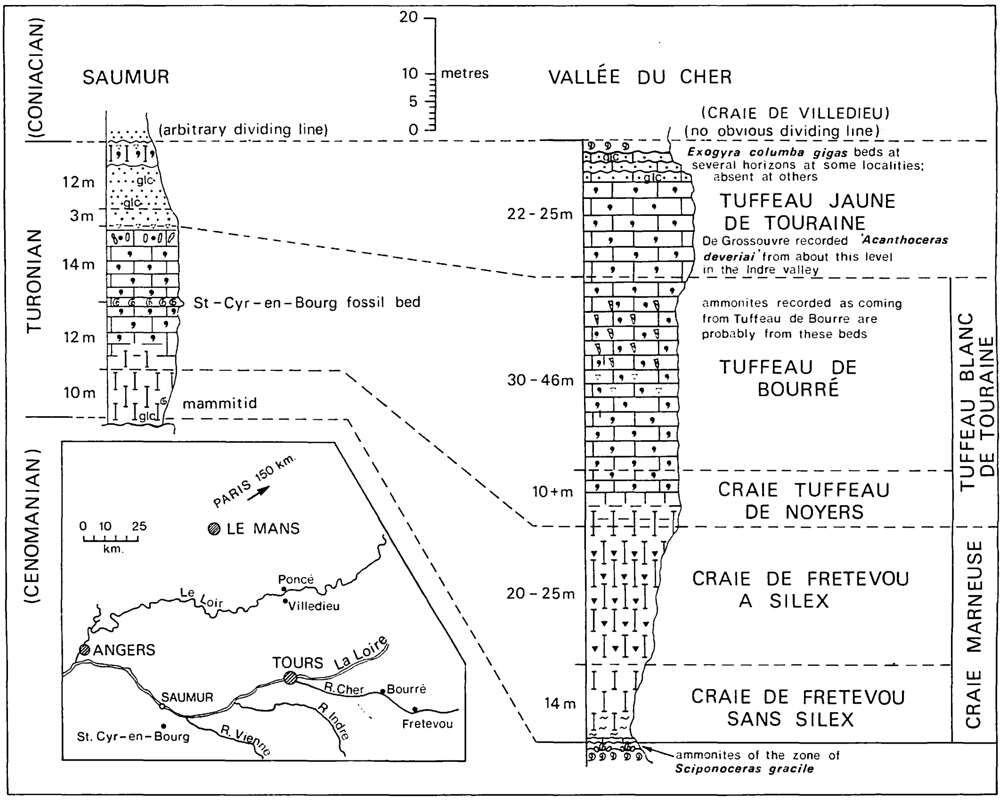

Fig. 1. Typical sections of the Turonian in Touraine, France. Based on our own observations and the works of ALCAYDÉ and LECOINTRE.

logical discontinuities in these passage beds.

The earliest undoubted Turonian ammonites certainly occur within the Craie Marneuse, but they are very rare. We have seen one poorly preserved mammitid from south of Saumur (Fig. 1); LECOINTRE (1960) recorded 'un gros *Mammites*' (elsewhere called *M. nodosoides* (SCHLOTHEIM)) and '*Pachydiscus peramplus* (MANTELL),' from both members of the Craie Marneuse, but no locality was given; ALCAYDÉ has recorded the same genera from the Amboise district, but none in his other explanatory booklets to the 1: 50,000 geological maps of the region. This is a much poorer assemblage than the early Turonian ones of northern France, southern England and Germany.

(2) **mid Turonian**

The Tuffeau Blanc de Touraine at Bourré in the Cher valley and its equivalents, to the west near Saumur and to the north at Poncé, have all yielded a considerable number of ammonites. In 1889 DE GROSSOUVRE recorded ammonites from all three districts, but did not try to separate them stratigraphically. In 1897 (but not published until 1901) he recognised that 'these different faunas, in spite of the forms in common that they contain, belong perhaps to slightly different horizons' (1901, p. 336). A few years later in the same work (pp. 779-781), he placed the three assemblages in a suggested stratigraphic order:

Poncé/Bourré/Saumur

on the basis that the *Romaniceras* at Poncé was a species that he had found also near the top of the Turonian, whilst the *Romaniceras* from Bourré was closer to the *Romaniceras* from Saumur than that from Poncé. These three assemblages, plus a *Romaniceras* '*deveriai*' Zone at the summit, are the basis of four *Romaniceras* zones of DE GROSSOUVRE, although he combined the bottom one of these with a *Mammites nodosoides* Zone in his tabular summary (1901, p. 830), Even if DE GROSSOUVRE's interpretation of these *Romaniceras* be correct, it does not prove the relative order of the Bourré and Saumur assemblages, but we agree with DE GROSSOUVRE on this point for other reasons. Firstly, from a careful examination of the Saumur district, we have found that ammonites occur there in only one bed in the Tuffeau, which since it is well exposed around St. Cyr-en-Bourg we call the St. Cyr-en-Bourg Fossil Bed (see Fig. 1). ALCAYDÉ (1970) refers to the same bed as forming the roof of workings in the Tuffeau near Saumur.

Whereas we know the lithic horizon of the Saumur ammonite fauna, the horizon of the Tuffeau de Bourré ammonites in the Cher valley is much less certain. We have failed to find a single ammonite near Bourré, but this is hardly surprising when one realises that scarcely a couple of ammonites a year were found by the workmen in the original underground workings (DE GROSSOUVRE, 1901, p. 335). However, we have noted that moulds of aragonitic fossils occur only in the upper half of the Tuffeau de Bourré, and therefore the Bourré ammonites are probably younger than those of Saumur. By analogy with the one bed occurrence of the Saumur fauna, it may be that the Bourré ammonites also came from a single bed.

With regard to the Poncé fauna, we have no reason to doubt DE GROSSOUVRE's conclusion that this is from yet another horizon, but at Poncé the exposures are now poor, and we ourselves were only able to find fossils of calcitic organisms.

Saumur fauna: From the St. Cyr-en-Bourg Fossil Bed we have collected:

Lewesiceras sp.
Neoptychites cephalotus (COURTILLER)
Romaniceras hispanicum WIEDMANN
Jeanrogericeras reveliereanum (COURTILLER)—common
Kamerunoceras salmuriense (COURTILLER)—common
Collignoniceras (*Collignoniceras*) *carolinum* (D'ORBIGNY)
Collignoniceras (*Selwynoceras*) *schlueterianum* (LAUBE and BRUDER)
Collignoniceras (*Selwynoceras*) aff. *papale* (D'ORBIGNY)
Collignoniceras (*Selwynoceras*) *fleuriausianum* (D'ORBIGNY)

In addition we have seen in the Angers museum specimens from the tuffeau labelled 'Saumoussay' which we believe are from the same fossil bed:

Sciponoceras aff. *bohemicum* (FRITSCH)

This total list agrees well with that given by COURTILLER (1867).

Bourré fauna: We have seen the following museum specimes which we are confident are from the Tuffeau de Bourré in the Cher valley:

Pseudotissotia (*Pseudotissotia*) *galliennei* (D'ORBIGNY)
Romaniceras deverioide (DE GROSSOUVRE)
Romaniceras deverioide armata (DE GROSSOUVRE)
Collignoniceras (*Selwynoceras*) gr. *papale* (D'ORB.)—two forms
Collignoniceras (*Collignoniceras*) cf. *C. woollgari sensu* MATSUMOTO, 1965 group E (*non C. woollgari* (MANTELL))
Collignoniceras (*Selwynoceras*) *canthus* (SORNAY ex D'ORBIGNY ms.)
Collignoniceras (*Selwynoceras*) *turoniense* (SORNAY)

Poncé fauna: We have seen museum specimens believed to be from Poncé:

Lewesiceras peramplum (MANTELL)
Romaniceras deverioide inerme (DE GROSSOUVRE)
Romaniccras deverioide armata (DE GROSSOUVRE)
R. deverioide (DE GROSSOUVRE) var. 3
Collignoniceras spp.

This was also the type locality of *Pseudotissotia galliennei* (D'ORBIGNY). DE GROSSOUVRE considered that the *Collignoniceras* from Poncé were the true *C. woollgari* (MANTELL) and never *C. papale* (D'ORBIGNY), the latter being common at Bourré.

This distribution of *Romaniceras* spp. between Bourré does not agree with DE GROSSOUVRE's observations (1901, 780-781) that *R. deverioide inerme* occurred only at Bourré and *R. deverioide armata* occurred only at Poncé.

(3) high Turonian

Ammonites are extremely rare in the higher part of the Turonian succession. The only specimens that we know of are those recorded by DE GROSSOUVRE. From the Tuffeau Jaune de Touraine near St. Georges-sur-Cher in the Cher valley, and also downstream from Clion in the Indre valley, he recorded *Ammonites deveriai* and *A. requieni* (1889, pp. 495, 499). To these he added *Gauthiericeras bravaisi* (presumably a *Subpriono-cyclus*) from Clion in 1901 (p. 336). We have seen only the two museum specimens from the Cher valley which are:

Romaniceras uchauxense COLLIGNON
Coilopoceras cf. *requienianum* (D'ORBIGNY)

DE GROSSOUVRE's most clear record is that from Clion where the ammonites were collected from a bed with a sandy texture in the upper part of the Pierre de Clion which itself forms the bottom of the Tuffeau Jaune de Touraine. This means that there are glauconitic beds with disconformities above the highest occurrence of Turonian ammonites in Touraine and below the overlying Craie de Villedieu (Coniacian), wherever one chooses to try to place the base of the Craie de Villedieu in the lithic passage beds.

England

Whereas in Touraine it is the middle Turonian which has yielded a reasonable number of ammonites, mid Turonian ammonites are few and poorly known in England, and it is the low and high Turonian chalk which has yielded numbers of ammonites (Fig. 2).

(1) low Turonian

Lewesiceras and *Mammites* are found occasionally in the *labiatus* Zone of most counties of southern England, but it is only in Devon that lower Turonian ammonites are sufficiently common to form any sort of assemblage or succession. Even in that county it is only in Haven Cliff, to the east of Seaton, that workable sections are easily found. The detailed lithology varies laterally over distance of a few hundred metres, but the most usual succession is shown in Fig. 2. The Neocardioceras Pebble Bed contains remanié ammonites generally considered to be *gracile* Zone forms, e. g. *Sciponoceras gracile*, accompanied by *Neocardioceras juddi* (BARROIS and GUERNE) which are also usually worn and have themselves been pebbles on the submarine disconformity, and we should therefore be inclined to date them as late *gracile* Zone. Occasional *Watinoceras coloradoense* (HENDERSON) and *Neocardioceras* sp. nov. are found in the same bed, but they are typically unworn, and their main occurrence is up to 50 mm above the base of the Pebble Bed; this is considered to be the earliest Turonian ammonite association in the area.

Mammites is reasonably common in the range 0.5 to 2.7 m above the base of the Neocardioceras Pebble Bed, and the rarer ammonites of the *Mammites nodosoides* assemblage zone probably come from the same range:

Lewesiceras peramplum (MANTELL)
Mammites nodosoides (SCHLOTHEIM)
Metasigaloceras rusticum (J. SOWERBY)
Plesiovascoceras catinum (MANTELL)
Fagesia pachydiscoides SPATH

In the Orval H. BAYLISS collection there is a *Plesiovascoceras* and a *Mammites* which are believed to be from higher in the Middle Chalk. The horizon within the *labiatus* Zone of *Kamerunoceras* aff. *salmuriense* is not known.

(2) mid Turonian

Ammonites are very rare in the upper half of the *labiatus* Zone. Apart from oc-

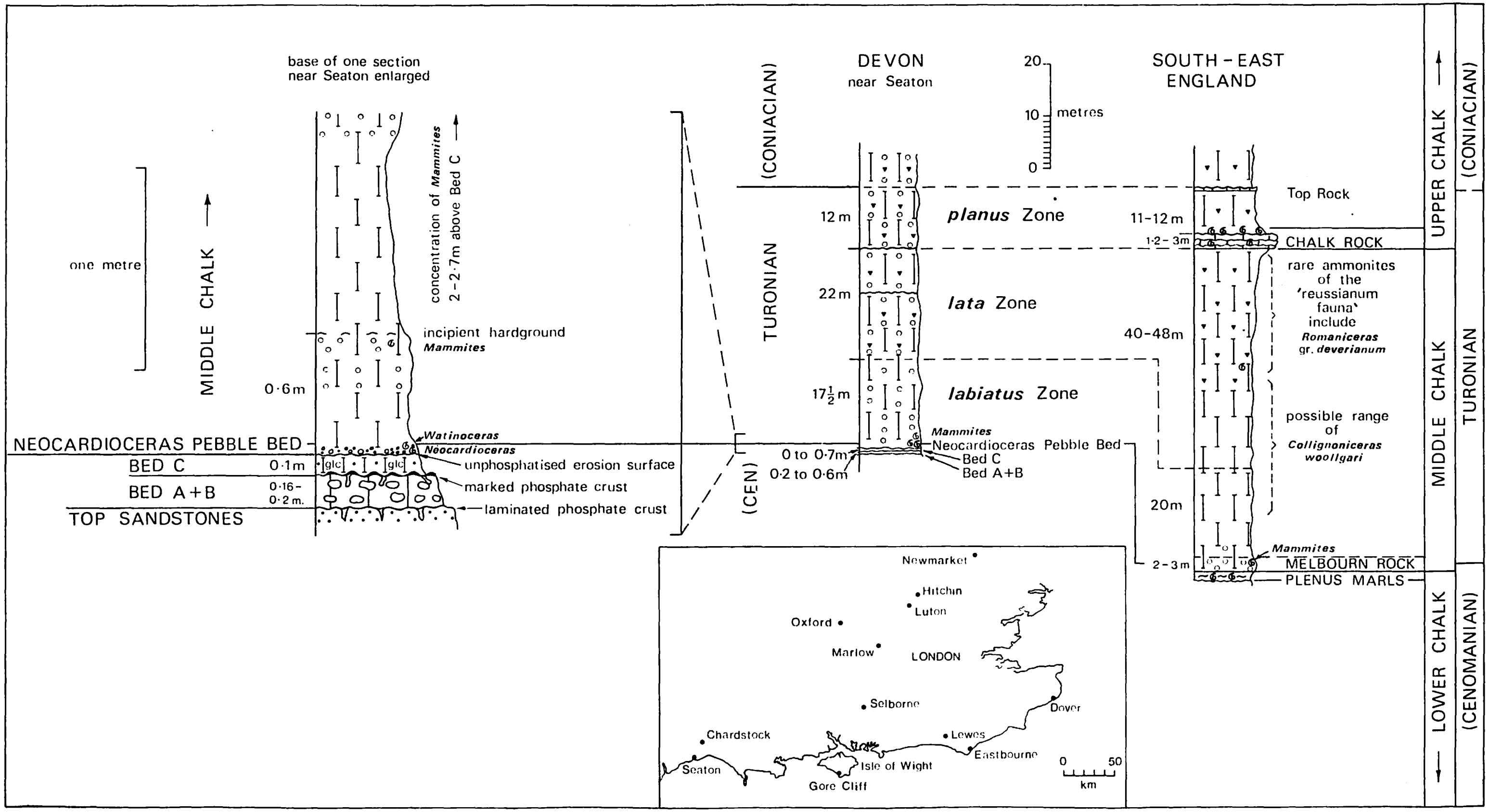

Fig. 2. Sections of the Turonian in southern England. The column for south-east England is generalised: the Chalk Rock in its typical from is not developed south of London. Based on our own observations and standard references quoted in the text.

casional *Lewesiceras* and possible *Austiniceras*, the only ammonites known are *Collignoniceras*. We have seen one *Collignoniceras* (*Selwynoceras*) sp. from the *labiatus* Zone of Surrey (J. HOLLIS coll.) and the old records of *Ammonites cunningtoni* from the *labiatus* Zone (e. g. JUKES-BROWNE and HILL, 1904, p. 468; ROWE, 1900, p. 366; 1901, p. 58) were probably *Collignoniceras*.

Ammonites are rare in the *lata* Zone, perhaps particularly so in the lower half. *Collignoniceras woollgari* (MANTELL) itself may be from the *lata* Zone. The holotype is a relatively large specimen (diameter 125 mm), but there are five museum specimens in front of us of a similar size to the series figured by MATSUMOTO (1965, pls. 1-3) from the Turonian of Wyoming. The English specimens do not agree with any of MATSUMOTO's individuals, although the closest approach is to MATSUMOTO's group E; the English form has a consistently lower rib density. It could be that none of the wide series of *Collignoniceras* from Wyoming and Colorado is the true *C. woollgari* (MANTELL), as has already been suggested by ADKINS (1928), MOREMAN (1942), and HAAS (1946).

There are a number of records of '*Collignoniceras woollgari*' from the English *lata* Zone of Sussex, e. g. JUKES-BROWNE and HILL, 1904, p. 469; GASTER, 1929, and three crushed specimens have been found in the upper part of the *lata* Zone of Mickleham, Surrey (C. W. WRIGHT coll.).

(3) high Turonian

The richest upper Turonian ammonite fauna of Europe is found in the lower part of the English *planus* Zone. It occurs in bands of nodular chalk in Kent and Surrey, but most of it has come from the Chalk Rock at the base of the Upper Chalk in the counties of Berkshire, Hertfordshire, Bedfordshire and Cambridgshire (Fig. 2). Howerever, really rich ammonite assemblages are very local; even a place famous for Chalk Rock ammonites—Cuckhamsley Knob, near Farnborough, 25 km south-south-west of Oxford—yielded no ammonites to JUKES-BROWNE when he visited the pit (1904, p. 202); most Chalk Rock localities yield no ammonites at all. The Chalk Rock is formed of up to seven hard-grounds in close succession (BROMLEY 1968; KENNEDY and GARRISON, 1975), and at places where ammonites are really common, they are usually concentrated at one level, which is often in and on the top of the highest hard-ground (WRIGHT, in press), as at Mount's Farm Pit, Marlow. At other localities the ammonites are concentrated in the bottom hard-ground, e. g. at Kensworth, 6 km south-west of Luton (KENNEDY and GARRISON, 1975, fig. 23). Therefore it cannot be assumed that all the ammonites recorded from the Chalk Rock belong to precisely the same stratigraphic horizon. Indeed, ammonites can occur at several levels within the Chalk Rock at one place, a feature observed many years ago by JUKES-BROWNE (1904, p. 210).

At localities like Underwood Hall, 7 km south-west of Newmarket, where instead of discrete hard-grounds there are patchy developments of lumpy chalk-rock facies, aragonitic fossils, such as ammonites, are spread over a thickness of more than 4 m, though most of them occur over 2 m (OSBORNE WHITE, 1932, p. 38). On the Guildford by-pass in Surrey, there are three nodular bands and ammonites occur in all three, as well as occasionally in between, but are most abundant in the top one. In Kent, where such originally aragonitic fossils (as moulds) are known to occur through considerable thicknesses of chalk, ammonites such as *Lewesiceras* cf. *mantelli* and *Hyphantoceras* (?), often thought of as typical Chalk Rock fossils, have been found up to 24 m below the base of the *planus* Zone (HOLMES *in* DINES *et al.*, 1969, p. 106). Collectively, the ammonites and other fossils of aragonitic organisms, from the upper part of the *lata* Zone plus those from the Chalk Rock are together widely known as the Reussianum Fauna, after *Hyphantoceras reussianum*, an oft-quoted Chalk Rock ammonite. We deplore this nomenclature which involves using what was intended to be the name for a zone as the name for a preservation fauna, embracing ammonites, gastropods and corals wherever they may happen to occur stratigraphically. We have used 'reussianum fauna' on Fig. 2 merely to emphasise that records of this fauna are not confined to the horizons of the Chalk Rock.

From scattered localities in the upper part of the *lata* Zone have been found:

Sciponoceras bohemicum (FRITSCH)
Scaphites geinitzii D'ORBIGNY
Hyphantoceras sp.
Lewesiceras mantelli WRIGHT and WRIGHT
Collignoniceras sp. (possibly from base of *planus* Zone)
Romaniceras gr. *deverianum* (D'ORBIGNY)

The occurrence of *R. deverianum* is of great importance in providing a link with Touraine and elsewhere. The record is based on three specimens: one from Latimer, Bucks, north-west of London (C. W. WRIGHT ex R. E. H. REID coll.); one from near Colemore, 5 km south-west of Selborne (Inst. Geol. Sci. 289H) (exact horizon not known); and one from south of Amberley station, Sussex (B. M. (N. H.) C34946; recorded by GASTER 1932), There are several other specimens of *Romaniceras* from England, but they are either unlocated or specifically indeterminable. The record of WRIGHT and WRIGHT (1951) from '? *subglobosus* Zone' (Cenomanian) is based on a remarkable specimen which develops *Romaniceras* tuberculation only on the outer whorl; its affinities are cryptic, but it could be a pathological individual of another genus. The *Romaniceras* figured by SHARPE (1857, pl. 19, fig. 5), the type of *Romaniceras sharpei* (ZÁZVORKA), is a *R.* gr. *deverianum*, as already pointed out by COLLIGNON (1939, p. 93), and probably came from the *lata* Zone. It is important to note that of the thousands of ammonites collected from the Chalk Rock, not a single one is a *Romaniceras* (WRIGHT, in press).

The Chalk Rock ammonite fauna includes the following, in addition to undescribed forms (WRIGHT, in press):

Metaptychoceras smithi (WOODS)
Sciponoceras bohemicum (FRITSCH)
Baculites undulatus ROMAN and MAZERAN, ex D'ORBIGNY
Allocrioceras angustum (J. DE C. SOWERBY)
Neocrioceras (*Schlueterella*) *multinodosum* (SCHLÜTER)
Didymoceras saxonicum (SCHLÜTER)
Hyphantoceras reussianum (D'ORBIGNY)
Scaphites geinitzii D'ORBIGNY
Scaphites kieslingwaldensis LANGENHAM and GRUNDY

Scaphites pseudoaequalis YABE
Otoscapoites bladenensis (SCHLÜTER)
Puzosia curvatisulcata CHATWIN and WITHERS
Lewesiceras mantelli WRIGHT and WRIGHT
Pseudojacobites farmeryi (CRICK)
Tongoboryoceras rhodanicum (ROMAN and MAZERAN)
Subprionocyclus hitchinensis (BILLINGHURST)
Subpriococyclus neptuni (GEINITZ)
Subprionocyclus branneri (ANDERSON)
Subprionocyclus normalis (ANDERSON)

Even with the knowledge that ammonites occur at various levels within the Chalk Rock complex, we have not been able to distinguish more than one Chalk Rock assemblage. It should be noted that *Subprionocyclus neptuni* and *S. normalis* are known to occur together at both Hitch Wood (11 km east of Luton) and Kensworth.

Speculations on the North-west European Succession

A sort of zonal scheme from the successions in southern England and northern France is given in Table 1. The type region in Touraine has most of its ammonites concentrated in the middle of the stage. It is clear that the earliest rich assemblage, that in the St. Cyr-en-Bourg Fossil Bed near Saumur, which characterises the *Romaniceras hispanicum* Zone, is already above the *Mammites nodosoides* assemblage zone of southern England, with which it only has *Lewesiceras* in common. By comparison with the records of WIEDMANN (1960) for the Iberian peninsula, particularly for the sequence in Navarra in north-east Spain, the *hispanicum* Zone correlates with WIEDMANN's Zone 7 which leaves four more Turonian zones in Spain beneath it. However, there is also in Spain a *Mammites nodosoides* assemblage-zone immediately beneath Zone 7 which also contains some species in common with the Saumur fauna. This means that the main gap in the Turonian record in northern Europe is close to the base of the stage.

All the horizons in the Tuffeau Blanc de Touraine are relatively close together. We doubt if the horizons of the Bourré and Poncé assemblages can be separated, and their assemblages define the Zone of *Romaniceras deverioide*. The exact relation of the *hispanicum* Zone and the *deverioide* Zone with the English *woollgari* Zone is uncertain because there is no species in common between the two regions, other than long-ranging *Lewesiceras*. The fact that many of the *lata* Zone records of *C. woollgari* are from Sussex makes us suspect that many specimens of this species come from a single hard-ground or incipient hard-ground in the Lewes district.

The few ammonites from the Tuffeau Jaune de Touraine are from low in that formation. The upper part of the formation, with its glauconitic beds and disconformities, has yielded no ammonites; this interval is believed to correlate with the Chalk Rock of southern England plus the non-ammonite bearing upper part of the *planus* Zone.

The much quoted Turonian fauna of Uchaux, 30 km north of Avignon in France, raises certain problems with regard to its use for correlation. It was monographed

Table 1. A correlation chart of the Turonian.

Hokkaido Inoceramid zones	Japan ammonite zones	Southern England classic assemblage zones	Southern England ammonites	Touraine, France ammonites
Inoceramus teshioensis-I. incertus	*Reesidites minimus*	*Holaster planus*	gap in ammonite record	gap in ammonite record
	Subprionocyclus normalis			
			assemblage zone of *Subprionocyclus neptuni*	
Inoceramus hobetsensis-I. teraokai	*Subprionocyclus neptuni*			
	Collignoniceras woollgari	*Terebratulina lata*	*Romaniceras* gr. *deverianum* occurs rarely	*Romaniceras* gr. *deverianum* occurs rarely
			Collignoniceras woollgari occurs somewhere here	*Romaniceras deverioide* assemblage zone
Inoceramus labiatus	gap in ammonite record	*Inoceramus labiatus*		*Romaniceras hispanicum* assemblage zone
			gap in ammonite record	
	Fagesia thevestensis	...(correlation difficult)		
				gap in ammonite record
			Mammites nodosoides Zone	*Mammites* occurs
	gap in ammonite record			
			gap in ammonite record	gap in ammonite record
			Watinoceras coloradoense	

in 1913 by ROMAN and MAZERAN, but no-one in modern times has been able to collect the large number of ammonites that they described. They appear to have included all ammonites from the district preserved in reddish silicified limestone. Such fossils range through 50-60 m of sandy marls and sandstones which make up the Grès d'Uchaux (=Grès de Boncavail of Mennessier) (SORNAY 1950, pp. 96-97) and it seems unlikely that the ammonites all came from one horizon. Indeed, ROMAN and MAZERAN described a specimen of the Cenomanian *Turrilites costatus* and a ' mut. *turoniensis* ' of *Scaphites equalis.* Above the Grès d'Uchaux there is another 160 m of sands (Grès de Montmout) that are probably Turonian, below the Coniacian rudistid limestone (SORNAY 1950). Revised names for the whole of the Uchaux fauna are given by WRIGHT (in press) and the following indicate a significant link with the Chalk Rock fauna of England:

Baculites undulatus ROMAN and MAZERAN
Hyphantoceras reussianum (D'ORBIGNY)
Lewesiceras mantelli WRIGHT and WRIGHT
Tongoboryoceras rhodanicum (ROMAN and MAZERAN)
Puzosia curvatisulcata CHATWIN and WITHERS
Subprionocyclus neptuni (GEINITZ)
Subprionocyclus cf. *branneri* (ANDERSON)
Subprionocyclus cf. *normalis* (ANDERSON)

Leaving aside the ammonites of Cenomanian type (see above), the most important difference is the occurrence of *Romaniceras* at Uchaux. Until it is known whether they occur with the ammonites of Chalk Rock affinities, or at some earlier horizon, the significance of this difference cannot be assessed. It is conceivable that *Romaniceras deverianum* is contemporary with *Subprionocyclus neptuni* in the earlier part of its range, or the horizons of *R. deverianum* and *S. neptuni* may be quite distinct.

Japan

Turonian sediments in Japan are known in Kyushu, along the outer zone of southwest Japan, in Hokkaido, and in Saghalien (MATSUMOTO, 1954). However, it is the Yezo geosyncline in Hokkaido which has yielded the majority of the ammonites known. At the time of writing we have not yet been to Hokkaido, and therefore our knowledge is totally dependent on the literature, most of it by our good friend Professor MATSUMOTO and his colleagues (especially MATSUMOTO, 1954, 1959, 1965, 1971 and 1975; MATSUMOTO and MURAMOTO, 1967; MATSUMOTO *et al.*, in press). Happily his work gives so much detail of where ammonites have been found that it is possible to analyse current knowledge with considerable precision.

As in Europe there are difficulties in Hokkaido for anyone who tries to work out a scheme of ammonite zones in the 300 m of Turonian. Steeply dipping beds in mountainous valleys mean that the outcrop of each unit is narrow; many of the ammonites have had to be collected from loose boulders in or beside the streams. Moreover, most of the known genera are of no value for correlation with Europe, either because they are unknown in Europe, e.g. *Tragodesmoceroides;* or because their species have long stratigraphic ranges, e.g. *Sciponoceras;* or both, e.g. *Damesites.*

The commonest genera in the Turonian of Hokkaido are: *Gaudryceras*, *Anagaudryceras*, *Scaphites* and *Mesopuzosia*. These are accompanied by the following genera which also do not help us for our correlation with Europe: *Tragodesmoceroides*, *Damesites*, *Puzosia*, *Pachydesmoceras*, *Neophylloceras*, *Scalarites*, *Madagascarites*, *Nipponites;* whilst *Hyphantoceras*, *Didymoceras*, *Sciponoceras* and *Otoscaphites* are of limited value. Ammonite correlation is therefore nearly wholly dependent on Collignoniceratinae and *Romaniceras* (and allied genera). The number of specimens of these groups from known horizons in Hokkaido is quite small: e. g. MATSUMOTO (1965) had only five specimens of *Subprionocyclus normalis* from the well measured sections in the Pombets and Ikushumbets valleys. Many species are, in effect, of no use for detailed correlation at present because their horizons are too poorly known, and these include:

Subprionocyclus branneri (ANDERSON)
Romaniceras pseudodeverianum (JIMBO)—but there is some suggestion that this is not Lower Turonian; type species of the subgenus *Proromaniceras* WIEDMANN, 1960
Romaniceras cf. *kanei* JONES
Romaniceras aequicostatum MATSUMOTO
Yubariceras aff. *adkinsi* (JONES)
Yubariceras pseudomphalum MATSUMOTO
Yubariceras fujishimai MATSUMOTO
Shuparoceras yagii MATSUMOTO—possibly *labiatus* Zone
Shuparoceras abei MATSUMOTO—possibly *hobetsensis* Zone

Other species are known to be from the Zone of *Inoceramus hobetsensis* but this embraces both the *woollgari* and *neptuni* Zones (see Table 1):

Romaniceras deverioide (DE GROSSOUVRE)
Romaniceras aff. *uchauxense* COLLIGNON
Yubariceras aff. *ornatissimum* (STOLICZKA)

Whilst *Yubariceras japonicum* MATSUMOTO, SAITO and FUKADA is known from both the *hobetsensis* and *teshioensis* Zones.

Zone of Fagesia thevestensis.—Five species of ammonites of stratigraphic value are known from this zone:

Vascoceras aff. *durandi* (THOMAS and PERON)
Fagesia thevestensis (PERON)
Fagesia cf. *rudra* (STOLICZKA)
Pseudaspidoceras sorachiense MATSUMOTO and HASHIMOTO
Mammites sp.

There is some suggestion that *V.* aff. *durandi* came from a higher level than *F. thevestensis* and *Mammites* sp., but the whole assemblage falls into the Japanese Zone of *Inoceramus labiatus* (see MATSUMOTO, 1973).

The index species has been doubtfully recorded from the Zone of *Neoptychites* and *Pseudaspidoceras* (Zone 7 of the Lower Turonian) by WIEDMANN (1960, p. 719) in the Puentedei valley of northern Spain; *F. rudra* occurs in the same valley in the Zone of *Wrightoceras munieri* (Zone 6), whilst *V. durandi* occurs in the Zone of

Paramammites (?) *saenzi* (Zone 4). On this basis we have correlated this Japanese zone with the *hispanicum* Zone of Touraine, but it could be slightly lower. In any case there must be a considerable gap in the Japanese ammonite record below the Zone of *Fagesia thevestensis*, and probably above it.

Zone of Collignoniceras woollgari.—There is a variety of species known from this zone. Unluckily the relative stratigraphic order of these species is not known except that the single specimen of *Romaniceras* aff. *deverianum* was collected 3 m above the single specimen of *Collignoniceras woollgari*. If the Japanese occurrences be on the same time planes as in Touraine, the list could be divided into *deverianum* and *deverioide* Zone faunas.

Collignoniceras woollgari (MANTELL)
Collignoniceras woollgari bakeri (ANDERSON)
Romaniceras aff. *deverianum* (D'ORBIGNY)
Romaniceras yezoense MATSUMOTO
Yubariceras yubarense MATUSMOTO SAITO and FUKADA—one specimen; most examples are either simply known as being from the *hobetsensis* Zone, or from an unknown horizon and this includes the holotype.
Yubariceras ? sp. nov.

The three species mentioned earlier as having been recorded as simply coming from the *hobetsensis* Zone (*R. deverioide*, *R.* aff. *uchauxense* and *Y.* aff. *ornatissimum*) probably came from the Japanese *woollgari* Zone if their horizons be the same as in Europe. *Yubariceras otatumei* (MATSUMOTO, SAITO and FUKADA) probably came from the same zone (information from MATSUMOTO).

We have followed the nomenclature used by MATSUMOTO, but we suspect that *Yubariceras* should be regarded at most as a subgenus of *Romaniceras*.

Zone of Subprionocyclus neptuni.—The principal ammonite of this zone is *Subprionocyclus neptuni* (GEINITZ) itself. We would include here Japanese records of *Subprionocyclus bravaisianus* (D'ORBIGNY) which we still believe to be a synonym of *S. neptuni* in spite of the study by MATSUMOTO and NODA (1966).

Zone of Subprionocyclus normalis.—The only distinctive ammonite of this zone is the index species *Subprionocyclus normalis* (ANDERSON). As described earlier, in England this species occurs alongside *S. neptuni* in the Chalk Rock. Even in Hokkaido the two species are found together at locality Ik 2014 in the Pombets valley. Indeed, it might be suggested that Ik 2014 correlates exactly with the Chalk Rock. We have left both zones in our column for Japan because both in the Pombets and Ikushumbets valleys the upper range of *S. normalis* is above the lower range of *S. neptuni*, but the small number of specimens involved (about 5 positioned specimens of *S. normalis*) must mean that their discrimination is weak.

Zone of Reesidites minimus.—The ammonites known from this zone are:

Reesidites minimus (HAYASAKA and FUKADA)
Prionocyclus wyomingensis MEEK
Prionocyclus cobbani MATSUMOTO
Prionocyclus aberrans MATSUMOTO

Lymaniceras planulatum MATSUMOTO
Subprionotropis muramotoi MATSUMOTO

In addition, *Reesidites elegans* MATSUMOTO and INOMA probably comes from this zone.

The whole assemblage is different from and presumably higher than anything known from the Turonian of north-west Europe, and therefore probably correlates with the upper part of the English *planus* Zone and the top part of the Tuffeau Jaune de Touraine.

Conclusions

1) The Turonian ammonite succession is too poorly known to consider setting up standard sub-stages.

2) The lowest parts of the Turonian, which are particularly rich in ammonites in countries such as Spain, Israel and Nigeria, are just that part of the stage which can only be correlated in a very general way between Japan and north-west Europe. The Japanese Zone of *Fagesia thevestensis* probably correlates with the Zone of *Romaniceras hispanicum* of Touraine.

3) The middle part of the Turonian can be subdivided in Touraine, but only speculatively on ammonites in England and Japan.

4) It is not yet clear if the ranges of *Romaniceras deverianum* and *Subprionocyclus neptuni* overlap.

5) The top part of the Turonian can be subdivided into three zones in Japan. None of these is represented by ammonite bearing beds in Touraine, but both the index species of the *neptuni* and *normalis* Zones are found in the Chalk Rock assemblage of southern England.

6) The ideal zonation, in our opinion, for boreal Turonian sequences would be based on the phylogeny of the Collignoniceratids, but this will only be possible when the origins and earlier systematics of the group have been determined, and when more is known about the relations between the classic European species such as D'ORBIGNY's *Ammonites carolinus*, *A. papalis*, *A. fleuriausianus* and *A. vielbancii;* and MANTELL's *Ammonites woollgari* which we have not yet found in Touraine.

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SYSTEMATIC, BIOSTRATIGRAPHIC, AND BIOGEOGRAPHIC RELATIONSHIPS BETWEEN MIDDLE CRETACEOUS EURAMERICAN AND NORTH PACIFIC INOCERAMIDAE

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Introduction

The utility of bivalves belonging to the Family Inoceramidae in global biostratigraphy and intercontinental correlation has now been firmly established (SEITZ, 1959; MATSUMOTO, 1959; NODA, 1975; KAUFFMAN, 1975, 1977a-e, in press; PERGAMENT, 1965, 1966, 1971; and others). These remarkable organisms, sessile epibenthos as adults, nevertheless commonly achieved rapid global dispersal at the species and subspecies levels equivalent to that of more mobile ammonites and pelagic microbiota. In addition, the Inoceramidae evolved at equal or greater rates than ammonites, foraminifera, or coccoliths, allowing them to become important species indices of refined biostratigraphic zonal systems (KAUFFMAN, 1970, 1972; 1977a, in press).

Rapid, widespread dispersal of the Inoceramidae was apparently achieved by means of long-lived, environmentally tolerant, teleplanic or planktotrophic larvae, and by amazingly broad environmental (habitat) range among adult populations (KAUFFMAN, 1975). Some workers (e. g. TANABE, 1973) further suggest that Inoceramidae were epiplanktonic on floating wood and vegetation as juveniles, accounting for their wide biogeographic distribution; KAUFFMAN (1975) has disputed the importance of this dispersal mechanism. Single species of inoceramids commonly occur in widely scattered parts of the world, and in most common marine facies. Approximately 75 percent of inoceramid species and subspecies have intercontinental to cosmopolitan distribution in the Cretaceous, in many cases exceeding that of co-occurring ammonite species or the marine planktonic microbiota. The most cosmopolitan inoceramid faunas seem to be those of the Middle to Late Albian, Middle and Late Cenomanian, Lower and Middle Turonian, Coniacian, Santonian, and Lower to Middle Campanian. Predictably, Inoceramidae therefore do *not* play an important role in the definition of paleobiogeographic units. They are a family which originated and flourished primarily in Temperate Zone marine environments, and they only occur as secondary elements of Tethyan faunas. Most known Tethyan species, however, are cosmopolitan in aspect (KAUFFMAN, 1968; 1977, in press; WIEDMANN and KAUFFMAN, 1977a-b, in press). The rapid evolution of the Inoceramidae (KAUFF-

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MAN, 1970, 1972; 1977a, in press) is seemingly incompatible with their wide rapid dispersal, since broad biogeographic distribution of marine mollusks is considered characteristic of slowly evolving group (JACKSON, 1972, 1973; 1976, in press). KAUFFMAN (1977a, in press) has argued, however, that the probable trophic strategy and known prime habitat of the Inoceramidae—i. e. selective suspension-feeding epibenthos of the shelf zone—is precisely that which promotes the most rapid evolution among fossil marine organisms. These are the taxa most readily stressed by unpredictable environmental perturbations and rapid changes in natural selective forces, living in a part of the marine environment where such perturbations are most commonplace. KAUFFMAN (1977a, in press) contends that these overriding ecological factors have a greater effect on rates of evolution than simple biogeographic distribution.

Despite these evolutionary and biogeographic factors, which seem to apply widely to the Inoceramidae of Euramerica and mainland Asia, Greenland, the Arctic, Africa, Central and South America, and the Antarctic, the North Pacific inoceramid fauna has, in the past, been considered to be largely endemic, comprised mainly of relatively long-ranging, more slowly evolving species of more limited biostratigraphic value compared to those of the Euramerican Region. The North Pacific Inoceramidae have thus been considered to be indicative of a distinct paleobiogeographic unit—the North Pacific Province (KAUFFMAN, 1973). The Middle Cretaceous and, to a large extent, Senonian Inoceramidae of Japan and the West Coast of North America, for example, are largely described as distinct species which are rarely known to range beyond the Pacific margins, or even across the Pacific from west to east (e. g. NAGAO and MATSUMOTO, 1939, 1940; MATSUMOTO, 1943, 1959; HAYAMI, 1975; NODA, 1975; NODA and MATSUMOTO, 1976; ANDERSON, 1902, 1958; ANDERSON and HANNA, 1935; MEEK, 1861; WHITEAVES, 1895; etc.). It has been assumed that the uniqueness of these eastern and western Pacific faunas (Japanese-East Asian Subprovince vs. Northeast Pacific Subprovince; KAUFFMAN, 1973) was in part due to the formidable Pacific oceanic barrier which existed at an even greater magnitude during the Cretaceous than it does today. The present Pacific acts as a barrier to east-west migration of even long-lived planktonic larvae for the great majority of modern benthonic metazoan organisms.

In part, the uniqueness of the northern Pacific inoceramid fauna has also been attributed to major land barriers between the Pacific and Temperate Euramerican biotas—the Chico-Shunie, Nevadan and older orogenic belts which comprise the Cretaceous Cordilleran Geanticline along the western margin of North America, and the emergent Siberian Platform region between the Temperate epicontinental seaways of of central and western Europe and the western Pacific margin of Japan and Siberia (see map of marine Cretaceous in KAUFFMAN, 1973, figs. 1, 2). Access to the main body of the North Temperate Pacific was thus mainly limited to the Circumboreal Seaway and the Tropical Tethyan Seaway during the Cretaceous; both of these seaways are known to bave more restricted inoceramid assemblages (especially Tethys) than found in the main part of the North Temperate Euramerican Region, and thus they probably represented non-optimum environments for inoceramids.

NAGAO and MATSUMOTO (1939, 1940), MATSUMOTO (1943, 1959), MATSUMOTO and NODA (1975), HAYAMI (1975) and NODA and MATSUMOTO (1976), among others, recognized rare cosmopolitan inoceramids in the Japanese faunas (e. g. *Mytiloides labiatus* s. l., *Birostrina sulcatus*, *B. subsulcatus*, "*Inoceramus*" *anglicus* s. l., "*I.*" sp. aff. "*I.*" *crippsi*, "*I.*" *balticus*) and suggested close similarities of others with Euramerican species, indicating at least some degree of biogeographic exchange between the North Pacific and the Euramerican faunas. MATSUMOTO (1959) more strongly emphasized these similarities by suggesting lineage relationships between Japanese and Euramerican or cosmopolitan species as follows: "*Inoceramus*" *concentricus nipponicus* and subsp. *costatus* from Japan with the cosmopolitan *Birostrina concentricus* lineage; *I. tenuistriatus* of Japan with the *I. tenuis-I. etheridgei* lineage of Euramerica; *I. teshioensis* of Japan with the *I. costellatus-I. perplexus* lineage of Euramerica; *I. hobetsensis* and *I. iburiensis* of Japan with the cosmopolitan *I. cuvieri-I. lamarcki-I. brongniarti* lineage; *I. iburiensis* of Japan with *I. flaccidus* of Euramerica; "*I.*" *incertus* of Japan with the cosmopolitan *Mytiloides* "*latus*"; *I. uwajimensis* with Euramerican *I. kleini* and "*I.*" *stantoni*; "*I.*" *mihoensis* with the cosmopolitan *Cremnoceramus inconstans*-"*I.*" *deformis* lineage; and "*I.*" *mukawaensis* with the *Cordiceramus cordiformis-C. gilberti* lineage of Euramerica. NODA (1975) suggested that "*I.*" *teraokai* was a member of the *Mytiloidese labiatus* lineage. MATSUMOTO (1959) noted a number of apparent age discrepancies between closely related Japanese and Euramerican species, and also that Japanese inoceramids were in general much longer ranging than those of Euramerica and other parts of the world. More recent work (e. g. NODA and MATSMOTO, 1976) have greatly refined Japanese inoceramid ranges and clarified some, but not all, of these discrepancies. Careful lineage studies applying population systematic concepts (e. g. TANABE, 1973; NODA, 1975) provide a new basis for refinement of species concepts and ranges among Japanese Inoceramidae, although at present even these are significantly broader than those of contemporaneous Euramerican inoceramid faunas. These factors together with apparently high levels of endemism in Japan made precise correlations with other areas of the world difficult using inoceramids. The apparent endemic nature of the northern Pacific inoceramid faunas was further emphasized by the work of ANDERSON (1958) who recognized almost no species in common between the Cretaceous of the eastern Pacific Coast, Japan, and the Western Interior United States (Euramerican Region).

A number of authors have subsequently suggested stronger ties between the northern Pacific inoceramid fauna and that found elsewhere in the world. For example, JONES (1960) recognized three species of cosmopolitan or Euramerican inoceramids in the Albian of Oregon, and no endemics. More recently PERGAMENT (1965, 1966, 1971) in his extensive studies of the Middle Cretaceous Inoceramidae from the Pacific Coast region of the USSR, has noted that the majority of his inocramid faunas are comprised of Euramerican or more extensively distributed species; much of the remainder of PERGAMENT's taxa have strong lineage relationships to Euramerican or cosmopolitan species. JONES and GRYC (1960), IMLAY (1961), JELETZKY (1967, 1969, 1970) and his colleagues (JELETZKY and TIPPER, 1968; MULLER and JELETZKY, 1967, etc.) have cited a predominance of widespred Euramerican inoceramid species in the Cretaceous of northern Alaska and western Canada associated with lesser numbers of Japanese-eastern Siberian species and forms endemic to the Western Interior of North America.

Thus, recent papers suggest much stronger similarities between the northernmost Pacific and Euramerican inoceramid faunas than had previously been described for more southerly faunas of Japan, the Pacific Coast of the United States, and southern British Columbia. This, in turn, suggests the possibility of defining much more precise biostratigraphic correlations between these areas than had previously been possible.

The main thrust of this paper is therefore to try and correlate more precisely the refined inoceramid biostratigraphy of Euramerica, which is also applicable over much of the rest of the world, with the still incompletely known North Pacific inoceramid fauna. Particular attention is paid to the relationship between the Inoceramidae of the Western Interior United States (KAUFFMAN, 1975, fig. 4), representing the Euramerican Region, the faunas of California, Oregon, and southwestern British Columbia, representing the Northeast Pacific Subprovince, and the inoceramids of Japan (e. g. NAGAO and MATSUMOTO, 1939, 1940; NODA, 1975; NODA and MATSUMOTO, 1976, and others), representing the Japanese-East Asian Subprovince. These faunas lie within the main Temperate climatic zone preferred by Cretaceous inoceramids, and yet they seem from the literature to the highly unrelated to each other. Biogeographic factors leading to their apparent isolation, despite the fact that they represent groups which are known to the high dispersal potential, are also considered.

An obvious first step in this study was an attempt at taxonomic re-evaluation of the Japanese and western United States-southwestern Canadian inoceramid faunas in light of modern generic and species concepts applied widely to the Euramerican faunas and to those of the northermost Pacific margin, especially eastern Siberia. How real is the apparent endemism of the Japanese, California, Oregon, and southwestern British Columbia inoceramid assemblages? This evaluation unfortunately had to be done for the current study with published illustrations and small U. S. National Museum collections from the areas concerned, as neither time nor finances permitted travel to examine relevant collections mainly housed in institutions around the Pacific margin. My results, and interpretations made from them are therefore to be regarded as tentative, a preliminary survey at best, designed to act as a potential set of suggestions for careful systematic re-evaluation of the Pacific Inoceramidae by concerned paleontologists. Illustrations can often be deceiving. Nevertheless, this survey revealed some important aspects of the northern Pacific Inoceramidae which had not been suspected, and which allowed more detailed biostratigraphic and biogeographic interpretations than had previously been possible.

In order to provide a data base for these interpretations, the basic observations made in comparing both the Japanese and the eastern Pacific inoceramids with those of the Euramerican Region are abstracted below. General comparisons with more northern Canadian, Alaskan, and Siberian faunas follows, and interpretation of the overall relationships between these faunas is presented at the end of the paper.

Suggested Taxonomic Relationships and Regional Correlations of Japanese Middle Cretaceous and Coniacian Inoceramidae (see Table 1)

Albian Taxa

(1) *Inoceramus* sp. aff. *I. bohemicus* LEONHARD (no illustrations or specimen seen): MATSUMOTO (1959) lists this from the Albian, K3β, Upper Miyakoan of Japan. *I. bohemicus* is characteristically a Middle-Upper Cenomanian species in Europe, belonging to the *I.* (*I.*) *pictus* lineage. TRÖGER lists it as latest Cenomanian to lowest Turonian (1967; as *I. pictus bohemicus*) in North Germany. The *I. pictus* lineage does not begin elsewhere before Cenomanian time, suggesting the Japanese form may belong to a different lineage. This name has been dropped from subsequent lists of Inoceramidae in Japan (e.g. NODA and MATSUMOTO, 1976).

(2) *Birostrina subsulcata* (WILTSHIRE): MATSUMOTO and HARADA (1964) recorded "*Inoceramus concentricus subsulcatus*" from the Upper Albian of the Yubari Dome, Hokkaido. HAYAMI (1975) correctly assigned the species to subgen. *Birostrina*, considered here as a full genus, and listed it as Albian. NODA and MATSUMOTO, in their survey of Japanese Inoceramidae, do not list it (1976). Whereas have not been illustrated, this is a distinctive, easily recognized, cosmopolitan Middle to Late Albian form which also occurs on the eastern side of the North Pacific (JONES, 1960) and its occurrence in Japan is to be expected.

(3) *Birostrina sulcata* (PARKINSON) · NODA and MATSUMOTO (1976) list this cosmopolitan and easily recognized species (as "*Inoc. sulcatus*") from throughout the Albian of Japan. It is diagnostic only of the Middle and Late Albian of other Cretaceous areas, however, and probably has the same restricted range in Japan. The specimen has not been listed elsewhere, to my knowledge, nor illustrated so that the identity can be confirmed. Assignment to *Birostrina* follows COX (1969) and HAYAMI (1975); consideration of this taxon as a genus is based on external shell morphology, especially radiating plicae, and internal features of musculature, umbonal septae, and ligamenture which, in combination, are clearly distinct from those of *Inoceramus* (*Inoceramus*).

(4) "*Inoceramus*" *anglicus* WOODS (n. gen.): NAGAO and MATSUMOTO (1939, tab. 1) first listed but did not illustrate this species as *I.* sp. alpha aff. *I. anglicus*, assigning in a Lower Cenomanian through Middle (?) Turonian range initially. HAYAMI (1975) and NODO and MATSUMOTO (1976) both recognize that "*I.* (*I.*)" *anglicus* is restricted to the Albian (undifferentiated). MATSUMOTO and HARADA (1964) recorded the species exclusively from Middle and Upper Albian strata in the Yubari Dome area of Hokkaido; this is compatible with the range of this cosmopolitan species elsewhere in the world (e.g. PERGAMENT, 1965; WOODS, 1911). Closely similar forms have beed found in basalmost Cenomanian strata of England and North America (personal observation) and PERGAMENT (1965) has recorded distinct Cenomanian subspp. *conjugalis* and *elongatus*. Without illustration of a suite of representative specimens it is not possible for me to determine which of PERGAMEN's subspp. are present in Japan, and whether or not they represent only Albian forms, or Lower Cenomanian forms as well. A distinct internal rib between the disc and the posterior auricle, a large umbonal septum, pedalbyssal muscles of large size, an a more centralized and rounded posterior adductor muscle clearly reparate members of this group from typical *Inoceramus* (*Inoceramus*) and indicate a new genus. "*Inoceramus*" *bellvuensis* REESIDE from the American Late Albian and Early Cenomanian is descended from "*I.*" *anglicus*.

Cenomanian Taxa

(5) "*Inoceramus*" (n. gen.) sp. aff. "*I.*" *crippsi* MANTELL (NODA and MATSUMOTO, 1976; Lower and (?) lowest Middle Cenomanian): This is questionably the same as "*Inoceramus* sp. β aff. *I. crippsi*" MANTELL (NAGAO and MATSUMOTO, 1940, pl. 2, figs. 3, 6, 7; Middle (?) Cenomanian to Middle and (?) Upper Coniacian), and presumably the same as *I.* sp. aff. *crippsi* MANTELL (MATSUMOTO, 1959) of Lower Cenomanian age. Two "species" may be present among illustrated specimens:

(a) "*Inoceramus*" (n. gen.) *crippsi* MANTELL as normally understood (e.g. WOODS, 1911, figs. 33, 34) appears to be represented by NAGAO and MATSUMOTO's pl. 2, figs. 3, 6a-b (1940). This species is restricted to Lower and Middle Cenomanian strata of Euramerica.

(b) NAGAO and MATSUMOTO's pl. 2, fig. 7 (1940) is a distinct, more erect form of *I. crippsi* with widely, subevenly spaced, more angular rugae; it is most closely allied to *"I." crippsi hoppensteetensis* TRÖGER (1967), from the middle Lower-Upper Cenomanian of Germany.

(6) *Inoceramus* (*Inoceramus*) *yabei* NAGAO and MATSUMOTO f. t. [1939, pl. 34(12), figs. 5a-c, 6a-b; Lower Cenomanian-Lower and (?) Middle Turonian range cited] now considered to be restricted to the Middle and Late Cenomanian (NODA and MATSUMOTO, 1976): Specimens illustrated by NAGAO and MATSUMOTO in pl. 34, figs. 5a-c are conspecific or very closely related to *Inoceramus pictus bannewitzensis* TRÖGER (1967, pl. 2, figs. 3a-b: pl. 4, figs. 1-3) of the Upper Cenomanian of North Germany, differing only in lacking well defined, raised, evenly spaced growth lines between the rugae over most of the shell, or in having these growth lines developed to a lesser extent. The Japanese name has priority. I do not know of similar forms elsewhere in the world in pre-Upper Cenomanian rocks. *Inoceramus propinguiformis* HEINZ (TRÖGER, 1967, pl. 8, figs. 1a-b) is an early Middle Turonian descendant with broader, more rounded rugae. The more coarsely rugate Japanese forms in pl. 34, figs. 6a-b do have Late Turonian homeomorphs, possibly related or descended, like *"I." lusatiae* ANDERT (part; 1911, pl. 8, fig. 5) and *I. winkholdioides* ANDERT. These comparisons suggest that *I. yabei* NAGAO and MATSUMOTO, as presently defined, may be part of a Cenomanian-Turonian plexus of several evolving species, beginning with Cenomanian *I. yabei* (=*I. pictus bannewitzensis* TRÖGER), including Middle Turonian *I. propinguiformis* HEINZ and terminating in Late Turonian-Early Coniacian forms like *"I." lusatiae* ANDERT (part), *I. winkholdioides* ANDERT, and possibly *I. protractus* SCUPIN.

MATSUMOTO (1943) cited several subspecies of *I. yabei*: *I. yabei concentricus* (Lower Cenomanian), *I. yabei constrictus* (Lower and Middle Cenomanian), and *I. yacei spengleri* (throughout Cenomanian). These have apparently since been abandoned as variants of *I. yabei* s. s., as they do not appear on subsequent lists (e. g. NODA and MATSUMOTO, 1976). Nevertheless, the initial recognition of these "variants" or "subspecies" seems to suggest that: (1) *I. yabei* s. l. may extend into the Lower Cenomanian substage; and (2) that population studies of stratigraphically closely spaced collections within the *I. yabei* lineage, similar to those carried out by TANABE (1973) and NODA (1975) on other lineages, may reveal the presence of biostratigraphically useful subspecies within *I. yabei*.

(7) *Inoceramus* cfr. *yabei* (deformed specimen) [NAGAO and MATSUMOTO, 1939, pl. 34(12), fig. 7, as *I. yabei* sp. nov. (deformed specimen)"], cited as Middle (?) and Upper Cenomanian-Lower Santonian. The illustrated specimen is difficult to evaluate, but looks close to some Late Turonian and Early Coniacian forms like *Inoceramus weisei* ANDERT (1934, pl. 4, fig. 1). I would suspect that deformed individuals of several distinct species may make up this "species" concept and that it has little biostratigraphic value as presently understood.

(8) *Birostrina ? concentrica nipponica* (NAGAO and MATSUMOTO) [1939, pl. 24(2), fig. 2, pl. 25(3), figs. 1a-d, 2a-b, 3-6a-c, cited originally as ranging from Lower Cenomanian to Middle Turonian and (?) into the lowest Coniacian of Japan], now considered to be restricted to the Middle Cenomanian, with questionable Lower and Upper Cenomanian occurrences (NODA and MATSUMOTO, 1976; HAYAMI, 1975). As originally illustrated, this seems to be a mixed group representing two or more species and genera, as follows:

(a) Pl. 24, figs. 2a-c of NAGAO and MATSUMOTO (1939) appears to be a more erect, coarsely rugate member of the cosmopolitan *I. pictus* Sowerby lineage. Although it lacks the even growth lines of most members of the *pictus* lineage, it matches specimens of *I. pictus pictus* illustrated by TRÖGER (1967, pl. 3, figs. 1-6) from Germany and except for poor development of fine raised growth lines, it is similar to the type concept of *pictus* (WOODS, 1911, text-fig. 36), suggesting a Middle-Late Cenomanian age. NAGAO and MATSUMOTO's specimen comes from an "unknown horizon", possibly within the *Scaphites* beds, at Obirasibe, Japan; these are considered to be Turonian in age by NAGAO and MATSUMOTO (1939, table 2) but possibly range into the Late Cenomanian according to

YABE (*ibid.*, table 2). *Inoceramus corpulentus* MCLEARN ("Late Turonian ?, *Prionotropis* zone") is a closely related North American form. It is actually most likely of Late Cenomanian age in the United States.

(b) The second species (or two ?) appears closely related to *Birostrina concentrica* (PARKINSON) (see NOGAO and MATSUMOTO, 1939, pl. 24, fig. 2b; pl. 25, figs. 1-6) and is probably derived from it; it is less regularly ornamented than normal Albian forms of the species plexus including the types (except for internal molds). Full species status is suggested and the name *Birostrina nipponica* s. l. is here used for this form. This species is as yet unknown in the Western Interior and may be represented by a single specimen from the latest Albian Paw Paw Formation of the western Gulf Coast, U. S. A·; it is sparsely known from the latest Albian and Early Cenomanian of Western Europe. "*Inoceramus* cf. *concentricus*" from the late Lower Cenomanian of Pacific Coast USSR (PERGAMENT, 1966, pl. 1, figs. 1-4) is this form. The broad variants of *B. nipponicus* s. l. (i. e. NAGAO and MATSUMOTO, 1939, pl. 25, fig. 4) are closely similar, if not the same as *I. scalprum* BOEHM of PERGAMENT (1966, pl. 25, figs. 1-4) of Late Cenomanian age on the Pacific Coast of the USSR and may not be *Birostrina*.

(9) *Birostrina concentrica costata* (NAGAO and MATSUMOTO) [1939, syntypes, pl. 24(2), figs. 1a-c, 4, 5a-b; pl. 27, figs. 2a-b; cited originally as ranging from the Middle Cenomanian through the Turonian and possibly into the lowest Coniacian], now considered to be of Middle and Upper Cenomanian age (TAMURA and MATSUMURA, 1974) ranging also into the basal Turonian (NODA and MATSUMOTO, 1976). Based on comparison of NAGAO and MATSUMOTO's original illustrations (1939), and subsequent illustrations of TAMURA and MATSUMURA (1974) and SHIKAMA (1952) with modern inoceramid systematic concepts, this again appears to be a plexus or partially unrelated grouping of three or more species rather than a single form, as follows:

(a) Finely ribbed Cenomanian forms (NAGAO and MATSUMOTO, pl. 24, figs. 1a-c; SHIKAMA, 1952, pl. 26, fig. 3) are very closely related to or possibly conspecific with *Birostrina concentrica porrecta* (WOODS; 1917, pl. 4, figs. 1a, b; *non* figs. 2, 3) from the New Zealand sequence (exact age unknown). Japanese forms which have been illustrated differ only in having a slightly more angular bend in the growth line trace over the posteroventral flank than the illustrated New Zealand specimens, and this is known to be a variable character in *B. concentrica* (PARKINSON) s. l. (see WOODS, 1911, pl. 45, fig. 11; pl. 46, figs. 1-10; pl. 47, fig. 1). Identical specimens have been found in the Lower Cenomanian of England, but not in the Western Interior of Gulf Coast, U. S. A. This appears to be true *Birosprina*. The New Zealand name has priority.

(b) TAMURA and MATSUMURA illustrated, as "*Inoceramus*" *concentricus costatus* (1974, pl. 1, figs. 1-7) a suite of very finely ribbed Middle-Upper Cenomanian specimens which have the general form of syntype *B. concentrica costata* (NAGAO and MATSUMOTO, 1939, pl. 24, figs. 1, 4, 5), but which have much finer concentric sculpture and a prominent sulcus extending posteriorly along the edge of the umbonal fold. Based on studies of variation in Albian species of this lineage from England (KAUFFMAN, 1977b, in press), the presence of a well defined sulcus does not appear to be an intraspecies variable. I conclude that this represents an undescribed species or subspecies of the *Birostrina concentrica* lineage and have listed it as *B.* n. sp. (sulcate). Among NAGAO and MATSUMOTO's syntypes, only the specimen figured on plate 24, fig. 1a (1939) shows rudimentary to this new form, but even this specimen has coarser concentric ornament and only a very weak posteroventral sulcus.

(c) Coarsely rugate Turonian forms (as illustrated) from Japan possibly comprise one or two species: the first, NAGAO an MATSUMOTO's specimens on pl. 24, figs. 4a-b (1939), Tk I-695, come from the Turonian *Scaphites* beds of the Obirasibe District and are characterized by moderate convexity, moderately coarse, subequal rugae with a subtle bend and distinct flattening of the growth line trace over the umbonal fold. The external morphology seems to be closer to that of *Inoceramus* s. s. than to *Birostrina*, although examination of internal structure (musculature, hinge features) would be necessary to prove this. If a true *Inoceramus*, this may be a distinct species closely related to Late Turonian European-American forms such as *I. frechi* FLEGEL (ANDERT, 1934, pl. 5, figs. 5-9) and *I. glatziae* ANDERT (ibid, pl. 6, figs. 2-5). NAGAO and MATSUMOTO's specimen Tk I-689 (1939, pl. 24, figs. 5a-b) from Pombetu, Province of Isikari (exact age unknown) may be the same thing, though it looks more coarsely rugate, like (d) below. Interestingly, WOODS (1917) illustrates almost identical forms from New Zealand *Birostrina concentrica porrecta* (WOODS, 1917, pl. 4, figs. 2, 3) ; even if subsequent examination proves this to be an unusual variant of "*Inoceramus concentricus costatus*", WOODS' name has priority.

(d) The Turonian form of "*I. concentricus costatus*" illustrated by NAGAO and MATSUMOTO (1939) on pl. 27, figs. 2a-b appears to be a true *Inoceramus* and I cannot distinguish it from *I. saxonicus* PETRASCHECK (see lectotype in TRÖGER, 1967, pl. 10, fig. 1) from the late Lower Turonian of Germany except for slight and probably insignificant differences in the trace of the rugae. At least one specimen included by WOODS in *Birostrina concentrica porrecta* (WOODS, 1917, pl. 4, fig. 2) from New Zealand looks identical.

Since no primary type was selected by NAGAO and MATSUMOTO (1939), and TAMURA and MATSUMURA (1974) have selected a lectotype which I think is identical with WOODS' priority subsp. *porrectus* (i. e. NAGAO and MATSUMOTO, 1939, pl. 24, fig. 1), I cannot suggest what to do with the subspecies name *costatus* at present. Logically, it would eventually be restricted to a new species within this group of specimens after restudy of the "species", or abandoned if none are found.

(10) *Inoceramus* sp. nov. ?, belonging to the group of "*Inoceramus*" *concentricus* (NAGAO and MATSUMOTO, 1939, pl. 27(5), figs. 1a-b; pl. 28, fig. 1) came from loose pebbles of unknown origin, presumed to be of Lower Turonian-Middle Coniacian age. This form clearly does not belong to the group of *Birostrina concentrica* (PARKINSON) but rather to the genus *Inoceramus* s. s. and to the lineage which contains *I. tenuis* MANTELL, *I. etheridgei* WOODS, *I. conicus* GUERANGER, *I. heinzi* SORNAY, *I. pedalionoides* NAGAO and MATSOMOTO, and *I. tenuistriatus* NAGAO and MATSUMOTO. It is broader and flatter than *I. conicus*, *I. tenuis*, and *I. pedalionoides*, and much more coarsely rugate than *I. etheridgei*. Whereas it is the same shape and similarly rugate to *I. tenuistriatus*, it is less convex and lacks the even, raised crowded growth lines between rugae that seem to characterize that species (NAGAO and MATSUMOTO, 1939, pl. 26, figs. 1-3 especially). The form is closest to *I. heinzi* SORNAY from the Middle and Late Cenomanian of Europe, Madagascar, and the Western Interior U. S. A., especially as illustrated by SORNAY (1965, fig. 3). The Japanese from is broader and flatter than the type of *I. heinzi* (*ibid*., pl. B, fig. 4) and probably represents a distinct subspecies.

(11) *Inoceramus pennatulus* PERGAMENT (1966, p. 35-38, pl. 5, figs. 1, 2; pl. 6, figs. 1, 2; pl. 7, figs. 1-3) from the early Middle to early Upper Cenomanian of the Pacific Coast of Russia has been definitely identified by MATSUMOTO and NODA (1975) from the Middle and Upper Cenomanian of Hokkaido. NODA and MATSUMOTO (1976) list its range as (?) Middle and Upper Cenomanian in Japan. This provides an important biostratigraphic tie to the detailed zonation of the Pacific Coast of Russia proposed for this interval by PERGAMENT (1966). No attempt has been made yet to assign the Japanese representatives to any of PERGAMENT's subspecies (1966), which have distinct range zones. When sufficient numbers of specimens are available, restudy of the lineage in Japan may provide even more refined biostratigraphic zonation based on subspecies of *I. pennatulus*.

(12) *Inoceramus reduncus* PERGAMENT (1966, p. 40-44, pl. 16, figs. 1, 2; pl. 17, figs. 1, 2; pl. 18, figs. 1-3; and for subsp. *singularis* PERGAMENT, pl. 20, figs. 1, 2; pl. 21, fig. 1; pl. 22, figs. 1, 2; and pl. 23, figs. 1, 2) from the Upper Cenomanian of the Pacific Coast of Russia has been mentioned in Japan by MATSUMOTO and NODA (1975) as present in the Middle and Upper Cenomanian of Hokkaido, but also they suggest it is probably conspecific with the cooccurring *I. pennatulus* PERGAMENT. Comparison of PERGAMENT's illustrations (1966) suggests that MATSUMOTO and NODA are probably correct in their interpretation. *Inoceramus reduncus* is listed here for completeness, therefore, since it is still regarded as a distinct species in Russia, and the synonymy of the two species has not yet been formally proposed in Japan.

(13) *Mytiloides* sp. cf. *M. labiatus* (SCHLOTHEIM) was listed by MATSUMOTO (1959, p. 85) and MATSUMOTO and NODA (1975) from Hokkaido in association with *Kanabiceras septemseri-*

atum, a widely distributed ammonite marker for the latest Cenomanian (zone of *Sciponoceras gracile* in the United States). Whereas it is widely recognized that *M. labiatus* and most other members of the lineage are of Lower Turonian age (e. g. see KAUFFMAN, 1975, fig. 4), one species, *M. submytiloides* SEITZ, ranges into the highest Cenomanian *S. gracile* zone in Euramerica (*ibid.*, fig. 4), and it is very possible that it is this species that is also represented in the Japanese Late Cenomanian; this cannot be confirmed without examination and/or illustration of the specimens.

Turonian Taxa

(14) *Inoceramus* (*Inoceramus*) *hobetsensis hobetsensis* NAGAO and MATSUMOTO [1939, pl. 28(6), figs. 3a-c; pl. 29(7), figs. 1-6; pl. 30(8), figs. 2, 3; cited originally as ranging from the (?) Middle and Upper Cenomanian through the Upper Turonian, and characteristic of the Middle Turonian). NODA (1975, p. 249-251; pl. 33, figs. 1-3, 5-7; pl. 34, figs. 1, 2, 4, 5(?); pl. 35, fig. 1; text-figs. 16, 20) most recently treated the species in detail from the standpoint of population systematic analysis, recognized the chronological changes in morphology within the lineage, and defined the range of *I.* (*I.*) *hobetsensis hobetsensis* as being restricted to the Middle Turonian, especially the middle and upper part. This is a unique Japanese species very closely related and possibly ancestral to *Inoceramus frechi* FLEGEL and to "*I.*" *lusatiae* ANDERT (part) of the Euramerican uppermost Turonian and lower Lower Coniacian. The presence of a sulcus extending along the anterior face of the umbonal fold, and a less prominent posterior auricle distinguishes the Japanese form. The larger, more coarsely rugate *I. flaccidus* WHITE is very closely related; it occurs in the late Middle Turonian of the Western Interior U. S. A. The "nodulose form" of "*I. hobetsensis*" NODA, 1975, pl. 33, figs. 4, 7(?); pl. 34, fig. 3) is herewith removed from this species and assigned to *I. flaccidus* WHITE, as detailed below (♯16).

(15) *Inoceramus* (*Inoceramus*) *hobetsensis nonsulcatus* NAGAO and MATSUMOTO [1939, pl. 27(5), figs. 3a-c; pl. 28(6), fig. 4; pl. 30(8), figs. 1a-b; cited originally as ranging from the Middle (?) and Late Cenomanian through the Turonian, being most prominent in the Middle Turonian; see also MATSUMOTO, 1959], now considered to range questionably from the uppermost Lower Turonian, through the lower and middle parts of the Middle Turonian. NODA 1975, p. 249-251, pl. 32, figs. 6-9; pl. 33, figs. 1-3; text-figs. 16, 20) recently treated the *I. hobetsensis* lineage in detail and noted that the earliest evolutionary forms were predominantly non-sulcate to weakly sulcate (subsp. *nonsulcatus*, not recognized as distinct by NODA) whereas late evolutionary forms were predominantly sulcate (subsp. *hobetsensis*). *I.* (*I.*) *hobetsensis nonsulcatus*, especially as illustrated by NODA (1975) in pl. 32, fig. 7, is closely related to rugate variants of *Inoceramus cuvieri* SOWERBY from Europe and North America (*I. cuvieri*, n. subsp. rugate form of KAUFFMAN, 1977b, in press), e. g. those illustrated by WOODS (1911, figs. 77, 82, 84), but is *not* similar to the type of *I. cuvieri*, which is smooth to weakly rugate; all are of Middle Turonian age. Some specimens assigned to *I. subpercostatus* ANDERT (1934, pl. 5, fig. 3) are conspecific, but characteristic valves of this species from the Late Turonian of Germany (*ibid.*, pl. 16, fig. 1) are higher, narrower, and more finely rugate. *Inoceramus securiformis* HEINZ (1932, p. 7; see WOODS, 1911, fig. 78, the type) is very closely related and may be conspecific, being slightly broader and having a more flared posterior auricle. *Inoceramus brongniarti* MANTELL is also closely related and especially similar to the more finely ribbed variants of *I. hobetsensis nonsulcatus* NAGAO and MATSUMOTO (1939, pl. 30, figs. 1a-b). The age range of these English species is not precisely known, but presumably they either come from the Late Turonian and/or Lower Coniacian part of the "chalk". Inasmuch as this species is closely allied to the nonsulcate *I. cuvieri* lineage than to the sulcate *I. lamarcki* lineage (including *I. hobetsensis* s. s.), I suggest the name *nonsulcatus* be given specific rank.

(16) *Inoceramus* (*Inoceramus*) *flaccidus* WHITE [see STANTON, 1893 (1894), pl. 13, fiig. 1] is a characteristic late Middle Turonian inoceramid of the Euramerican succession which is large, has an erect growth form, a prominent triangular posterior auricle, a deep posteroventrally directed sulcus on the flank of the umbonal fold, and coarse, moderately distant, subangular concentric rugae which are nodose along the edge of the sulcus. Among the specimens of *I. hobetsensis* illustrated by NODA (1975), there are several which have features

identical to those of *I. flaccidus* (*ibid.*, pl. 33, especially fig. 4, possibly fig. 7; pl. 34, fig. 3; (?) pl. 35, fig. 1). These are called the "nodulous form" of *I. hobetsensis* because of swellings on the rugae along the margins of the posteroventral sulcus, also a feature of *I.* (*I.*) *flaccidus*. These specimens differ from typical *I.* (*I.*) *hobetsensis* in being more erect in growth form, with a larger triangular posterior auricle, a longer hinge line, in having a deeper and more prominent postumbonal sulcus, and in having much coarser and more widely spaced rugae than *I. hobetsensis*, s. s.. The species is unquestionably recognized in Japan for the first time here, and provides an important biostratigraphic link wink the Western Interior Cretaceous zonation (see KAUFFMAN, 1975, fig. 4).

(17) *Inoceramus* sp. *γ* aff. *I. yabei* NAGAO and MATSUMOTO (1940, pl. 2, figs. 4, 5, 8) cited at ranging from the Middle (?) and Upper Cenomanian through the Coniacian. This form is very closely related to a series of Late Turonian-Early Coniacian taxa which characterize the German "Emscherian" sequence and the stage boundary zone of Euramerica. The closest form, possibly conspecific, is *I. protractus* SCUPIN from the Late Turonian-(?) Early Coniacian of Germany and America. Unfortunately the illustrated specimen of ANDERT 1934, pl. 4, figs. 8a-b) is incomplete and may be somewhat deformed, but it seems to possess most of the characteristics of *I.* sp. *γ* aff. *I. yabei*, differing mainly in having somewhat less regular umbonal rugae. *Inoceramus rotundatus*, from the basal Coniacian of Euramerica is probably descended from and closely related to this form, being more erect, narrower, and having more numerous rugae with a more angular growth trace. Some specimens referred to "*I.*" *lusatiae* ANDERT (e. g. 1934, pl. 7, figs. 1a-b, 2) of the highest Turonian-Lower Coniacian of Euramerica, also belong to this plexus and are closely related. The posterior auricle of typical "*I.*" *lusatiae* is markedly larger and more projecting. Thus *I.* sp. *γ* aff. *I. yabei* is probably a Late Turonian form descended (?) from the Cenomanian *I. yabei* s. s.

(18) *Inoceramus* (*Inoceramus*) *tenuistriatus* NAGAO and MATSUMOTO (1939, pl. 24(2), figs. 3, 8a-c; pl. 26(5), figs. 1-4) cited originally as ranging from the Upper Cenomanian (?) through the Turonian, and possibly into the basal Coniacian in Japan, is now thought to be restricted to the Turonian (MATSUMOTO, 1943; HAYAMI, 1975) and in particular the upper Middle and Upper Turonian (NODA and MATSUMOTO, 1976). This species, a member of the *I.* (*I.*) *etheridgei* lineage, seems to be relatively common in (?) Middle and Late Cenomanian rocks of Euramerica, including the Western Interior (KAUFFMAN, 1975, fig. 4), but is not known above this level in these areas. Its range in Japan is thus younger and possibly more extensive, suggesting Euramerican origin of the stock. Japanese Turonian and Euramerican Cenomanian specimens appear to be identical externally. Detailed study on their morphology still needs to be done to demonstrate they are conspecific rather than a case of precise homeomorphy.

(19) *Inoceramus* (*Inoceramus*) *teshioensis* NAGAO and MATSUMOTO (1939, pl. 24(2), figs. 6, 7, 9a-b; pl. 26(5), figs. 7a-b, cited originally as ranging from (?) Upper Cenomanian and Lower Turonian, definitely through the Middle and Upper Turonian, and possibly into the Middle Coniacian in Japan) has been restudied by NODA (1975, p. 251-253, pl. 35, figs. 2-7; text-fig. 15b) who gives its restricted range as Late Turonian and (?) lowest Coniacian; NODA and MATSUMOTO (1976) concur. This species has been previously referred to as *Inoceramus vancouverensis* SHUMARD (e. g. TRÖGER, 1967, pl. 9, figs. 6-9) and its subsp. *parvus* (TRÖGER, 1967, pl. 9, figs. 1-5; pl. 10, fig. 3) of Upper Turonian-lowest Coniacian age; the name *vancouverensis* is incorrectly applied in this case, SHUMARD's species being a distinct Campanian form which is unrelated. Similar if not conspecific forms are described under *I. kleini* MÜLLER (e. g. HEINE, 1929, fig. 13; ANDERT, 1934, pl. 4, fig. 10-part); typical *I. kleini* are much more inclined and alate. Recently PERGAMENT (1971) has illustrated numerous conspecific specimens under the name *I. multiformis* PERGAMENT from the Coniacian of the Pacific Coast, USSR. *I.* (*I.*) *teshioensis* has priority and should be the name applied. A Late Turonian age is suggested as typical for the species elsewhere, as in Japan. It is seemingly limited to Late Turonian and earliest Coniacian rocks in Euramerica.

(20) *Inoceramus* (*Inoceramus*) *pedalionoides* NAGAO and MATSUMOTO (1939, pl. 26(4), figs. 8, 9; cited originally as ranging from the (?) Upper Cenomanian through the Turonian, and (?) into the Lower Coniacian) is considered now to have a restricted late Middle through

Upper Turonian range (NODA and MATSUMOTO, 1976). This apparent member of the *I.* (*I.*) *pictus-I.* (*I.*) *apicalis* lineage, with its coarse, raised subequal growth lines between faint, subregularly distributed rugae is probably derived from *I.* (*I.*) *pictus* s. s. and may even be conspecific with some coarsely-ribbed forms referred to *I. pictus*, e. g. by WOODS (1911, pl. 49, fig. 5), SORNAY (1965, pl. B, figs. 3, 5a), and HEINZ (1933, pl. 16, figs. 3, 4, especially fig. 4a), although these are cited as Cenomanian in age. The type of *I. pictus* SOWERDY (WOODS, 1911, fig. 36) has fine raised growth lines and small subequal rugae that are nearly twice as numerous as on *I. pedalionoides*. *I. pictus vardonensis* SORNAY (1951, p. 321) with its exceptionally coarse raised growth lines and scattered but coarse constricted rugae is closely related and possibly conspecific; *I. pedalionoides* would have priority as a name over *vardonensis*. All closely comparable or conspecific taxa are of Late Cenomanian age in Euramerica, and it is unusual to find an *Inoceramus* of the *pictus* lineage, so similar to Cenomanian forms referred to *I.* (*I.*) *pictus*, in strata of Middle and Upper Turonian age. The question is raised as to whether or not this is another example of discrepant ages between Euramerican and North Pacific taxa, possibly resulting from biogeographic factors. Typical Turonian members of the lineage, represented by *I.* (*I.*) *apicalis* WOODS are narrower, with smaller posterior auricles, finer concentric raised growth lines, much weaker rugae, and a less projecting beak-umbo. Broader, more coarsely ornamented forms closely similar to *I. pedalionoides* have been noted by me, however, but not described, in collections from the Turonian of England (BM L31246, L89451, L22529, L31260).

(21) *Inoceramus iburiensis* NAGAO and MATSUMOTO (1939, pl. 31(9), figs. 1, 2; pl. 32(10), fig. 2), originally considered to range throughout the Turonian (also HAYAMI, 1975) is now known to be restricted to the Upper Turonian, possibly ranging into the late Middle Turonian of Japan (MATSUMOTO, 1943; NODA and MATSUMOTO, 1976). NAGAO and MATSUMOTO suggested a relationship to *I. percostatus* MÜLLER (1888) with its single, relatively shallow mid-shell sulcus. I cannot easily distinguish certain illustrated specimens of *I. iburiensis* (e. g. NAGAO and MATSUMOTO, 1939, pl. 31, figs. 2a, b; pl. 28, fig. 2) from specimens of *I. percostatus* (which has priority) such as illustrated by HEINE (1929, pl. 3, figs. 14-16) from the lower Middle Coniacian (*schloenbachi-involutus* zones) of Germany, or by DOBROV and PAVLOVA (1959, pl. 12, fig. 3) from Russia. This species is also provisionally identified in the Coniacian part of the Austin Chalk, Texas. Other specimens of *I. iburiensis* illustrated by NAGAO and MATSUMOTO (1939) are seemingly distinct from *I. percostatus* in being more inclined and more weakly sulcate (*ibid.*, pl. 31, figs. 1a-c) or less convex and more erect (*ibid.*, pl. 32, fig. 2), thus closely resembling some Turonian forms of *I.* (*I.*) *lamarcki* PARKINSON (see illustrations in WOODS, 1911), and especially *I.* (*I.*) *lamarcki stumckei* HEINZ, 1926, as illustrated by TRÖGER (1967, pl. 5, fig. 9; pl. 6, fig. 6). *Inoceramus iburiensis* thus appears to be a species plexus rather than a single form, derived from the *I. lamarcki* lineage and including *I.* (*I.*) *stumcki* HEINZ (which has priority), eventually giving rise to and possibly including, in part, *I. percostatus* MÜLLER. Since NAGAO and MTSUMOTO (1939) selected no holotype, the taxonomic problems which surround this plexus, and valid retention of the name *iburiensis*, would best be served by selecting the unique variant of the "species" (*ibid.*, pl. 31, figs. 1a-c) as the lectotype).

(22) *Mytiloides* (="*Inoceramus*") *incertus* (JIMBO) (1894, pl. 8(24), fig. 7; NAGAO and MATSUMOTO, 1940, pl. 3, figs. 1-4), cited originally as ranging from Lower to Upper Turonian, (?) to Middle Coniacian, and characteristic of the Middle and Upper Turonian in Japan (*ibid.*, and MATSUMOTO, 1959), the species is now thought to be restricted to the Middle (?) and Upper Turonian in this area (NODA and MATSUMOTO, 1976). The form, ornament and lineage relationship suggest placement in the genus *Mytiloides*. This distinctive species occurs only in the latest Turonian of the Western Interior U. S. A. as part of a characteristic "Emscherian" assemblage of inoceramids which includes numerous species of European affinities. In both Europe and America, this latest Turonian-lowest Coniacian boundary fauna of Inoceramidae is remarkably diverse, and in one or a few stratigraphically closely-spaced beds two to several described "species" which are lineage related commonly occur. This includes the *Mytiloides incertus* lineage, where several related "species" have been described from the "Emscherian" or "boundary" interval. NAGAO and MATSUMOTO (1940) have recorded and illustrated several

morphological types under the species name "*incertus*" which have been given distinct species or subspecies names elsewhere by European workers, and all of which occur in this Late Turonian, earliest Coniacian interval. I have attempted to point out these taxonomic relationships below without passing judgment on whether or not they are (a) valid taxa or variants within a single species; (b) are rapidly evolving taxa which may occur at distinct but closely spaced stratigraphic intervals; (c) are sympatric species representing niche partitioning within a single zone; or (d) are found together in many parts of the world due to stratigraphic condensation. Japanese specimens of "*I. incertus*" illustrated by NAGAO and MATUMOTO (1940, p. 11) all come from a very narrow stratigraphic interval in the "lowest" part of the upper ammonite beds along the Pombetu, Ikusyunbetu district, Hokkaido. One specimen illustrated by NAGAO and MATSUMOTO (*ibid.*, pl. 10, fig. 2) is clearly distinct from *M. incertus* of JIMBO.

Japanese representatives of *M. incertus* are very similar and possibly only subspecifically distinct from "*I.* (*Platyceramus*) *chouberti*" SORNAY from the Lower Coniacian of Tarfaya, Morocco, differing only in the development of medium-size, raised, equally and closely spaced growth lines over the entire valve (not restricted to umbo as on "*I.* (*P.*) *chouberti*") and in having more weakly defined rugae. *Mytitoides incertus chouberti* (SORNAY) seems to be a better designation for this descendant of Late Turonian *M. incertus* s. s. "*Inoceramus*" *waltersdorfensis afghanicus* SORNAY from the Late Turonian of Herat Province, Afghanistan, is certainly closely related, as is "*I.*" *sturmi* ANDERT. The fragment of "*I. sturmi*" illustrated by ANDERT (1934, pl. 6, fig. 6) from the Emscherian of Germany (Late Turonian, ?earliest Coniacian) appears conspecific with *M. incertus.* If further study should prove the two species identical, the German name must be synonymized with *M. incertus*. *Mytiloides incertus* appears to be the evolutionary link between Late Turonian-earliest Coniacian *Mytiloides fiegei fiegei* (TRÖGER, 1967, pl. 11, fig. 3) and "*I.*" *waltersdorfensis* ANDERT (ibid, 1967, pl. 12, figs. 1-4) from the Lower Coniacian. Some specimens included in "*I.*" *waltersdorfensis* s. l. by ANDERT (1934, pl. 4, fig. 7) which are more elongated than typical for the species, are probably conspecific with *Mytiloides incertus* (JIMBO).

(23) *Mytiloides meekianus* (ANDERSON). The specimen of "*Inoceramus incertus*" JIMBO illustrated by NAGAO and MATSUMOTOT (1940) on pl. 10, fig. 2 from the Middle-Upper Turonian of Japan, differs from typical *Mytiloides incertus* in being much more rounded, less prosocline, and in lacking a distinct subangular bend in the growth line trace over the umbonal fold. The specimen is very closely allied instead to *Mytiloides fiegei fiegei* (TRÖGER), differing only in being even more rounded than this species. *M. fiegei fiegei* occurs in the latest Turonian and earliest Coniacian of Europe, and in the latest Turonian of Western Interior U. S. A. along with forms such as those illustrated from Japan by NAGAO and MATSUMOTO (1940, pl. 10, fig. 2). The popular (but incorrect) concept of "*Inoceramus latus* SOWERBY" (e. g. WOODS, 1911, fig. 41; HATTIN, 1962, pl. 14, figs. A, C, E) is a closely related species which is probably ancestral to this somewhat more rounded form of "*I. incertus*"; late Middle Turonian forms of "*I. latus*" from the Western Interior of the United States (e. g. HATTIN, 1962, pl. 22, fig. E) are conspecific with it. "*Inoceramus*" *meekianus* ANDERSON (1958) from the "Coniacian" (age uncertain) of California seems also to be conspecific and has priority over *M. fiegei* as a name. Thus "*I. incertus*" of NAGAO and MATSUMOTO (1940, pl. 10, fig. 2 only) (=*M. meekianus* herein) is possibly an evolutionary link between *Mytiloides* "*latus*" (sensu WOODS, 1911, fig. 41 only) and *Mytiloides fiegei fiegei* (TRÖGER), suggesting that its principal age range should be late Middle and early Upper Turonian, as NODA and MATSUMOTO documented for "*I. incertus*".

(24) "*Inoceramus* sp. cfr. *I. incertus*" JIMBO (NAGAO and MATSUMOTO, 1940, pl. 3, fig. 5) of Middle (?) to Upper Turonian and possibly lowest Coniacian age in Japan is a poorly preserved, strongly prosocline shell with moderately coarse, closely spaced rugae and no apparent development of regular growth lines as on *Mytiloides incertus* s. s. It appears to me very closely comparable if not conspecific with *Mytiloides dresdensis ? labiatoidiformis* (TRÖGER) (1967, pl. 10, figs. 5, 6) from the highest Turonian strata of Germany and Western Interior U. S. A., and is age-equivalent.

(25) *Inoceramus* (*Inoceramus*) *angulosus* JIMBO (1894, p. 43, pl. 8, fig. 6) was first redescribed from Japan by MATSUMOTO (1963, p. 45, pl. 67, fig. 6), mentioned by MATSUMOTO

and HARADA (1964, p. 97), and listed by HAYAMI (1975) as coming from the Turonian (substage undifferentiated). The species is extremely rare and is thus not listed in NODA and MATSUMOTO (1976) as being biostratigraphically important. It is cited here for completeness.

(26) *Mytiloides "labiatus"* (SCHLOTHEIM) s. l. MATSUMOTO (1959) cited "*Inoceramus* sp. cf. *I. labiatus*" as occurring sparsely in the Lower Turonian of Japan. MATSUMOTO and HARADA (1964) constructed a basal Turonian zone based on "*Inoceramus* cf. *labiatus*". Collection of numbers of additional specimens provided material for a detailed systematic treatment of the species and its definite determination (MATSUMOTO and NODA, 1975) from throughout the Lower Turonian of Japan. These authors, like many others in the world, have applied the broad species concept of *M. labiatus*; SEITZ (1934 1935)), however, provided an alternative treatment, illustrating specimens which are very similar to the lost SCHLOTHEIM type (*ibid.*, pl. 38, fig. 1; text-fig. 5a), which he had seen at one time, and recognizing that this type concept was distinct from the species concept of *labiatus* applied by most workers. SEITZ described several distinct "varieties" (used as subspecies) and "forms" (used as varieties) of *I. labiatus*, but did not note that they had distinct stratigraphic ranges, and were thus useful in zonation of the Lower Turonian. KAUFFMAN (1975; 1977, in press) has described these as separate species and subspecies in the Western Interior of North America and recognized that they form a succession of Lower Turonian biostratigraphib zones at closely spaced stratigraphic intervals, repesenting a rapid evolutionary event (KAUFFMAN, 1977a, in press). These zones have subsequently been widely traced in Europe (KAUFFMAN, 1977b, d, in press; KAUFFMAN, COBBAN and EICHER, 1977, in press; WIEDMANN and KAUFFMAN, 1977, in press). Study of illustrations of the Japanese specimens of "*I. labiatus*" in MATSUMOTO and NODA (1975, pl. 18, figs. 1-6; text-fig. 5), and of plaster casts kindly provided to me by Dr. MATSUMOTO, convinces me that true *Myuiloides labiatus* (SCHLOTHEIM) s. s. is not yet known from Japan, and that three, possibly four (including possible *M. submytiloides* from the latest Cenomanian) of the biostratigraphically useful taxa of SEITZ and others, originally incorporated under the broad concept of *M. labiatus*, are present in the same stratigraphic order as elsewhere in the world, as follows:

(a) *Mytiloides opalensis* (BÖSE) s. s., and its subsp. *elongata* SEITZ (see SEITZ, 1934 (1935), pl. 38, figs. 4-6; pl. 39, figs. 1-4; text-fig. 14a-c; 15a-c) are characterized by rounded to ovate shells of moderate convexity having equally developed and relatively coarse concentric rugae which rarely if ever have intercalated raised growth lines between them in the umbonal area of the shell. This is the lowest of the wholly Turonian zones based on the *M. labiatus* lineage (KAUFFMAN, 1975) and seems to be represented by specimens illustrated by MATSUMOTO and NODA (1975, text-fig. 5c; pl. 18, fig. 2), both of which seem closest to *M. opalensis elongata*.

(b) *Mytiloides mytiloides* (MANTELL) (see SEITZ, 1934 (1935), pl. 36, figs. 1-4; pl. 37, figs. 4, 5; text-figs. 2a-f, 3a-f) is the species most often cited as *M. "labiatus"* in the literature and is characterized by its elongated-ovate (labiatoid) outline, moderate to moderately low convexity, low beaks, and subeven concentric ornament of alternating rugae and raised, evenly spaced growth lines over the entire shell, or nearly so. It forms a prominent, cosmopolitan, middle Lower Turonian biostratigraphic zone. SEITZ divided it into typical forms (subsp. *mytiloides*) and forms with strongly curved shells and inflated beaks and umbos (subsp. *arcuata*) which are transitional to true *M. labiatus*. Both forms seem to be present in the middle part of the Japanese Lower Turonian as defined by MATSUMOTO and NODA (1975). *M. mytiloides mytiloides* appears to be represented by their pl. 18, figs. 3a, b, and possibly the younger specimen in fig. 5; *M. mytiloides arcuata* (SEITZ), transitional to the elongated and finely ornate veriety of *M. labiatus* illustrated by SEITZ (1934 (1935), pl. 38, fig. 3; text-figs. 9c, 11c), seems to be represented by MATSUMOTO and NODA's pl. 18, figs. 1, 4. The two subspecies commonly co-occur in the upper part of the *M. mytiloides mytiloides* range zone.

(c) *Mytiloides subhercynicus* (SEITZ) [1934 (1935), pl. 40, figs. 1, 2, 5a, b; text-figs. 18a-f] is the form transitional between *M. labiatus* and *M. subhercynicus transiens* (SEITZ), which in turn gives rise to *M. hercynicus* (PETRASCHECK) of the Middle Turonian. *M. subhercynicus* occurs in the highest part of the Lower Turonian with *M. labiatus* in many parts of the world. It is clearly represented in form and equivalent stratigraphic position by MATSUMOTO and NODA's pl. 18, fig. 6.

Inasmuch as *M. labiatus* is the type-species of *Mytiloides* BRONGNIART (subgenotype in COX, 1969, p. N317), and all of these taxa are lineage-related to *M. labiatus*, they have been reassigned here from *Inoceramus* to *Mytiloides*, which I consider to be a good genus.

(27) *Mytiloides* (="*Inoceramus*") *teraokai* MATSUMOTO and NODA (1968, pl. 32, figs. 1-5; text-fig. 2) from the Middle to early Upper Turonian of Japan (NODA and MATSUMOTO, 1975). NODA (1975) found it only in the early Middle Turonian of southwest Japan. This unusual species, with its prominent rounded anterior auricle and large, flattened posterior auricle, is not yet known outside of Japan, although some similar and possibly related forms occur in Western Interior United States, generally placed within the concept of *Mytiloides* "*latus*" s. l. of HATTIN (1962, pl. 14, figs. A, C, E; pl. 22, fig. E). However, these have a much less expanded dorsoanterior flank and lack a true anterior auricle. Superficially the species resembles *Sergipia* MAURY, and especially inclined forms like *S. posidonomyaformis* MAURY and subsp. *scheibei* of HEINZ (1928, pl. 5, fig. 3; pl. 5, fig. 6) but not of MAURY (1936, pl. 8, fig. 15)—a more erect form with larger, more angular auricles. But whereas *M. teraokai* has a broad flat anterior auricle typical of *Sergipia* and unusual for other Inoceramidae, it is more rounded than that of *Sergipia*. *M. teraokai* also has a much different ornamentation than *Sergipia* (compare MATSUMOTO and NODA, 1968, text-fig. 2, and pl. 32, figs. 1-5, with COX, 1969, fig. C48-6) with irregular to subregular, closely spaced, angular rugae between and on which are coarse, raised growth lines. "*Inoceramus*" *teraokai* seems therefore most closely related to rounded members of the Turonian *Mytiloides* lineage like *M.* "*latus*" and *M. hercynicus* (PETRASCHECK: especially as illustrated by BÖSE, 1923, pl. 12, figs. 2-5). MATSUMOTO and NODA's pl. 32, figs. 4, 5 (1968), in fact, have regulary alternating rugae and raised growth lines and are nearly identical to certain variants of *M. hercynicus* (e. g. BÖSE, 1923, pl. 12, fig. 4; ZAGARELLI, 1942, pl. 9, fig. 1) except for greater development of the anterior auricle. *M. teraokai* is presumbly descended from Middle Turonian *M. hercynicus*.

(28) *Sergipia akamatsui* (YEHARA) [=*Inoceramus* (*Sergipia* ?) *akamatsui* YEHARA, 1924, pl. 2, fig. 2-4; NAGAO and MATSUMOTO, 1940, pl. 13, figs. 1, 5; pl. 22, fig. 6], cited by these authors, MATSUMOTO (1959), and NODA and MATSUMOTO (1976), as ranging from the Middle Turonian through the Middle and (?) early Late Coniacian of Japan. Assignment of the figured specimens to *Sergipia* is correct and should not be questioned. NODA (1975) and NODA and MATSUMOTO (1976) assigned the species to the Coniacian genus *Didymotis*, but specimens I have seen lack the prominent radial ribs and plicae of *Didymotis*. Recollection of MAURY's Brazilian localities of *S. posidonomyaformis* along with ammonites by Peter BENGTSON at Uppsala University suggests a Middle to Late Turonian and (?) an earliest Coniacian age for the species instead of a Maastrichtian age (MAURY, 1939; MATSUMOTO, 1959, p. 87); this is more compatible with the Japanese occurrence. If the delicate auricles are broken off of the illustrated Japanese specimens, then it is likely they are conspecific with *S. posidonomyaformis* (MAURY), or at best a distinct subspecies, and MAURY's name must be synonymized. If the Japanese forms lack distinct auricles, then the species *akamatsui* is distinct from *posidonomyaformis*. BÖSE (1923, pl. 12, fig. 5) illustrated specimens of *Sergipia* from the Turonian of Mexico within his concept of "*Inoceramus hercynicus*", which are related and possibly conspecific with *S. akamatsui*. The collections of RUTSCH and SALVADOR (1954, pp. 417-426) from the Turonian-Lower Coniacian part of the La Luna Formation, western Venezuela contain identical specimens, as do as yet unpublished collections from Colombia, Mexico, and Trinidad. More inclined species of *Sergipia* (e. g. *S. posidonomyaformis scheibei* HEINZ and affiliated forms) occur in rocks of the same age in South America, Europe, California, and (?) in the Western Interior United States.

Coniacian Taxa

(29) "*Inoceramus incertus yubariensis*" (=*I. waltersdorfensis yubariensis* of this paper). NAGAO and MATSUMOTO (1940, pl. 6, figs. 1a-c) cited this species originally as ranging from the Lower (?) and Middle Coniacian into the Santonian of Japan. NODA and MATSUMOTO (1976) give it full species status and restrict the range from Middle Coniacian through the

Lower Santonian of Japan. This distinct Japanese species is clearly closely related to, and possibly descended from, *Inoceramus waltersdorfensis* ANDERT from the highest Turonian and Lower Coniacian of Euramerica and the Caribbean. Typically, *I. waltersdorfensis* is much less convex and has a more angular bend in the growth line trace over the umbonal fold, with more distinct flattening of the growth lines on the posteroventral flank of the shell (see TRÖGER, 1967, pl. 12, figs. 1-4), but ANDERT has illustrated identical forms to "*I. incertus yubariensis*" as "*I. waltersdorfensis*" (1934, pl. 4, figs. 2a-b, 3a-b) and as a holotype of *I. waltersdorfensis* has not been selected, "*I. incertus yubariensis*" still lies within the species concept of *I. waltersdorfensis* ANDERT. "*I. incertus yubariensis*" also would be incorporated into the species concept of early *I. inconstans* WOODS (1911; also see ANDERT, 1934, pl. 3, fig. 1) and is closely related, perhaps ancestral to this species as strictly defined. In view of the clear affinities of "*I. incertus yubariensis*" to the *I. waltersdorfensis* lineage rather than to the *Mytiloides incertus-M. fiegei* lineage, and considering TRÖGER's (1967) emendation of *I. waltersdorfensis* s. s. and subsp. *hannovrensis* to exclude the inflated, more rounded forms like "*I.*" *incertus yubariensis*, I suggest that the subsp. *yubariensis* be retained as a subsp. of "*I.*" *waltersdorfensis*. A primarily Coniacian age is suggested by global data for "*I.*" *waltersdorfensis yubariensis* NAGAO and MATSUMOTO.

(30) *Inoceramus uwajimensis* YEHARA (NAGAO and MATSUMOTO, 1939, pl. 33(11), figs. 1a-c, 3a-b, 4, 6; pl. 34(12), figs. 1-3; NODA, 1975, pl. 36, ẏgs. 1-8; text-fig. 17) was cited originally as ranging through most of the Coniacian, with its principal occurrences (MATSUMOTO, 1959) in the Lower and Middle Coniacian of Japan (NODA, 1969; NODA and MATSUMOTO, 1976). NAGAO and MATSUMOTO noted relationships to a number of Late Turonian-Lower Coniacian European species such as *I. kleini*, *I. frechi*, *I. glatziae*, *I. stillei*, *I. gürichi*. *I. uwajimensis* clearly lacks the flared posterior auricle and more erect beak-umbo of *I. kleini*. *I. frechi* is similar in body form and closely related, but also possesses a more prominent auricle and more erect beaks. *I. glatziae* is a much taller and more erect shell. Neither *I. stillei* nor *I. gürichi* appear to be closely related. Some illustrated specimens of *I. uwajimensis* are very similar to the common American Middle Coniacian species *I. stantoni* SOKOLOW, 1914 (non *I. stantoni* ANDERSON, 1945), proposed by SOKOLOW to replace the preoccupied name *I. acuteplicatus* STANTON (1899; non SCHAFHAUTL, 1863), as documented below. MATSUMOTO noted this relationship (1959, p. 85; 1961) and the fact that both developed weak radial riblets in the upper part of their range (? grading to *I. subquadratus* SCHLÜTER in the Upper Coniacian). YEHARA's original type lot (1924) contains two forms, and these are expressed in subsequent treatment of the species, as follows:

(a) *Inoceramus uwajimensis* YEHARA s. s. is an exect, coarsely rugate form with only a moderately prosogyrous beak and lacking prominent expansion of the anterior flank below the beaks (e. g. 1924, pl. 3, fig. 1; pl. 4, fig. 1). In his superb revision of the species, utilizing population systematic methods, NODA (1975, pp. 253-256, pl. 36, figs. 1-8; text-fig. 17) has applied this concept of the species and has further recognized an upaward increase in species variation and significant broadening of the shell in some members of the youngest populations, suggesting possible biostratigraphic utility for these variants.

(b) *Inoceramus stantoni* SOKOLOW. Some specimens of *I. uwajimensis*, especially those illustrated originally by YEHARA (1924) on pl. 3, fig. 2, and pl. 4, figs. 2, 3, and by NAGAO and MATSUMOTO (1939, pl. 34, figs. 2-4) are more inclined than typical *I. uwajimensis*, have a more asymmetrical growth line-rugae trace, more evenly distributed rugae, and have a twisted, strongly prosogyrous beak-umbo below which the anterior margin is projecting and rounded. These forms are indistinguishable from *I. stantoni* SOKOLOW (=*I. acuteplicatus* STANTON) from the American Coniacian (see illustrations in STANTON, 1899, pl. 65, figs. 9, 10), which has priority as a name.

(31) *Inoceramus uwajimensis yeharai* NAGAO and MATSUMOTO (1939, pl. 33, figs. 2, 5; pl. 34, fig. 4), cited originally as ranging from the Upper Turonian (?) and definitely through the Coniacian in Japan, is now considered to be Lower, Middle and (?) Upper Coniacian in age. "*Inoceramus inconstans* WOODS" of ANDERT (in part, 1934, pl. 2, figs. 5a-b) from the German "Emscherian" (highest Turonian, lowest Coniaciau) is identical, but is not typical of *inconstans* s. s. *I. glatziae* FLEGEL, 1905, especially as illustrated by ANDERT 1934, pl. 6, figs.

4a-c), is very closely related, differing only in being slightly narrower and more erect than subsp. *yeharai*. Considering that the Japanese specimens illustrated by NAGAO and MATSUMOTO are crushed, the two may be conspecific, in which case the German name has priority over all others. *I. winkholdioides* ANDERT (1934, pl. 8, figs. 1a-b) also appears conspecific with *I. uwajimensis yeharai* (compare ANDERT, 1934, pl. 8, fig. 1a, with NAGAO and MATSUMOTO, 1939, pl. 34, fig. 4). These forms have a more restricted range in Euramerica than in Japan, late Turonian-early Coniacian, and are considered ancestral to the Euramerican Lower Coniacian index species *I. rotundatus* FIEGE; this species has more numerous, more clearly bent rugae. They are possibly ancestral also to the more regularly rugate *I. ernsti* HEINZ (see TRÖGER, 1967, pl. 12, figs. 5, 6; pl. 14, fig, 6 for comparison). *Inoceramus winkholdioides* (=subsp. *yeharai*) is widespread in latest Turonian and Lower Coniacian strata of Euramerica. NODA (1975) treated *I. uwajimensis* in detail, but synonymized subsp. *yeharai* with sp. *uwajimensis* s. s. I consider the two valid subspecies based on concepts currently applied to the diverse Lower Coniacian inoceramids of Euramerica, where they have somewhat different stratigraphic ranges.

(32) *Mytiloides* ? (="*Inoceramus*") *naumanni* YOKOYAMA, emd. NAGAO and MATSUMOTO (1940, pl. 13, fig. 4; pl. 14, figs. 1-10; pl. 15, figs. 1, 2; pl. 17, fig. 6), cited originally as ranging questionably into the highest Turonian and lowest Coniacian, and characteristically from middle Lower Coniacian into the Lower Santonian. NODA and MATSUMOTO (1976) have revised the range as Middle (?) and Late Coniacian through the Santonian. UEDA, MATSUMOTO and AKATSU (1962) report it from Lower Campanian strata as well. NODA (1969) notes a restricted Late Coniacian-Early Santonian range for the species in Kyushu. Two related forms seems to be present under this name and should be distinguished if it can be shown that they do dot intergrade and are stratigraphically distinct in their ranges. Both seem closer to the genus *Mytiloides* than the *Inoceramus* s. s., although studies of interior shell features will be necessary to demonstrate this conclusively. HAYAMI (1975) assigns it to *Sphenoceramus* BÖHM, but it lacks the radial ornament of that genus.

(a) The specimens illustrated by NAGAO and MATSUMOTO (1940) in pl. 14, figs. 2, 9; pl. 15, fig. 1? seem conspecific with *Mytiloides* ? *striatoconcentricus* GÜMBEL aff. *M* ? *striatoconcentricus carpathicus* SIMIONESCU (sensu HEINZ, 1928) as defined and illustrated by TRÖGER (1967, pl. 9, fig. 18). This form should be given a new specific name inasmuch as the type of *M. carpathica* (SIMIONERCU, 1899, pl. 2, figs. 1a-b) has a prominent posterior auricle and strongly bent growth line trace over the umbonal fold which are not found on TRÖGER's (1967) or NAGAO and MATSUMOTO's (1940) specimens. Nevertheless this species is distinct from *M.* ? *naumanni* in having close-spaced, rounded, strongly raised, equally developed growth lines over the entire shell without clearly defined regular rugae. TRÖGER cites a latest Turonian and Lower Coniacian age for this taxon in Europe, and it has a similar range in the Western Interior U. S. A., but also extends into the Middle Coniacian, as in Japan.

(b) *Mytiloides* ? *naumanni* s. s. (NAGAO and MATSUMOTO, 1940, pl. 13, fig. 4; pl. 14, figs. 1, 3a-b, 4-8, 10; pl. 15, fig. 2) has closely set small angular rugae, double in some cases, with finer raised growth lines between and on them in most specimens. This appears ancestral to "*I.*" *inconstans* s. s., insofar as that species has an identical early growth stage. *M.* ? *naumanni* is common in the Lower and lower Middle Coniacian of the United States.

(33) *Cordiceramus* (="*Inoceramas*") *cordiformis mukawaensis* [=*I.* sp. nov ? (*I. mukawaensis* OTATSUME Ms.) (NAGAO and MATSUMOTO, 1939, pl. 32(10), figs. 1a-d, 3a-b)] was cited originally as ranging through the Upper Coniacian into the Santonian. NODA and MATSUMOTO (1976) question the Santonian range. Both weakly sulcate (*ibid.*, figs. 1a-d) and strongly sulcate (ibid, figs. 3a-b) forms are included in this species; comparison with other inoceramids in Euramerica suggests that they may be distinct, as follows:

(a) The strongly sulcate forms without well defined, regular, angular rugae (*ibid.*, pl. 32, figs. 3a-b) are seemingly closely related to or even conspecific with WOODS (1911, pl. 54, figs. 1a-b) "*I. lamarcki*....variety connecting *I. lamarcki* with *I. cordiformis*", "probably" from the Late Turonian *Holaster planus* zone (similar forms are known from the

Coniacian). This form also lies within the broad concept of *Inoceramus* (*Cordiceramus*) *cordiformis* SOWERBY as most recently defined by SEITZ (1961, pp. 114-121), and seems related to but not consubspecific with forms like "*I.* (*Cordiceramus*) *cordiformis* subsp. indet." of SEITZ (ibid, pl. 7, fig. 1) with strong medial and auricular sulcae; these are primarily of Santonian age, and characterize especially the Lower Santonian of Euramerica. The preferred designation for the Japanese form might therefore be *Cordiceramus cordiformis mukawaensis* NAGAO and MATSUMOTO. Radial riblets are described on the surface of this species, which seems from the illustrations to be represented mainly by internal molds with thin portions of shell adhering. Whereas fine radial lines are irregularly and sparsely distributed over the surface of some *C. cordiformis* shells (see SEITZ, 1961, pl. 6, figs. 5b, 7b), radial "lines" are common on internal molds and in the nacreous layers of this and many other inoceramids, representing the tracks of the mantle retractor muscles which form the pallial line. These are not significant in species determination, whereas those of the shell exterior (prismatic layer) are highly significant.

(b) *Inoceramus frechi* FLEGEL, n. subsp. The forms of *I. mukawaensis* illustrated in plate 32(10), figs. 1a-d (NAGAO and MATSUMOTO, 1939) appear to me distinct from those of figs. 3a-b (*ibid.*). The shell is larger, less inflated, more prosogyrous, more regularly rugate, with a less strongly projecting beak and at best a very shallow medial sulcus. This does not closely resemble any Santonian forms that I know from Euramerica, but does closely resemble Upper Turonian-Lower Coniacian taxa such as *I. frechi* FLEGEL (see ANDERT, 1934, pl. 5, figs. 6-8), and *I. seitzi* ANDERT (1934, pl. 16, fig. 2), as noted by NAGAO and MATSUMOTO. Some of NAGAO and MATSUMOTO's specimens (e. g. pl. 32, fig. 1a) are identical to specimens of *I. frechi* (e. g. ANDERT, 1934, pl. 5, fig. 6) in having only a broad flattening or very shallow broad depression of the mid-shell slope rather than a distinct shellow sulcus as seen in pl. 32, fig. 1d of NAGAO and MATSUMOTO (1939). *Inoceramus seitzi* has a rounder trace of the rugae and no medial depression. I would suggest that this form in Japan is at best subspecifically distinct and descended directly from *I. frechi.*

(34) *Cordiceramus cordiformis* (SOWERBY). NODA and MATSUMOTO (1976) describe "*Inoceramus*" *cordiformis* as coming from the Middle Coniacian through Lower Santonian rocks of Japan. I have not seen the specimens, and do not know if this report encompasses some forms included under *C.* (*C.*) *cordiformis mukawaensis* by NAGAO and MATSUMOTO (1939; see discussion in No. 33 of this survey), and originally assigned to *Inoceramus*, or not. *C. cordiformis* s. s. is typically of Santonian age in Euramerica, so I suspect the Japanese forms are an ancestral subspecies or species.

(35) *Inoceramus* sp. indet. aff. *I.* sp. nov. ? (*I. mukawaensis*, OTATSUME Ms.) of NAGAO and MATSUMOTO (1939, pl. 30(8), figs. 4-7), of supposed Upper Coniacian and Santonian age. These incomplete and deformed specimens are too poorly preserved for confident comparison, but they do suggest two well known, cosmopolitan, Late Coniacian species of the genus *Magadiceramus*, as follows. Neither are recognized in Japan by NODA and MATSUMOTO (1976).

(a) NAGAO and MATSUMOTO's pl. 30(8), figs. 5 and 7 (1939) strongly suggest affinities to "*I.* (*Magadiceramus*) *subquadratus subquadratus* SCHLÜTER", in particular where deformed, as illustrated by SEITZ (1970, pl. 1, fig. 2b; pl. 9, fig. 1) and/or the closely related *I. soukupi* MAČAK (SEITZ, 1970, pl. 6, fig. 1; pl. 10, fig. 3). The fine radial ribs and midshell flattening or shallow depression described for the Japanese specimens by NAGAO and MATSUMOTO (1939) closely match the characteristics of *Magadiceramus subquadratus*, and the ages are compatible.

(b) NAGAO and MATSUMOTO's pl. 30(8), figs. 4 and 6 (1939) have strong, fluted, expanding but discontinuous exterior radial ribs and a broadly flattened ventral growth line and rugae trace. This strongly suggests affinities to "*I.* (*Magadiceramus*) *austinensis* HEINZ" (cf. SEITZ, 1970, pl. 7, figs. 1, 2), the only member of this species group which has these unusual radial ribs combined with this type of growth line trace. This is a typically Late Coniacian species in Euramerica.

(36) *Inoceramus mihoensis* MATSUMOTO (1957, pl. 21, figs. 1-4), who originally reported this species from the Upper Coniacian and lowest Santonian of Japan. NODA (1969) and NODA and MATSUMOTO (1976) adjust the range to Middle and Late Coniacian. *Inoceramus mihoensis*

belongs to the characteristic Lower and Middle Coniacian species group of *I. rotundatus-I. erectus-I. deformis* and the less closely related *I. ernsti* lineage, as evidenced by its size, moderate inflation, blunt slightly projecting beaks, coarse subregular rugae, subquadrate outline, and by the ventrally and posteriorly flattened growth line trace with its distinct angular bend across the umbonal fold. It is closest in size and morphology to *I. erectus erectui* MEEK (1877, pl. 13, figs. 1, 1a; STANTON, 1894, pl. 15, fig. 1) from the lower Lower Coniacian of the Western Interior and Gulf Coast United States and especially to middle Lower Coniacian forms transitional between this species and *I. deformis* MEEK. These transitional forms have been called *I. erectus* n. subsp. (late form of KAUFFMAN, 1966; KAUFFMAN, COBBAN and EICHER, 1977, in press, pl. 15, fig. 6), differing from *I. mihoensis* mainly in being relatively longer and squarer in outline, and in having slightly smaller, more numerous rugae. *Inoceramus ernsti* HEINZ is clearly a more erect and inflated form. MATSUMOTO (1959, p. 85) notes affinities of this species to *I. inconstans* WOODS (in part), and the Japanese form does appear to be conspecific with some forms of "*I. inconstans*" WOODS (1911, fig. 46) supposedly from the "*Holaster planus* zone" (Turonian, probably basal Coniacian) of England; this form does not have the ornament nor strong break in slope of the types of *inconstans* selected by WOODS (1911, figs. 42, 44) and instead falls broadly within the subspecies concept of *I. erectus* MEEK, n. subsp. (late form) of KAUFFMAN. *I. mihoensis* therefore presents a problem in that it is most closely related to or conspecific with Lower Coniacian species of Euramerica (which do not range above the Lower Coniacian), and yet it is reported only from Middle and Upper Coniacian strata of Japan. Whether this is a problem of biogeographic dispersal, of problematical dating, or whether this is an endemic descendant of *I. erectus*, retaining many characteristics of the ancestor, remains to be determined.

(37) *Sphenoceramus ? yokoyamai* (NAGAO and MATSUMOTO, 1940, pp. 44, pl. 16, fig. 2; pl. 20, fig. 2; pl. 21, fig. 2) was originally assigned to *Inoceramus* and cited as ranging from the Santonian through the Campanian; NODA and MATSUMOTO (1976) consider it now as Middle (?) and Late Coniacian in age. This form appears to be ancestral to true *Sphenoceramus* of the *S. lingua* (GOLDFUSS) species group, as has been noted by PERGAMENT (1965), and is tentatively placed in this genus; early evolutionary forms tend to lack the strong postumbonal sulcus that characterizes typical younger (Santonian) *Sphenoceramus*. Two forms seem to be present in NAGAO and MATSUMOTO's illustrated suite of specimens (1940), as follows:

(a) *Sphenoceramus ? yokoyamai* (NAGAO and MATSUMOTO) s. s. as represented by their plate 16, figs. 2a, b and plate 20, figs. 2a-c (*ibid.*, 1940) is a distinct species closely related to *S. lingua* (compare PERGAMENT, pl. 11, fig. 5 with fig. 6) and apparently ancestral to it, but differing in having a blunter and more inflated beak and umbo. PERGAMENT's specimens of *S. ? yokoyamai* are listed as coming from Santonian-Campanian strata, suggesting that the species may range higher than most recently determined by NODA and MATSUMOTO (1976). "*Inoceramus*" *contracostae* ANDERSON (1958, pl. 18, figs. 3, 4) from the "Lower Senonian-Middle Campanian" of California appears conspecific and becomes a junior synonym of *S. ? yokoyamai.*

(b) *Sphenoceramus lingua* (GOLDFUSS) subsp. *lingua* ? (see PERGAMENT, 1965, pl. 10, figs. 1, 6; pl. 11, figs. 6, 7; pl. 12, fig. 9) seems to be represented by the more elongated specimens of "*I. yokoyomai*" figured by NAGAO and MATSUMOTO in plate 21, fig. 2 (1940); this has a prominent but shallow postumbonal sulcus, as in typical *Sphenoceramus lingua.* The Japanese specimen appears slightly more inflated, with a somewhat blunter beak than typical for subsp. *lingua*, but is within the range of variation of the species. *S. lingua* is a Santonian-Campanian form characteristically (PERGAMENT, 1965; SEITZ, 1965) but may have Late Coniacian representatives. For example, "*Inoceramus*" *klamathensis* from the California "Senonian" (Coniacian ?-Campanian) is conspecific and synonymous with *S. lingua*; elongate varieties of Coniacian *I. waltersdorfensis* ANDERT (1934, pl. 4, fig. 7) are apparently ancestral and very closely similar to NAGAO and MATSUMOTO's specimen. Typical *I. waltersdorfensis* (ANDERT, 1934, pl. 4, figs. 2-6; TRÖGER, 1967, pl. 12, figs. 1, 2; pl. 13, figs. 1-5) are more erect, rounded to subquadrate forms with similar ornament.

(38) *Mytiloides* (?) (="*Inoceramus*") *pilvoensis* SOKOLOW (NAGAO and MATSUMOTO, 1940,

pl. 22, fig. 5); its precise range is unknown but it was originally judged by these authors to be possibly from the Upper Turonian through the Coniacian, and into the Santonian of Japan. MATSUMOTO (1943) restricted its possible range to Upper Coniacian-Campanian. Neither HAYAMI (1975) or NODA and MATSUMOTO (1976) list the species in Middle Cretaceous or Coniacian strata. Both the original description and NAGAO and MATSUMOTO's emendation of the species (1940) are based on fragments and imperfect specimens. If the species truly lacks an anterior auricle, then it should be placed in the genus *Mytiloides* (?) and closely allied to Middle Turonian *M. ? hercynicus* (PETRASCHECK). Similar forms have been incorporated into the concept of *M. ? hercynicus* (e.g. DOBROV and PAVLOVA, *in* MOSCVIN, 1959, pl. 2, fig. 5; BÖSE, 1923, pl. 12, figs. 2, 4, 5), but NAGAO and MATSUMOTO are correct in noting that the Japanese specimen is more elongate-ovate, with a less rounded growth line trace, than found in typical *Mytiloides hercynicus*. *Mytiloides ? pilvoensis* is also more extended anteriorly. It could also be closely related to, or even a secondarily compressed specimen of *M. fiegei fiegei* (TRÖGER, 1967, pl. 11, fig. 3), a Lower to Middle (?) Coniacian Euramerican species with a more anteriorly situated beak when well preserved. Based on the occurrence of similar species in Euramerica and Central America, it seems likely that *M. ? pilvoensis* may represent a Middle Turonian through Middle Coniacian interval.

Post-Coniacian Taxa Originally Cited as Coniacian in Age

(39) *Inoceramus ezoensis* YOKOYAMA and subsp. *vanuxemiformis* NAGAO and MATSUMOTO (1940, pl. 7, fig. 1; pl. 10, figs. 3, 4; pl. 11, figs. 2, 3) were originally reported questionably from the Upper Coniacian and definitely from the Santonian of Japan. These appear to be closely related or conspecific with *Platyceramus cycloides* and its subspp. and are typically Santonian taxa not yet definitely reported from the Coniacian elsewhere in the world. NODA and MATSUMOTO (1976) correctly restrict this species to Santonian and younger strata in Japan.

(40) *Inoceramus japonicus*, form α, NAGAO and MATSUMOTO (SASA Ms. name) (1940, pl. 5, fig. 2; pl. 6, figs. 2, 3; pl. 9, fig. 2) was first questionably reported as ranging into the Upper Coniacian, and definitely into the Santonian of Japan. This distinct member of the *Cladoceramus undulatoplicatus* (ROEMER) lineage is confined to the Santonian, usually Lower to Middle Santonian, elsewhere in the world. NODA and MATSUMOTO (1976) now restrict its range to the upper half of the Santonian in Japan.

(41) *Inoceramus amakusensis* NAGAO and MATSUMOTO (1940, pl. 3, figs. 6a-b; pl. 4, figs. 1, 3, 4; pl. 5, fig. 1) was questionably reported from the Upper Coniacian, and definitely from the Santonian of Japan. NODA (1969) and NODA and MATSUMOTO (1976) restrict its range to the Lower and Middle Santonian. This form is, to date, unknown from the Western Interior and Gulf Coast United States, and only questionably related forms are known from Europe. A nearly identical specimen occurs in Santonian rocks of Jamaica. To date no Coniacian reports of the species have been verified. This probably belongs to the genus *Platyceramus*.

Preliminary Taxonomic and Biostratigraphic Survey of Middle Cretaceous and Coniacian Inoceramidae of the Pacific Coast United States and their Comparison with Those of the Euramerican Region and Japan

Albian Taxa

(1) *Birostrina* (="*Inoceramus* (*Actinoceramus*)") *concentrica* (PARKINSON) of JONES (1960, pl. 29, figs. 1, 2), late Lower to Middle Albian of southwestern Oregon. This left valve is unusual for "*I.*" *concentricus* in having a relatively low beak, broad rounded form and subcircular growth line trace (compare with WOODS, 1911, pl. 47, figs. 1, 2; pl. 46, figs. 3a, 4a, 5a, 7; pl. 45, fig. 11; all typical left valves). In a preliminary restudy of the species of *Birostrina* from throughout the English and French Albian, KAUFFMAN (1977b, in press) suggested the *Birostrina concentricus* (PARKINSON), as currently defined, represented a plexus of several species and subspecies which replaced one another in evolutionary sequence through

the Albian and Lower Cenomanian. In this series, forms with rounded left valves, rounded growth line trace, and relatively low beaks (n. subsp.) were mainly found from the Middle Albian *loricatus* Zone ranging upward into the basal Upper Albian *cristatum* Zone of the English sequence; their age is compatible with the Oregon occurrence. COX (1969, p. N315) notes that *Actinoceramus* MEEK, 1864 is a junior objective synonym of *Birostrina* SOWERBY, 1821. I suggest this form be called *Birostrina concentrica* (PARKINSON), n. subsp. (rounded form).

(2) *Birostrina* (="*Inoceramus* (*Actinoceramus*)") *salomoni* (D'ORBIGNY) of JONES (1960, pl. 29, figs. 3, 4) from the late Lower to Middle Albian of Oregon. *Birostrina salomoni* normally has a restricted Lower Albian (mainly *D. mammillatum* Zone) range in England (KAUFFMAN, 1977b, in press) and does not normally range into the Middle and Late Albian. JONES's specimen seems most closely referable to *B. salomoni* in general form and ornament, but differs in having slightly more prosogyrous beaks, a much broader and shallower mid-shell sulcus which, from the growth line trace, suggests an incipient pair of shallow sulci rather than one, in having a much flatter ventral growth line trace which bends sharply over the umbonal ridge, and in having smaller, more irregular raised growth lines than is typical of *B. salomoni.* IMLAY has described a *Birostrina "subsulcatiformis"* (BÖSE) from the Middle Albian Tamaulipas Limestone from Mexico (1937, pl. 27, figs. 1-15) which is not strictly *B. subsulcatiformis* (BÖSE, 1927, pl. 18, figs. 1-5) and represents a new species transitional between Lower Albian *B. salomoni* and Middle (?) to Upper Albian *B. subsulcata* (WILTSHIRE) (WOODS, 1911, pl. 47, figs. 3-14). Some of IMLAY's specimens of this n. sp. are strikingly similar to JONES's *B. salomoni* from Oregon (e. g. IMLAY, 1937, pl. 27, figs. 1, 3, 13), and some have more than one sulcus. But the Mexican forms have generally finer concentric ornament and greater shell inclination than "*B. salomoni*" of JONES. JONES' specimen is thus morphologically transitional between typical Lower Albian *B. salomoni* and IMLAY's Middle Albian *B. "subsulcatiformis"* (=n. sp.) and is best termed *B. salomoni* n. subsp. trans. to *B. "subsulcatiformis"* (n. sp.) of IMLAY (1937).

(3) *Birostrina* (="*Inoceramus* (*Actinoceramus*)") "*subsulcatus*" (WILTSHIRE) of JONES (1960, pl. 29, fig. 6) from the "late Early (?) to Late Albian" of Oregon is a strongly prosocline, doubly sulcate, finely ornamented form which is distinct from *Birostrina subsulcata* (WILTSHIRE) (see WOODS, 1911, pl. 47, figs. 3-14) but clearly assignable to *Birostrina* n. sp. (=*B.* "*subsulcatiformis*" (BÖSE) of IMLAY, 1937) from the Middle Albian of Mexico.

Cenomanian Taxa

(4) "*Inoceramus eolobatus*" ANDERSON (1958, p. 99, pl. 18, fig. 13) from the "Early Cenomanian" of California. This poorly preserved internal mold appears to be closely related to or even conspecific with "*Inoceramus*" (n. gen.) *crippsi* MANTELL, s. s., and in particular is similar to the type illustrated by WOODS (1911), the specimen of HEINZ (1928, pl. 4, fig. 1), and to *I.* sp. *β* aff. *I. crippsi* of NAGAO and MATSUMOTO (1939-1940, pl. 2, fig. 7). "*Inoceramus*" (n. gen.) *crippsi crippsi* is of Lower and Middle Cenomanian age in Europe, and in North America, where it is rare.

(5) "*Inoceramus jacksonensis*" ANDERSON (1958, pl. 43, figs. 1, 2) from the "Upper Turonian" of Oregon, three miles west of Phoenix, in a locality which has subsequently been dated as Cenomanian to Lower Turonian, with only questionably higher beds. These specimens appear to be conspecific with "*Inoceramus*" (n. gen.) *crippsi* MANTELL s. l. (cf. WOODS, 1911, the type, and text-figs. 33, 34; HEINZ, 1928, pl. 4, fig. 1) of Lower and Middle Cenomanian age in many parts of the world. Somewhat less related but still morphologically similar Middle Turonian-Lower Coniacian taxa include *I.* sp. ex gr. *crassus* PETRASCHECK of SORNAY (1972, pl. 1, fig. 7) and variants of *I. costellatus* WOODS (1911, pl. 54, fig. 5a), both of which, however, have fine raised secondary growth lines subequally placed between on the rugae.

Turonian Taxa

(6) *Mytiloides* (="*Inoceramus*") *glennensis* (ANDERSON) (1958, p. 99, 100, pl. 17, figs. 1, 2) from "a horizon not higher than Lower Turonian, or possibly Upper Cenomanian" in California. This is clearly a *Mytiloides* BRONGNIART rather than an *Inoceramus.* If the poor illustrations and ANDERSON's description are representative, the species seems to lack regularly developed

raised growth lines between the rugae as found in the closely related *Mytiloides mytiloides* (MANTELL), and thus it would be included within the concept of *M. opalensis elongata* (SEITZ, 1934, pl. 38, figs. 4-6; text-figs. 7b, c; pl. 39, figs. 2-4). This is an unusually elongated variant of subsp. *elongata* transitional to *M. mytiloides*, and marks a lower Lower Turonian faunal zone widely distributed throughout the world.

(7) *Mytiloides* (="*Inoceramus*") *duplicostatus* (ANDERSON) (1958, pl. 17, figs. 3, 4) from the "Lower or Middle Turonian" of California. This species is identical in form to *M. submytiloides* (SEITZ), the lowest Turonian zonal inoceramid in many parts of the world (see SEITZ, 1934, text-fig. 8, pl. 37, figs. 1-3), but has an ornamentation of alternating regularly spaced rugae and coarse raised growth lines more closely similar to that of the middle Lower Turonian *M. mytiloides* (MANTELL). *Mytiloides duplicostatus* is thus ėvolutionarily transitional between these two species, differing from both by its doubly "carinate" rugae. Interestingly, *M.* aff. *duplicostatus* occurs sparsely with *M. opalensis* (BÖSE) in the Western Interior Cretaceous sequence in just this position, with the basal Turonian zone of *Mytiloides submytiloides* below, and *M. mytiloides* above. *Mytiloides duplicostatus* seems to be transitional to *M. mytiloides* through the similarly shaped *M. mytiloides arcuata* (SEITZ).

(8) *Inoceramus aduncus* ANDERSON (1958, ppl. 18, figs. 11, 12) from the "Turonian" of Oregon. This specimen is too poorly illustrated for comparison and the types have not been restudied.

Coniacian-Santonian Taxa

(9) *Mytiloides* (="*Inoceramus*") *meekianus* (ANDERSON) (1958, pl. 22, figs. 5, 6) from the "Coniacian" of California. Figure 6 is too poorly preserved for confident interpretation of its affinities. Fgure 5 (the holotype) seems closely related to the species group of "*Inoceramus*" *incertus* JIMBO and "*I.*" *fiegei fiegi* TRÖGER, both of which can probably be placed within the genus *Mytiloides* along with the morphologically similar *Mytiloides* "*latus*" of the *M. labiatus* lineage, even though typical *Mytiloides* are strongly inclined, elongated and labiate in outline. "*Inoceramus*" *meekianus* is also very closely similar and possibly ancestral to *Platyceramus cycloides* (WEGNER), differing mainly in having strongly defined, raised, subequal growth lines between and on the rugae, as in *Mytiloides fiegei fiegei* (TRÖGER) and *M. incertus*. To the extent that a comparison can be made from ANDERSON's illustration, *Mytiloides meekianus* is possibly conspecific with the rounded specimen placed in "*M. incertus*" by NAGAO and MATSUMOTO (1940, pl. 10, fig. 2) and also referred to in this report as *Mytiloides fiegei* n. subsp. (round form). The rugae of *M. meekianus* are slightly more widely spaced and the raised growth lines sowewhat coarser and much more weakly defined dorsally than on *M. fiegei fiegei* or on NAGAO and MATSUMOTO's (1940, pl. 10, fig. 2) *M.* "*incertus*" (=*M. fiegei* n. subsp. (round form)). Thes small differences may prove to be insignificant at the species level, although both names are herein retained for the present. If further examination shows the Japanese and California specimens to be conspecific; the species name *meekianus* ANDERSON (1958) has priority over the name *fiegei* TRÖGER (1967) and should be used. *Mytiloides meekianus* seems to lie morphologically and stratigraphically between *Mytiloides fiegei fiegei* of the Late Turonian-Lower Coniacian of Euramerica, and the *Platyceramus cycloides* group of the Lower Santonian.

(10) "*Inoceramus*" *contracostae* ANDERSON (1958, pl. 18, figs. 3, 4; pl. 55, fig. 3), listed as occurring in the "Lower Senonian" and "Middle Campanian" of California. Two forms are represented, and both are more charcteristic of rocks older than Campanian. Since many of ANDERSON's localities and age assignments are suspect, it is quite possible that these are in part Coniacian and certainly Santonian species, rather than higher Senonian forms.

(a) The "hypotype" of "*I. contracostae*" ANDERSON illustrated on pl. 55, fig. 3 (1958) is closely similar to quadrate variants of *Sphenoceramus lingua submedia* PERGAMENT (Lower Santonian) (1965, pl. 10, fig. 4) though slightly more quadrate and more finely ribbed than typical for this subsp. Even closer and probably conspecific relationships occur with finely ribbed, broad, quadrate variants of "*Inoceramus naumanni*" NAGAO and MATSUMOTO (e.g. 1940, pl. 14, figs. 2, 9; PERGAMENT, 1965, pl. 12, fig. 7), which I have referred to *Mytiloides ? striatoconcentricus* n. subsp. aff. *M. striatoconcentricus carpathicus*

(SIMIONESCU) of TRÖGER (1967, pl. 9, fig. 17). "*I. naumanni*" is an Upper Coniacian-Santonian species. This Lower Senonian form is remarkably similar to *Inoceramus pictus concentricoundulatus* TRÖGER (1967, pl. 2, figs. 1a-b; pl. 3, figs. 7a-b, 8) from the Upper Cenomanian of Europe (not yet reported in North America) being somewhat more elongated than this species. Whether this is an exceptional case of homeomorphy or close evolutionary relationship is still not known, and the solution to this requires careful examination of all specimens concerned. The specimen comes from Chico Creek, Butte Co., California.

(b) The primary types of "*I.*" *contracostae* (*ibid.*, pl. 18, figs. 3, 4) are distinct from the hypotype of pl. 55, fig. 3 of ANDERSON (1958) in being much more elongated and inclined, without a well defined posterior auricle, and with blunter, less prosogyrous but more strongly inflated and incurved beaks and umbos. These appear to be conspecific with "*Inoceramus*" *yokoyamai* NAGAO and MATSUMOTO (1940, pl. 16, figs. 2a-b; pl. 20, figs. 2a-c; pl. 21, fig. 2; PERGAMENT, 1965, pl. 10, figs. 7a-d; pl. 11, fig. 5). ANDERSON's specimens are slightly more finely ribbed than some of NAGAO and MATSUMOTO's syntypes, but within the range of variation of the species, especially as illustrated by PERGAMENT (1965). "*Inoceramus yokoyamai* is regarded as an early non-sulcate ancestor of the *Sphenoceramus lingua* lineage and is tentatively placed in this genus. This species is closely related and probably derived from "*Inoceramus*" (=*Mytiloides* ?) *striatoconcentricus* s. s. GÜMBEL (e. g. in TRÖGER, 1967, pl. 9, figs. 17, 18) of Late Turonian-Lower Coniacian age. *Sphenoceramus* ? *yokoyamai* differs from *Mytiloides* ? *striatoconcentricus* in having a blunter, more inflated and more erect beak-umbo, and in being more prosocline with greater curvature of .the growth axis. Some specimens included in the Santonian *Sphenoceramus lingua* s. l. (GOLDFUSS) by SEITZ (1965) and others may be this species. *Sphenoceramus yokoyamai* is restricted to the Middle and Upper Coniacian in Japan (NODA and MATSUMOTO, 1976) ; PERGAMENT cites a Santonian-Campanian range (1965) ; ANDERSON indicates a Lower Senonian (Coniacian ?)-Campanian range. From an evolutionary standpoint, an Upper Coniacian-Lower Santonian range is most logical but not proved. It best fits west-Pacific occurrences.

(11) *Sphenoceramus* (="*Inoceramus*") *klamathensis* (ANDERSON) (1958, pl. 18, figs. 1, 2) cited as coming from the Senonian at levels similar to those yielding "*I.*" *contracostae* ANDERSON (Conianian ?, Santonian, Campanian ?). ANDERSON provides only drawings of the syntypes, making critical comparison with other species difficult, but these clearly show a strong postumbonal sulcus and medium-sized, equally developed, raised growth lines on the surface. These characters and the characteristic shape indicate the early growth stages of a *Sphenoceramus*. It is most similar to early growth stages of *S. lingua* (GOLDFUSS) (see SEITZ, 1965, pl. 16, fig. 4; pl. 18, figs. 3, 4; PERGAMENT, 1965, pl. 10, figs. 1-6) being most probably *S. lingua lingua* (cf. PERGAMENT, 1965, pl. 10, figs. 1a-b).

The Genus Sergipia

(12) *Sergipia* n. sp. aff. *S. posidonomyaformis scheibei* HEINZ, recently the first specimen of *Sergipia* reported from the eastern Pacific Coast of North America was found in Franciscan-age rocks of the Diablo Range of California. This specimen is very similar in size, ornamentation and nature of the posterior auricle (anterior one broken) to *Sergipia posidonomyaformis* MAURY (1925, pl. 22, fig. 6; HEINZ, 1928, pl. 5, fig. 3), but it is markedly more inclined like subsp. *Sergipia posidonomyaformis scheibei* HEINZ (1928, pl. 4, fig. 6; pl. 5, fig. 6) reported from South America in Cenomanian ? and Turonian age rocks. The California specimen is more broadly and weakly rugate than subsp. *scheibei* and represents a new subspecies or species seemingly transitional between *Sergipia posidonomyaformis* and subsp. *scheibei*.

Middle Cretaceous Inoceramidae of the Northernmost Pacific Margins

The main purpose of this paper is to compare Mid- to Warm Temperate inoceramid faunas from the Middle Cretaceous and Coniacian of Japan and the Pacific Coast of the United States, with those of equivalent climatic zones of Euramerica in an attempt to establish precise biostratigraphic correlations and biogeographic relationships. But extensive inoceramid assemblages also occur in the Mid- to Cool Temperate Middle Cretaceous regions of the Pacific—eastern Siberia and the Pacific Coast of the USSR and western Canada, and in northern Alaska—which are relevant to interpretation of the more southerly Pacific faunas. These are generally summarized below.

Pacific Coast of the USSR.—The best known inoceramid faunas of the northernmost Pacific are those of eastern Siberia and the Pacific Coast of the USSR which have been recently monographed in a set of excellent papers by PERGAMENT (1965, 1966, 1971). In these works, PERGAMENT clearly documents that the Middle Cretaceous-Coniacian Inoceramidae of this region are diverse and represent a biogeographically mixed asssemblage of typical cosmopolitan or Euramerican and, secondarily, Japanese species associated with varying percentages of endemic Siberian taxa. Endemics, however, apparently represent a smaller proportion of the fauna than indicated by the literature for either Japan or the Pacific Coast United States, exclusive of Alaska (see subsequent discussion). This situation obviously reflects extensive marine connection between the northernmost Pacific and the predominantly shallow seas of the Euramerican Region during the Middle Cretaceous and Coniacian. The Cretaceous Mid- to Cool Temperate "Circumboreal Seaway" (KAUFFMAN, 1973), and possibly short-lived marine connections between the American Western Interior Sea and the northeastern Pacific Ocean, were apparently the principal disperasl routes of Euramerican taxa into the North Pacific Province. Wide dispersal of Euramerican taxa into the northern Pacific was further enhanced by closer proximity of continental and shallow shelf margins across the northernmost Pacific (e. g. Siberia-Alaska, northern Canada) than across the north-central Pacific (e. g. Japan-California), and by apparent closing of the north Pacific during Middle Cretaceous plate movements, bringing distinct northeastern and northwestern Pacific faunas into contact (KAUFFMAN, 1973). This set of interpretations is compatible with the increase in numbers and diversity of Euramerican North Temperate species from south to north in the central and northern Pacific during the Middle Cretaceous.

Interestingly, whereas widely spread Euramerican taxa became well established in the northern Pacific during this time, presumably as a result of environmentally tolerante, long-lived planktonic larvae dispersed on both eastward- and westward-flowing oceanic currents (KAUFFMAN, 1975, fig. 2), members of principal endemic Middle Cretaceous inoceramid lineages of the Western Interior of North America (e. g. the "*Inoceramus*" *dunveganensis*, "*I.*" *athabaskensis*, "*I.*" *nahwisi-moberliensis* lineages) apparently rarely migrated this far, even though they co-occur with more widely spread inoceramids in Alaska and Canada and thus probably had the same geographic opportunity for wide dispersal. Only rare specimens related to "*I.*" *dunveganensis* are questionably reported by PERGAMENT (1966) from the Pacific Coast of the USSR. Predominance of west to east oceanic circulation (and thus larval drift) coupled with as yet undefined biological differences between these two inoceramid groups which affected their dispersal potential, and thus were probably related to their larval history, are postulated to account for this discrepant biogeographic pattern.

Thus in the Upper Albian PERGAMENT (1965) records as assemblage of cosmopolitan or intercontinentally distributed inoceramids in the Pacific Coast region of the USSR such as *Birostrina concentrica* and *B.* ex. gr. *B. sulcata*, "*Inoceramus*" (n. gen.) *anglicus* and its subspecies, "*I.*" sp. cf. "*I.*" *comancheanus*, "*I.*" sp. cf. "*I.*" *bellvuensis*, "*I.*" *subangulus*, and possibly "*I.*" *serotinus*; these are not associated with true endemic taxa. Earlier Albian inoceramids (*I.* sp. nova; *I. kedroviensis* PERGAMENT) are rare and apparently largely endemic (44 percent), although "*I.*" *anglicus* also ranges into the Middle Albian of the Pacific Coast USSR (PERGAMENT, 1965, fig. 6).

PERGAMENT (1966) records somewhat greater Cenomanian endemism (25 percent) in the Pacific Coast USSR than found in the Late Albian of this region, but it is associated with an increase in numbers of non-endemic taxa from the Euramerican Region. Thus, biogeographically widespread inoceramids such as *I. pictus* and its subspecies *neocalidonicus*, *I. etheridgei*, *I. ginterensis*, *I. crippsi reachensis* (?=*I. atlanticus*), *I. corpulentus*, *I. scalprum*, *I. tenuis*, *I. tenuistriatus*, *Birostrina concentrica costata* (?*B. porrecta*), the Japanese species *B. nipponica*, and the typically Western Interior North American species *I. dunveganensis* all occur in the Cenomanian of the Pacific Coast USSR. *I. incelebratus* PERGAMENT is shared with the Canadian Pacific Coast fauna. Endemic Western Pacific inoceramid species of the USSR and (in part) Japan include *I. beringensis*, *I. gradilis*, *I. pennatulus*, and *I. reduncus* PARGAMENT,

Similar, relatively low levels of species provincialism exist in the Turonian (32%), among Turonian-Coniacian boundary species (33%), and in the Coniacian Inoceramidae (8%) of the Pacific Coast USSR, coupled with high levels of diversity among widespread Euramerican taxa. PERGAMENT (1971) records the biogeographically widespread taxa *I. cuvieri* and its subspp., *I. cuvieriformis* (=*I. cuvieri* s. l., rugate form), *I. obeliscus* (=*I. cuvieri* s. l., rugate form), *I, pseudocuvieri* (?=*I. flaccidus*), *I. lamarcki*, *I. perplexus*, *I. sachsi*, *I. callosus*, *I. annulatus*, *I. koegleri*, *I. auritus*, *I. concinnus*, *I. gibberosus*, *I. iburiensis* (=*I. percostatus*), *I. allani* and *Mytiloides* ? *lusatiae* from the Turonian associated with eight apparently endemic Russian species. *Inoceramus ernsti*, *I. teshioensis* (=*I. multiformis*), *I. australis*, and *Birostrina* ? sp. aff. *B. concentrica costata* are biogeographically widespread forms which transgress the Turonian-Coniacian boundary according to PERGAMENT (1971) along with two endemic taxa. The dominantly cosmopolitan Coniacian biota of this area contain *Mytiloides striatoconcentricus*, *Mytiloides* ? *stantoni*, *Inoceramus inaequivalvis*, *I. websteri*, *I. sturmi*, *I. waltersdorfensis*, *I. schroederi*, *I. mihoensis* (=*I. erectus* s. l., late form), *I. oculatus*, *I. pacificus*, *Volviceramus involutus*, *V. umbonatus*, and *Cremnoceramus inconstans* associated with the endemic subspecies *I. annulatus ochoticus* PERGAMENT.

Thus in summary, the Middle Cretaceous and Coniacian inoceramid assemblage of the Pacific Coast of the USSR contains low to moderate numbers of endemic taxa, and present endemism generally (but irregularly) decreases through the studied sequence in a manner broadly comparable with that of the Western Interior of North America. Sufficient intercontinental to cosmopolitan Inoceramidae are present in this biota to allow precise regional correlation of the section. Similarly, sufficient Japanese forms are present in the section, mixed with the Euramerican taxa, to not only allow biostratigraphic ties with Japan, but also to allow rather precise integration of the Japanese and Euramerican inoceramid biostratigraphies, as PERGAMENT (1965, 1966, 1971) has attempted to do. The Pacific Coast of the USSR is thus a key area in global inoceramid biostratigraphy.

Alaska.—The Alaskan Middle Cretaceous-Coniacian inoceramid fauna is possibly as rich as that of the USSR and is very similar, but it has not received the intense study which PERGAMENT has provided for eastern Russia. IMLAY (1961), GRYC (in PAYNE et al., 1951), and JONES and GRYC (1960) account for most of what is published about the Alaskan inoceramid faunas. These authors have not reported any endemic taxa restricted to the Pacific and northern coasts of Alaska. The biota is almost equally divided between cosmopolitan taxa and inoceramids which are related to endemic groups that are more widespread in North America, and in particular those of the Western Interior basin. As in Russia and Western Interior North America, there is a marked decrease in percent North American endemism through the Middle Cretaceous-Coniacian sequence of Alaska.

Thus, the sparse Albian inoceramid assemblage reported from nothern Alaska (IMLAY, 1961) contains only one cosmopolitan species *I. anglicus* Woods and its sub-spp., and two North American (but not specifically Alaskan) endemics, *I.* sp. cf. *I. altifluminis* McLEARN and *I.* sp. cf. *I. cadottensis* McLEARN (66% endemism). The Cenomanian inoceramids of this area, as presently known (GRYC, 1951; JONES and GRYC, 1960) are also largely North American endemics. Only "*I.*" *dunveganensis* s. s. McLEARN is as yet known outside of North America questionably (in eastern Russia). Related forms which I regard as distinct species but which JONES and GRYC placed within the species concept of *I. dunveganensis*, and which are restricted to North America, include "*I.*" (n. gen.) *athabaskensis* McLEARN, "*I.*" *nahwisi* McLEARN and its subsp. *moberliensis*, "*I.*" *goodrichensis* McLEARN, and possibly "*I.*" *mcconnelli* WARREN. These taxa range into Warm Temperate climatic zones of the Western Interior Basin as far south as Colorado, and the lineage extends to Texas (as *I. eulessanus* STEPHENSON) during the Cenomanian; but none of these forms range out of North America insofar as is now known.

In contrast, Alaskan Turonian Inoceramidae are almost wholly cosmopolitan taxa: *Mytiloides opalensis, M. mytiloides,* and *M. labiatus* (elongated subspecies) seem to be present in Lower Turonian strata and probably mark successive zones here as they do elsewhere in the world. Both rugate (n. subsp.) and typical forms of *I. cuvieri* occur in Middle Turonian strata (e. g. see JONES and GRYC, 1960, pl. 18, fig. 3, and pl. 19, fig. 5). *Inoceramus brongniarti* MANTELL is represented in the Alaskan Middle or Upper Turonian by JONES and GRYC's "*Inoceramus* sp. aff. *I.* (*Inoceramus*) *cuvierii*" illustrated on pl. 19, fig. 1 (1960). Thus, no endemic taxa are definitely known from the Alaskan Turonian. No Coniacian has yet been reported from this area (JONES and GRYC, 1960, fig. 31).

Western Canada.—The Inoceramidae of the Pacific Coastal regions of Canada are even less well known, but recently JELETZKY (e. g., 1967, 1969, 1970), JELETZKY and TIPPER (1968), and MULLER and JELETZKY (1967) have given us a preliminary insight into their composition with a series of careful stratigraphic studies in western British Columbia and Vancouver Island. Though apparently sparse compared to other bivalves, especially Lower Cretaceous Buchiidae, known Lower and Middle Cretaceous inocermids of this area are virtually all cosmopolitan or intercontinentally distributed species. Middle and Upper Albian strata of the Taylor Creek Group, southwest British Columbia, yield the cosmopolitan "*Inoceramus*" (n. gen.) ex. gr. "*I*" *anglicus*, *Birostrina subsulcata* and *B. sulcata.* Cenomanian strata of Vancouver Island yield "*I.*" (n. gen.) sp. ex. gr. "*I.*" *crippsi* (cosmopolitan), and *I.* sp. aff. *I. incelebratus* PERGAMENT, known also from the Pacific Coast USSR fauna. Turonian inoceramids are not yet reported from this region. The Coniacian-Lower Santonian, Japanese-Euramerican species *Mytiloides*? *naumanni* is reported from "Santonian" rocks of Vancouver Island. Probably a much larger inoceramid fauna will be recovered from these areas as work progresses.

Thus on both sides of the northern Pacific, Middle Cretaceous inoceramid diversity, and numbers of cosmopolitan to intercontinentally distributed, predominantly Euramerican taxa increase from south (Japan, West Coast of the United States) to north (Pacific Coast USSR, Alaska, west coast of Canada), reflecting increasing connection to Euramerican seas through the circumpolar seaway, and greater proximity of favored shallow shelf habitats across the northernmost Pacific, apparently within range of larval dispersal for many Inoceramidae.. This, in turn, suggests that precise correlation of Japanese and west coast United States inoceramids with the well established Euramerican inoceramid biostratigraphy might best be accomplished in the northernmost Pacific, where these faunas are most extensively mixed.

Conclusions

Systematic analysis.—Cretaceous Inoceramidae of both the Pacific Coast of the United States and Japan, monographed many years ago, are badly in need of restudy in light of new systematic concepts developed throughout the world during the last decade. This has started in Japan (e.g. NODA, 1975; TANABE, 1973), but not yet in Western North America. Provincialism in these areas at the species and subspecies level is nowhere near what it would seem from existing literature, although it is still significant. Critical comparisons between illustrated specimens and museum collections on hand from Japan, California and Oregon, with Euramerican and more cosmopolitan inoceramids reveal many striking similarities, summarized in Table 1. Eighty-three percent of the Middle Cretaceous-Coniacian Inoceramidae described by NAGAO and MATSUMOTO in 1939 and 1940 were considered to be new and/or endemic to Japan or the Japanese-East Asian Subprovince. This percentage has decreased only slightly in modern work. Preliminary restudy of these taxa now suggests to me that only 14 percent of these species and subspecies are endemic to Japan, and only 20 percent are endemic to the northwestern Pacific margin. Most of the endemics belong to species groups which occur widely in Euramerica, and elsewhere in the world. The rest of the Japanese inoceramids appear to be conspecific or consubspecific with cosmopolitan or Euramerican, and to a lesser degree, Caribbean-South American or South Pacific inoceramids. In some cases this results from recognition of Japanese species (e. g. *I. tenuistristus* NAGAO and MATSUMOTO) in many parts of the world as a result of intensive collecting and systematic research during the last decade; some Euramerican names may have to be synonymized as a a result (e. g. *I. pedalionoides* NAGAO and MATSUMOTO probably=*I. pictus vardonensis* SORNAY). In other cases, Japanese species are obviously conspecific with Euramerican forms which have nomenclatural priority (e. g. *I. iburiensis* NAGAO and MATSUMOTO, 1939 in part=*I. percostatus* MÜLLER, 1888 in part=*I. lamarcki stumckei* HEINZ, 1924), a fact not fully recognized by Japanese workers.

Similarly, ANDERSON (1958) described eight new species of Middle Cretaceous and Coniacian Inoceramidae from the Pacific Cost of the United States (100 percent apparent endemism). JONES' (1960) recognition of three additional Albian taxa, all cosmopolitan forms, reduced the apparent endemism of the eastern Pacific inoceramid fauna to 73 percent. Preliminrry restudy of ANDERSON's species suggests that four and possibly five are conspecific with cosmopolitan or widespread Euramerican species with nomenclatural priority, two are found also in the Western Interior of North America and in Japan, and possibly only one poorly represented species (*I. aduncus*) is truly endemic to the American west coast. Thus total endemism for this area is, at best, nine percent of the inoceramid assemblage. The assumption of provincialism in systematic paleontology of such widely scattered regions as Japan, California, and Europe is understandable when one considers that when this work was originally done neither plate tectonic relationships, nor the larval distribution potential of benthonic marine invertebrates was well studied, much less applied to paleontological research.

Northern Pacific inoceramid assemblages of the eastern USSR, Alaska, and Canada have been more recently studied and more clearly reflect modern systematic concepts. These fauna are dominated by cosmopolitan or intercontinentally distributed Euramerican inoceramids and have relatively few endemic taxa (0% endemism for Westernmost Canada, 32% for northern Alaska and the Canadian Western Interior, 0% for Alaska alone during the Middle Cretaceous and Coniacian stages). The Alaskan and westernmost Canadian inoceramid faunas, as published, are deceivingly low in diversity. Faunas from both areas appear to be equally as diverse as those from the eastern USSR, but they are badly in need of detailed systematic study based on additional collecting.

Generic and subgenric concepts applied to Inoceramidae of the North Pacific Province are also well out of date. Virtually all species have been lumped under a single generic name, i. e. *Inoceramus* SOWERBY, 1814, and "subgenera" (*Actinoceramus*, or *Birostrina*, *Sergipia*, *Inoceramus*) have been very sparsely used except for HAYAMI's recent systematic survey (1975), which generally follows the subgeneric designations of COX (1949). Whereas the tremendous generic-subgeneric splitting of the Inoceramidae based on small differences in external form and sculpture suggested by HEINZ (1932) is unreasonable, it is equally unreasonable to assume that the great diversity of taxa and major morphological features found in the Inoceramidae represents a single genus, or even a very few, when this group is taxonomically compared to the treatment given other major families of Bivalvia. The classification scheme of COX (1969), as applied in Japan by HAYAMI (1975), and based mainly on external

Table 1. Summary: Preliminary comparison of Japanese, American Pacific Coast, and Euranerican Inoceramidae.

Japanese Taxon	Cited Range	Suggested Assignment based on Preliminary Study	West Coast USA Counterpart	Age	EURAMERICAN				
					Counterpart Taxon	Western Interior	Gulf Coast	Europe	Euramerican Age Range
Inoceramus sp. aff. *I. bohemicus*	Albian, K3β	(?) *Birostrina* ex. gr. *concentrica*							
Inoceramus sp. β aff. *I. crippsi*	Middle Cenomanian-Middle and (?) Upper Coniacian	(a) "*I.*" *crippsi crippsi*	"*I. jacksonensis*" Anderson and "*I. eolobatus*" Anderson ="*I.*" (n. gen.) *crippsi crippsi*	Lower Cenomanian	(a) "*I.*" (n. gen.) *crippsi crippsi*	×	×	×	Lower-Middle Cenomanian
		(b) "*I.*" *crippsi* aff. subsp. *hoppenstedtsnsis*			(b) "*I.*" (n. gen.) *crippsi hoppenstedtensis*			×	Middle Lower-lower Upper Cenomanian
Inocermus yabei	Lower Cenomanian-Lower and (?) Middle Turonian	(a) *I. yabei* (?=*I. pictus bannewitzensis*)			(a) *I. pictus bannewitzensis*				upper Upper Cenomanian
		(b) *I. propinquiformis?*			(b) *I. propinquiformis*			×	lower Middle Turonian
		(c) "*I.*" sp. aff. "*I.*" *lusatiae* and *I. winkholdioides*			(c) "*I.*" *lusatiae* (part)			×	uppermost Turonian-Lower Coniacian
Inoceramus cfr. *yabei* (deformed)	Middle (?), Upper Cenomanian-Lower Santonian	(a) *I.* sp. aff. *I. weisei*			(a) "*I.*" *weisei*	×	×	×	uppermost Turonian-Lower Coniacian
		(b) probably others			?	?	×	×	
Inoceramus concentricus nipponicus	Lower Cenomanian-Middle Turonian, (?) to lowest Coniacian	(a) *I. pictus*, s. l.			(a) *I. pictus*	×	×	×	Middle to Upper Cenomanian
		(b) *Birostrina nipponica*			(b) *Birostrina* cf. *concentrica* of PERGAMENT (1966)			×	Lower Cenomanian
		(c) *I. scalprum*, s. l.			(c) *I. scalprum*	×	?	×	Upper Cenomanian
		(d) ? *I. cuvieri* (early form			(d) *I. cuvieri*	×	×	×	Middle Turonian
Inoceramus concentricus costatus	Middle Cenomanian-Turonian, (?) Lower Coniacian	(a) *Birostrina concentrica porrecta*			(a) *Birostrina concentrica porrecta*			×	Lower Cenomanian

		(b) *I.* sp. aff. *I. glatziae-I. frechi*			(b) *I. glatziae*	×	×	×	uppermost Turonian-?lower Coniacian
		(c) *I. saxonicus*			(c) *I. saxonicus*	?		×	upper Lower Turonian
Inoceramus sp. nov., ? belonging the group of *I. concentricus*	(?) Lower Turonian-Middle Coniacian(?)	*I. heinei*, n. subsp.			*I. heinzi*, s. l.	×	×	×	Middle-Upper Cenomanian
Inoceramus hobetsensis	(?) Middle, Upper Cenomanian Upper Turonian	*I. hobetsensis*, s. l.			(a) *I. flaccidus*	×	?		upper Middle Turonian
					(b) *I. frechi*	×	×	×	uppermost Turonian Lower Coniacian
Inoceramus hobetsensis nonsulcatus	(?) Middle, Upper Cenomanian -Upper Turonian	*I. nonsulcatus*			(a) *I. cuvieri*, n. subsp. (rugate)	×	?	×	middle to upper Middle Turonian
					(b) *I. securiformis*	?		×	Upper Turonian-Lower Coniacian (?)
					(c) *I. brongniarti*	×		×	Upper Turonian-Lower Coniacian (?)
Inoceramus sp. γ aff. *I. yabei*	Middle (?), Upper Cenomanian-Coniacian	"*I.*" sp. aff. *I. protractus* (possibly a *Cremnoceramus*)			(a) *I. protractus*	×	×	×	uppermost Turonian, Lower Coniacian (?)
					(b) "*I.*" *lusatiae* (part)	×	×	×	uppermost Turonian, Lower Coniacian
Inoceramus tenuistriatus	Upper Cenomanian(?) -Turonian (?) basal Coniacian	*I. tenuistriatus*			(a) *I. tenuistriatus*	×	×	×	Middle (?) -Upper Cenomanian
					(b) *I. etheridgei* s. l.	×	×	×	Cenomanian
Inoceramus teshioensis	Upper Cenomanian(?) Turonian, (?) to Middle Coniacian	*I. teshioensis*			(a) *I.* "*vancouverensis*"	×	?	×	uppermost Turonian-Lower Coniacian

Japanese Taxon	Cited Range	Suggested Assignment based on Preliminary Study	West Coast USA Counterpart	Age	EURAMERICAN				
					Counterpart Taxon	Western Interior	Gulf Coast	Europe	Euramerican Age Range
					(b) *I. "vancouverensis" parvus*	×		×	upper Middle - Upper Turonian
					(c) *I. multiformis*	×	?	×	Coniacian
Inoceramus pedalionoides	Upper Cenomanian(?), Turonian, (?) Lower Coniacian	*I. pedalionoides*			(a) *I. pictus*, s. l.	×	×	×	Upper Cenomanian
					(b) *I. pictus vardonensis*	×	×	×	Upper Cenomanian
Inoceramus iburiensis	Turonian	*I. percostatus*			*I. percortatus*		×	×	Lower-Middle Coniacian
Inoceramus incertus	Turonian, (?) to Middle Coniacian	(a) *Mytiloides incertus*			(a) *Mytiloides incertus*	×	?	×	uppermost Turonian
					(b) *"I." (Platyceramus) chouberti*			×	Lower Coniacian
					(c) *"I." waltersdorfensis afghanicus*	?		×	Upper Turonian
					(d) *"I." sturmi* (part)	×	?	×	Upper Turonian (?) Lower Coniacian
					(e) *"I." waltersdorfensis* (part)	×	×	×	uppermost Turonian Lower Coniacian
		(b) *Mytiloides meekianus* (?=*M. fiegei*, n. subsp., round form)	*"I. meekianus"* ANDERSON= *Mytiloides meekianus*	Coniacian	(a) *Mytiloides fiegei*, n. subsp. (round form)	×		×	Upper Turonian
					(b) *Mytiloides meekianus*	×		?	Upper Turonian
					(c) *Mytiloides "latus"* s. l. (part)	×	×	×	Middle Turonian
Inoceramus sp. cfr. *I. incertus*	Turonian, (?) Lower Coniacian	*Mytiloides dresdensis labiatoidiformis?*			*Mytilodes dresdensis? labiatoidiformis*	×	×	×	uppermost Turonian
Inoceramus incertus yubariensis	Lower (?), Middle Coniacian - Lower Santonian	*"I." waltersdorfensis yubariensis*			(a) *I. waltersdorfensis* (part)	×	?	×	uppermost Turonian - Lower Coniacian

					(b) *"I." inconstans* (part)	×	×	×	Lower Coniacian
Inoceramus (Sergipia) akamatsui	Middle Turonian-Coniacian	*Sergipia akamatsui*	*Sergipia* n. sp. aff. *Sergipia posidonomyaformis scheibei* Heinz	(?) Cenomanian-Turonian	*Sergipia posidonomyaformis*	?		×	Middle-Upper Turonian, ? lowest Coniacian
Inoceramus sp. cf. *I. labiatus*	Lower Turonian	(a) *Mytiloides opalensis*	*"I. glennensis"* Anderson =*Mytiloides opalensis elongatus*	lower Lower Turonian	*Mytiloides opalensis* and subspp.	×	?	×	lower Lower Turonian
		(b) *Mytiloides mytiloides*			(a) *Mytiloides mytiloides* and subpp.	×	×	×	middle Lower Turonian
					(b) *Mytiloides labiatus* and subspp.	×	?	×	upper Lower Turonian
Inoceramus pilvoensis	Upper Turonian - Lower Santonian	*Mytiloides pilvoensis*			*Mytiloides hercynicus* s. l. (part)	×		×	Middle Turonian
Inoceramus teraokai	lower Upper Turonian	*Mytiloides teraokai*			*Mytiloides hercynicus* s. l. (part)	×		×	Middle Turonian
Inoceramus uwajimensis	Coniacian	*"I." stantoni*, s. l.			*"I." (Mytiloides?) stantoni*	×	×	×	Middle Coniacian
Inoceramus uwajimensis yeharai	(?) Upper Turonian Coniacian	*I. winkholdioides*			(a) *I. winkholdioides*	×	×	×	uppermost Turonian - Lower Coniacian
					(b) *"I. inconstans"*, s. l. (part)	×	×	×	Lower-Middle Coniacian
					(c) *I. glatziae*	×	×	×	uppermost Turonian - Lower Coniacian
Inoceramus naumanni	(?) uppermost Turonian, Lower Coniacian - Lower Santonian	(a) *Mytiloides? striatoconcentricus* Gümbel n. subsp. aff. *carpathica* Simionescu	*"I. contracostae"* Anderson (1958, fig.3) = *Mytiloides striatoconcentricus* n. subsp. aff. *M. s. carpathicus?*	Lower Senonian (Coniacian? -Santonian	(a) *Mytiloides? striatoconcentricus* aff. *carpathicus* of Tröger (1967)	×	?	×	uppermost Turonian - Lower Coniacian
		(b) *Mytiloides naumanni*, s. s.			(b) *Mytiloides naumanni*	×	×	?	Lower-lower Middle Coniacian
Inoceramus mukawaensis	Upper Coniacian Santonian	(a) *Cordiceramus cordiformis mukawaensis*			(a) *"I. lamarcki"* trans. to *"I. cordiformis"* of Woods (1911)	×		×	(?) Upper Turonian - Lower Coniacian

Japanese Taxon	Cited Range	Suggested Assignment based on Preliminary Study	West Coast USA Counterpart	Age	EURAMERICAN				
					Counterpart Taxon	Western Interior	Gulf Coast	Europe	Euramerican Age Range
					(b) *I.* (*Cordiceramus*) *cordiformis*, s. l.	×	×	×	Lower-Middle Santonian
		(b) *Inoceramus frechi*, n. subsp.			(c) *I. frechi*	×	×	×	Upper Turonian - Lower Coniacian
					(d) *I. seitzi*	×	?	×	Upper Turonian - Lower Coniacian
Inoceramus sp. indet. aff. *I.* sp. nov? (*I. mukawaensis*, OTATUME MS.)	Upper Coniacian Santonian	(a) *Magadiceramus subquadratus subquadratus*			(a) "*I.*" (*Magadiceramus*) *subquadratus subquadratus*	×	×	×	Upper Coniacian
					(b) "*I.*" (*Magadiceramus*) *soukupi*		×	×	Upper Coniacian
		(b) *Magadiceramus* sp. aff. *M. austinensis*			(c) "*I.*" (*Magadiceramus*) *austinensis*	×	×	×	Upper Coniacian
Inoceramus ezoensis	(?) Upper Coniacian Santonian	*Platyceramus cycloides ezoensis*			*Platyceramus cycloides* and subspp.	×	×	×	Santonian mainly Lower - Middle
Inoceramus japonicus, form *α*	(?) Upper Coniacian Santonian	*Cladoceramus japonicus*, n. subsp. *α*			*Cladoceramus undulatoplicatus*	×	×	×	Santonian mainly Lower
Inoceramus amakusensis	(?) Upper Coniacian Santonian	*Platyceramus amakusensis*			*Platyceramus?* n. sp. aff. *P. amakusensis*		×	?	Santonian
Inoceramus mihoensis	Upper Coniacian - Lower Santonian	*Inoceramus erectus mihoensis*			(a) *I. erectus erectus*	×	×	×	lower Lower Coniacian
					(b) *I. erectus*, n. subsp. (late form)	×	×	×	middle Lower Coniacian
					(c) *I. inconstans* s. l. (part)	×	×	×	Lower-Middle Coniacian
			"*I.* (*Actinoceramus*) *concentricus*" of JONES (1960) = *Birostrina concentrica*, n. subsp.	middle Middle Albian	*Birostrina concentrica*, n. subsp.		×	×	Middle Albian

			"*I.* (*Actinoceramus*) *salomoni*" of Jones (1960) = *Birostrina salomoni*, n. subsp. trans. to *B.* "*subsulcatiformis*" of Imlay (1937)	(?) upper Lower - Middle Albian	*Eirostrina* "*subsulcatiformis*" (Böse) of Imlay (1937)		×	×	Middle Albian
			"*I.* (*Actinoceramus*) *subsulcatus* (Wiltshire)" of Jones (1960) = *Birostrina* n. sp. aff. *B.* "*subsulcatiformis*" (Böse) of Imlay (1937)	Middle Albian	(a) *Birostrina* "*subsulcatiformis*" (Böse) of Imlay (1037)		×	×	Middle Albian
					(b) *Birostrina subsulcatus* (Wiltshire)		×	×	Middle (?) - Upper Albian
			"*I. duplicostatus*" Anderson = *Mytiloides duplicostatus*	Lower Turonian	*Mytiloides duplicostatus*	×		?	lower Lower Turonian
			"*I. aduncus*" Anderson	Turonian	?				
			"*I. jacksonensis*" Anderson	"Upper Turonian" (Cenomanian-Lower Turonian)	"*Inoceramus*" (n. gen.) *crippsi crippsi*	×	×	×	Lower-Middle Cenomanian
Inoceramus yokoyamai	Santonian	*Sphenoceramus? yokoyamai*	"*I. contracostae*" Anderson (1958, pl. 18, figs. 3, 4 = *Sphenoceramus? yokoyamai*	"Lower Senonian - Middle Campanian" (Coniacian, Santonian, Campanian)	(a) *Sphenoceramus? yokoyamai*	?		×	Santonian
					(b) ?*Sphenoceramus lingua* s. l. (part)	×		×	Upper Santonian - Lower Campanian
			"*I. klamathensis*" Anderson = *Sphenoceramus lingua*, subsp. *lingua*?	"Senanian" (Coniacian? Santonian, Campanian)	*Sphenoceramus lingua*	×		×	Upper Santonian - Lower Campanian

ornamentation and form, but also incorporating ligamental features, seems a reasonable compromise for the present. But even this system of classification is outdated in the sense that interior shell features such as musculature, ligamenture, nature of the umbonal septum, presence or absence of "teeth" and "sockets" ("pseudodentition"), nature of the byssal slit or gape, where present, and the structure of internal ribs have been almost totally ignored in classification. These structures differ in major ways throughout the family, even in forms which may have developed external similarities through convergent homeomorphy in their evolution. Further, ontogenetic development, and particularly the nature of the juvenile and adolescent shell morphology, have been ignored in classification, whereas they are important in classification of many other bivalve groups.

KAUFFMAN (in manuscript) is currently revising the generic and subgeneric classification of the Inoceramidae based on both internal and external shell features as well as shell structure. Initial results suggest that the family can be split into numerous well-defined genera and subgenera, more so than suggested by COX (1969) or HAYAMI (1975), and that many subgenera used by these authors (e. g. *Mytiloides*) should be elevated to generic status. The Pacific Inoceramidae can be readily placed into both this pending new system of classification, and also into the currently accepted generic and subgeneric classification of COX (1969) and HAYAMI (1975); in many cases tne Pacific species are well enough preserved to show details of both interior and exterior shell features. In this paper I have attempted to upgrade the generic and subgeneric classification of the Pacific Inoceramidae to fit both COX's and HAYAMI's concepts, and those that I will use in my forthcoming revision. A total restudy of Pacific species is necessary, however, to confirm the propositions on generic classification put forth here.

This preliminary comparison of North Pacific species of Inoceramidae with the more extensively studied Euramerican fauna reveals yet another serious systematic problem confronting us. The Japanese and, to a lesser extent, the Pacific Coast American literature cites unusually long stratigraphic ranges for most described species and subspecies of Inoceramidae (usually throughout one-half stage or more; see NODA and MATSUMOTO, 1976) when compared to species ranges in the Euramerican Region and elsewhere (KAUFFMAN, 1975, text-fig. 4). NAGAO and MATSUMOTO (1939, 1940), and MATSUMOTO (1959) have noted this, and also some examples of stratigraphically disparate ranges between Japanese and Euramerican counterpart species. This seems unusual when one compares Japanese-West Coast American range data for Inoceramidae against American Western Interior (e. g. KAUFFMAN, 1975, fig. 4), and European data (e. g. TRÖGER, 1967, fig. 43), and when one takes into consideration the fact that evolutionary rates of Euramerican Inoceramidae, where measured against a radiometric time scale (KAUFFMAN, 1970, 1972, 1977a, in press) are among the fastest yet recorded for marine organisms, reaching one species per .08-.12 million years within Middle Cretaceous (especially Middle Cenomanian through Lower Coniacian) lineages.

Preliminary re-evaluation of published North Pacific Inoceramidae undertaken for this study suggests that this is primarly a result of philosophy and methodology in systematic research, and is thus more apparent than real. Many described Japanese and West Coast American "species" are equivalent to Euramerican species groups, lineages, or plexus of evolving species, which have been distinguished through population systematic analysis of large collections taken at closely-spaced stratigraphic intervals. For example, the current Japanese concept of *Mytilosdes labiatus* (SCHLOTHEIM) (MATSUMOTO and NODA, 1975, p. 188-208, pl. 18, text-figs. 1-7), recorded from (?) highest Cenomanian through Lower and (?) Middle Turonian in Japan, incorporates at least four biostratigraphically successive, lineage-related species and subspecies which have found wide use and recognition in the Euramerican system [SEITZ, 1934 (1935); KAUFFMAN, 1970, text-fig. 4; 1975, text-fig. 4], from oldest to youngest: *Mytiloides submytiloides* (SEITZ: questionable occurrence in Japan; latest Cenomanian to lowest Turonian); *Mytiloides opalensis* (BÖSE) (lower Lower Turonian); *Mytiloides mytiloides* (MANTELL) s. s. (middle Lower Turonian); *M. mytiloides arcuata* (SEITZ) including forms transitional to *M. labiatus* (SCHLOTHEIM) s. s. (middle Lower to upper Lower Turonian); and *Mytiloides subhercynicus* (SEITZ) (upper Lower to lowest Middle Turonian). In some cases, specimens included in a single northern Pacific "species", as presently defined, seem to belong to more than one species and may even represent two superficially similar (homeomorphic) genera or subgenera (e. g. "*Inoceramus contracostae*" ANDERSON, "*Inoceramus concentricus nipponicus*" and "*I. concentricus costatus*" NAGAO and MATSUMOTO).

Whereas it is not always possible to study inoceramids from the standpoint of population systematics and lineage evolution, their occurrence and preservation being variable, it is a methodology which yields a refined and consistent taxonomy of short-ranging species and subspecies upon which can be based regionally applicable and temporally refined biostratigraphic systems (KAUFFMAN, 1970). Restudy of the North Pacific Inoceramidae applying this methodology where possible, is urged, and has already begun (TANABE, 1973; NODA, 1975). Such studies will make it immensely easier to correlate the Pacific Cretaceous inoceramid fauna with those elsewhere in the world, at a much more refined scale, and will enhance geological interpretation based on biostratigraphic correlation in this area.

Biogeographic Interpretations.—High levels of Middle Cretaceous endemism among northern Pacific Inoceramidae were suggested by the literature prior to this review and the works of PERGAMENT (1965, 1966, 1971). This, coupled with well documented Pacific endemism among other groups (e. g. ammonites: MATSUMOTO, 1973; other bivalves: KAUFFMAN, 1973; etc.), seemed to imply great restriction of marine connection between the Cretaceous North Pacific Province, the Euramerican Realm, and the "Circumboreal Seaway" in order to explain this degree of isolation among organisms which were otherwise widely and rapidly dispersed. It further suggested the development of other effective biogeographic barriers to migration of Euramerican North Temperate Realm organisms into this area, such as important marine temperature boundaries (especially the Tethyan-North Temperate Realm boundary to the south); vast expanses of open ocean without intervening areas for settlement of benthonic larvae; and perhaps even current barriers to extensive larval drift. MATSUMOTO (1973, p. 428) noted a sharp contrast between Cretaceous ammonites of the North Pacific Province and both endemic and widespread Euramerican taxa of the Western Interior of North America. To explain this he proposed a "circum-

North Pacific orogenic mountain system" between the North Pacific and the Western Interior-"Arctic" ("Circumboreal") seas. Indeed, seemingly high endemism among North Pacific Inoceramidae, a group which otherwise is largely cosmopolitan or intercontinentally distributed, appeared to support MOTSUMOTO's hypothesis.

KAUFFMAN (1973, figs. 1, 2) on the other hand proposed major connections between the "Circumboreal" Cretaceous seaway and the North Pacific through which both North American Western Interior and more widespread Euramerican organisms (from the northeast), and North Temperate European organisms (from the northwest) could have entered the North Pacific. KAUFFMAN further proposed short-term but more direct connections between the Western Interior and Northern Pacific across the Cretaceous Cordilleran Geanticline. KAUFFMAN's hypothesis was based on the paleogeographic distribution of Cretaceous marine sediments and close faunal similarities between certain Mid- to Cool Temprate bivalves (KAUFFMAN, 1973) and gastropods (SOHL, 1967, 1971) of the Western Interior Coast of North America. These "shared" mollusks (species, species groups, suggenera, and genera) were of a type that did not inhabit Tropical Tethyan or marginal Tethyan seas, thus ruling out migration into the Pacific through the Caribbean across what is now northern Mexico and Baja California.

A final point which bears on the biogeography of northern Pacific Inoceramidae is the fact that these bivalves are uncommon but relatively diverse in Tropical Caribbean Cretaceous rocks of both shallow and deep-water facies. KAUFFMAN (1966, 1968, 1977c, and manuscript in preparation) has noted that the inoceramid fauna of the Caribbean is a mixture of taxa characteristic both of widespread Euramerican assemblages and those of the western Pacific, mainly Japan. This clearly indicates some migration of Inoceramidae, probably through planktotrophic larval drift, from Temperate Euramerica into the Temperate Pacific, and vice versa, through the Caribbean Province of the western Tropical Tethyan Sea. The natural question that is posed by this fact is whether or not migrations through the Caribbean (or through eastern Tethys and the Indo-Pacific) can account for all of the known Inoceramidae of Temperate Euramerican affinities that occur in the North Pacific Province (thus supporting MATSUMOTO's northern mountain chain barrier hypothesis), or whether immigration from both northern and southern sources is apparent, supporting the concept of marine connections between the North Pacific and the Circumboreal Seaway during the Cretaceous. Several facts stemming from the present study bear on this question.

(a) Absolute endemism among North Pacific Inoceramidae changes little from south (Japan) to north (eastern Russia, Siberia) in the northwestern Pacific, and decreases slightly to the north between California, Canada, and Alaska; relative endemism decreases to varying degrees. Diversity seems to increase slightly to moderately to the north (data incomplete on the eastern part of the North Pacific). These trends are primarily due to an increase in the number of typical Euramerican North Temperate species and (to a lesser degree) characteristic Western Interior North American species from south to north in the North Pacific Province.

(b) Systematic re-evaluation of inoceramids from the Middle Cretaceous of Japan and the Pacific Coast of North America reveal much greater affinities to Temperate

Euramerican stocks than has previously been suspected (see previous documentation), a fact that has been generally masked by provincial taxonomy in older monographs. PERGAMENT (1965, 1966, 1971) reports numerous Euramerican inoceramids on the Pacific Coast of the USSR. As presently understood, the great *majority* of North Pacific inoceramids are either conspecific and consubspecific with common European and North American taxa, or are closely related within the same species groups, or are taxa apparently of Pacific origin that have now been recognized as occurring also in the Eurmerican region. This, in turn, suggests large-scale migration of Cretaceous Inoceramidae in and out of the Pacific.

(c) The number of shared inoceramid taxa between the North Pacific and the Euramerican region exceeds by many times the number that are also known to occur in the Caribbean Province during the Middle and Upper Cretaceous. Most of the species shared between the North Pacific and Euramerica do *not* occur in the Tethyan Caribbean Province or its margins. This strongly suggests a northern migration route between the Pacific and Euramerican areas.

(d) Typical Japanese inoceramids are known now from Russia, western Canada, and the Western Interior of North America, and species described from Russia have been identified from western Canada, and northern Alaska near the northern limits of the Western Interior Seaway south to Oklahoma. Conversely, specimens probably belonging to "*Inoceramus*" (n. gen.) *dunveganensis* McLEARN, representing a species group which is almost wholly endemic to the Western Interior, have now been reported from eastern Russia by PERGAMENT (1965). Since this species group has not been reported south of Colorado in the Interior Seaway, it is suggested that it could only have reached the Pacific Coast of Russia through a northern connection between the Western Interior Circumboreal Seas and the North Pacific.

In conclusion, evidence accumulated in this and other studies during the last two decades clearly points to free migration of diverse cosmopolitan, intercontinentally distributed, and Euramerican inoceramid and other molluscan taxa into the North Pacific Province from at least Albian onward. Migrations of Inoceramidae were predominantly from the northeast and northwest, via the "Circumboreal Sea", but some taxa also had access through Tethys, mostly through the Caribbean Province insofar as the Tethyan inoceramid faunas are now known. The fact that most other North Pacific Cretaceous mollusks, including ammonites, do not show such close affinities to faunas outside of this area is strong evidence for the exceptional dispersal potential and thus biostratigraphic utility of inoceramid bivalves. These were benthonic organisms as adults, and thus wide, rapid dispersal could only have been accomplished through exceptionally long-lived planktotrophic larvae, with broad environmental tolerance, drifting for long periods of time on oceanic currents (KAUFFMAN, 1975). Even greater adult environmental tolerance among the Inoceramidae, as exhibited by broad facies and paleoenvironmental distribution patterns for species populations, further enhanced the wide and rapid dispersal of species and subspecies. Obviously the inoceramids were primarily a Temperate Zone group; relatively few species found Tethyan Tropical and Subtropical environments, especially in shallow water zones, marginally habitable. The Tethyan margins therefore acted as a formidable biogeographic barrier to the distribution of predominantly

Temperate Zones Inoceramidae in shallow water environments, especially in areas where the temperature gradient was severe and accentuated by currents. The Caribbean-Western Interior and east Pacific Tethyan margins could well have such areas (see KAUFFMAN, 1975, fig. 2 for Cretaceous paleocurrents). On the other hand, Cold Temperate marine climates which might have acted as a similar northern temperature barrier to inoceramid migration were apparently not developed during the Cretaceous; Mid-Temperate and possibly more restricted Cool-Temperate marine climatic zones seem to have extended all the way to the north polar regions during the Cretaceous (based on biological evidence) and these were prime environments for the Inoceramidae from the Jurassic onward (IMLAY, 1965; KAUFFMAN, 1975). It is apparently through these North Temperate seas, including the " Circumboreal Seaway ", that the main exchange of North Pacific, Euramerican and cosmopolitan took place during the Cretaceous, and this strongly suggests prolonged marine connections between the two areas. Interestingly, the periods of greatest exchange of Inoceramidae between the North Pacific and Euramerica, i. e. the Late Albian, Cenomanian-Early Turonian, and Late Turonian-Coniacian, etc., are also periods of major global transgression of epicontinental seas onto the world's cratons as a result of major sealevel rises generated by active plate tectonic movement and seafloor spreading (KAUFFMAN, 1973a, b). These transgressive events caused drowning of low physical barriers to migration between Cretaceous seas, and significantly enlarged existing marine connections.

Both systematic and biogeographic analysis of North Pacific Middle and Upper Cretaceous inoceramids therefore supports the contention that this fauna is so closely related to inoceramids throughout the North Temperate Realm, and to those of the Euramerican Region, that detailed taxonomic comparisons and precise biostratigraphic correlations can be made. This is a major step toward defining a global system of biostratigraphic correlation for the Cretaceous.

Biostratigraphic Interpretations: *Correlation of North Pacific and Euramerican Inoceramid Zones.*—Numerous difficulties impede the precision with which the highly refined Euramerican inoceramid zonation can be correlated with that of the northern Pacific. Yet this must be accomplished if we are to construct a global biostratigraphy based on these ubiquitous Bivalvia. Among problems already described are: (a) differences in taxonomic philosophies and methodology which have produced broadly defined long-ranging " species " and " subspecies " over much of the northern Pacific, but which contrast with the morphologically more restricted and temporally short-ranging taxa of the Euramerican region; it is still difficult to critically compare " species " in the two regions; (b) taxonomic provincialism, which has in the past masked the real relationships between northern Pacific and Euramerican Inoceramidae; (c) low to moderate levels of endemism in the Northern Pacific and northern part of the Western Interior Seaway which restricts the level of faunal overlap possible between biogeographic regions at their main junction point in the " Circumboreal Seaway "; (d) for inoceramid " species " that are supposedly shared between the North Pacific Province and the Euramerican Region, stratigraphic ranges (as measured with European stages) cited for the Pacific taxa are in some cases longer, or rarely even disjunct, from those of Euramerica; whether this represents differing species concepts, differing stage concepts, stratigraphic error in one or the other region, or biogeographic effects (e. g. stratigraphic displacement as a result of time lag in long migrations) is not clear in every case; (e) differing faunal diversity, lower for inoceramids in the North Pacific, coupled with the fact that much more is known of the Euramerican inoceramid fauna due to a long history (including modern times) of monographic works. Pacific inoceramids have at best been monographed only once, and other than the studies of PERGAMENT in eastern Russia (1965, 1966, 1971), and TANABE (1973), NODA (1975) and HAYAMI (1975) in Japan, these are older works which precede the development of modern concepts in inoceramid systematics. Other factors which hinder regional correlation of the Pacific inoceramid assemblage include (f) limited integration of the Pacific inoceramid biostratigraphy with that based on widespread planktonic microbiota, or ammonites, of the same age; and (g) communication between scholars interested in Pacific and Euramerican Inoceramidae.

Despite these drawbacks, this preliminary revision of the North Pacific Inoceramidae, coupled with PERGAMENT's work in eastern Russian (1965, 1966, 1971) and an emerging wealth of information on the inoceramids of Alaska and western Canada collectively provide a more detailed basis for biostratigraphic zonation and correlation than had previously been possible (e. g. MATSUMOTO, 1959; NODA and MATSUMOTO, 1976). This is further enhanced by the discovery that the Inoceramid fauna of the northernmost Pacific margin (e. g. Russia, Alaska, British Columbia including offshore islands) contains a mixture of cosmopolitan to intercontinentally distributed Euramerican taxa, endemic North Pacific Province taxa, and endemic Western Interior taxa from North America. This area obviously lay within migratory routes (via long-lived planktonic larvae) of Euramerican and endemic North American inoceramids into the North Pacific (and vice versa) through the "Circumboreal Seawey" (KAUFFMAN, 1973, figs. 1, 2; 1975, fig. 2), and also possibly via short-lived marine connection to the Western Interior Seaway through the Cordilleran Geanticline which separated Pacific from Warm- to Mid-Temperate Western Interior biotas during most of the Cretaceous.

Based on these new data, and the recognition in the North Pacific Province of previously undetected Euramerican inoceramids of high biostratigraphic utility (Table 1), it is now possible to propose new biostratigraphic zonations based on inoceramids of the Middle Cretaceous-Coniacian sequence in Japan and the West Coast of the United States, and to correlate them generally with each other and with the more refined zonations of eastern Russia, northern Canada-Alaska, the Western Interior United States, and the Euramerican intercontinental sequence. These biostratigraphic zonations and their correlation, still tentative pending detailed systematic restudy of the northern Pacific fauna, is presented in Fig. 1. It is my belief that following detailed systematic revision of the Pacific Inoceramidae, incorporating new material that is being accumulated (especially in North America) at a rapid rate and employing, where possible, population systematic techniques within evolving inoceramid lineages, a biostratigraphic zonation of equal refinements to that currently used in Euramerica will be developed, allowing precise correlations on a global scale.

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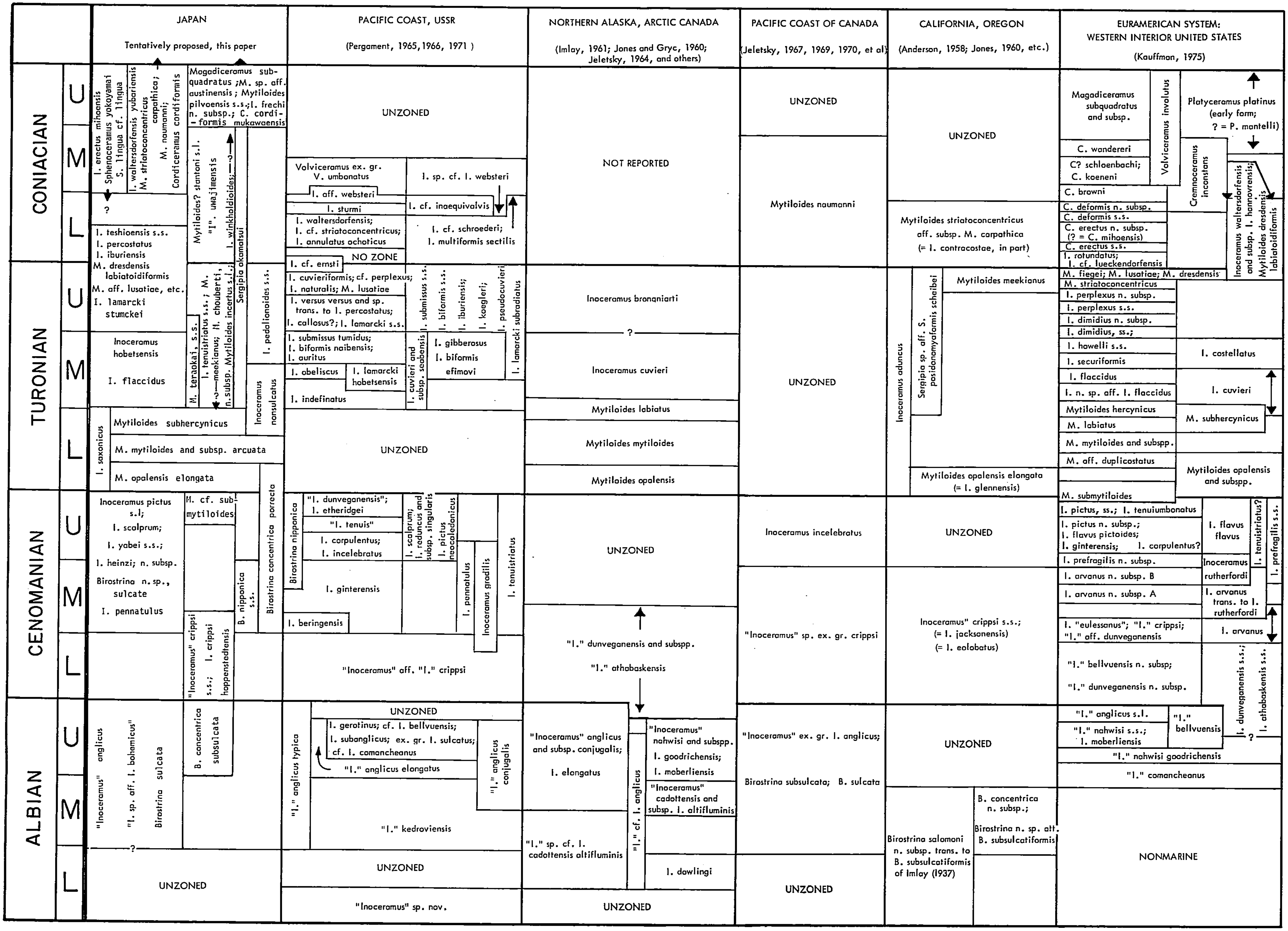

Fig. 1. Correlation of North Pacific and Euramerican Middle Cretaceous-Coniacian Inoceramid Zonations.

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ESSAI DE COMPARAISON DES FAUNES D'AMMONITES AU CRÉTACÉ SUPÉRIEUR (TURONIEN À MAËSTRICHTIEN) AU JAPON ET À MADAGASCAR

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Résumé

En étudiant les travaux des Paléontologues qui se sont occupés des Faunes japonaises et malgaches on constate de très grandes affinités qui permettent de nombreuses corrélations.

Au point de vue des Familles d'Ammonites il ressort que les principales sont représentées en proportions parfois identiques, parfois très différentes.

Les Desmoceratidae comprennent de nombreux Puzosiinae avec *Bhimaites*, *Pachydesmoceras*, *Jimboiceras*, *Mesopuzosia*, *Neopuzosia;* des Desmoceratinae avec *Desmoceras*, *Pseudouhligella*, *Damesites*, *Desmophyllites;* des Hauericeratinae avec *Gardeniceras*, plus abondants d'ailleurs à Madagascar; des Kossmaticeratidae très inégalement répartis; des Pachydiscidae avec des espèces communes, mais *Lewesiceras* manque au Japon, tandis que *Eupachydiscus* et *Anapachydiscus* abondent des deux côtés; mais *Menuites* manque à Madagascar.

Chez les Hoplitidae, les Cleoniceratinae abondent dans l'Albien malgache et paraissent inconnus au Japon; les Hoplitinae manquent de part et d'autre, mais *Lemuroceras* pullule dans l'Albien malgache.

Les Acanthoceratidae sont également répartis avec des Mantelliceratinae tels que *Mantelliceras*, *Calycoceras*, *Eucalycoceras*, et des Acanthoceratinae tels *Romaniceras*.

Les Vascoceratidae sont inégalement répartis puisque *Fagesia* et *Pseudaspidoceras* sont rares au Japon, de même que *Vascoceras*, rare des deux côtés.

Les Collignoniceratidae sont partiellement surtout japonais (*Reesidites*, *Pseudobarroisiceras*) ; les Peroniceratinae ont en commun *Yabeiceras;* et les Texanitinae sont abondants tant à Madagascar où il pullulent du Santonien au Campanien supérieur qu'au Japon où ils paraissont moins nombreux en genres et en espèces.

Il est remarquable de constater que le genre *Pseudoschloenbachia* qui pullule dans le Santonien-Campanien inférieur malgache ne parait pas représenté au Japon. Plus curieuse encore est la coexistence d'un genre réputé endémique à Madagascar, *Hourcquia*, qui existe aussi, mais plus rare au Japon.

Parmi les Heteromorphes il faut citer *Hyphantoceras*, *Madagascarites*, *Eubostrychoceras*, *Pseudoxybeloceras*, et bien d'autres.

Si on recherche une comparaison avec l'Inde, on remarque de très notables différences (par exemple, les Texanitinae n'y existent pas). Il semble que les affinités entre le Japon et Madagascar soient dûes, pour le moment, à ce que ce sont les Faunes de ces deux régions qui ont été, jusqu'ici, le plus complètement étudiées.

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En 1971, à la fin d'une étude sur le Bassin Côtier du Golfe du Menabe, à Madagascar dans laquelle j'avais fait ressortir le caractère endémique des Faunes d'Ammonites, d'Inocérâmes et de Crustacés, j'avais fait la remarque " dans l'ensemble circumpacifique et indien, les Faunes Japonaises et Malgaches avaient bien des points d' analogie " et, sans autre commentaire, j'ajoutais " peut-être aussi est ce parce que ce sont, jusqu'ici, les plus complètement et les plus abondamment décrites " (COLLIGNON, 1972).

L'étude qui va suivre n'est qu'un essai, limité surtout par des impératifs d'édition qui ne me permettent que d'écrire un nombre restreint de pages, mais qui sera développé ultèrieurement. C'est aussi un hommage à mes Amis Japonais dont l'Oeuvre est, à ce jour, considérable.

J'examine successivement les différentes Familles d'Ammonites dans l'ordre du Treatise (C. W. WRIGHT) et je ne compare que les genres et espèces les plus suggestifs de facon à faire ressortir au mieux les analogies et parallélismes existants.

1. **Phylloceratidae** ZITTEL, 1884

Les Phylloceratidae sont rares dans le Crétacé Supérieur du Monde. Toutefois ils sont relativement abondants au Japon et à Madagascar, et, plus généralement, dans les régions circumpacifiques.

Déjá, dès 1934, SHIMIZU avait pu créer le genre *Neophylloceras*, et ultèrieurement, MATSUMOTO décrivait *N. subramosum* (SHIMIZU) MATSUMOTO, *N. compressum* MATSUMOTO, et *N. hetonaiense* MATSUMOTO, qui montent jusqu'au sommet du Crétacé. A Madagascar, les *Phylloceras* abondent dès le Turonien avec *Hyporbulites masiaposensis* COLLIGNON et surtout au Santonien avec *H. woodsi* v. HOEPEN et au Campanien où les gros exemplaires ne sont pas rares (*H. tessonnierei* COLLIGNON, *H. bererensis* COLLIGNON). Mais leur déclin est définitif au Maëstrichtien avec *Epiphylloceras* COLLIGNON, qui a fourni deux espèces, les dernières.

Il n'est pas exclu que l'étude dès cloisons de ces divers Phylloceratidae ne conduisent à les rèunir dans le genre unique *Hypophylloceras* SALFELD, comme l'a déjá fait C. W. WRIGHT dans le Treatise, et ainsi serait affirmée une analogie plus complète entre les *Phylloceras* du Japon et de Madagascar.

2. **Tetragonitidae** HYATT, 1900

A. **Gaudryceratinae** SPATH, 1927

Dans cette Sous-Famille, *Gaudryceras* DE GROSSOUVRE est le genre le plus abondant ; il est d'ailleurs ubiquiste. A Madagascar ses représentants pullulent dans le Cénomanien, mais ils sont rares au-dessus, tandis que, au Japon, ils restent extrèment abondants.

On trouve en commun : *G. denseplicatum* (JIMBO) au Coniacien, *G. tenuiliratum* YABE au Santonien. D'autres espèces existent aussi dans les deux régions, mais quoique abondantes, sont différentes.

Chez *Anagaudryceras* SHIMIZU il y a en commun *A. sacya* (FORBES). J'ai expliqué en 1956 comment je concevais "*sacya*" qui, pour moi, ne représente que les tours internes de Gaudryceratinae plus évolués; cette conviction est établie sur la dissection de nombreux *Gaudryceras* qui invariablement me donnent des tours internes qui sont des "*sacya*". Il semble que je n'ai pas été suivi; mais il n'a pas été fait allusion à cette opinion. Une espèce malgache comme *A. yokoyamaiforme* COLLIGNON, du Campanien infèrieur (à *Maorites*) est bien voisine à la fois de *A. yokoyamai* (YABE) et de *A. yamashitai* (YABE).

Zelandites MARSHALL est un genre commun, mais avec des espèces spéciales. Le genre est très rare à Madagascar, mais très abondant au Japon. Une seule espèce pourrait être commune: *Z. mihoensis* MATSUMOTO.

Quant à *Vertebrites* MARSHALL il ne parait pas exister au Japon tandis qu'it se trouve à Madagascar dans le Maëstrichtien.

B. **Tetragonitinae** HYATT, 1900

Cette Sous-Famille, longuement étudiée depuis YABE, est très abondante au Japon et à Madagascar.

Le genre *Tetragonites* KOSSMAT, est abondant dans le Mesocrétacé des deux régions. Il est plus rare au-dessus et ne comporte pas d'espèces communes. Mais les autres genres de la Sous-Famille sont bien représentés. Ainsi *Epigoniceras* SPATH existe au Japon, en particulier avec *E. glabrum* (JIMBO) du Turonien au Campanien; il existe dans le Campanien infèrieur du Menabe avec sa variété *problematica* MATS. A Madagascar le genre est également réparti, mais surtout au Santonien avec *E. epigonum* (KOSSMAT).

Pseudophyllites KOSSMAT est représenté au Japon et à Madagascar avec *P. indra* (FORBES) mais à Madagascar il pullule littéralement depuis le Santonien jusqu'au Maëstrichtien. Mais c'est à la limite Santonien-Campanien qu'il est le plus abondant, parfois en très gros exemplaires.

Saghalinites SHIMIZU est rare dans les deux régions. *S. nuperus* v. HOEPEN y est commun. Il est parfois assez difficile à distinguer de *Anagaudryceras* (*S. zelandlicus* SHIMIZU).

3. **Baculitidae** MEEK, 1876

Il s'agit d'une Famille très bien représentée au Japon, aussi bien qu'en Amérique du Nord où COBBAN a pu établir une stratigraphie basée sur les *Baculites*. A Madagascar elle est également bien représentée, mais elle n'est pas encore complètement étudiée, sauf dans le Campanien moyen où 11 niveaux successifs à *Baculites* caractèristiques on y pu être distingués.

Lechites NOWAK et *Sciponoceras* HYATT n'intéressent au Japon et à Madagascar que le Mesocrétacé, quoique *S. intermedium* MATSUMOTO apparaisse au Turonien supérieur. Mais *Baculites* LAMARCK est abondant dans les deux régions et les espèces communes ne sont pas rares. A Madagascar le genre n'existe pas dans le Turonien et parait dans le Coniacien avec *B. besairiei* COLLIGNON, très abondant, et *B. bailyi* WOODS rare; et c'est seulement au Santonien que les mêmes *Baculites* existent en nombre: *B. capensis* WOODS se trouve alors à Madagascar et au Japon, de même que *B. boulei* COLLIGNON. C'est au Campanien que dans les 2 régions le genre devient vraiement abondant. Beaucoup d'espèces ont été décrites à Madagascar : *B. menabensis* COLLIGNON dérive de *B. capensis* WOODS, et plusieurs autres dont l'épanouissement se réalise dans le Campanien moyen où elles pullulent. *B. tanakaeformis* COLLIGNON est bien voisin de *B. tanakae* MATSUMOTO, toutes deux du Campanien inférieur *B. rectangulatus* COLLIGNON est voisin de *B. regina* MATSUMOTO et OBATA, du Campanien moyen.

Il est remarquable de constater que les *Baculites* maëstrichtiens de Madagascar sont souvent communs avec l'Inde : ce sont d'ailleurs des *Eubaculites* encore inconnus au Japon.

4. **Nostoceratidae** HYATT, 1894

Cette Famille, abondante dans le Crétacé Supérieur du Japon et de Madagascar, renferme de nombreux genres ayant bien des points communs dans les deux régions.

Bostrychoceras HYATT est extrèmement abondant à Madagascar où les espèces indiennes telles que "*indicum*" et "*saxonicum*" se trouvent déjà dans le Coniacien et se prolongent jusque dans le Campanien moyen. *B. indicum* STOLICZKA pourrait être *B. pacificum* MATSUMOTO de la Zone à *I. uwajimensis:* limité à cette Zone il est bien moins abondant au Japon. Le Campanien inférieur a fourni à Madagascar plusieurs des espèces décrites dès 1904 par YABE ; elles abondent dans le Campanien inférieur. Dèjà, à cette époque, le savant Paléontologue avait décrit *Nipponites* dont des fragments existent peutêtre dans le Coniacien malgache. Mais il est remplacé dès cet étage par *Bostrychoceras* et *Eubostrychoceras*, et il est accompagné de genres voisins comme *Madagascarites* COLLIGNON, du Santonien moyen, retrouvé au Japon dans le Turonien supérieur, et par une grande abondance de *Hyphantoceras* HYATT qui en est la souche probable.

Ce n'est que dans le Maëstrichtien qu'apparaissent à Madagascar les genres très spécialisés *Nostoceras* HYATT, *Didymoceras* HYATT, *Emperoceras* HYATT, *Axonoceras* STEPHENSON, malheureusement encore inconnus au Japon où la partie la plus élevée du Crétacé est rarement présente.

5. **Diplomoceratidae** SPATH, 1924

Les genres *Scalarites* WRIGHT et MATSUMOTO, *Pravitoceras* YABE, *Polyptychoceras* YABE, *Ryugasella* WRIGHT et MATSUMOTO, ne sont pas connus à Madagascar.

Par contre, *Pseudoxybeloceras* WRIGHT et MATSUMOTO, et *Diplomoceras* HYATT abondent au Japon et Madagascar ; le premier de ces genres a fourni de nombreux exemplaires dans le Coniacien inférieur et moyen de Madagascar, tandis que le deuxième pullule en gros exemplaires dans le Maëstrichtien.

Glyptoxoceras SPATH, rare au Japon, est représenté à Madagascar par plusieurs espèces et surtout par les genres voisins *Neoglyptoxoceras* COLLIGNON, et *Epiglyptoxoceras* COLLIGNON, qui abondent dans le Campanien inférieur.

6. **Scaphitidae** MEEK, 1876

C'est une Famille rare au Japon. YABE en a cité *Yezoites* qui est peut-être un *Worthoceras.*

A Madagascar le genre *Scaphites* PARKINSON, est présent depuis le Turonien. Mais c'est seulement au Campanien qu'il devient abondant avec 2 espèces (*S. reesidei* COLLIGNON, et *S. aquisgransiformis* COLLIGNON). La première de celles-ci pullule dans la Sous-Zone à laquelle j'ai donné son nom.

7. **Desmoceratidae** ZITTEL, 1895

A. **Puzosiinae** SPATH, 1922

Cette Sous-Famille est abondamment représentée au Japon et à Madagascar. Le genre *Puzosia* BAYLE et les genres ou sous-genres nouveaux créés par MATSUMOTO existent depuis le Turonien inférieur à Madagascar où se trouvent *P. orientalis* MATSUMOTO, *Mesopuzosia pacifica* MATSUMOTO Au-dessus *Pachydesmoceras hourcqui* COLLIGNON, annonce *P. pachydiscoides* MATSUMOTO, du Coniacien. C'est aussi au Turonien supérieur que se trouve au Menabe *Jimboiceras* MATSUMOTO, avec une variété *madagascariensis* COLLIGNON, proche de *J. planulatiforme* (JIMBO), et aussi *Mesopuzosia yubarensis* (JIMBO).

Au Coniacien *Puzosia* est représenté par *P. orientalis* MATSUMOTO, à côté d'espèces spéciales; *Mesopuzosia* par des espèces mal conservées et non dénommées. Mais *Neopuzosia* MATSUMOTO, a fourni *N. matsumotoi* COLLIGNON, et on y note l'apparition de *Austiniceras* SPATH, déjà disparu au Japon depuis le somment du Turonien.

Au Santonien et au Campanien les Puzosiinae fournissent de nouveau *Mesopuzosia* et de nombreux *Parapuzosia* NOWAK, qui, d'après MATSUMOTO n'existent pas au Japon.

B. **Desmoceratinae** ZITTEL, 1895

Comme la précédente cette Sous-Famille est bien représentée au Japon et à Madagascar. *Pseudouhligella* MATSUMOTO, n'existe plus à Madagascar au Turonien. Mais *Damesites* MATSUMOTO, et *Desmophyllites* SPATH y sont abondants. Le premier de ces genres est apparu au Coniacien, et peut-être déjà au Turonien supérieur avec *D.* aff. *damesi* (JIMBO), passe dans le Santonien avec *D. sugatus* (FORBES), commun au Japon, *D. damesi* (JIMBO), et monte dans le Campanien inférieur avec *D. rabei* COLLIGNON, dont le port et les cloisons rappellent plusieurs espèces japonaises, en particulier *D. ainuanus* MATSUMOTO, et *D. laticarinatus* SAITO et MATSUMOTO.

Quant à *Desmophyllites* SPATH, il est également répandu dans les deux régions avec *D. diphylloides* (FORBES) au Santonien et au Campanien.

C. **Hauericeratinae** MATSUMOTO, 1938

Hauericeras DE GROSSOUVRE, et le sous-genre *Gardenicras* MATSUMOTO sont très abondants au Japon et surtout à Madagascar. Toutefois les espèces sont différentes. *H. angustum* YABE existe dans le Campanien du Japon, tandis que *H.* (*G.*) *gardeni* (BAILY) existe dans le Campanien malgache à profusion. Cette espèce m'a servi à caractériser l'ensemble du Campanien inférieur: mais le genre existe depuis le Santonien inférieur. Un niveau particulier du Campanien inférieur a fourni de nombreux exemplaires de *H.* (*G.*) *madagascariense* COLLIGNON.

En résumé, malgré les différences locales, les Desmoceratidae très abondants au Japon et à Madagascar, y ont poursuivi une évolution parallèle comme le prouve le grand nombre d'espèces communes.

8. **Kossmaticeratidae** SPATH, 1922

L'évolution et la répartition des Kossmaticeratidae sont sensiblement différentes au Japon et à Madagascar.

La Famille est déjà florissante au Japon à l'Albien-Cénomanien avec *Marshallites* MATSUMOTO, qui y abonde, comme en Alaska, mais est totalement inconnue à Madagascar. Pour ces Ammonites, MATSUMOTO a créé la Sous-Famille des Marshallitinae, et ce avec raison, car il semble qu'il s'agisse d'un rameau aberrant sans descrendance (Miyakoan sup.+Paleogyliakian). Son origine pourrait être recherchée dans le groupe de *Puzosia reesidei* ANDERSON.

Les Kossmaticeras sensu stricto du Japon et de Madagascar ont alors rendu nécessaire la création d'une Sous-Famille des Kossmaticeratinae MATSUMOTO, 1955 dans le sein de laquelle MATSUMOTO a reconnu 3 groupes également présents au Japon et à Madagascar. Le groupe de *K. recurrens* KOSSMAT, existe dans le Turonien supérieur de Madagascar (en même temps que *Jimboiceras*). Les *Kossmaticeras* du groupe *theobaldianum* KOSSMAT, sontrares au Japon où ne coexiste que *K. pachystoma* KOSSMAT, mais par contre ont fourni dans le Coniacien malgache une profusion d'espèces toutes reprèsentèes par de nombreux individus. Mais *Yokoyamaoceras* WRIGHT et MATSUMOTO, n'existe pas à Madagascar, tandis que *Karapadites* COLLIGNON, y est extrémement abondant au Santonien supérieur et surtout dans le Campanien inférieur dont il caractèrise une Zone; et *Maorites* MARSHALL très abondant à Madagascar n'existe pas au Japon: c'est d'ailleurs un genre caractèristique du Campanien inférieur de l'Hemisphère Sud (Régions antarctiques, Nouvelle-Zélande et Nouvelle-Calédonie).

9. **Pachydiscidae** SPATH, 1922

C'est une Famille qui a son origine dans le Mesocrétacé. Mais c'est au Turonien qu'elle prend un développement considérable tant au Japon qu'à Madagascar.

A Madagascar, au Turonien, elle est représentée par *Lewesiceras* SPATH avec plusieurs espèces et beaucoup d'individus; mais le genre ne parait pas exister au Japon à cette époque, et *Pachydiscoides* y est rare. Par contre, le groupe des Pachydiscidae bituberculés avec *Menuites* SPATH est remarquablement développé au Japon, tandis qu'il ne parait avoir que des représentants malgaches encore douteux (*M.* (*Besairieites*) *pseudorotalinus* COLLIGNON du Santonien). Au Japon *Menuites* persiste jusqu'au Campanien supérieur avec *Teshioites* MATSUMOTO et *Urakawites* MATSUMOTO, eux aussi absents de Madagascar.

C'est au Santonien et surtout au Campanien que les Pachydiscidae vont prendre un essor remarquable et parallèle dans les deux régions avec *Anapachydiscus* YABE et SHIMIZU, *Eupachydiscus* SPATH (=*Mesopachydiscus* YABE et SHIMIZU), *Canadoceras*

SPATH (=*Pseudopachydiscus* YABE et SHIMIZU) et finalement *Neodesmoceras* SAITO et MATSUMOTO. Les espéces communes ne sont pas rares: *A. subtilobatus* (JIMBO), *A. sutneri* (YOKOYAMA), *E. teshioensis* (JIMBO) et surtout *E. haradai* (JIMBO). *Canadoceras* est plus abondant à Madagascar qu'au Japon. Et *Pachydiscus* ZITTEL, ne parait pas exister au Japon, alors qu'à Madagascar il est très abondant, surtout dans le Maëstrichtien avec des espèces ubiquistes (*P. gollevillensis, P. fresvillensis* d'ORBIGNY).

10. **Muniericeratidae** WRIGHT, 1952

Cette Famille est limitée dans le "Treatise" à deux genres seulement: *Muniericeras* GROSSOUVRE, et *Tragodesmoceras* SPATH.

Aprés avoir receuilli et étudié des milliers de *Muniericeras* et de *Pseudoschloenbachia* SPATH du Santonien-Campanien de Madagascar, et en avoir disséqué beaucoup, je pense qu'il faut retirer ce dernier genre de la Sous-Famille des Lenticeratinae HYATT où d'ailleurs il n'est que douteusement placé, et qu'il faut l'intégrer à la Famille des Miniericeratidae.

Je divise alors celle-ci en 2 Sous-Familles: Muniericeratinae WRIGHT, 1952 qui contient *Tragodesmoceras* SPATH, le genre *Muniericeras* GROSSOUVRE et les nouveaux genres *Praemuniericeras* COLLIGNON, 1966 (Santonien inférieur et moyen) et *Lehmaniceras* COLLIGNON, 1966 (Santonien moyen)—et la Sous-Famille des Pseudoschloenbachiinae COLLIGNON 1969 qui contient avec *Pseudoschloenbachia* SPATH tous les sous-genres (ou genres) dérivés que j'ei créés en 1966 et 1969: *Fournierella, Vendegisiella, Besairiella, Hourcquiella, Condamyella, Bühreriella, Rabeiella, Rabenjanahariella, Termiericeras* (au lieu de *Termierella* préemployé), *Hirtziella* (Santonien pour *Fournierella* —Santonien et Campanien inférieur pour tous). A cette Sous-Famille je suis enclin à ajouter *Lymaniceras* MATSUMOTO qui pourrait être un intermédiaires entre *Muniericeras* et *Pseudoschloenbachia*.

Cette classification me parait plus équilibrée et plus conforme à l'évolution de cet ensemble qui joue un rôle capital dans le Santonien et le Campanien malgache. Malheureusement la presque totalité des représentants de cette Famille est encore inconnue au Japon et est extrèmement rare dans l'Inde.

11. **Acanthoceratidae** HYATT, 1900

C'est une Famille très abondamment représentée au Japon et à Madagascar, principalement dans le Mesocrétacé, au Cénomanien.

Au Turonien les 2 Sous-Familles des Acanthoceratinae HYATT et Mammitinae HYATT sont représentées par différents genres tandis que celle des Metoicoceratinae HYATT, rare à Madagascar, à la limite Cénomanien-Turonien, n'existe pas au Japon.

Romaniceras SPATH n'est abondant qu'au Turonien supérieur tant au Japon qu'à Madagascar, avec les mêmes espèces. *Mammites* LAUBE et BRUDER est assez rare à Madagascar absent au Japon de même que *Kamerunoceras* REYMENT. *Pseudaspidoceras* HYATT est très répandu à Madagascar dans le Turonien moyen (*P. conciliatum* STOLICZKA) et rare au Japon avec une seule espèce (*P. sorachiense* MATSUMOTO). Enfin *Yubariceras* MATSUMOTO, SAITO et FUKADA, a donné la même espèce dans le

Turonien inférieur des deux régions (*Y. yubarense* MATSUMOTO, SAITO et FUKADA).

12. **Placenticeratidae** HYATT, 1900

Cette Famille bien représentée à Madagascar où elle ne dépasse pas le Coniacien, n'existe au Japon que dans le Campanien supèrieur, où *Paraplacenticeras* MATSUMOTO, joue le rôle de *Hoplitoplacenticeras* SPATH abondant dans le Campanien supérieur malgache.

13. **Vascoceratidae** SPATH, 1925

C'est une Famille téthysienne qui a essaimé vers Madagascar avec *Vascoceras* CHOFFAT, *Fagesia* PERVINQUIÈRE, *Thomasites* PERVINQUIÈRE, et *Neoptychites* KOSSMAT, où elle est bien répandue, tandis que, au Japon, elle est relativement très rare.

Seuls y sont communs: *V.* aff. *durandi* (THOMAS et PERON), et 2 espèces de *Fagesia* (*F. rudra* (STOLICZKA), et *F. thevestensis* (PERON)) du même niveau turonieninférieur.

Un fait remarquable est la présence au Japon d'un autre genre de la Famille (Sous-Famille des Neoptychinae COLLIGNON, 1965): c'est *Hourcquia* COLLIGNON. Ce genre et son allié, *Masiaposites* COLLIGNON, sont extrêmement répandus dans le Turonien supérieur de Madagascar où ils sont un des caractères principaux de l'endemisme des faunes crétacées malgaches. *Hourcquia* a été retrouvé au Caucase.

14. **Tissotiidae** HYATT, 1900

Cette Famille est à peu près inconnue à Madagascar où j'ai receuilli 2 exemplaires d'un rare *Hemitissotia* (*Betiokytes*) et où E. BASSE a cité *Pseudotissotia*. Ces deux Ammonites sont datées du Turonien inférieur.

Par contre, au Japon, elle parait inconnue jusqu'ici.

15. **Collignoniceratidae** WRIGHT et WRIGHT, 1951

Avec cette Famille les conditions d'analogie que j'estimais éphèmères et précaires au Turonien semblent avoir gagné en ampleur si on considère les Faunes d'Ammonites, même dans le détail, et c'est avec ses représentants que j'estime les rapports et relations les plus grands entre Japon et Madagascar.

A. **Collignoniceratinae** WRIGHT et WRIGHT, 1951

Plusieurs genres sont représentés au Japon et à Madagascar: *Subprionocyclus neptuni* (GEINITZ), existe dans le Turonien supérieur. Mais *Collignoniceras* BREISTROFFER, s. str. n'existe pas à Madagascar, tandis que *Selwynoceras* WARREN et STELCK, y est extrêmement rare, de même que *Prionocycloceras* SPATH. MATSUMOTO a fait remarquer que cette Sous-Famille était beanucoup plus abondante en Amérique du Nord que partout ailleurs.

B. **Peroniceratinae** HYATT, 1900

Presque tous les genres de cette Sous-Famille sont représentés en abondance, parfois par des espèces identiques, au Japon et à Madagascar. *Peroniceras* GROS-

SOUVRE, est ubiquiste, homogène et très abondant. Sa souche est, d'après MATSUMOTO, et avec raison, *Protexanites bourgeoisi* (d'ORBIGNY), du Coniacien, d'où dériveraient d'ailleurs à la fois Peroniceratinae et Texanitinae. De nombreuses espèces ont été décrites à Madagascar ou le genre parait plus répandu qu'au Japon. Il en est de même de *Gauthiericeras* GROSSOUVRE. Mais *Ishikariceras* MATSUMOTO, est très rare à Madagascar, et les nouveaux genres *Cobbanoceras* MATSUMOTO, et *Sornayiceras* MATSUMOTO, n'y ont pas encore été décelés.

C. **Barroisiceratinae** BASSE, 1947

Comme la précédente, presque tous les genres de cette Sous-Famille existent conjointement au Japon et à Madagascar.

Le principal d'entre eux *Barroisiceras* GROSSOUVRE, est d'une extrême abondance à Madagascar dont il caracterise la Zone moyenne du Coniacien: mais *Barroisiceras* s. str. n'existe pas au Japon. Il est d'ailleurs remarquable que toutes les Ammonites que j'ai utilisées pour caractériser les 3 Zones du Coniacien malgache se retrouvent au Japon. Dans le détail, *Basseoceras* COLLIGNON, *Harleites* REESIDE et *Forresteria* REESIDE se retrouvent aussi bien à Madagascar qu'au Japon, et ce dernier genre y est particulièrement abondant. Et *Yabeiceras* TOKUNAGA et SHIMIZU, est très abondant dans le Coniacien malgache. Les genres spéciaux seuls ne coexistent pas; mais l'un d'eux *Muramotoa* est bien voisin d'espèces malgaches.

D. **Texanitinae** COLLIGNON, 1948

C'est de tous les Collignoniceratidae, la Sous-Famille la mieux parallélisée entre Japon et Madagascar. Déjà en 1948 j'avais esquissé une classification en genres bien définis. Depuis, MATSUMOTO a amélioré et complété ce tableau et défini les origines; et il a décrit 20 espèces japonaises.

Protexanites MATSUMOTO, est à la base de la Sous-Famille par l'intermédiaire de *Subprionocyclus*. *P. planatus* (LASSWITZ), existe au Japon comme à Madagascar, mais *Anatexanties* est essentiellement japonais. *Paratexanites* COLLIGNON, abonde au Japon, et *Parabevahites* COLLIGNON, y est commun: les espèces japonaises et malgaches sont bien voisines (*P. serrato-marginatus* (REDTENBACHER)).

Texanites SPATH est très répandu. Plusieurs espèces malgaches existent au Japon (avec *Plesiotexanites* MATSUMOTO) et même sont communes avec l'Europe (*T. quinquenodosus* (REDTENBACHER)). La différentiation en genres autonomes, principalement malgaches, s'effectue partiellement à la limite Santonien-Campanien avec *Bevahites* COLLIGNON, qui abonde à Madagascar, mais est rare au Japon. Ici il faut citer *Australiella* COLLIGNON, du Campanien moyen de Madagascar retrouvé au Japon avec une espèce voisine d'une espèce américaine, ce qui prouve que cette Sous Famille est largement répandue. Etant ici limité dans cet " essai " je ne puis qu'apprécier sommairement les multiples rapports de toutes les espèces connues de Texanitinae, surtout japonaises et malgaches, car ils méritent d'être approfondis. C'est d'ailleurs un travail qui m'occupe depuis plusieurs années et auquel je ne pourrai mettre une conclusion que lorsque j'aurai achevé la préparation des 800 exemplaires complets que j'ai receuillis à Madagascar depuis le Santonien inférieur jusqu'au sommet du Campanien moyen.

E. Lenticeratinae HYATT, 1900

J'ai expliqué plus haut comment j'avais été amené à extraire de cette Sous-Famille le genre *Pseudoschloenbachia*. C'est une Sous-Famille non représentée au Japon. En ce qui concerne Madagascar, je signale seulement l'abondance de *Eulophoceras* HYATT à la base du Campanien, et la rareté de *Diazicceras* SPATH au même niveau.

Conclusion

Cet " essai " de comparaison reste encore trop insuffisant : il faudrait étendre cette enquête au pourtour indo-circum pacifique. Et bien des problèmes restent en suspens, comme celui-ci : comment se fait-il que les Texanitinae soient absents de l'Inde (une citation douteuse), alors qu'à la même époque les Pachydiscidae y abondent, comme à Madagascar et au Japon ; et il y a beaucoup d'espèces communes.

Les recherches sur l'écologie, les courants, la nature et les niveaux des mers doivent maintenant faire l'objet de recherches particulières.

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Tableau comparatif des Subdivisions stratigraphiques au Japon et à Madagascar

Etages		Zones definies par des Ammonites				
Japon	Madagascar	Japon		Madagascar		Particularités malgaches
Upper Hetonaian	Maëstrichtien superieur	*Pachydiscus subcompressus*	*Brahmaites saghalinensis*	Z. à *Sphenodiscus* (mal définie)		
	Maëstrichtien inferieur	*Neodesmoceras japonicum*	*Patagiosites compressus*	Z. à *P. gollevillensis* et *P. neubergicus*		
Lower Hetonaian superieur	Campanien superieur			Z. à *Hoplitoplacenticeras marroti*		
Lower Hetonaian inferieur	Campanien moyen	*Canadoceras kossmati*	*Metaplacenticeras subtilistriatum*	Z. à *Delawarella subdelawarensis* et *Australiella australis*		Niveau à *Manambolites* 3 niveaux à *Baculites*
				Z. à *Pachydiscus grossouvrei*	S. Z. à *Pachydiscus bassae*	2 niveaux à *Baculites*
					S. Z. à *Eupachydiscus lamberti*	6 niveaux à *Baculites*
Infra Hetonian	Campanien inferieur	*Neopachydiscus naumanni*		Z. à *Menabites boulei* et *Anapachydiscus arrialoorensis*	S. Z. à *Termiericeras lenticulare*	Niveau à *Bostrychoceras protractum* Niveau à *Epiglyptoxoceras*
					S. Z. à *Rabeiella orthogonia*	Niveau à *Hauericeras* (*Gardeniceras*) *madagascariense*
				Z. à *Karapadites karapadensis*	S. Z. à *Scaphites reesidei*	Niveau à *Praemanambolites* Début de *Menabites* Fin de *Bevahites*
					S. Z. à *Maorites aemilii*	
				Z. à *Anapachydiscus wittekindi* et *Eulophoceras jacobi*	S. Z. à *Hourcquiella bererensis*	Niveau à *Neoglyptoxoceras magnificum*
					S. Z. à *Besairiella besairiei*	Niveau à *Bostrychoceras elongatum* Niveau de base à *Neogauthiericeras zafimahovai*
Upper Urakawan	Santonien	*Anapachydiscus sutneri*	*Submortoniceras* sp?	Z. à *Pseudoschloenbachia umbulazi*		Niveau à *Karapadites planissimus* Abondance de *Muniericeras*, de *Pseudoschloenbachia* et de *Texanites*
		Anapachydiscus fascicostatus	*Texanites pacificus*	Z. à *Texanites hourcqui*		Fin de *Praemuniericeras* Niveau à *Madagascarites* et *Lehmaniceras Pleurotexanites Texanites Protexanises*
			Protexanites fukazawai	Z. à *Texanites oliveti*		*Protexanites* Début de *Praemuniericeras* et de *Pseudoschloenbachia*
Lower Urakawan	Coniacien	*Kossmaticeras theobaldianum*	*Paratexanites orientalis* *Peroniceras* aff. *platicostatum*	Z. à *Prioncycloceras guyabanum* et *Gauthiericeras marge*		Niveau à *Proplacenticeras satriense* et *Prionocycloceras multicostatum* Niveau à *Basseoceras colcanapi*
			Prionocycloceras guyabanum	Z. à *Kossmaticeras theobaldianum* et *Barroisiceras onilayense*		Niveau à *Neokanabiceras* Abondance de *Kossmaticeras*, *Lewesiceras Forresteria* et *Yabeiceras*
			Barroisiceras sp.	Z. à *Peroniceras dravidicum*		Niveau à *Yabeiceras costatum*
Upper Gyliakian	Turonien	*Tragodesmoceroides subcostatus*	*Reesidites minimus* *Subprionocyclus normalis*	Z. à *Coilopoceras requieni* et *Romaniceras deveriai*		Niveau à *Masiaposites* et *Hourcquia* Niveau à *Proplacenticeras* et *Subprionocyclus*
		Scaphites planus	*Subprionocyclus neptuni* *Collignoniceras woollgari* (+*Romaniceras* et *Yubariceras* sp.)	Z. à *Pseudaspidoceras conciliatum*		Présence de *Vascoceras*, *Thomasites*, *Schindewolfites*
			Fagesia thevestenssis *Kanabiceras septemseriatum*	Z. à *Fagesia superstes*		Niveau à *Yubariceras yubarense*

THE CRETACEOUS PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHY OF PAKISTAN

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Abstract

The Cretaceous succession of Pakistan is discussed, with emphasis on the planktonic foraminifera. Cretaceous sediments are represented by distinct facies, the majority of which are characterized by pelagic deposits of Tethyan type. These deposits were examined in each of three sedimentary basins. The well exposed Gaj River Section of the Lower Indus Basin provides a complete succession of planktonic foraminifera ranging in age from Neocomian to Maestrichtian, in which the middle Cretaceous (Cenomanian) deposits are characterised by *Rotalipora* species. The Cretaceous deposits of Pakistan are divided into sixteen planktonic foraminiferal zones, which closely resemble those of the Carribean region. The benthonic foraminifera provide little evidence for zoning, because they are restricted to relatively narrow ecological environments, but they resemble those of the eastern coastal plains of the United States.

1. Introduction

The Cretaceous is one of the most widely exposed systems in Pakistan. It is predominantly marine with a minor intercalation of non-marine sediments in the Upper Cretaceous, which represents a regression of the Tethys sea in certain parts of Pakistan. The marine deposits belong to various facies ranging from neritic to pelagic environments. The lithology is predominantly argillaceous, and rich in assemblages of foraminifera, particularly planktonic species. These species are restricted in stratigraphic occurrence, and their limits mark the boundaries of various biostratigraphic zones.

Although scattered Cretaceous outcrops are widespread in various parts of the country, a complete section of Cretaceous deposits is exposed in the Gaj River section of the Lower Indus Basin. This section is divided into the Belemnite Shale, the Parh Formation and the Korara Shale ranging in age from Neocomian to Maestrichtian. The Cretaceous period was one of orogenic movements, which started in the Early Cretaceous and continued throughout the period. As a result a complete section through the system is not preserved in many parts of the country. By the end of the Cretaceous period enormous igneous bodies had been intruded in the Lower Indus and Baluchistan Basins.

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In the past the foraminiferal studies were confined to generic identifications by oil companies' micropaleontologists, but recently more systematic work has been published by HAQUE (1959), LATIF (1970), KURESHY (1970, 1972a, 1972b, and 1976) and DORREEN (1974). The author has examined extensive Cretaceous samples from different stratirgaphic sections, and recognised sixteen biostratigraphic zones based on planktonic foraminifera from the Cretaceous section of the Gaj River, ranging in age from Neocomian to Maestrichtian. In such biostratigraphic studies the problems of nomenclature are enormous, because the different identifications of taxa by the various authors in different publications may cause confusion. Therefore this author has based his identifications on the original figures of the holotypes.

2. Stratigraphy

The Cretaceous sediments are well exposed in the Gaj River in the Lower Indus Basin where they are represented by three major stratigraphic units: the Belemnite Shale (Early Cretaceous), the Parh Formation (Middle and Late Cretaceous) and the Korara Shale (Late Cretaceous). As a result of orogenic movement the Cretaceous

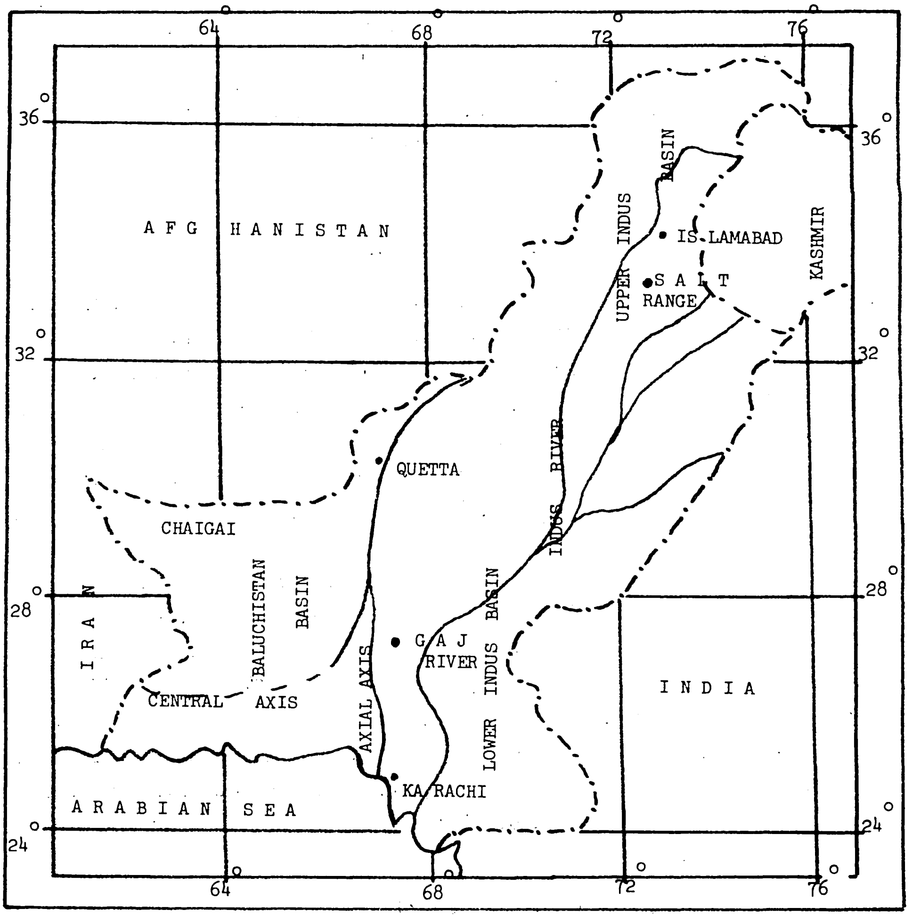

Fig. 1. Map of sedimentary basins of Pakistan.

deposits are not fully exposed in the Upper Indus and Baluchistan Basins (Fig. 1).

A. Baluchistan Basin

The geographic location of the Baluchistan Basin extends from longitude 66°E to the border of Iran in the west. In the north it is bounded by Afghanistan, and in the south by the Arabian Sea. This basin is separated from the Lower Indus Basin by the Axial Axis which runs through Khuzdar. A restricted outcrop of Upper Cretaceous is recorded in the vicinity of the Chaigai hills, known as the Parh Formation, which is characterized by *Globotruncana* species. These deposits are severely affected by the igneous intrusions which are common in the area.

B. Lower Indus Basin

The geographic location of the Lower Indus Basin is south of latitude 32°, bounded by the Baluchistan Basin to the west and the Indian Shield to the east. The Lower Indus Basin is divided into two parts (KURESHY, 1969), a folded belt and an alluvial plain. The Cretaceous rocks cover a vast area of the folded belt, where they constitute the cores of huge anticlines, and are characterized by igneous intrusions which contain deposits of chromite.

The Early Cretaceous sediments are exposed in a series of splintery purple coloured shale known as Belemnite Shale. These deposits are characterised by foraminifera of Neocomian to Albian age. The Belemnite Shale is unconformably overlain by the Parh Formation. This consists of marls and marly limestones with interbedded shales. These deposits are characterized by foraminifera ranging in age from Cenomanian to Campanian. The Parh Formation is succeeded by the Korara Shale. This embraces both Maestrichtian (Late Cretaceous) and Danian (Paleocene), and is dated by foraminiferal assemblages.

C. Upper Indus Basin

This basin extends from latitude 32° to the north, where it is bounded by Pre-Cambrian outcrops. The Cretaceous sequence is not completely exposed in any part of this basin, although Cretaceous deposits outcrop in Hazara, the Salt Range, the Sammana Range, and at Chharat (NAGAPPA, 1959; KURESHY, 1966; and LATIF, 1970). The stratigraphic relationships and the biostratigraphic zones of the Cretaceous sediments are shown in Table 1.

3. Planktonic Foraminiferal Zones

The foraminiferal assemblages of the Cretaceous can be used to diagnose divisions of the system, because they are cosmopolitan. The planktonic and larger foraminifera are more reliable as index fossils for geochronology. The benthonic species, such as *Bolivinoides draco draco* (MARSSON), *Stensioina americana* CUSHMAN and DORSEY, *Neoflabellina jarvis* (CUSHMAN), *Bulimina kickapooensis* COLE, *Dorothia bulleta* (CARSEY), *Marsonella oxycona* (REUSS), *Bolivina incrassata* REUSS and *Globorotalites* (D'ORBIGBY) are also characteristic, but they are more controlled by ecological environments, thus vary in distribution and relative abundance in different geographic areas (KURESHY, 1972a).

Table 1. Biostratigraphic correlation of Cretaceous succession of Pakistan.

Geologic age	European Stages		Planktonic Foraminiferal Zones	Sedimentary Basins		
				Lower Indus Basin (Gaj River)	Upper Indus Basin (Salt Range)	Baluchistan Basin (Makran)
Late Cretaceous	Maestrichtian		*Abathomphalus mayaroensis*	Korara Shale	Not exposed	Not exposed
			Globotruncana gansseri			
	Senonian	Campanian	*Globotruncana calcarata*	Parh Formation		Parh Formation
			Globotruncana elevata			
		Santonian	*Globotruncana carinata*			
			Globotruncana concavata			
		Coniacian	*Globotruncana renzi*		Lumshiwal Sandstone	Not exposed
	Turonian		*Globotruncana helvetica*			
Middle Cretaceous	Cenomanian		*Rotalipora cushmani*			
			Rotalipora greenhornensis			
			Rotalipora appenninica			
Early Cretaceous	Albian		*Planomalina buxtorfi*	Belemnite Shale	Belemnite Shale	
			Globigerinelloides breggiensis			
			Ticinella roberti			
	Aptian		*Globigerinelloides barri*			
	Neocomian		*Hedbergella infracretacea*			

However, they closely resemble the assemblages of the coastal plains of eastern United States described by CUSHMAN (1946). The planktonic foraminifera are widely distributed and characteristically have short stratigraphic ranges, similar to the Cretaceous fauna of Trinidad described by BOLLI (1959). All these assemblages are separately dicussed under their respective sedimentary basins.

A. Baluchistan Basin

The outcrops of Cretaceous sediments are restricted in this basin to the northern part of the area. These deposits are characterized by *Globotruncana* and *Heterohelix* species.

B. Lower Indus Basin

The Cretaceous deposits are well exposed in this basin, and occupy the cores of anticlines in the folded belt area, ranging in age from Neocomian to Maestrichtian. In the Gaj River section a complete sequence of the Cretaceous System is exposed. These deposits are divided into sixteen planktonic foraminiferal zones by KURESHY (1976), which can be summarized as follows:

Lower Cretaceous: this comprises the Neocomian, Aptian, and Albian stages. They are represented by the Belemnite Shale, which is divided into five planktonic zones:

Hedbergella infracretacea Zone	(Neocomian)
Globigerinelloides barri Zone	(Aptian)
Ticinella roberti Zone	(Albian)
Globiqerinelloides breggiensis Zone	(Albian)
Planomaline buxtorfi Zone	(Albian)

Middle Cretaceous: the Middle Cretaceous is equiralent to the Cenomanian stage. It is represented by the Parh Formation and is divided into three zones based on *Rotalipora* species:

Rotalipora appenninica Zone	(Cenomanian)
Rotalipora greenhornensis Zone	(Cenomanian)
Rotalipora cushmani Zone	(Cenomanian)

Upper Cretaceous: the Upper Cretaceous epoch is made up of the Turonian, Senonian and Maestrichtian stages. These are represented by the Parh Formation and the Korara Shale, which are divided into eight zones based on *Globotruncana* species:

Globotruncana helvetica Zone	(Turonian)
Globotruncana renzi Zone	(Coniacian)
Globotruncana concavata Zone	(Santonian)
Globotruncana carinata Zone	(Santonian)
Globotruncana elevata Zone	(Campanian)
Globotruncana calcarata Zone	(Campanian)
Globotruncana gansseri Zone	(Maestrichtian)
Abathomphalus mayaroensis Zone	(Maestrichtian)

C. Upper Indus Basin

The planktonic foraminifera of the scattered outcrops of Cretaceous in this basin are listed by KURESHY (1966) and LATIF (1970). The fauna found in this basin is characteristic of the Senonian:

Globotruncana lapparenti BROTZEN, *G. tricarinata* (QUEREAU), *G. fornicata* PLUMMER, *G. carinata* DALBEIZ, *G. concavata* (BROTZEN), *G. calcarata* CUSHMAN, *Rugoglobigerina rugosa* (PLUMMER), *Hetrohelix reussi* (CUSHMAN), *H. globocarinata* (CUSHMAN), *H. globulosa* (EHRENBERG), and *Pseudotextularia elegans* (RZEHAK).

4. Biostratigraphy

The Cretaceous deposits of Pakistan are divided into sixteen planktonic foraminiferal zones. These zones encompass all the Cretaceous European stages. The European stages are used as they are well established and accepted as international standard of reference. The Cretaceous period is divided into three divisions as proposed by BANDY (1967) and VAN HINTE (1976). There are differences of opinion in grouping the European stages into their respective epochs. I have followed BANDY's (1967) concept of the European terminology, since he adopts boundaries for these stages which are well marked by the planktonic foraminiferal assemblages.

A. Early Cretaceous

The Belemnite Shale of the Gaj River section is divided into five planktonic foraminiferal zones belonging to Neocomian, Aptian and Albian.

Neocomian: The basal part of Belemnite Shale belongs to the *Hedbergella infracretacea* Zone, which is characterized by the first appearance of *Hedbergella infracretacea* (GLAESSNER), and *H. delrioensis* (CARSEY).

Aptian: In the Aptian stage only one zone can be recognised, the *Globigerinelloides barri* Zone. The lower boundary is marked by the first appearance of *Globigerinelloides barri* (BOLLI, LOEBLICH and TAPPAN), associated with *Hedbergella delrioensis.* The Neocomian and Aptian stages of the Lower Cretaceous are poorly represented by planktonic foraminifera, but benthonic assemblages are common.

Albian: The upper part of Belemnite Shale belongs to the Albian. Planktonic foraminifera are more common in the Albian than in the preceeding stages. The Albian is divided into three zones. The bottom Zone of *Ticinella roberti* is characterized by the first appearance of *Ticinella roberti* (GANDOLFI), which is associated with *Hedbergella planispira* (TAPPAN) and *H. trocoidea* (GANDOLFI). The middle Zone of *Globigerinelloides breggiensis* is marked by the first appearance of *Globigerinelloides breggiensis* (GANDOLFI). The other species of this zone are *Rotalipora ticinensis* (GANDOLFI), *Hedbergella trochoidea* and *H. planispira* (TAPPAN). The top Zone of the Belemnite Shale is that of *Planomalina buxtorfi.* The lower boundary of this zone is marked by the first appearance of *Planomalina buxtorfi* (GANDOLFI): other diagnostic species are *Rotalipora ticinensis, Hedbergella planispira* and *H. trochoidea.*

B. Middle Cretaceous

The Cenomanian stage makes up the Middle Cretaceous in the classification of BANDY (1967). The planktonic foraminiferal assemblages of the basal part of the Parh Formation can be divided into three zones. The boundary between the Albian and Cenomanian is marked by extinction of *Planomalina buxtorfi* and the first appearance of *Rotalipora appenninica* (RENZ).

Cenomanian: The Cenomanian is characterized by the evolution of *Rotalipora* whose species mark the boundaries of the various zones of this stage. The basal Zone of *Rotalipora appenninica* is marked by the first appearance of *Rotalipora appenninica,* associated with *Hedbergella planispira* and *H. trochoidea.* The base of the *Rotalipora greenhornensis* Zone is characterized by the first appearance of *Rotalipora greenhornensis* (MORROW) and other diagnostic species are *Praeglobotruncana stephani* (GAN-

DOLFI), *Hedbergella planispira* and *H. trochoidea* (GANDOLFI). The uppermost Zone is that of *Rotalipora cushmani*, which is marked by the first appearance of *Rotalipora cushmani* (MORROW) and *P. recheli* MORNAD, associated with *Hedbergella planispira, H. trochoidea*, and *Praeglobotruncana stephani* (GANDOLFI).

The Early and Middle Cretaceous planktonic foraminifera are not extensively reported around the world. However, Pakistan planktonic foraminiferal assemblages of the Early and Middle Cretaceous closely resemble those described by GANDOLFI (1955) from Columbia.

C. Late Cretaceous

The planktonic foraminifera of the Late Cretaceous are found in the Parh Formation and the Korara Shale of the Gaj River section. These deposits are divided into eight biostratigraphic zones representing the Turonian, Senonian (Coniacian, Santonian, and Campanian) and Maestrichtian stages. The boundary between the Middle Cretaceous and Upper Cretaceous is marked by the extinction of *Rotalipora* species at the top of the Cenomanian and the first appearance of *Globotruncana* species at the base of the Turonian.

Turonian: The Turonian Zone of *Globotruncana helvitica* is characterized by the first appearance of *Globotruncana helvetica* BOLLI itself, associated with *Globotruncana imbricata* and *G. schneegansi.*
Coniacian: The Coniacian Zone of *Globotruncana renzi* is marked by the first apperance of *Globotruncana renzi* GANDOLFI itself, associated with *Globotruncana imbricata*, and *G. schneegansi.*

Santonian: Santonian foraminifera are recorded from the Parh Formation. This stage is divided into two zones. The lower Zone of *Globotruncana concavata* is characterized by the first appearance of *Globotruncana concavata* (BROTZEN) and *G. lapparenti* BROTZEN. The upper Zone of *Globotruncana carinata* contains *Globotruncana carinata* DALBIEZ, associated with *G. tricarinata* QUEREAU, *G. lapparenti* BROTZEN, *Hetrohelix reussi* (CUSHMAN) and *H. globosa* (EHRENBERG).

Campanian: The Campanian deposits are characterized by a great diversity of planktonic foraminiferal genera and species which are globotruncanids, rugoglobigerines and heterohelicids.

This stage is divided into two zones, the lower of which is that of *Globotruncana elevata.* Other diagnostic species of this zone are *Globotruncana ventricosa* WHITE, *G. fornicata* PLUMMER, *G. linneiana* (D'ORBIGNY), *G. rosetta* (CARSEY), *G. lapparenti*, *G. tricarinata*, along with *Hetrohelix reussi, H. globosa*, and *H. punctulata* (CUSHMAN). The upper Zone of *Globotruncana calcarata* is characterized by the first appearance of *Globotruncana calcarata* CUSHMAN, *G. arca* (CUSHMAN), *G. scutilla* GANDOLFI, *Rugoglobigerina voluta* (WHITE), *R. naussi* (GANDOLFI), *R. rugosa* (PLUMMER), *R. inflata* (BRONNIMANN), *Gublerina robusta* de KLASZ, *G. semicostata* (CUSHMAN), *Planoglobulina glabarata* (CUSHMAN), and *Praeglobotruncana hauanensis* (VOORWIJK). *Globotruncana calcarata* CUSHMAN, *Rugoglobigerina volutus, R. naussi* and *R. inflata* are restricted to this zone, but other species continue into the zone above.

Maestrichtian: The Maestrichtian is distinguished by the rapid evolution of *Rugoglobigerina* and single keeled species of *Globotruncana.* The Korara Shale contains Maestrichtian assemblages, which are divided into two zones. The lower zone of the Korara Shale is that of *Globotruncanan gansseri*, which is marked by the first appearance of *Globotruncana gansseri* BOLLI, *G. aegytiaca* Nakkady, *G. calciformis* (DE LAPPARENT), *G. conica* WHITE, *G. stuarti* (de LAPPARENT), *Abathomphalus intermedia* (BOLLI), *Globotruncanella petaloidea* (GANDOLFI), *Rugoglobigerina rotunda* BRONNIMANN, *R. hexacamerata* BRONNIMANN, *R. pustulosa* BRONNIMANN, *Pseudotextularia elegans* (RZEHAK), *Pseudoguembelina excolata* (CUSHMAN), *Racemiquembelina fructicosa* (EGGER) and *Planoglobulina eggeri* (CUSHMAN). The upper zone of the Korara Shale is that of *Abathomphalus mayaroensis*, which is characterized by the first appearance of *Abathomphalus mayaroensis* (BOLLI), and *Rugoglobigerina scotti* (BRONNIMANN), along with many species which range up from the *Globotruncana gansseri* zone.

The Late Cretaceous planktonic foraminiferal assemblages closely resemble those of the Middle Eastern countries described by SAYYAB and KURESHY (1969), NAGGAR (1966), KURESHY (1971), BARR (1972), and DARMOIAN (1975). The zones of Pakistan can also be correlated with the Cretaceous planktonic foraminiferal zones described by BOLLI (1959) from Trinidad, and ASANO and TAKAYANAGI (1965) from Japan.

5. Summary

A complete succession of Cretaceous deposits is exposed in the Gaj River area near Dadu, although scattered incomplete sections of the Cretaceous are widespread all over the folded belt of the Lower Indus Basin. These deposits are predominantly argillaceous and can be subdivided by their planktonic foraminifera into sixteen biostratigraphic zones, ranging in age from Neocomian to Maestrichtian. The Cretaceous period is divided into three, Early, Middle and Late, since there is a clear demarcation on the basis of the planktonic foraminifera for a three-fold division.

The Lower Cretaceous groups together the Neocomian, Aptian, and Albian stages, which are poor in planktonic foraminiferal assemblages, which are dominatnd by species of *Hedbergella* and related forms. The planktonic species of these stages were recorded from the Belemnite Shale and divided into five biostratigraphic zones. The Middle Cretaceous comprises the Cenomanian stage. The deposits of this stage belong to the Parh Formation, and are characterized by species of *Rotalipora*, on the basis of which three distinct zones were established. The Upper Cretaceous comprises the Turonian, Senonian and Maestrichtian, represented by the Parh Formation and the Korar Shale, and dominated by species of *Globotruncana*, *Heterohelix* and *Rugoglobigerina.* The *Globotruncana* species of Turonian age are single keeled, but Senonian (Coniacian, Santonian, and Campanian) forms are double keeled, whilst the Maestrichtian species are mostly single keeled again. On the basis of the *Globotruncana* species the Upper Cretaceous is divided into eight biostratigraphic zones.

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CAUSES OF CRETACEOUS OSCILLATIONS OF SEA LEVEL IN WESTERN AND ARCTIC CANADA AND SOME GENERAL GEOTECTONIC IMPLICATIONS

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Introduction

The following text is a somewhat edited and expanded version of the talk given at the Hokkaido Meeting of the International Middle Cretaceous Events project of IGCP. Therefore, the text is but a summary of the most important conclusions of the speaker. It does not include any supporting data and acknowledgments and includes only a few of the most indispensable references to the literature. The supporting data and other supplementary information are contained in the complete report which is unsuitable for publication in the Proceedings Volume of the Hokkaido Meeting because of its great length. It was submitted for publication in the Paper series of the Geological Survey of Canada.

The choice of the subject of the talk was prompted by an urgent feeling on the speaker's part that the extraordinary advances made in marine geology and geophysics in the last twenty years or so have resulted in considerable neglect of some of the most fundamental aspects of continental geology. The extremely strong overestimation of the role of the so-called eustatic movements of sea level in controlling the large-scale transgressions and regressions of the geological past (e. g. HANCOCK, 1975, p. 113; *see* below for complete reference), is believed to be one of the most prominent examples of this neglect. Furthermore, this overemphasis is combined with an even greater underestimation of the role of the vertical tectonic movements of the continental blocks of the lithosphere in controlling these same transgressions and regressions. The models used by the recent adherents of the global eustatic control of the sea level, in the sense of SUESS, tend to treat the continental blocks of the lithosphere as relatively inactive to almost stationary geotectonic objects. According to them, these stable objects were affected by world-wide, geologically instantaneous transgressions and regressions caused by much stronger tectonic movements of mid-oceanic ridges and other submarine structures. This talk has the following objectives:

(1) To analyze critically these ideas of recent adherents of the eustatic control of the ancient transgressions and regressions based on the example of the Cretaceous

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oscillatory history of the better known orogenic and intracratonic depositional basins of Western and Arctic Canada;

(2) To compare the results obtained with oscillatory data now available for the foreign Cretaceous basins and other Phanerozoic basins; and

(3) To formulate some general conclusions about the relative roles of the eustatic movements of the sea level and the vertical tectonic movements of the continental blocks in controlling major transgressions and regressions of Phanerozoic time.

History of Cretaceous Oscillations of Sea Level in Western and Arctic Canada

Remarks about the Early Cretaceous basins studied

Figure 1 shows the approximate geographical positions of the Early Cretaceous depostional basins, the oscillartory histories of which will be analyzed in this talk. They include two orogenic successor basins of the Canadian Western Cordillera, namely the Tyaughton Trough and the Insular Trough. Another orogenic successor basin studied is the Sverdrup Basin of the Innuitian Orogen. The remaining two

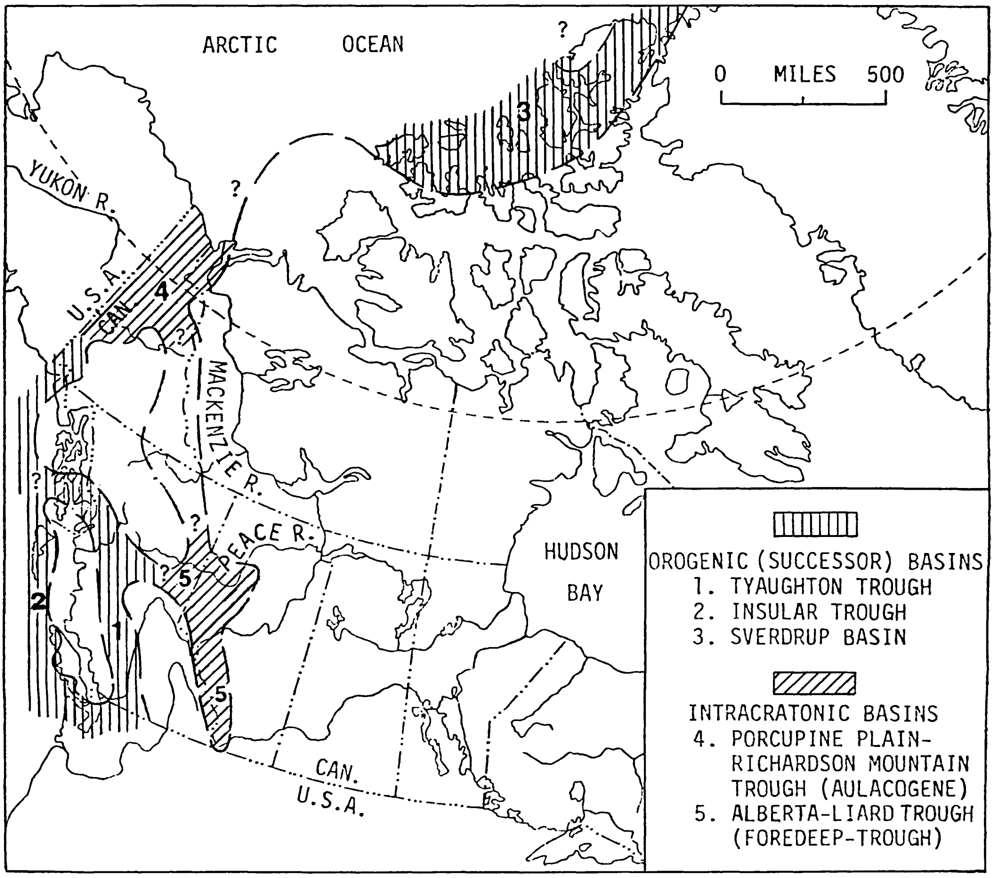

Fig. 1. Principal Early Cretaceous marine basins of Western and Arctic Canada (on example of mid- to late Valanginian time) [modified from JELETZKY, 1971, fig. 6].

basins are the intracratonic basins of the Western Shelf of the Canadian Shield. They are the Richardson Mountain—Porcupine Plain aulacogenic trough and the Alberta—Liard foredeep trough of the Columbian Orogen.

Comparative analysis of Early Cretaceous oscillatory movements

Figure 2 summarizes the Early Cretaceous oscillations of sea level in the orogenic and intracratonic basins shown in Figure 1.

Lack of time prohibits commenting in any detail on the methods used in the compilation of the oscillation graphs. However, I may mention that the methods and basic data used are essentially the same as those used by Professor Tatsuro MATSUMOTO (1952) in the compilation of oscillatory graphs published in his paper on the Cretaceous transgressions and regressions in the Circum-Pacific Province and in that on the Cretaceous tectonic history in the Circum-Pacific Province (*see* below for full citations). The straight vertical dashed line in the middle of each graph of Figure 2 denotes the inferred approximate position of mean sea level. Each of these lines is crowned by a zero to make this more obvious. The heavy solid lines meandering

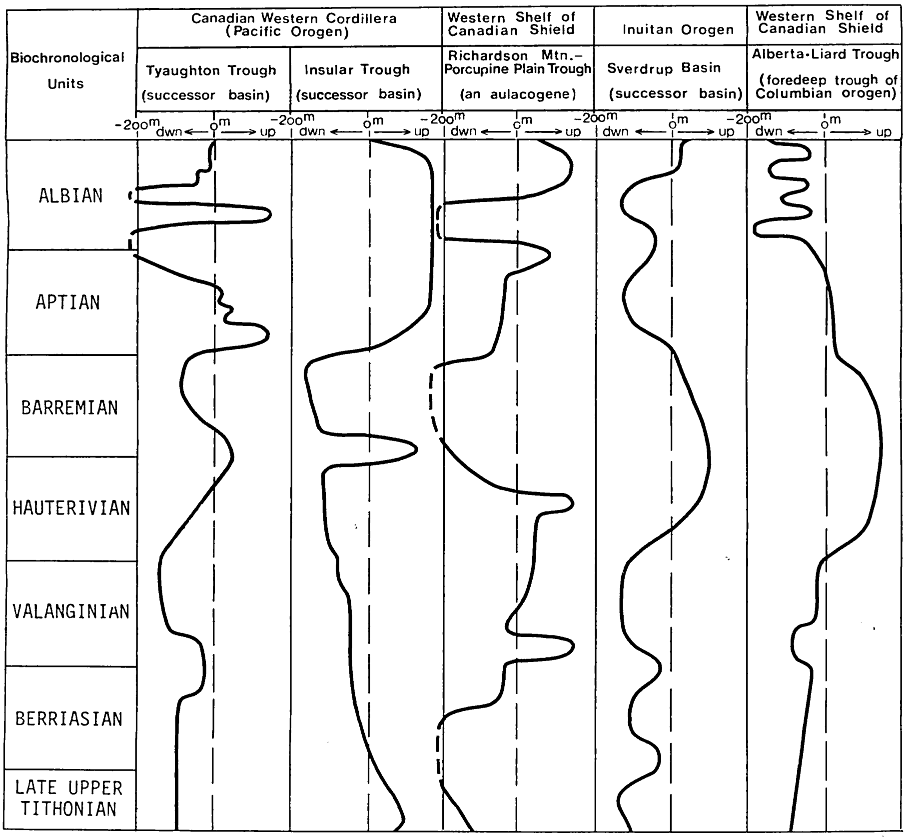

Fig. 2. Summary of Early Cretaceous oscillations of sea level in the orogenic and intracontinental basins of Western and Arctic Canada.

across the lines denoting mean sea level in each graph are plots of transgressions and regressions in the individual basins against the biochronological time scale.

The position of the transgression-regression graph to the left of the mean sea level line indicates the submergence of at least most of the basin concerned. However, it does not imply necessarily a complete submergence of the basin even at the transgression's peak. Any roughly estimated flooding of 60 to 65 per cent of the basin is rated somewhat arbitrarily as its complete flooding.

The numbers in the left upper corners of all graphs represent the shelf sea less than 200 m deep, except where the graphs are shown to continue as dotted lines into the adjacent parts of the next left columns. The latter relationship depicts an inferred, temporary prevalence of the bathyal (>200 m) regime in the basin concerned.

The positions of the individual transgressional peaks and segments within the individual graphs roughly correspond to the prevalent depths of shelf sea inferred from their macroinvertebrate biofacies and lithofacies. However, no attempt was made to calibrate closely these depths.

The position of the transgression-regression graph to the right of the mean sea level line signifies the estimated emergence of at least 60 to 65 per cent of the basin's space above sea level. Like the above-mentioned transgressive episodes, these regressive episodes are inferred from the palaeoenvironmental analysis of lithofacies and macroinvertebrate biofacies of the basins concerned. All of the regressions shown in Figure 2 are, in particular, documented by the presence of major arenaceous to rudaceous, predominantly or entirely nonmarine wedges commonly accompanied by at least some hiatuses within the basins concerned. These regressive clastic wedges correspond to major hiatuses at the margins of the same basins. Conversely, all of the transgressions shown in Figure 2 are documented by more or less extensive onlaps of open-marine, sometimes bathyal rocks onto the regressive arenaceous wedges and, in some instances, beyond them into the surrounding source-areas.

The most characteristic feature of the oscillatory Early Cretaceous histories of the orogenic and intracratonic basins shown in Figure 2 is an almost complete lack of interbasinal correlation of the transgression-regression episodes and their peaks.

For example, the late upper Tithonian to late Barremian time is characterized by an almost steadily progressing regional transgression throughout the western part of the Western Cordilleran belt of Canada usually referred to as the Pacific Orogen. This transgression, which is equally prominent in the Tyaughton and Insular Troughs, peaked in the latest Barremian with Barremian rocks transgressive on older rocks everywhere. This peak is shown in Figure 2. However, this transgression was interrupted by a brief but marked regressive episode at the Hauterivian-Barremian boundary in the Tyaughton and Insular Troughs. Furthermore, there is a marked regressive episode at the Jurassic-Cretaceous boundary in the Insular Trough which is totally unknown in the Tyaughton Trough. The latter trough exhibits, in contrast, a considerable but unique shallowing at the Berriasian-Valanginian boundary.

The late upper Tithonian to Barremian oscillatory histories of the remaining three basins are rather unlike those of the Tyaughton and Insular Troughs.

In the aulacogenic Porcupine Plain-Richardson Mountain Trough, which was the most mobile of the three, there was a major, late upper Tithonian-early Berriasian transgression which peaked in the early to mid-Berriasian when the sea reached bathyal depth. This transgression was followed by a prolonged early Valanginian to mid-Hauterivian regression which has no equivalent in any of the other four basins studied. This regression is followed, then, by a very extensive late Hauterivian to late Barremian transgression which peaked in the mid-Barremian and resulted in bathyal depths of the sea in a greater part of the trough.

The late Hauterivian to late Barremian transgression of the Richardson Mountain —Porcupine Plain Trough corresponds fairly closely to the Barremian peak of the Berriasian to late Barremian transgression in the Tyaughton and Insular Troughs. It may be that the trough was involved belatedly in the subsidence in the adjacent orogenic belt. However, this transgression corresponds to the prolonged Hauterivian-Barremian regressions in the Sverdrup Basin and Alberta-Liard Trough.

The oscillatory histories of the Sverdrup Basin and the Alberta-Liard Trough are closely matched, while being quite unlike those of the other three basins. In each of the two basins a prolonged late upper Tithonian to late Valanginian flooding is followed by a strong and regional early Hauterivian to late Barremian regression. The latter is juxtaposed by a strong transgression in the other three basins.

Aptian time is characterized by a strong regional regression in the Pacific Orogen which drained the Insular Trough completely and markedly reduced the marine part of the Tyaughton Trough. The regression lasted into the Albian in the Insular Trough but, in latest Aptian was replaced by a strong transgression in the Tyaughton Trough. This regression was felt also in the Richardson Mountain—Porcupine Plain aulacogenic trough as shown in Figure 2. However, it failed to drain the larger central part of that trough even at its peak and was followed by an extensive latest Aptian transgression as in the Tyaughton Trough.

In contrast to the above discussed three basins, the Sverdrup Basin and the Alberta-Liard Trough subsided strongly throughout the Aptian. Only the Sverdrup Basin, however, was flooded regionally by epeiric Aptian seas. The Alberta-Liard Trough was merely transformed from an elevated source-area into the site of a paludal to deltaic deposition until the end of the Aptian as shown in Figure 2.

The almost complete lack of interbasinal co-ordination of the transgressive-regressive pattern is characteristic also of Albian time. Even the oscillatory patterns of the Tyaughton and Insular Troughs within the Pacific Orogen are utterly different at that time. The Tyaughton Trough experienced a series of closely spaced, major transgressive-regressive episodes ending in its complete emergence at the end of the Albian. The Insular Trough, in contrast, remained emergent and strongly uplifted through the Albian and then became submergent at the onset of the Cenomanian.

The oscillatory histories of the other three basins agree with each other and with the history of the Tyaughton Trough in recording the occurrence of a strong but brief earliest Albian transgression, but their later Albian histories are different. In the Richardson Mountain—Porcupine Plain Trough the transgression was replaced by a regional emergence at the end of the early Albian. This emergence lasted until the end of the Albian. In the Sverdrup Basin the regression and regional emergence began at the end of the middle Albian. Finally, the Alberta-Liard Trough did not experience any regional regression and emergence until the end of the Albian, after its transformation into a much larger Canadian Western Interior basin by the earliest Albian transgression. However, the sea of this trough was repeatedly becoming deeper and shallower alternatively evidently in response to the tectonic pulses in the adjacent parts of the Columbian Orogen.

The only discernible overall regularity of the Early Cretaceous transgressions and regressions in Western and Arctic Canada appears to be a compensatory pattern. For example, transgressions in the Western Canadian Cordillera were compensated for by regressions in the intracratonic and orogenic successor basins situated east and north therefrom, and *vice versa*. This compensatory pattern is clearly discernible in the late Hauterivian and Barremian when the Tyaughton, Insular, and Richardson Mountain—Porcupine Plain Troughs were being flooded while the Sverdrup Basin and Alberta-Liard Trough were completely emergent. The pattern is equally evident in the Aptian when the Tyaughton, the Insular, and the Richardson Mountain—Porcupine Plain Troughs were emergent while the Sverdrup Basin and the Alberta-Liard Trough were either submergent or at least downwarped. This compensatory pattern appears to conform closely to the " law of epeirogenic compensation " proposed by the French geologist, Emile HAUGH, at the turn of this century. However, the writer prefers to explain it by large-scale rotational or by lever-like tectonic movements of the whole Canadian part of the Cordilleran Orogen around a north-trending axis situated near its middle. The reason is that, as we shall see, this compensatory pattern is limited to Western and Arctic Canada.

Remarks about the Late Cretaceous basins

Figure 3 shows the approximate geographical positions of the Late Cretaceous orogenic and intracratonic depositonal basins which will be analyzed in this talk. Of the previously discussed Early Cretaceous orogenic successor troughs of the Pacific Orogen (Fig. 1), the Tyaughton Trough ceased to exist as a marine depositional basin at the end of the Albian and then was transformed into an elevated source-area sometime in the Turonian. The Early Cretaceous Insular Trough (*see* Fig. 1) only existed as such until about the mid-Turonian. In the mid- or late Turonian it was transformed into an elevated tectonic land which lasted until the end of the mid-Santonian. Then, in the late Santonian, parts of the Insular Trough became submerged again forming the Queen Charlotte Trough and the Georgia Basin shown in Figure 3.

On the eastern side of the Canadian Cordilleran Belt, the Alberta-Liard foredeep trough continued to exist. However, it now formed the most rapidly subsiding, westernmost part of the Albian to Late Cretaceous supracratonic basin of the Canadian Western Interior (Fig. 3).

The Porcupine Plain—Richardson Mountain aulacogenic trough was closed by the mid- to late Albian orogenic movements. In its place formed a much smaller and much more stable Late Cretaceous Porcupine Plain—Richardson Mountain Basin. This typically intracratonic basin also formed part of the large supracratonic basin of the Canadian Western Interior region shown in Figure 3.

Although it remained genetically an orogenic successor basin, the Sverdrup Basin acted as an only moderately mobile intracratonic basin within the moderately stable Late Cretaceous marine basin of the Arctic Canada.

Comparative analysis of Late Cretaceous oscillatory movements

The summary of the Late Cretaceous oscillations of sea level in the orogenic and intracratonic basins shown in Figure 4 is arranged exactly like the previously discussed summary of the Early Cretaceous oscillations (Fig. 2). It should be noted, however, that the two figures overlap in the Albian to elucidate the continuity of the oscillatory development.

The Late Cretaceous oscillation graphs of the basins studied (Fig. 4) are characterized by the same lack of interbasinal co-ordination as their previously discussed Early Cretaceous oscillation graphs. The only exception is the final, latest Cretaceous regression of seas which affected all four basins that persisted into the Maestrichtian (Fig. 4).

The allegedly world-wide Cenomanian-Turonian transgression is not apparent in Western and Arctic Canada. The Tyaughton Trough emerged at the end of the Albian and, so far as we know, was rising and wasting steadily thereafter. The adjacent Insular Trough was, in contrast, flooded early in the Cenomanian and con-

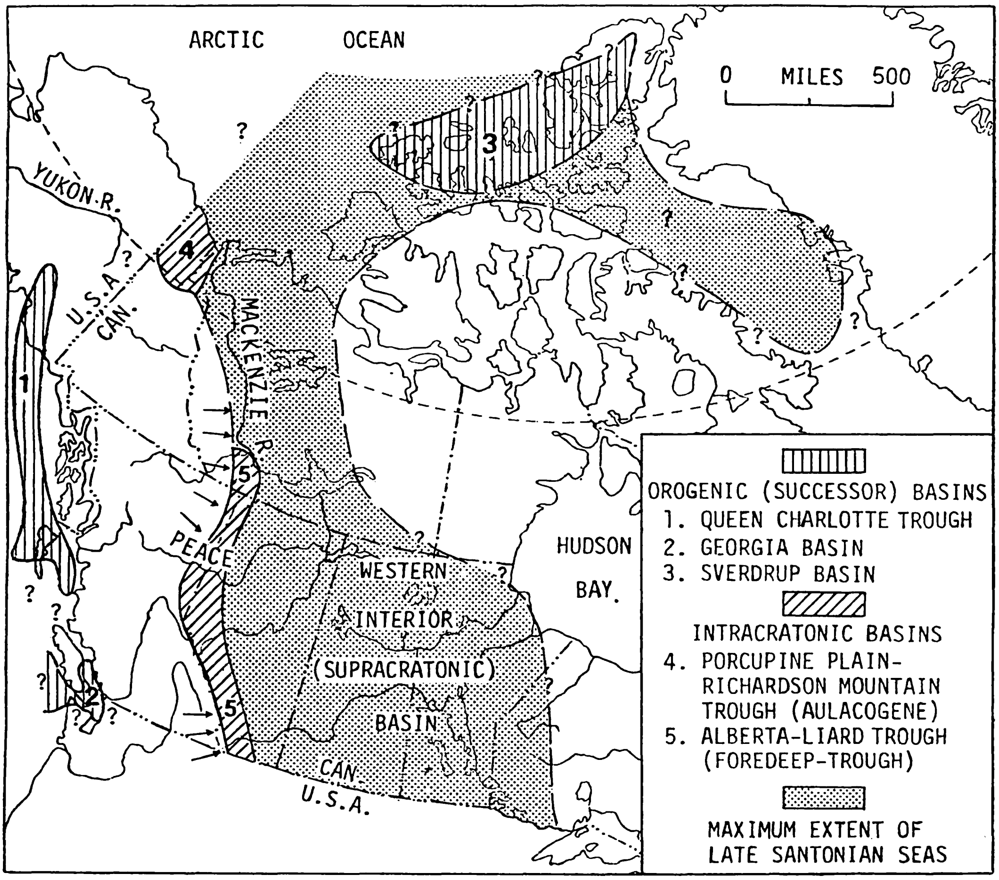

Fig. 3. Principal Late Cretaceous marine basins of Western and Arctic Canada (on example of late Santonian time) [modified from JELETZKY, 1971, fig. 15].

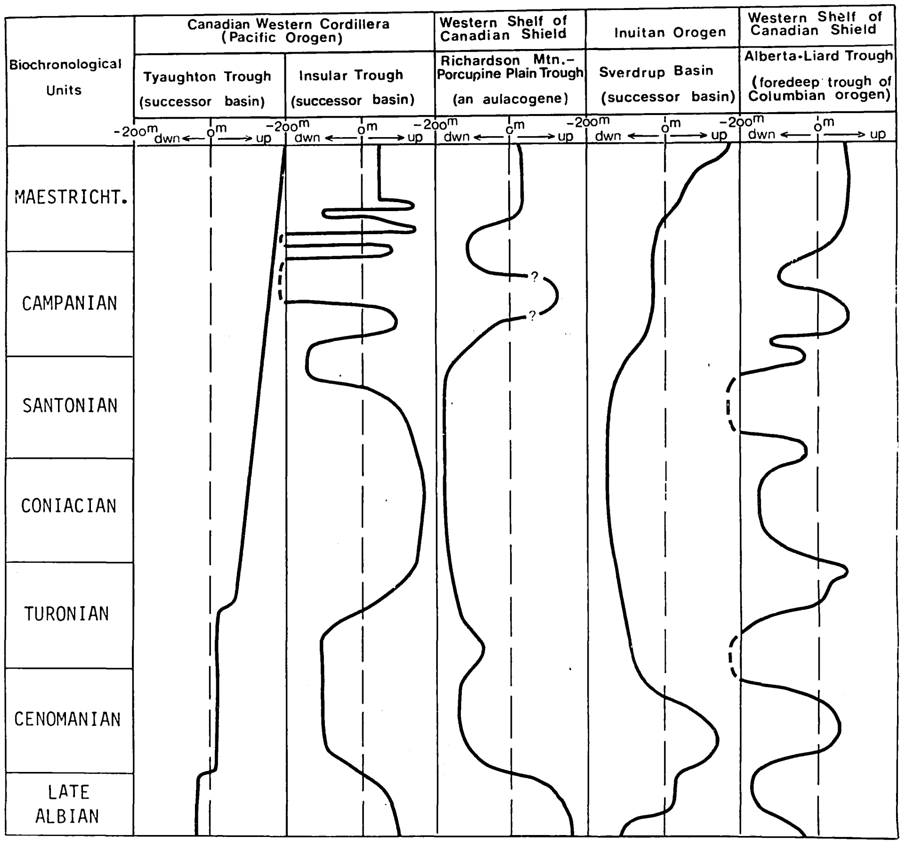

Fig. 4. Summary of Late Cretaceous oscillations of sea level in the orogenic and intracratonic basins of Western and Arctic Canada.

tinued to subside at least until the mid-Turonian (Fig. 4). The same is true of the Porcupine Plain—Richardson Mountain Basin. However, the Sverdrup Basin became emergent in the late Albian and remained a dry land until the late Cenomanian. Finally, the Alberta-Liard Trough experienced an extensive late Albian to early Cenomanian transgression; it became largely emergent in the late Cenomanian only to be deeply submerged again in the early Turonian.

The late Turonian to mid-Santonian oscillation regimes are just as different. The Tyaughton Trough continued to be emergent, the Insular Trough became completely emergent and the whole extent of the Canadian Western Cordillera apparently represented an elevated source-area. The remaining three basins experienced, in contrast, prolonged large-scale transgressions. The transgression patterns of the Porcupine Plain—Richardson Mountain Basin and the Sverdrup Basin are simple and almost identical with their transgressions peaking around the mid-Santonian. However, the oscillatory pattern of the Alberta-Liard Trough is complicated by a number of short-lived regressions (Fig. 4). Except for that in the late Turonian, these regressions only resulted in the emergence of smaller, marginal parts of the basin and in the shallowing of its remaining, greater part. The late Turonian to early Campanian oscillatory regime of the Alberta-Liard Trough was obviously much more active than those of the Porcupine Plain—Richardson Mountain Basin and the Sverdrup Basin.

The Campanian to earliest Maestrichtian oscillatory regimes of basins studied are even more unlike each other than are their late Turonian to mid-Santonian regimes. The Queen Charlotte Trough and the Georgia Basin of the Insular Trough experienced a large amplitude, regional, late Santonian transgression which lasted into the early Campanian. This transgression was followed by a regional late early Campanian regression which apparently ended the Cretaceous marine regime in the Queen Charlotte Trough. In contrast, the Georgia Basin continued to experience a series of extremely brief and closely spaced, large amplitude transgressions and regressions throughout the remainder of the Campanian and into the earliest Maestrichtian before becoming finally emergent.

In the Porcupine Plain—Richardson Mountain Basin the late Santonian witnessed the beginning of a large amplitude, regional regression which peaked in the mid-Campanian and resulted in complete emergence of the basin. This regression was followed by a large amplitude, more localized transgression which peaked either at the end of the Campanian or early in the Maestrichtian (Fig. 4). This simple oscillatory history is quite unlike the "violent" oscillatory history of the Georgia Basin. However, it almost duplicates that of the Alberta-Liard Trough, except for a slightly different timing of the peaks of transgressions and regressions. This is not surprising when it is realized that these two basins were situated along the eastern flank of the same rapidly rising Columbian Orogen and may have been directly connected.

The late Santonian to earliest Maestrichtian oscillatory history of the Sverdrup Basin differs radically from those of all other basins studied. It consists of a gradual, apparently steady, regional shallowing of the basin which began in the late Santonian and ended in the early Maestrichtian (Fig. 4)..

The final late early to latest Maestrichtian oscillatory phase of the basins studied consists in a roughly simultaneous emergence of all four basins which were still flooded in the earliest Maestrichtian. The only exception is the Tyaughton Trough which became emergent much earlier. This late early to latest Maestrichtian emergent regime is extremely variable in detail from one basin to another as shown in Figure 4. However, all five basins remained above sea level throughout this period of time and no localized phases of marine ingression are known in any of them. Nor was any one of the basins re-invaded by the early Tertiary sea, with the sole exception of the northern part of the Porcupine Plain—Richardson Mountain Basin.

Except for the final Maestrichtian emergence of all Cretaceous basins studied, the only discernible overall regularity of their Late Cretaceous oscillatory regime is the compensatory pattern resembling the previously mentioned "Law of epeirogenic compensation" of Emile HAUGH. Namely, the large amplitude, prolonged regional late Turonian to mid-Santonian regression in the Insular Trough of the Pacific Orogen is compensated for by an equally large amplitude, prolonged regional transgression in the Porcupine Plain—Richardson Mountain Basin, Sverdrup Basin, and Alberta-Liard Trough (*see* Fig. 4). The only deviation from this pattern consists in the interruption of this transgression by several brief regressive episodes in the Alberta-

Liard Trough. As with the Early Cretaceous oscillatory episodes, the writer prefers to explain the late Turonian to mid-Santonian episode of "epeirogenic compensation" by large-scale rotational or lever-like tectonic movements of the whole Canadian part of the Cordilleran Orogen around a north-trending axis situated near its middle.

The almost total lack of co-ordination of transgressive-regressive patterns of the individual Cretaceous basins of Western and Arctic Canada militates against the idea that these transgressions and regressions could have been caused by instantaneous, (geologically speaking) world-wide eustatic fluctuations of sea level. However, it remains to find out whether or not this oscillatory pattern is an exception or the rule in the Cretaceous depostional basins of the globe.

Comparison of the Cretaceous Oscillatory Histories of the Canadian Basins Studied with Those of Some Foreign Basins

To find out whether or not the oscillatory histories of the Cretaceous basins of Western and Arctic Canada discussed above are an exceptional phenomenon, I have compared the results obtained with the oscillation graph compiled for the Cretaceous epeiric seas of the globe by KAUFFMAN (1973, p. 364, fig. 7), the oscillation graphs compiled for the Cretaceous seas of northern Europe and the Western Interior of the United States of America by HANCOCK (1975, p. 85, 104, expl. of fig. 5), and those compiled for the Cretaceous epeiric and geosynclinal seas of the Circum-Pacific Province by MATSUMOTO (1952, figs. 2-5; 1967, p. 39-55). There is no time to discuss the results in detail. However, Figure 5 clearly indicates that the major transgressional-regressional episodes observed in the Canadian basins studied are, as a rule, not co-ordinated at all with the major transgressional-regressional episodes registered in any of the foreign basins mentioned. Although the data available are far from complete, they are believed to be ample to conclude that there was, as a rule, no intercontinental or global co-ordination of major Cretaceous transgressions and regressions.

The Significance of Phanerozoic Oscillation Graphs of Major Regions of the Globe Composed by A.L. YANSHIN

The oscillatory graphs recently compiled by A. L. YANSHIN (1973) for all Phanerozoic systems in all better known major blocks of the continental lithosphere, are extremely important for the purpose of the writer's research. YANSHIN's results permit a decision as to whether or not the above-documented nearly total absence of co-ordination of the Cretaceous transgressions and regressions on the global scale is valid for other Phanerozoic systems as well. The principal results of YANSHIN's research are summarized in text-figs. 6 and 7 of his paper. Textfigure 6 reproduced herein as Figure 6 presents the transgression-regression graph for the following major regions of the continental crust:

(1) The western half of USSR, (2) The erstern half of USSR, (3) North America, (4) South America, (5) Japan and adjacent areas of the Western Pacific region, and

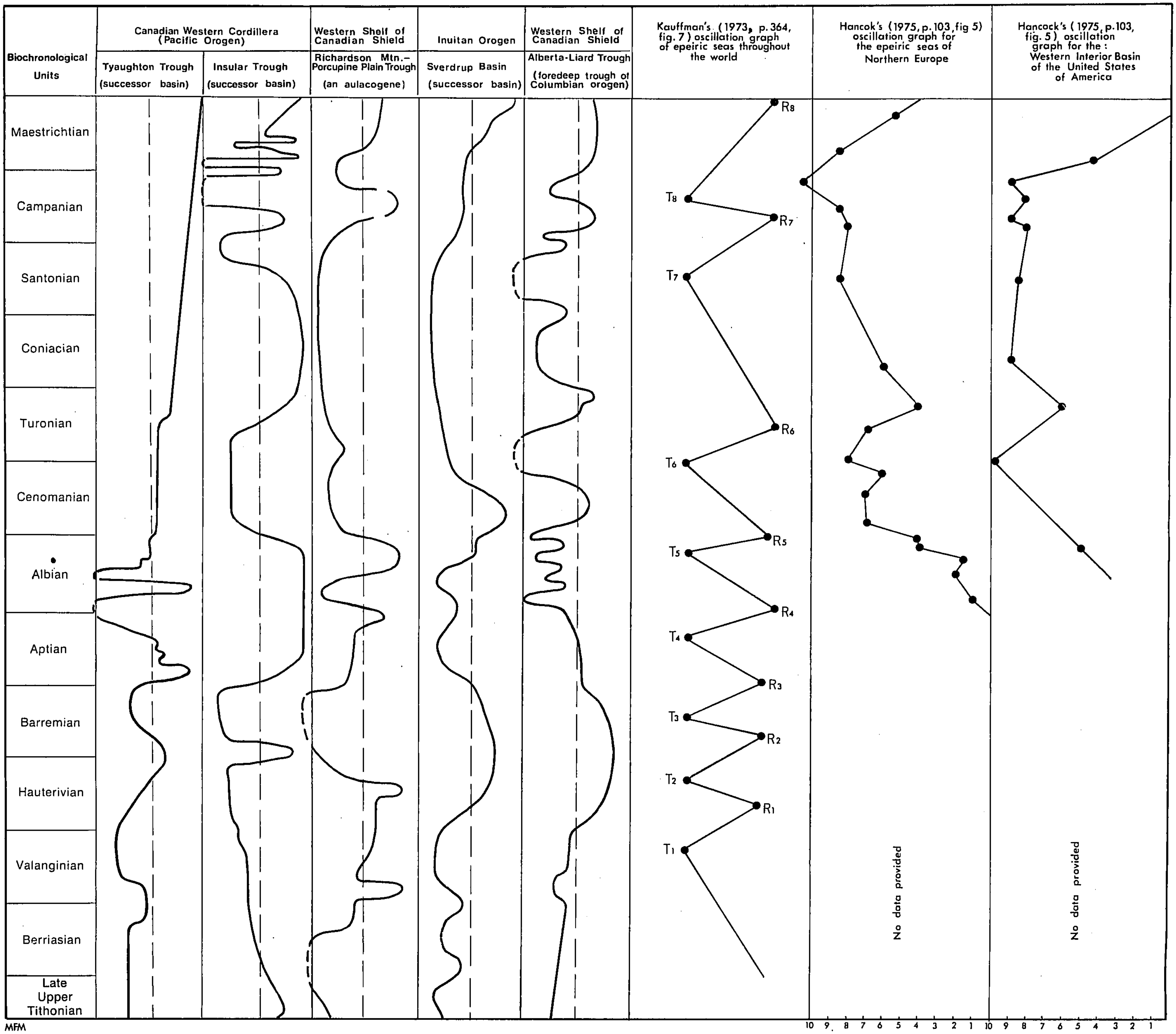

Fig. 5. Comparison of the Cretaceous oscillation graphs of the Canadian basins summerized in Figs. 2, 4 with the oscillation graphs compiled by Kauffman (1973a, p. 364, fig. 3) and Hancock (1975, p. 103, fig. 5). Kauffman's (1. cit.) graph is reversed to conform with the orientation of the peaks of transgressions and regressions adopted by Hancok (1. cit.) and the writer (*see* Figs. 2, 4). The inferred positions of the mean sea level and all other semiquantitative data indicated elsewhere (*see* Figs. 1-4) for the Canadian graphs are omitted. No attempt was made to reproduce the relative levels of the peaks of transgressions and regressions shown in the original graph of Kauffman (1. cit.) as it was not possible to infer their relative positions to the mean sea level. All radioactive ages indicated in the original diagrams of Kauffman (1. cit.) and Hancock (1. cit.) are omitted. The writer considers all such attempts at the radioactive dating of the Cretaceous oscillatory events to be meaningless and hence misleading.

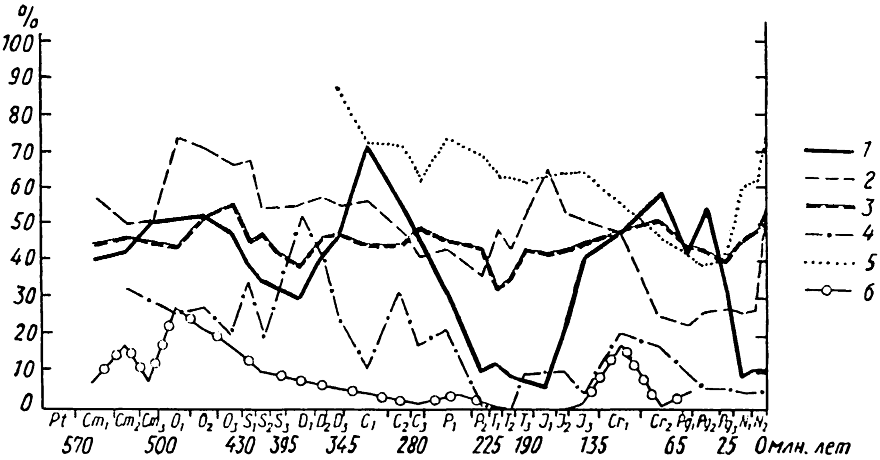

Fig. 6. Graphs of development of transgressions and regressions in different major regions of the continental lithosphere [from YANSHIN, 1973, fig. 6]. 1 = western half of USSR, 2 = eastern half of USSR, 3 = North America, 4 = South America, 5 = Japan and regions adjacent to it, 6 = Australia.

(6) Australia.

The graphs have been compiled by means of a rough planimetric computation of spaces which were shown to be occupied by ancient seas on the best available series of regional to continental palaeogeographic maps comiled by various workers for successive ages or epochs of the Phanerozoic time. These estimates were used then to determine the ratios to the above-mentioned major regions of the lithosphere occupied by the ancient seas.

The writer omit to discuss the oscillation graphs of Figure 6 in detail. However, it can be seen that there is very little co-ordination of their Cretaceous parts. Furthermore, the same is true of the graphs of all other Phanerozoic systems included in Figure 6.

Textfigure 7 of YANSHIN's paper summarizes the transgression-regression graphs of all Phanerozoic systems for the following ancient (i. e. Precambrian) platforms of the globe: (1) East European or Russian platform, (2) Siberian platform, (3) North American platform, (4) Australian platform, and (5) South American platform.

As shown by YANSHIN (1973, p. 33, 34), the Cretaceous parts of the oscillation graphs of epeiric seas which covered these ancient platforms exhibit just as litte co-ordination as the corresponding parts of the graphs of the major regions of the globe shown in Figure 5. Furthermore, the same is true of those parts of the graphs pertaining to all other Phanerozoic systems of the ancient platforms.

Conclusions

The sum total of the data presented above, combined with LYELL's principle of uniformitarianism, appears to the writer to be ample to conclude that, contrary to the claims of many recent marine geologists and geophysicistes, either no or very few recognizable vestiges of geologically instantaneous, world-wide transgressions and regressions are preserved in the Phanerozoic rocks. This conclusion appears to be valid not only for the mobile (orogenic) belts of the continental crust but also for its stable blocks, including the Precambrian shields. There is no doubt in my mind that the late W. J. ARKELL's conclusion (1956, p. 742) that there was no recognizable pulse of the earth at any time in the Jurassic, applies equally to the remainder of Phanerozoic time. However, I hasten to add that I do not doubt at all the actual existence of several kinds of eustatic fluctuations of sea level in the geological past. Therefore, I conclude that the record of these eustatic oscillations must have been destroyed entirely or almost entirely by the influence of concurrent tectonic movements. This interpretation is quite probable. It is well established and made apparent once more by Figures 2 and 4 that many, and possibly most, of the orogenic phases and epeirogenic pulses recorded in the Phanerozoic rocks of the globe were brief to very brief events which lasted anywhere from a fraction of a zonal moment to about four palaeontological zonal moments. Furthermore, these tectonic movements commonly have been frequent and closely spaced in terms of the palaeontological clock. Finally, the *minimum* values of vertical uplifts registered by these tectonic movements may be estimated at from 800 to 2000 m because of the character of biofacies and lithofacies. The involved medium to large uplifts reflected in a basin-wide deposition of a coarse arenaceous to conglomeratic piedmont deposits, a few hundred to a couple of thousand metres thick, within a single zonal moment or parts of a palaeontological stage, must have been in order of from 3000 to 4000 m at least judging by the depositional environments of their modern counterparts. Equally rapid and large subsidences were necessary to reflood the sedimentary basins after the large-scale uplifts.

The above comments should make it obvious that the writer believes in the commonly and probably predominantly episodic, brief to very brief (geologically) character of ancient orogenic phases and epeirogenic pulses. In this respect I follow the ancient tectonic ideas which were so strongly favored by the late Hans STILLE (e. g. 1924) and his school. However, I agree entirely with GILLULY (e. g. 1949), YANSHIN (1973), and a number of other modern continental geologists and palaeontologists that there were no global or even intercontinental tectonic pulses and hence no global or intercontinental sedimentary rhythms and cycles. The reasons have been given earlier in this talk.

The scale of the previously discussed tectonic movements (i. e. of the orogenic phases and epeirogenic pulses alike) combined with their brief to very brief duration and close spacing, is judged to be ample to either overprint completely or, at least, to render unrecognizable any traces of the eustatic fluctuations of sea level that may have occurred in the geological past. Most recent workers accept that the vertical amplitudes of these movements do not exceed 200 m and the speaker does not know of any credible estimate in excess of 300 m (that is from about −150 to +150 m). Therefore, the maximum amplitudes of the eustatic fluctuation of sea level are 8 to 10 times, or almost an order of magnitude smaller than the *minimum* estimated amplitudes of the above-discussed tectonic movements. I do not even mention the amplitudes of medium to large tectonic movements responsible for so many of the Cretaceous oscillations demonstrated earlier in this talk.

There does not seem to be much doubt that the geologically instantaneous, world-wide eustatic fluctuations of sea level did not control the ancient transgressions and regressions of the continental blocks of the lithosphere either in Cretaceous time or in any other part of Phanerozoic time. The controlling role belongs instead to recurrent, interregional (but apparently never global!), regional or local tectonic movements of either entire continental blocks of the lithosphere or their greater or lesser parts (down to the individual tectonical structures). The attempts of recent adherents of the hypothesis of the eustatic control of ancient transgressions and regressions either to ignore these tectonic movements or to dismiss them as an unimportant tectonic noise (e.g. HANCOCK, 1975, p. 113), occasionally obscuring the view of orderly, eustatically controlled, world-wide changes of sea level are, in the writer's opinion, erroneous.

I repeat, however, that, because of the undoubted occurrence of eustatic fluctuations of sea level throughout the geological past, one should expect some exceptions to this controlling role of the tectonic movements. Namely, the record of the eustatic fluctuations conceivably could be preserved on a global scale during infrequent quiescent periods known to exist in the tectonic history of the globe. Furthermore, this record may be preserved on a regional or continental scope within the most stable tectonic elements of the continental lithosphere; the Precambrian shields and their most stable shelves which were accumulating only thin veneers of Phanerozoic sediments. An example of such an exceptional preservation of the record of eustatic fluctuations of the sea level appears to be provided by the previously discussed late early to latest Maestrichtian episode of emergence of the Canadian depositional basins studied (Figs. 2, 4). In Canada this episode of emergence affected four out of five basins studied. Furthermore, the fifth basin—the Tyaughton Trough—apparently was too strongly uplifted to register the episode. Outside of Western and Arctic Canada, the global nature of this late early to latest Maestrichtian regressive episode was demonstrated by decades of research on most of the continental blocks of the lithosphere and is stressed repeatedly by modern workers. This was the time when the seas retreated either completely, or at any rate predominantly, from all continental blocks of the lithosphere. This universal character of the Maestrichtian regression, and even more the fact that the sea in the Tertiary never achieved their Cretaceous extent on any of the continental blocks of the lithosphere, strongly suggests its having been caused by a large-scale eustatic oscillation of sea level. However, this regression is an exception rather than a rule in the Cretaceous oscillatory history of Western and Arctic Canada and, so far as we know, in the oscillatory history of the Cretaceous basins of the globe.

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CRETACEOUS TRANSGRESSIONS AND REGRESSIONS EXEMPLIFIED BY THE SOUTH ATLANTIC

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Abstract

Major transgressions, involving epicontinental seas, took place in the South Atlantic during the late Middle Albian, Cenomano-Turonian, Coniacian, Campano-Maastrichtian, and Maastrichto-Paleocene. The first three of these can be identified with synchronous transgressions in other parts of the world, while the latter two appear to be confined to the South Atlantic realm, with the main epicontinental development over the trans-Saharan inner seaway. It is thought that the chief cause of the large-scale simultaneous transgressions was changes in the volumes of the oceanic basins brought about by the lateral movements of the continents and the growth of the mid-oceanic ridges. The anomalous transgressions, those that do not have counterparts elsewhere in the world, may have been caused by geoidal eustasy. There appears to be a correlation between the pattern of occurrence of geomagnetic reversals and the incidence of epicontinental transgressions.

1. Introduction

The Cretaceous Period is marked by a series of large-scale epicontinental transgressions, three of which can be identified in many parts of the world and the maxima of which were synchronous, and two which seem to be confined to the northern and western parts of Africa and the southeastern margin of South America. There is nothing remarkable about epicontinental transgressions having occurred in the South Atlantic. That which is unusual is the oscillatory nature of these inundations and the short duration of particularly the last three.

A second phenomenon of interest in the Cretaceous is that of the special statistical properties of the sequence of geomagnetic reversals. The statistical nature of the reversal pattern changed abruptly in the late Middle Eocene. This is about the time at which rapid seafloor spreading appears to have ceased in the South Atlantic.

There would seem to be a reasonable possibility of the various dramatic events

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of the Cretaceous Period being connected. In this paper, we examine the nature of some of these events and attempt to point out possible causal relationships between them.

2. On the Causes of Epicontinental Transgressions

Observed sea level changes are the combined effect of real changes in the level of the ocean and crustal movements. They are therefore termed relative sea level changes as opposed to absolute or "eustatic" changes in sea level. This concept is illustrated in Fig. 1.

Available information on crustal movements in the areas bordering the South Atlantic ocean seems to indicate that these are mainly long-term, unidirectional movements; hence, they can be neglected in the present qualitative analysis of short-term changes in sea level. Locally, however, earth movements caused by faulting may be responsible for significant relative changes in sea level.; for example, the coastal basins of Brazil and those of Angola, Cabinda, Zaire and Gabon.

Mörner (1975, 1976) has shown that absolute or "eustatic" changes in the level of the ocean depend on the following three factors (Fig. 1):

1) Changes in the volume of the ocean basins—termed tectono-eustasy;

2) Changes in the volume of water in the oceans—termed glacial eustasy;

3) Changes in the configuration of the geoid (the equipotential surface of the attraction and rotation potentials)—termed geoidal eustasy.

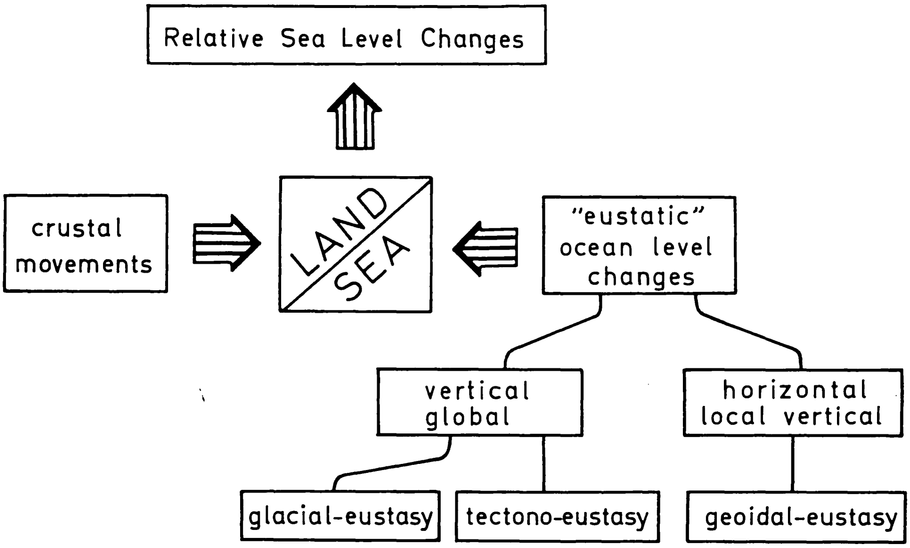

Fig. 1. The relative, observed changes in sea level are a function of land-sea changes, the land being controlled by crustal movements and the sea by eustatic changes in the level of the ocean. There are three main eustatic variables (glacial eustasy, tectono-eustasy and geoidal eustasy), two of which lead to global vertical changes in the level of the ocean and one of which changes the horizontal distribution of the level of the ocean, leading to local vertical shifts that may even be of opposite sign (modified from Mörner, 1976, fig. 5).

The concept of eustasy in relation to geoidal changes is discussed in detail in MÖRNER (1976).

Tectono-eustasy.—Vertical earth movements as well as the outgrowth of oceanic ridges and seafloor spreading will bring about changes in the total volume of the oceanic basins of the Earth giving rise to corresponding eustatic changes in sea level. This might be called the "Archimidean effect".

According to DAMON (1971, figs. 3, 5), all major Phanerozoic regressions coincide with orogenetic events. It is obvious that the growth of the huge oceanic ridges would, in principle, unless compensated by other earth movements, diminish the volume of the oceanic basins, thus causing a global tectono-eustatic transgression.

The tectono-eustatic effect can be demonstrated by a simple experiment. A schematized initial Atlantic rift was modelled as shown in Fig. 2a. For purposes of simplicity, it was made to have parallel sides and the lowest-lying land areas were made flat but not of equal height. A ridge growth corresponding to a displacement of 9.5 per cent by volume resulted in the transgressionary pattern shown in Fig. 2b. The relatively slight increase in volume of the simulated oceanic ridge produced a

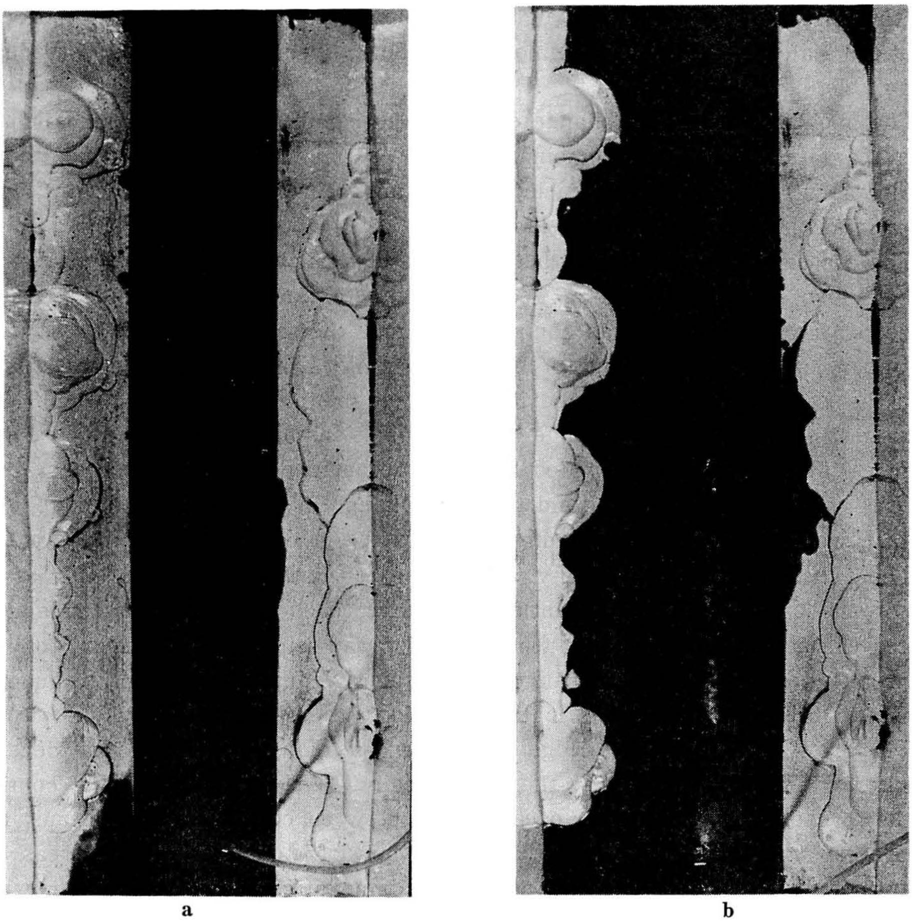

Fig. 2. Results of a simple experiment showing how an increase in volume of about 9 per cent in the volume of the mid-oceanic ridge produces a 'large-scale' epicontinental transgression.

transgression covering a large part of the pre-growth land surface.

Inasmuch as all oceans are in contact with each other, a shift in the volume of a particular basin will occasion a rise in sea level on a worldwide scale and not just in that basin in which the event took place. During the Cretaceous Period, a time of extensive lateral change in the floor of the ocean and of the development of oceanic ridges, tectono-eustasy may be considered to have been of primary importance in the initiation of large-scale transgressions and, probably, also regressions. RONA (1973) has calculated the effects of ridge subsidence during static periods of oceanic evolution and the effects this would have on lowering the level of the sea.

Glacial eustasy.—There is no evidence for ice ages during the Cretaceous Period and glacial effects are therefore not taken into account in the present analysis.

Geoidal eustasy.—MÖRNER (1975, 1976) has demonstrated that the real ocean surface, i. e. the geoid or geodetic sea level, is uneven, being characterized by humps and depressions of several tens of metres. The geoid is the equipotential surface of the gravity field as determined by the attraction and rotation potentials. As an example of an extreme difference in the present geoidal configuration, MÖRNER (1976) cites the difference between the height of the hump at New Guinea and the depression at the Maldive Islands, which amounts to 180 m, over a distance of 50-60 degrees of longitude.

The geoidal pattern can change either by horizontal drifting, by vertical changes in its magnitude, or by a combination of the two. The theory of geoidal eustasy provides a useful and logical vehicle for explaining some of the Cretaceous epicontinental transgressions and regressions.

The present configuration of the geoid has little in common with the main pattern of heat flow, seafloor spreading, tectonic belts, etc. and it must derive from other, and deeper-seated, sources than compositional and thermal differences in the crust and upper mantle. According to HIDE and MALIN (1969), there is a correlation between the Earth's gravity field and its non-dipole magnetic field, MÖRNER (1976, fig. 17), suggesting the presence of huge bumps-depressions and eddies at the core-mantle interface. MÖRNER (1976) intimated that the present geoidal configuration originated from the core-mantle interface, and that any change in the core-mantle coupling and interface would also affect the configuration of the geoid.

The extreme oceanic instability with the extensive redistribution of mass and heat of the crust and upper mantle of the Cretaceous Period must, certainly, have affected the geoidal configuration (the attraction as well as the rotation potentials) and produced geoidal eustatic changes of considerable magnitude (e. g., the anomalous transgression of the Late Maastrichtian to Paleocene, discussed below).

The growth of an oceanic ridge will add mass (of increasing relative density as it cools) and, consequently, raise the geoid locally. The drifting apart of continents and the spreading and sinking of oceanic floor between continents and oceanic ridges will decrease the mass (negative gravity) and lower the geoid over those areas. With the lowering of the geoid over the new areas of negative gravity, one may expect a corresponding rise of the geoid over the coastal areas (registered as local transgressions). The movements in mass connected with ridge growth and seafloor spreading must also affect the rotation of the Earth, hence, accordingly, changing the main geoidal ellipse of the Earth. Finally, the drift-provoking processes in the Earth are certainly linked to fundamental geophysical changes that have both direct and indirect effects on the geoid.

3. Eustatic Effects of the Opening of the South Atlantic

The effects of the opening of the South Atlantic on the "eustatic" ocean level are illustrated in Fig. 3. The opening of the South Atlantic must have had an influence on:

1) The volume of the ocean basin giving rise to tectono-eustatic changes in sea level of global significance;

2) The rotation of the Earth giving rise to geoidal-eustatic changes in sea level that are partly dependent on latitude (changing the rotational ellipsoid) and partly local (changing the magnitude of the relief of the geoid);

3) The local gravity distribution thus causing geoidal-eustatic changes in sea level that are of local significance only.

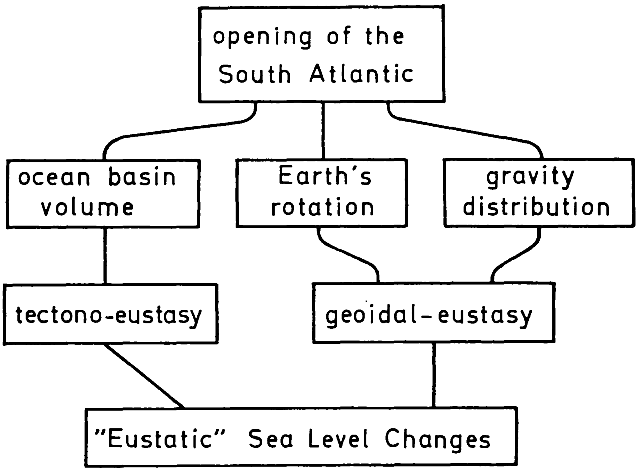

Fig. 3. The theoretical geophysical effects of the opening of the South Atlantic (or any other region) that would bring about eustatic changes in sea level. Tectono-eustatic changes seem to have dominated in the mid-Cretaceous (during the Mercanton Normal Geomagnetic Epoch), while geoidal eustatic changes seem to have been dominant at the Cretaceous-Tertiary transition (during the Beringov Mixed Geomagnetic Epoch).

4. Sealevel Changes in Summary

The foregoing concepts can be formalized by means of a simple equation. Denote the observed change in sea level as ΔS, the net change in volume of the oceans due to ridge growth and seafloor spreading as ΔV, the change in the mass of polar ice as ΔP, the change in the geoidal configuration as ΔG and local isostatic shifts in landmass and crustal tectonic effects as ΔI. Sea level shifts may then be represented by the model

$$\Delta S \propto \Delta V + \Delta P + \Delta G + \Delta I .$$

In the Pleistocene, for example, ΔV and, in a global sense, ΔI, are not very important variables in relation to ΔP, to a lesser extent, ΔG, and locally, in glaciated areas, ΔI. In the Cretaceous, on the other hand, ΔV is the most important term, while ΔG and ΔI are locally important. During times of quiescence in the ocean-building processes, i. e. halts in seafloor spreading and ridge growth, we not only have a change in the pattern of geomagnetic reversals (REYMENT, 1976) but the geoidal configuration would have had a mondial effect on transgressional histories, such that in some places, a large scale transgression could have taken place along the usual routes of the Cretaceous whereas in other areas, for apparently inexplicable reasons, there was no transgression. This, as we shall see, is seemingly what happened in the Late Maastrichtian to Paleocene transgressional episode.

The foregoing schematic representation of sea level shifts can be readily simplified for the Cretaceous as

$$\Delta S \propto \Delta V + \Delta G + \Delta I$$

It is natural to wish to exclude the term ΔI for the purpose of simplifying the constant freeboard model. However, in analyzing the Cretaceous epicontinental transgressions it must be retained (but now made to include tectonic shifts in the shield over which the sea is advancing). For northwestern Africa, this term is often of some considerable importance.

5. The Epicontinental Transgressions

The Valanginian.—The first major transgressionary episode in the South Atlantic took place in the Late Valanginian (REYMENT and TAIT, 1972). Although still incompletely known and understood, this transgression appears to have occurred simultaneously in South Africa and Argentina, the indication for which being that there are considerable agreements in the associations of olcostephanid ammonites and the pelecypods (REYMENT and TAIT, 1972) and in the foraminifers (MALUMIÁN and BÁEZ, 1976).

The late Middle Albian.—The late Middle Albian transgression was preceded by the Late Aptian salt episode, the exact dating of which is still unknown. The Aptian transgression is not of mondial importance, although it is undeniably connected with the earlier stages of the opening of the South Atlantic rift and, consequently, the initial episode of seafloor spreading.

The late Middle Albian was marked by a rather extensive transgression in many parts of the world, the origin of which appears to have been eustatic in the classical sense (e. g. COOPER, 1976; KENNEDY and COOPER, 1975; REYMENT *et al.*, 1976). This transgression rapidly attained its maximum extension in the early part of Late Albian and then switched to an equally rapid regression.

Late Cenomanian to Early Turonian.—The next epicontinental transgression began quite suddenly in latest Cenomanian time in many parts of the world. The information seemingly to the contrary has been shown to be the result of incorrect dating and complete agreement on this point was reached at the meeting held in Uppsala in October, 1975. The transgression was initiated during the time interval marked by the Zone of *Sciponoceras gracile* (SHUMARD). The apparently anomalous position for Nigeria has now been resolved by recent fieldwork by R. A. REYMENT and M. E. OFFODILE in that a typical fossil of the above-mentioned zone, *Kanabiceras septemseriatum* (CRAGIN) has been found in beds immediately underlying earliest Turonian in the middle Benue Valley. Analogous beds have also been shown to occur in the Anambra State. By Early Turonian, the narrow inland sea had reached its fullest extent and had united with the arm advancing from the Tethys. This connexion was of short duration (REYMENT *et al.*, in press). The Early Turonian fauna of ammonoids and pelecypods is locally rich and diverse; it is characterized throughout the entire extent of the 'trans-Saharan sea' by similar associations of vascoceratids and other molluscs.

The Early Turonian ammonite associations of the Benue and Gongola valleys (BARBER, 1957; OFFODILE and REYMENT, in press) are older than those known at present from the Ezeaku Formation (REYMENT, 1955). Most of the Ezeaku material has been obtained from around Nkalagu (Anambra State), near the top of the formation, and there is a considerable thickness of sediment between these beds and the latest Cenomanian of the Western Aboine River.

The youngest beds of the Ezeaku Formation are Middle Turonian in age, as shown by a typical association of inoceramids (OFFODILE and REYMENT, in press), whereas the youngest Turonian in the middle Benue Valley is Early Turonian. This suggests that Turonian sedimentation in the Benue trough ceased earlier than it did in the Anambra embayment, an outcome of the gradual withdrawal of the sea after the maximum transgressionary phase of the Cenomanian-Turonian transition.

Coniacian.—The Middle Turonian sediments of the Nkalagu area (Anambra State), as far as can be judged from the exposures in the Nigercem quarries, are unconformably overlain by marls with *Barroisiceras* sp. nov., which dates the beginning of the Coniacian transgression. This transgression extended into Niger Republic for some distance and sediments with Coniacian fossils of the same species as recorded from southeastern Nigeria and the Mungo River Formation of Cameroun have been described by FAURE (1966). Sediments with Coniacian fossils occur in northeastern Nigeria and in the middle Benue Valley, where workable seams of a coking coal occur, cyclically interbedded in marine and non-marine shales. The Coniacian transgression can be identified in other parts of the world. A schematic representation is given in Fig. 4.

Late Campanian to Early Maastrichtian.—The most extensive epicontinental transgression across northwestern Africa of the Cretaceous Period began in Late Campanian time and attained its maximum early in the Maastrichtian. This interval marks another period of great transgressions in many parts of the Earth. In some regions, the Campano-Maastrichtian transgression was less important than in Africa, while in others, it marked the first major encroachment of the sea. Marine Campano-Maastrichtian occurs in northeastern Nigeria, near Gombe (REYMENT, 1955), as is indicated by the presence of *Libycoceras* sp. Logically, one would have expected the Campano-Maastrichtian transgression to have followed the same route as the earlier ones, namely along the Benue trough, but marine Maastrichtian has not been found

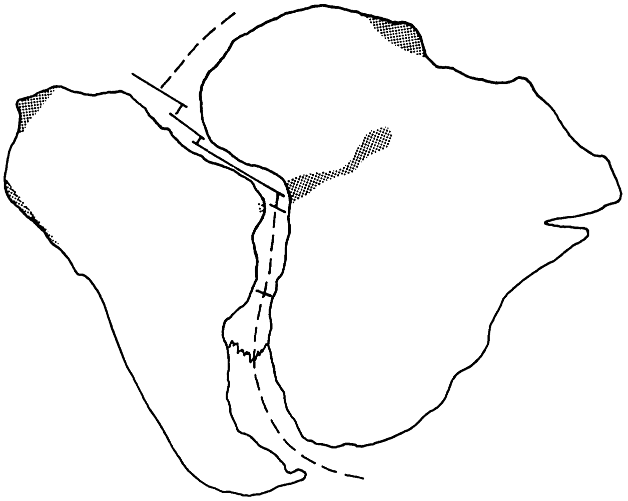

Fig. 4. Palaeogeography of the South Atlantic region during the Coniacian. The dotted areas denote the extent of the maximum transgression of Coniacian time in northwestern Africa and South America. The inferred locations of the Rio Grande Rise and Walvis Ridge are indicated. (Based on REYMENT and TAIT, 1972.)

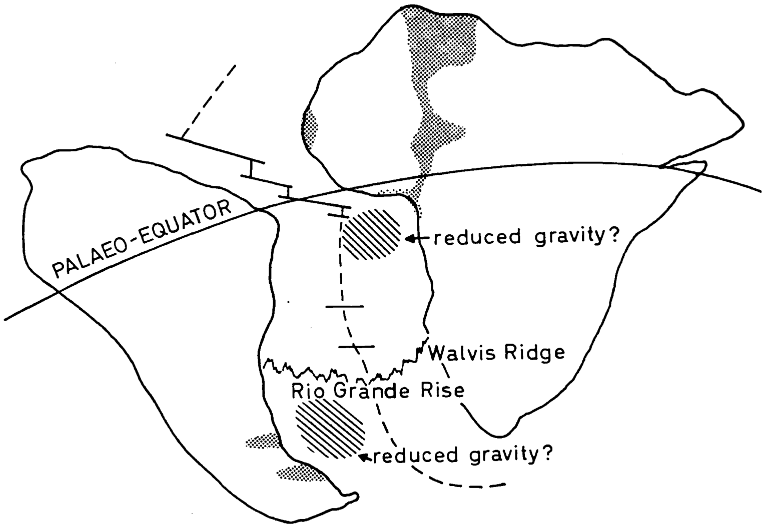

Fig. 5. Palaeogeography of the South Atlantic at the Maastrichtian to Paleocene transition (based on several recent sources). Dotted areas give the extent of the Sokoto (and correlative) transgressions. Hatched areas mark hypothetical regions of low gravity. A theoretical geoid profile (cf. MÖRNER, 1976, fig. 6) from northwestern Africa to Southern Argentina would be expected to exhibit (1) a high geoid over Africa (hence the transgression), (2) a low geoid over the region of low gravity postulated to lie off West Africa, (3) a high geoid over the mid-Atlantic ridge and the Rio Grande Rise-Walvis Ridge, (4) a low geoid over the region of postulated low gravity east of Argentina, and (5) a high geoid over southern Argentina (hence the transgression). This theoretical profile is consistent with the interpretation of the Sokoto transgressive cycle as caused by geoidal eustatic changes in sea level.

in the middle Benue Valley. On the basis of our current knowledge, it seems more likely that the connexion between the Tethyan arm of the epicontinental sea and the Gulf of Guinea was established through the Niger Valley (KOGBE, 1975) and that the Benue seaway ceased to exist after the Santonian folding. The marine Maastrichtian of northeastern Nigeria is thus a backwater of the epicontinental transgression (cf. Fig. 5).

The Paleocene.—The evidence for the transgression of the last part of Late Maastrichtian to Paleocene is twofold, micropalaeontological and sedimentological. The main line of evidence is provided by the ostracods (BARSOTTI, 1963; REYMENT, 1966), but support is also forthcoming from the molluscs (KOGBE, 1975). This transgression cannot be recognized on a worldwide scale and it seems to be confined to the trans-Saharan region and Argentina. The Danian is generally considered to be a time of pronounced regression, as far as can be concluded from the available evidence.

As regards the information provided by the ostracods, although many species do characterize in common the epicontinental seaway, some of these are also found in coastal sedimentary basins between Nigeria and Senegal. BARSOTTI (1963) was the first to draw definite conclusions from the striking agreement in the Paleocene ostracod associations of Libya, Mali and West Africa. He concluded that there was an epicontinental marine connexion between the Sirte Basin of Libya and those of West Africa and that the invading sea came from the southwest. As noted above, some of the species in common with Libya could well have arrived there from West Africa by way of the coast. However, of the numerous species recorded from the Paleogene of West Africa, the following would appear to have migrated from the coast to the inner part of the continental sea: *Isohabrocythere teiskotensis* APOSTOLESCU, *Actinocythereis modesta* APOSTOLESCU, *Bradleya vesiculosa* APOSTOLESCU. There are more species in the Libyan and Nigerian deposits which seem more likely to have reached their relative positions by coastal migration, these being ten in number on our present knowledge.

The relationships across the Atlantic have only been treated by two authors up to the present, namely, NEUFVILLE (1973) and BERTELS (1969). NEUFVILLE (1973) reported the Malian genus *Soudanella* from Danian sediments in Brazil. BERTELS (1969) has recorded a few species related to Nigerian forms in the Cretaceous-Tertiary passage beds of the Argentine. As noted by NEUFVILLE (1973), there are no obvious faunal relationships between the ostracods of South America and West Africa from Late Paleocene onwards, the affinities of the Brazilian faunas lying then with the Gulf of Mexico.

The Paleocene transgression from the Gulf of Guinea apparently advanced by way of the Niger Valley and the Iullemeden Basin of western Niger and northwestern Nigeria. There is no evidence for a throughgoing connexion up the Benue Valley and the Damergum area of Niger. The different route from the earlier transgressions seems to have been brought about by the folding episodes in the Benue trough, the last of which seems to be 'post-Maastrichtian' in age (WRIGHT, 1975).

6. Generality of the South Atlantic Transgressions

It is enlightening to compare the transgressions of northwestern and West Africa with the well known and much better exposed Cretaceous sequence in the Western Interior of the United States.

The earliest transgression, the Kiowa-Skull Creek cycle, began in latest Middle Albian time (KAUFFMAN *et al.*, in press) and attained a maximum in middle Late Albian. This seems to be the least extensive of the five epicontinental transgressions that took place over the 40 million years between Late Albian and Early Maastrichtian. The second transgressionary episode, the Greenhorn cycle, began in latest Albian time and reached its maximum in latest Cenomanian and earliest Turonian. The third episode, the Niobrara cycle, began in Late Turonian and reached its maximum in Early Coniacian time.

There are two lesser post-Coniacian transgressions. The larger of these began in late Early Campanian time and terminated in the early Late Campanian. The second began in the middle Late Campanian and had terminated before the Maastrichtian. There is a small transgressive pulse identifiable in the Gulf Coast area (with *Sphenodiscus*) and Late Maastrichtian is everywhere regressive. There is, however, proof of a Danian transgression in the Atlantic and Gulf Coast regions, although this seems to be a coastal episode of small magnitude. On comparing the history of the transgressional peaks of the Gulf of Guinea with the Western Interior, we find that the Kiowa-Skull Creek cycle corresponds exactly with the Asu River cycle (Table 1), the Greenhorn cycle corresponds exactly with the Ezeaku cycle and the Niobrara cycle agrees with the Awgu cycle. The discrepancy in the dating of the termination of the Awgu cycle in relation to the Niobrara is due to the effects of the Santonian folding in the Benue trough.

The reason why the Asu River transgression did not attain the same relative extent as the Kiowa-Skull Creek flooding may be ascribed to local geoidal-eustatic differences or to local crustal movements. The evidence available suggests that the

Table 1. Formalization of the Nigerian transgressive cycles.

Transgression	Name	Time
First	Asu River cycle	Began in latest Middle Albian, peaked in latest Middle Albian, terminated in latest Albian-Early Cenomanian
Second	Ezeaku cycle	Began in latest Cenomanian, peaked in Early Turonian, terminated in Middle Turonian
Third	Awgu cycle	Began in latest Turonian, peaked in Early Coniacian, terminated in earliest Santonian
Fourth	Nkporo cycle	Began in Late Campanian and terminated in Early Maastrichtian, peaked in earliest Maastrichtian.
Fifth	Sokoto cycle	Began in latest Maastrichtian, peaked in earliest Paleocene, terminated in Paleocene

Benue trough was still being formed in the Albian. By the close of the Cenomanian, the structural evolution of the Benue trough has passed to the end of its first phase and a period of tectonic stability took over; this continued until the Santonian. The "trans-Saharan seaway" developed simultaneously and, in its southern extension at least, it seems to have originated from the same regional influences as created the Benue trough.

The Benue trough has been variously interpreted in the literature. CRATCHLEY and JONES (1965), on the grounds of circumstantial evidence, put forward a tentative argument in favour of a rift valley origin. LEES (1952, p. 12) termed it a flexure valley and pointed out that it is not bounded by marginal faults. It is nevertheless a deep furrow that traverses rigid crystalline rocks. The folding, be it noted, encompasses both the crystalline basement and the sedimentary cover. WRIGHT (1975), summarizing opinions of the origin of the Benue trough, observed that there is a maximum of 6,000 m of sediment in it and he reaffirmed LEES' (1952) conclusion that evidence for marginal rifting is slight. He accepts that the trough is part of an RRR-junction and, as indicated in the foregoing, the Benue arm of this triple junction

Table 2. Summary of biological and geotectonic events.

	Biological events	Geotectonic events
Late Albian	Temporary interchanges between north and south Atlantic via the Gulf of Guinea. Austral elements enter the Atlantic rift sea.	Episode of ridge growth and seafloor spreading with eustatic rise of sea level causing an inundation in the land connexion in the Gulf of Guinea. Transgressions occurred simultaneously in many parts of the world.
Early to Middle Cenomanian	Land area between South America and Africa emerged. No interchange of organisms.	Static period. Eustatic fall of sea level.
Latest Cenomanian to Earliest Turonian	Mobile organisms and nekroplankton pass over the swamped connexion in the Gulf of Guinea, now increasingly narrower. For very short periods of normal salinity, stenohaline organisms pass along the narrow trans-Saharan epicontinental sea.	Active phase of ridge growth and seafloor spreading. Accelerated movement apart of South America and Africa. Eustatic rise of sea level causing vast epicontinental transgressions, often centred along graben lines.
Middle to Late Turonian	Narrow permanent connexion between the north and south Atlantic. Benthonic littoral organisms (e.g. pelecypods) begin to spread slowly along the coasts. Powerfully swimming land animals can still pass across the Atlantic at one or more points at times of low sea level.	Quiescent period. Eustatic fall of sea level. Epicontinental seas disappear.
Coniacian	Terrestrial organisms can no longer cross the Atlantic other than by freak methods. Modern system of surface currents appears in the Atlantic. Resemblances between the organisms of South America and Africa become successively less.	Episode of ridge growth and seafloor spreading. Rapid movement apart of South America and Africa.

was in the process of development during the Albian.

The Late Maastrichtian to Paleocene folding episode provides the reason as to why the epicontinental transgression of this age did not seek its way up the Benue trough, as did the earlier ones (excepting the Campano-Maastrichtian, as it now seems) and the rising sea was forced to hunt out another route, to wit, the Niger trough, which appears to have come into existence during the Santonian folding episode.

7. Interpretation of the Transgressions and Regressions

It seems reasonably certain that during the period of rapid seafloor spreading in, for example, the southern part of the Atlantic, the change in volume of the ocean basins occurred episodically; that is, ridge growth and seafloor spreading took place in spasms. During the dynamic periods, the effects of global tectono-eustasy were dominant and large-scale epicontinental transgressions occurred especially in areas of marginal shelves and low cratonic relief.

During the static periods, it is to be expected that either crustal isostatic adjustment to the redistribution of mass and ridge subsidence gave rise to tectono-eustatic regressions, for example, those of the Late Albian, the Early Turonian and the Coniacian, or that geoidal eustasy became the dominant factor (i. e. for the transgressions and regressions of the Cretaceous-Tertiary passage).

Insofar as MÖRNER (1976) relates geoid changes to changes in the core-mantle coupling and interface, it may be significant that the Asu River, Ezeaku and Awgu cycles all occurred within the long geomagnetic epoch of stable polarity, the Mercanton Normal, while the Nkporo and Sokoto cycles took place within the Beringov Mixed Geomagnetic Epoch. The former three cycles are those we have thought due to tectono-eustasy and the latter two cycles are those we have put down to geoidal eustasy, the earlier only in part as it has some mondial significance, and the later in its entirety, as it lacks global validity.

8. The Sequence of Polarity Reversals

The sequence of polarity reversals, from Kimmeridgian to the present, shows significant trend in the statistical sense (REYMENT, 1976). When, however, the sequence of events is analysed in detail, it is found that the section from Kimmeridgian to Barremian is trend-free, as is also the section from Middle Eocene to Recent. These are both stationary in the statistical meaning of the word, whereas the section from Barremian to Paleocene is non-stationary.

It may be significant that the non-stationary part of the series of magnetic reversals corresponds with the interval during which the South Atlantic was undergoing its major period of evolution. Allowing that the first appreciable lateral movements began in Valanginian, there would have been by Barremian time a certain expanse of seafloor in the southern part of the region.

The mathematical analysis (REYMENT, 1976 and unpublished) indicates that a phase of pronounced trending was initiated in the Late Barremian and that there was a long period of stable polarity from Late Barremian until Late Coniacian. The series of polarity reversals from then on displays highly significant trend until the Late Paleocene, after which significant trending ceased, apart from minor episodes of short duration in the Middle Eocene to Late Oligocene interval (a phase of short-lived pulsations). The plot of the cumulative time to events from Campano-Maastrichtian to Recent shows a distinct and significant change in slope in the Late Paleocene.

MÖRNER (1975) has pointed out that the available data would seem to indicate that over the last 150,000 years, geoid changes have followed a cyclic pattern which he thinks may be correlatable with changes in the core-mantle coupling and interface. This is consistent with REYMENT's (1976 and unpublished) observation that geomagnetic reversals of the Cenozoic display a repeated pattern of occurrence. This is somewhat indistinct for the interval Middle Eocene to Late Oligocene owing to the existence of pulsations or surges which tend to be superimposed on the basic pattern, but it becomes clearer for the interval Miocene to Recent, a period during which seafloor spreading has been slower than in the Cretaceous to Oligocene.

Conceding that geomagnetic reversals are relatable to mechanisms in the core and mantle interface, it might be reasonable to postulate that there is an association between the whole set of phenomena of geoidal variations, geomagnetic reversals and changes in the configuration of ocean floors. Admittedly conjectural, it is submitted that the agreements observed would seem to offer a useful starting point for further investigating the outward and visible signs, to wit, changes in sea level, of processes operating within the Earth and not directly observable.

9. Conclusions

The Cretaceous sea level record for the South Atlantic region includes five major transgressive cycles, the first three of which seem to have global significance, the fourth of which has some global significance and the fifth apparently only significance in the South Atlantic.

The opening of the South Atlantic must have (1) affected the total volume of the ocean basins giving rise to tectono-eustatic changes in sea level, (2) affected the rate of rotation of the Earth, giving rise to geoidal eustatic changes in sea lvel, and (3) affected the local gravity distribution thus causing geoidal eustatic shifts in sea level.

The first three transgressions in the South Atlantic, all located within the Mercanton Normal Geomagnetic Epoch, seem to have been brought about by tectono-eustatic changes in sea level. The fourth transgressionary episode appears to owe its origin in part to this agency but in part also to geoidal eustasy, while the last great transgression seems to have been caused by geoidal eustatic changes in sea level. The two latter epicontinental transgressions took place during the Beringov Mixed Geomagnetic Epoch.

There seems to be close correlation between variations in the growth of mid-oceanic ridges, seafloor spreading, geomagnetic changes and major sea level shifts, indicating the possibility of a causal relationship or mutual origin.

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CLOSING ADDRESS—I

Superbly hosted and organized, the Hokkaido Meeting gave some 20 participants in the MCE Project an excellent opportunity of studying the Upper Albian to Coniacian sequences of central Hokkaido in detail. Particular attention was paid to the Turonian. Many of the participants were successful in obtaining large and representative collections of molluscs, mostly inoceramids and ammonites. The remarkable rarity of acanthoceratid ammonites and the abundance of such genera as *Desmoceras*, *Pachydesmoceras*, *Gaudryceras*, *Mesopuzosia*, etc. and heteromorphs in the Japanese Province was clearly brought out by the field study.

Two days of the meeting were reserved for the presentation of reports. One day was devoted to several aspects of the stratigraphy and palaeontology of Hokkaido and one day to talks on comparisons between Western Europe and Japan, a regional report for the eastern USSR and the dating of events of the mid-Cretaceous. These papers are published in this volume.

The well-known collector family MURAMOTO went to great trouble to put on a representative display of fossils from the area. The collections of several private collectors were on show in the Town Hall, and the Mikasa City Museum featured a display of the famed MURAMOTO collection. In addition, the excellent material of the Hokkaido Colliery and Steamship Company was made available for our inspection, thanks to the kind cooperation of Mr. HONDA, Chief Geologist. These displays offered a unique opportunity to specialists of the Cretaceous to study the remarkable palaeontology of Japan. We are indeed grateful to the Japanese Society for the Promotion of Science and Professor MATSUMOTO and his co-workers for arranging this memorable scientific meeting. Official recognition of the conference was given through the personal participation of the Deputy Governor of Hokkaido and the Mayor and Deputy Mayor of Mikasa.

R. A. REYMENT

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CLOSING ADDRESS—II

Professor Tatsuro MATSUMOTO—an appreciation from abroad

One day in 1953 whilst I was a research student at Cambridge, the late W. J. ARKELL told me that he had a visitor from Japan whom he thought I ought to meet. This introduction to Tatsuro MATSUMOTO was the simple start to many years friendly exchange of letters and papers—mainly in a stream from Professor MATSUMOTO to me!

Although Tatsuro MATSUMOTO has been publishing on Japanese ammonites and stratigraphy since 1936, it was only about the time of that visit to Britain that his work became widely known outside Japan. Looking back to the early 1950's, it is now difficult to appreciate the state of ammonite studies then. Because of the greater cost and difficulties of travel, the smaller number of workers in this field was seldom able to visit other countries, and their knowledge of foreign ammonites was wholly dependent on the literature and museum specimens. One of the results was that new species were often based on ancient inadequate figures of specimens from unknown horizons; validly introduced, but a headache to those who have continued in the field. Without the personal experience of successions in other countries, the only way to make international correlations was to use, and accept rather uncritically, descriptions in the literature, which may have been misleading or out of date. It was possible to assume that every ammonite genus had a world-wide distribution, and the absence of an ammonite family in one region meant a gap in the succession there. Widely quoted schemes of supposedly international zones were often based more on intuition than field observation.

In Jurassic ammonite stratigraphy a marked improvement in practice was largely due to ARKELL who ensured that he saw not only the ammonites he was naming but as much comparable material as possible, and went to see for himself critical sections in other areas of the European Jurassic. From this approach he had been able to confirm the earlier ideas of UHLIG and others that many Jurassic ammonites had limited geographical distributions.

It is part of Professor MATSUMOTO's achievement to show that a proper assessment of any Cretaceous ammonite taxon demands a knowledge of comparable material from all over the world. Since much of this will have been inadequately described and figured, he has found it necessary to visit the countries where the ammonites have been collected and stored. On a series of visits to such countries, including England, France, Germany, the United States and India, Tatsuro MATSUMOTO has examined and made records of thousands of non-Japanese ammonites. Wherever one goes, whether it be in Paris or Austin, you will find museum specimens which have with them slips of paper with MATSUMOTO's valuable observations. All this comes out in his monographs, where his descriptions are so constructed that the reader shall know how the species or genus under discussion relates to all other comparable taxa. In these ways Tatsuro MATSUMOTO has set a new standard against which future work will have to be matched.

Some knowledge of the Cretaceous system in Japan and its ammonites has existed since the last century, especially from the work of YOKOYAMA and JIMBO. The early papers of YABE between 1901 and 1904 made known a new range of Lytocerataceae and heteromorph ammonites (such as *Nipponites*) which together showed Japan to have been a distinctive faunal province during the Late Cretaceous. Further work by YABE, later joined by SHIMIZU, monographed a wider and wider range of Japanese Cretaceous ammonites, but the stratigraphy of these ammonites was often crude and obscure. The use of divisions such as 'Upper Ammonite Beds' or ill-defined local lithic names such as 'Himenoura Group' made it impossible for foreign workers to assess the significance of these finds. For example, in his survey of Mesozoic ammonites in 1938, ROMAN could only record *Nipponites* as being Senonian instead of Turonian-Coniacian. As a result of such records it was commonly assumed that the more unusual heteromorphs were characteristic of the highest Cretaceous (e. g. SWINNERTON 1950), and hence were quoted as evidence for an evolutionary theory in which biologic groups became 'decadent' and 'senile' shortly before their extinction. In fact, as MATSUMOTO has shown, the Nostoceratidae, a family which includes some of the more bizarre-looking forms, had origins in the Albian, was represented by at least six genera in the Turonian, but has only three genera which survive into the Maastrichtian (MATSUMOTO, 1967).

MATSUMOTO's second major achievement for work on Cretaceous ammonites has been to set the Japanese successions firmly in the standard framework of international stages. Under his influence, names such as 'Gyliakian' and 'Urakawan', introduced by YABE in 1927, and still in sole use until the 1960's, have been phased out of the literature. Their replacement by the system of international stage names has meant that all geologists can now understand more easily the significance of the Japanese Cretaceous successions. This has also given less excuse for the retention of local stage-names for the Cretaceous in other countries such as New Zealand. To achieve this standardisation, Tatsuro MATSUMOTO has made special studies of those groups of ammonites, such as the Acanthoceratidae and Collignoniceratidae, which are of value for long distance correlation, when he could have taken an easier path and concentrated only on the more common, essentially endemic elements of the Japanese fauna.

I shall not discuss Professor MATSUMOTO's many other achievments within Japan: quite apart from his regional studies, his work on geosynclinal developments and his surveys of world sea-levels, it is obvious that he is held in high regard by his colleagues, not only in Kyushu University, but throughout Japan. His kindness and modesty make it natural for him also to be thought of affectionately. Internationally, his vast knowledge of ammonite faunas, his generosity in giving help and advice, and his energy and skill in publishing his results, have earned him gratitude and respect throughout the world.

A complete list of Professor MATSUMOTO's publications is to appear in Sci. Rept. Dept. Geol., Kyushu Univ., vol. 12, no. 3, 1977.

J. M. HANCOCK

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